Karst ,

and

it’s influence on Tailings Dams

I have known and loved

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- What is karst?
- Where is it found?
- How does it form?
- How do we recognize it?
- How do we explore, describe and classify it?
- How do we design for it in engineering?

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What is Karst?

The term karst was first used to describe a geomorphic unit in the Dinaric Alps between Slovenia and Italy. Krs in Slavic or Kras in German means "barren land").

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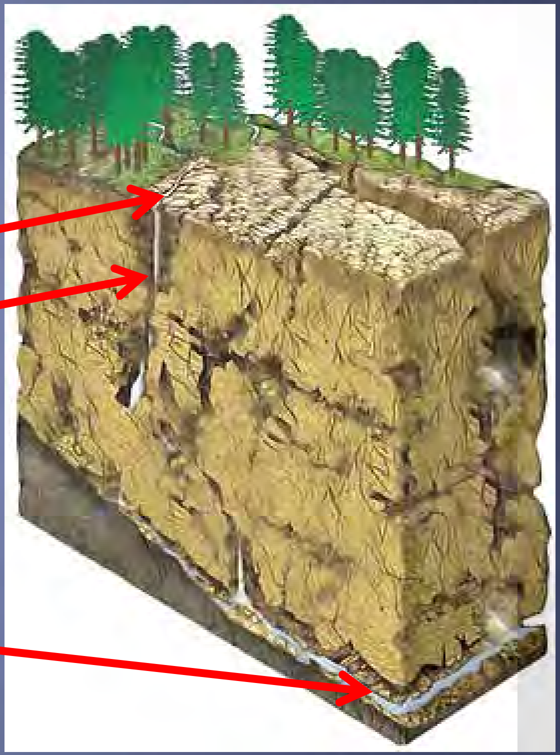
a distinctive geomorphic unit caused by dissolution of soluble bedrock (usually limestone, dolomite or marble, and, to a lesser extent, evaporites),

Landscape is characterized by;

- •fluted and pitted rock surfaces,
- •vertical shafts,
- •sinkholes,
- •sinking streams,
- •subsurface drainage systems caves
- •springs,



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Where is it found?

Found in any rocks susceptible to dissolution

Evaporites
Gypsum,
Anhydrite
Halite

→

Limestone
Dolostone

→

Carbonatites,
(igneous rocks
composed of
carbonate
minerals)

Outliers include
Monomineralic
siliceous rocks
that form karst
very slowly

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Evaporites form the soft rock end of the spectrum

Halite	$NaCl$
Gypsum	$Ca\ SO_4$
Anhydrite	$Ca\ So_4.2H_2O$

Evaporites are present in 32 of the 48 contiguous United States, and they underlie about 35–40% of the North American land area.

Evaporite karst, both natural and human-induced, is prevalent.

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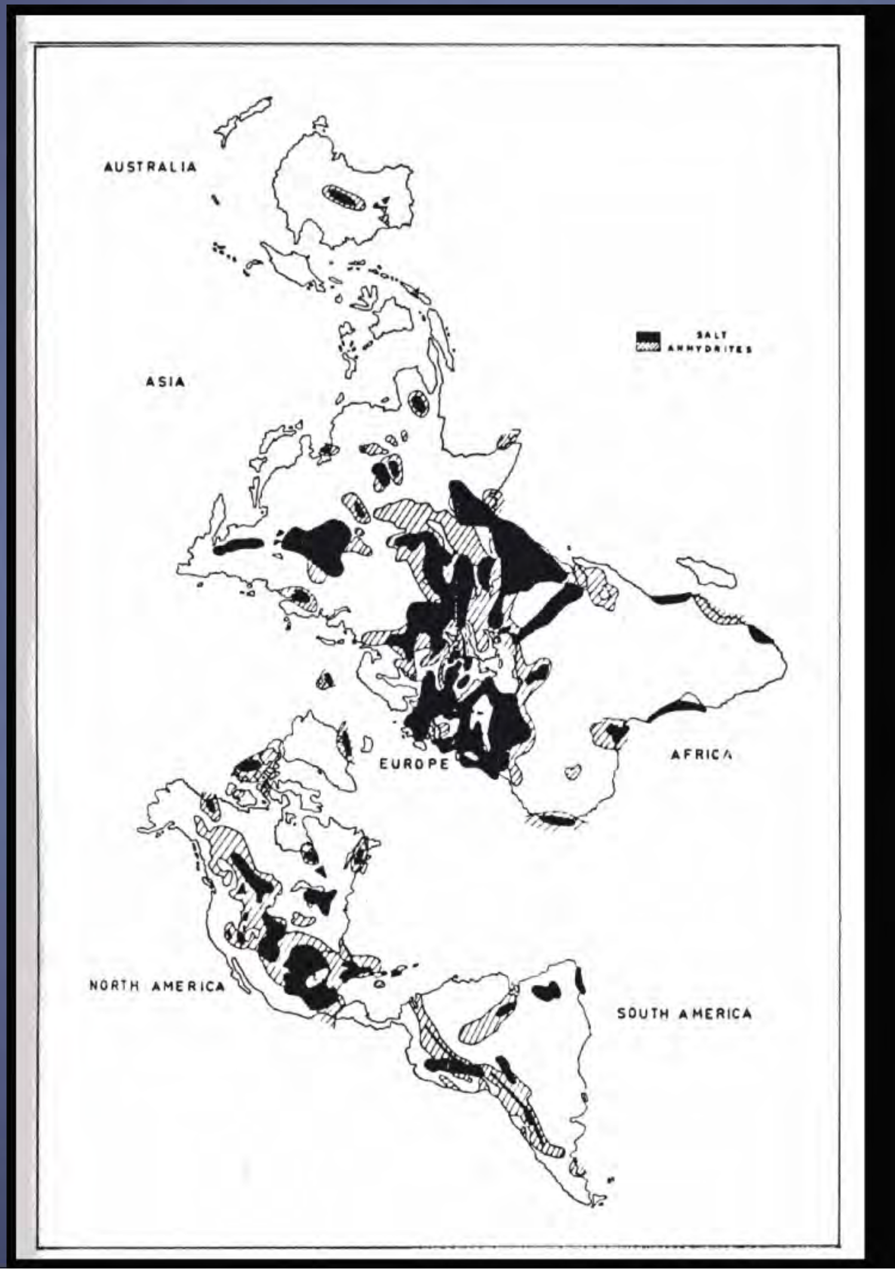

Figure 1.-Global occurrence of evaporites

90% of gypsum/ anhydrite, 99% of halite) are covered (Kozary et al., 1968).

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Evaporites form the soft end of the spectrum

Erode rapidly by molecular dissolution ,
(doesn't need acidic waters)

Human activities such as drilling and modifying drainage features have caused rapid development of evaporite karst, primarily in salt deposits.

Soft rock won't support large karst features .

Very rapid dissolution happens within the life of a project

Rates of dissolution can be as much as 0.2 mm/sec.
Nasty for dam foundations…

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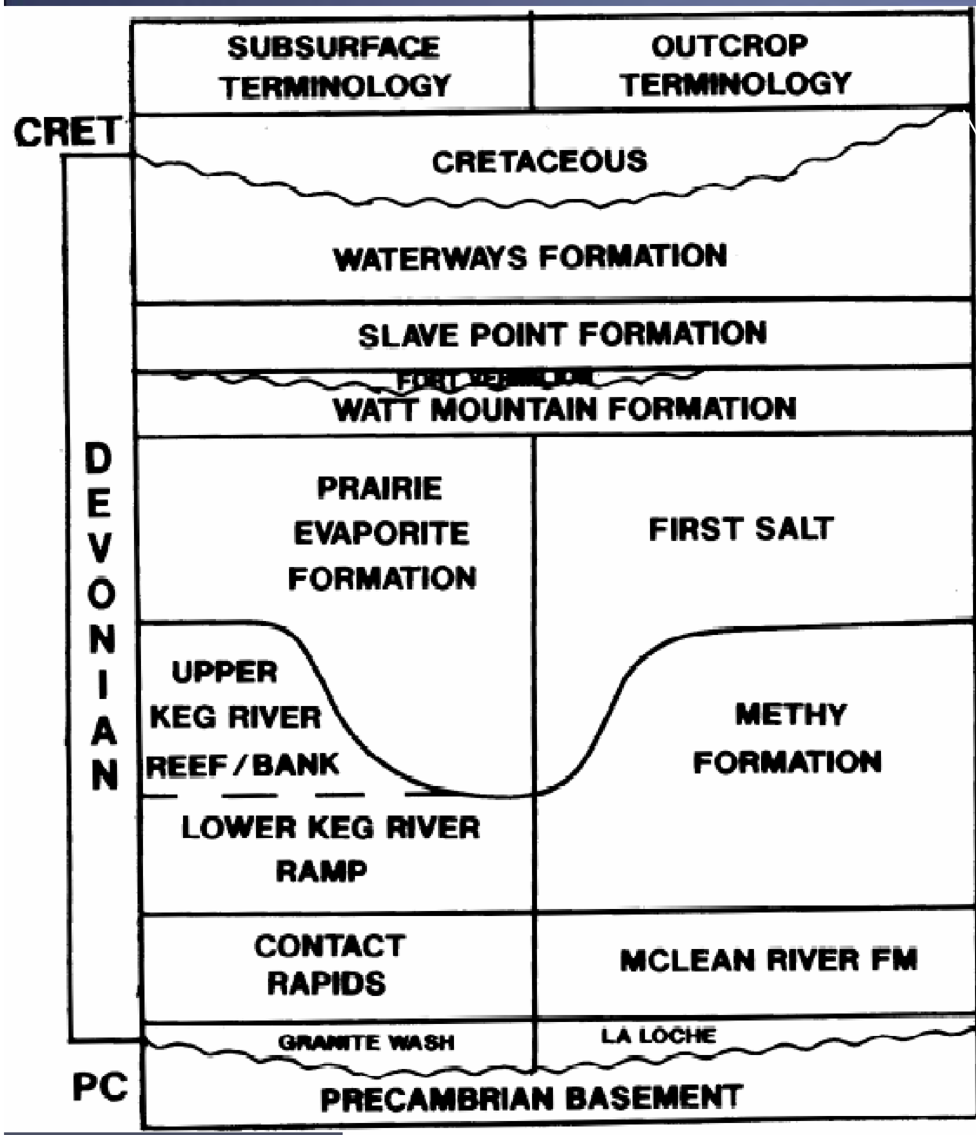
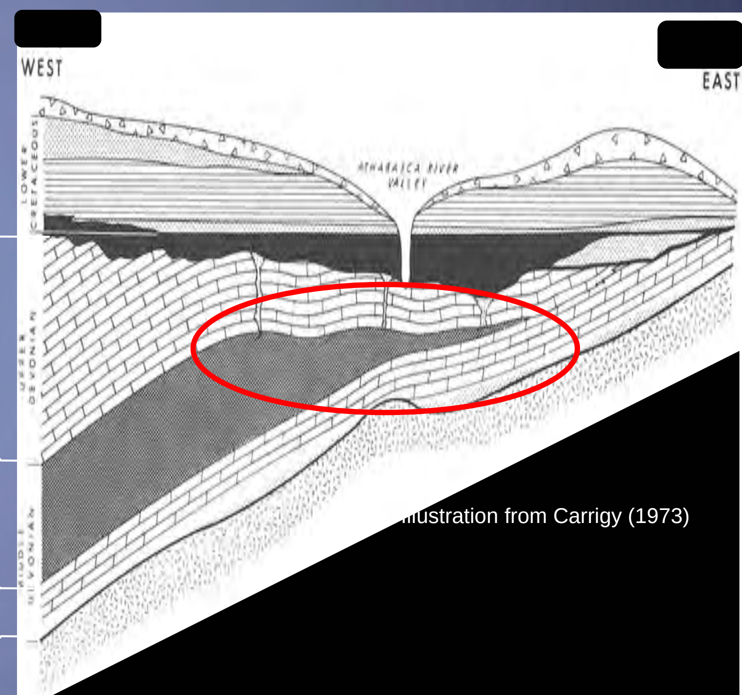
Fort McMurray, Alberta

Evaporites removed and reversed dips of overlying bedrock





Nomenclature provided by SCG (2009)

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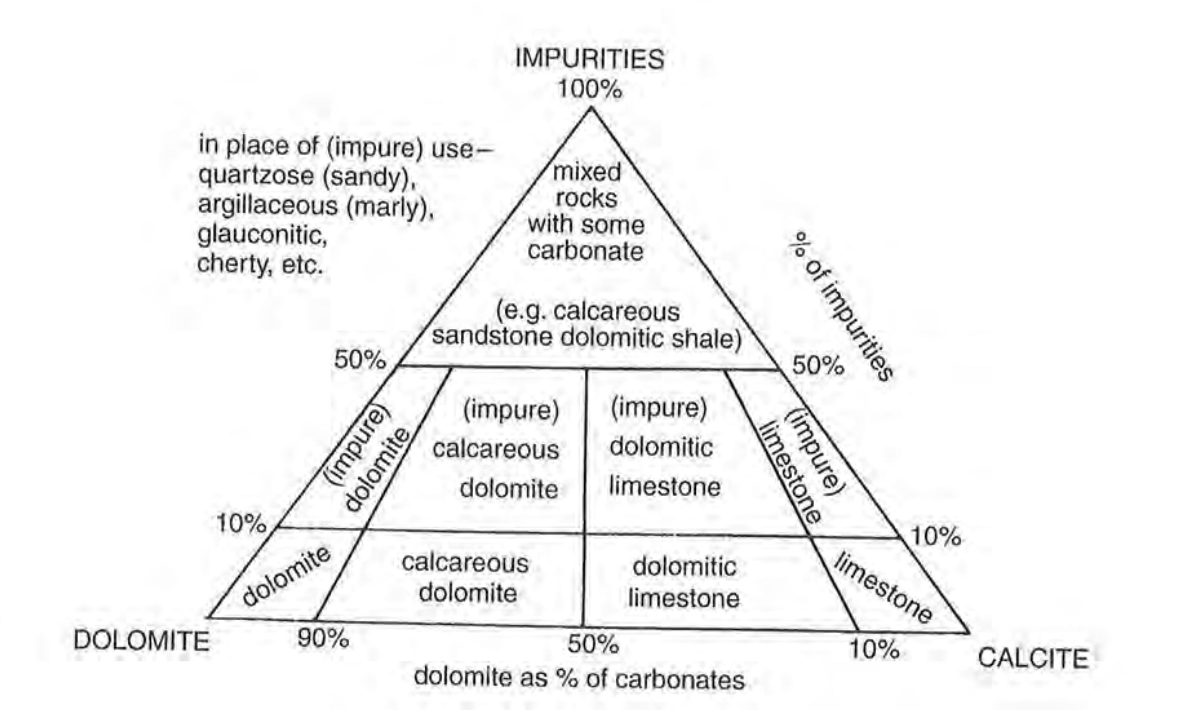
Typically we think of karst in limestones, dolostones, and marbles.



