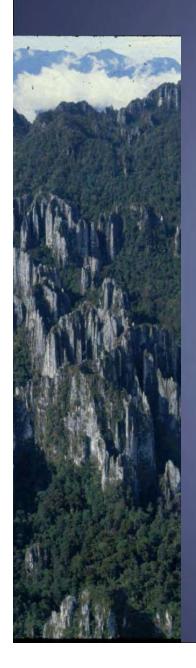


Karst, and it's influence on Tailings Dams I have known and loved



- •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?

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").

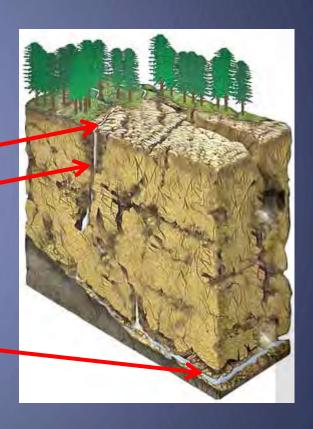




a distinctive geomorphic unit caused by dissolution of soluble bedrock (usually limestone, dolomite or marble, and, to a lesser extent, evaporites),

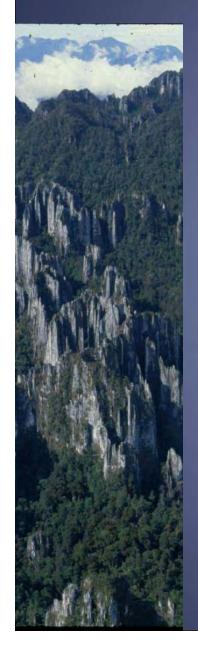
Landscape is characterized by;

- •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 Limestone Carbonatites,

Gypsum, Dolostone (igneous rocks

Anhydrite composed of

Halite minerals)

Outliers include Monominerallic siliceous rocks that form karst very slowly



Evaporites form the soft rock end of the spectrum

Halite NaCl

Gypsum Ca SO4

Anhydrite Ca So4.2H2O

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.



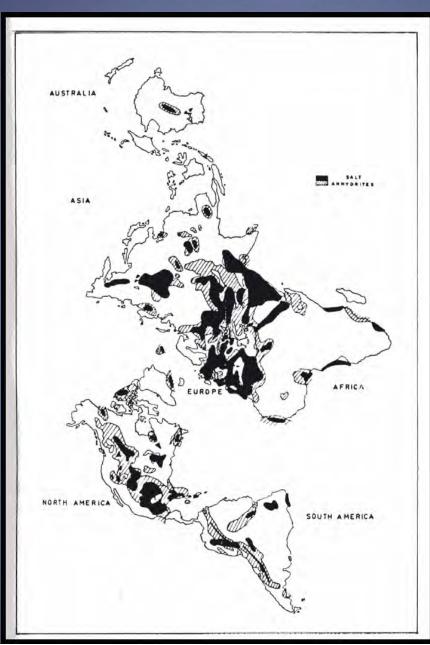
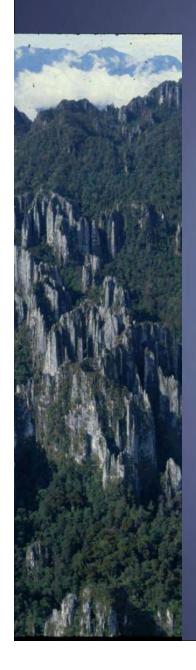


Figure 1.-Global occurrence of evaporites

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





Evaporites form the soft end of the spectrum

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

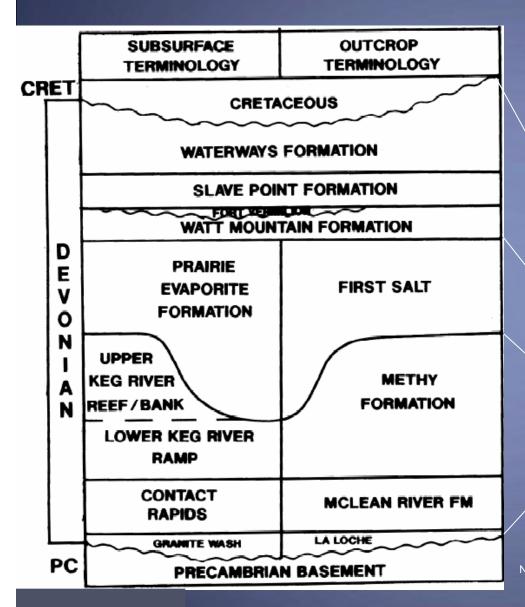
Human activities such as drilling and modifying drainage features have caused rapid development of evaporite karst, primarily in salt deposits.

Soft rock won't support large karst features.

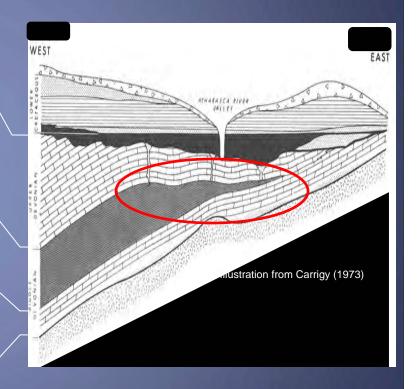
Very rapid dissolution happens within the life of a project

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

Fort McMurray, Alberta

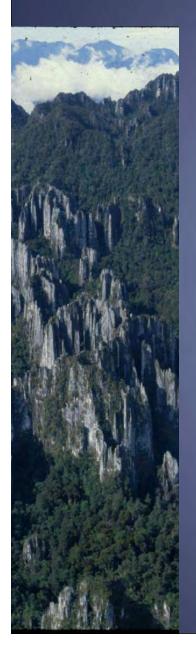


Evaporites removed and reversed dips of overlying bedrock

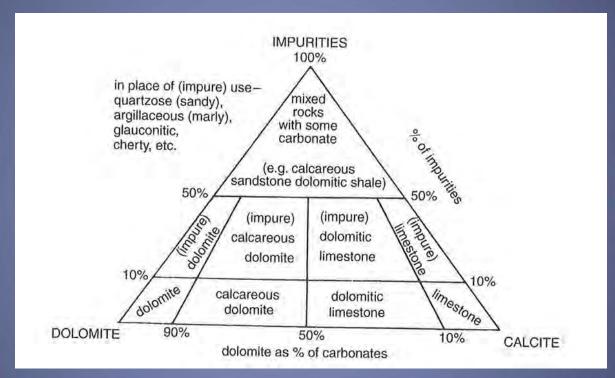


Nomenclature provided by SCG (2009)



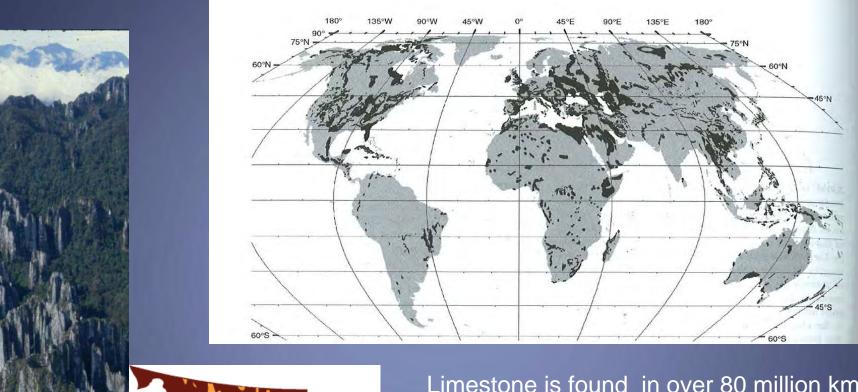


Typically we think of karst in limestones, dolostones, and marbles.



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





Carbonate Bedrock

WWW.for.gov.bc.ca

Limestone is found in over 80 million km<sup>2</sup>, 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

