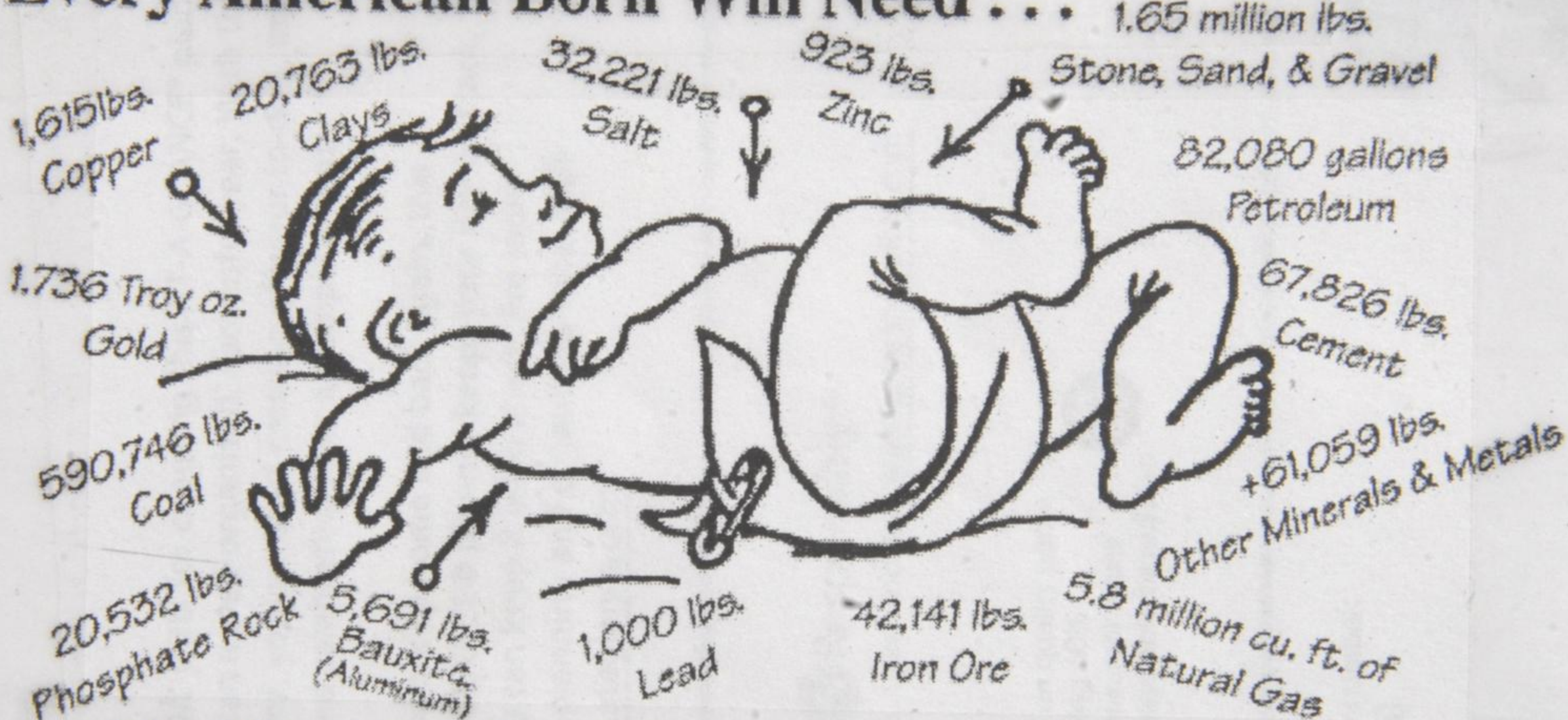
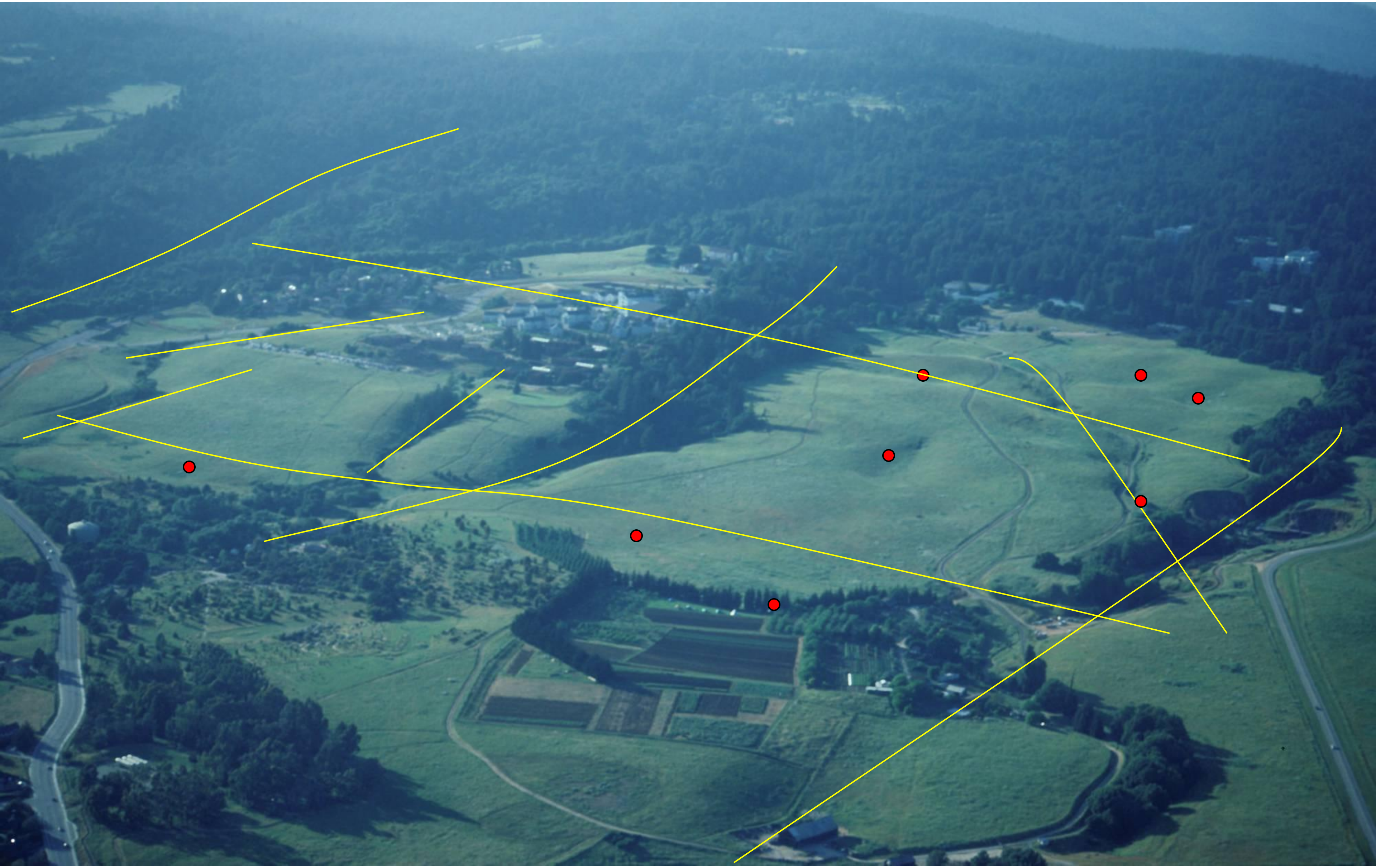
Every American Born Will Need . . .



3.6 million pounds of minerals, metals, and fuels in a lifetime


KARST LANDSCAPES
Geology & Hydrology
Dr. Gerald E. Weber



Aerial Oblique Photograph of the UCSC Campus – looking northwest

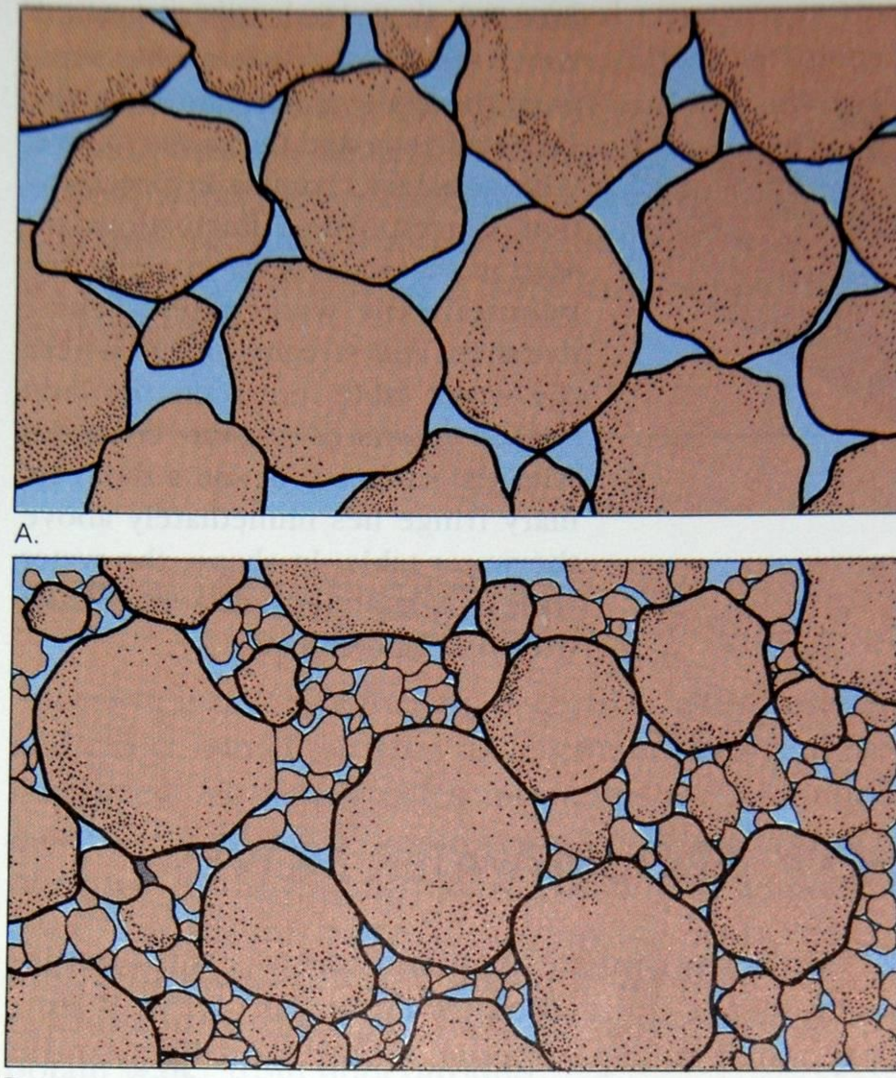
Karst – **A type of topography that is formed on limestone, gypsum, and other soluble rocks by solution, and that is characterized by sinkholes, caves, and underground drainage. There is no integrated surface drainage system. It is not a fluvial (stream formed) landscape.**

Doline – **A "sinkhole" or "closed depression" in which surface runoff collects and percolates into the underground drainage system.**

Swallow Hole – **a closed depression or doline into which all or part of a stream disappears underground.**

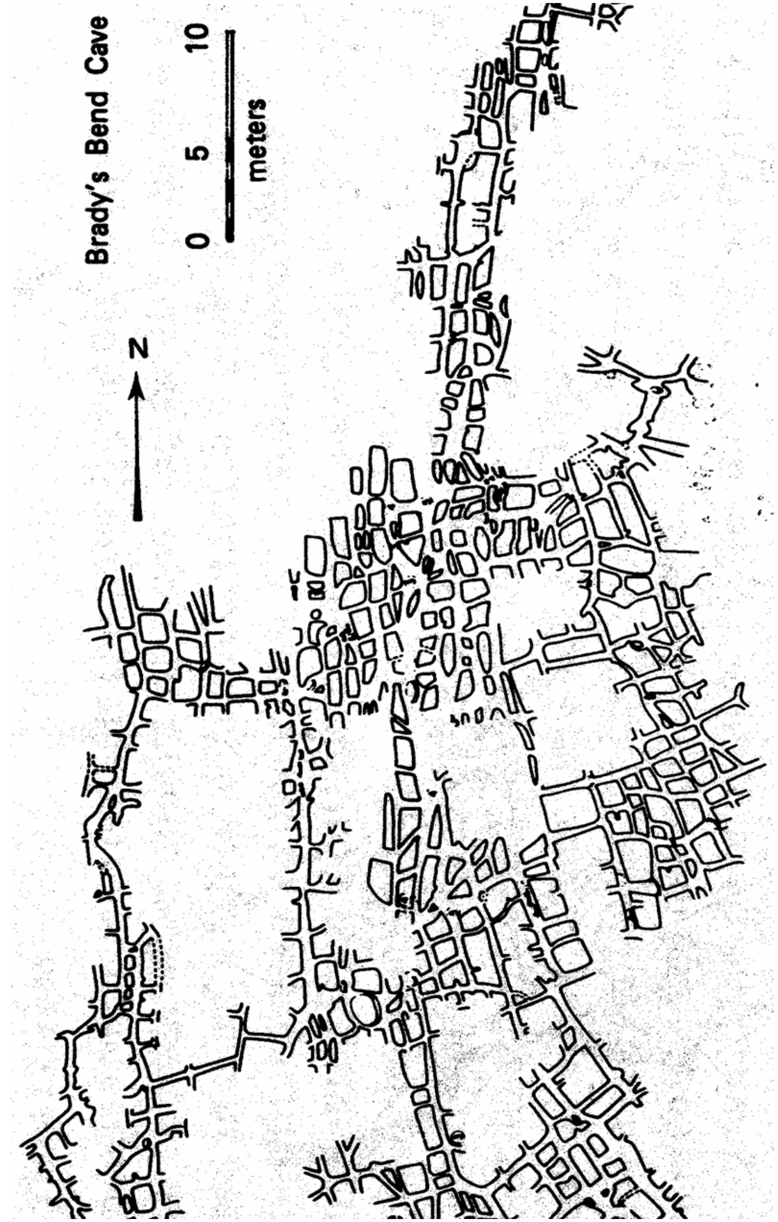
Limestone – **a rock composed of calcium carbonate ($CaCO_3$) that is soluble in carbonic acid.**

Marble – **a limestone that has been metamorphosed - essentially "cooked"by high temperatures resulting in recrystallization of the original rock. It's still $CaCO_3$ but the original texture has been destroyed.**