Typically karst forms in rocks with 60 to 70% pure CO3

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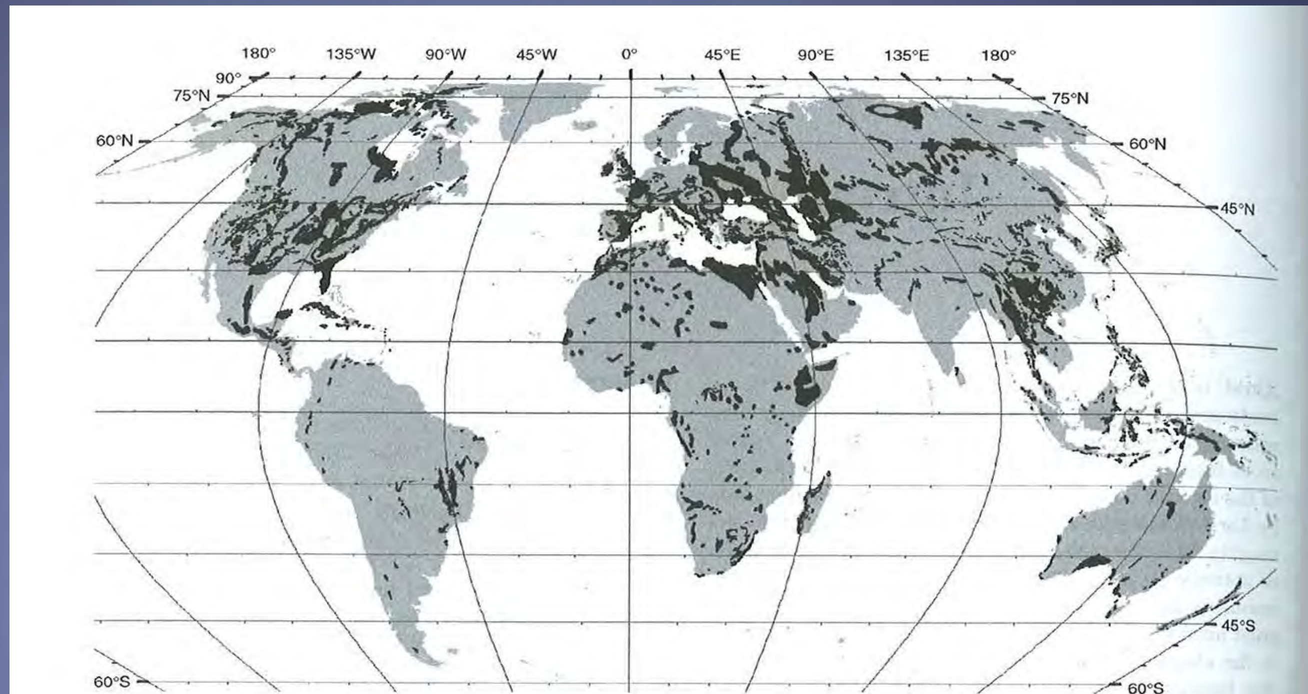

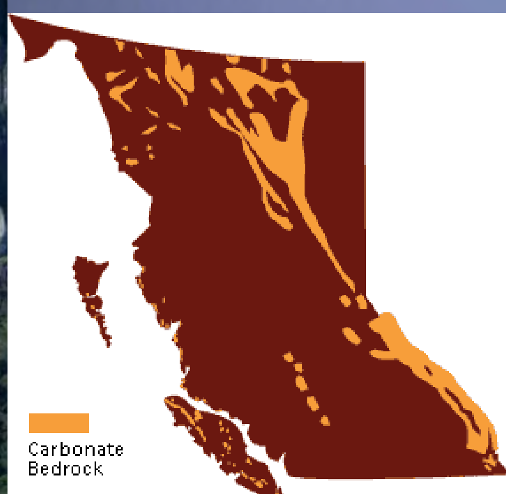

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Limestone is found in over 80 million km^2, about 12 to 15% of earths surface and 25 to 30% of earths drinking water comes from karst sources. So there is a 1 in 8 to 1/10 chance of finding karst at your project.

Limestone is found under 15 % of USA and over 10% of BC

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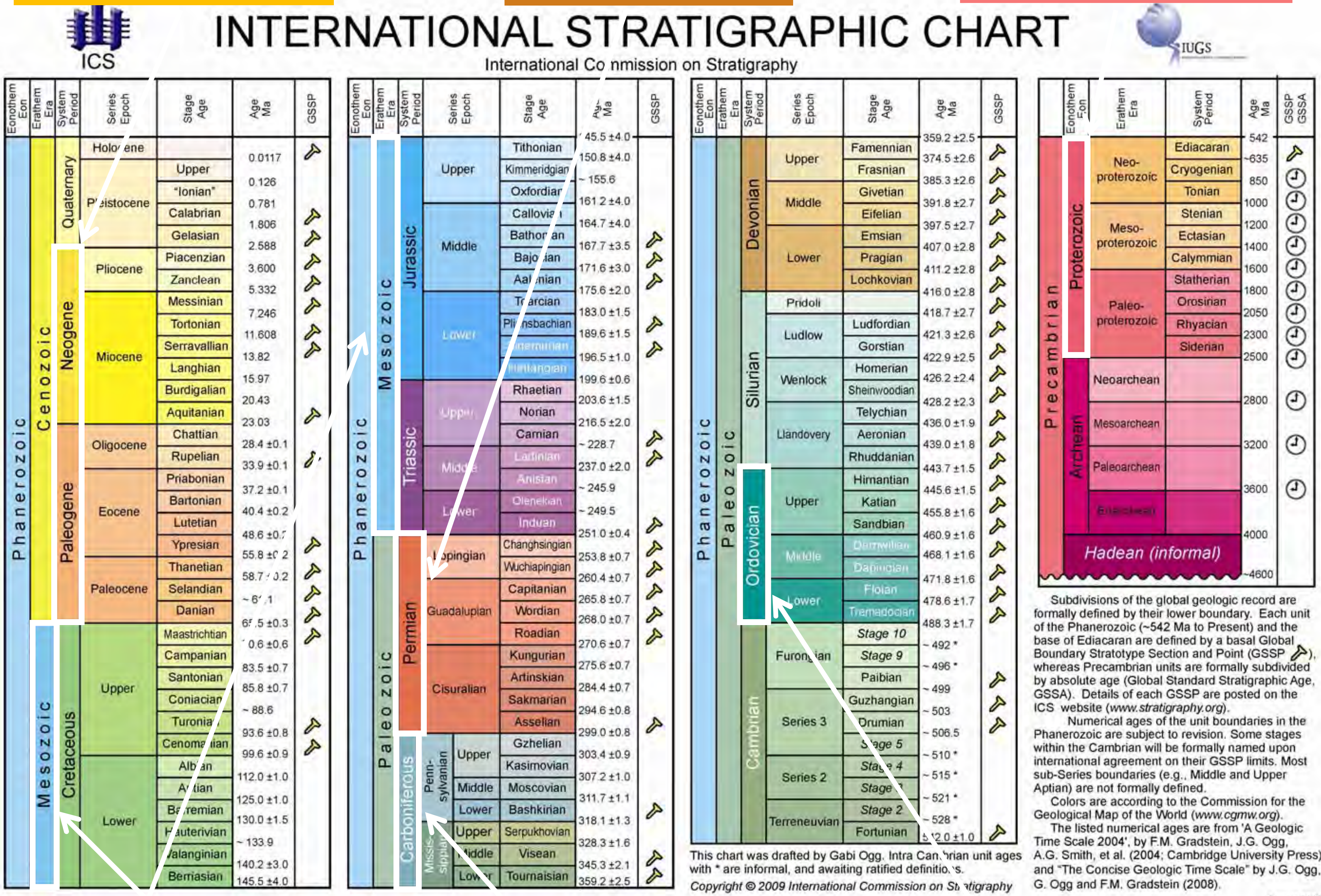
Malaysia - Tertiary

China - Permian

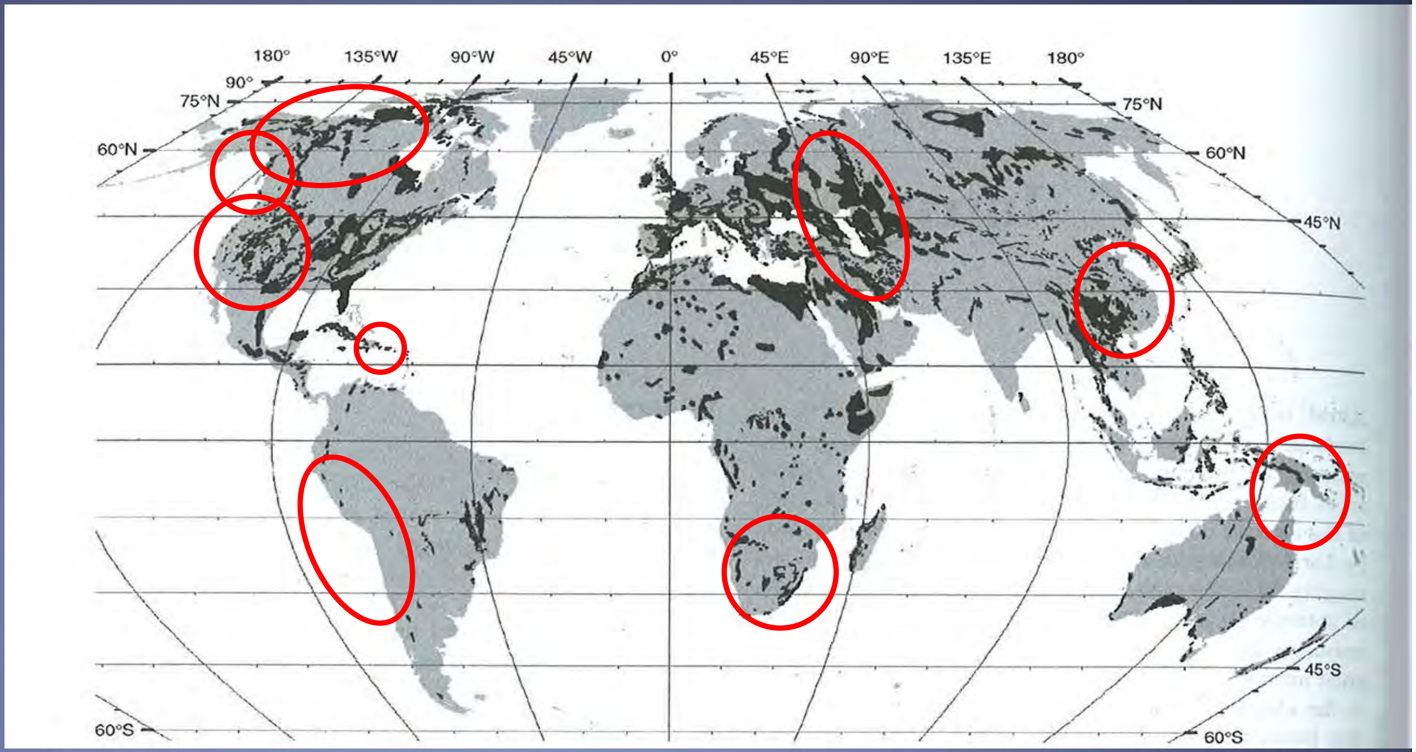
Brazil - Proterozoic

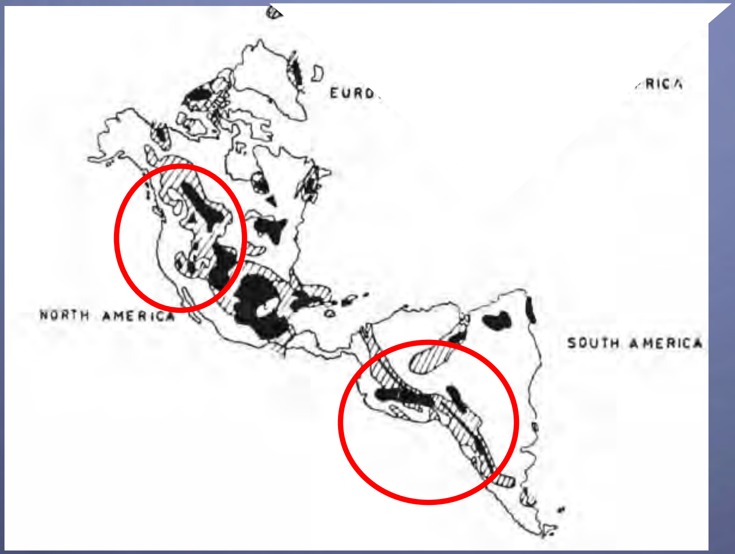


Europe - Mesozoic

Great Britain - Carboniferous

USA - Pennsylvania - Ordovician





Mining Areas overlying Karst areas suggest the chance of encountering chance of karst are about 1 in 3 to 1 in 5.

