

If you are interested in receiving a PowerPoint copy of either the data uncertainty or model uncertainty module, please contact Cristina Wilson

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Uncertainty in Data

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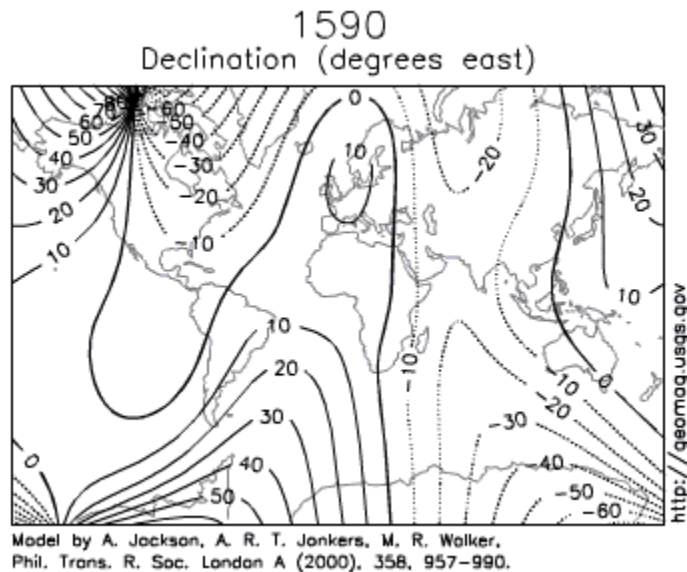
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The world is naturally variable

As a geology student, you have experienced this variability, even if it was not apparent to you at the time.

You have experienced that magnetic declination varies over space and time

This is why you always reset the declination on your compass from place to place.



[By U.S. Geological Survey \(USGS\)](#)



By Randy Williams

You have experienced variation in planes

What we call 'planes' are more often curvilinear. This is why you get different plane orientations depending on where you take a measurement.

Fault 'plane' in Genoa, NV

The presence of variability means there will always be some degree of uncertainty in data from the natural world.

Variability may be *systematic*, meaning it is predictable and consistent, and uncertainty can therefore be reduced.

This type of variability most often occurs due to problems with the calibration of equipment. Consider the example from the last slide on magnetic declination - If you take readings from different compasses at the same location and time, and get different results, some of this variation may be due to improperly set declinations. In this case, the variation would be predictable, e.g., a compass would be consistently off 20 degrees, and could be corrected or eliminated.



Photograph of compass
[By Matt Affolter \(QFL247\), CC BY-SA 3.0](#)

OR

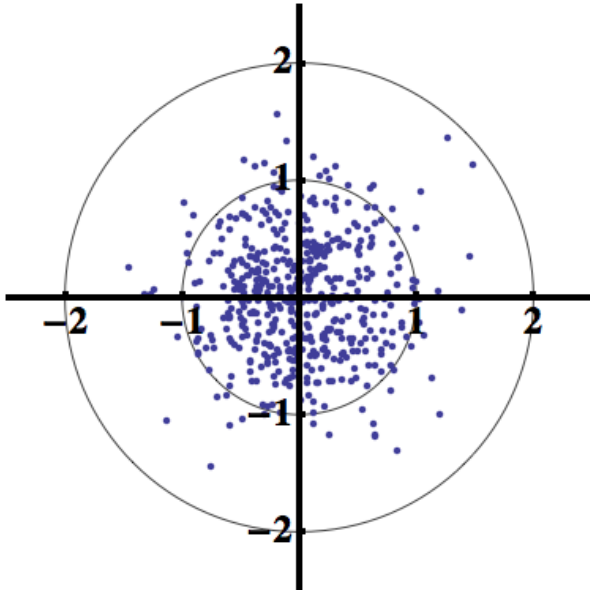
Variability may be *random* and *inherent to data*, so uncertainty cannot be eliminated and instead must be communicated to consumers of science

THE FOCUS OF THIS MODULE WILL BE HOW SCIENTISTS HANDLE AND COMMUNICATE UNCERTAINTY IN DATA

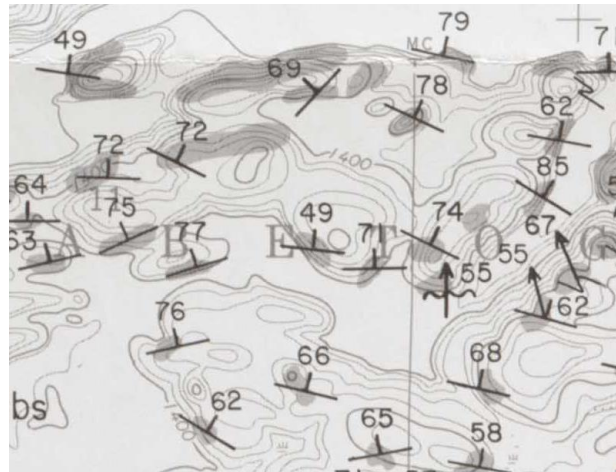
What counts as data?

When you think of data, you probably think of...

Numerical sensor data



Strike and dip measurements



Map from Norweigan Bay quadrangle, MN, by R. Bauer

BUT, data in geology can also be observations that involve small scale interpretations - which we refer to as inferences.

For example...

- Is this rock in place?
- What rock type is this?
- Is there a lineation?
- Are the sigmoidal veins in an en echelon array?
- And so on...

So there's uncertainty in data...

Why should I care?

Unless uncertainty is acknowledged and communicated effectively, scientists may put too much or too little faith in data.

- Scientists who place too little certainty in data can waste time and resources gathering new data with no practical value, and miss interpretation opportunities.
- Scientists who place too much certainty in data can make premature or false interpretations

Uncertainty in models (large-scale interpretations) will be discussed in the next module. However, it is important to keep in mind that uncertainty in data and models are very much connected!

Listen to expert geologist Randy Williams discuss with cognitive scientist Cristina Wilson how his uncertainty in observational data (what rock unit am I seeing?) feeds forward into his model uncertainty of the kinematics of the Sage Hen Flat (eastern California) field area.



Hopefully now you buy into the idea that taking full advantage of scientific research requires knowing how much uncertainty surrounds it.

Expert geologists believe so too, and that is why they have techniques for handling and communicating uncertainty

Technique 1:

When possible, take multiple data points at the same location and time.

Instead of reporting a single data point, report the average of all points and include information on the data range (e.g., standard deviation, standard error).

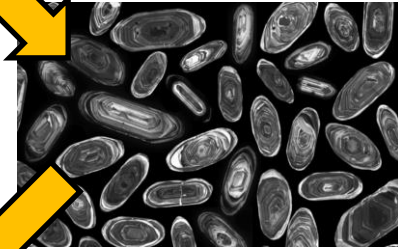
Technique 2:

If taking multiple data points is not possible (because of constraints on time, resources, etc.), assign an uncertainty ranking to your data.

Example of Technique 1: Geochronological Dates

Computing a geochronological date requires many steps:

1. Collect multiple appropriate samples
(in this case, a Neoproterozoic ash bed)
2. Separate out the component you want to date
(in this case, the mineral zircon)
3. Evaluate the radioactive and radiogenic elements (N and D respectively) on a mass spectrometer
(pictured is a thermal ionization mass spectrometer)
4. Calculate the date using the radioactive decay equation
(here rearranged to have time= t on the left-hand side)
5. **Infer the date as an age with geological significance
(here a U-Pb age on zircon for Cryogenian sediments)**



$$t = \frac{1}{\lambda} \ln \left(1 + \frac{D}{N} \right)$$

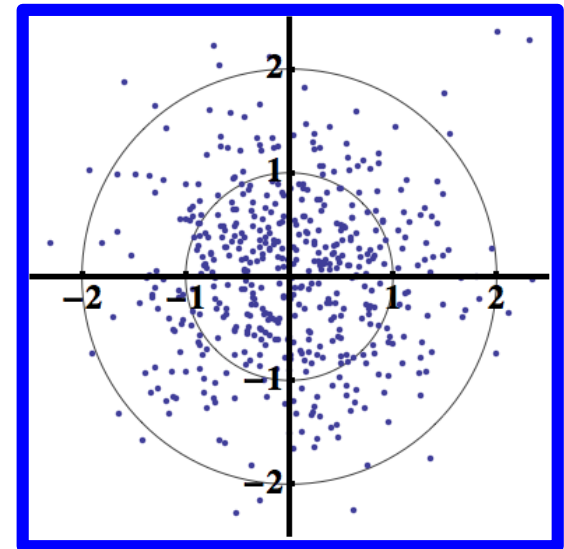
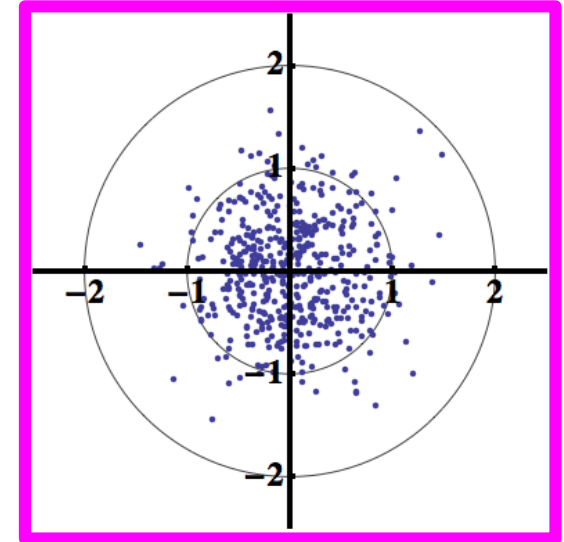
...ary rocks of the Ghaub Formation within
ta (Swakop Group) in central Namibia contain
c ash beds. U-Pb zircon geochronology of an
glaciomarine sediments to 635.5 ± 1.2 Ma,
ed as a “Marinoan-type” glaciation. In addi-
the proposed lower boundary of the terminal

Example of Technique 1: Geochronological Dates

Inferring geochronological age (step 5, previous slide) involves consideration of sample variability, and resulting uncertainty.

With instrumental data, in which it can be assumed that the instrument is generally accurate, the uncertainty has to do with the uncertainty of the measurements. The top (pink box) one is more precise because there is less spread of data.

Does one of these plots have a smaller magnitude of uncertainty?



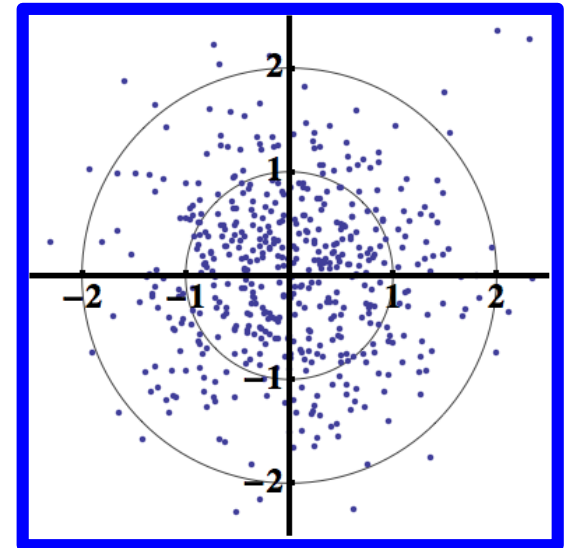
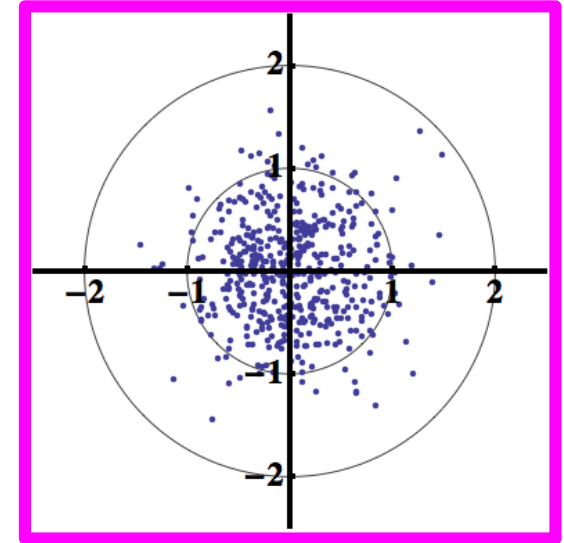
Example of Technique 1: Geochronological Dates

The plot outlined in **pink** has the smaller magnitude of uncertainty because it is less variable.

Some amount of uncertainty in the **blue** plot could be reduced by altering our methodology to get more precise, less variable data, e.g., using different volumes of zircon or different types of mass spectrometry.

However, as discussed on slide 3, some amount of variation and uncertainty is inherent to the data, and is therefore irreducible.

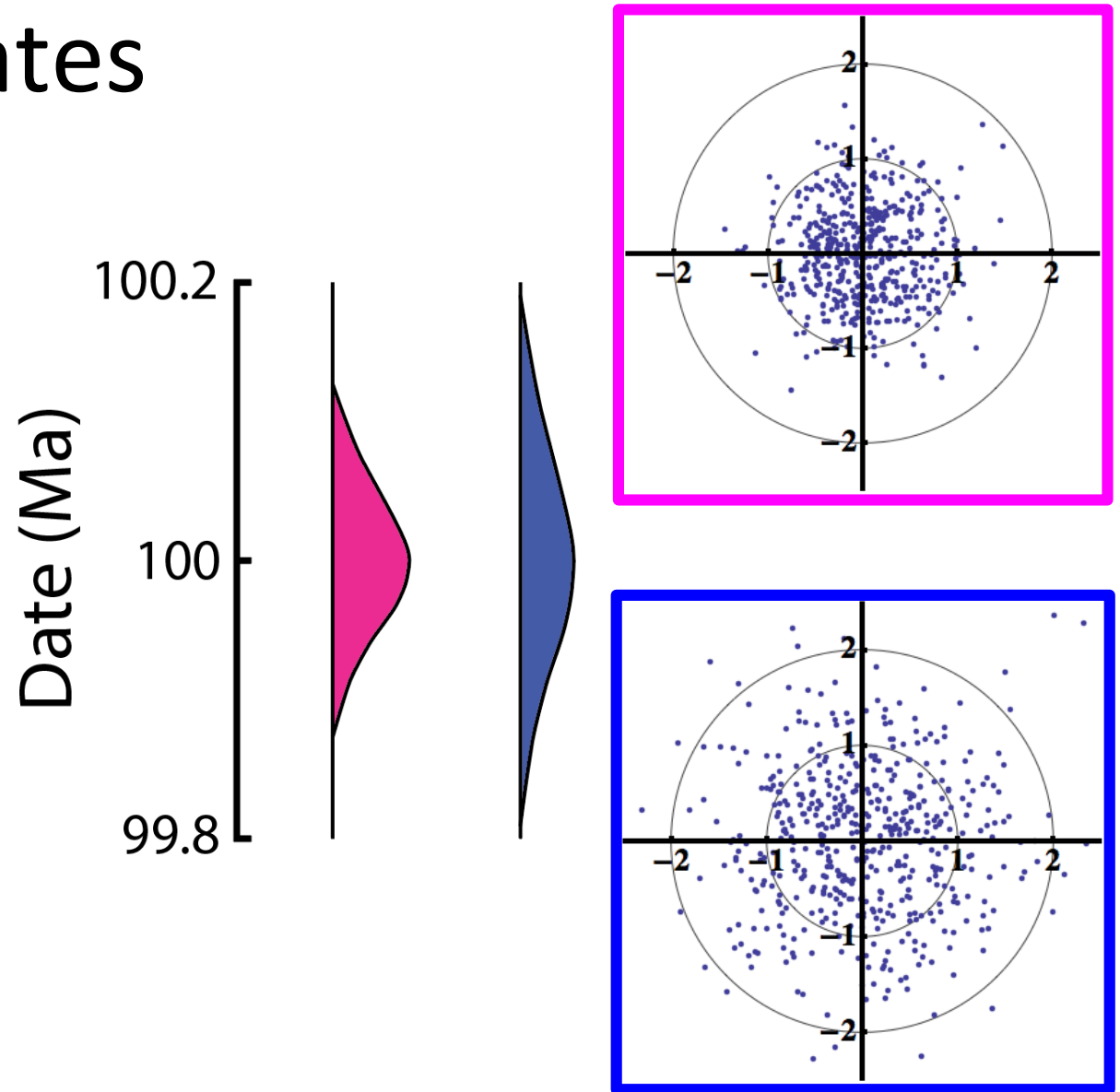
HOW IS THIS UNCERTAINTY COMMUNICATED?



Example of Technique 1: Geochronological Dates

One way is to plot the probability of any individual measurement giving a particular age. These are called probability density functions. The **pink** curve is taller and goes less distance out from the center, and it correlates to the data in the pink box. The **blue** curve correlates to the data in the blue box.

There are other methods of presenting this type of data, but they all involve explicitly showing uncertainty in some manner.



Moving from geochronological dates to ages...

Moving from data to model

Uncertainty in geochronological date data will have an influence on uncertainty in models of rock age.

Example 1: Determining the maximum age of a sandstone by dating the youngest detrital zircon in it. Certainly the rock must be younger than the age of the youngest zircon, but it could be significantly younger.