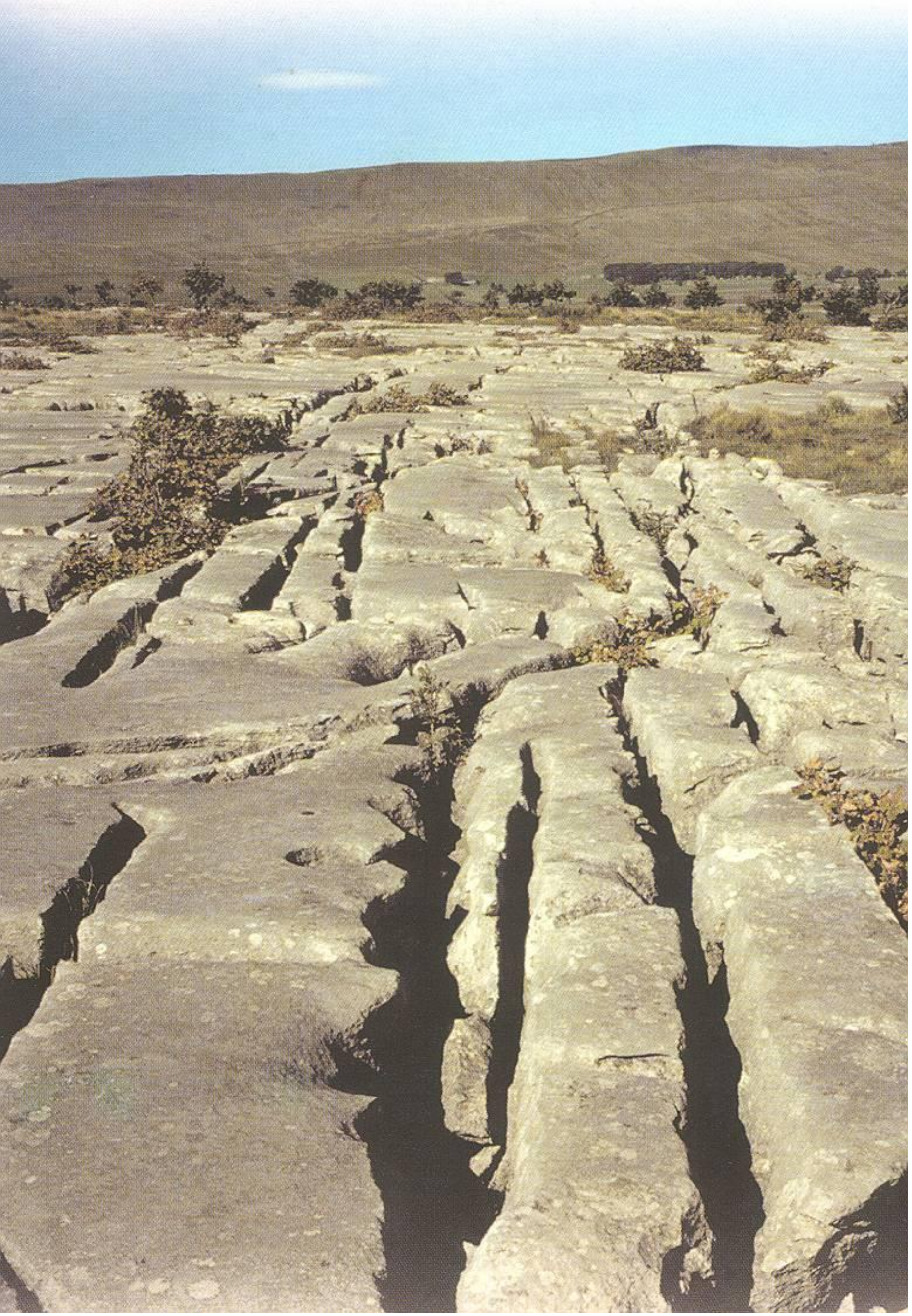
0 10 mm

Intergranular porosity



Map of Fracture porosity

Two Major Types of Porosity



Chemical Weathering of Limestone

<u>Limestone</u> – $CaCO_3$ Is dissolved by carbonic Acid: H_2CO_3

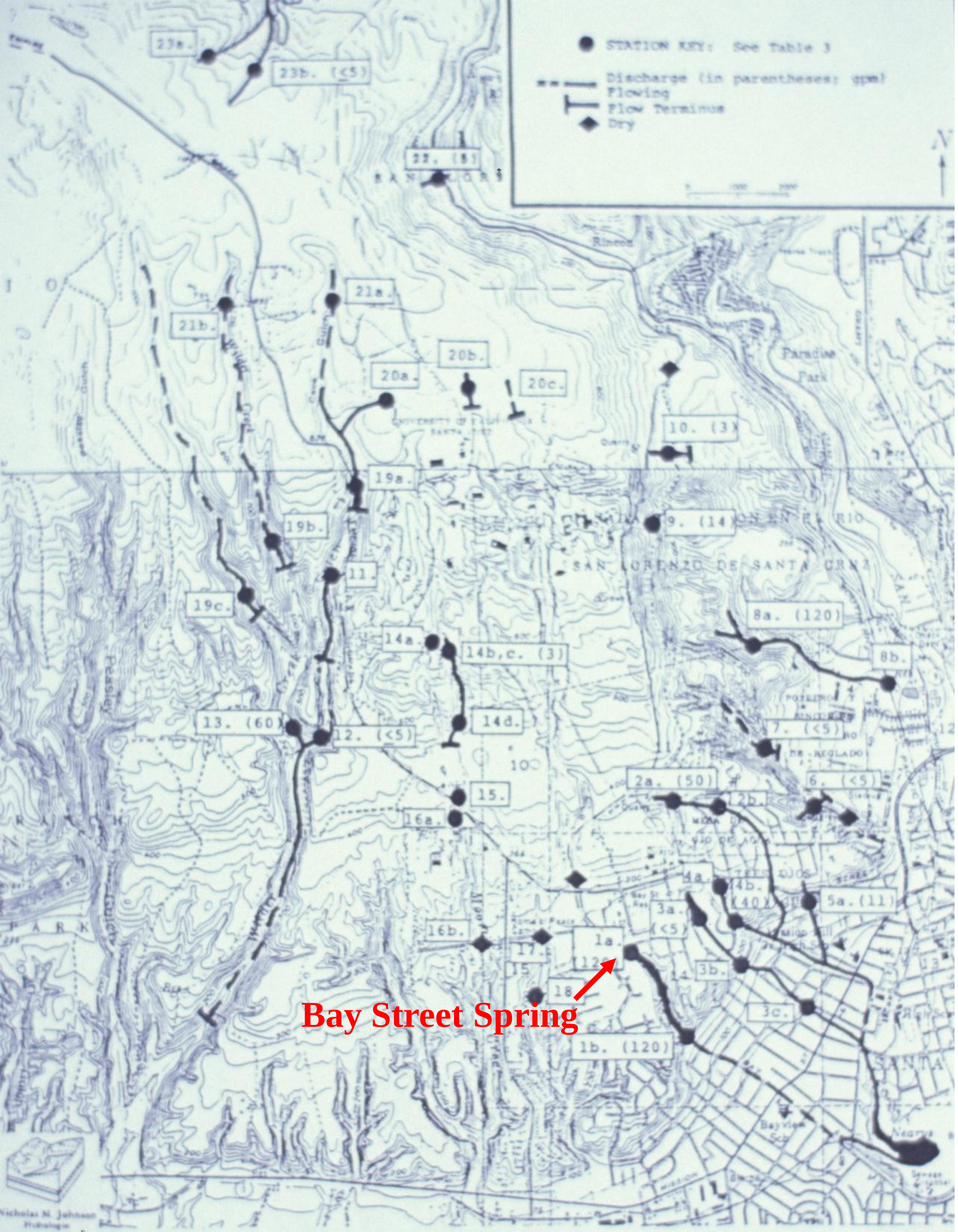
$CaCO_3 + H_2CO_3 = Ca^{2+}$ and $2(HCO_3)^{1-}$

The carbonic acid is formed in the atmosphere during rainfall as carbon dioxide goes into solution:

$H_2O + CO_2 = H_2CO_3 = H^{1+}\ HCO_3{}^{1-}$

Photo: An example of pavement karst. All soil has been stripped from the underlying bedrock surface revealing the solution weathering along preexisting fractures.

Steep walled doline in front of the Engineering building – UCSC Campus.



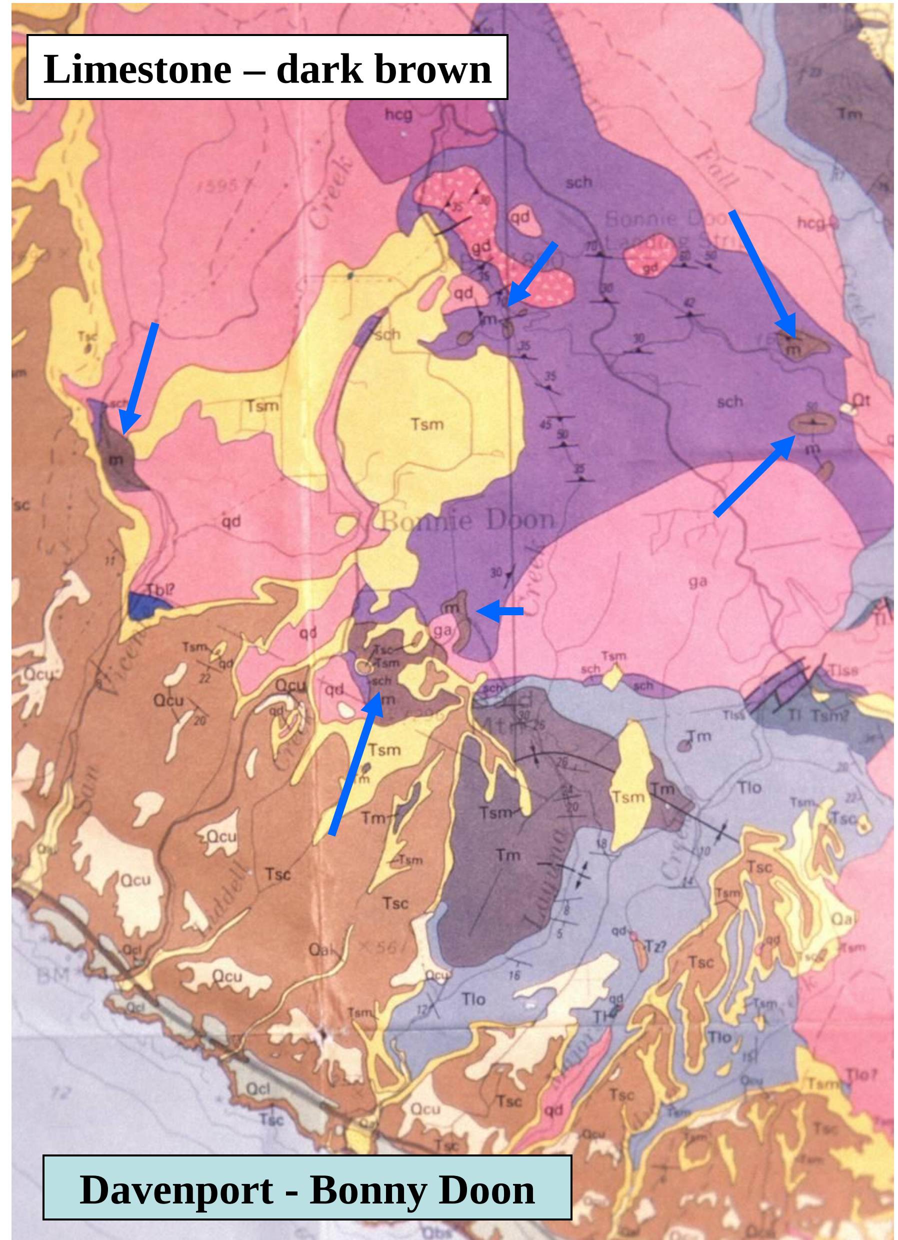
Spring locations and monitoring sites to determine flow volumes for the subterranean streams that drain the campus. It is a complex and rather poorly understood system.

The round dots are springs.
The lines below the springs are the streams fed by the springs.

The "T" at the end of the streams are the flow termini – the stream goes underground.

Note that almost all of the streams reenter the subsurface at some point.

Karst Landscape in Santa Cruz County



Regional Geologic Map

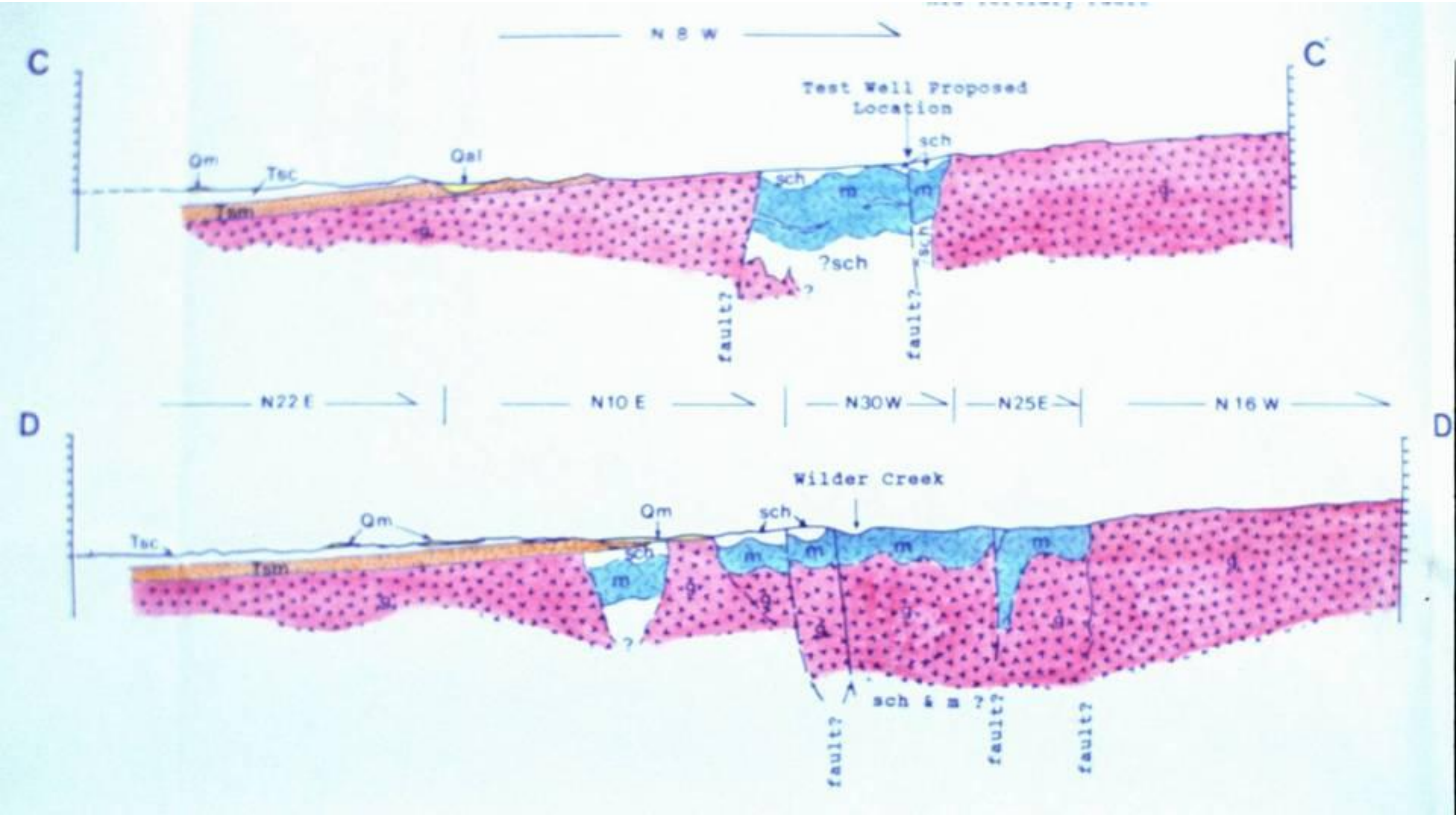
UCSC

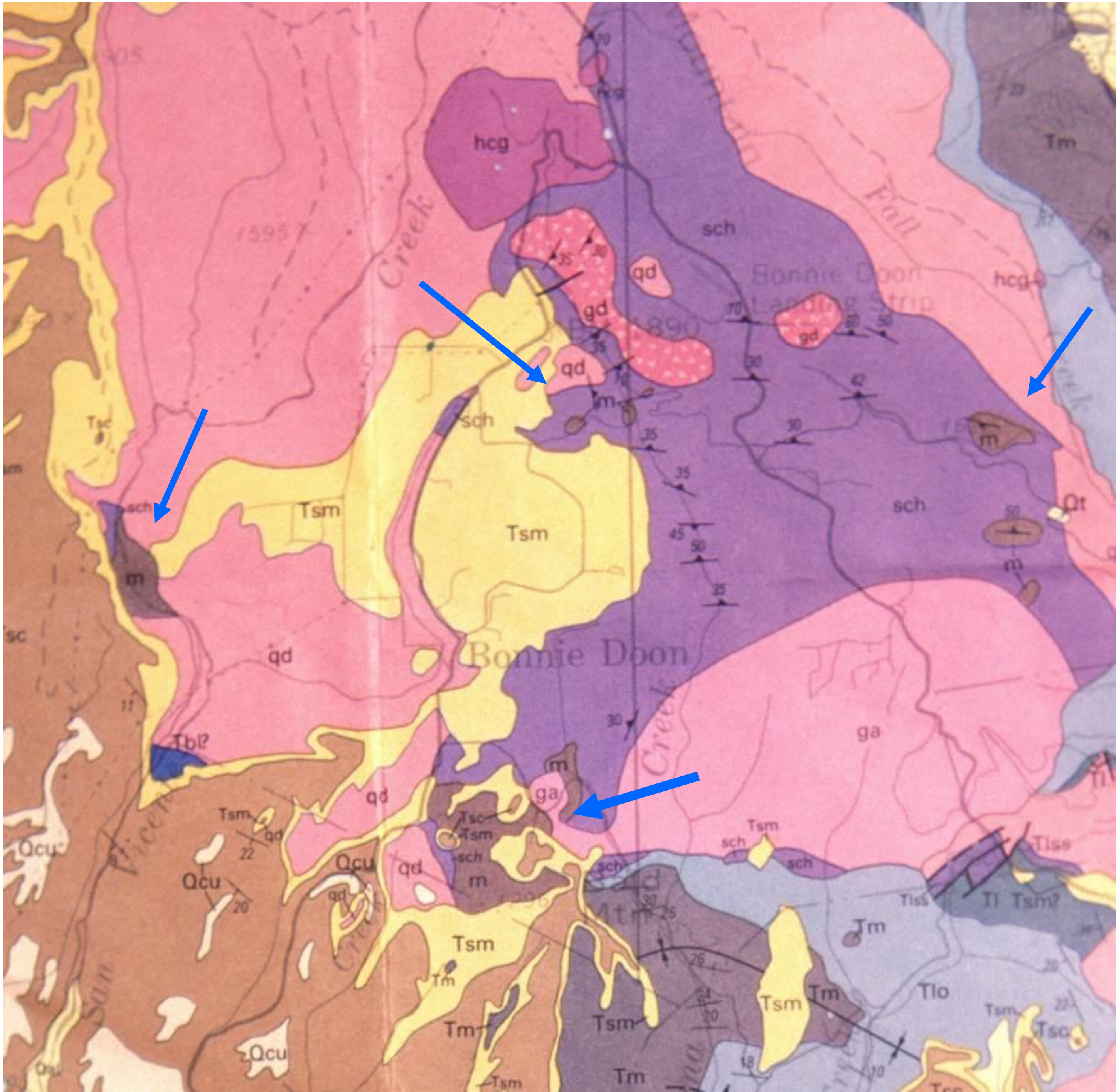
Tan – recent alluvium
Yellow - terraces
Orange – sedimentary rocks
Red - granite
Light purple – schist
Dark purple – marble

Marble = recrystallized (cooked) limestone
The mineral is calcite
Calcium carbonate = $CaCO_3$
Soluble in acids

North –South cross sections across the UCSC campus

Note that the marble (blue) is a small sliver of marble that has been "down dropped" along faults into the hard non-soluble granitic basement rock.