BGC

### Malaysia - Tertiary

### China - Permian

### Brazil - Proterozoic



### INTERNATIONAL STRATIGRAPHIC CHART



on Stratigraphy

_			ICS				Te l	_	_		ternationa	Co nmi	SSIO
Eon	Erathem Era	System	Series	Stage Age	Age	GSSP	Eonothem	Erathem	System	Series Epoch	Stage	Ma Wa	GSSP
	zoic		Holor ene		0.0447	8 88	9	Mesozoic	Jurassic	Upper	Tithonian	45.5 ±4.0	
		Quaternary	P'aistocene	Upper	0.0117 0.126 0.781 1.806						Kimmeridgian	150.8 ±4.0	
				"lonian"							Oxfordiar	~ 155.6	
				Calabrian						Middle	Callovia I	161 2 ± 4.0	
				Gelasian							Bathor an	164.7 ±4.0	8
		<b>o</b>	Pliocene	Piacenzian	2.588	A					Bajo ian	167.7 ±3.5	2
				Zanclean	3,600	A	Phanerozoic				Aal mian	171.6 ±3.0	0
			Miocene	Messinian	5.332	8				Lawer	Tr arcian	175.6 ±2.0	1
		len		Tortonian	7,246	100					Pli nsbachian	183.0 ±1.5	2
anerozoic		Neogene		Serravallian	11.608	2					memilian	189.6 ±1.5	2
				Langhian	13.82						Hinterngran	199.6 ±0.6 203.6 ±1.5 216.5 ±2.0	8
	0 1			Burdigalian	15.97				Permian Triassic	Uppil) Middle	Rhaetian		
	Cer			Aquitanian	20.43	A					Norian		
				Chattian	23.03	S AAAAA A					Camian		
			Oligocene	Rupelian	28.4 ±0.1 33.9 ±0.1						Lartinian	~ 228.7	2
		Paleogene	Eocene	Priabonian							Anistan	237.0 ±2.0	
				Bartonian	37.2 ±0.1 40.4 ±0.2 48.6 ±0.7 55.8 ±0.2					Liwer	Olenekian	~ 245.9	
				Lutetian							Induan	~ 249.5	0
				Ypresian						Lopingian	Changhsingian	251.0 ±0.4	0
Ь			Paleocene	Thanetian							Wuchiapingian	253,8 ±0,7	1
				Selandian	58.7 / 0.2					Guadalupian	Capitanian	260.4±0.7	2
				Danian	~6'.1						Wordian	265.8 ±0.7	A
ı				Maastrichtian	6f.5±0.3			eo zoic			Roadian	268.0 ±0.7	0
	Mesozoic	Cretaceous		Campanian	0.6 ±0.6					Cisuralian	Kungurian	0.303	
				Santonian	83.5 ±0.7						Artinskian	275.6 ±0.7	
			Upper	Coniacian	85.8 ±0.7						Sakmarian	284,4±0,7	
			SOOR	Turonia	~ 88.6						Asselian	294.6±0.8	0
				Cenoma iian	93.6 ±0.8	8		ale	Carboniferous	Widdle Lower Upper	Gzhelian	299.0 ±0.8	0
			Lower	Alb'an	99.6 ±0.9			Pa			Kasimovian	303,4 ±0.9	
				A tian	112.0 ±1.0						Moscovian	307.2 ±1.0	
				Be remian	125.0 ±1.0						Bashkirian	311.7±1.1	A
				H auterivian	130.0 ±1.5						Serpukhovian	318.1 ±1.3	0
				/alanginian	~ 133.9					V diddle	Visean	328.3 ±1.6	1
				Bernasian	140.2 ±3.0 145.5 ±4.0					Low Y	Tournaisian	345.3 ±2.1 359.2 ±2.5	2

Eonothem	Erathem Era	System	Series Epoch	Stage	Age	GSSP
			Descrip	Famennian	359.2 ±2.5	8
	H		Upper	Frasnian	374.5 ±2.6	
		ian	A Property Co.	Givetian	385.3 ±2.6	88
	П	on	Middle	Eifelian	391.8 ±2.7	4
	ш	Devonian		Emsian	397.5 ±2.7	a
	П		Lower	Pragian	407.0 ±2.8	36
	Ш			Lochkovian	411.2 ±2.8	A
			Pridoli		416.0 ±2.8	88
				Ludfordian	418.7 ±2.7	8
			Ludlow	Gorstian	421.3 ±2.6	8
		ian	1000	Homerian	422.9 ±2.5	8
		Silurian	Wenlock	Sheinwoodian	426.2 ±2.4	8
		S		Telychian	428.2 ±2.3	8
0	0		Llandovery	Aeronian	436.0 ±1.9	8
0	zoic			Rhuddanian	439.0 ±1.8	8
0	2			Himantian	443.7 ±1.5	-
Phanerozoic	e 0		Upper	Katian	445.6 ±1.5	2
_		au		Sandbian	455.8 ±1.6	8
4	Ра	Ordovician		Candolan	460.9 ±1.6	8
۵		ê	Militale	Daniuminu	468,1±1.6	8
		ō		Plates	471.8 ±1.6	888
		n	Lower	Floian	478.6 ±1.7	0
		_		Tramadocian	488.3 ±1.7	1
			A 100 A 100 A	Stage 10	~ 492 * ~ 496 *	
			Furon ian	Stage 9		1.2
				Paibian	~ 499	0
		au	Series 3	Guzhangian	~ 503	333
		ğ		Drumian	~ 506.5	8
		am		3 age 5	~510*	
		0	Series 2	Stay 9 4	~515*	
			Julius 2	Stage 1	~521 *	
			Terreneuvian	Stage 2	- 528 *	
			retremenylati	Fortunian	5 12.0 ±1.0	8

This chart was drafted by Gabi Ogg, Intra Can, rian unit ages with \* are informal, and awaiting ratified definitio. 's.

Copyright @ 2009 International Commission on Startigraphy

	Eonothem Fon	Erathem	System	Age	GSSP
			Ediacaran	- 542 - -635	A
		Neo- proterozoic	Cryogenian	850	0
		Process and	Tonian	1000 1200 1400 1600 1800 2050	00
	Oic	Barrier I	Stenian		0
	rozoic	Meso- proterozoic	Ectasian		3
	Sei	<b>P</b> ASSO ASSO	Calymmian		9
_	Pro		Statherian		@@@
a		Paleo-	Orosirian		0
=		proterozoic	Rhyacian		0
Ĕ			Siderian	2500	0
Precambrian		Neoarchean		2800	0
	Pari	Mesoarchean			
	Arch	Dalvankan		3200	①
	A	Paleoarchean		3600	①
			4000		
	1	Hadean (ir	4000		
~	W	icione of the o	••••	~4600	

Subdivisions of the global geologic record are formally defined by their lower boundary. Each unit of the Phanerozoic (~542 Ma to Present) and the base of Ediacaran are defined by a basal Global Boundary Stratotype Section and Point (GSSP A whereas Precambrian units are formally subdivided by absolute age (Global Standard Stratigraphic Age, GSSA). Details of each GSSP are posted on the ICS website (www.stratigraphy.org).

Numerical ages of the unit boundaries in the Phanerozoic are subject to revision. Some stages within the Cambrian will be formally named upon international agreement on their GSSP limits. Most sub-Series boundaries (e.g., Middle and Upper Aptian) are not formally defined.

Colors are according to the Commission for the Geological Map of the World (www.cgmw.org).

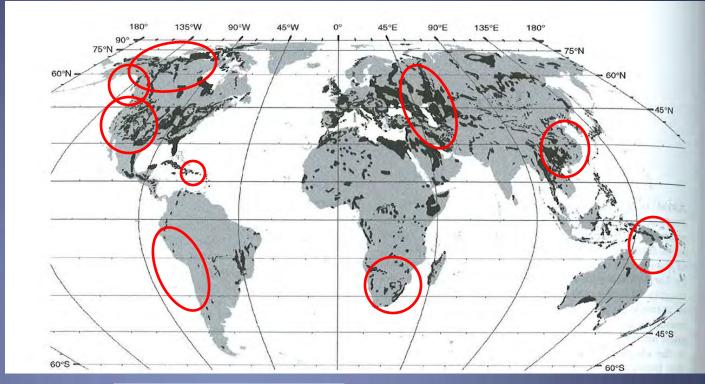
The listed numerical ages are from 'A Geologic Time Scale 2004', by F.M. Gradstein, J.G. Ogg, A.G. Smith, et al. (2004; Cambridge University Press) and "The Concise Geologic Time Scale" by J.G. Ogg, G. Ogg and F.M. Gradstein (2008).

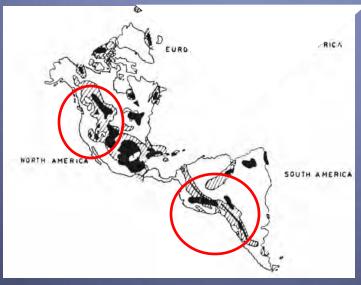
August 2009

Europe - Mesozoic Great Britain - Carboniferous

USA - Pennsylvania -

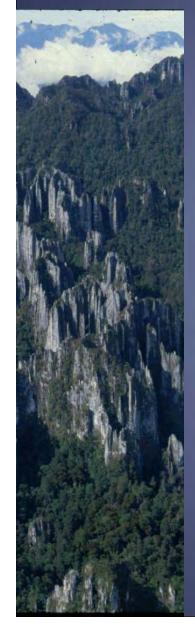






Mining Areas overlying Karst areas suggest the chance of encountering chance of karst are about 1 in 3 to 1 in 5.

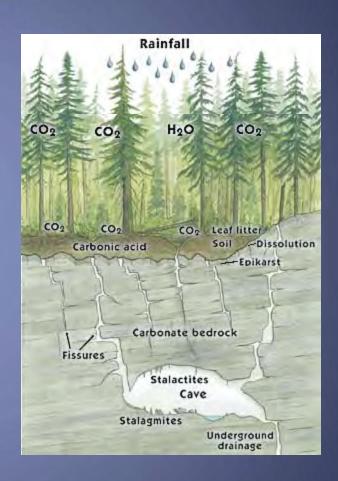
BGC



How does karst form?