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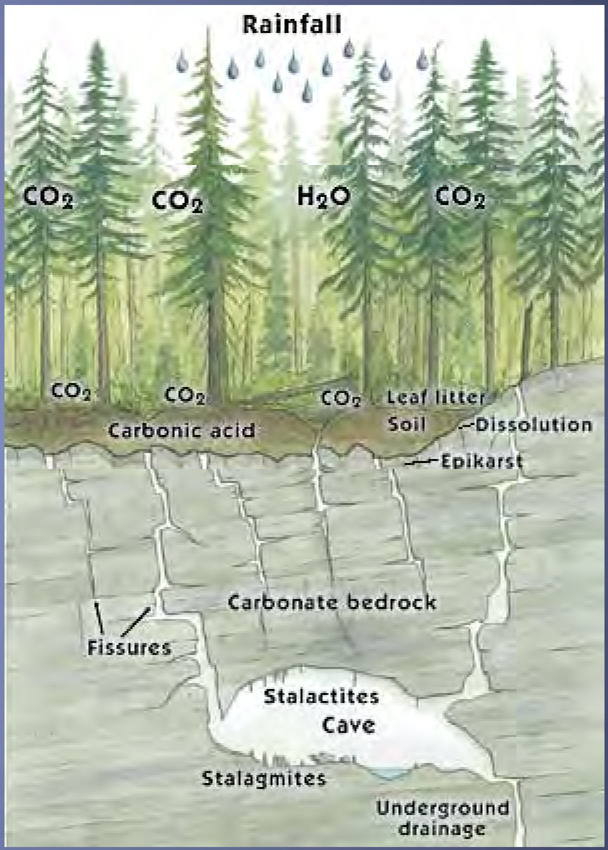
How does karst form?

CO_2 Cascade

$H_2O + CO_2 = H_2CO_3$

H_2CO_3 dissolves $CaCO_3$



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Typically karst initiates along structures such as joints, faults and bedding planes

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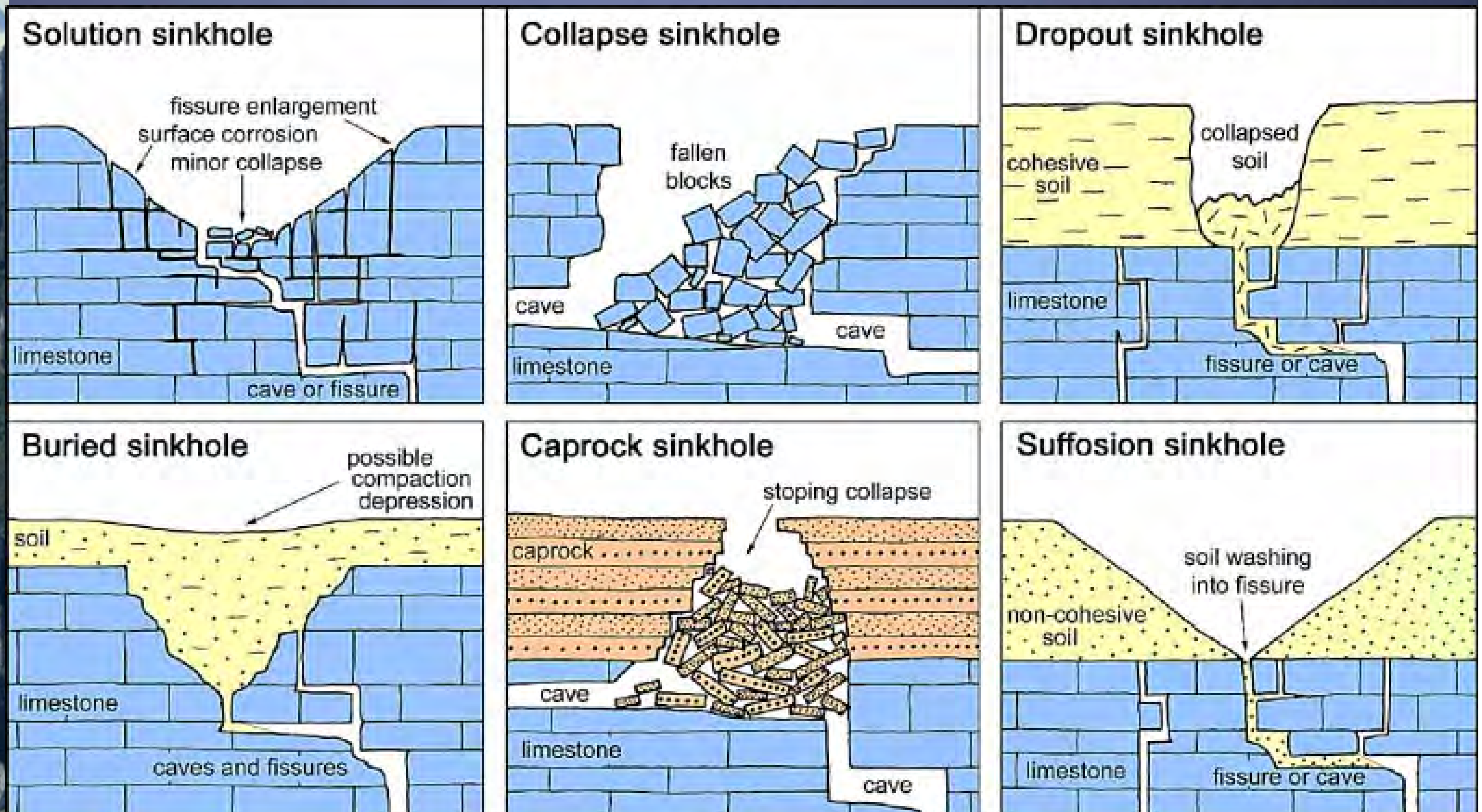

Engineering classification of karst ground conditions
A. C. Waltham1 and P. G. Fookes2

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Rate of dissolution varies with temperature, amount of organics in the soils and rock type

In the north karst forms more easily than for the same precipitation in the south

In areas with more organics, the carbonic acid is stringer
‘but in reality it all depends on rainfall

0.1 to 0.005 mm/yr
loss on joints

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How do we recognize karst?

Geology map

When you encounter clay shale, assume Φ residual and prove otherwise.

Cruden, Morgenstern, and Thompson

When you encounter carbonates, assume karst until proven otherwise !

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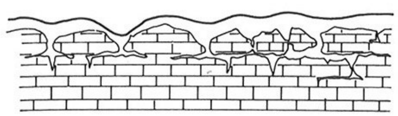
How do we recognize it?

Table 6.6. Sedimentary rocks: Limestone (humid and arid)

Humid

Topography

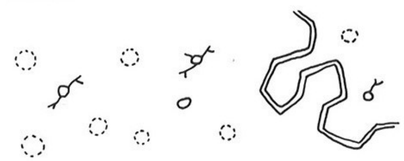
Karst



Chemical weathering dissolves the rock along jointing and bedding planes, thus developing a collapsing surface of sinkholes and depressions known as "karst topography." The ground surface is undulating and forms indistinct transitional boundaries with other, associated sedimentary rocks. Sinkholes are rounded in flat-laying beds, elongated in tilted beds.

Drainage

Internal

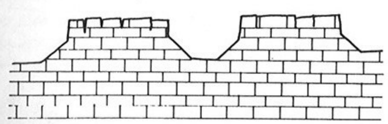


The solution cavities within the rock and the high permeability of the residual soil cause humid limestone regions to be drained internally, leaving little water to be collected in a surface water system. Major streams follow angular alignments of old jointing patterns. Typical sinkholes average 10 to 40 feet in depth and 50 to 500 feet in width.

Arid

Topography

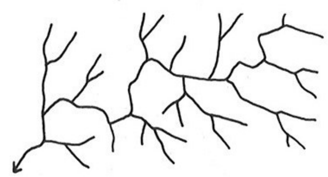
Table Rocks



Since little moisture is available for chemical weathering in arid climates, the limestones present erode very little. Pure, thick limestone deposits form cap or table rocks, developing none of the characteristics associated with karst topography.

Drainage

Angular dendritic: Medium to fine



The surface drainage system is well developed (karst topography does not exist in arid climates.) The pattern is very angular, following jointing alignments in the bedrock, and is medium to fine textured. All but major streams are intermittent.

Topographic map

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Remote sensing

Dry valleys, lakes with no drainage, barren ground

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Sinkholes and collapsed dolines

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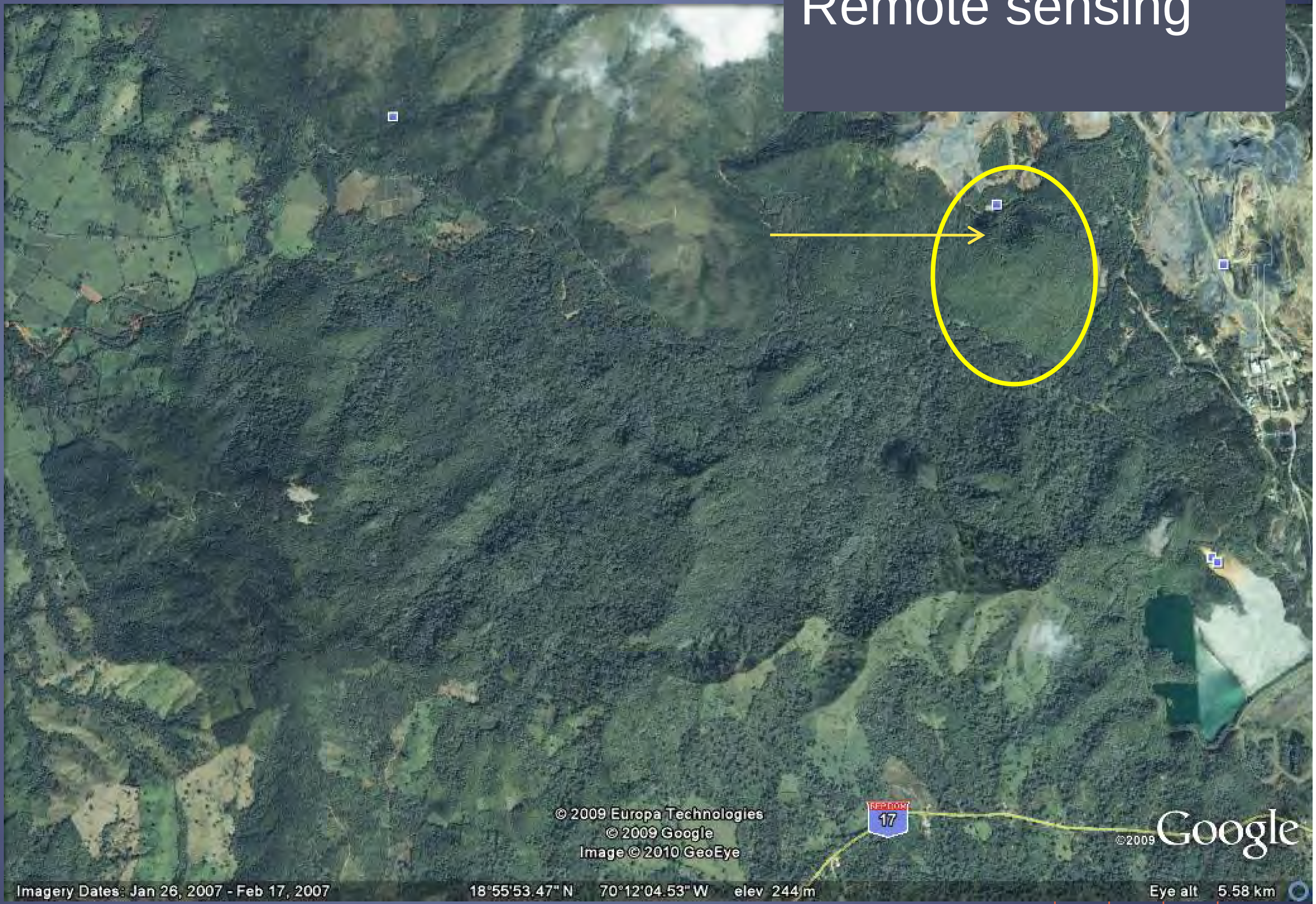

Remote sensing

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How do we explore for karst?