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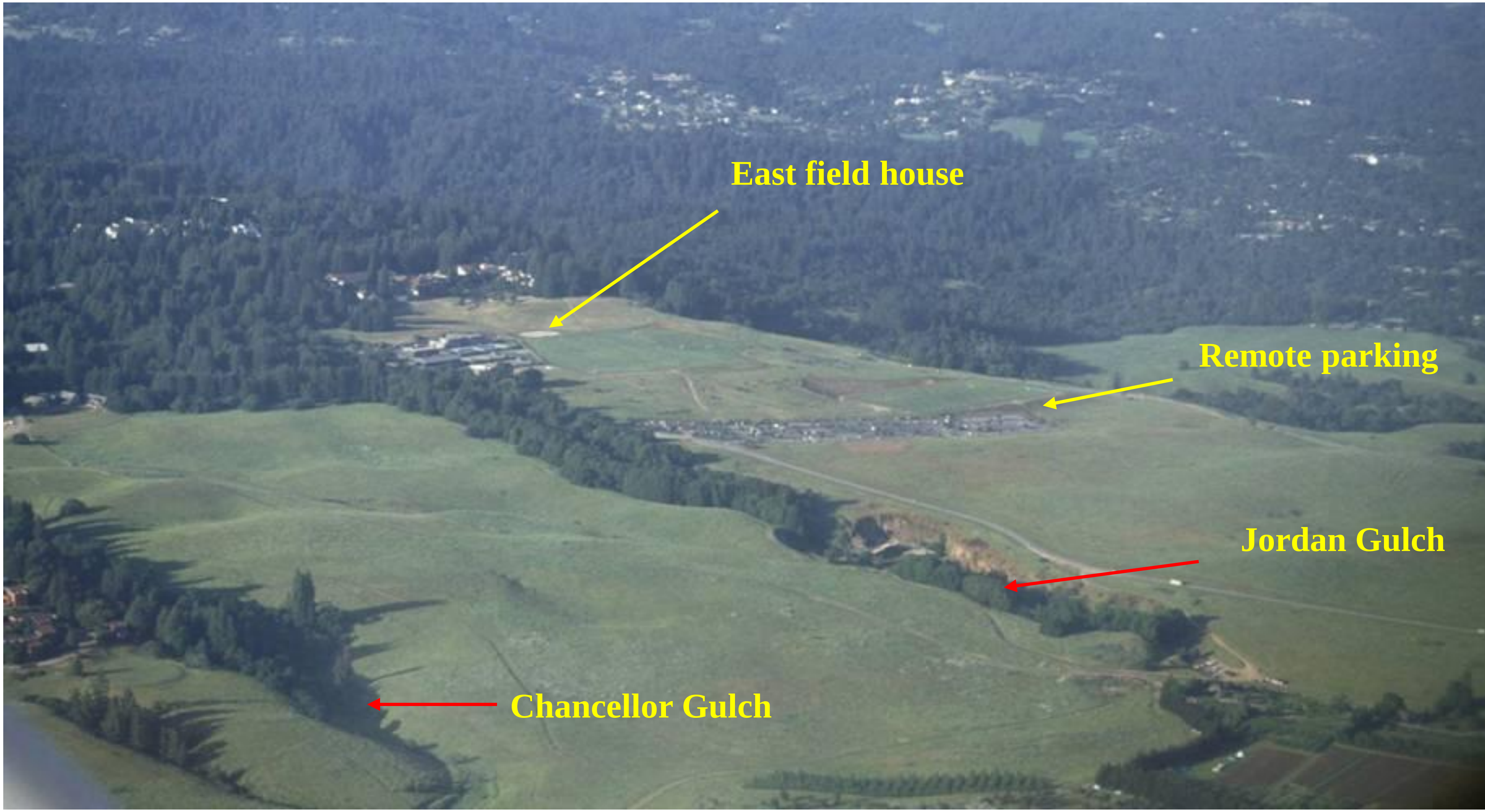
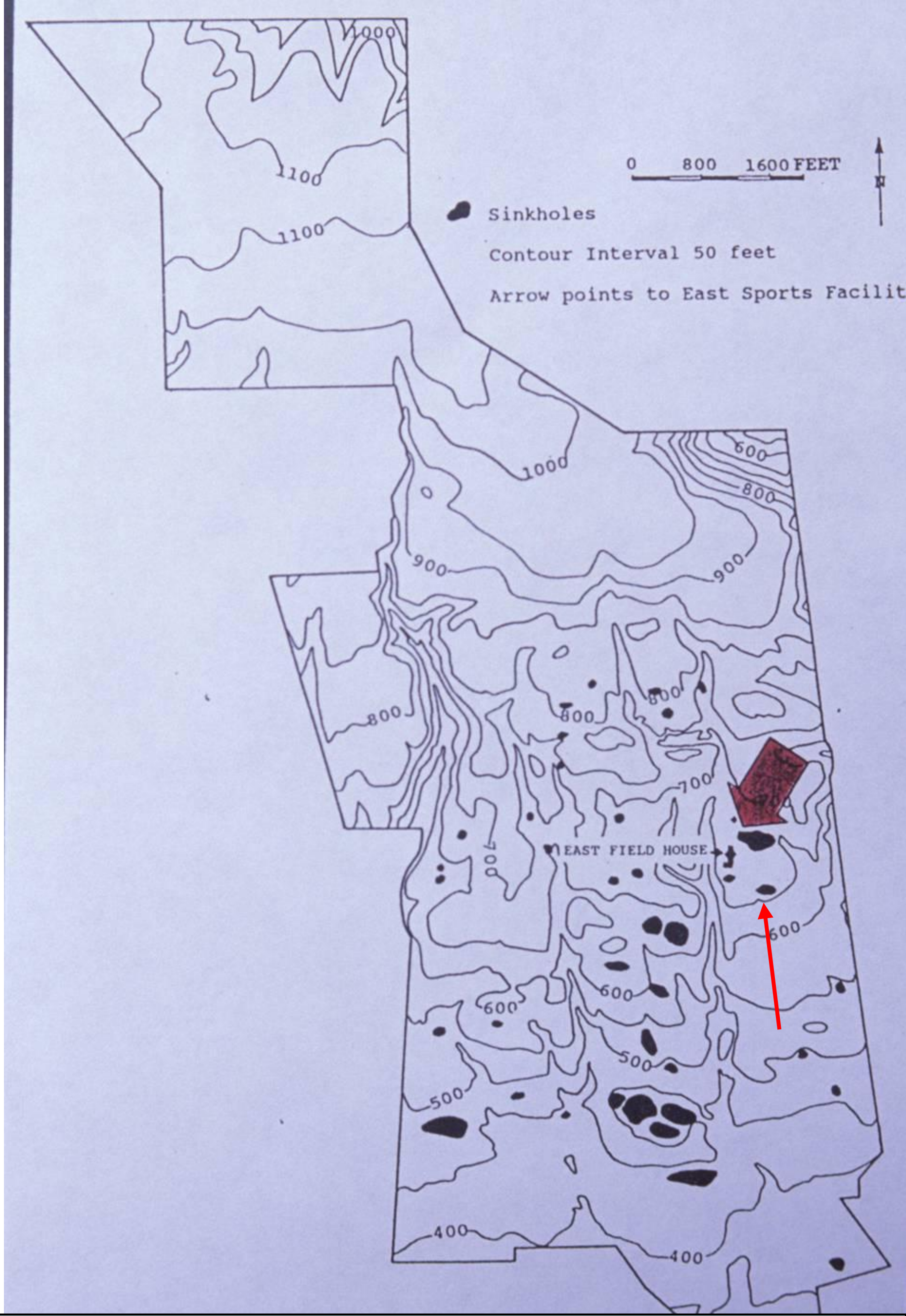
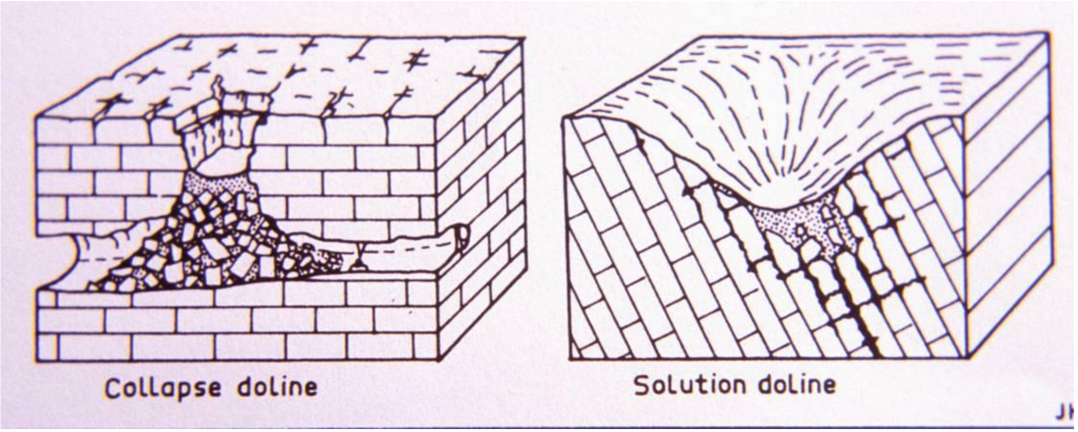


Aerial oblique view of the UCSC campus – looking northeast.

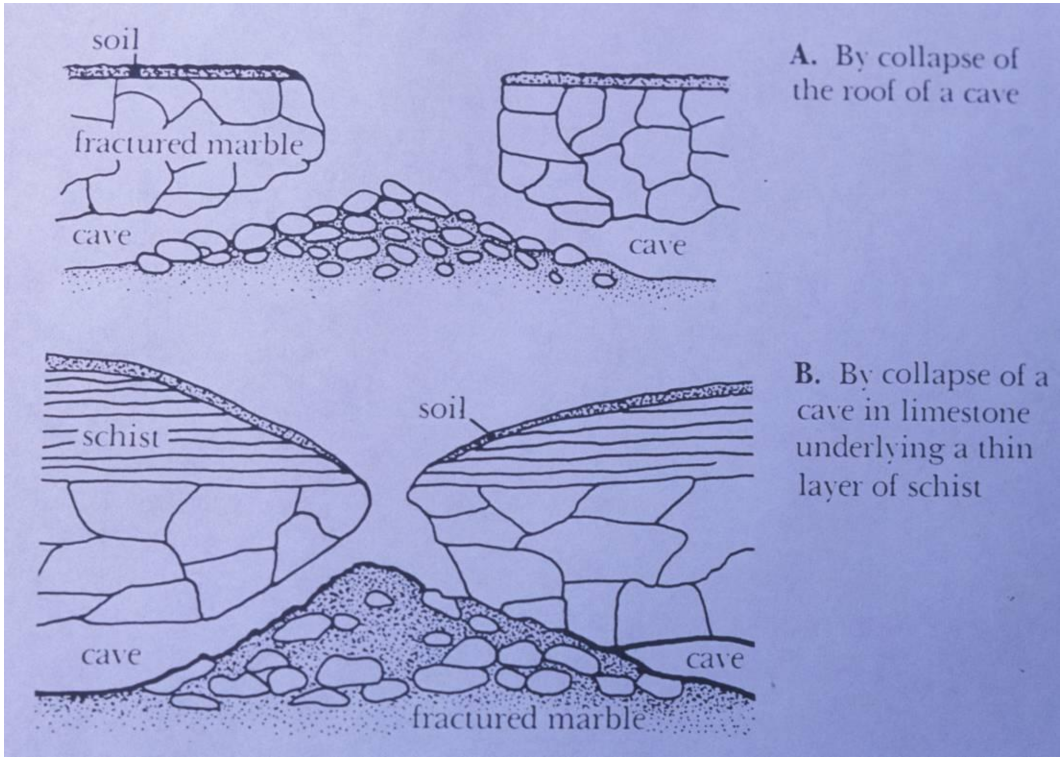
Note the two thoroughgoing streams – Jordan and Chancellor Gulch. They have no true tributaries and flow only during the largest storms…and only for a short time. The vast majority of the water that falls on campus goes straight down into the solution cavities.

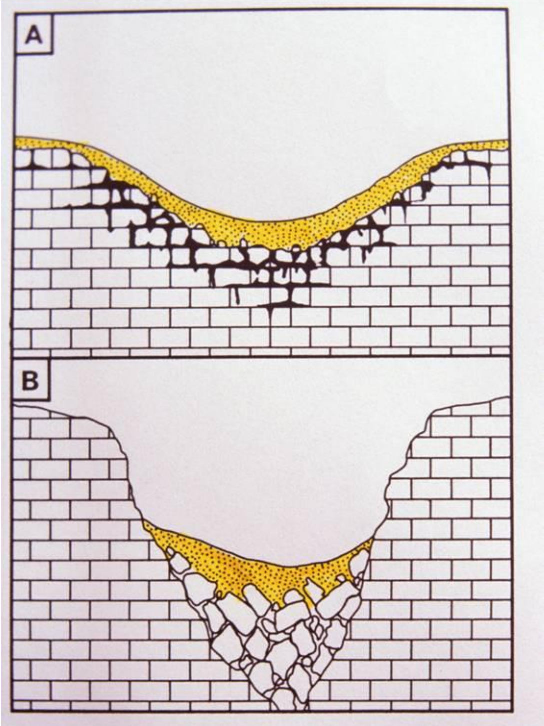


The thin red arrow points to the location of the sinkhole



Examples of doline and cavern formation – all occur as a result of an underground void that increases in size till the overlying ground eventually collapses into the void.





68 The formation of dolines by solution (A) and collapse (B)

Geologic Problems Associated With Karst

1. Doline Formation – ground failure or collapse. May be triggered by:
   a. Construction – grading, excavation, overloading
   b. Changes to surface water and/or ground water flow.
   c. Acts of God
2. Changes to Ground Water System
   a. Contamination
   b. Changes in flow volume and direction

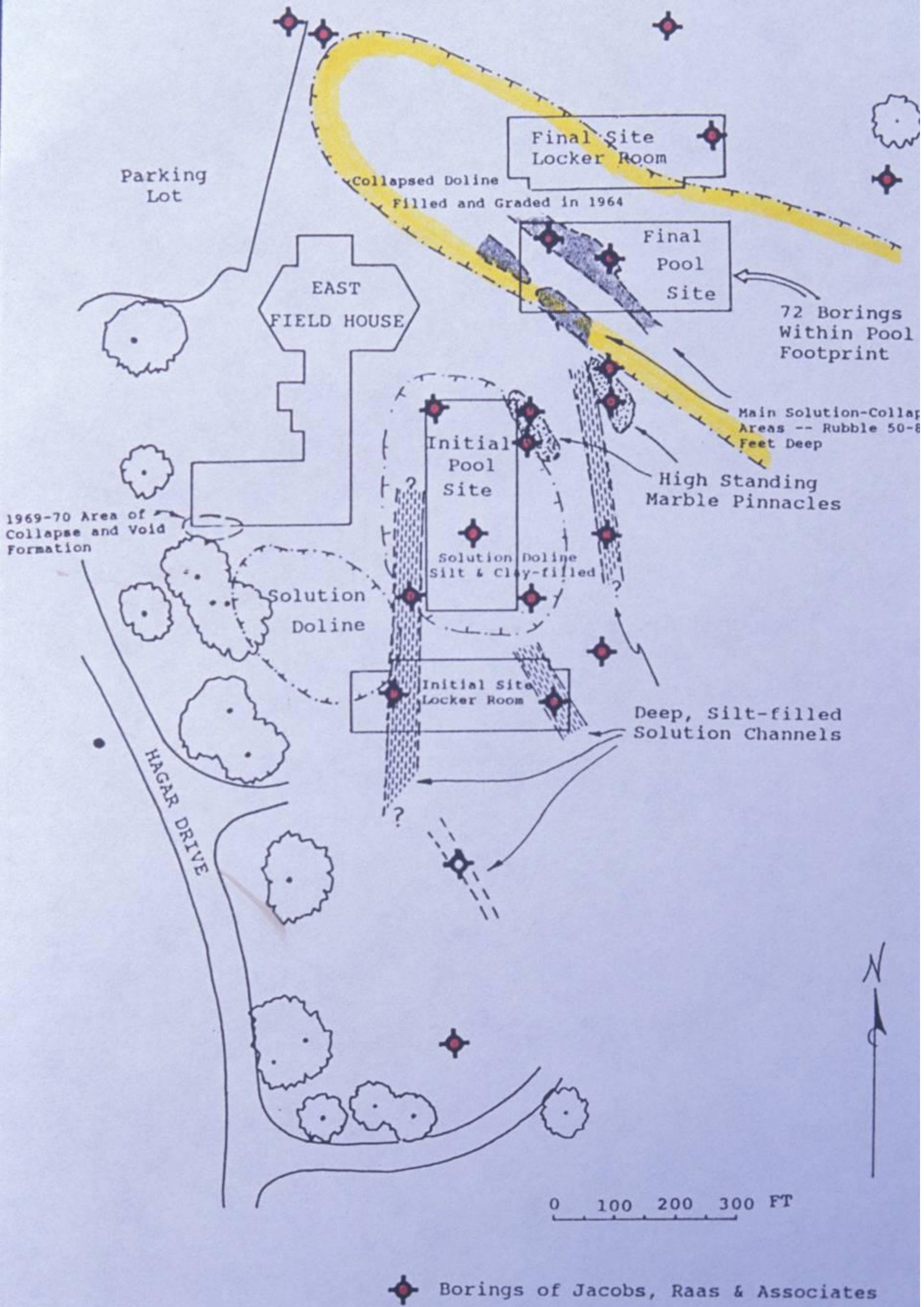


Figure 2. Site map of the East Sports Complex.