CO<sub>2</sub> Cascade

 $H_2O + CO_2 = H_2CO_3$  $H_2CO_3$  dissolves  $CaCO_3$ 



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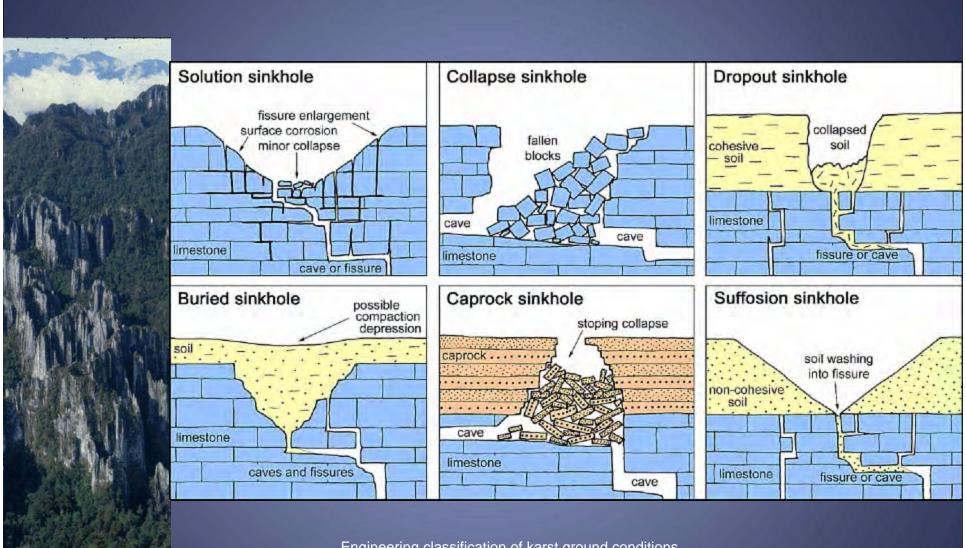






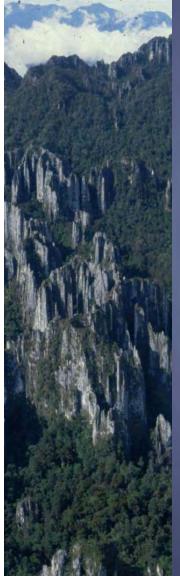
Typically karst initiates along structures such as joints, faults and bedding planes





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





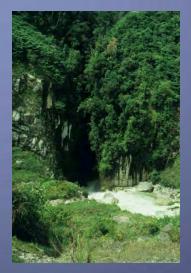
Rate of dissolution varies with temperature, amount of organics in the soils and rock type

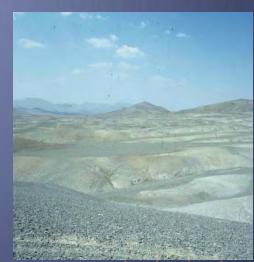
In the north karst forms more easily than for the same precipitation in the south

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

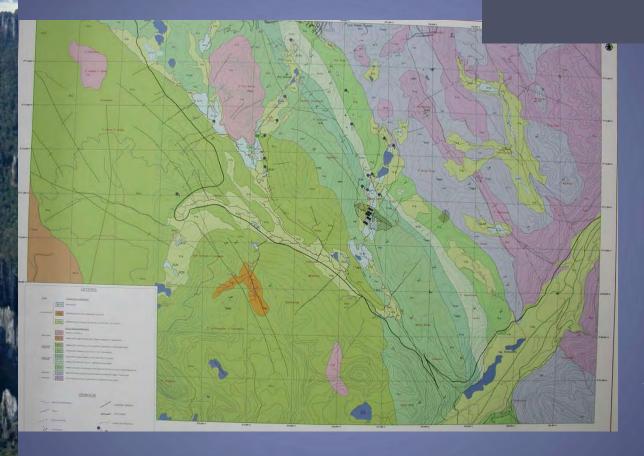






How do we recognize karst?

Geology map



When you encounter clay shale, assume  $\Phi$  residual and prove otherwise.

Cruden, Morgenstern, and Thompson

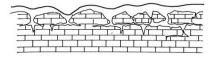
When you encounter carbonates, assume karst until proven otherwise!



### How do we recognize it?

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

### 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 rounded in flat-laying beds, elongated in tilted beds.

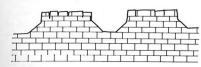
### Drainage Internal



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 indistinct transitional boundaries with other, surface water system. Major streams follow associated sedimentary rocks. Sinkholes are angular alignments of old jointing patterns. Typical sinkholes average 10 to 40 feet in depth and 50 to 500 feet in width.

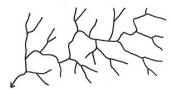
### Arid

### 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.

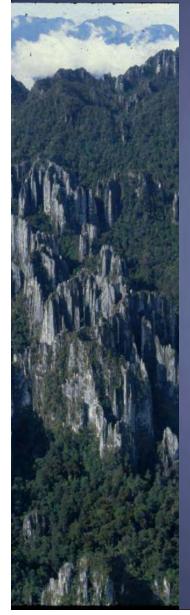
Angular dendritic: Medium to fine

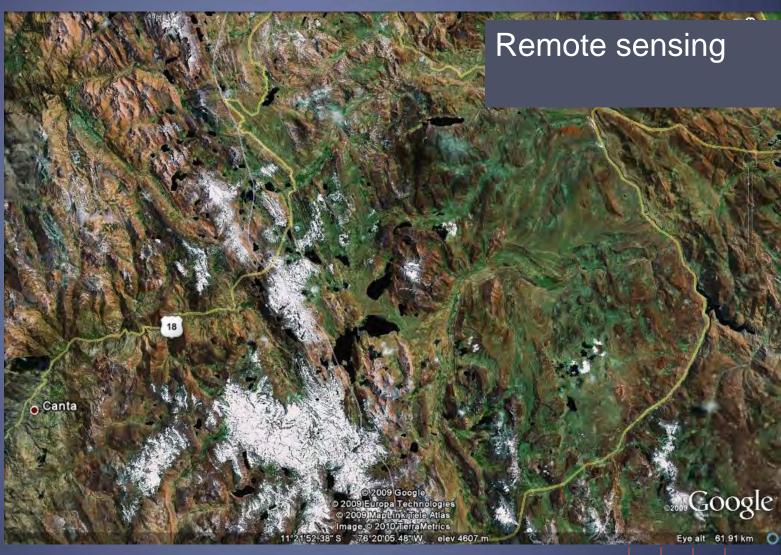


The surface drainage system is well developed (karst topography does not exist in arid climates.) The pattern is very angular, following jointing alignments in the bedrock, and is medium to fine textured. All but major streams are intermittent.