A model is only as good (certain) as the data that informs it - the more uncertain the data, the more uncertain the model. BUT, even if data has high certainty, a model may be uncertain.

Model uncertainty will be discussed more in the next module.

Sometimes collecting multiple data points is just not possible...

- A single data point can have too high a cost (in time or money)
- Limited field time and the need for good spatial resolution of data can make it impossible to collect multiple data points in a single location.

In these situations, scientists can apply technique 2 to communicate uncertainty

Technique 1:

When possible, take multiple data points at the same location and time.

Instead of reporting a single data point, report the average of all points and include information on the data range (e.g., standard deviation, standard error).

Technique 2:

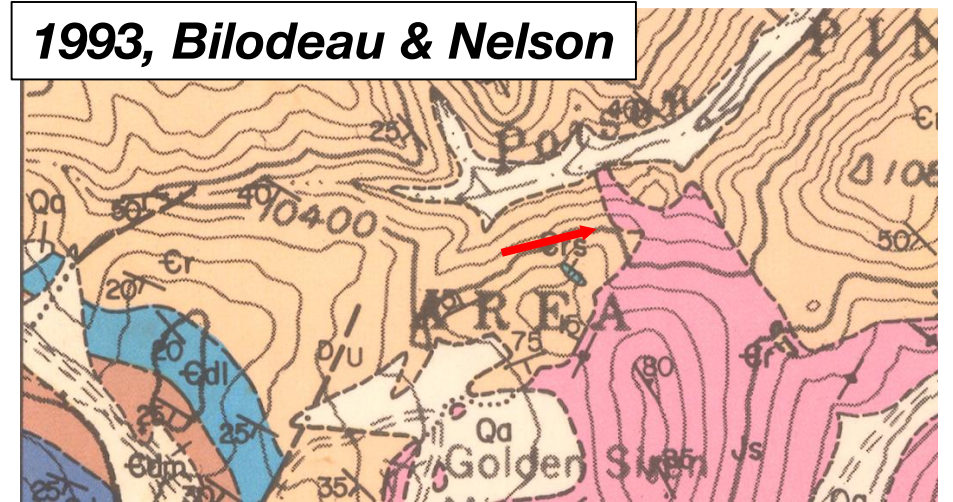
If taking multiple data points is not possible (because of constraints on time, resources, etc.), assign an uncertainty ranking to your data.

Example of Technique 2: Geologic Mapping

Geologic mapping involves the collection of mostly observational data, where there can be high degrees of uncertainty.

Some of this uncertainty is communicated - for example, with contacts and faults, uncertainty is indicated via dashed lines.

Note on the map, the contact between the Reed Dolomite (**peach**) and the Sage Hen (**pink**) is dashed approximate. **Take a moment to imagine what an approximate contact looks like - what range of observations fits within this category?**

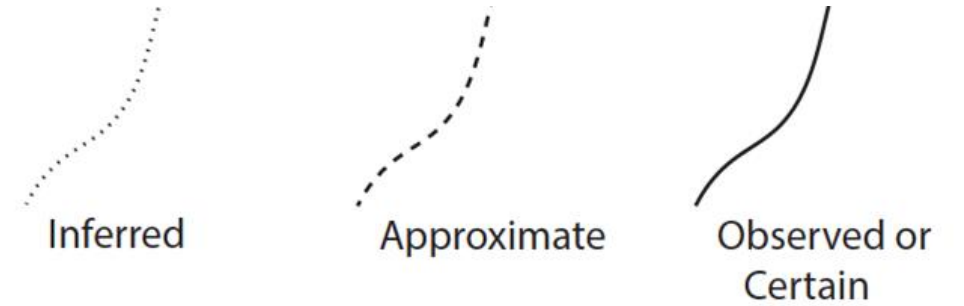
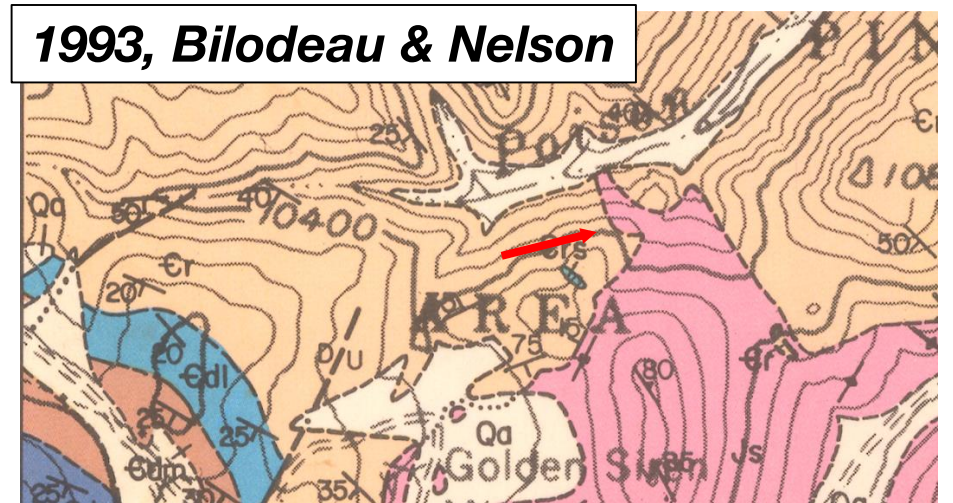




By Thomas Shipley

Here are photos of what the contact actually looks like.

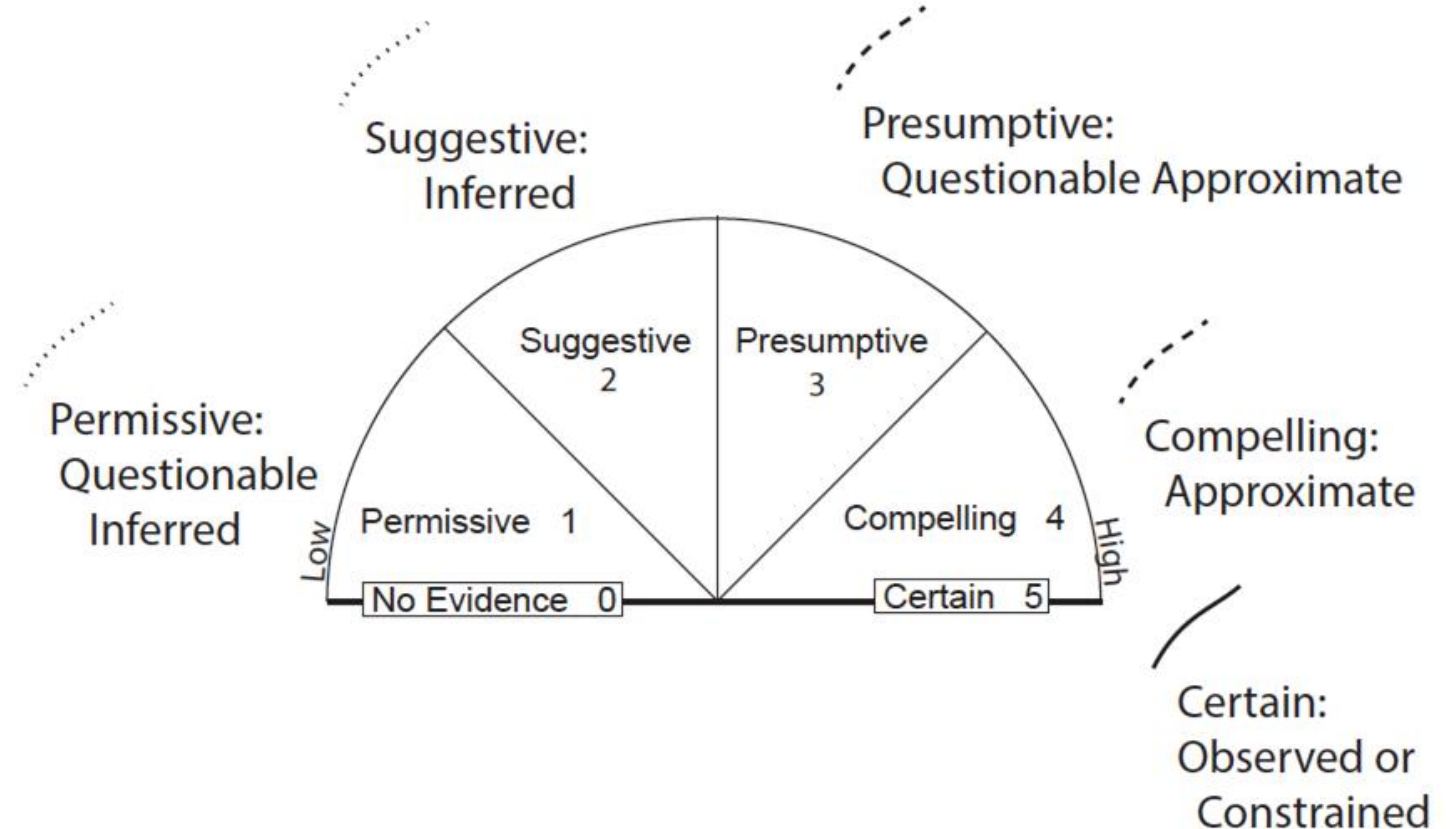
Was this what you expected?



Example of Technique 2: Geologic Mapping

Current methods of communicating uncertainty in contacts may collapse across meaningfully distinct categories

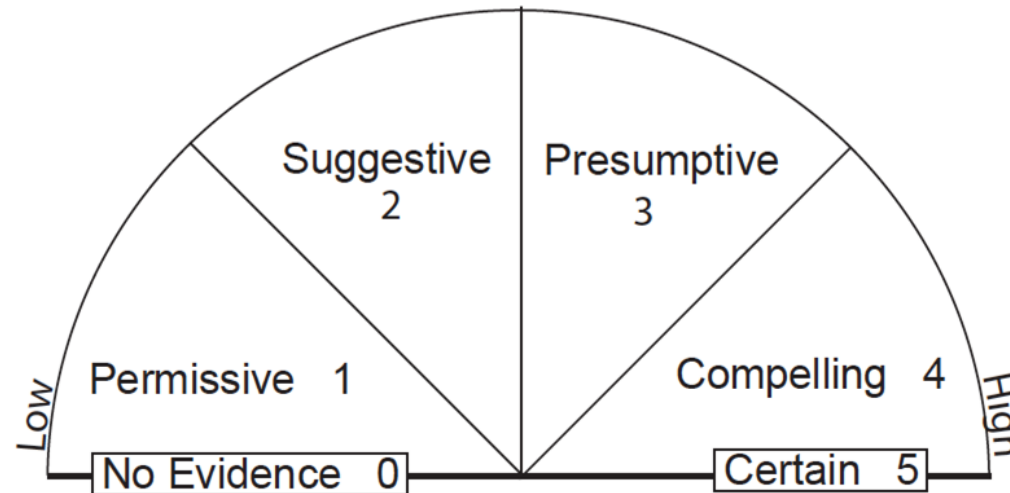
We propose a more precise 5-fold ranking system (or *Evidence Meter*) for characterizing the uncertainty associated with a particular observation inference.



Suggestive indicates that there is positive evidence for a particular inference, but that the evidence also allows the possibility for other inferences.

Presumptive – defined as “presumed in the absence of further information” – indicates that an inference is “more likely right than wrong”.

Permissive is the least certain form of evidence. Permissive suggests that a particular idea or inference cannot be ruled out, but it is also not the only available solution.



Compelling indicates that the evidence is strongly supportive of the inference. Compelling evidence for an inference is based on a preponderance of positive evidence.

No evidence indicates there is no information that constrains an inference in any way.

“No evidence” and “Certain” are end members, because there is no variability within these categories.

The middle four categories – Permissive, Suggestive, Presumptive, Compelling – have a range of possible values.

Certain indicates that there is a direct and resolvable link between the evidence and a particular inference.

Example of Technique 2:

Geologic Mapping

The nice thing about our ***Evidence Meter*** is that it can be applied to geologic features besides contacts and faults. Here are 4 features of an outcrop that an uncertainty ranking could be applied to:

1. Attachedness

The determination of whether the rock at the Earth's surface is directly connected – and therefore is representative of – the rocks below the surface at that location.

2. Lithological Correlation

The determination of whether a particular rock belongs to a larger group of rocks. An expert geologist will be able to determine a rock type with high certainty at most outcrops – the bigger question is whether they can unambiguously decide what formation it belongs to.

3. 3D Geometry

The determination of the internal features of an outcrop. An example of 3D Geometry is the determination of strike and dip of bedding. Again, most expert geologists in well understood field settings can do this with high certainty – but there are some cases where one is not certain.

4. Kinematics

The determination of the movement of the rock. In most cases, for sedimentary rocks, this is the determination of paleoflow based on sedimentological features. For deformed rocks, this is the determination of relative movement, such as along a fault.

Example of Technique 2: Geologic Mapping

Uncertainty in *Attachedness*

How sure are you the Rock is attached (is this the true location/orientation?)

What evidence is there in this image that the rock is attached?

- Size
- Connection to rock under it
- Consistency of features with surrounding rocks (rock type and orientation)
- No source topographically higher that it might have moved from
- No known processes (e.g., glaciers) that could have moved large rocks over large distances



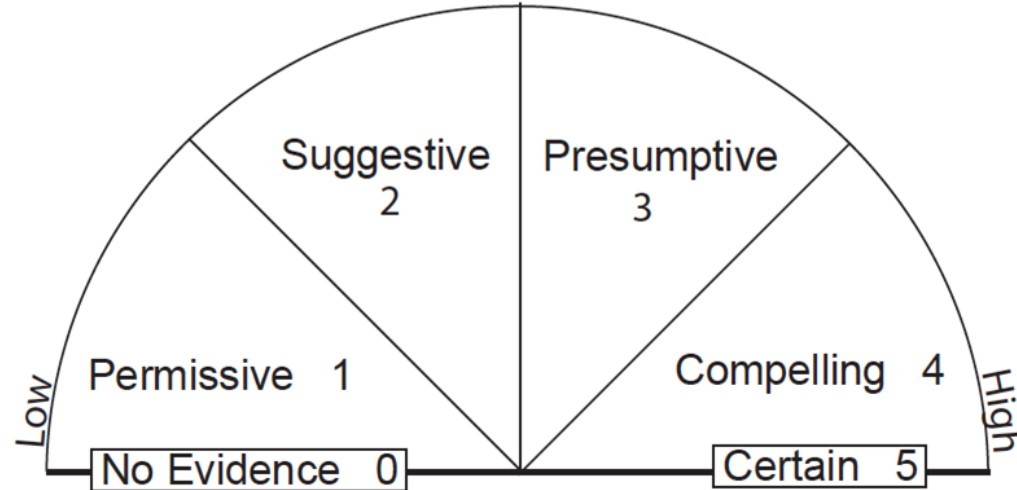
[By Ramesh Meda, Sonarpulse - originally posted to Flickr as Yana Rock, CC BY 3.0](#)

Yana Rock, India

Example of Technique 2: Geologic Mapping

Uncertainty in *Attachedness*

How sure are you the rocks in photos A and B are attached? Why?



A

Vasquez Rocks, CA



[By Thomas from USA - Vasquez Rocks](#) Uploaded by PDTillman, CC BY 2.0

B



Silesian Stones, Poland

[CC BY-SA 3.0](#)

Example of Technique 2: Geologic Mapping

Uncertainty in *Attachedness*

How sure are you the rocks in photos A and B are attached?

Experts rated photo A ***compelling***, because it is large in size, and consistent with context (but could still be part of massive landslide)

Experts rated photo B ***suggestive***, because they are not clearly attached to the group. If internal foliations were all consistent in the separate blocks, it would likely increase to ***presumptive***.

A

Vasquez Rocks, CA



[By Thomas from USA - Vasquez Rocks](#) Uploaded by PDTillman, CC BY 2.0

B



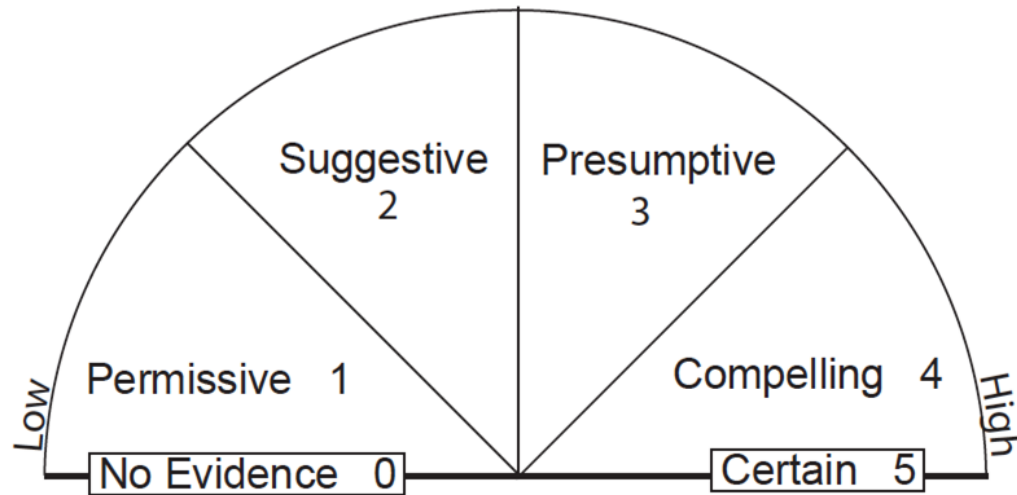
Silesian Stones, Poland

[CC BY-SA 3.0](#)

Example of Technique 2: Geologic Mapping

Uncertainty in *Attachedness*

How sure are you the rock in the photo is attached? Why?