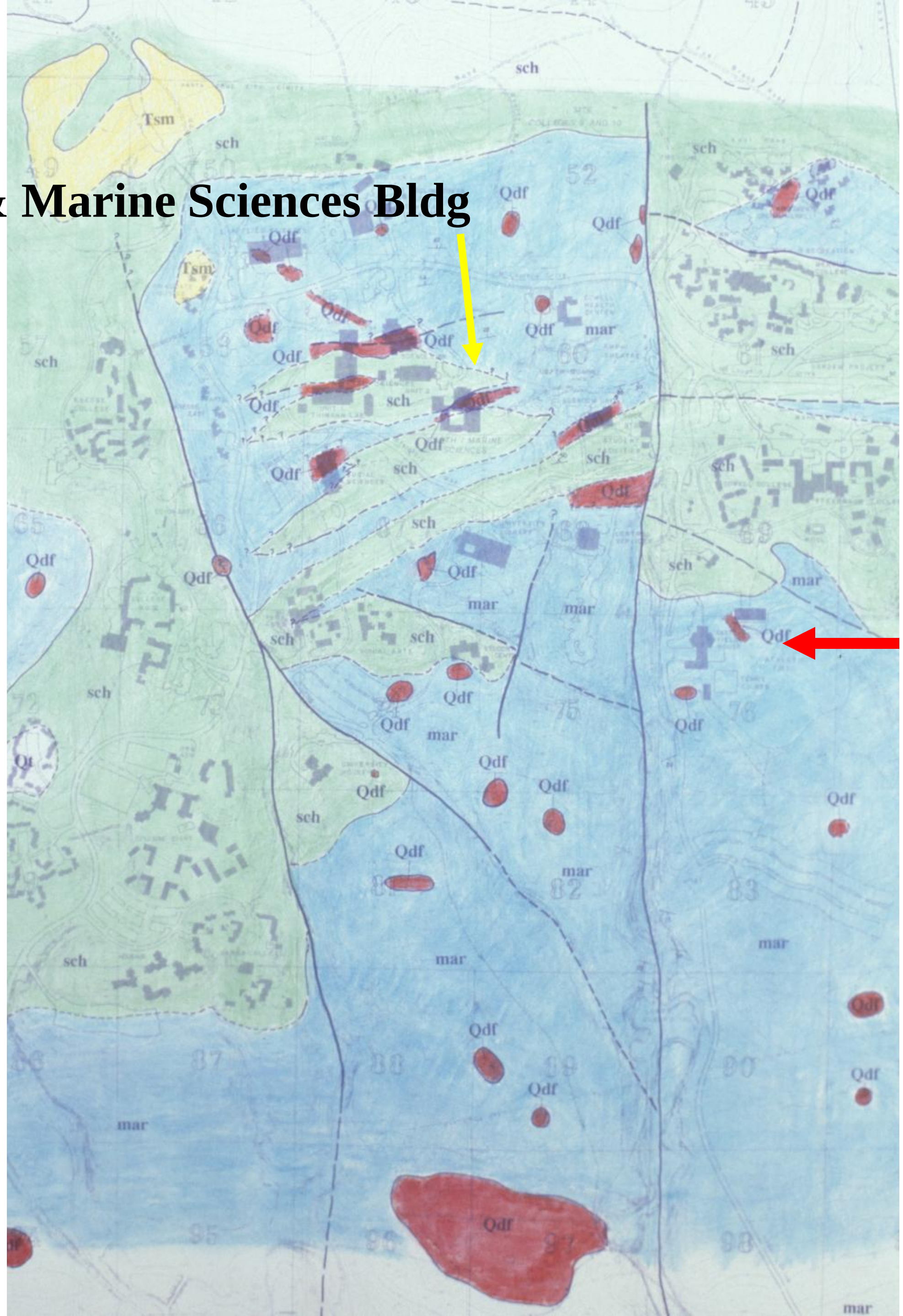
Map of the East Sports Complex

The original site for the east complex swimming pool was directly on top of a collapse doline. At that site there was the probability of additional collapse in the future that would have been hard to mitigate during construction.

It was moved to an area where there were "only" two small solution channels in a doline formed in an area with a high density of fractures – not a collapse.

Note that 72 exploratory borings were drilled in the pool footprint. This allowed an accurate understanding of the under-lying geology and the development of an adequate foundation.

Earth & Marine Sciences Bldg



Red area are sediment filled sinkholes (dolines)

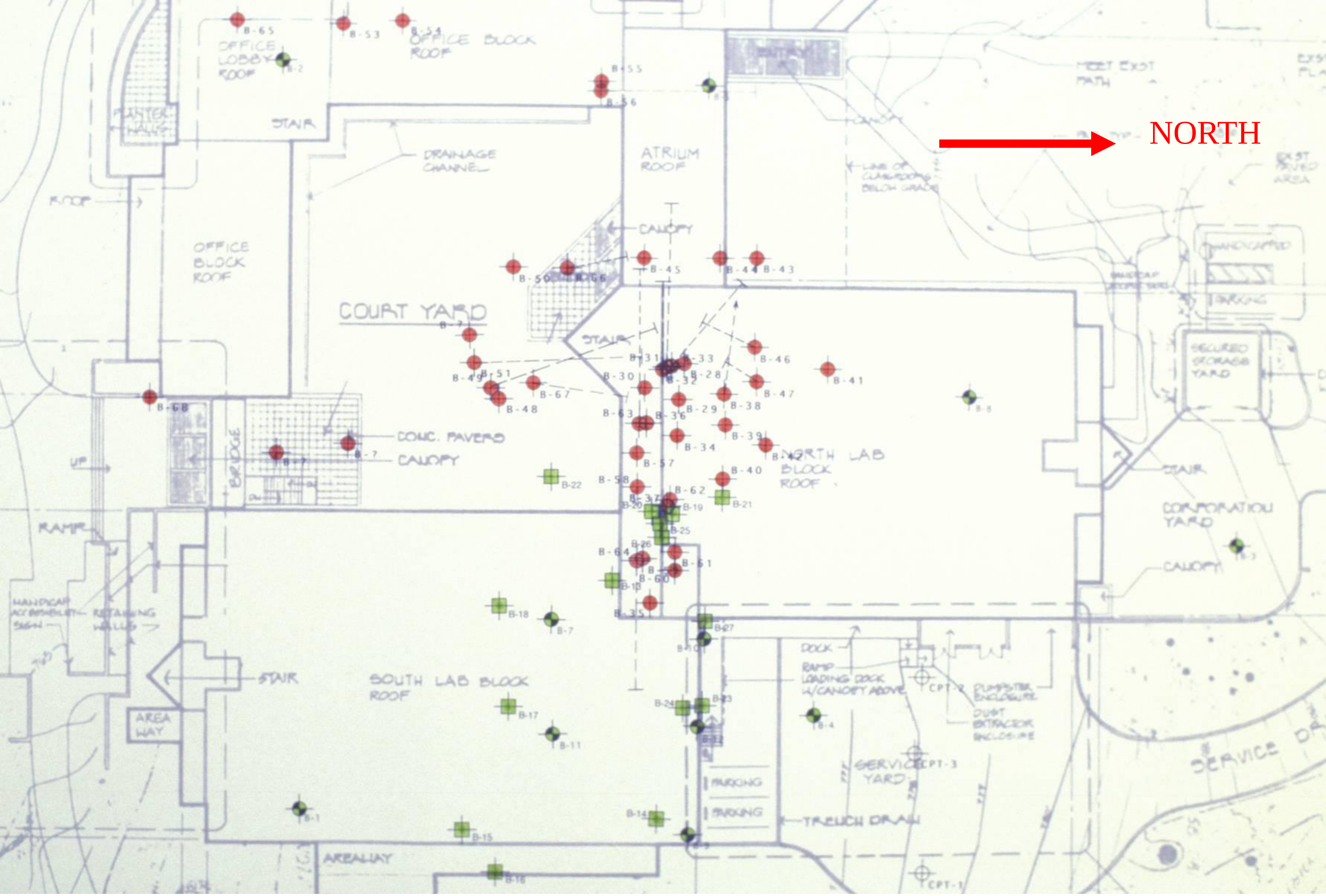
Note – East Field House & pool

blue = marble
green = schist
yellow = sandstone


FORD


DANGER
RESTRICTED AREA


DANGER
RESTRICTED AREA



NORTH
OFFICE LOBBY ROOF
OFFICE BLOCK ROOF
OFFICE BLOCK ROOF
ATRIUM ROOF
ENTRY
MEET EXST PATH
CANOPY
LINE OF CLASSROOMS BELOW GRADE
PLANTER WALLS
STAIR
DRAINAGE CHANNEL
ROOF
CANOPY
COURT YARD
STAIR
CONC. PAVERS
CANOPY
BRIDGE
UP
RAMP
NORTH LAB BLOCK ROOF
SECURED STORAGE YARD
STAIR
CORPORATION YARD
CANOPY
HANDICAP ACCESSIBILITY SIGN
RETAINING WALLS
STAIR
AREA WAY
SOUTH LAB BLOCK ROOF
DOCK
RAMP LOADING DOCK W/CANOPY ABOVE
DUMPSTER ENCLOSURE
DUST EXTRACTOR ENCLOSURE
SERVICE YARD
PARKING
PARKING
TRENCH DRAIN
AREAWAY
SERVICE DR
CPT-1
CPT-2
CPT-3
B-1
B-2
B-3
B-4
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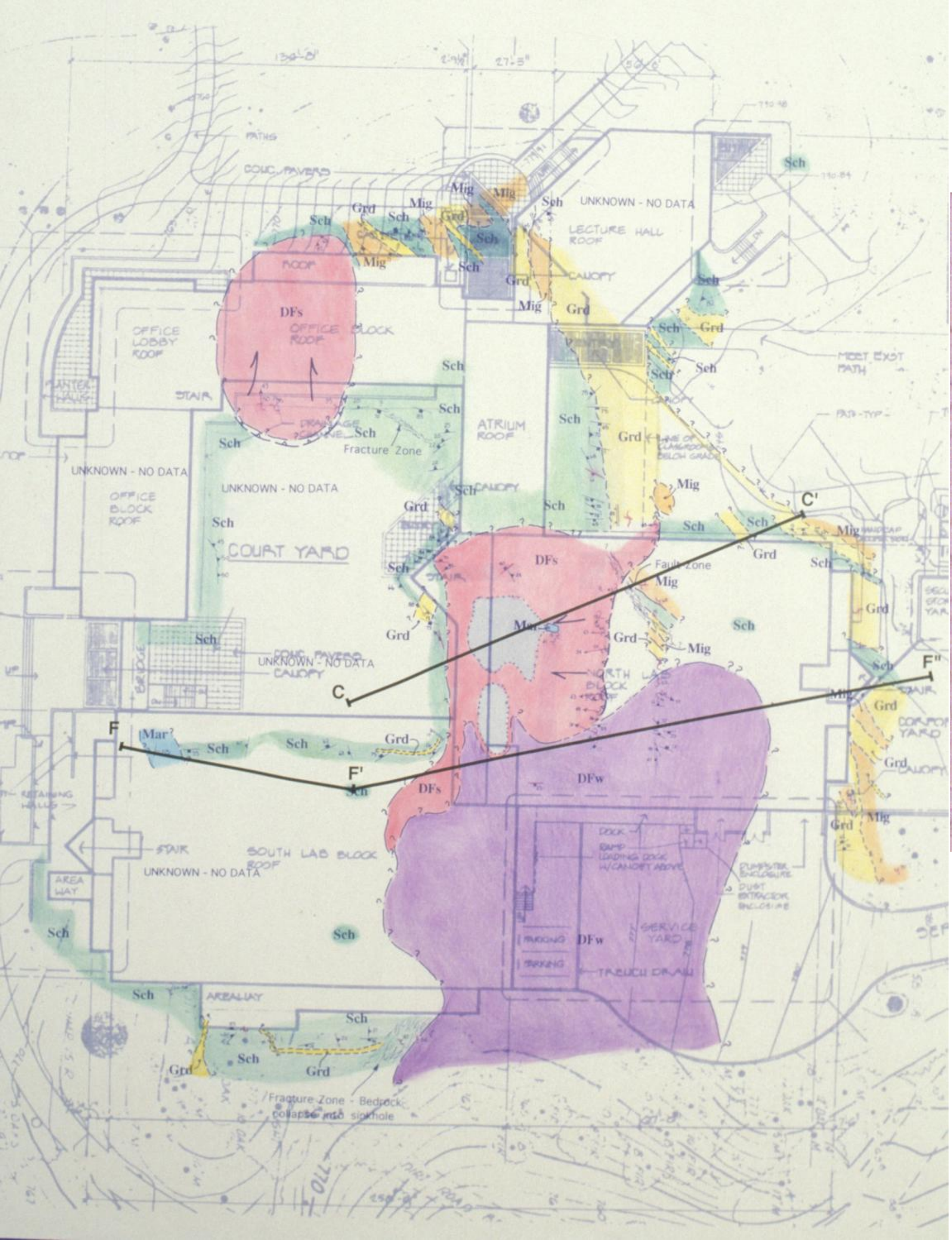
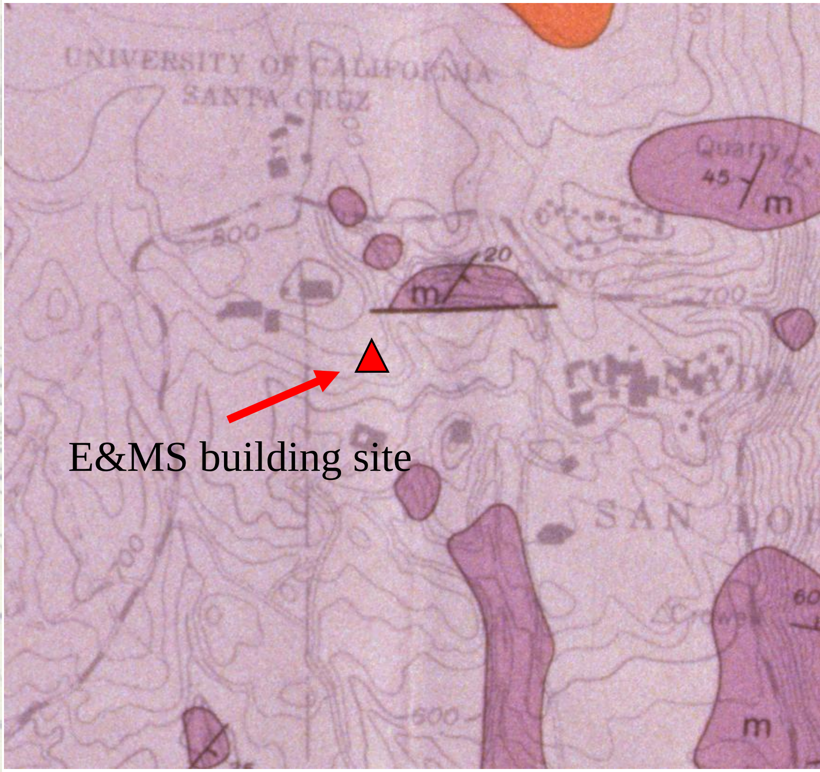
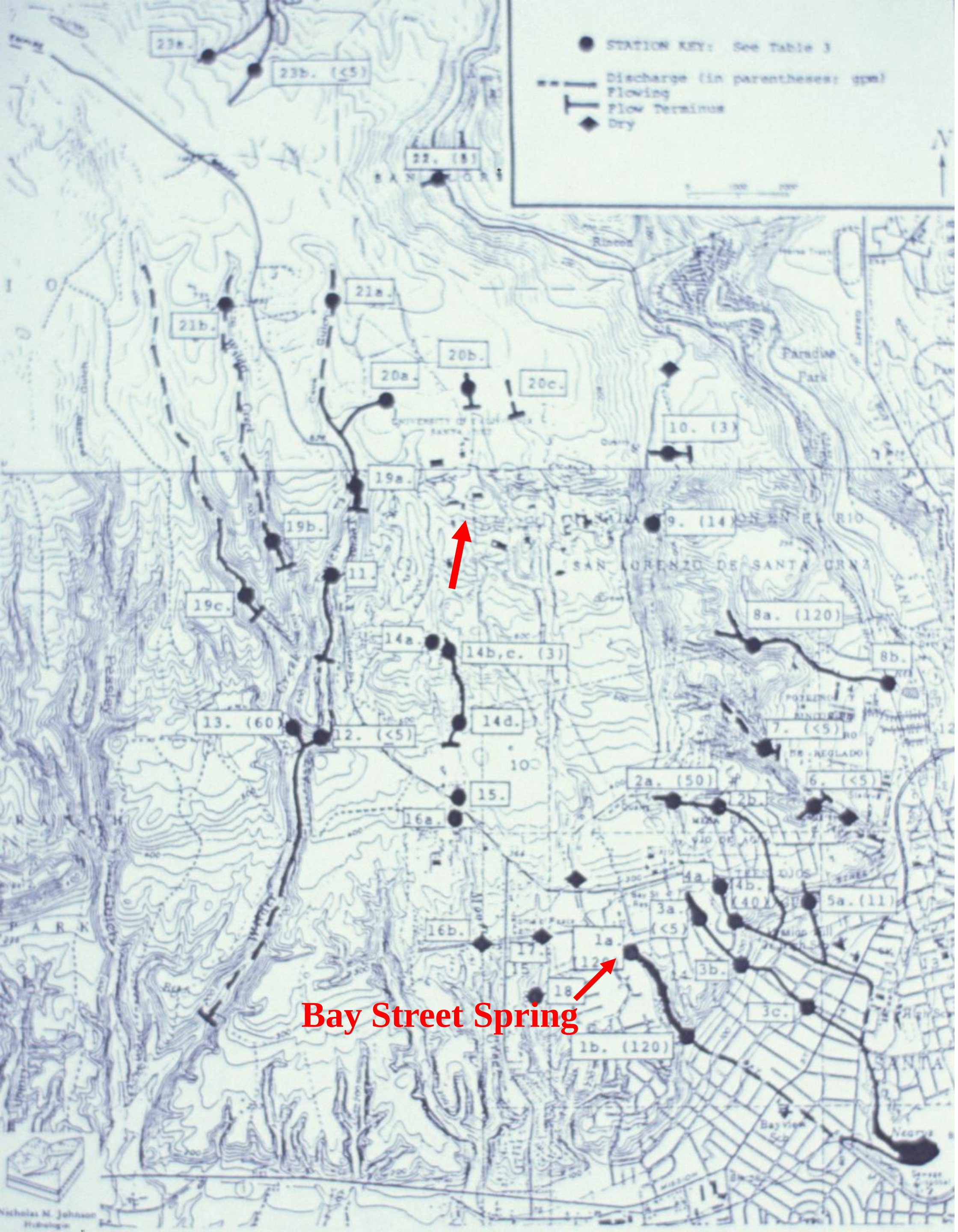