### Topographic map







Dry valleys, lakes with no drainage, barren ground

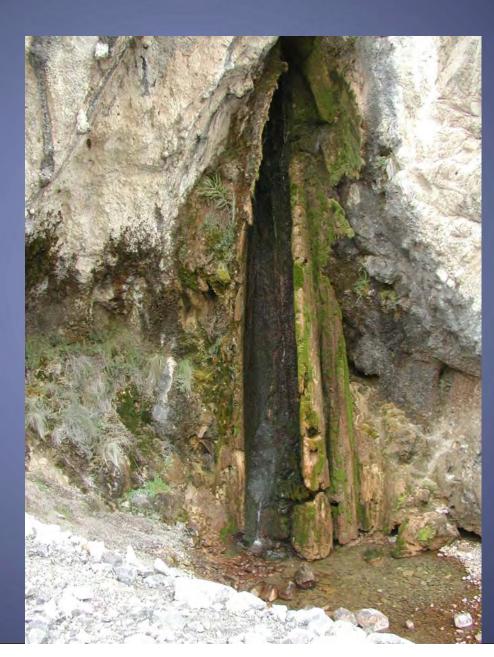
BGC



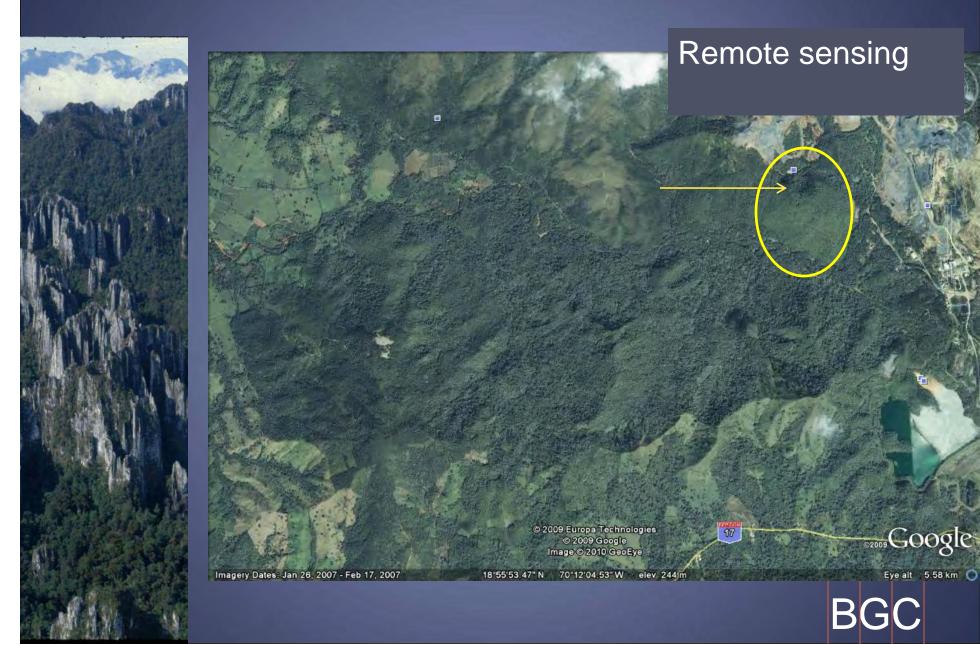
Sinkholes and collapsed dolines

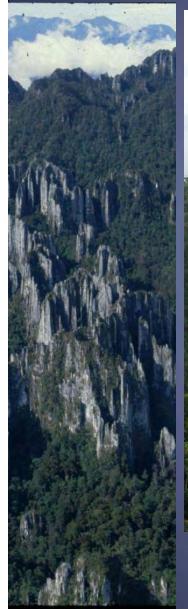


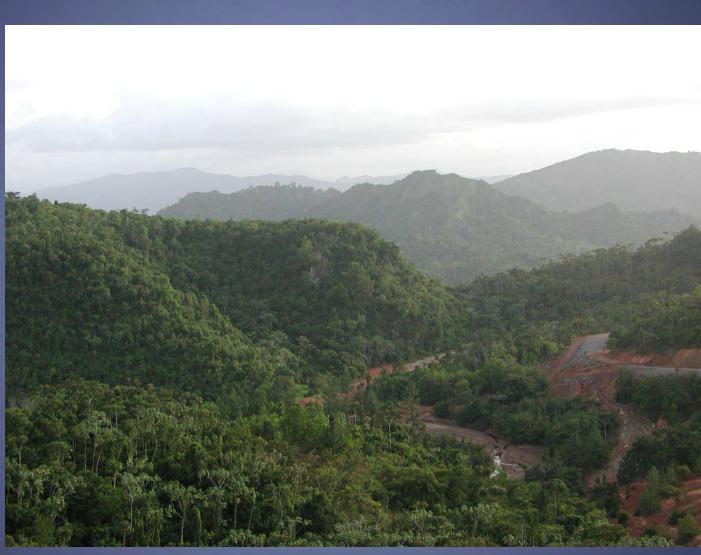




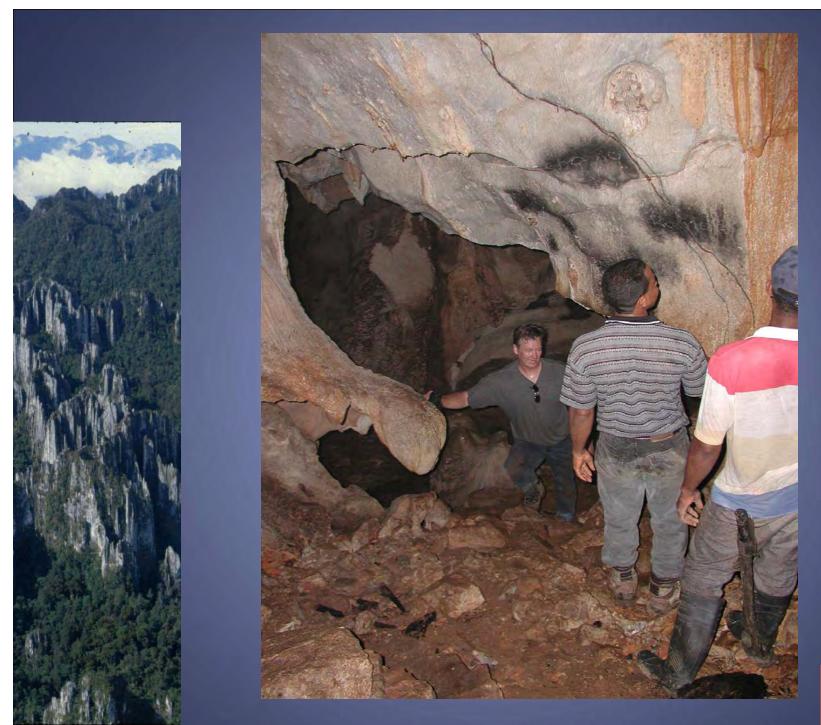
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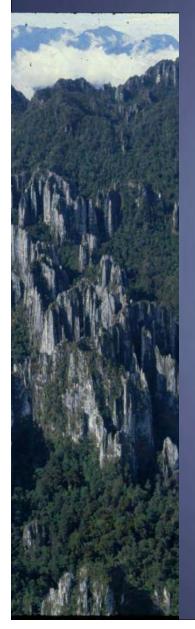




BGC



BGC



How do we explore for karst?



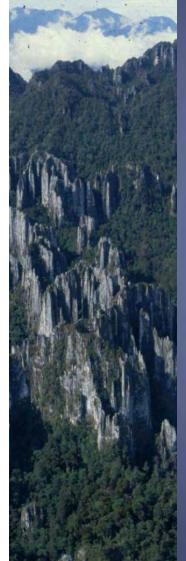
Drilling?

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...





# drilling

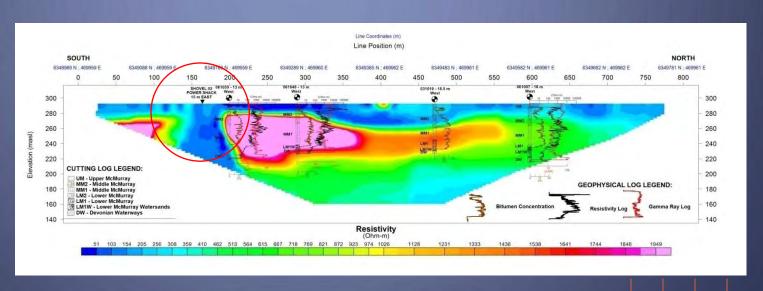
Drilling the chances are remote and if you do hit a cave the chances are pretty high you have swiss cheese



Geophysics?

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

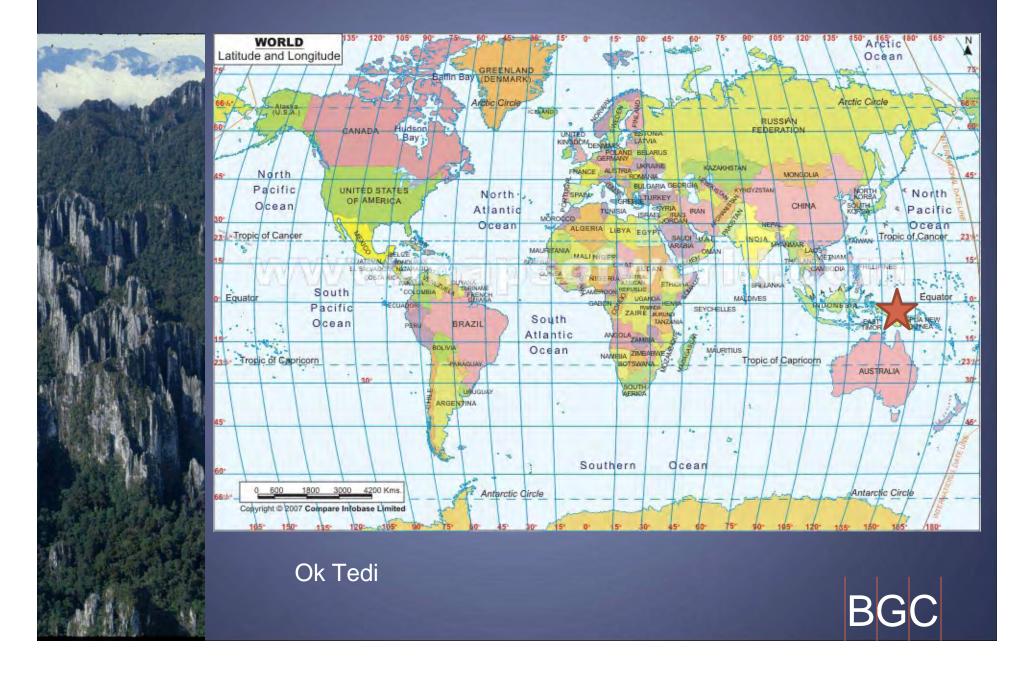
Nothing successful for finding karst although delineating karst you know is there is possible.