By Thomas Shipley

Example of Technique 2: Geologic Mapping

Uncertainty in *Attachedness*

How sure are you the rock in the photo is attached? Why?

Experts rated this photo ***presumptive***, because it is consistent with context, did not have evidence of having moved downhill (although its size would have allowed for movement in the environment), and is not visibly detached.



By Thomas Shipley

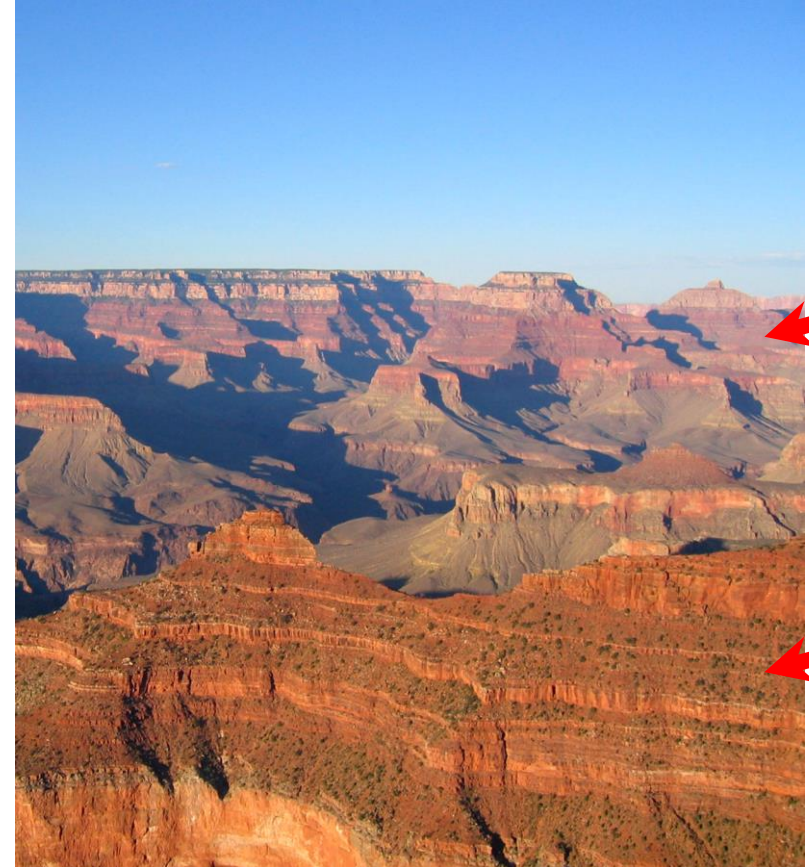
Example of Technique 2: Geologic Mapping

Uncertainty in *Lithological Correlation*

How sure are you the Rock is part of a specific formation?

What evidence is there in this image that the rock is a member of the same group?

- Color, texture, rock ID
- Diagnostic characteristics
- Consistency with surrounding rocks
- No other formations are likely to be confused with it



[CC BY-SA 3.0](#)

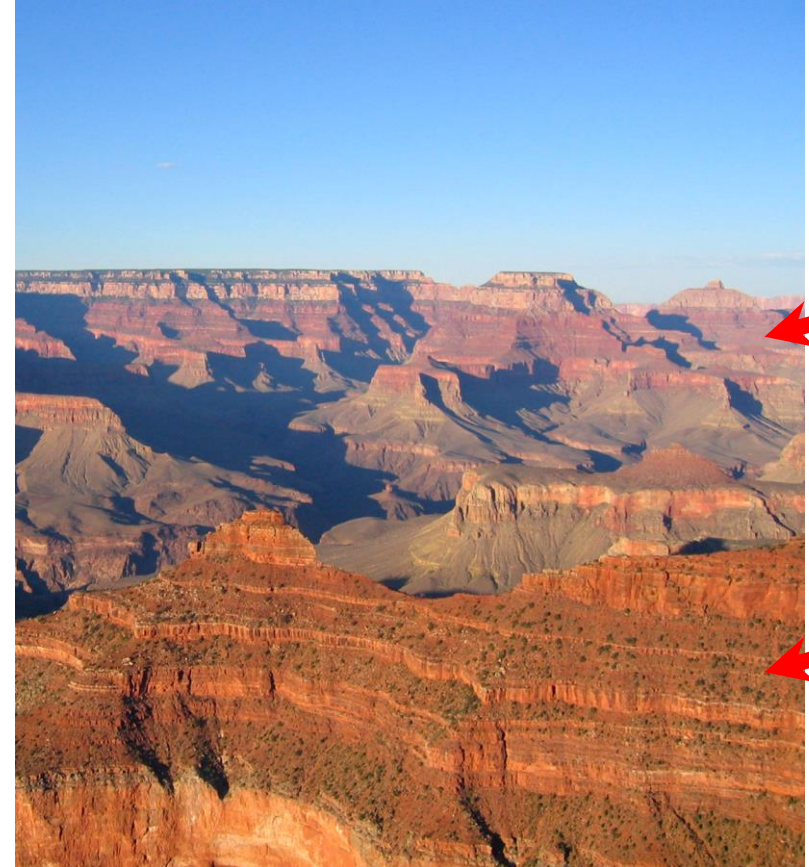
from Yavapai Point, South
Rim, Grand Canyon,
Arizona, USA

Example of Technique 2: Geologic Mapping

Uncertainty in *Lithological Correlation*

How sure are you the Rock is part of a specific formation?

Experts rated this photo ***compelling***, because the excellent exposure of the Grand Canyon allows one to trace the layers from one area to another in continuity.



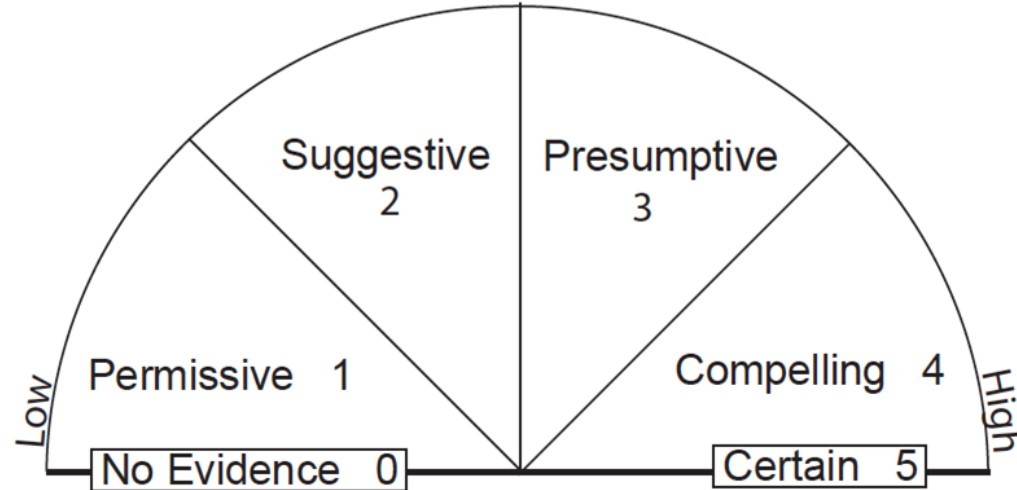
[CC BY-SA 3.0](#)

from Yavapai Point, South
Rim, Grand Canyon,
Arizona, USA

Example of Technique 2: Geologic Mapping

Uncertainty in *Lithological Correlation*

Both pictures show cross-bedded sandstones. How sure are you the rocks in photos A and B are a member of the same formation? Why?



A



[By National Park Service](#)

B



[By Callan Bentley](#)

Example of Technique 2: Geologic Mapping

Uncertainty in *Lithological Correlation*

How sure are you the rocks in photo A are a member of the same group? Photo B? Why?

If just shown these two pictures without context, an Expert would rate this correlation as ***permissive***, because cross-bedding in sandstones is not particularly diagnostic. Several formations in the US West have cross-bedded sandstones.

Experts would rank this correlation ***suggestive*** or ***presumptive*** if they knew that the outcrops were from the same region (depends on region).

A



Navajo
Sandstone,
Zion
National
Park

[By National Park Service](#)

B

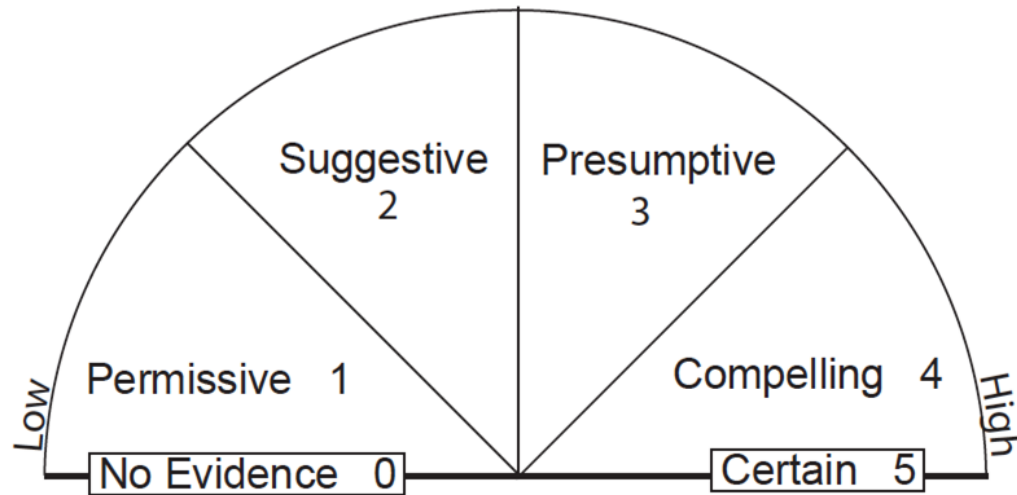


[By Callan Bentley](#)

Example of Technique 2: Geologic Mapping

Uncertainty in *Lithological Correlation*

How sure are you the limestones in the photos are from the same unit? Why?



Sage Hen Flat, CA



By Thomas Shipley

Example of Technique 2: Geologic Mapping

Uncertainty in *Lithological Correlation*

How sure are you the limestones in the photos are from the same unit? Why?

Experts rated this photo ***presumptive***, because there are few limestones in the region. While there are limestones in other formations, they are surrounded by schists. The lack of schists surrounding this limestone make it presumptive that it belongs to the Deep Springs formation.



Sage Hen Flat, CA



By Thomas Shipley

Example of Technique 2: Geologic Mapping

Uncertainty in *3D Geometry*

How sure are you the rock has particular spatial orientation?

What evidence is there in this image that the rock has a specific orientation

- Consistent planar features
- Consistency with orientations seen in surrounding rocks of a similar type
- Features (bedding) are penetrative and are not just on the surface



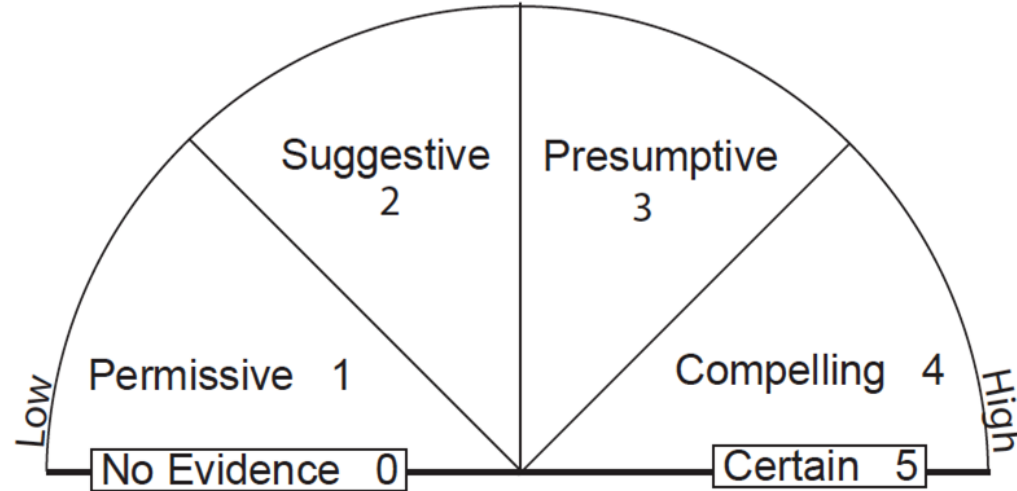
[By Takakkaw at English Wikipedia - Transferred from en.wikipedia to Commons., Public Domain.](#)

The south-facing (right) side of Mount Rundle in Canada is a good example of a dip slope. The ledge-forming dipping strata consists of Rundle Group dolomite.

Example of Technique 2: Geologic Mapping

Uncertainty in *3D Geometry*

How sure are you the rocks in photo A have a specific orientation? Photo B? Why?



A

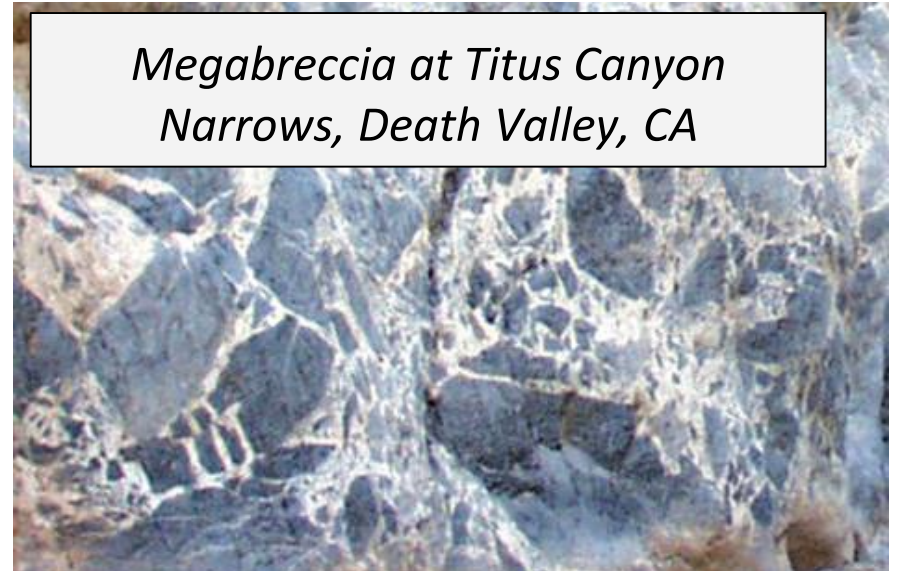
Faults in Bishop Tuff, CA



By Thomas Shipley

B

Megabreccia at Titus Canyon Narrows, Death Valley, CA



[By National Park Service](#)

Example of Technique 2: Geologic Mapping

Uncertainty in *3D Geometry*

How sure are you the rocks in photo A have a specific orientation? Photo B? Why?

Experts rated photo A ***certain***, because there is enough three dimensional exposure on this outcrop that there is no uncertainty.

Experts rated photo B ***permissive*** for any particular rock fragment, because it is on a wall that does not provide 3D relief.

A

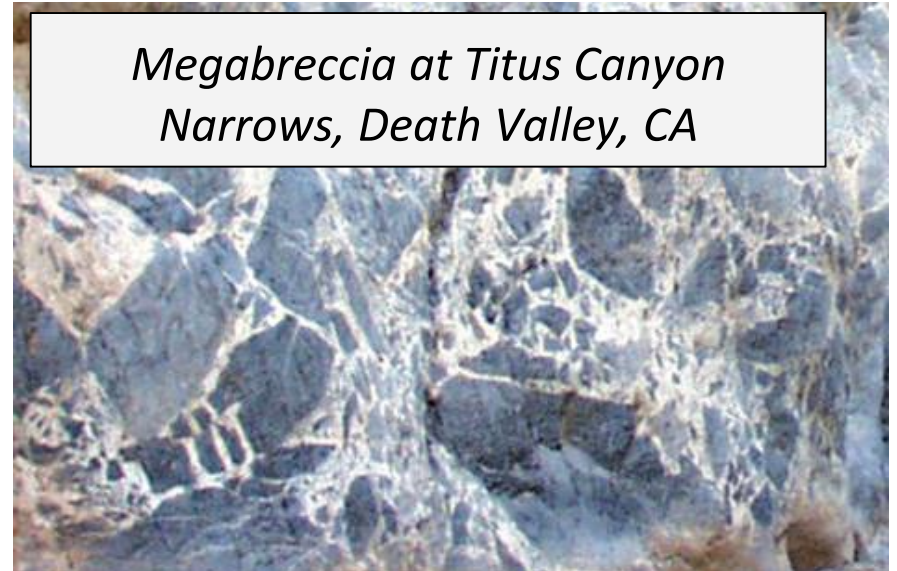
Faults in Bishop Tuff, CA



By Thomas Shipley

B

Megabreccia at Titus Canyon Narrows, Death Valley, CA



[By National Park Service](#)

Example of Technique 2: Geologic Mapping

Uncertainty in *Kinematics*

How sure are you that you determine the relative motion or distortion?