Light purple - schist
Dark purple - limestone

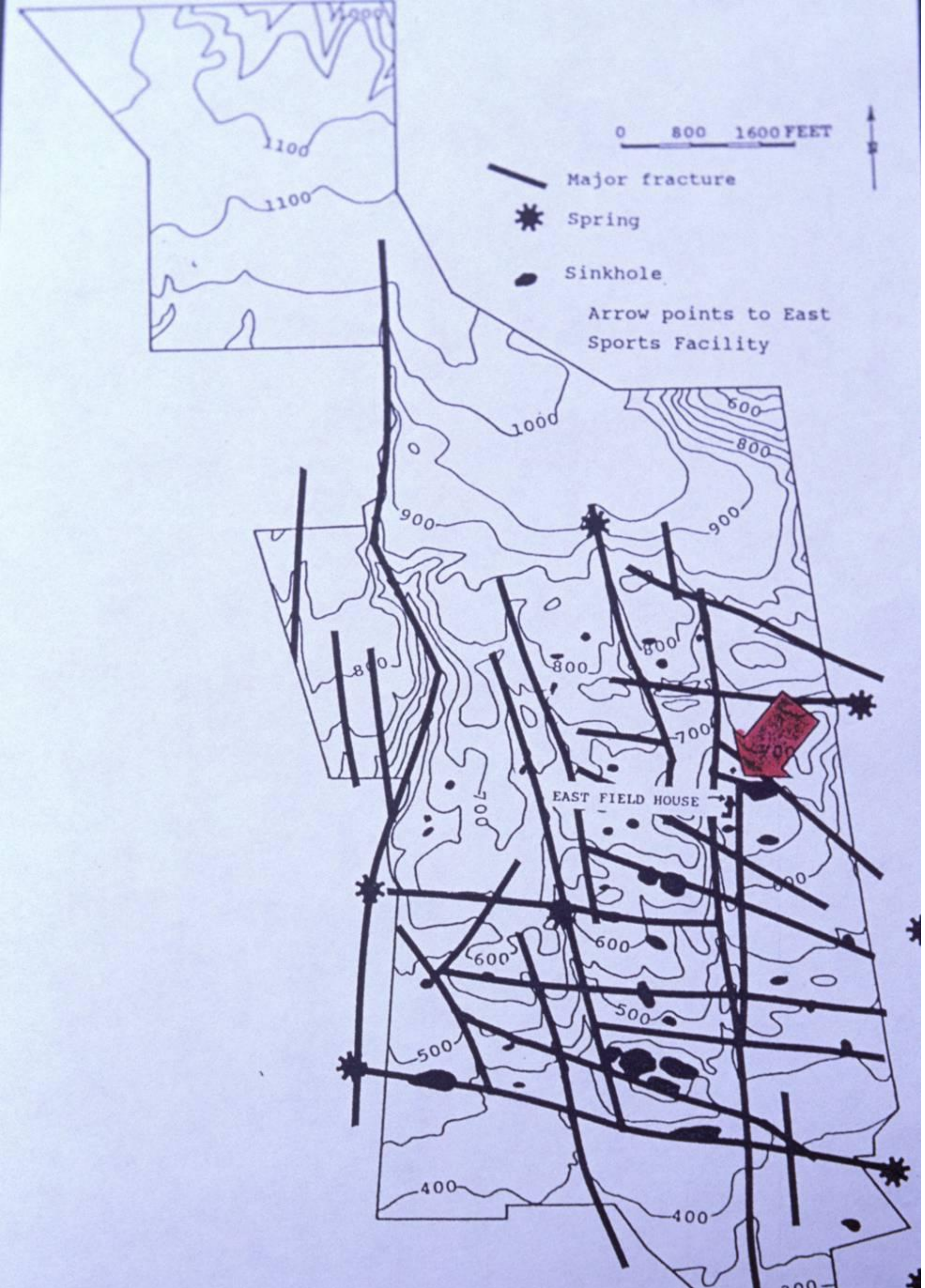


Spring locations for the subterranean streams that drain the campus. It is a complex and rather poorly understood system.

The round dots are springs.
The lines below the springs are the streams fed by the springs.

The "T" at the end of the streams are the flow termini – the stream goes underground.

The red arrow points to the E&MS building site.



IGURE 5. Map showing relation between fractures, sinkholes, and springs on and near UCSC campus.

Interpretive map of the Major fracture systems, and therefore subterranean passages, along which water flows under the campus. There are Also numerous smaller fractures and solution passages between these major passages.

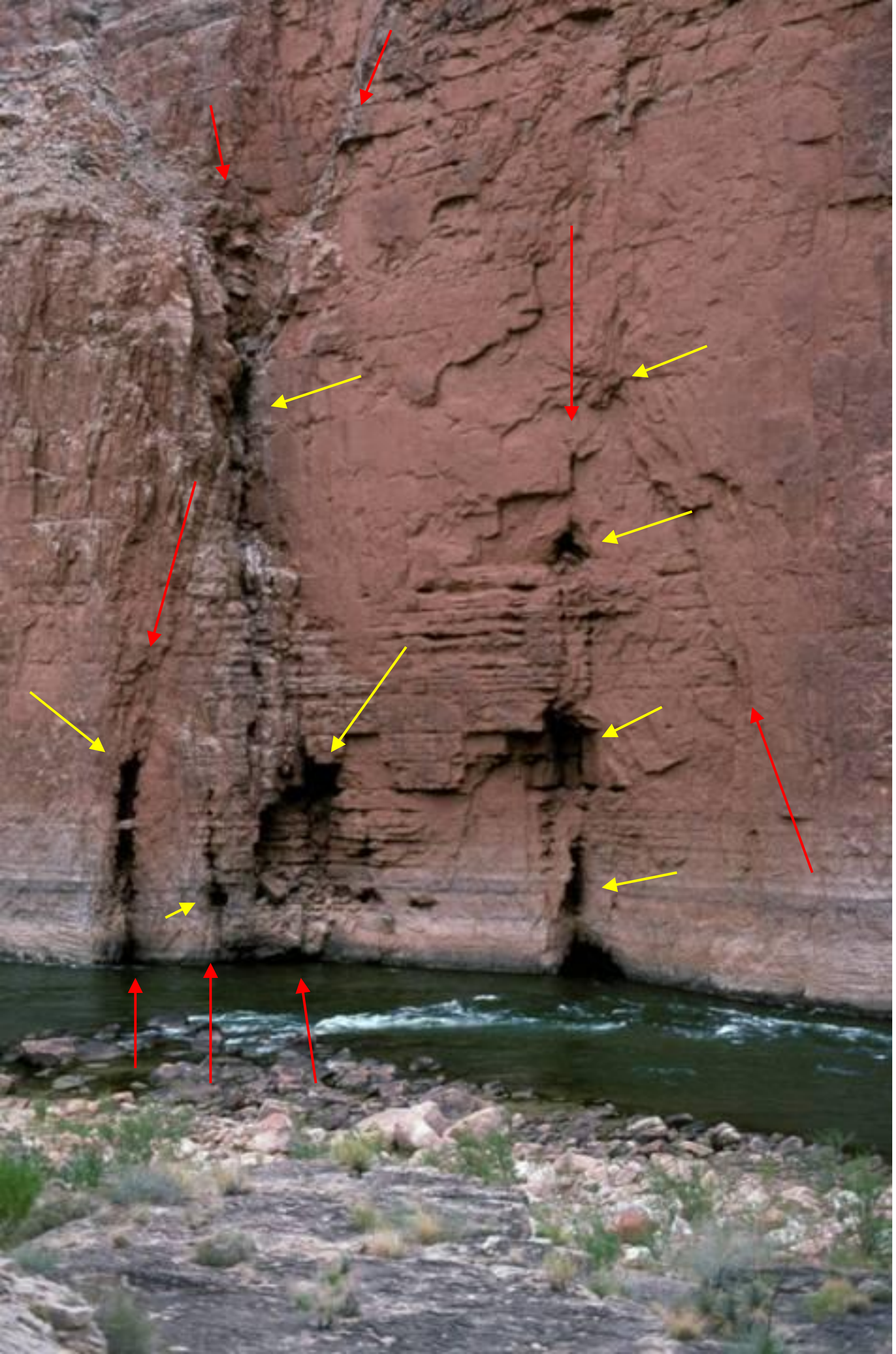
So…what does this look like underground??

What would the UCSC campus (or Bonny Doon) look like if we could see a full cross section through the karst areas??

This can be imagined by viewing an active karst terrain exposed in the walls of Marble Canyon – the northerly portion of the Grand Canyon.

Go to next slide for an interpretation.

Colorado River



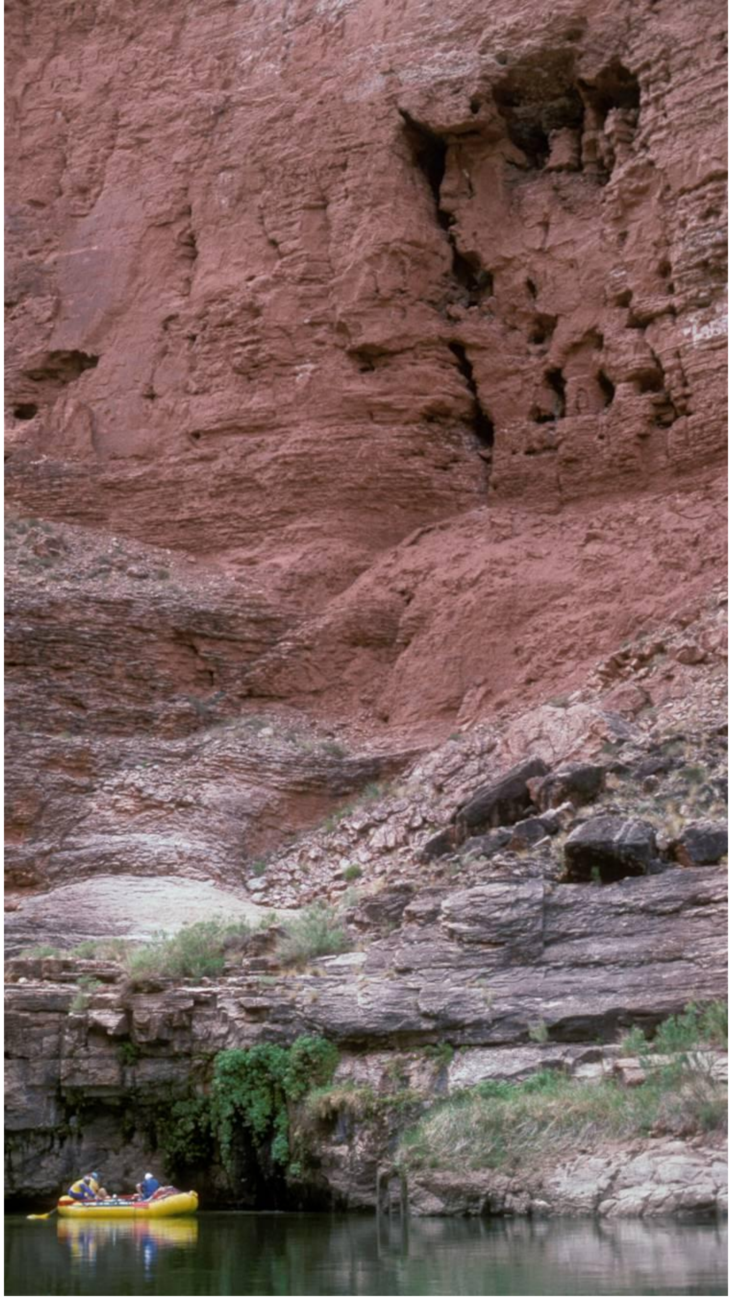
What would the campus look like if we could see a full cross section through the campus??

This can be imagined by viewing an active karst terrain exposed in the walls of Marble Canyon – the northerly portion of the Grand Canyon.

The yellow arrows point to obvious voids along which water moves in the sub surface. The red arrows point out the major fracture systems along which the voids formed.