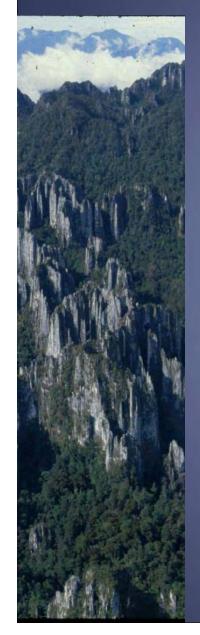














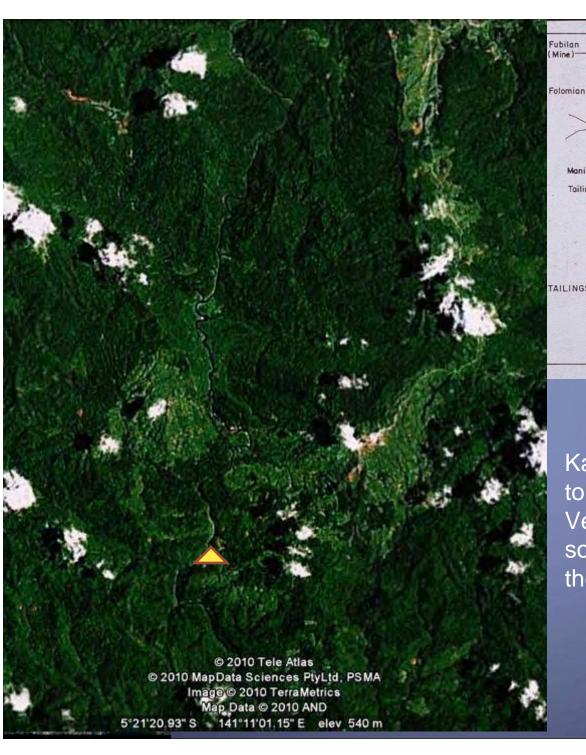
People go to PNG just to explore the karst...

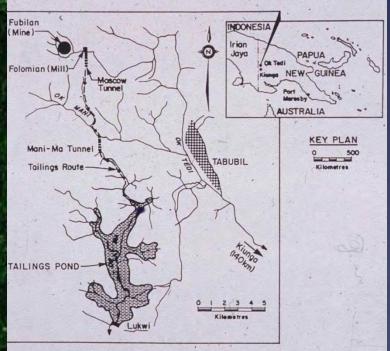












Karst here is much tougher to find.
Vegetation masked it so you had to get on the ground.