Drilling?

2500 holes per hectare to have 90% chance of hitting a 2.5 m diameter void.

Beecher

So if you actually drill into a cave…

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- drilling

Drilling the chances are remote and if you do hit a cave the chances are pretty high you have swiss cheese

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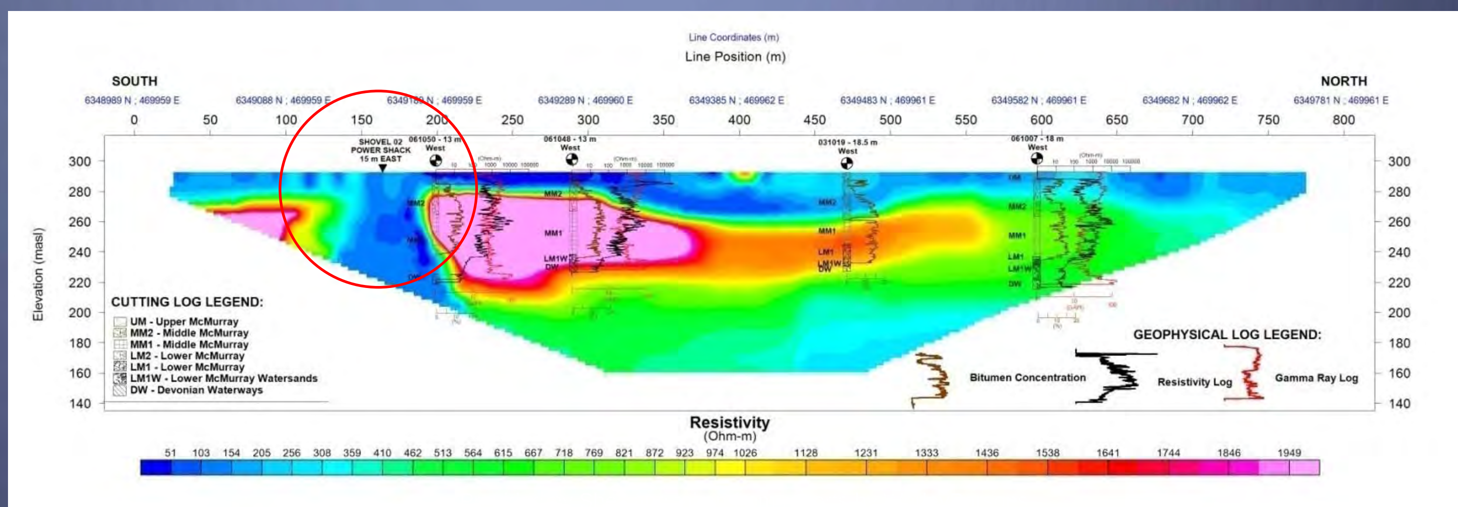
Geophysics ?

Ground Penetrating radar, seismic refraction, resistivity and gravity all tried

Nothing successful for finding karst although delineating karst you know is there is possible.



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Mapping !

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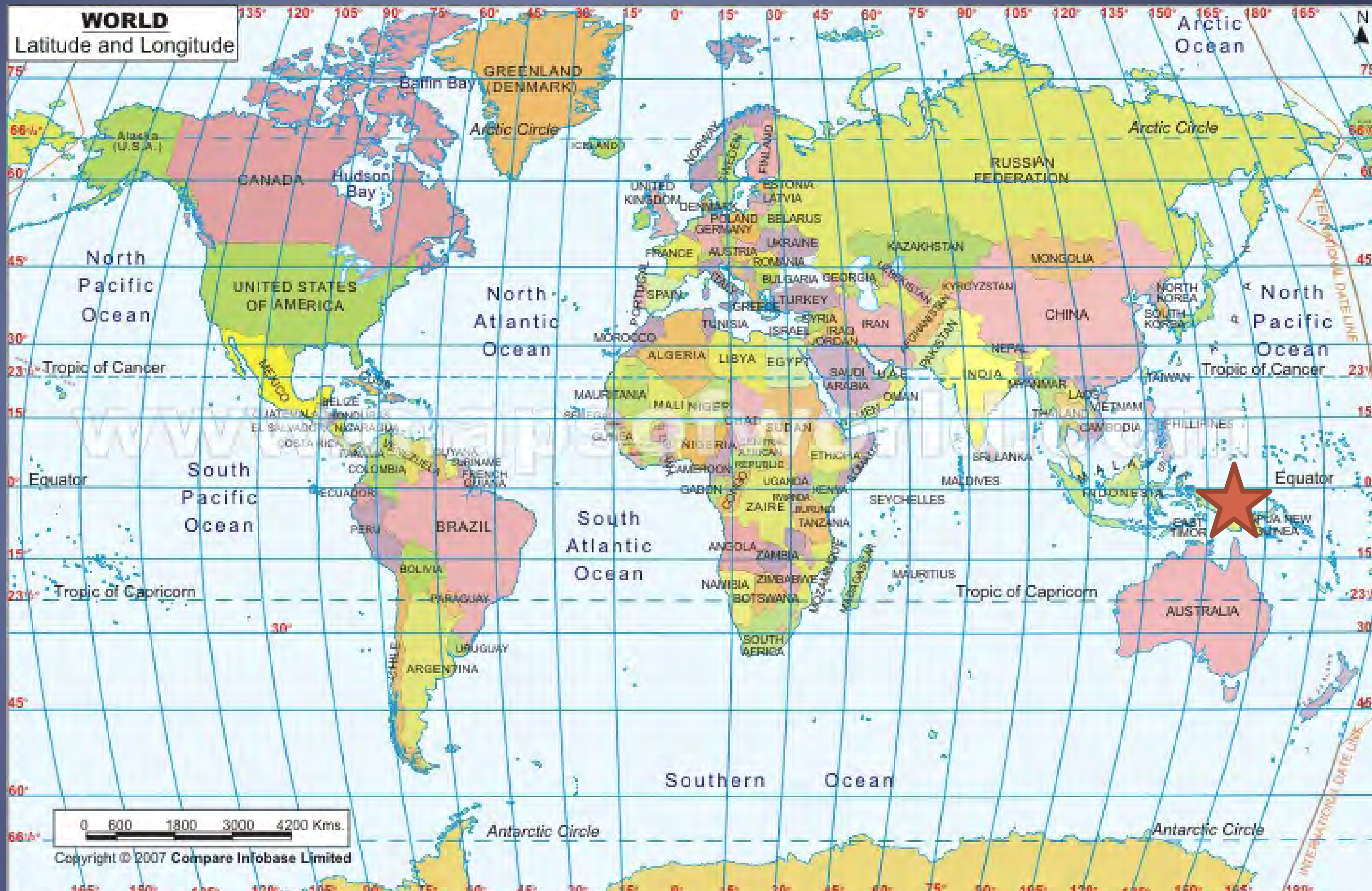

Ok Tedi

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People go to PNG just to explore the karst…

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For scale…

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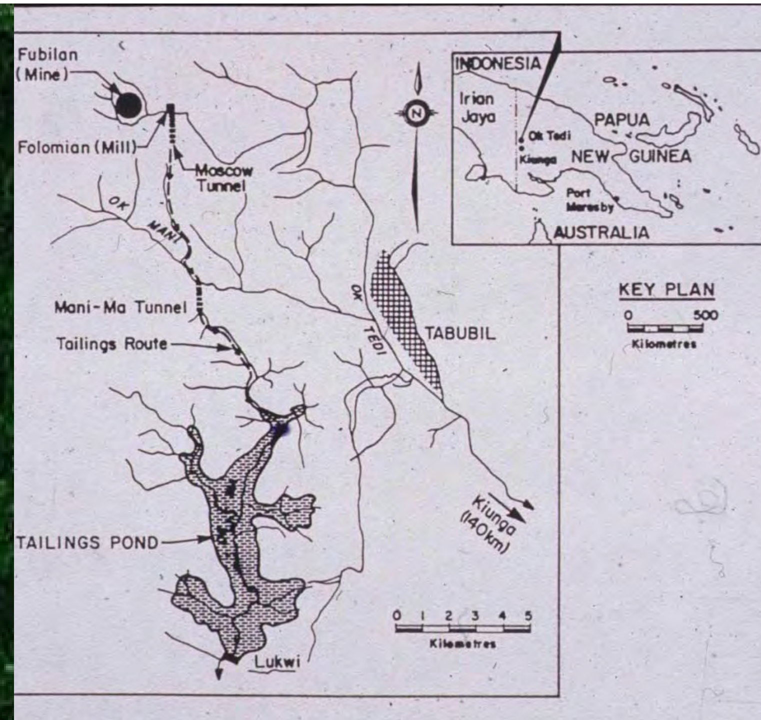

Karst here is much tougher to find. Vegetation masked it so you had to get on the ground.

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Warre Limestone

Dreaded Pnyang

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Springs at the base of Warre Limestone

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Crevices at the top

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Sinkholes invisible through trees

No caves found in borehole

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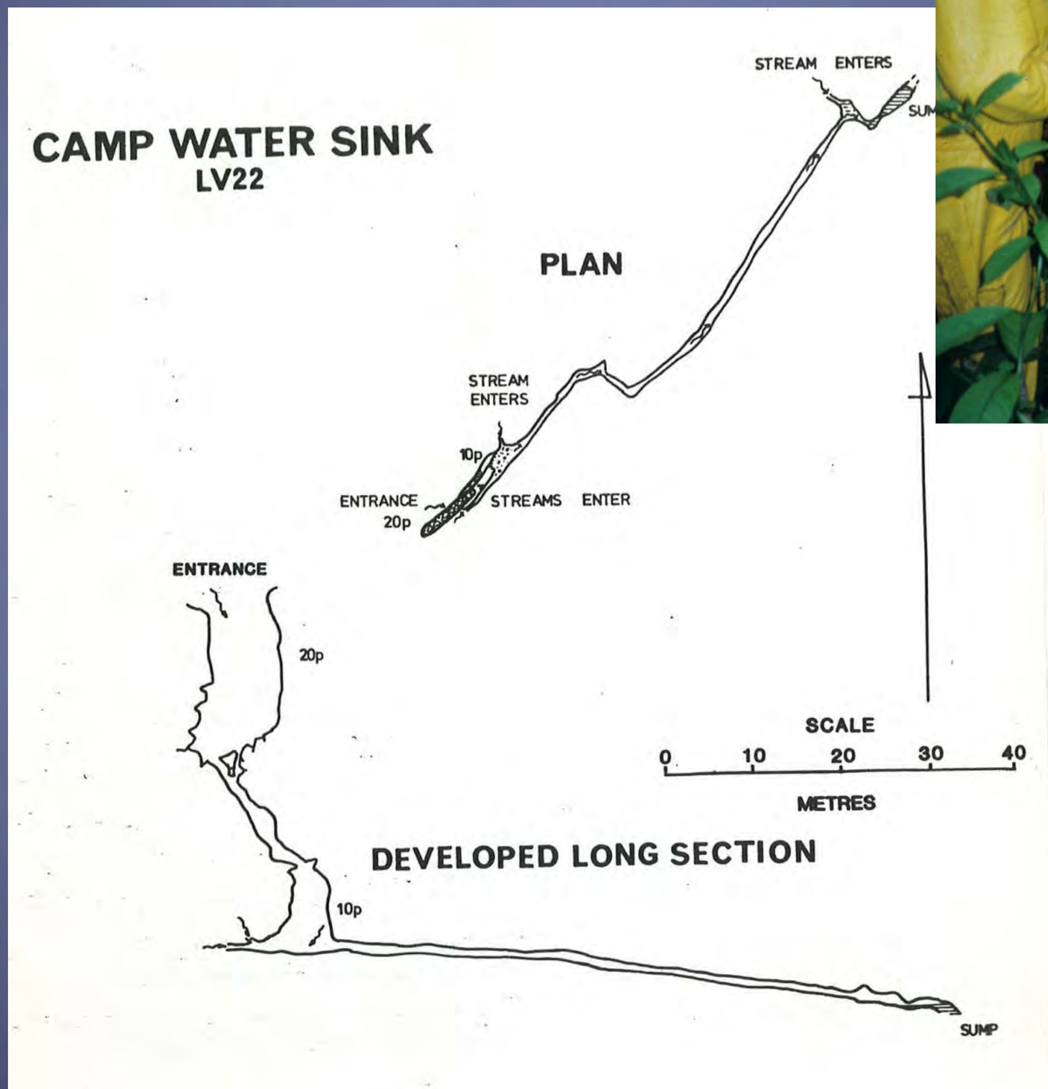