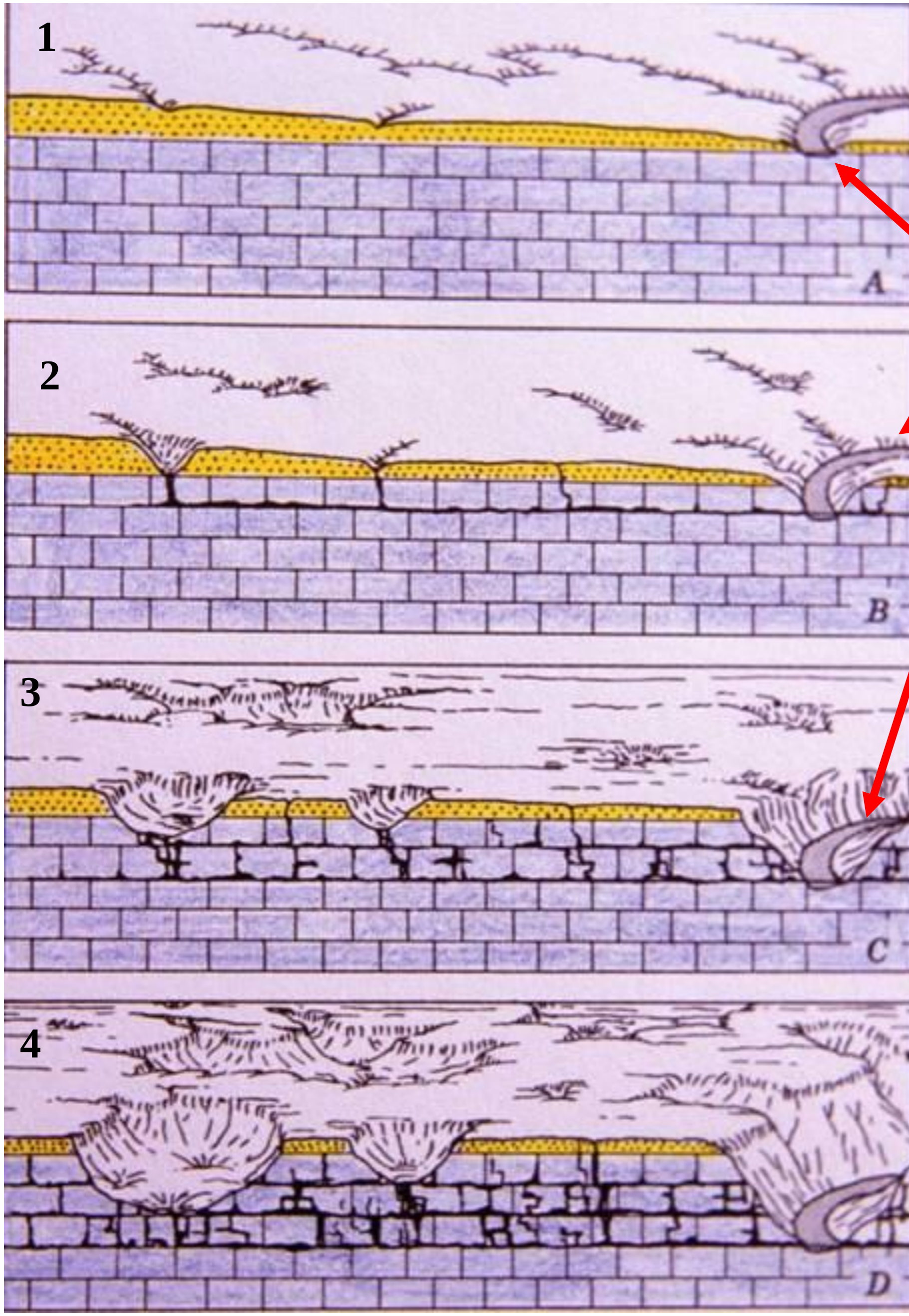
Note that the large voids do not occur every-where along a single fracture.

Karst solution channels along fractures in the Redwall Limestone in the Grand Canyon



Marble Canyon

Thunder Spring – tributary to Tapeats Creek



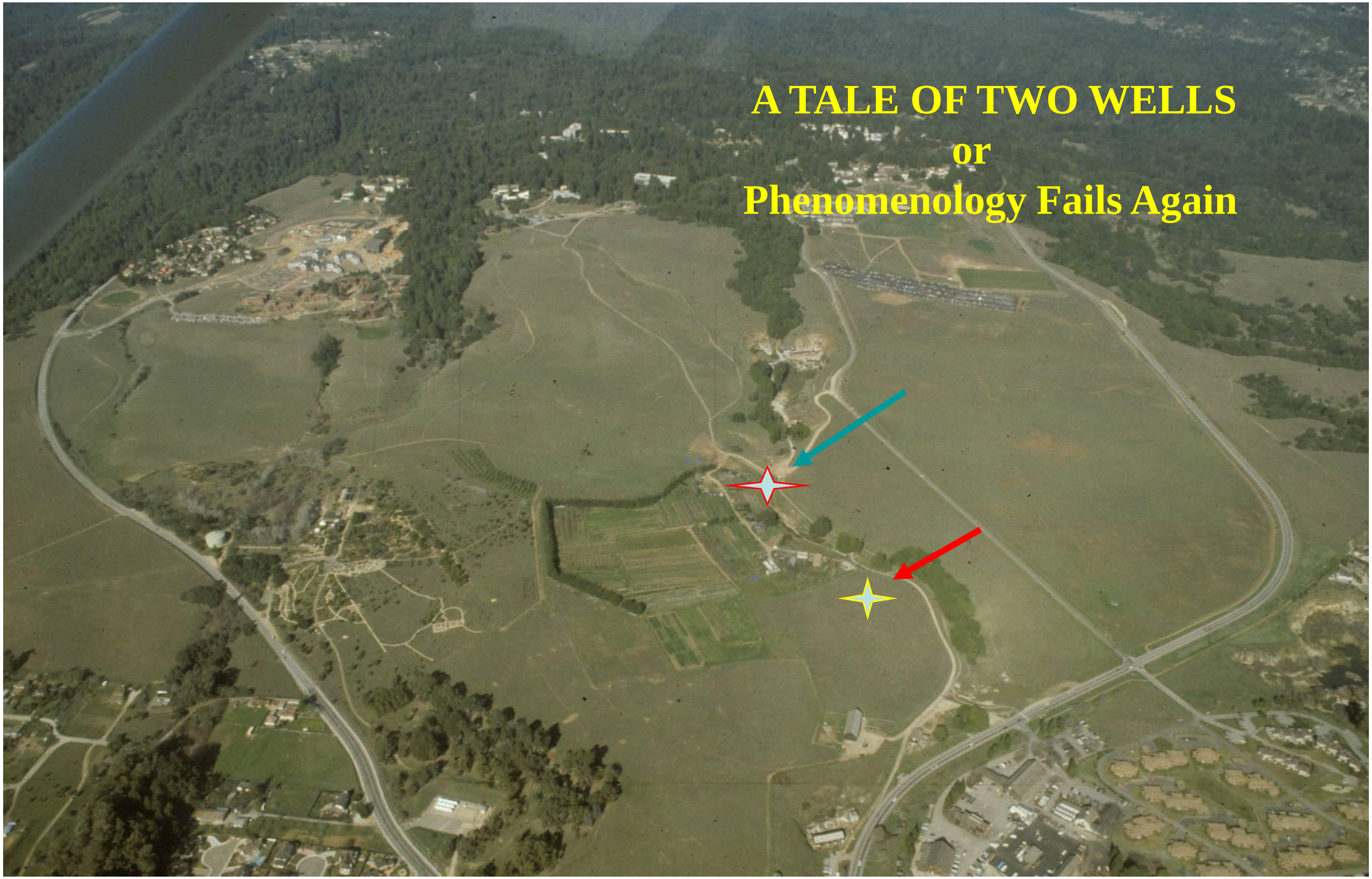
Development of a karst system over time. The UCSC campus is at about the stage of #3.

Note the through going stream.
San Lorenzo River
As it cuts down it provides the "base level" to which the underground flow can reach. The deeper the river cuts down the deeper the cavern system grows.

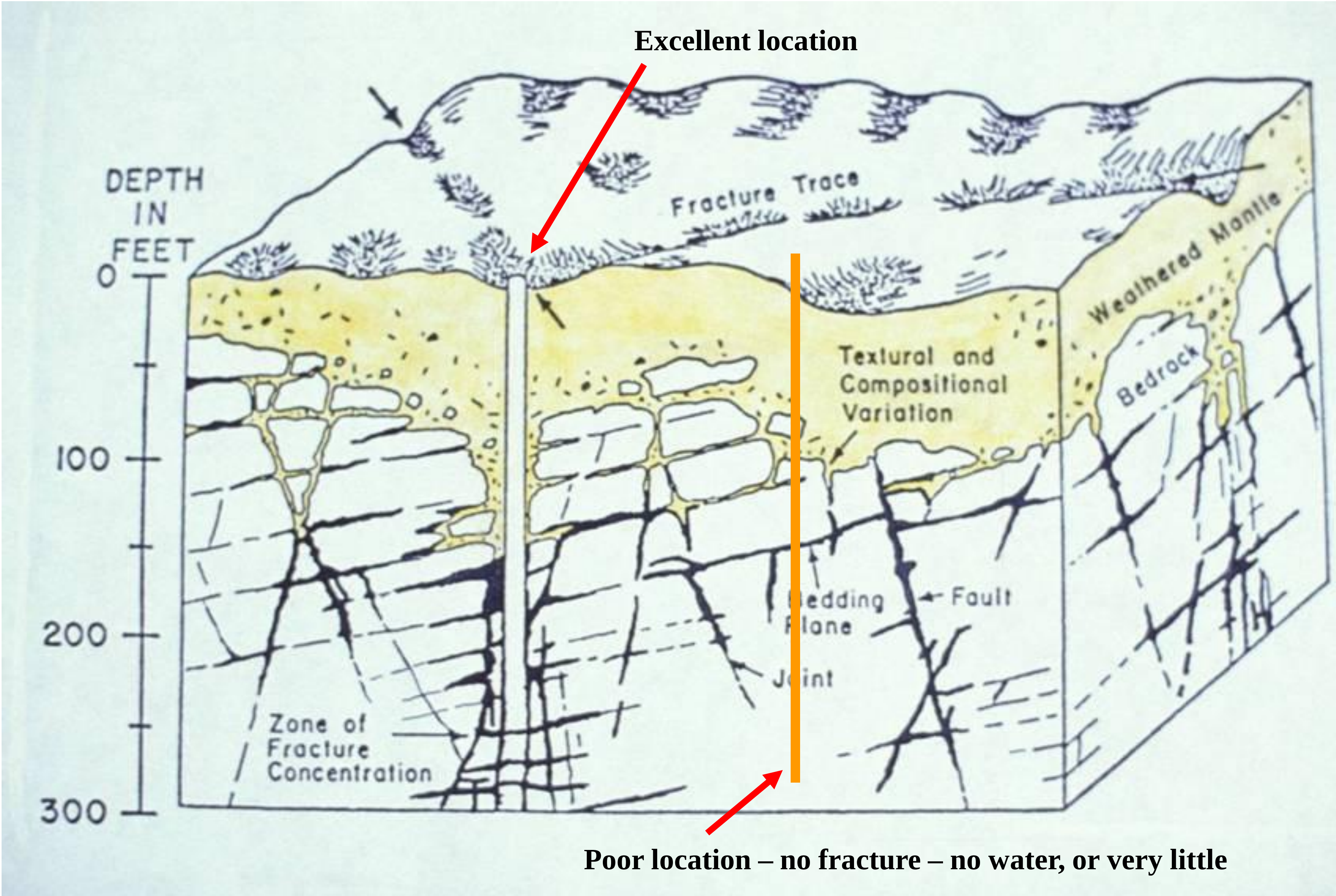
In respect to the UCSC campus the San Lorenzo river is the equivalent of the stream in this diagram.

The Role of the San Lorenzo River in the formation of the UCSC karst terrain

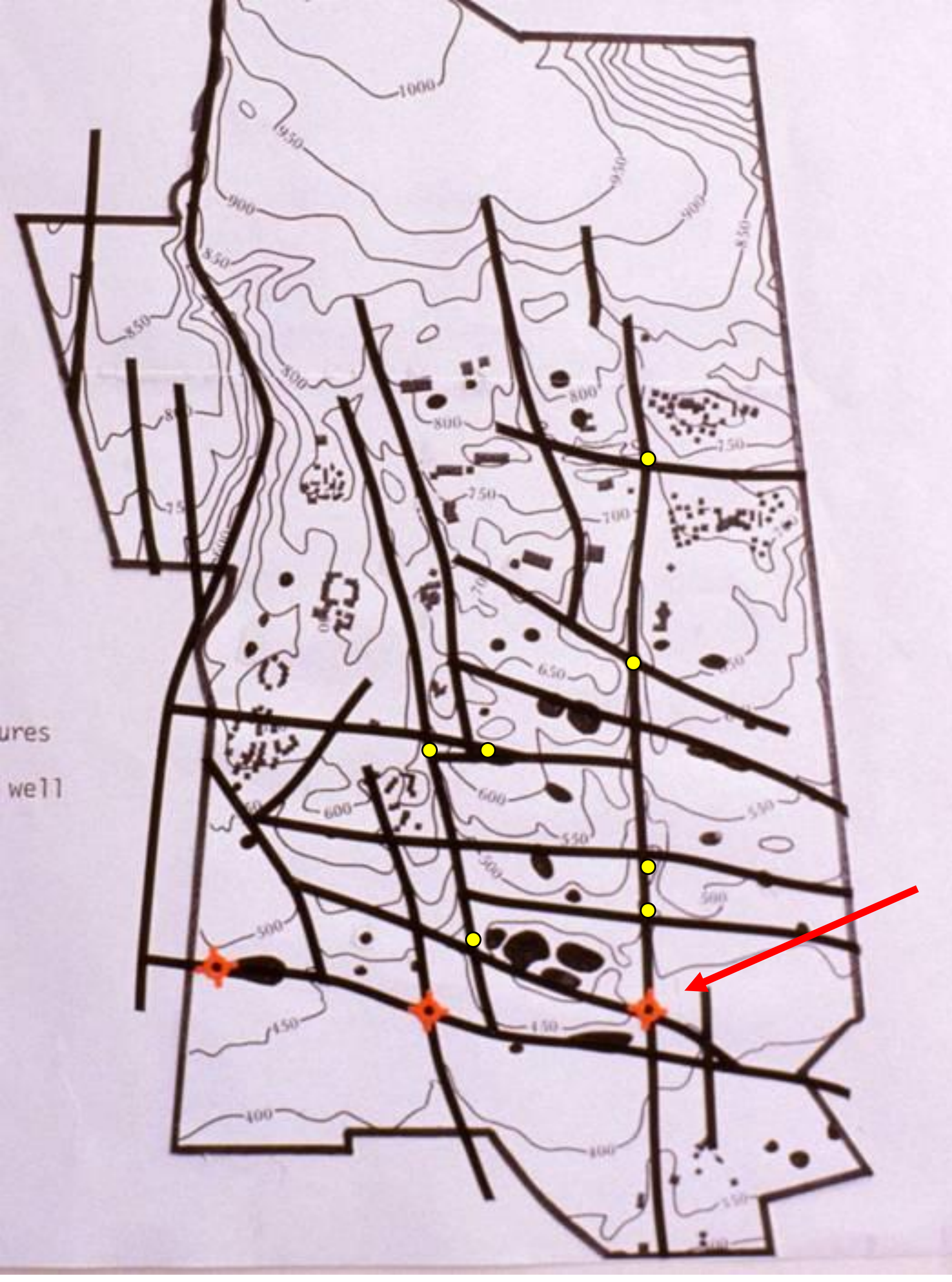
Something completely different…Namib Dune Field



To dowse or not to dowse – that is the question?



How to site a well in karst terrain. Drill into a fracture trace – preferably at the intersection of two major fractures.



There are numerous potential sites for water wells on the campus as indicated by yellow dots (not all potential sites are shown). Almost any fracture intersection will do.

The three red dots are along the largest and best developed fracture system on campus. It also lies at the southern edge of the campus which is down hill from the rest of campus. Therefore it is where most of the water that percolates through the campus will end up. Two of the locations are at intersections, while the other is at the edge of the largest collapse doline on campus.

The red arrow is the location where we drilled a well which produced water at a hundred gallons per minute for a full week (1 million gallons produced) with no appreciable drawdown of the water table.