BGC



Warre Limestone

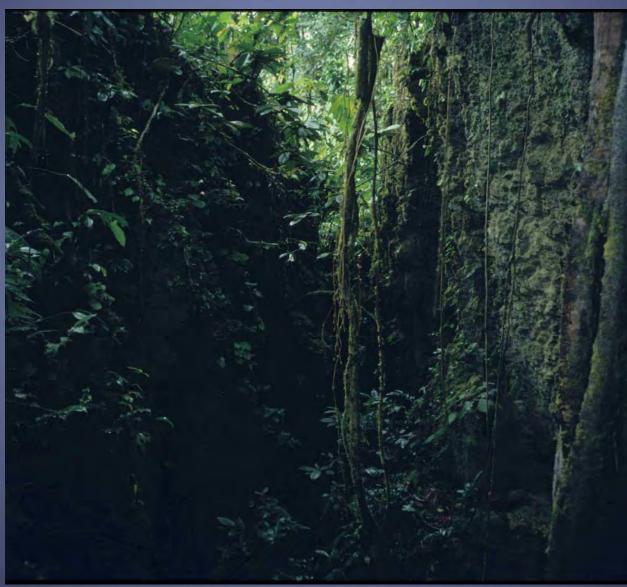
Dreaded Pnyang





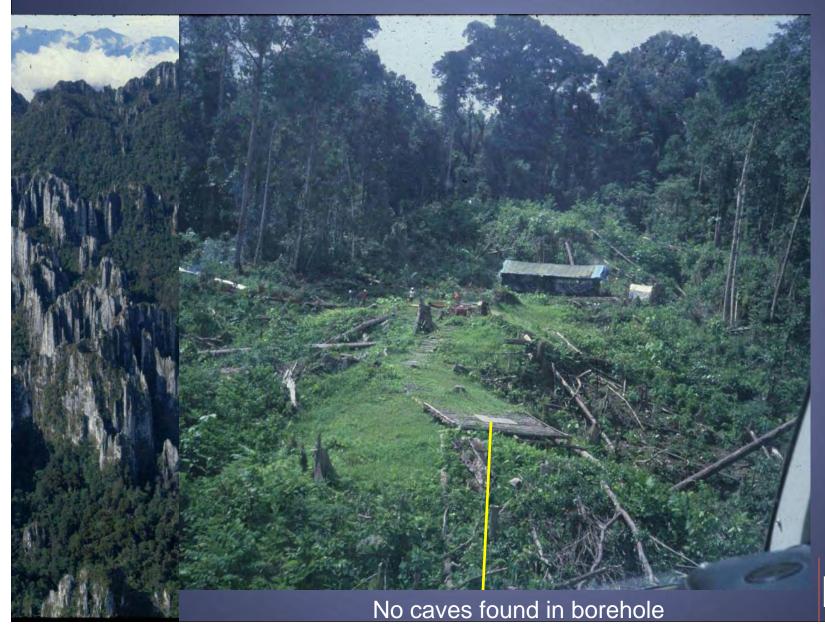




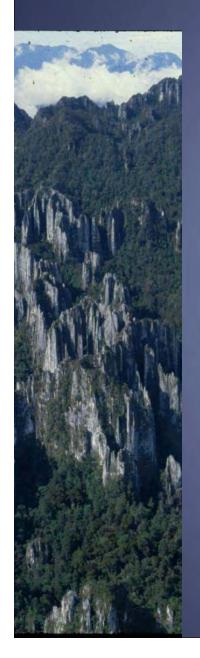


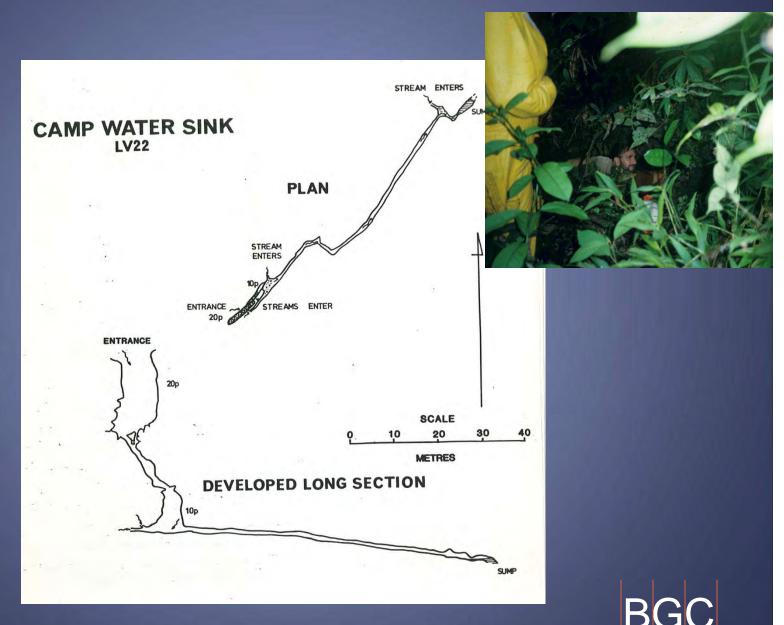
Crevices at the top

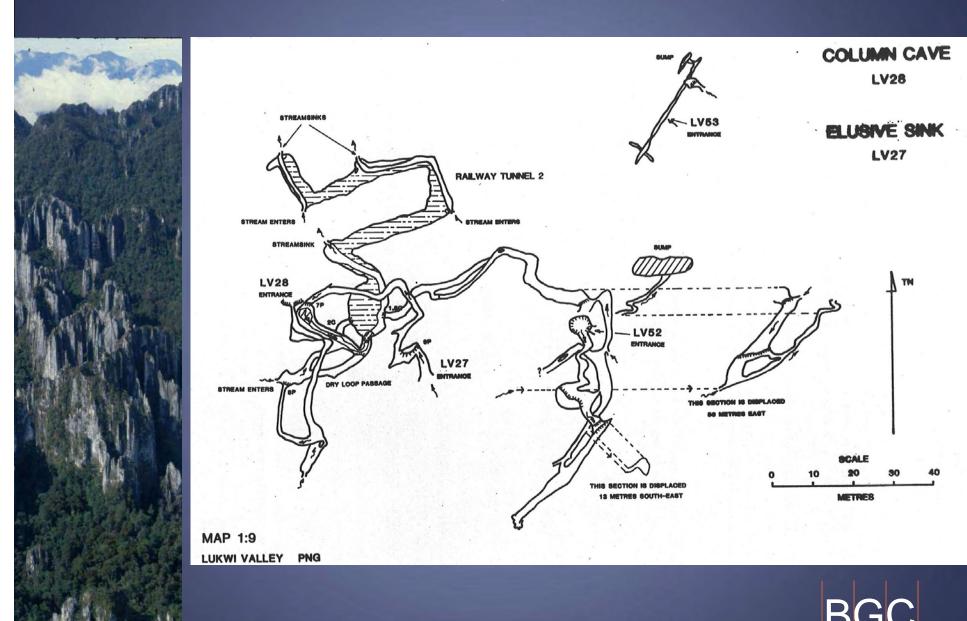




Sinkholes invisible through trees



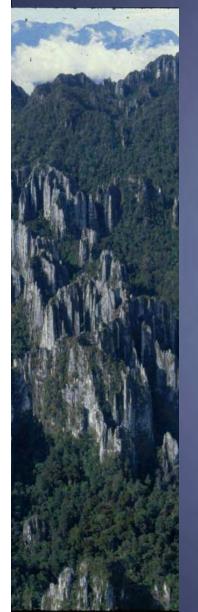


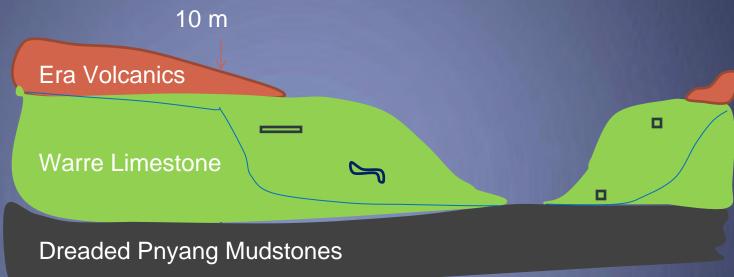






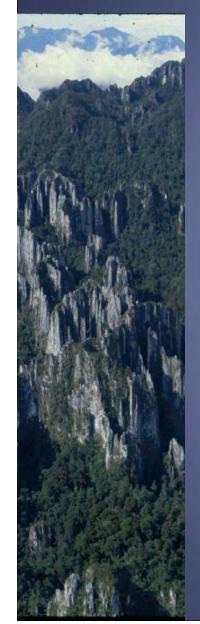


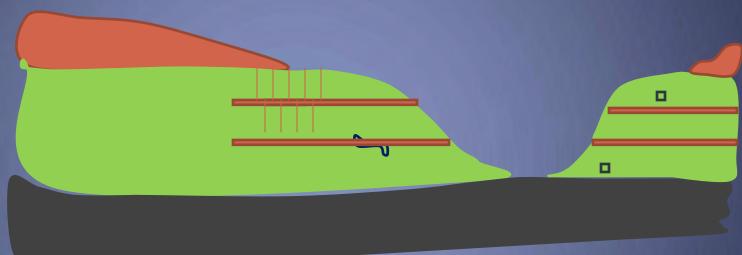




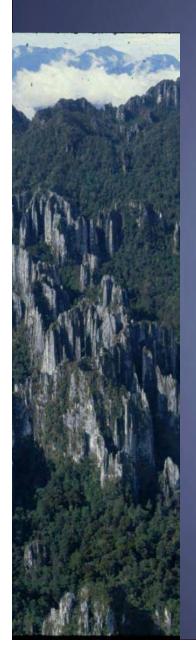
Drilling did not materially find caves but piezometric readings confirmed the lowered water level surfaces





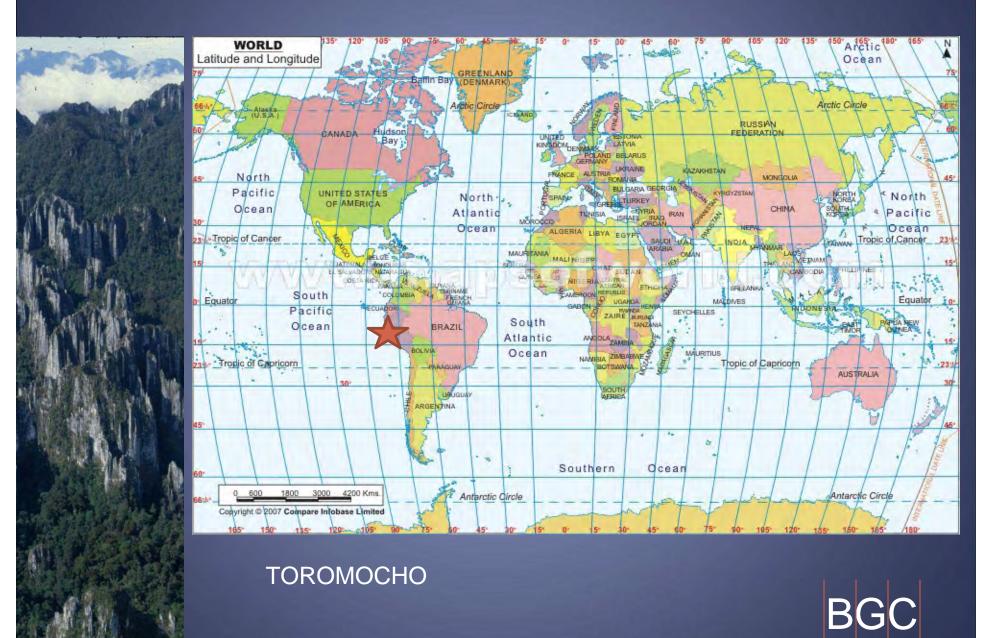


Drive adits at 1/3 valley heights, intercept any caves and build a concrete wall then drill and grout a curtain both up and down.



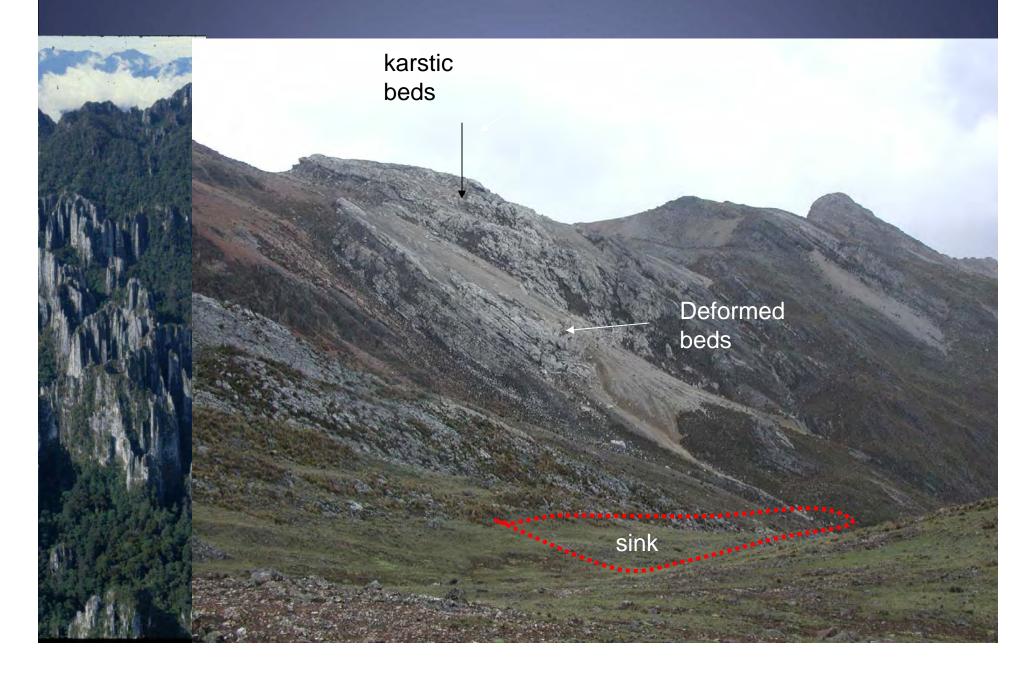
Never built due to other priorities

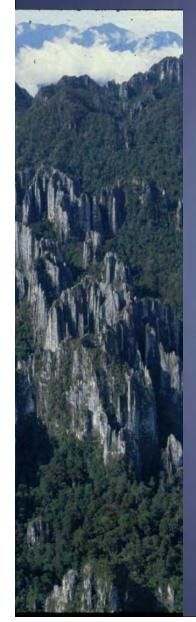
### the influence of karst on tailings dams