What evidence is there in this image that the fault is a reverse fault?

- You can find an offset marker (particularly bedding horizon) on both sides (Offset)
- There is minor fault drag (folding adjacent to fault) that is consistent with the reverse shear sense. (Asymmetry)
- Distortion can also provide information about kinematics, but does not in this case



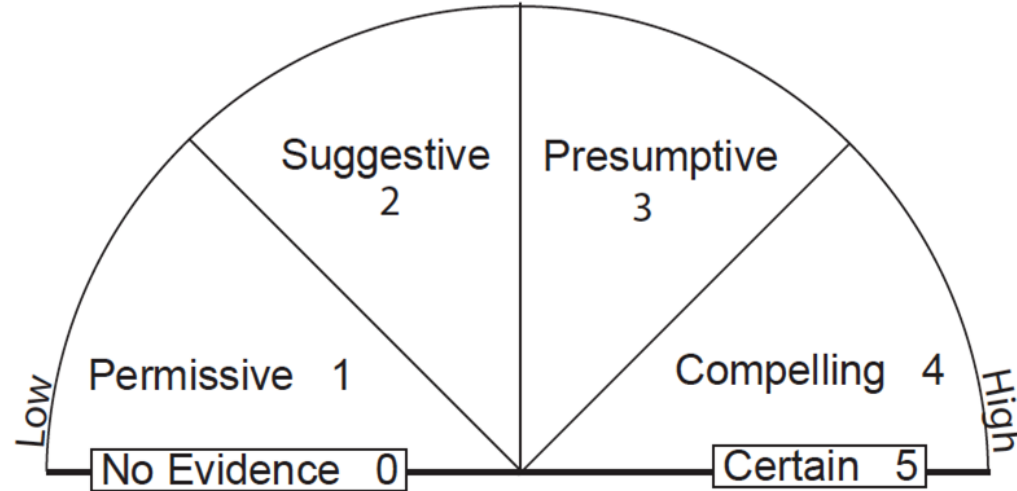
From H. Fossen (Structural Geology)

Reverse fault in sandstone

Example of Technique 2: Geologic Mapping

Uncertainty in *Kinematics*

How sure are you the rocks in photo A are part of a strike-slip fault? Photo B? Why?



A



Slickenlines. Corona Beach, CA. Jackson

B



Faults in volcanic layers. El Salvador. C. DeMets

Example of Technique 2: Geologic Mapping

Uncertainty in *Kinematics*

How sure are you the rocks in photo A are part of a strike-slip fault? Photo B? Why?

Experts rated photo A **compelling**, the slickenlines provide information on slip direction for the last movement. But, there is also a dip-slip component of motion.

Experts rated photo B **permissive**, because although the offset *appears* normal, strike-slip displacement (in and out of the cliff face) of beds cannot be ruled out.

A



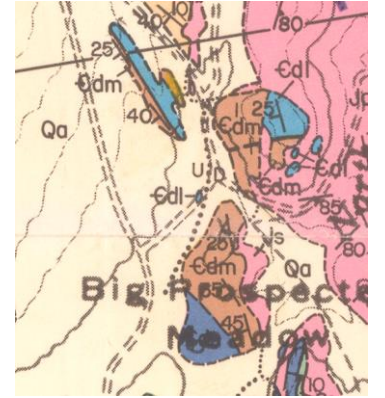
Slickenlines. Corona Beach, CA. Jackson

B



Faults in volcanic layers. El Salvador. C. DeMets

Imagine how uncertainty in observations at an outcrop (attachedness, lithology, 3D geometry, kinematics) propagates to uncertainty in geologic models.

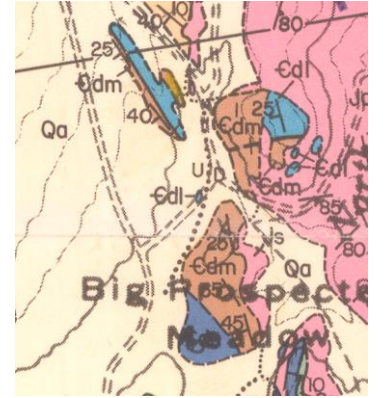


Earlier in this module, you listened to Randy Williams explain how his uncertainty in observational data (what rock unit am I seeing?) fed forward into his model uncertainty of the kinematics of the Sage Hen Flats field area.

Here is another video of Randy Williams, discussing with cognitive scientist Cristina Wilson, his uncertainty about the lithological correlation of rock units - how it agrees or disagrees with inferences made in the Bilodeau & Nelson (1993) map - and how the high degree of uncertainty in unit data makes his interpretation of fault kinematics challenging



Imagine how uncertainty in observations at an outcrop (attachedness, lithology, 3D geometry, kinematics) propagates to uncertainty in geologic models.



The video illustrates two points about the relationship between data-model uncertainty

- A model is only as good (certain) as the data that informs it - the more uncertain the data, the more uncertain the model. *We saw this with geochronological age interpretations, and here we see it with fault interpretations.*
- Disagreements about models are often based on explicit (or implicit) disagreements about data uncertainty.



Uncertainty propagates through all of science

In “Uncertain science, Uncertain world”, Henry Pollack makes the point that uncertainty is inevitable, **“Scientific knowledge is always tentative and uncertain”**. This uncertainty ends up being a strong stimulus for, and important ingredient of, creativity in science.

For the purposes of field mapping, the topics we gave you (attachedness, lithology, 3D geometry, kinematics) are probably the most basic and important to record uncertainty for. However, there are other observations you will make (such as metamorphic grade, fossils) that we have not explicitly addressed - you will need to keep track of these observations when you encounter them in the field.

To be a good scientist, you need to accurately evaluate what you know, and how well you know it. It helps to record both!

In the next module, you will learn more model uncertainty and its influence on data inferences - the relationship between data-model uncertainty is bi-directional.

Data Uncertainty Transcripts

Slide 5

Randy: Basically I thought this was a conformable section (lower deep spring, middle deep spring, upper deep spring). When we walked up over it, we started walking up to this big outcrop, and we should have come across those, like, kind of big, brown quarzitic sandstones between the two -

Cristina: mmmhmm

Randy: between lower deep spring and upper deep spring - we didn't find those.

Cristina: mmhmm

Randy: So then we come over here, there's this blue-grey, super well-bedded limestone with a little bit of dolomite on top, and then above that, I start finding a bunch of fragments of, like, the brown quarzitic sandstone.

Cristina: Mmmhmm, the middle deep spring

Randy: The middle deep spring, right. So, one of two things is kind of possible here. I think all models have to have a fault in front of us. If I'm correct, if I was correct and that's lower deep spring, then it means that a fault has brought the east side up and it's chopped off part of that quarzitic sandstone bit. If I'm incorrect, and that is middle deep spring and we're sitting on lower deep spring, then it means there's a fault still in the same place, but it's brought the east side down.

Cristina: So it's really about the – there has to be a fault, but how that fault moves changes depending on what the units really are.

Randy: That's exactly right, and there's (end audio file mid-sentence.)

Slide 35

Cristina: Okay, so the question is how you would change the current map to fit what you have observed on this hill.

Randy: Apparently, I would change this bit right here marked as lower deep spring, I think is actually middle. I think that extends all the way to the break in the topography here. The only thing I'm not certain about is if there is a tiny sliver of lower deep spring here. And if true, then there has to be a fault coming through here somewhere.

Cristina: Do they have a fault marked there?

Randy: There is a fault marked there, yeah. It would... it would be in the right orientation, from what I think it would be, except I think they have it much further out than where I would have put it. I'm not sure they're not putting it there to – so this the bit, the other bit of deep spring that we looked at

Cristina: mmhmm

Randy: and it's in the grand scheme of things, it's higher than it should be, based on where we're standing, so, uh, they might well have put that fault there to explain that. It's a dotted line,

Cristina: Yeah.

Randy: clearly they're really not quite sure if that's true or not. So that's how I would change it.

Cristina: Ok. Does this experience make you feel any differently about this map generally?

Randy: Uh no.

Cristina: Or is this just a difficult problem and so maybe they didn't spend as much time here?

Randy: It's a difficult problem. I mean, so, for example, the reason I think that is middle, is because part of the middle is described as well-bedded, blue-grey limestone topped by fine-grained buff-colored dolomitic sandstone which is there, which we were just looking at.

Cristina: Mmhmm, mmhmm,

Randy: But if you look at the top of the lower, what we have is fine grained blue limestone in brown calcareous sandstone capped by course-grained, buff-colored dolomite. Like, those are not dramatically different -

Cristina: Right.

Randy: - descriptions. The main thing that's missing is the sandstone between the blue grey unit and the buff unit, and the lower isn't described as being well bedded.

Cristina: Hmm.

Randy: And I would definitely describe that as well bedded, so. It doesn't make me trust the map less, I just think this is just a really tricky problem.

Cristina: Yeah, okay!

Uncertainty in Models

Created by:

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B. Tikoff & R. Williams (University of Wisconsin-Madison)

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Geologists use data to generate large-scale interpretations (models) of geologic processes.

A lot of the time, models have to be generated with sparse data of variable quality/certainty. *So, in the absence of good resolution, high certainty data, what informs model development?*

The answer

Whatever is most accessible in your mind

Usually the thing you work on most frequently, or most recently, or is most salient

EXAMPLE 1:

[Bond et al. \(2007\)](#) found that experts' interpretations of seismic images were related to their primary field of expertise in tectonic settings - geoscientists who study a lot of strike-slip faults tended to see evidence of strike-slip faults in the seismic image.

EXAMPLE 2:

Listen to expert geologist Ake Fagereng discuss with cognitive scientist Cristina Wilson how his working model of a thrust fault could be informed by his experience.



Geologists' reasoning under uncertainty is vulnerable to bias

Biases arise from reliance on **rules-of-thumb** (a heuristic, if you like that fancy word) that serve as cognitive shortcuts. Though efficient and satisfactory for some decisions, rules-of-thumb can lead us to make predictable mistakes (biases).

On the last slide you heard from expert Ake Fagereng about his tendency to default to a thrust fault model. This is known as the **availability bias**, the tendency to think of what readily comes to mind as occurring more frequently - “I work on thrust faults, so I see thrust faults”.

Note the rule-of-thumb is not inherently bad, only when it is misapplied or in conflict with the current environment. In an area with many thrust faults, interpreting something as a thrust fault is great! However, relying on the rule-of-thumb, you run the risk of misapplying it (say to a normal fault), resulting in bias.

Other rules-of-thumb are natural properties of the human mind (prepotent). For example, all humans tend to seek information that confirms our beliefs and avoid information that contradicts beliefs. When this propensity leads us to ignore important contradictory information, it is called **confirmation bias**.

Geologists need a way to avoid bias in models.

Geologist Grove Karl (G.K.) Gilbert came up with idea of **multiple working hypotheses** as a method for avoiding bias in interpretations.

The great investigator is primarily and preeminently the man who is rich in hypotheses. In the plenitude of his wealth he can spare the weaklings without regret; and having many from which to select, his mind maintains a judicial attitude. The man who can produce but one, cherishes and champions that one as his own, and is blind to its faults. With such men, the testing of alternative hypotheses is accomplished only through controversy. Crucial observations are warped by prejudice, and the triumph of the truth is delayed.

(Inculcation of Scientific Method by Example, 1886, p. 287)



[By Unknown author - USGS Denver Library Photographic Collection](#)

The method of multiple working hypotheses was later expanded upon by Thomas Chrowder (T.C.) Chamberlin.

[What is required] is to bring up into view every rational explanation of new phenomena, and to develop every tenable hypothesis respecting their cause and history and with this method, the dangers of parental affection for a favorite theory can be circumvented. *(Method of Multiple Working Hypotheses, 1890, p. 756)*



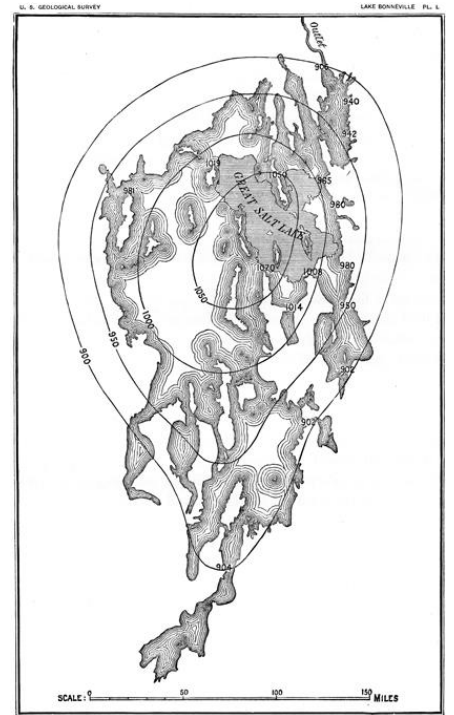
[By Roloso - University of Wisconsin-Madison Archives](#)

G.K. Gilbert noticed that the shorelines of glacial Lake Bonneville (bottom photo) occurred at different elevations (top photo). While he made observations of the shoreline, he found that either of two different interpretations could be called on:

1. Differential fault uplift

1. Uplift caused by water removal (what came to be known as isostasy)

A map of shoreline of glacial Lake Bonneville, with the outline of the Great Salt Lake superimposed on it. The contours are of elevation of the highest shoreline, with a 50 m contour interval.



Both diagrams from Gilbert, G. K. (1890), *Lake Bonneville, Monogr. U.S. Geol. Surv.*, vol. 1, U.S. Geol. Surv., Washington, D. C..



At its heart, the method of multiple working hypotheses is a check against over attachment to a single model.

By purposefully considering multiple plausible interpretations simultaneously, you resist the tendency to seek information that confirms your favorite model. It is a useful field strategy, because the different hypotheses/models make different predictions about what you would expect to observe in data.

So, data uncertainty influences model uncertainty, BUT the reverse is also true! For example, having a model with relatively low uncertainty might make you re-evaluate the uncertainty of an inconsistent observation.

Watch the two videos of expert geologist Terry Pavlis discussing a hypothesis about kinematics (presence of anticline) with trainee Naomi Barshi and cognitive scientist Cristina Wilson. Note how a change in Terry's interpretation of data (top indicators in crossbeds) influenced his hypothesis, and vice versa.

1



2



Now, watch this video of expert geologists Terry Pavlis and Randy Williams discussing different models for the origin of fault gouge (photo right) -- highly sheared red clay beds of Borrego formation with large deposits of Palm Spring formation embedded.

Pay attention to how disagreements between the discussed models are linked to underlying data uncertainty.



Let's check-in on what we've learned from the videos about the relationship between data and model uncertainty

A model is only as good (certain) as the data that informs it - the more uncertain the data, the more uncertain the model.



You saw this in the first videos of Terry Pavlis (Slide 6) discussing his increased uncertainty in an interpretation of an anticline. His model (anticline) was only as good as the underlying data (top indicators in crossbeds).



In the videos you also heard Terry explain how when his model of an anticline no longer made sense, it led him to revise his initial inferences about the crossbed data. A change in model uncertainty fed backward into data uncertainty.

Changes in model uncertainty can feed backward into data uncertainty



You saw this in the last video of Terry Pavlis and Randy Williams (Slide 7) discussing the origin of highly deformed red clay beds with large deposits of Palm Spring formation embedded. Terry and Randy were certain that the red clay was faults gouge of the Borrego formation, but still had uncertainty about the competing models of origin.

Even if data has high certainty, a model may be uncertain.



In the video, you also saw that disagreements between different models was often linked to differences in underlying data uncertainty - what is the lithology of the large sand beds that are also embedded in the gouge?

Disagreements about models are often based on explicit (or implicit) disagreements about data uncertainty.

Models are never certain

Models are an approximation of reality. Because models “fill in” between available data points, there is always extrapolation and interpretation in a model.

Even models that seem obviously true -- think of Newtonian mechanics -- do not hold under all conditions (e.g., for objects moving at high speeds, one must adopt ideas from Einstein’s relativity). Thus, scientists have adopted the idea that models must be treated only as the best available approximation.

BUT, some models are better than other models, because they come closer to approaching certainty.