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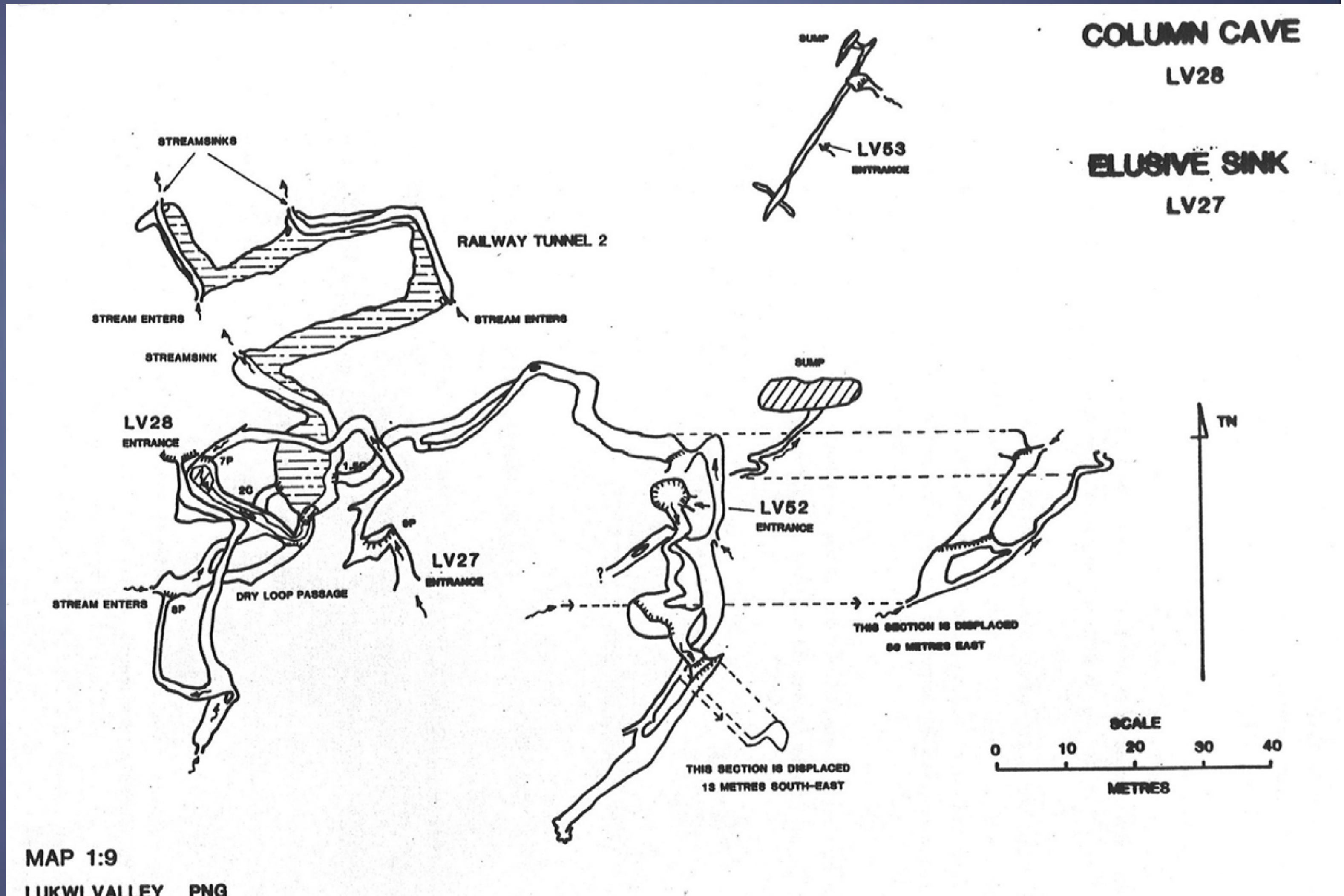

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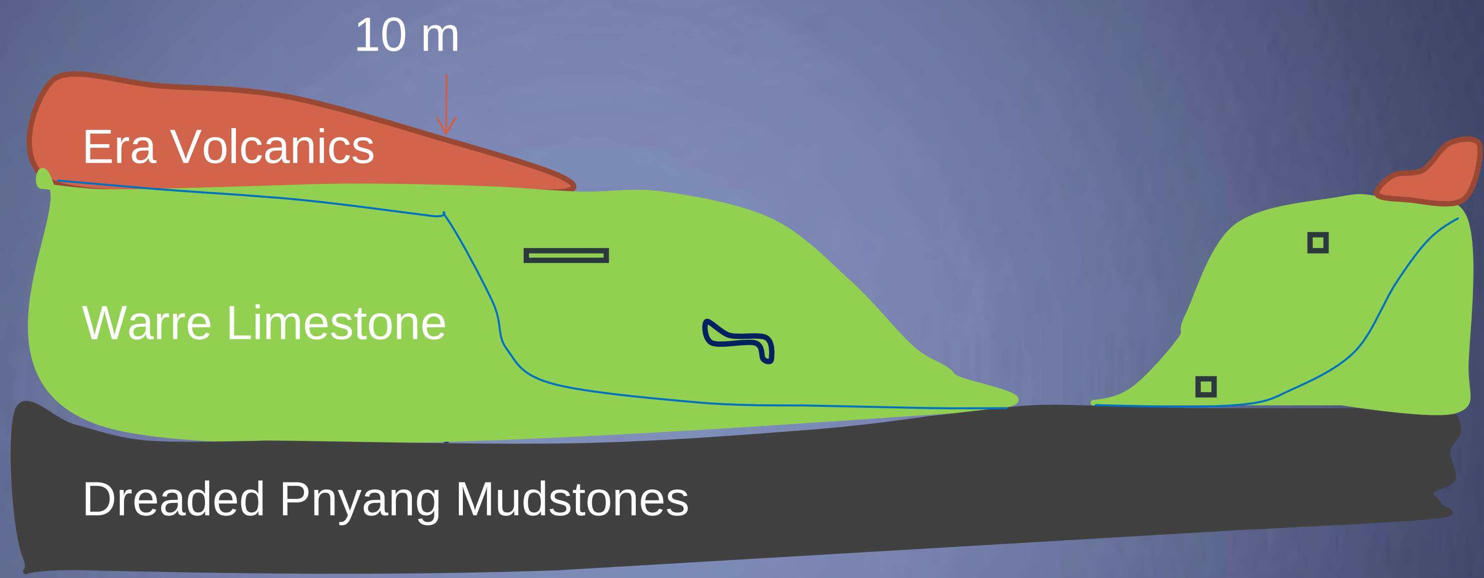

Drilling did not materially find caves but piezometric readings confirmed the lowered water level surfaces

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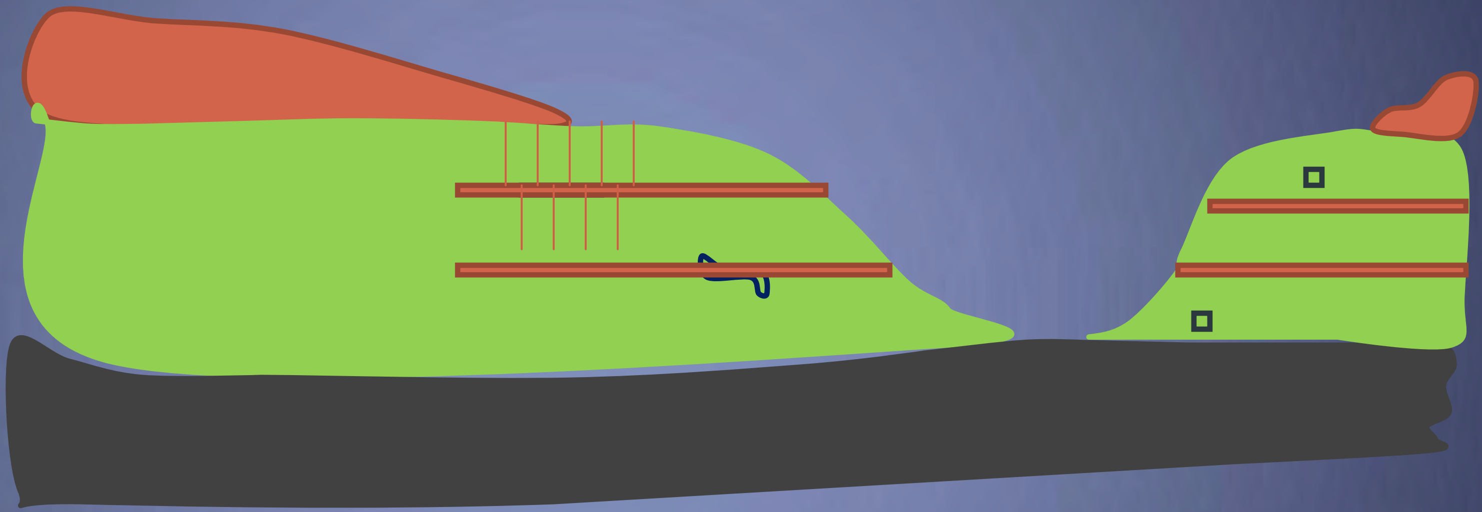

Drive adits at 1/3 valley heights,
intercept any caves and build a concrete wall
then drill and grout a curtain both up and down.

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Never built due to other priorities

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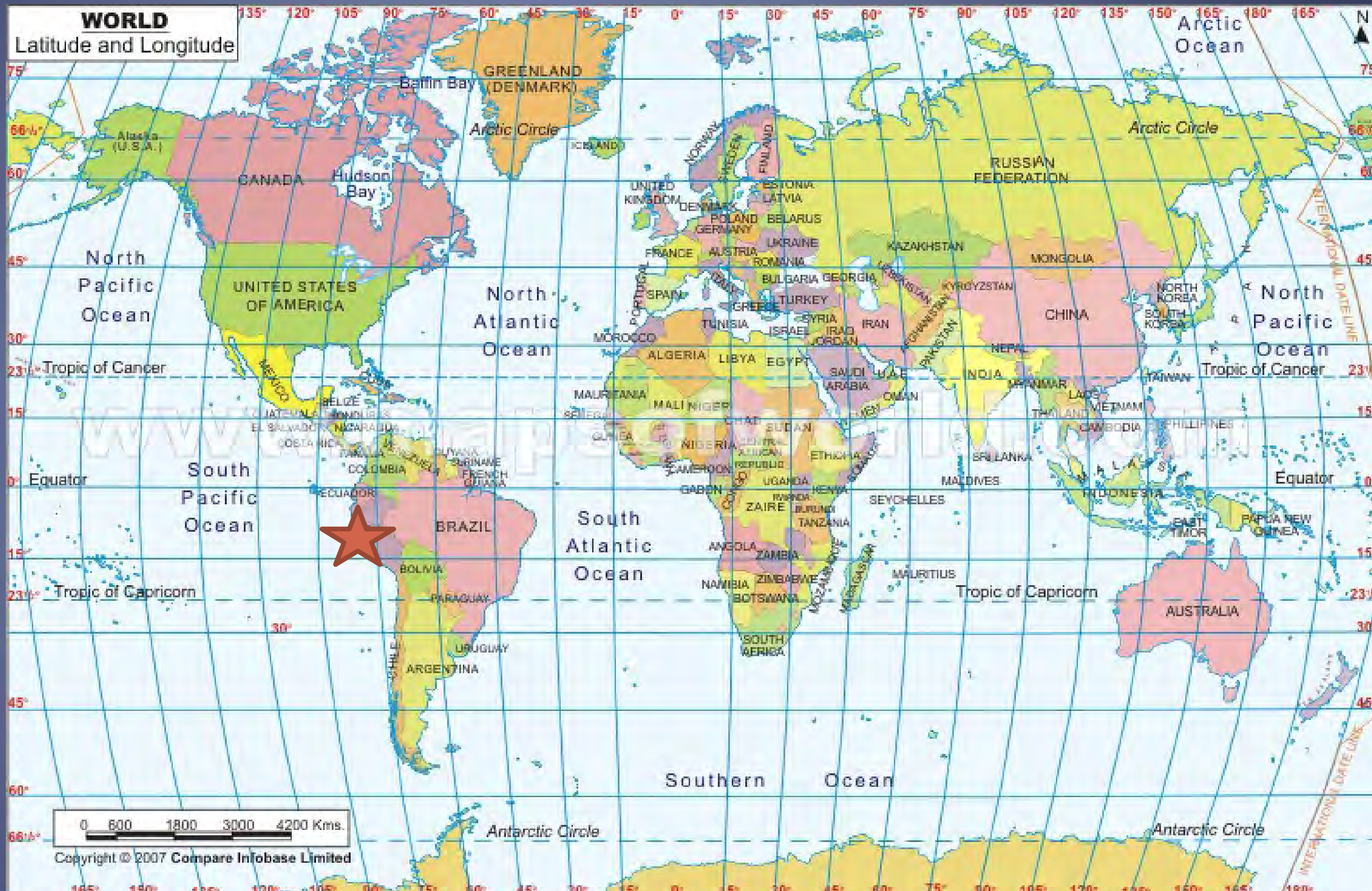