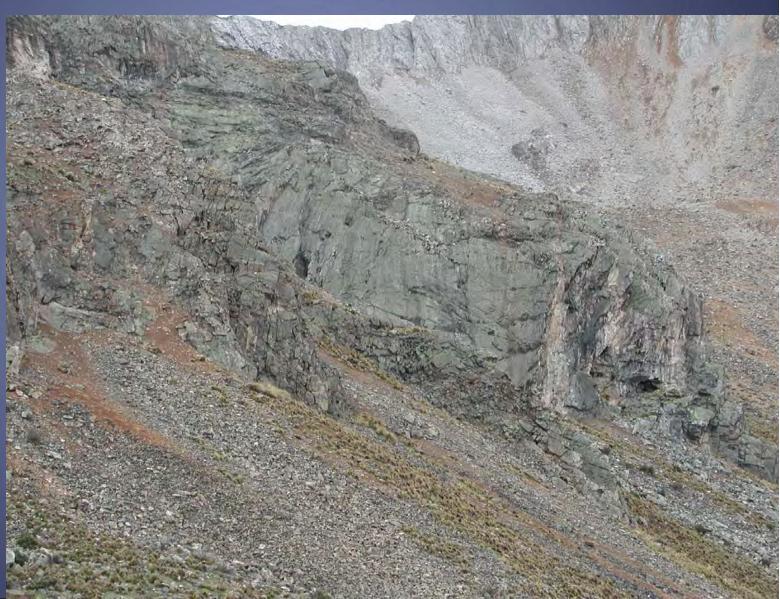
















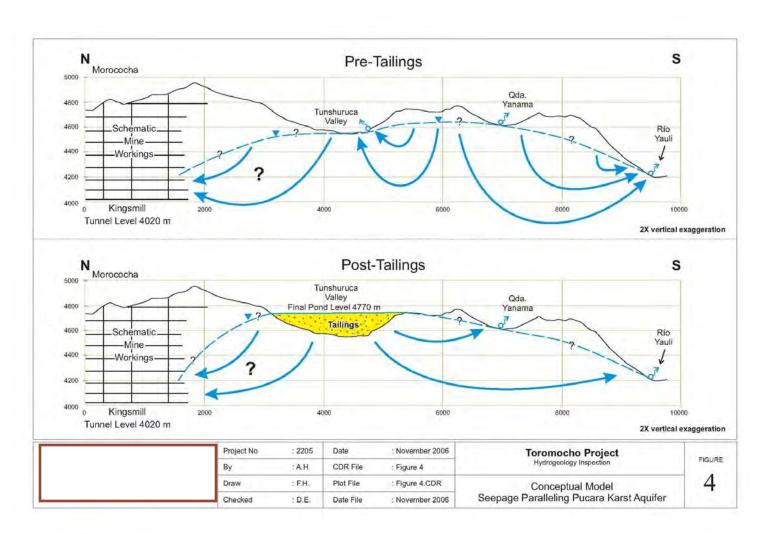






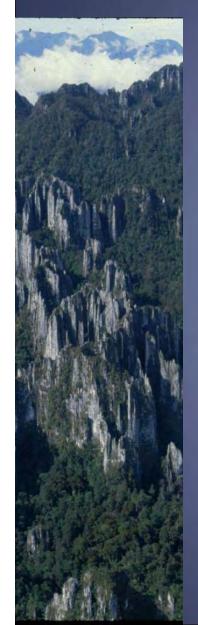
So what is the problem?



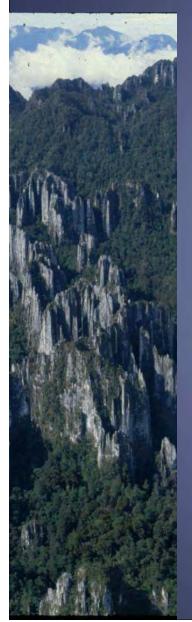






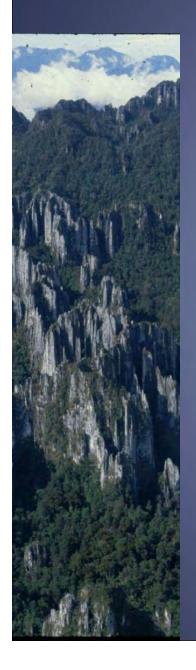


- The extent of karst formation is unknown.
- Once extent of karst is better defined, then mitigation strategies can be formulated.
- Additional mapping of the surface geology and structural geology is required



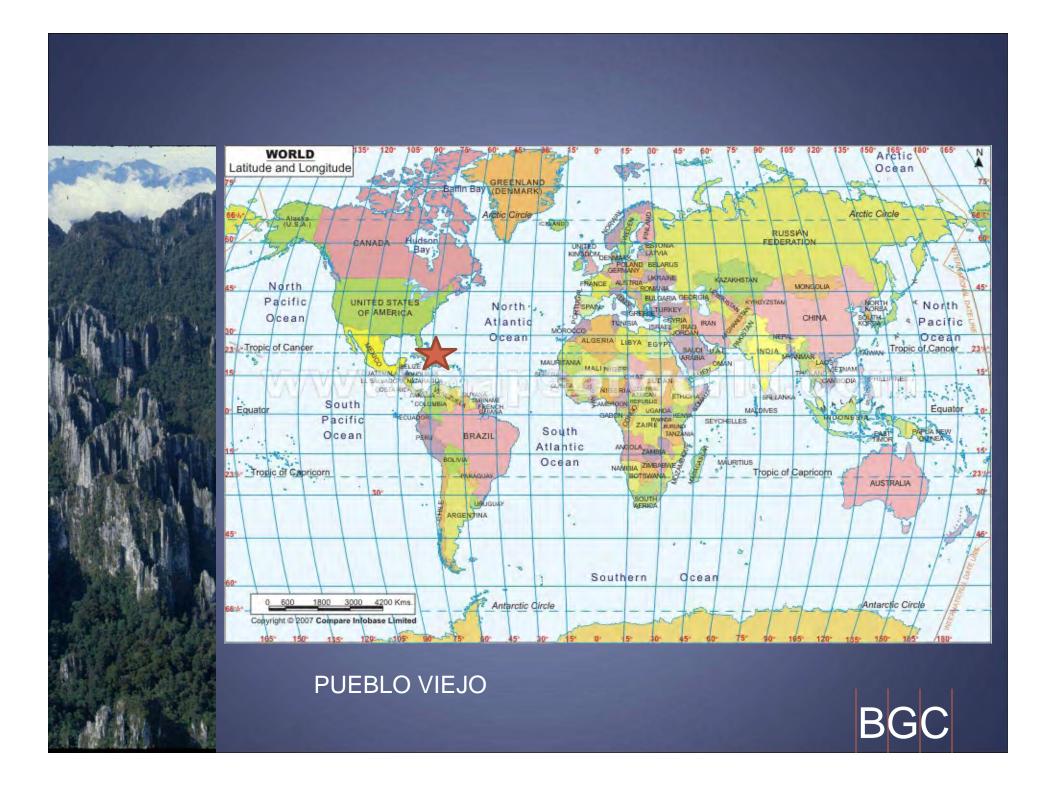
#### **HYDROGEOLOGIC MAPPING**

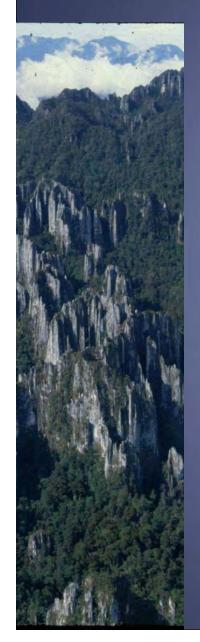
- Compile all available spring mapping for Tunshuruca and west Yauli River valley, including springs along base of Yauli valley.
- Conduct additional spring surveys as needed to address data gaps
- Data collected will include coordinates, elevation, estimated flow, temperature, pH, electrical conductivity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

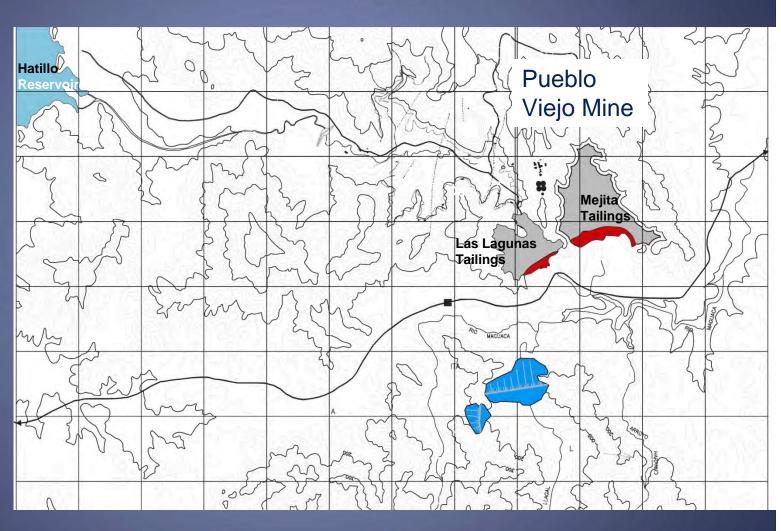


The new owners are going to use paste tailings to fill the valley and the karst mapping project was cancelled.

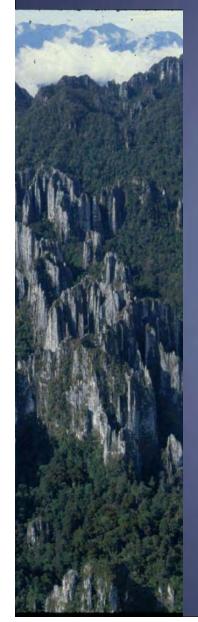
It rains hard here...