“Goodness” in a model is defined by several criteria:

- Logical consistency - i.e., parts of it don’t contradict other parts
- Agreement with best available data (and data of different types)
- Suggests verifiable causes that explain and/or predict
- Advanced comparisons - e.g., Occam’s razor: The best solution is generally the simplest solution
- Balanced tradeoff between generality (making many testable predictions) and specificity (agreeing with available data)

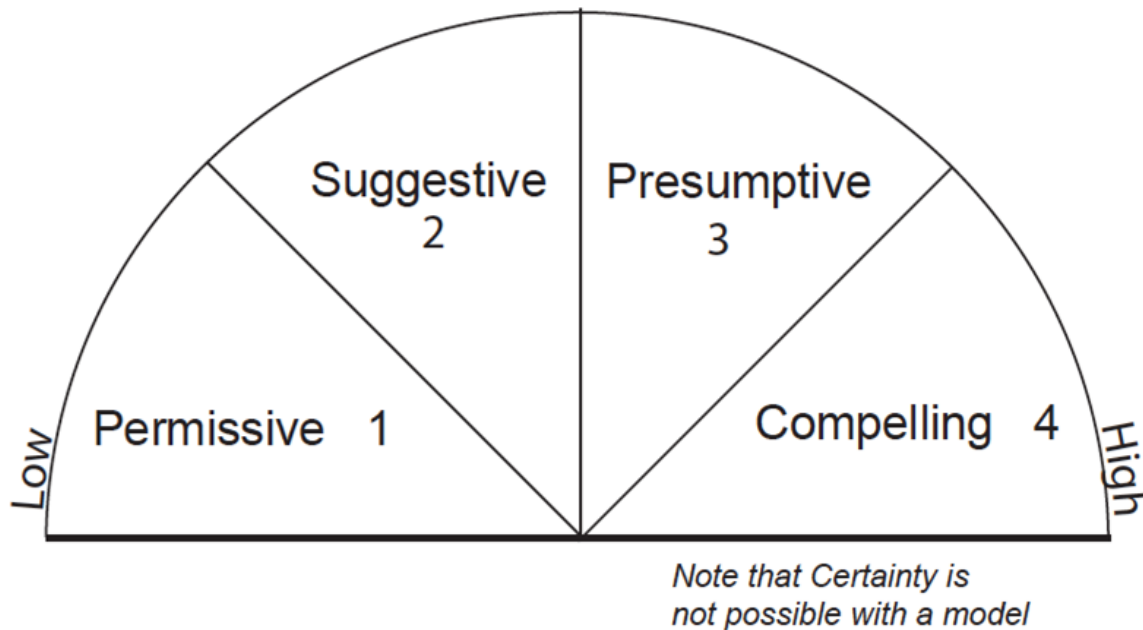


G.E. Box

All models are wrong;
some models are useful

From p.240 in
A conversation with statistician
George Box, *Statistical Science*, 2
(1987), 239-258.

We can use an “Evidence Meter” to rank uncertainty for any particular model



If you completed the module on data uncertainty, you will note that the relative order of model uncertainty is the same as for observational data.

The only difference is that there is no “certain” category for a model. All models in science are subject to revision.

All the “goodness criteria” discussed on the last slide are taken into account when making an uncertainty judgment about a model.

The uncertainty associated with a model relates to the data and the uncertainty of that data

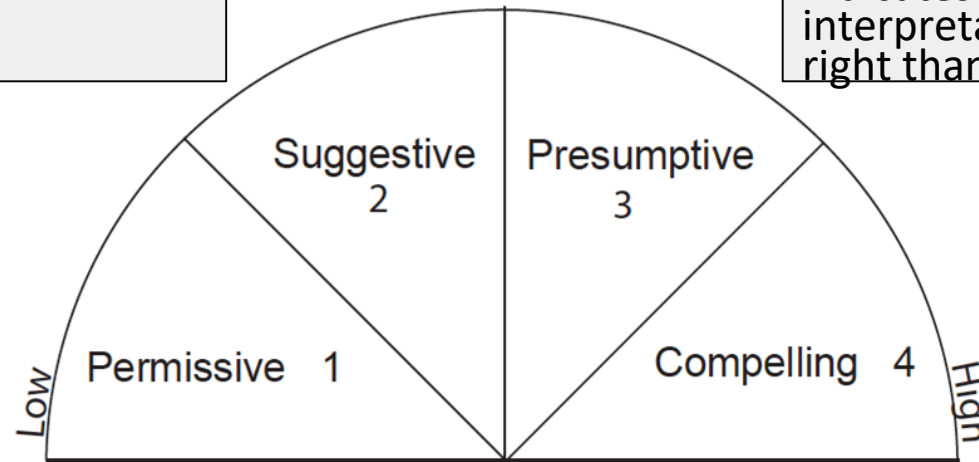
General considerations for ranking model uncertainty:

- What is uncertainty of the data that are consistent with the model?
- What is uncertainty of the data that are inconsistent with the model?
- What is the balance of uncertainty in consistent and inconsistent data? (consistent data should ideally be low uncertainty)
- How well does the model provide predictions?
- Are other models available and better?

Suggestive indicates that there is positive evidence for a particular interpretation, but that the evidence also allows the possibility for other inferences.

Presumptive – defined as “presumed in the absence of further information” – indicates that an interpretation is “more likely right than wrong”.

Permissive is the least certain form of evidence. Permissive suggests that a particular idea or interpretation cannot be ruled out, but it is also not the only available solution.



Note that Certainty is not possible with a model

Compelling indicates that the evidence is strongly supportive of the interpretation. Compelling evidence for an interpretation is based on a preponderance of positive evidence.

The uncertainty associated with a model relates to the data and the uncertainty of that data

General considerations for ranking model uncertainty:

- What is uncertainty of the data that are consistent with the model?
- What is uncertainty of the data that are inconsistent with the model?
- What is the balance of uncertainty in consistent and inconsistent data? (consistent data should ideally be low uncertainty)
- How well does the model provide predictions?
- Are other models available and better?

Suggestive

- Consistent with some suggestive and permissive data
- Inconsistent with only permissive (or very small number of suggestive) data
- Makes some predictions that are verifiable
- There may be other models that accounts for the same data

Presumptive

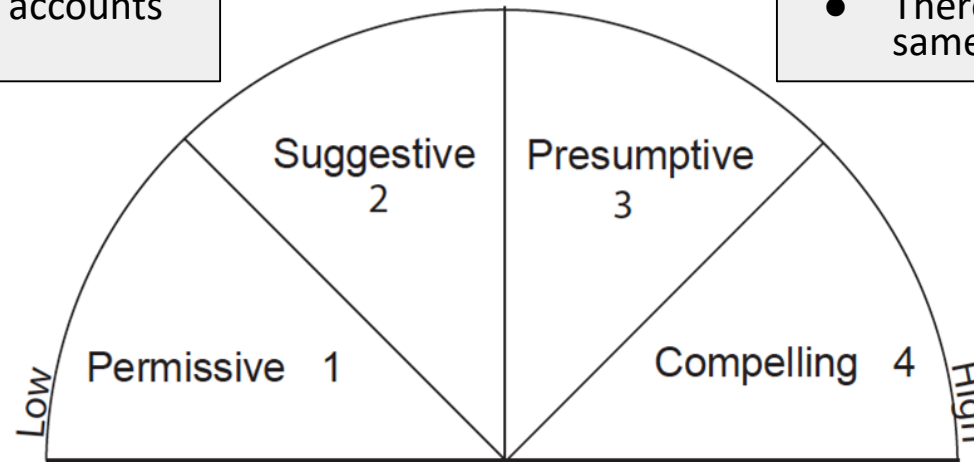
- Consistent with some presumptive data or a lot of suggestive data
- Inconsistent with only some suggestive or permissive data
- Makes some predictions that are verifiable
- There is no other model that accounts for the same or more data

Permissive

- Consistent with some permissive data
- Inconsistent with less permissive data
- Makes a few predictions that are verifiable
- There may be other models that accounts for the same data

Compelling

- Consistent with some compelling & presumptive data
- Inconsistent with only suggestive and permissive data
- Makes many predictions that are verifiable
- There is no model that accounts for the same or more data



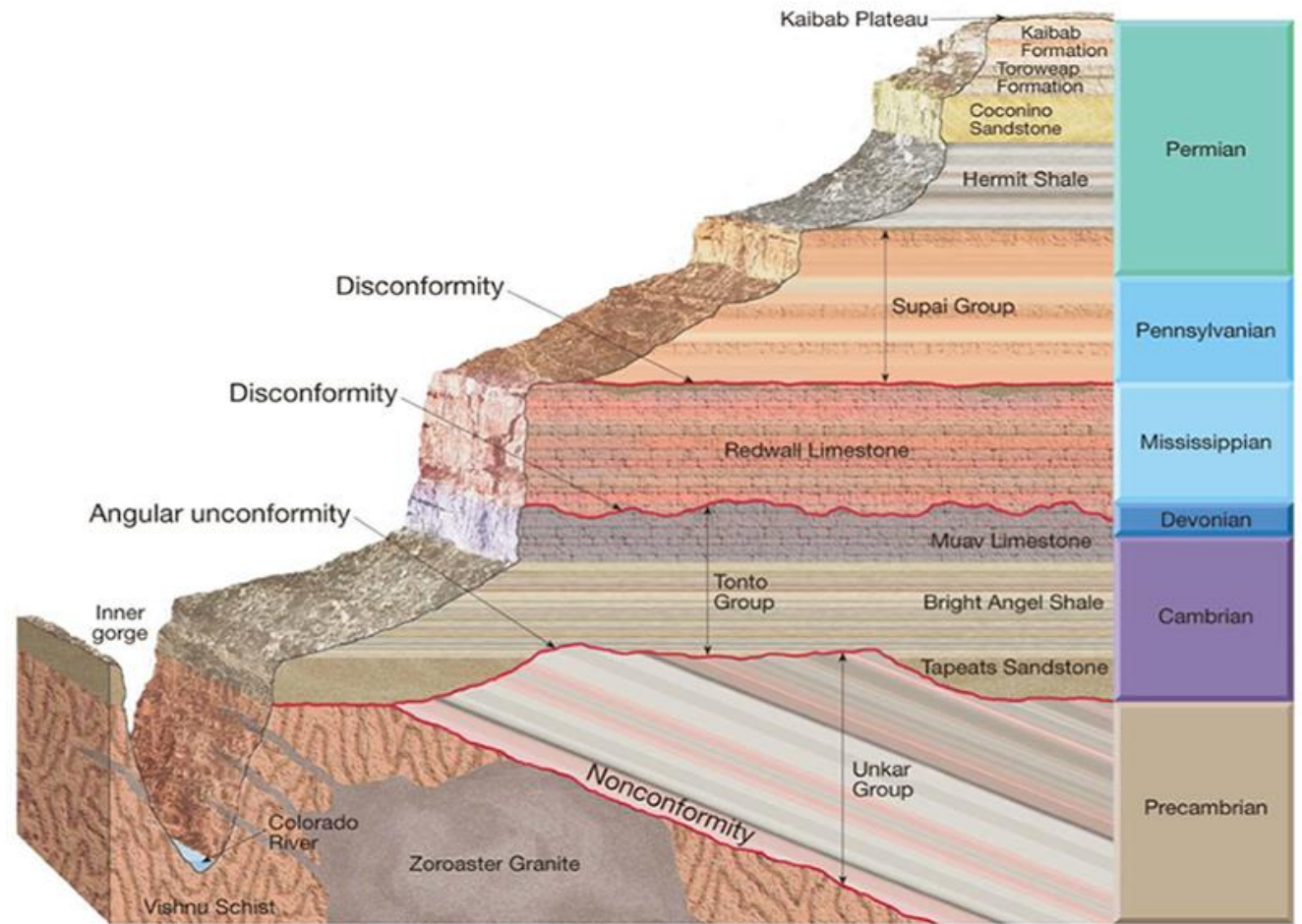
Note that Certainty is not possible with a model

Let's consider an example of uncertainty in competing models, and how model preference is influenced by uncertainty in the underlying data.

Geological maps, though based on observational data, are interpretations in areas that are not 100% exposed. **Cross sections are always models (interpretations)**, because it is not possible to directly view the subsurface. Even in the Grand Canyon (or other areas of superb exposure), cross sections are interpretations, because you do not know what was eroded away or what lies in the subsurface.



[Photo by National Park Service](#)



Generalized stratigraphic column for the Grand Canyon showing major rock units and unconformities

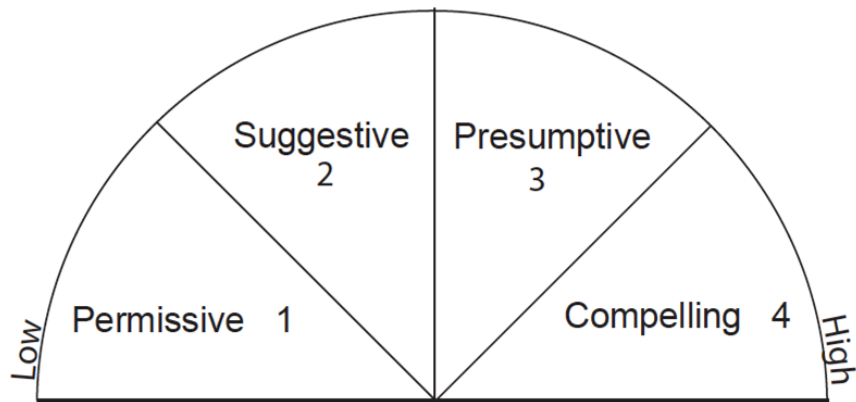
In the next sequence of slides you will practice ranking the uncertainty of cross sections.

You will be presented strike and dip data and be asked to develop a simple cross section.

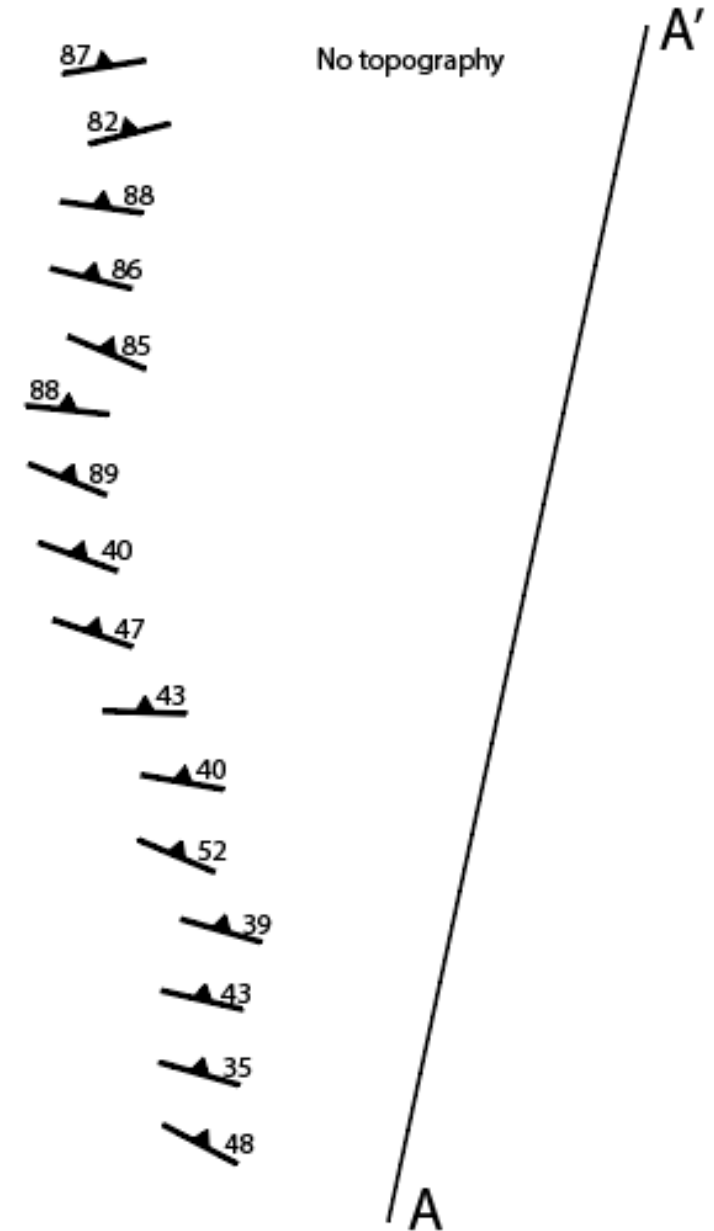
In each case consider how the data and potential alternative models influence the certainty of your preferred cross section.

You make a transect on a flat outcrop and find this map pattern.
Assume that all strike-dip symbols have a presumptive uncertainty.

What is your uncertainty in your cross-section interpretation along A-A'?



Note that Certainty is not possible with a model



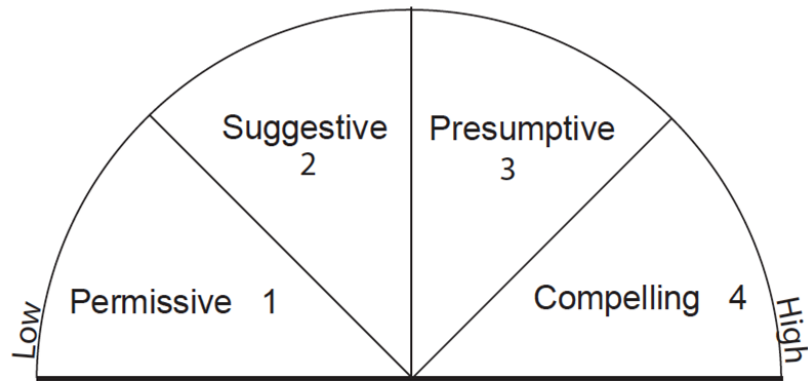
Reflect on whether you are considering multiple cross-section interpretations.