TOROMOCHO

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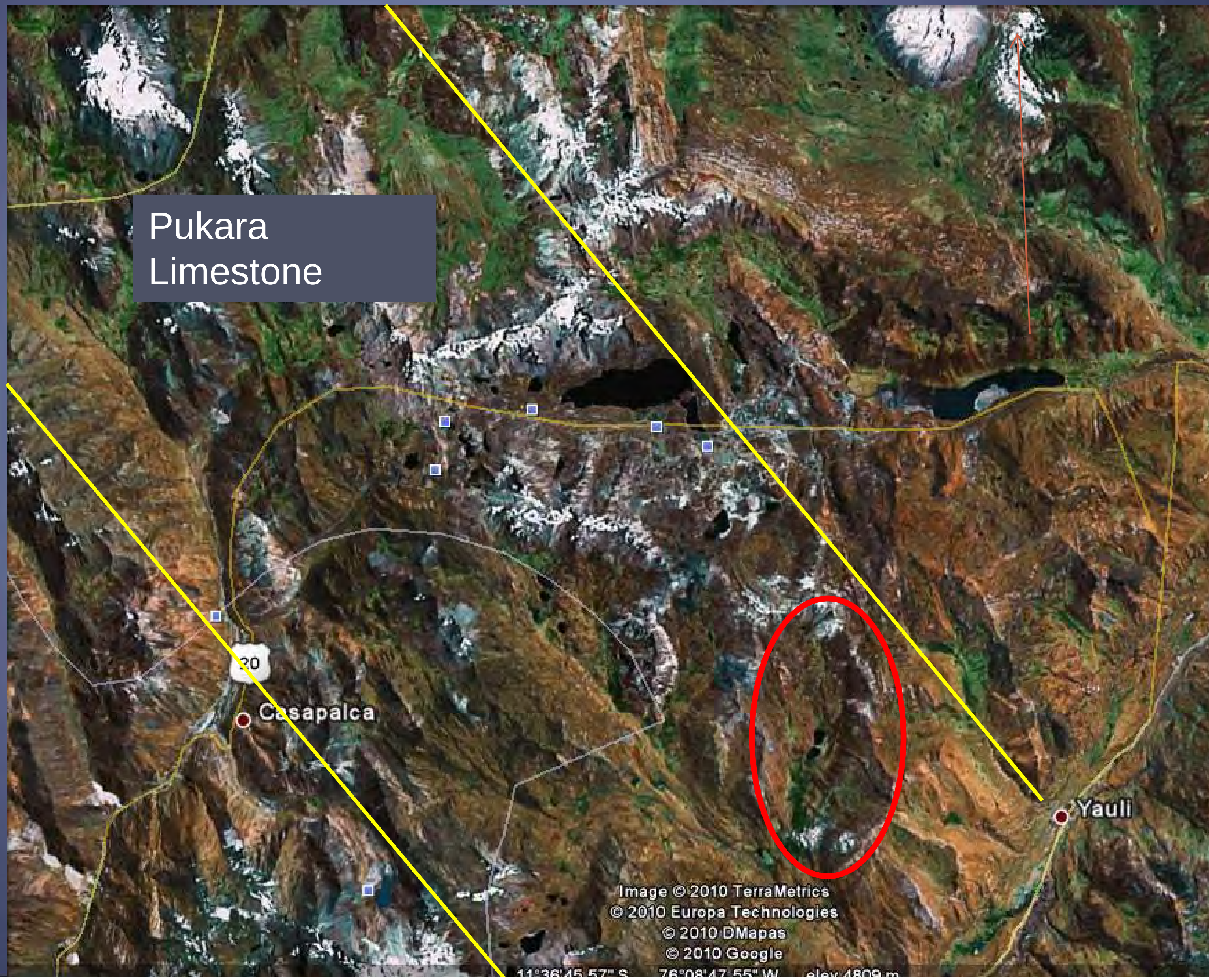

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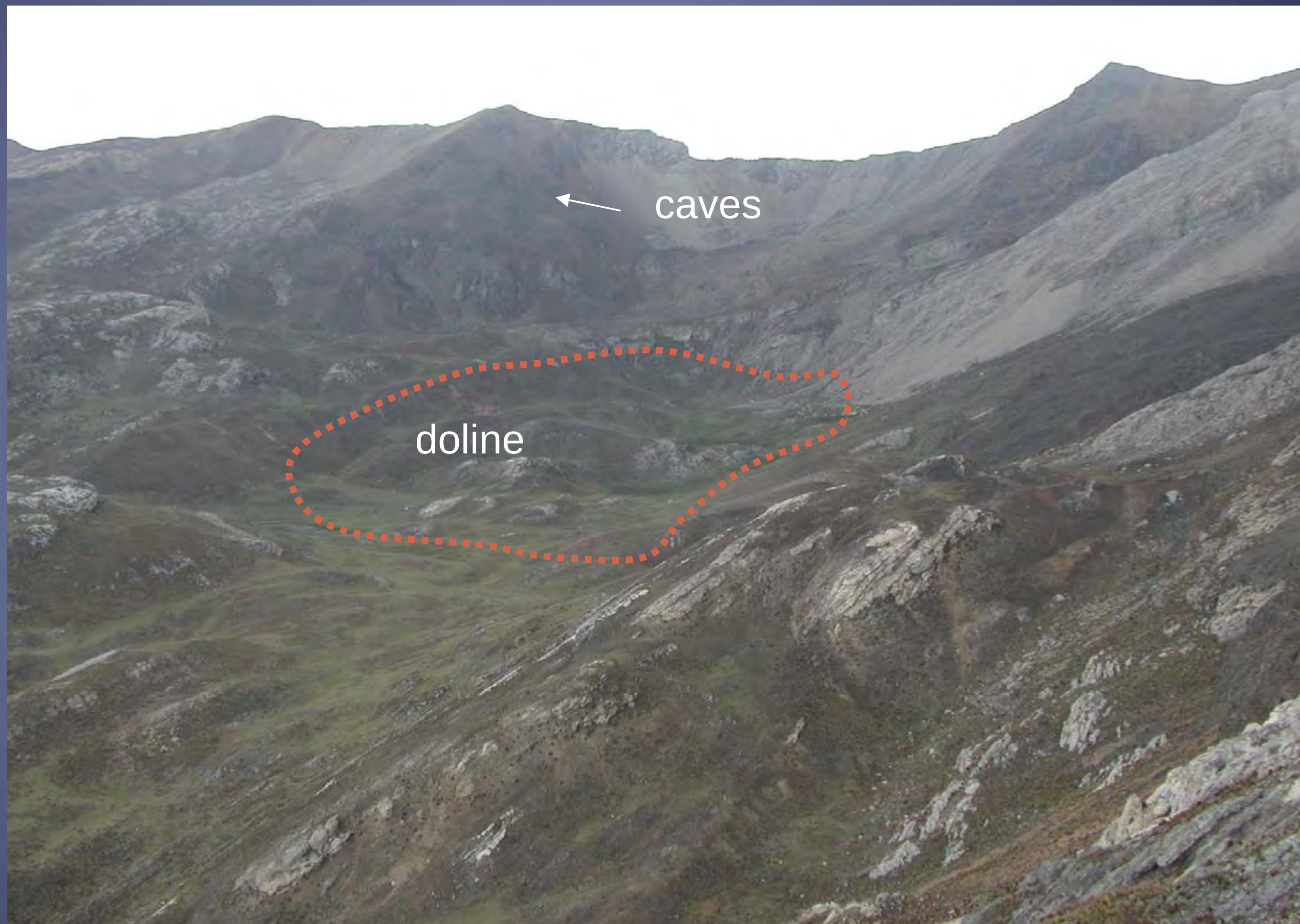

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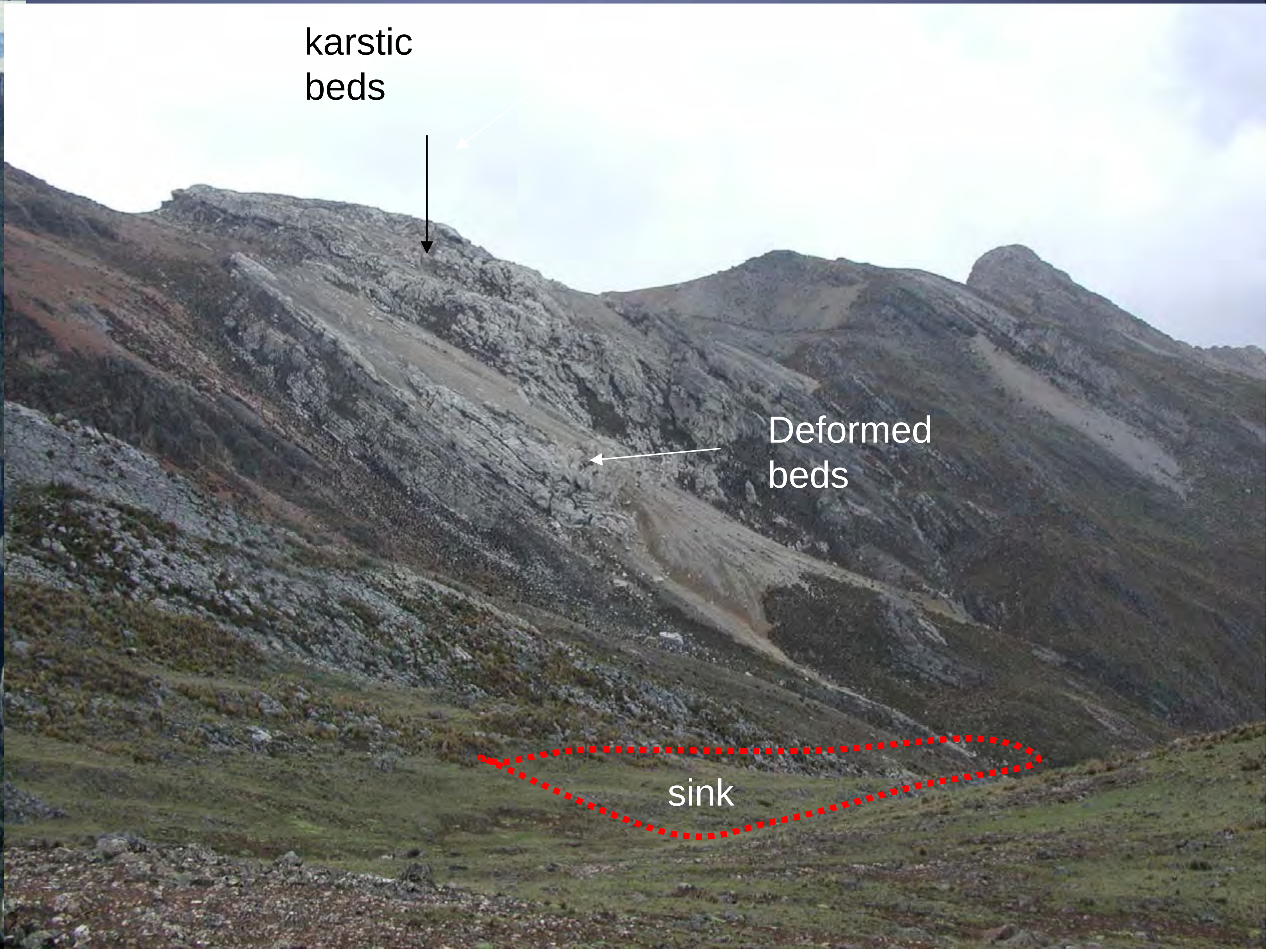