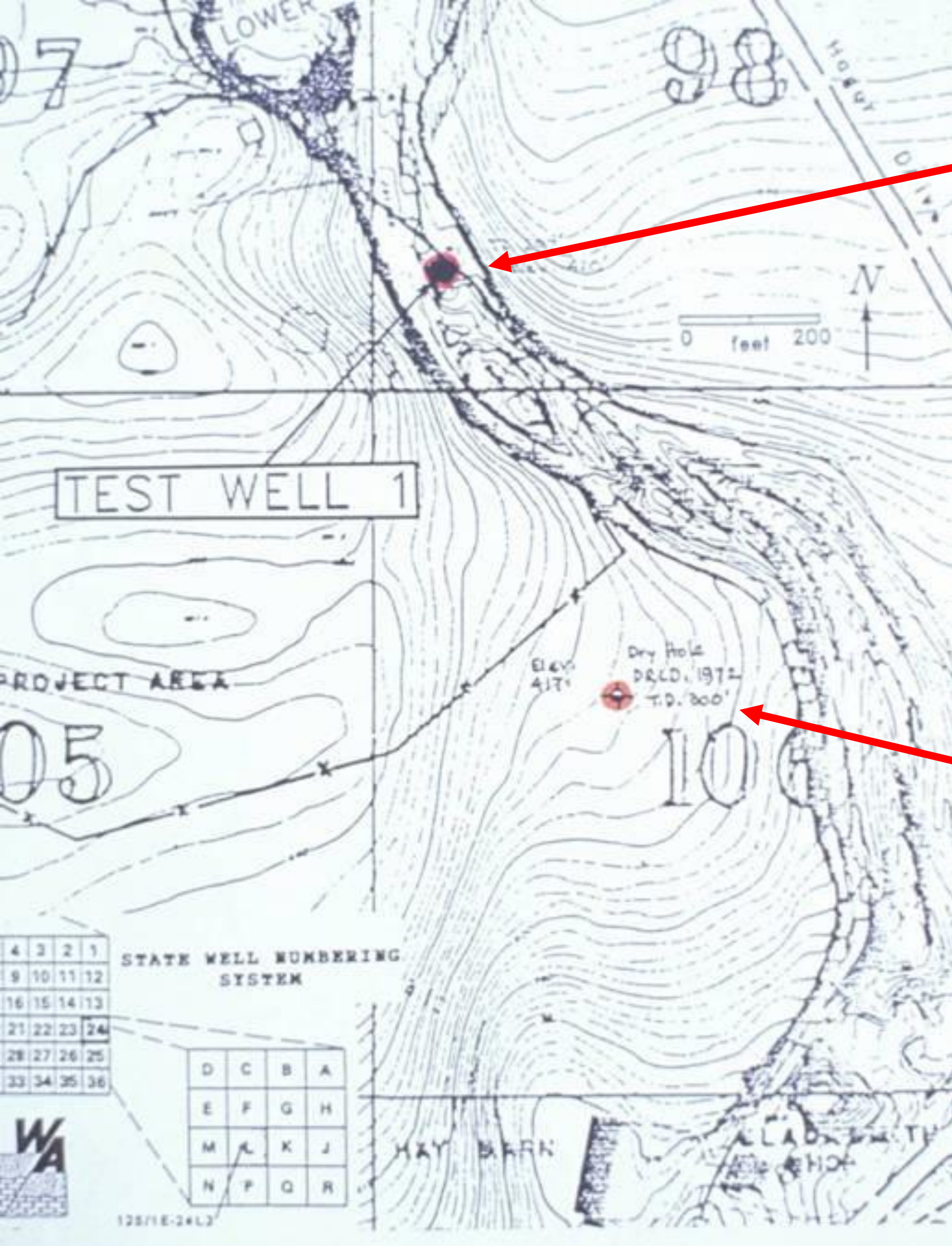


Figure 6. Test Hole No. 1 Location Map (UCSC base map)

Well located at intersection of two fractures as shown on last slide. Drilled in 1989 to a depth of 220 feet, with the water table at 100 feet. Produced at 100 gallons per minute during a week long pump test resulted in a 2.5 foot draw down. Capable of producing 200-300 gallons per minute, or more.

Well site located by two different dowsers on separate days. Drilled to a depth of 300 feet in 1972. A non productive site. They were only able to produce 2-3 gallons per minute.

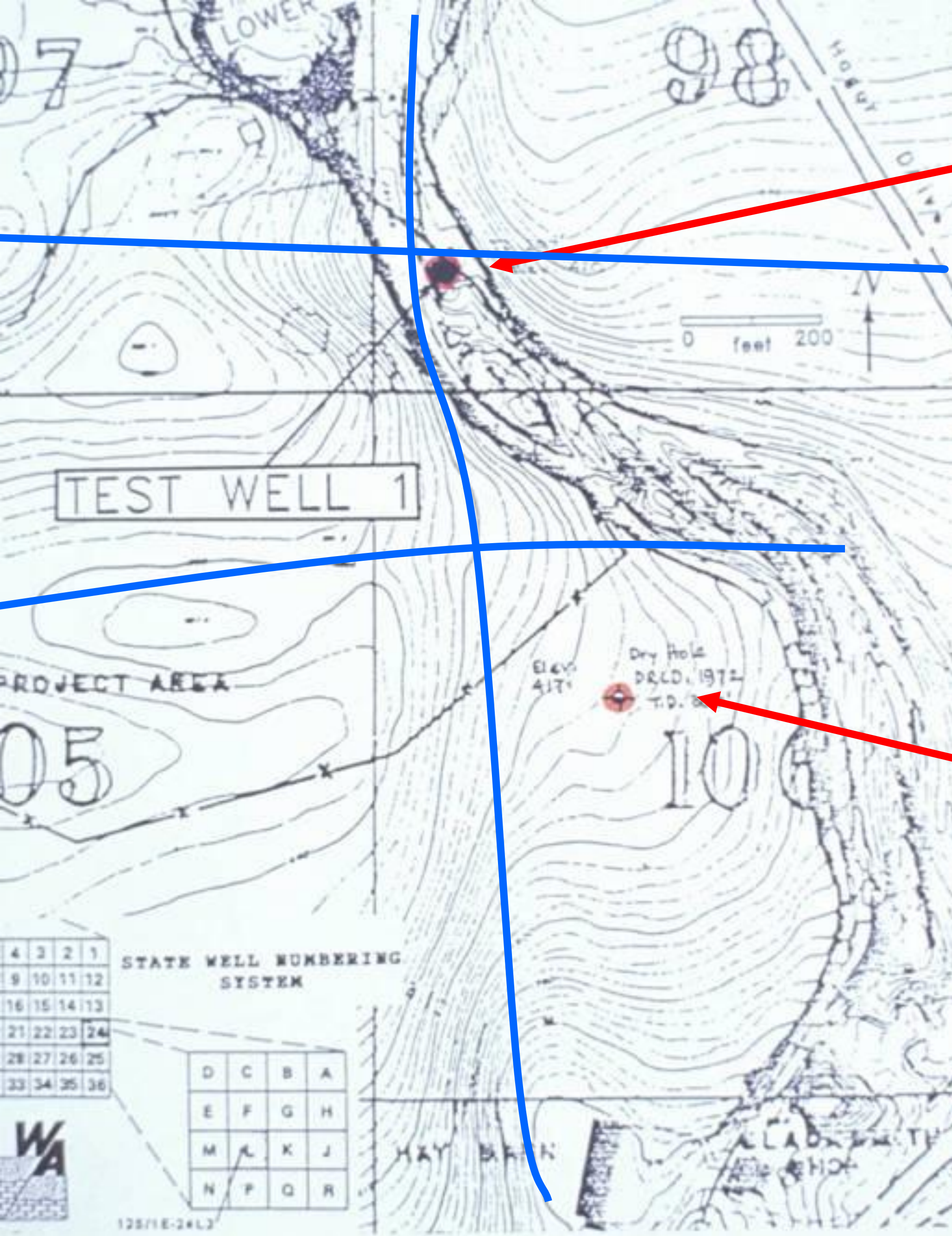


Figure 6. Test Hole No. 1 Location Map (UCSC base map)

Well located at intersection of two fractures as shown on last slide. Drilled in 1989 to a depth of 220 feet with the water table at 100 feet. Produced over 100 gallons per minute and was capable of 300 – 400 gallons per minute.

Blue lines indicate fractures.

Well site located by two different dowsers on separate days. Drilled to a depth of 300 feet in 1972. A non productive site. They were only able to produce 2-3 gallons per minute.

Drilling the well

Vulnerability of Karst to Contamination

1. Once contaminants in surface waters get into the water in the void system in the limestone there is no filtering effect. Other sedimentary rock types (sands and silts) provide a filtering effect as the water slowly moves through the small pore spaces and come into contact with a variety of minerals – including clays. Consequently, contaminated water cannot be allowed to enter the karst system because it will not be filtered without percolation through soils and sediments.

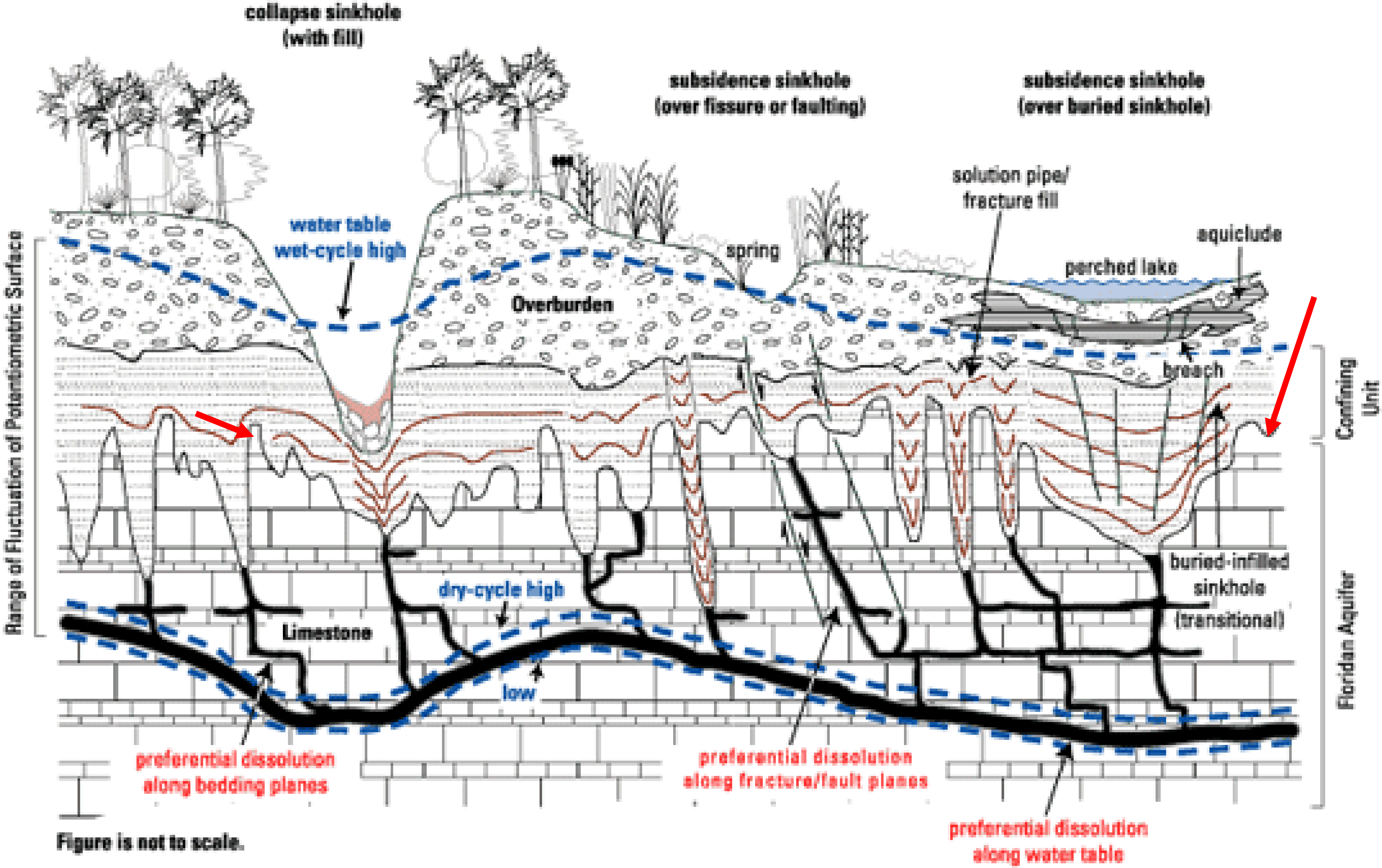
2. Requirements in respect to the disposal of "contaminated water" that are acceptable for most types of terrains are in most instances not applicable to karst. This includes the horizontal distance to streams or other bodies of water.

3. The thickness of sediments overlying the karst, and the composition of those sediments are the most important considerations. The sediments must be of the proper composition and thickness to be able to filter out all of the contaminants from the surface waters prior to their reaching the karst system.

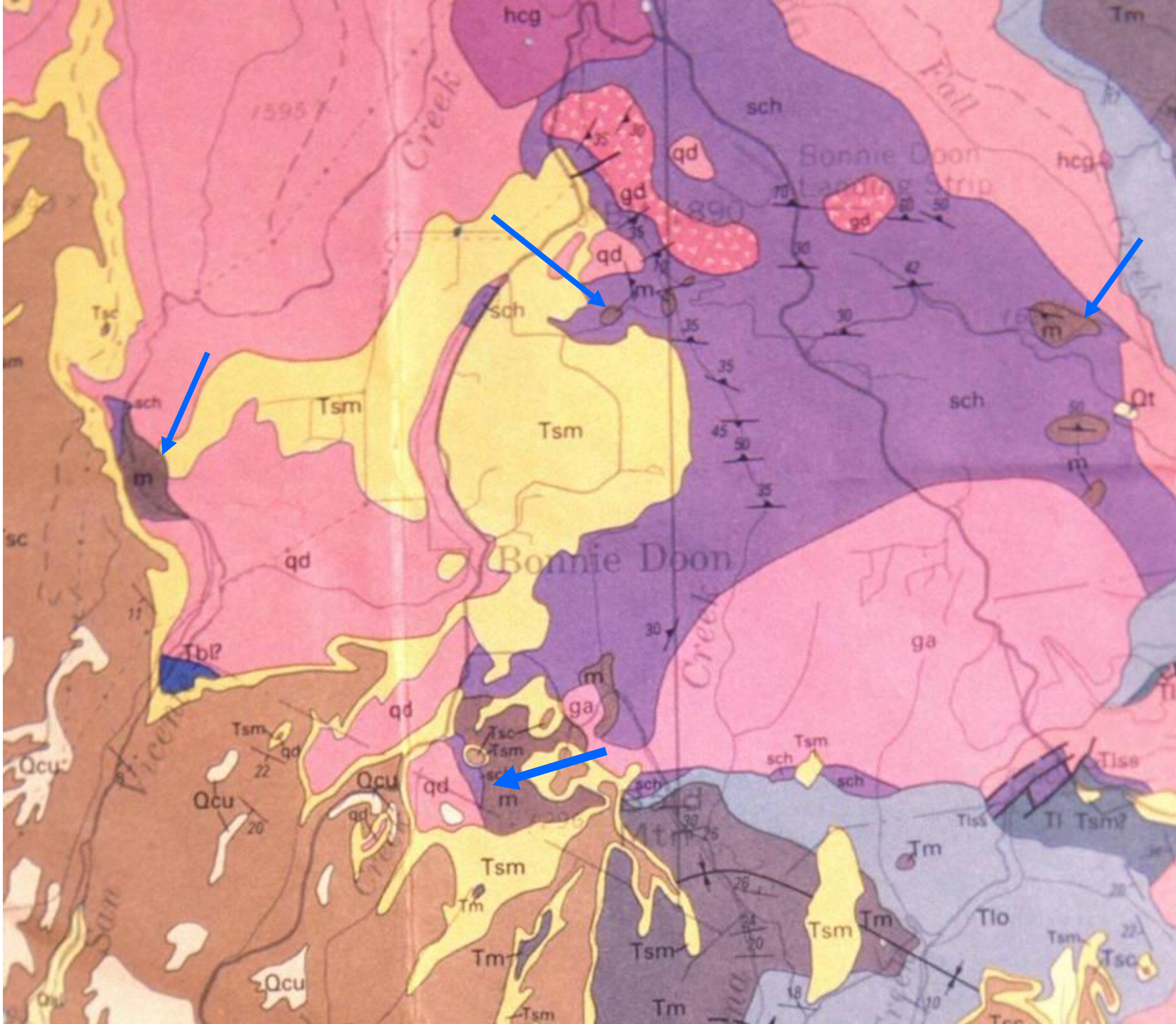
4. The biggest problem in dealing with contaminants in karst terrain is trying to determine the thicknesses of these sediments – combined with the shape of the underlying limestone mass. These are exceedingly difficult to determine from surface exposures alone. Consequently, extensive subsurface studies need to be prepared for each site. (continued - next slide)

Vulnerability of Karst to Contamination

5. Types of sub-surface studies include (but not limited to): 1. wells and borings, 2. exploratory trenches, 3. geophysical techniques. Without such studies it is impossible to know what lies beneath the soil. The contact between the overlying sediments that cover the limestone can be exceedingly complex. The photo below and the next two slides are examples of the complexity of the limestone surface where the overlying sediment has been removed by erosion. The complexity of the bedrock surface makes it impossible to really ever know what lies beneath the overlying sediments.


collapse sinkhole
(with fill)
subsidence sinkhole
(over fissure or faulting)
subsidence sinkhole
(over buried sinkhole)
solution pipe/
fracture fill
water table
wet-cycle high
spring
aquiclude
perched lake
Overburden
breach
Confining Unit
Range of Fluctuation of Potentiometric Surface
dry-cycle high
low
Limestone
buried-infilled
sinkhole
(transitional)
Floridan Aquifer
preferential dissolution
along bedding planes
preferential dissolution
along fracture/fault planes
preferential dissolution
along water table
Figure is not to scale.