Is there an alternative model to explain the data that you haven't considered?

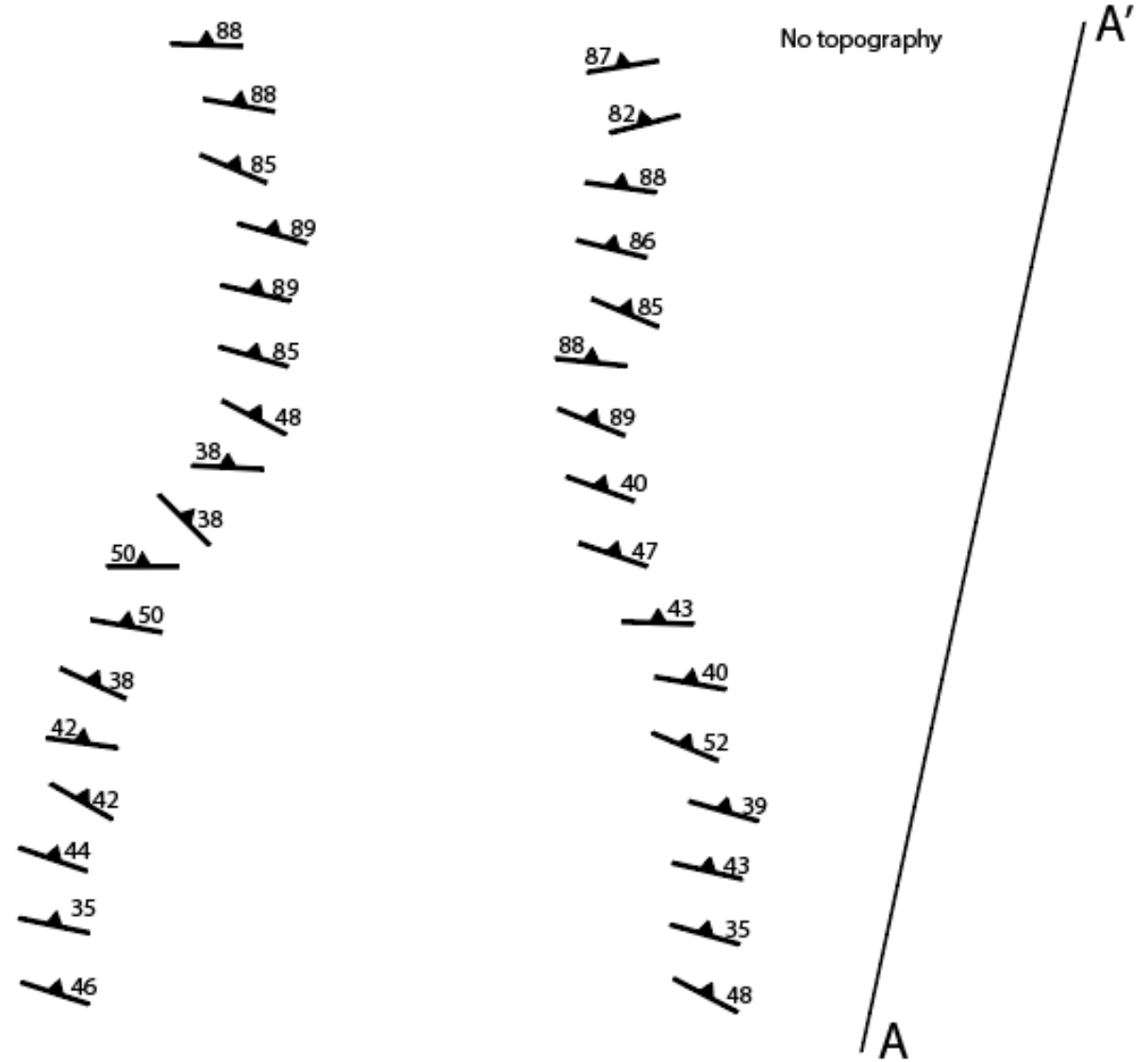
How does your uncertainty differ between different models?

You make another transect on the flat outcrop.

Has your uncertainty in your cross-section interpretation(s) along A-A' increased or decreased?

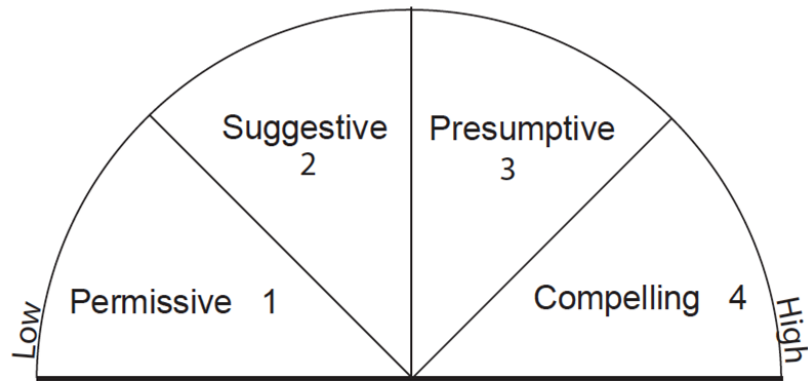


Note that Certainty is not possible with a model

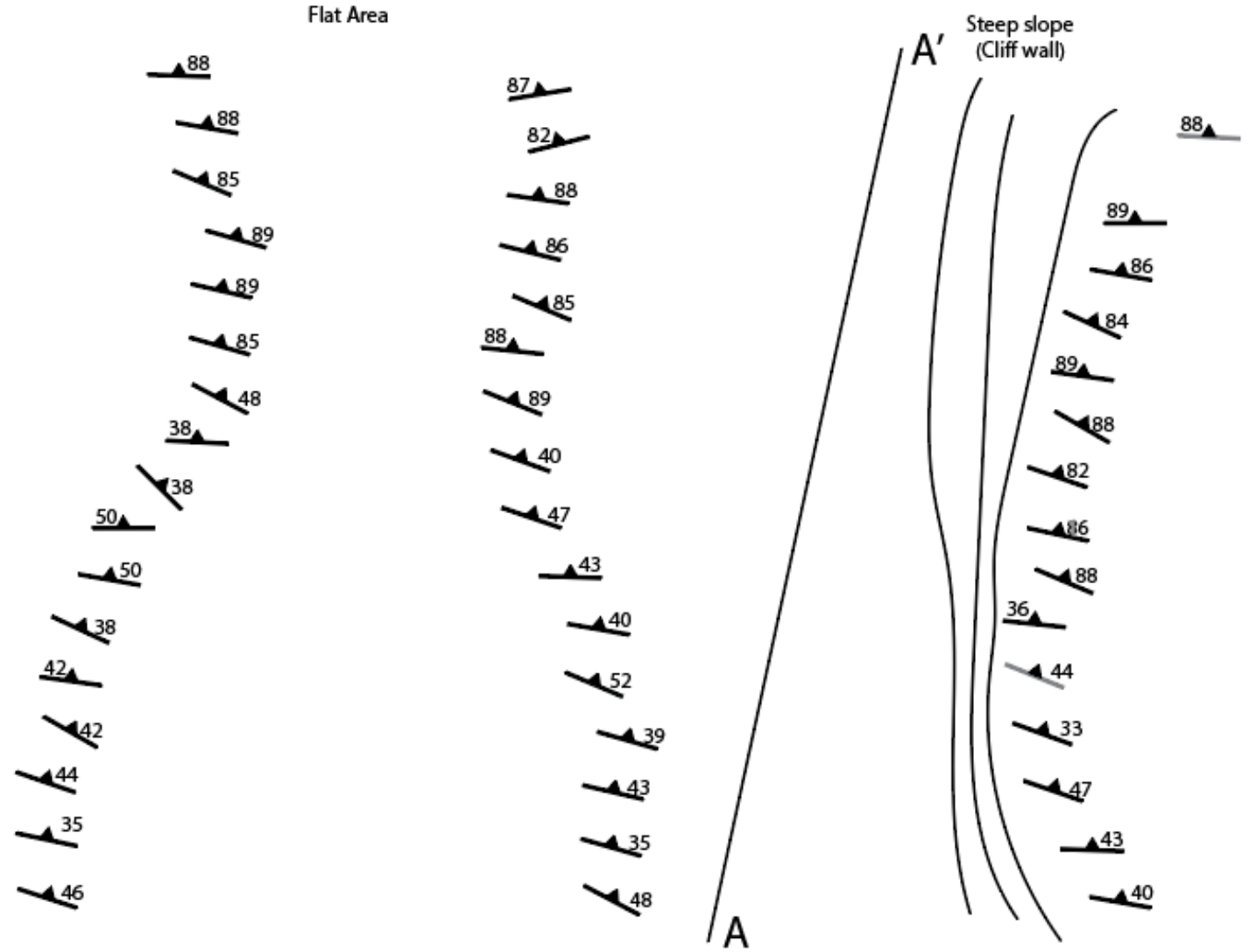


**You make a third transect, but
on top of a large cliff.**

**Has your uncertainty in your
cross-section interpretation(s)
along A-A' increased or
decreased?**

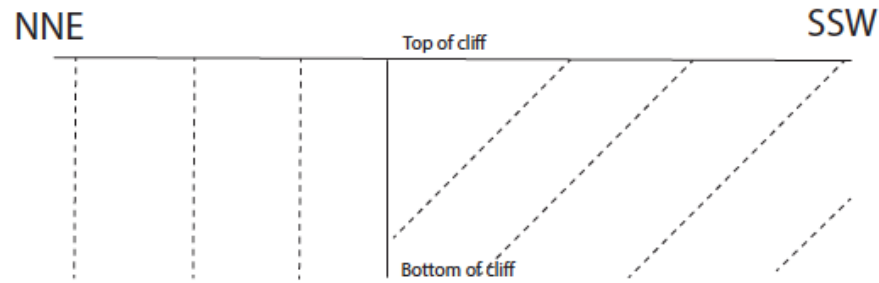


*Note that Certainty is
not possible with a model*

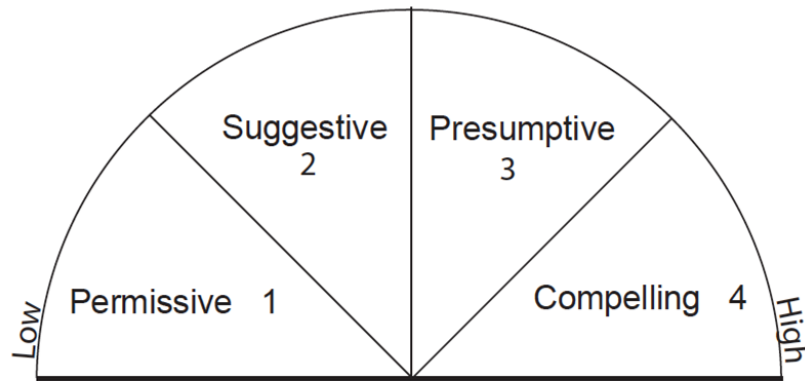


You come back the next day after a rainstorm has cleared the cliff face for you

Looking at cliff face

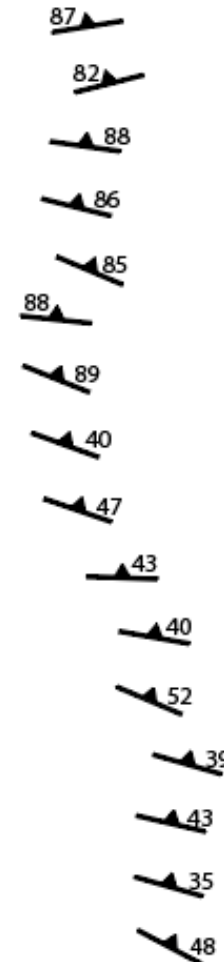
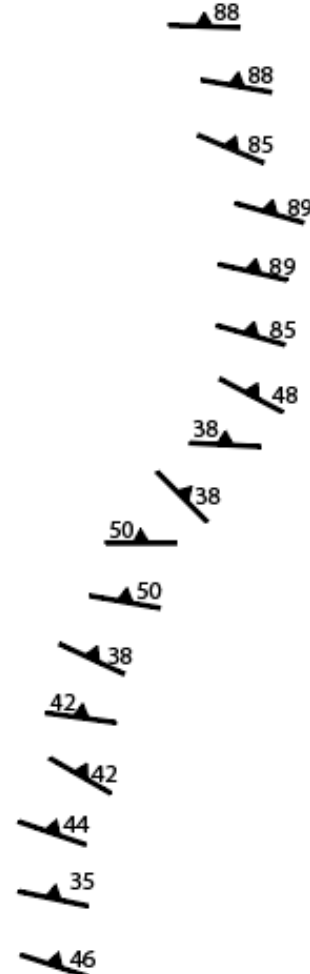


Has your uncertainty in your cross-section interpretation(s) along A-A' increased or decreased?

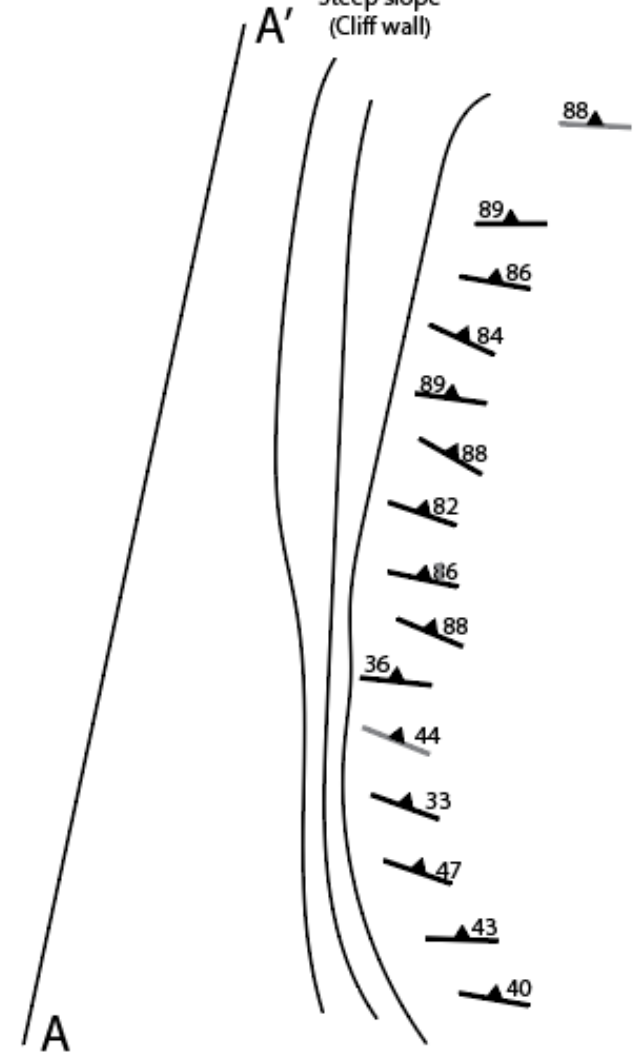


Note that Certainty is not possible with a model

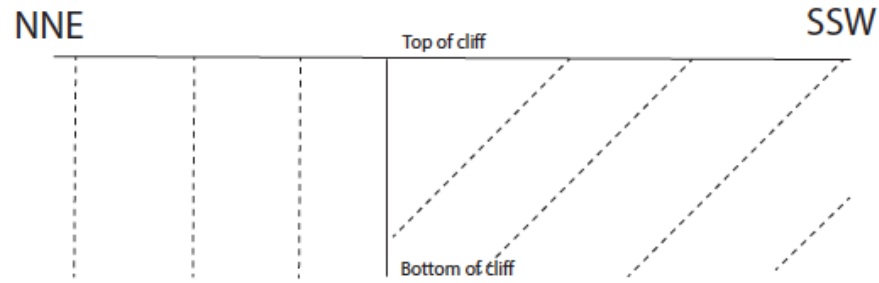
Flat Area



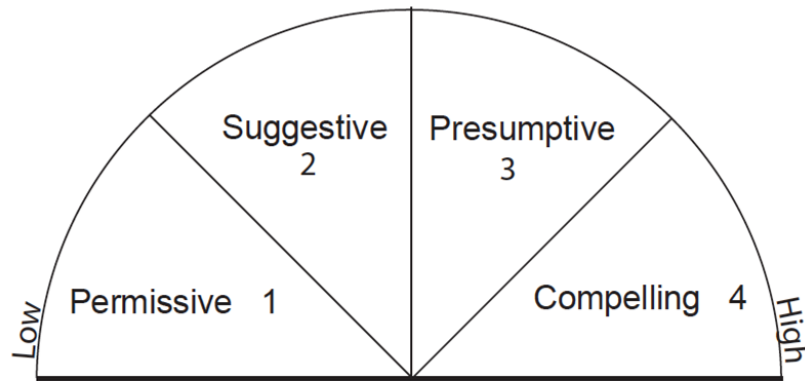
Steep slope (Cliff wall)