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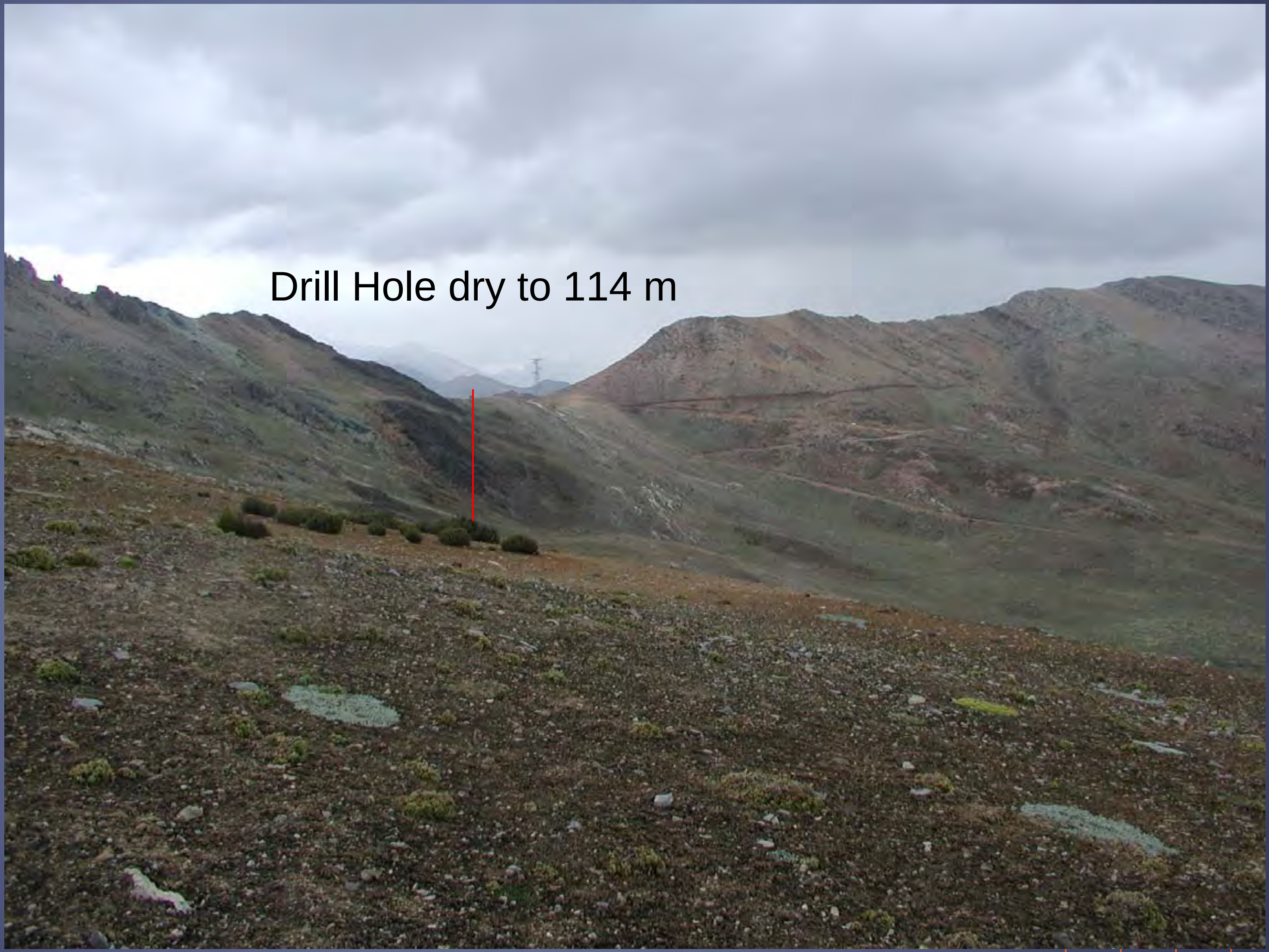

So what is the problem?

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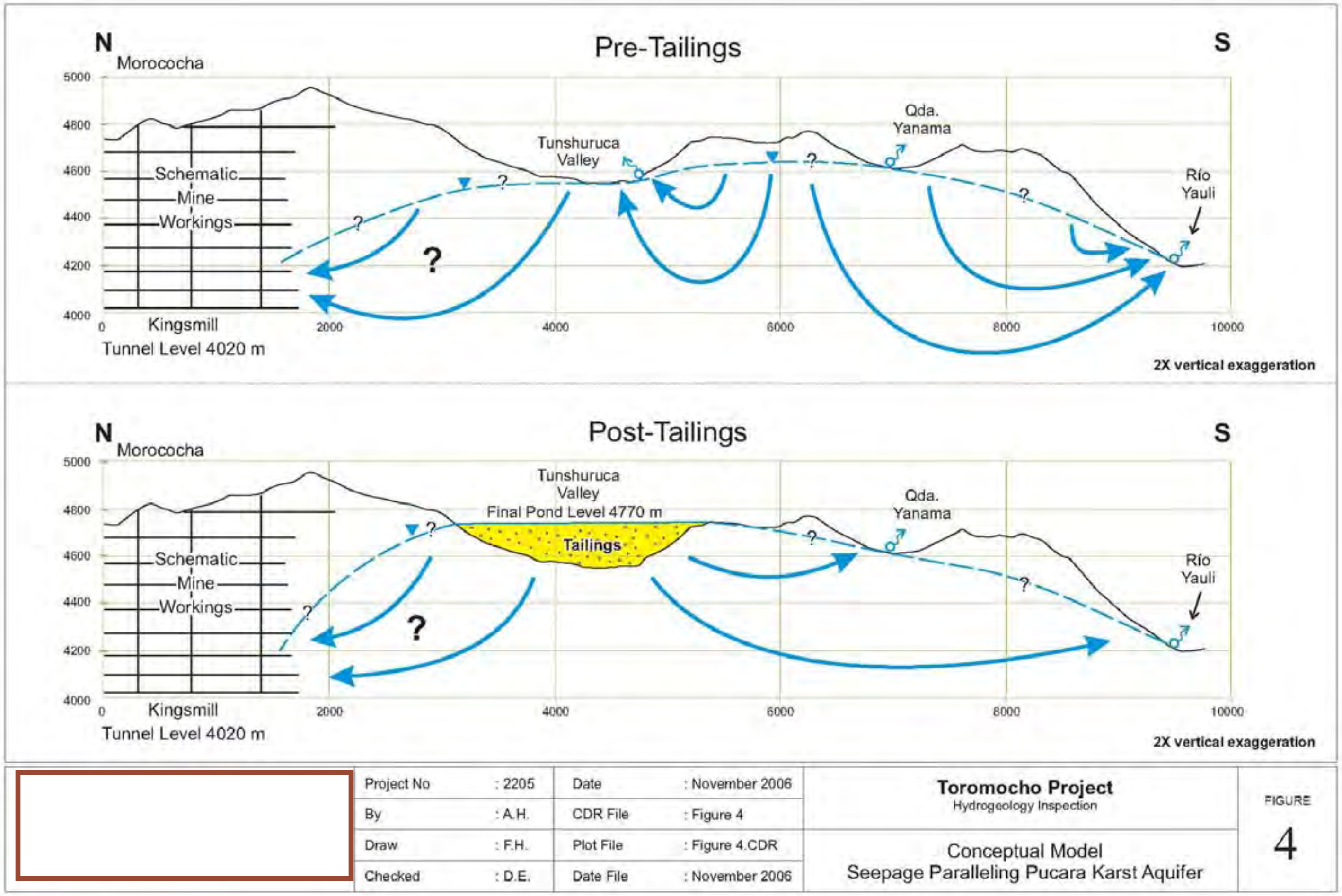

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Springs in the adjacent valley to the tailings

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- The extent of karst formation is unknown.
- Once extent of karst is better defined, then mitigation strategies can be formulated.
- Additional mapping of the surface geology and structural geology is required

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HYDROGEOLOGIC MAPPING

- Compile all available spring mapping for Tunshuruca and west Yauli River valley, including springs along base of Yauli valley.
- Conduct additional spring surveys as needed to address data gaps
- Data collected will include coordinates, elevation, estimated flow, temperature, pH, electrical conductivity
- Confirm location and elevation of travertine deposits in Rio Yauli valley

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The new owners are going to use paste tailings to fill the valley and the karst mapping project was cancelled.

It rains hard here…

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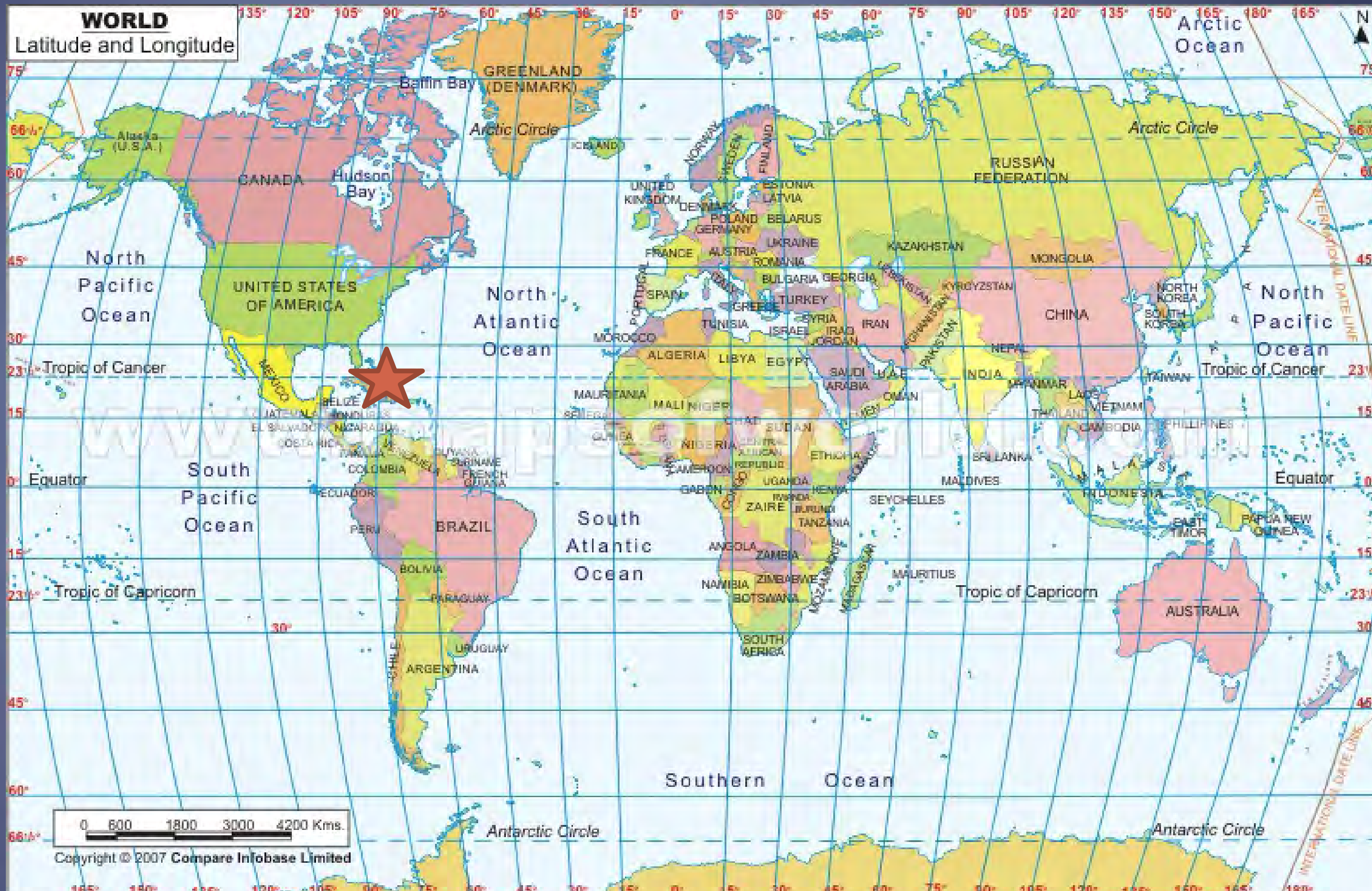

PUEBLO VIEJO

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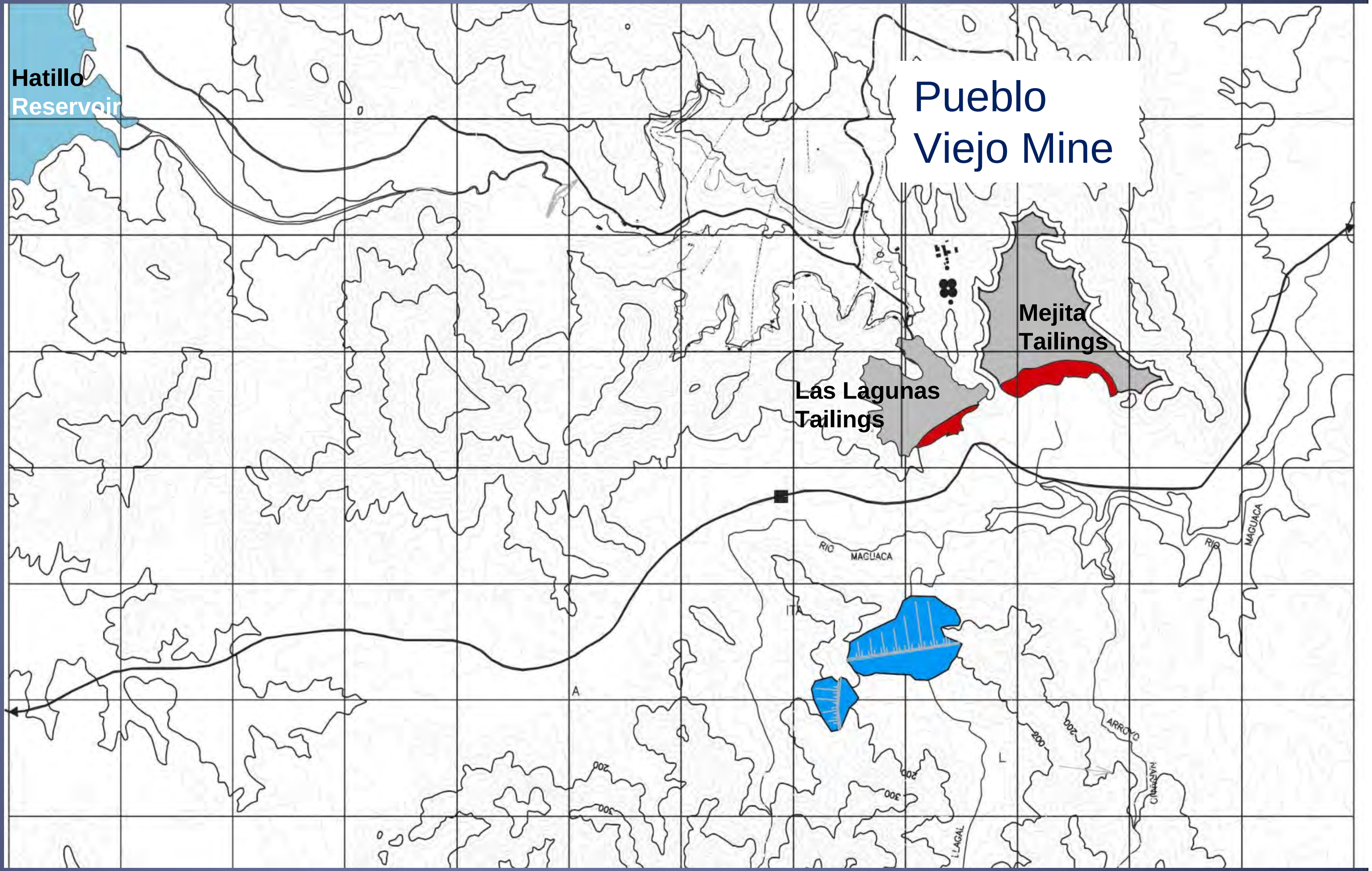