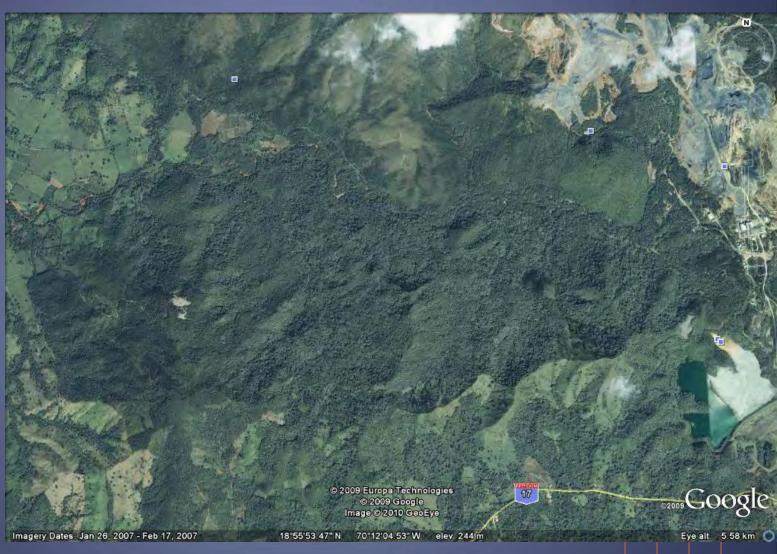




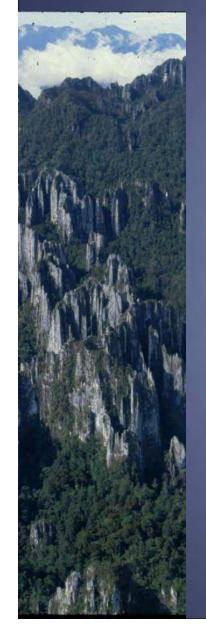






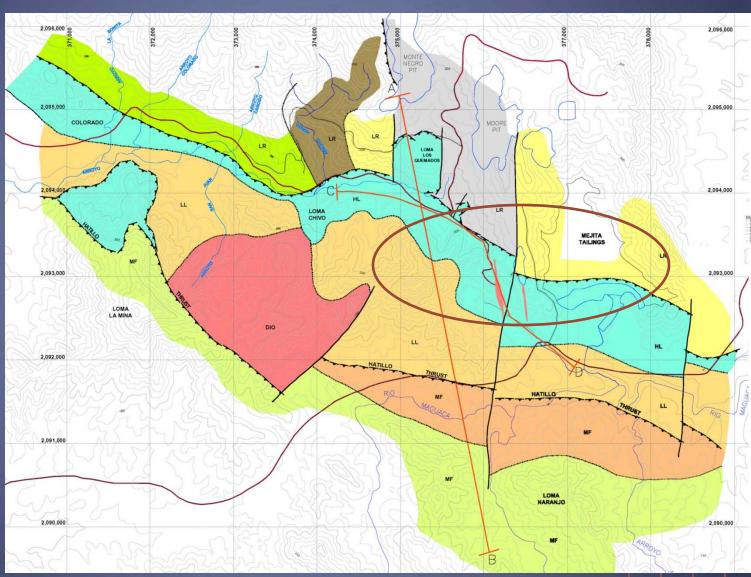


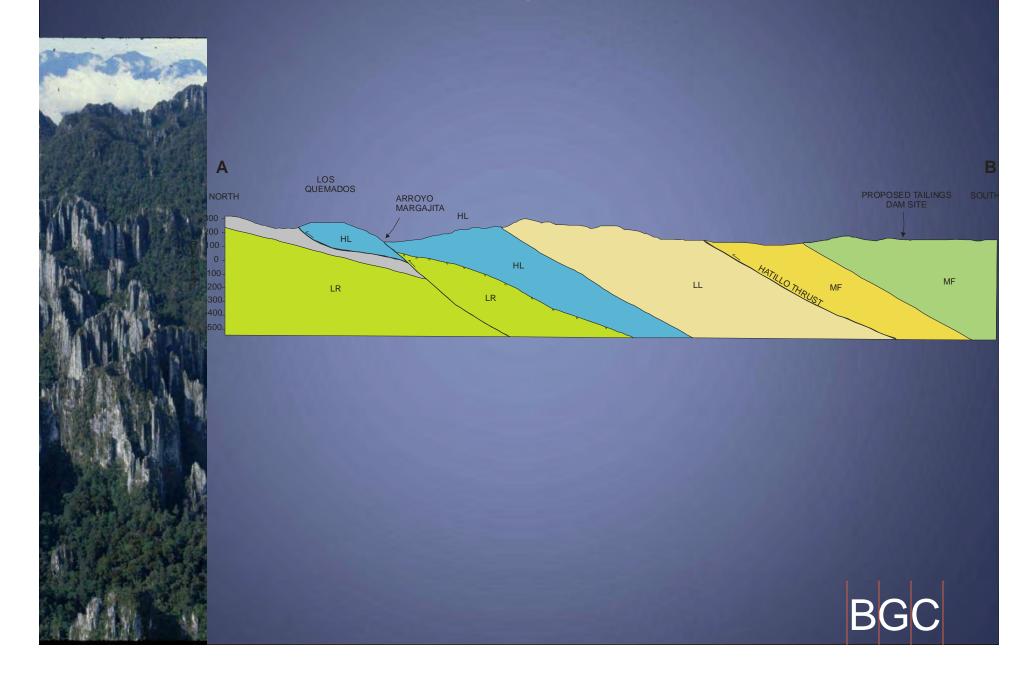






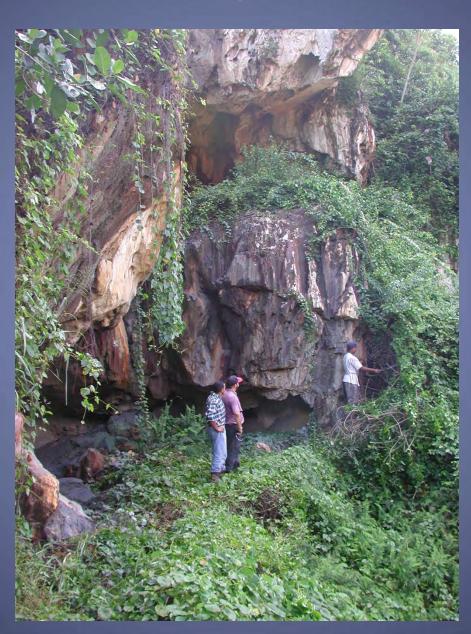








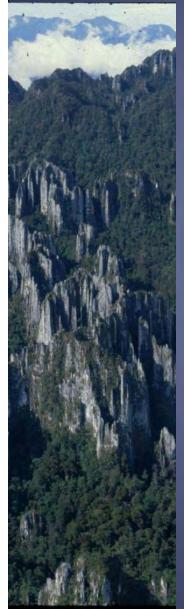


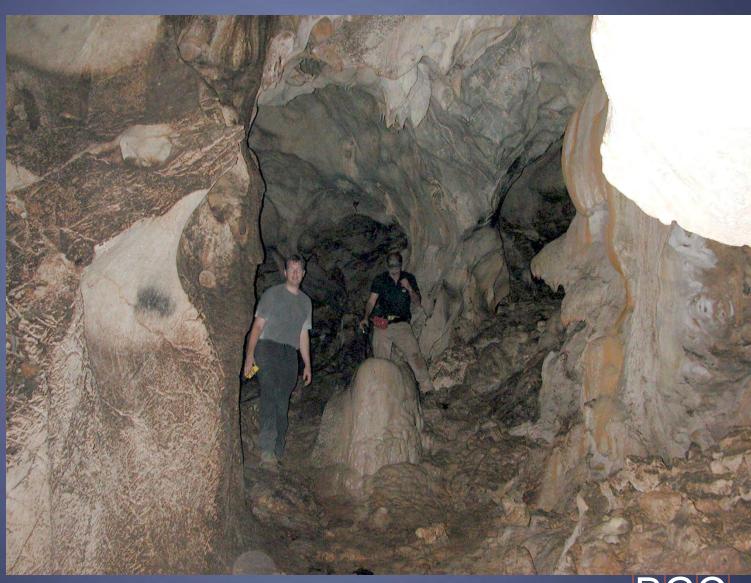




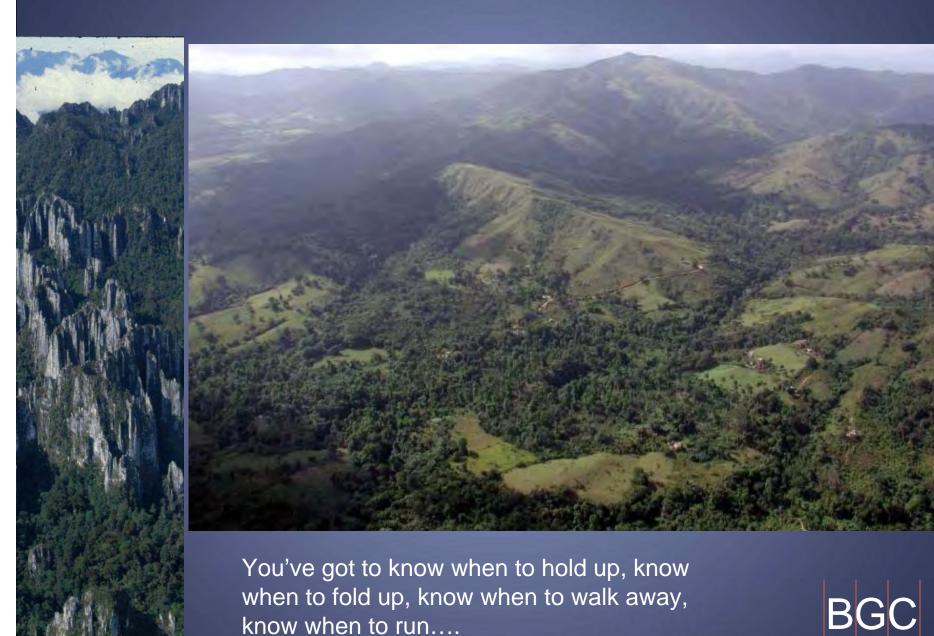












## the influence of karst on tailings dams ATACAMA DESERT









### the influence of karst on tailings dams Guidelines for you