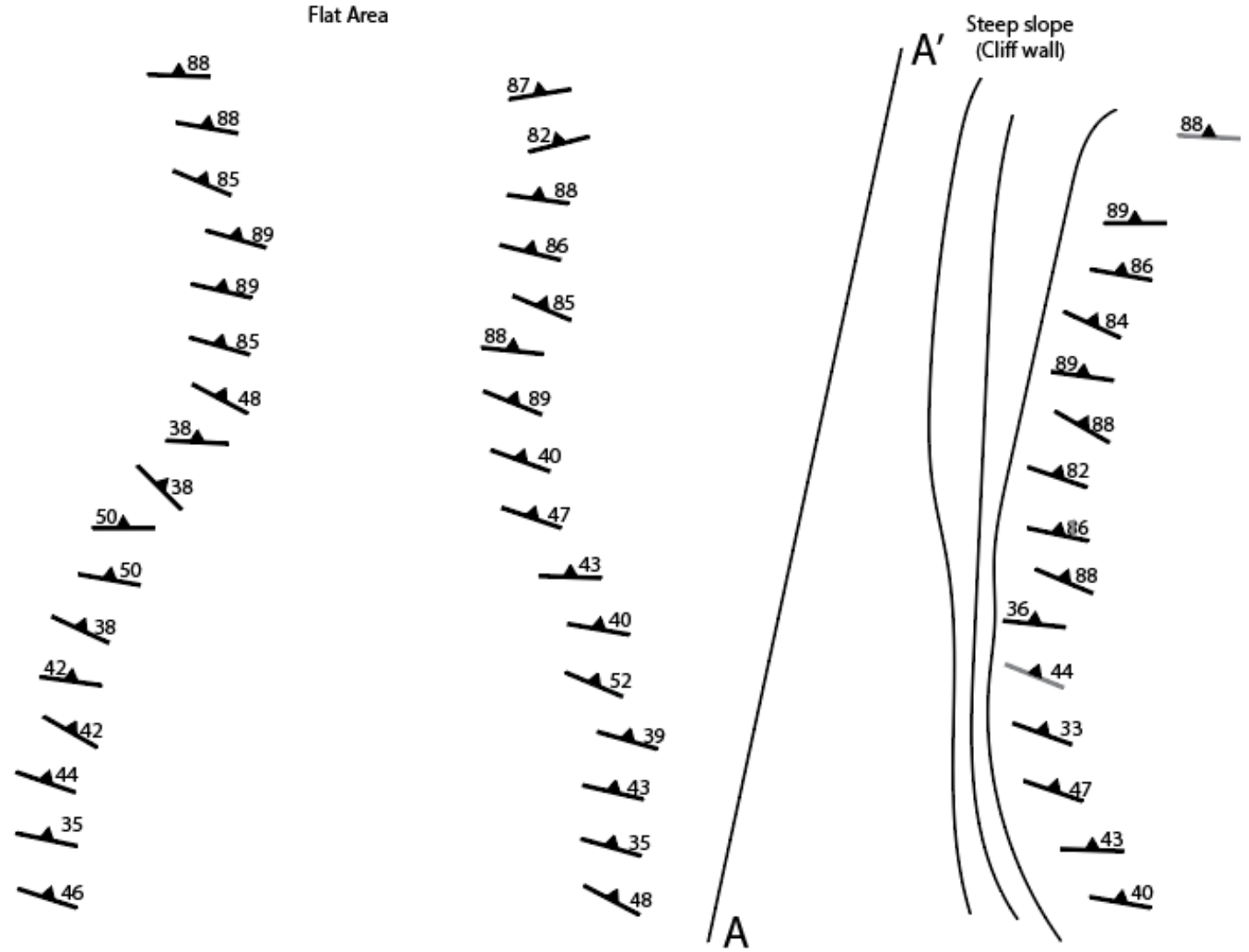
Looking at cliff face



Given all you know, are you CERTAIN about any one interpretation of cross-section A-A' ?



Note that Certainty is not possible with a model



When you were asked for your preferred cross section how many did you choose from among the alternatives? By the end of the sequence did you come up with additional possible cross sections?

For each data set there is no “right” answer! But you can do a better or worse job at assessing how certain an interpretation should be.

Now let’s consider a case where two experts came up with different answers.

Our example comes from the Sage Hen flat pluton, in the White Mountains in California. We will look at two cross sections made for the thick black line on the map.



This map is located at the black square in eastern California

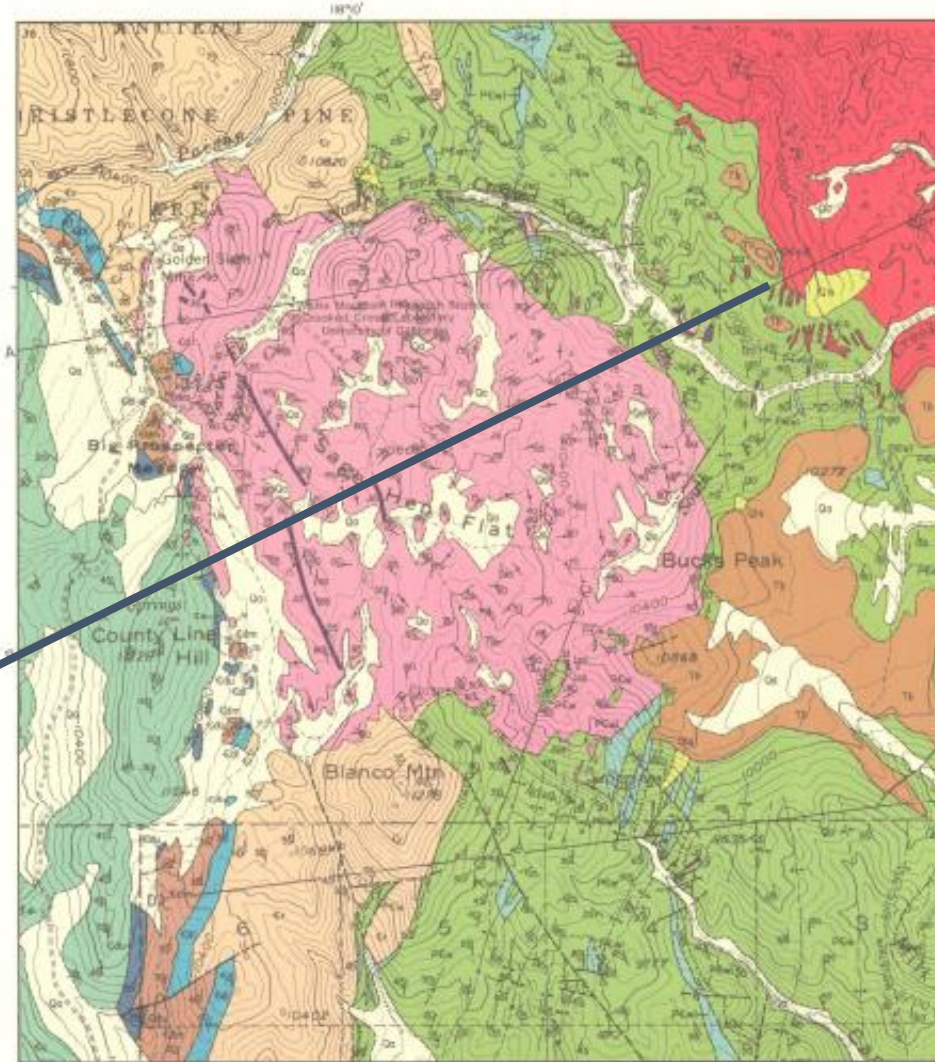
GEOLOGY OF THE SAGE HEN FLAT PLUTON, WHITE MOUNTAINS, CALIFORNIA

Published by:
The Geological Society of America, Inc.
3300 Penrose Place • P.O. Box 9140
Boulder, Colorado 80501

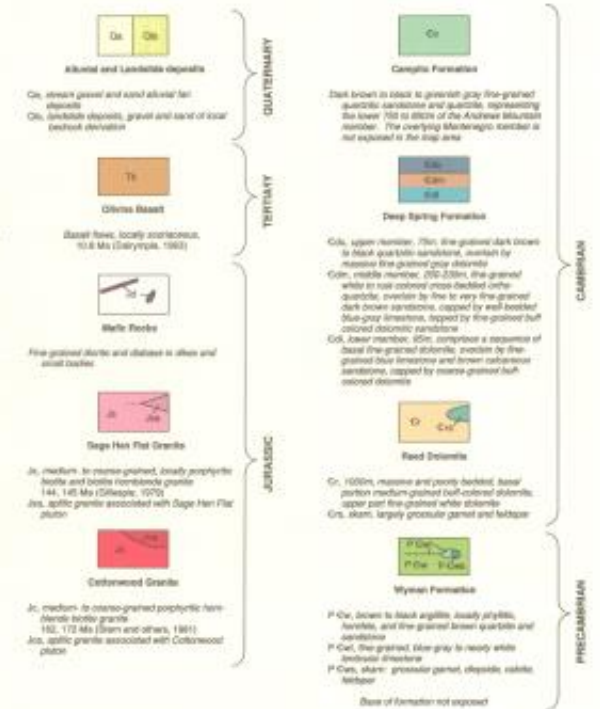
Bruce J. Bilodeau and C. A. Nelson

MAP AND CHART SERIES MCH077

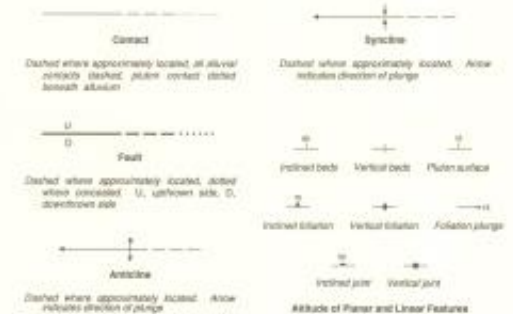
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Printed in U.S.A.



EXPLANATION



GEOLOGIC SYMBOLS

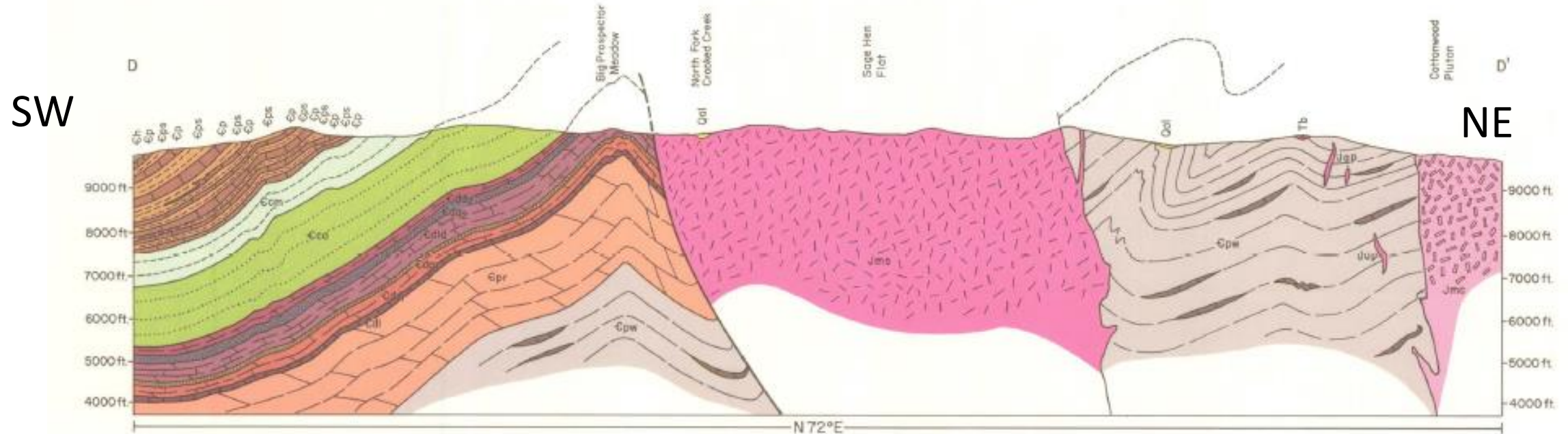


SCALE 1:24000
KILOMETERS
MILES
CONTOUR INTERVAL 80 FEET
Mapping by Nelson, 1966 and 1986-1991, and by Bilodeau, 1981 and 1986-1991; incorporates mapping by Kouskopyl (1971).

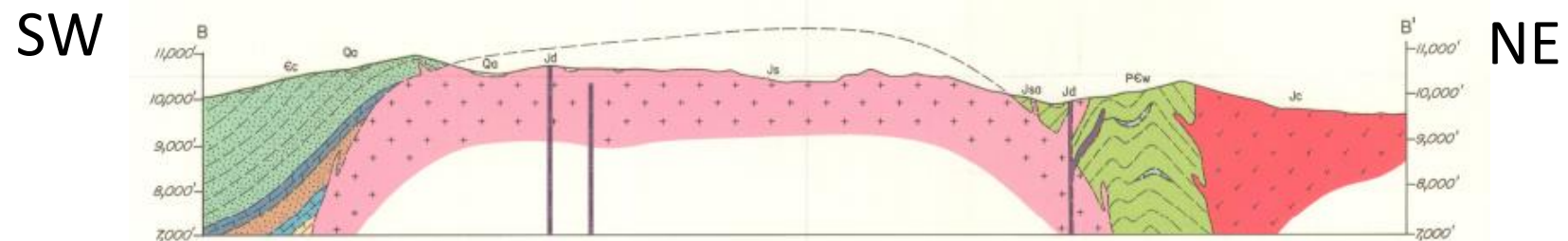


Two approximately NE-SE oriented cross sections were made, along the same line, by two different sets of authors. What are the differences?

Note: Cross-sections are shown at approximately the same spatial scale.



Hall & Ernst, 1987



Bilodeau & Nelson, 1993

As you might expect, the difference in interpretation results from a difference in observations.

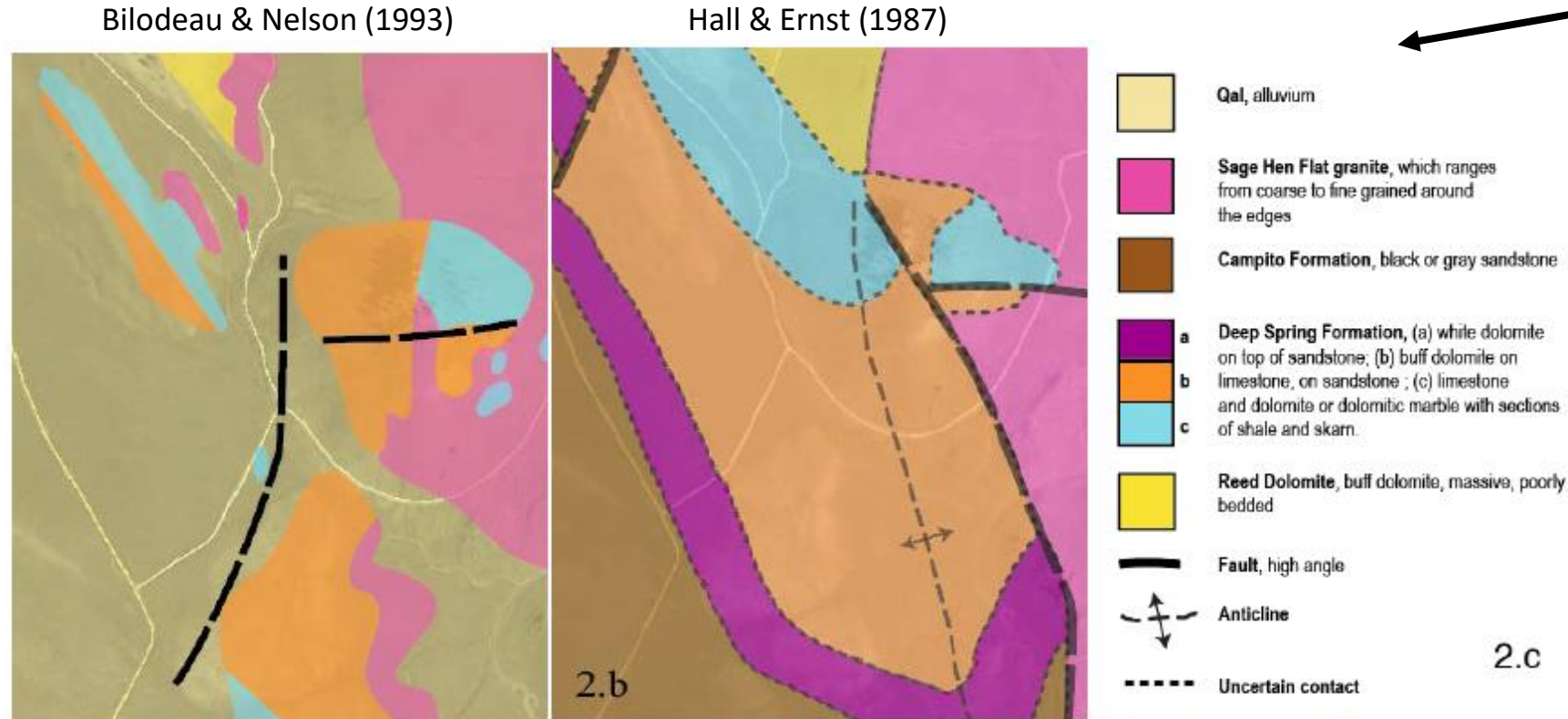
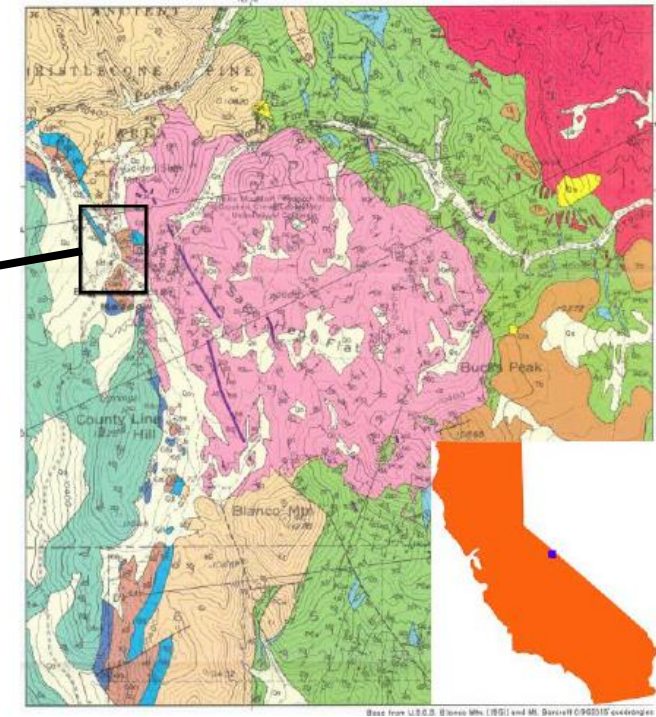


Figure 2. (a) Simplified version of the map created by Bilodeau and Nelson (a) in which the contact with the pluton is intrusive (Bilodeau and Nelson 1993). (b) Simplified version of the map created by Ernst and Hall in which the contact is a simple straight fault rather than an intrusion (Ernst and Hall 1987). (c) Composite stratigraphic key to the two maps above.