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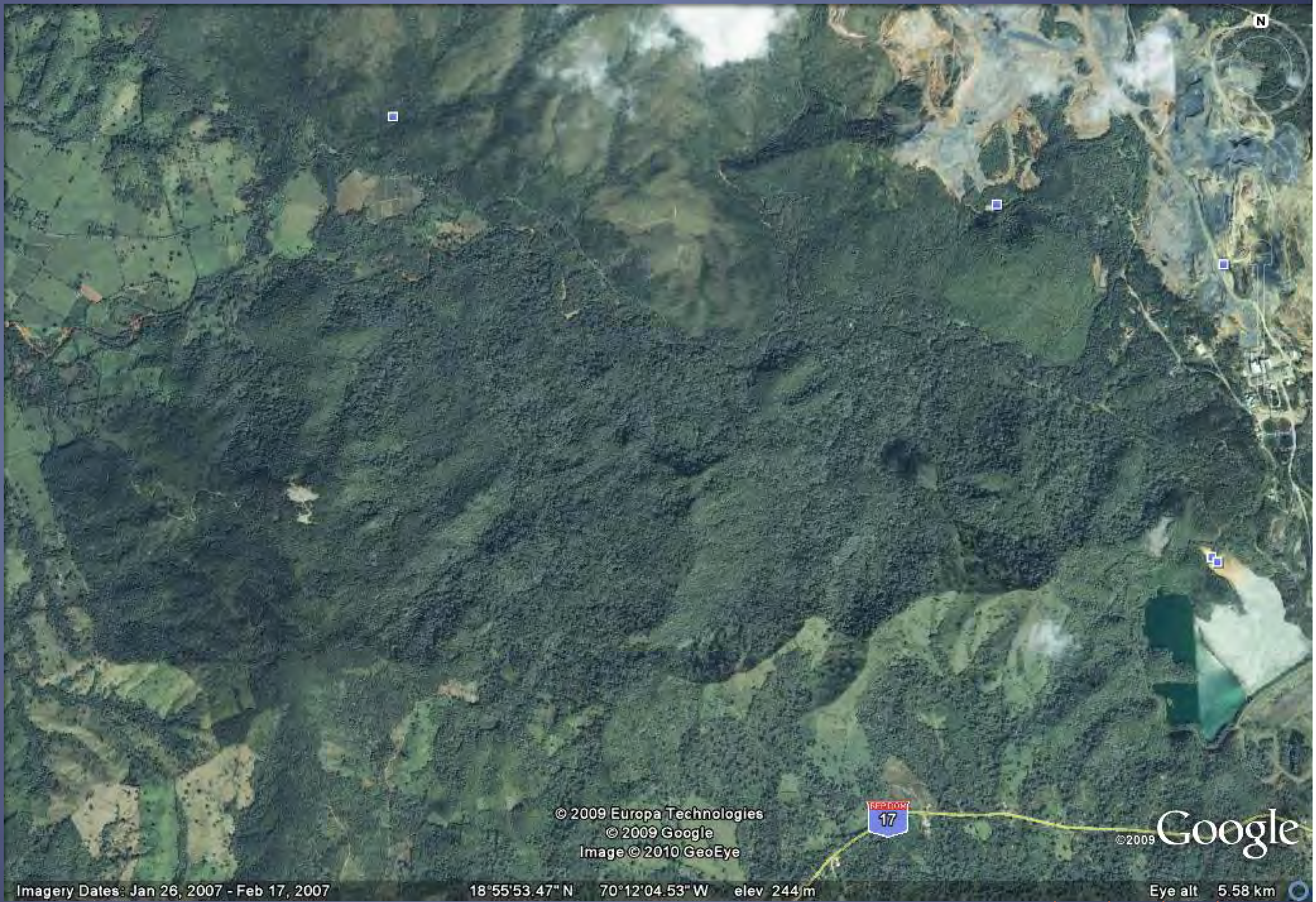

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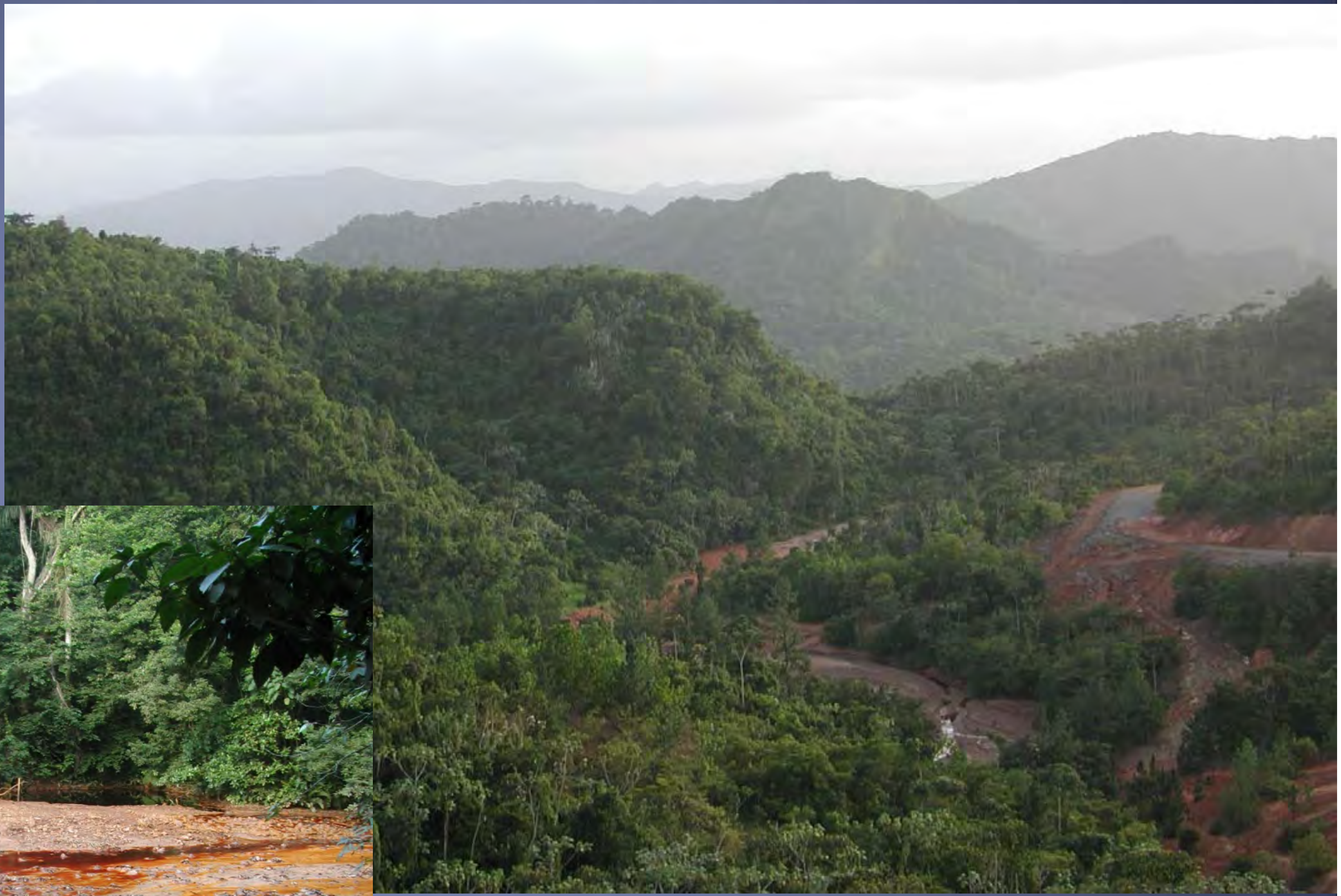

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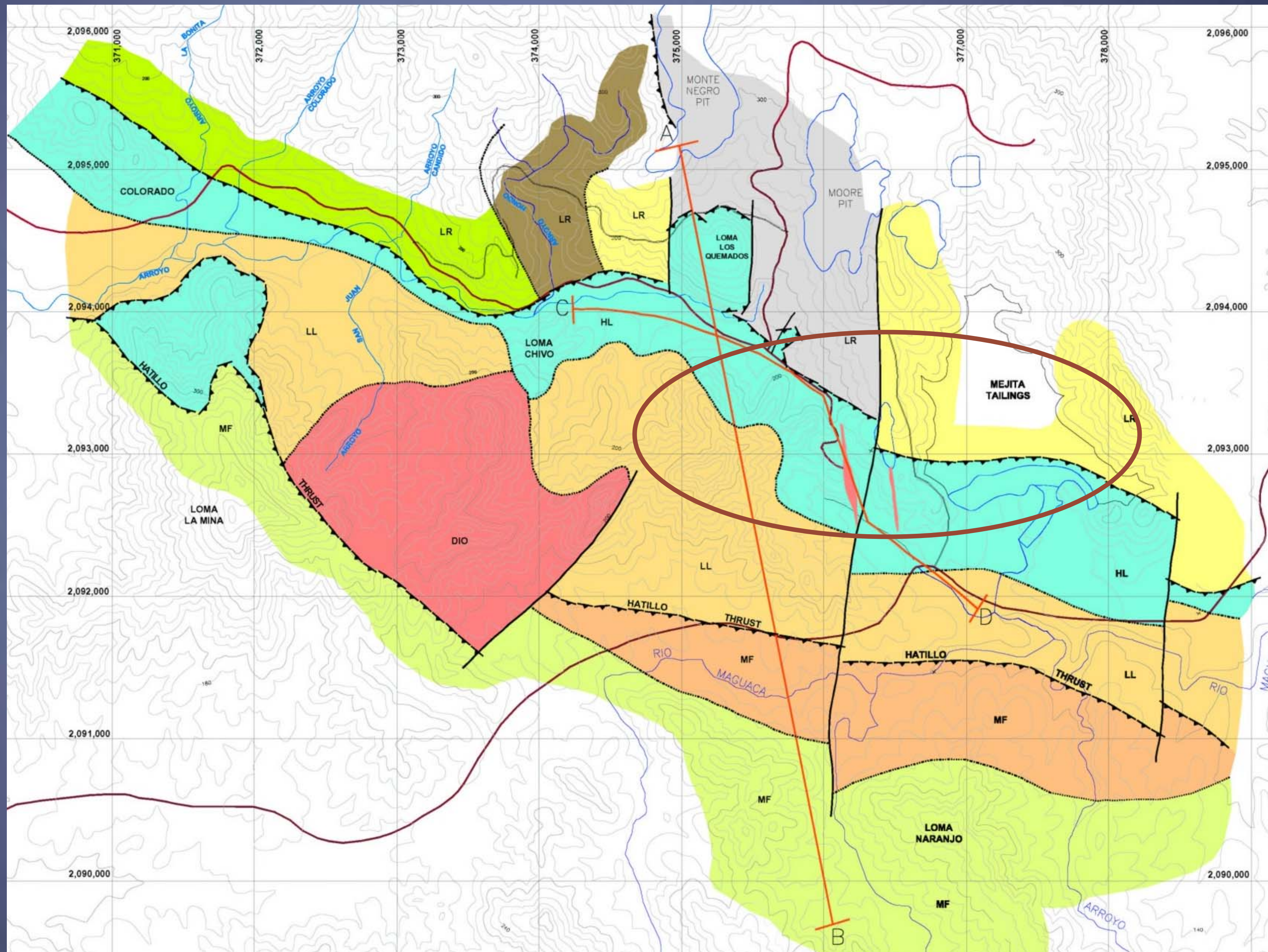

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You've got to know when to hold up, know when to fold up, know when to walk away, know when to run….

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the influence of karst on tailings dams ATACAMA DESERT

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Galore Creek, B.C.

Drilling didn't find this karst, only walking and mapping did…

the influence of karst on tailings dams Guidelines for you

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