Karst terrain on the island of Niue near Tonga in the southwest Pacific.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Tsm?
Tlo
Qt
Creek
Fall

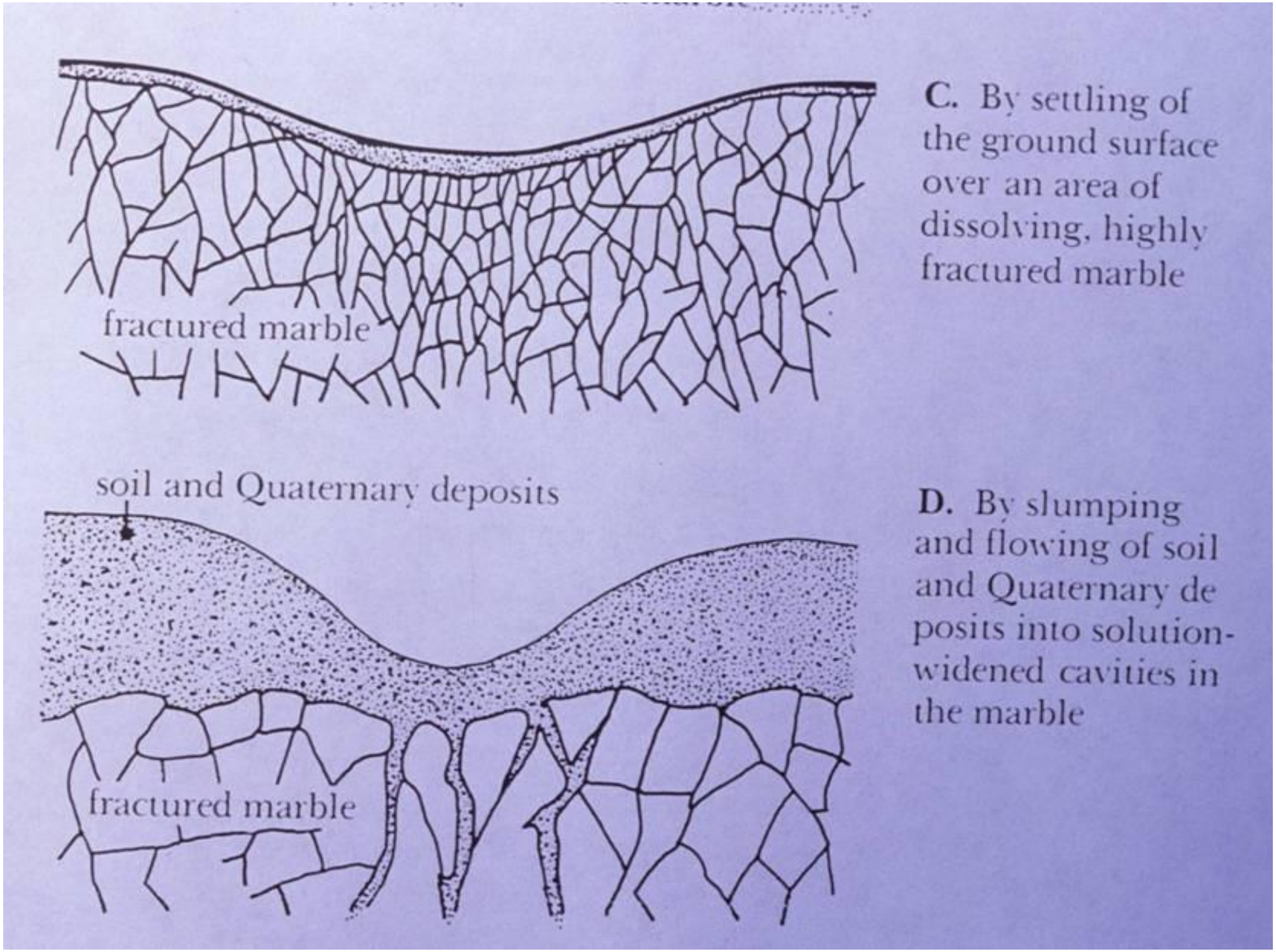
Food for thought – from: ”When the Rivers Run Dry”
by Fred Pearce

1. It takes between 250 and 650 gallons of water to grow a pound of rice.
2. It takes about 65 gallons to grow a pound of potatoes.
3. It takes 3000 gallons of water to grow the feed for enough cow to make a quarter pound hamburger.
4. A one pound jar of coffee requires 2650 pounds of water.
5. A glass of milk - 65 gallons.
6. A small steak – 1320 gallons.

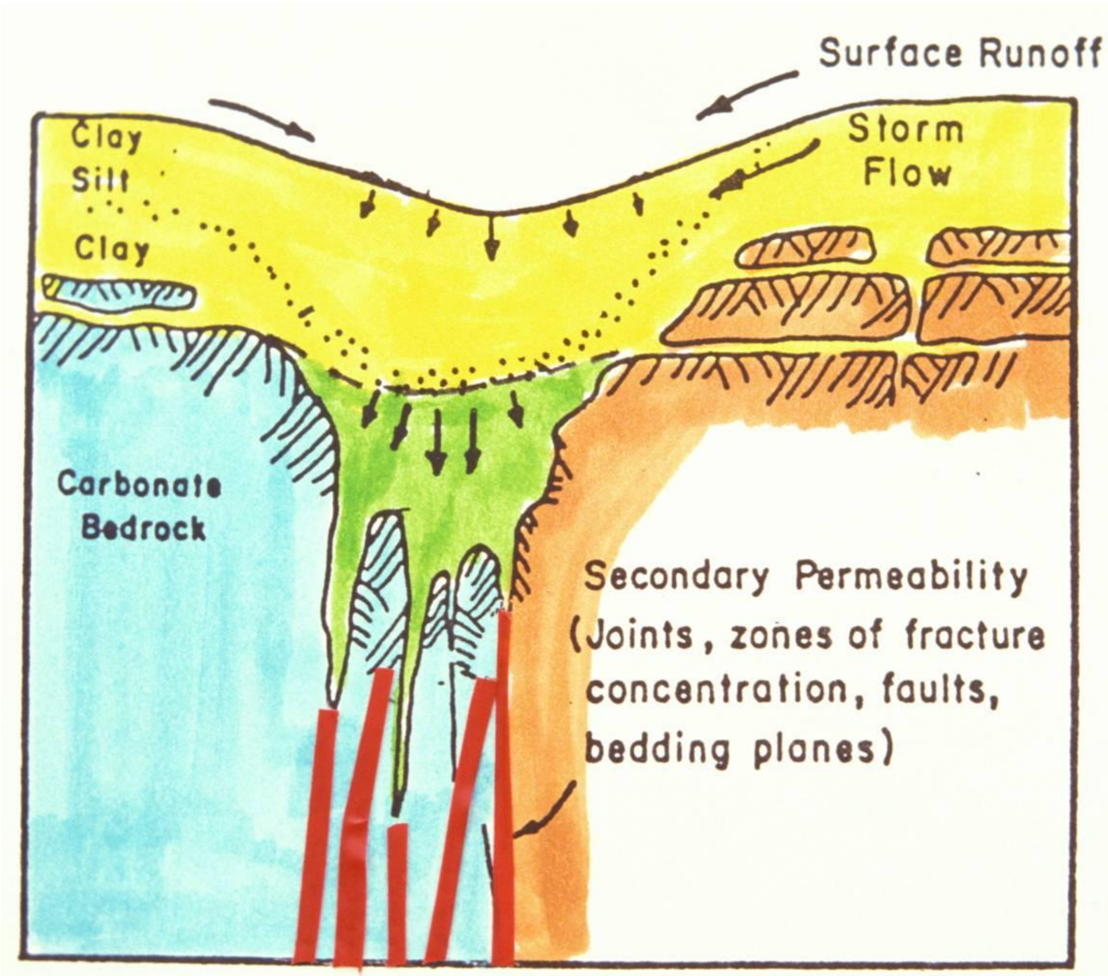
This brief presentation should be considered an introduction to limestone karst terrains, their hydrologic systems, their unique topography, and their susceptibility to contamination. If you wish to expand your understanding of these terrains I suggest searching the internet. The USGS website and numerous others go into far greater detail than I have. An excellent publication is "Living with Karst – A fragile foundation" by the American Geological Institute.

For the geology of the UCSC Campus I suggest the recently published "The Natural History of the UC Santa Cruz Campus" edited by Haff, Brown and Tyler. The second chapter covers the campus geology and the limestone karst.

With the book in hand you should also take some time to visit the campus and examine some of the features that are described there and discussed here.



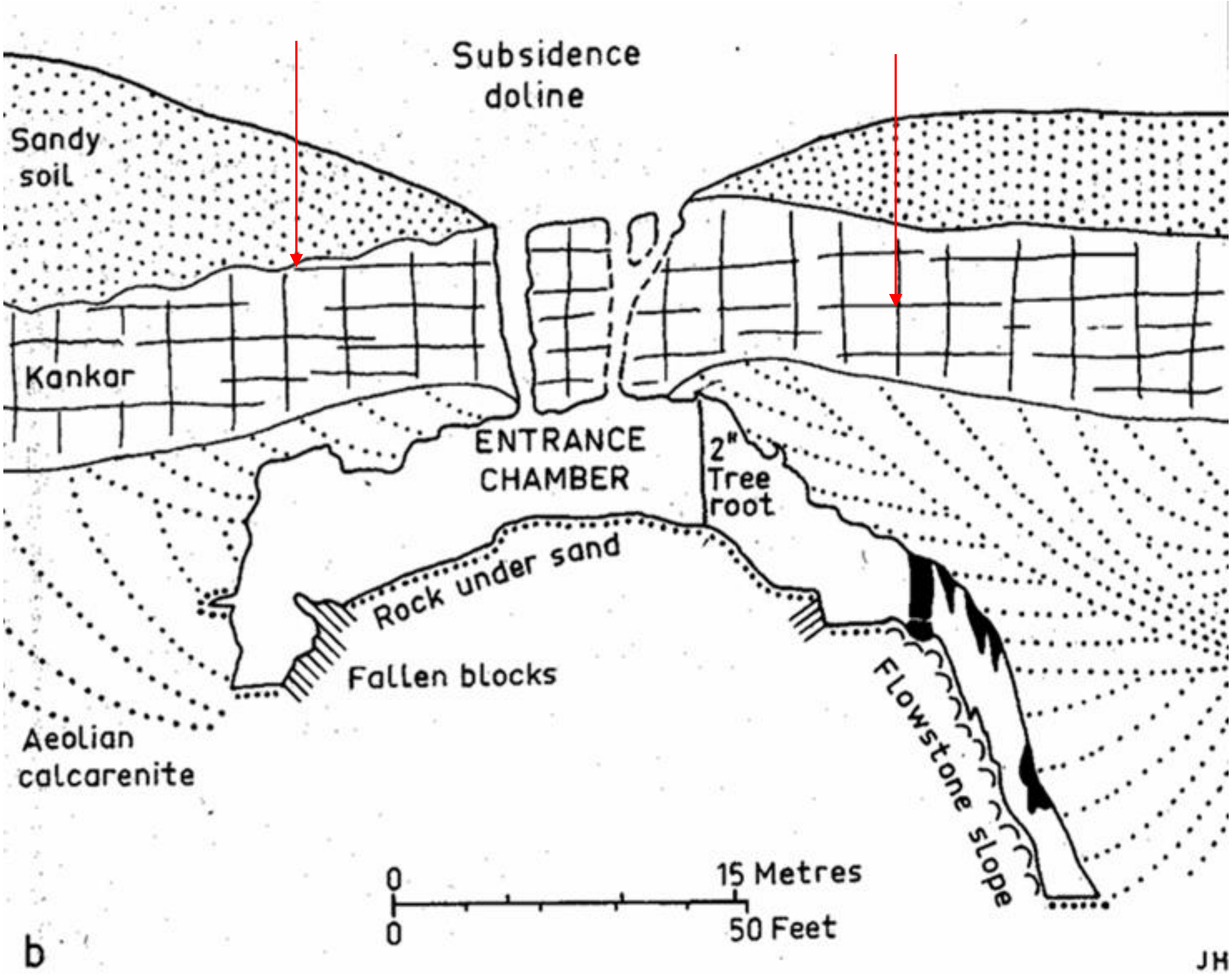
Two methods of doline formation – based only on fracture density. There has been no collapse or formation of a large void underground.



Doline (sinkhole) Formation

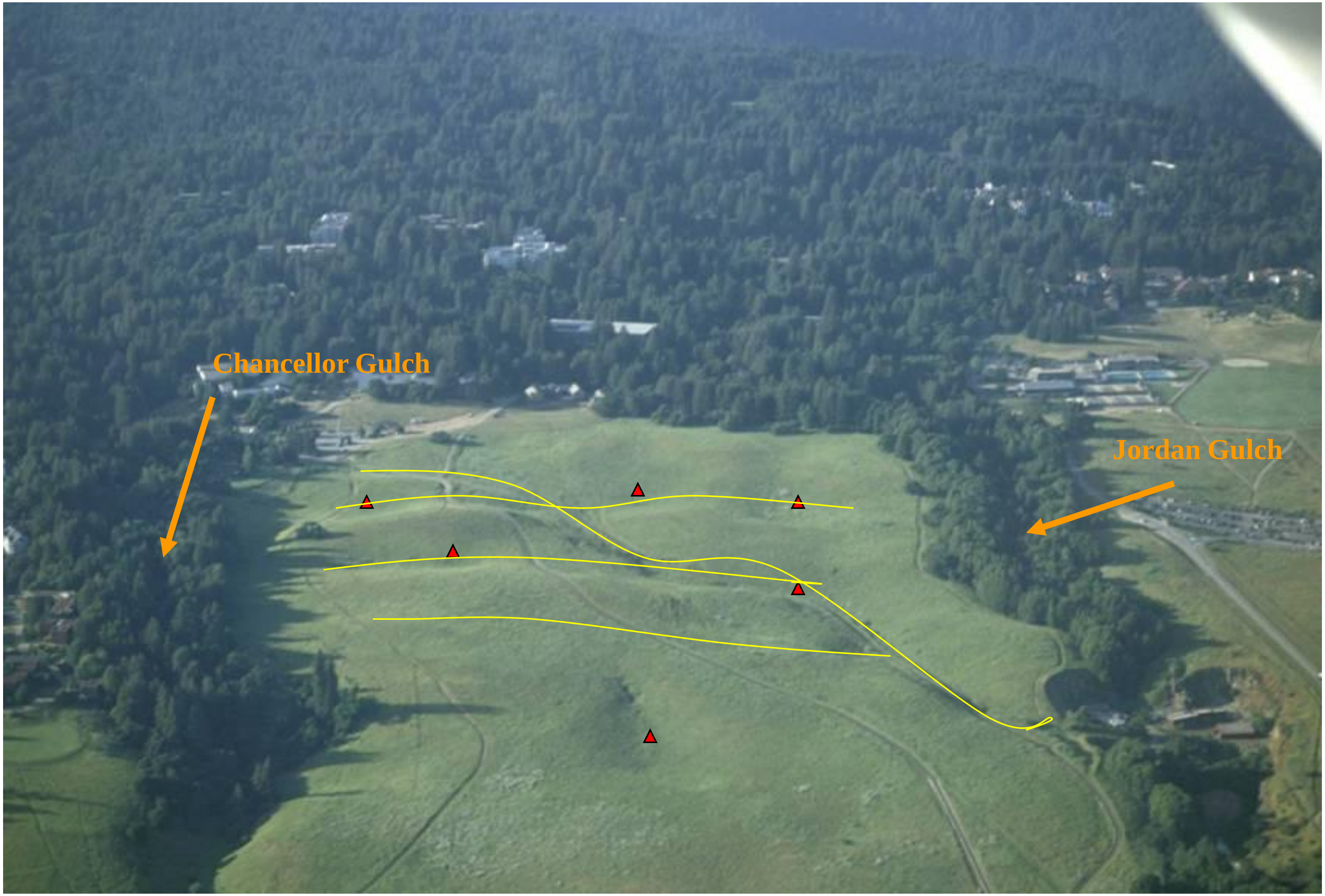
Dolines are formed in areas where there is sufficient solution of limestone at depth to generate subsidence of the overlying soils or sediments.

Limestone karst in Marble Canyon on the Colorado River



Doline formed by the collapse of the roof of a cavern – forming an entrance to the underground system.

Dolines formed along fractures – near the bike path


Chancellor Gulch
Jordan Gulch