Data from student project by L.D. Wison, J.D. Higdon, and J.A. Davidson; Courtesy of A. Glazner

Zoomed-in area in Figure 2



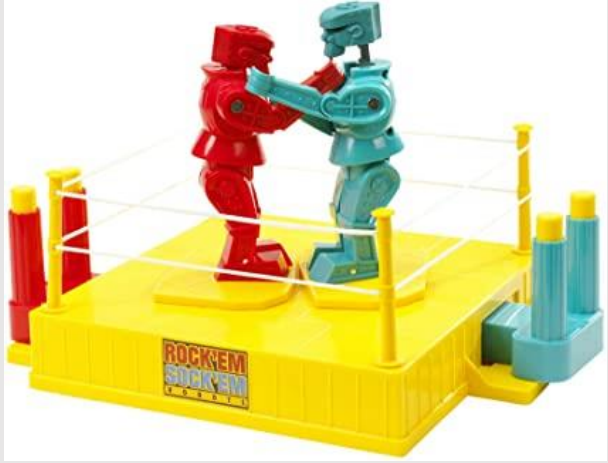
Pink shows extent of Sage Hen pluton
Bilodeau & Nelson (1993) map

The fact that these two maps are so different indicates that:

- 1) Geological maps are interpretations**
- 2) There is uncertainty of observations even on professional maps.**

This is a poor metaphor for science.

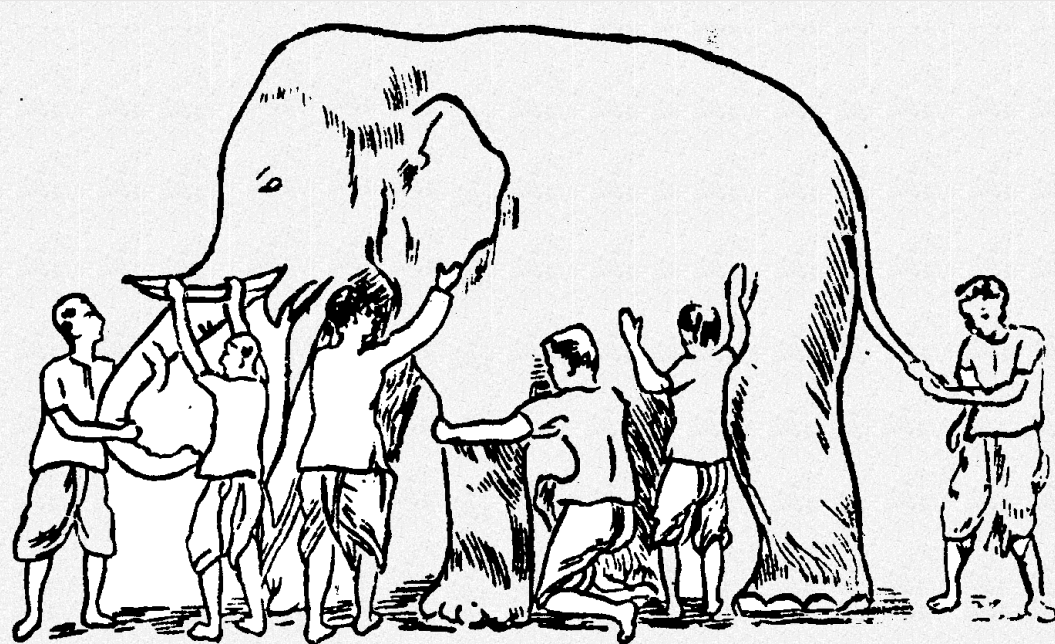
Rock-em-sock-em robots, where the game is won when one player knocks the head off of the opponent



For any scientific disagreement, its resolution is not a matter of who is right and who is wrong - that is not very interesting. What is interesting is what is the actual geometry and what that tells us about how the world works.

This is a much better metaphor for science.

The parable of the seven blind men trying to understand what an elephant is, having not experienced one beforehand



Science is the process of separating out the demonstrably false from the probably true.

It is possible that the two interpretations are both partly right, in which case one needs to make one's own interpretation.

What is a new scientist to do?

To start, find a mentor and learn the skills from that person.

We will use G.K. Gilbert, because he is one of the best.

- Be open to new ideas (rich in hypotheses).
- Be fair about how you interpret observations (maintains a judicial attitude).
- Do not be warped by prejudice (judge the hypothesis as an idea, regardless of its source (including yourself)).
- Do not be blind to the faults of any model, even the one you ultimately choose. It isn't certain; it can't be certain.



[By Unknown author - USGS Denver Library Photographic Collection](#)

Perhaps the best advice ever given to a new geologist (from Paul Bateman, USGS)

“You don't have to be right; you do have to be consistent with your data”

A working set of guidelines:

- Collect good data and honestly evaluate your uncertainty
- Be more skeptical of your models than you are of your data
- It might not be possible to ever get to even a presumptive model for any area; you might not have enough data or the right kind of data to evaluate it
- Published models are likely to be *suggestive* or better; however, they are never certain
- AND finally, **what makes your data and model most useful is an accurate evaluation of the uncertainty associated with each**

Model Uncertainty Transcripts

Slide 2

Ake: And then there's this gouge layer, that's there for some reason. At least in places embedded in the fault, but weirdly, there's some more gently dipping, so the fault system is probably a bit more complicated than what I've drawn. We get into something horizontal there, it just bends, not quite sure what it does. Then it gets offset by this gouge, that's there for some reason. Which seems - I mean, it's in the fault, but whether it's just a deformed bed, or whether it's transported from some other distance I don't know. My preferred model, in my head, is that there is just enough thrusting going on here, so that this is just being, so this is being brought on top of something.

Cristina: Do you have any intuition as to why that's your preferred?

Ake: I might be biased by having seen a lot of thrusts. I was thinking this when I was walking here, I am fitting thrust models to this because I mostly work on collisional zones –

Man (offscreen): Sure

Ake: - and I kind of if I can fit a thrust to what I'm seeing I'm intuitively going to do it.

Cristina: Yeah.

Ake: But it also seems physically to me the simplest way of moving material up, is to put it on a fault and push it up.

Cristina: (laughing) Yeah, right

Ake: That seems much simpler to me than having some way of, okay, if you're squeezing rocks together then maybe the shortening of depth can make things pop up further up the system.

Cristina: But in the space of probability-

Ake: In the space of probability, I like to put things on top of each other along faults rather than doing something more complicated. I like simple models.

Slide 6

Video 1

Terry: And it is an anticline, because the tops face that way, and then they top, they face that way.

Naomi (off screen): Yup.

Terry: Right there.

Naomi (off screen): What were your tops, I'm just curious?

Terry: Crossbeds.

Naomi (off screen): Crossbeds. Yeah. I mean, I think that's usually the easiest thing in the Palm Spring.

Terry: I have to double check and make sure I'm correct.

Naomi (off screen): Formation

Terry: I happen to walk up here first

Naomi (off screen): Uh, yup, yeah I believe you. There's some, maybe even some other ripply things.

Terry: Yup.

Naomi (off screen): Yeah. Cool. Yeah those are –

Terry: And over here they switch the other way.

Naomi (off screen): -maybe like a-

Terry: These are even better. here

Naomi (off screen): Oh! Actually –

Terry: (too quiet to hear, gesturing at evidence he sees in rock) Did I get these right over here? Oh wait a minute!

Naomi (off screen): I –

Terry: I think they might be facing that way.

Naomi (off screen): That's what I'm getting from -

Terry: (cross talk) Lots simpler that way

Naomi (off screen): - this kind of a little frame structure–

Terry: Yup, yup.

Naomi (off screen): I know that's a specific term and I'm not using the right one.

Terry: This is a (inaudible) mark

Naomi (off screen): - a dewatering?

Terry: Oh it might be

Naomi (off screen): If it's a ripple mark it would be up this way

Cristina (offscreen): Are you saying it tops where the top is, or is -

Terry: Stratigraphic tops.

Cristina (offscreen): Okay, yes.

Terry: Where was I looking that made me think it was facing that way?

Naomi (off screen): Umm, this crossbed.

Terry: Yeah, oh no, that's still... that would be tops that way.

Naomi (off screen): Oh, that's true actually. Yeah.

Terry: What was I looking at that made me think it was looking that way? Let me take my glasses off. That helps a little. It was something down lower on the outcrop, but I'm pretty sure.

Naomi (off screen): Yeah now we're all shadows around it.

Terry: That's an example of you got to keep score. That's a but, that's definitely not, this is false.

Video 2

Terry: My eye was first attracted to this, because I thought it was a fold.

Cristina: Mmhmm

Naomi (off screen): Right.

Terry: That was my hypothesis, which just got killed because I was sloppy when I first got here, but I wanted to look at other stuff first. So I sort of orbited around. Got a feel for the whole thing by sketching. I did come back to my credit, to make sure I was right. And I was wrong.

Naomi (off screen, cross talk): Right, right, right

Terry: Cause that stuck out-

Cristina: Uh-huh

Naomi (off screen): Yeah

Terry: -when I had that in there, and said, well that doesn't make any sense. Because that would mean, um, that these were overturning or something. Well these still are overturning there.

Cristina: Yeah, that's interesting how you kind of move back and – so you initially come up and you're really driven by the data, and what you're seeing close up and then that informs some broader picture and allows you to step back. But then you come back in and you test it again.

Terry: Yeah. But that's what, I've learned that over the years, that when you get in too close there are things that can confuse you.

Naomi (off screen): Right

Terry: So yeah, I always like to zoom. If I have the cap(abilities), if I can do it, like here, I like to go back and forth to get the scale to get a feel for different things.

Cristina: Yeah

Slide 7

Terry: I'm a little intrigued about how the Palm Spring gets sliced in there like that.

Randy: (laughing)

Terry: I wonder if- it's not- it's probably extending out what we saw down there I guess. It must be that the Palm Spring is depositional on this, but then following deposition, there is a lot more motion, and then it gets sliced and diced in or something.

Randy: I think -

Terry: Is that a reasonable hypothesis?

Randy: I think I'm- I'm working around to the idea that like that material is somehow sedimentary basically and then, the, the, yes, it's, it's large depositional that's now being sheared.

Terry: except that, the red stuff, is very deformed.

Randy: Yeah, no question. Yeah, that's what I mean, it's now being, there's now a lot of deformation occurring there.

Terry: Yeah, yeah.

Randy: Like, deformation across the San Andreas I think at this level is in many ways being accommodated by that material.

Terry: Yeah

Randy: within that material

Terry: Yeah, but I would -

Randy: But in terms of its origin, like, has it been squeezed up the fault? I, I'm starting to think no I don't really think that's -

Terry: Well I think it's in part true. I think it's been brought up.

Randy: Well brought up, yes. Yeah, so it's just -

Terry: But it's not, but it might not, but it's also I think my perspective from what I've seen so far is that it's older so it's accumulated a lot more deformation.

Randy: Yeah.

Terry: And, uh, so it's got this composite effect of whatever it started out got caught up in the fault,

Randy: Yeah

Terry: Then it got buried by Palm Springs, and then deformation continued, brought it up, and so its got all that deformation, whereas Palm Springs has only got the last part of that.

Cristina (off-camera): Mmmh.

Randy: Okay, yeah, I see what you're -

Terry: And that's why it's so fubar.

Randy: I see what you're saying. Yeah I totally, totally see what you're saying.

Terry: That would be a time perspective. I would - that's a hypothesis. You'd have to-

Randy: I -

Terry: You'd have to confirm some of that by looking more about that contact relationship with the Palm Spring probably.

Cristina (off-camera): Mmmh.

Randy: I actually think that's right. I-I-I-I actually think you're right about that. I think that it is in fact part of the Borrego formation, or material from the Berego formation as people have

hypothesized. I think it's been brought up along the fault, rather than this idea of like being like squeezed up

Terry: (choral response): squeezed up

Randy: along the fault um, and I think you might, I think one of the places where you were putting your hand on it and saying 'oh that might be an unconformity,' I think you might be right about that too.

Terry: Actually that would really help too because that would even be consistent with the- then you have a major fault out here that ramps it all up,

Randy: Exactly, yeah, and like I-

Terry: So it's brought it all up like that.

Randy: Yeah, and I think it makes me think that the estimates out here of how far down the Borrego is from us I don't, I think it's probably not as far down as people thought it was is kind of my guess.

Terry: That could be right. There's so much deformation -

Randy: Exactly

Terry: In the Palm Spring though, you kinda - hard to - its always that difficulty of knowing how far something down, is down especially if that's a buttressing unconformity too that would make it -

Randy: Well actually you know, ooh, wait, does that work? Because if the Mecca conglomerate should be between the two.

Terry: oh is that right?

Randy: it should be yeah. So maybe

Terry: But that would be okay if it was brought up, and the, and then the Palm Spring on that

Randy: Well it's all okay assuming that it was brought up kind of during the time of the Mecca deposition and then the Palm Spring deposited on top of it. So, that would mean the stratigraphic relationship between those units at this particular spot is much more complicated and in fact, has a syntectonic component of the San Andreas-

Terry: Which is what you might expect.

Randy: Which is what you might expect, and that's, it's another thing we kind of talked about a bit yesterday was that like, in all of our time with Art out here we never really got into the story

of sort of combined deposition and deformation associated with the San Andreas which had to be happening out here.

Terry: So you think back on Art's history here, people weren't thinking about stuff like that when he-

Randy (cross talk): yeah

Terry: -was doing his original work here.

Randy: Sure

Terry: That was a, a development of 'oh shit why didn't we think of this kind of thing!'

Randy: Yeah

Terry: from like in the late 80s early 90s,

Randy: Exactly

Terry: and uh, he did most of that work here back in like in the 70s.

Randy: Because I think this, I mean you may know more about this, I think the San Andreas here is about 6 or 8 million years old-

Terry: Yeah I don't know much about -

Randy: -which means it should be, it's been active well before any of this stuff was deposited here,

Terry: Yeah.

Randy: So there's got to be some sort of history there.

Terry: Yeah.

Randy: (unintelligible) Yeah, I think- I'm- I don't quite understand- I'm thinking about the Mecca conglomerate I don't think I quite understand like, is that an unconformity over there, is it something else, I'm not sure.

Terry: Remind me of that stratigraphy?

Randy: So it's, it's Borrego, Mecca, Palm Spring.

Terry: Okay,

Randy: Is, is how it goes.

Terry: So the Mecca is missing.

Randy: The Mecca is missing.

Terry: This is sitting unconformably on it.

Randy: But from what we've seen out here so far, I'm more and more convinced this is not like, like a gouge extrusion story. This is, this stuff's been brought up along the fault -

Terry: Yeah it is a gouge

Randy: It is a gouge.

Terry: But I think -

Randy: There's no question, yeah. Like the gouge -

Cristina (off-camera): But it hasn't been injected

Randy: That's the - yeah, that's the thing, the gouge part, I always thought, based on the amount of-

Terry (cross-talk): Yeah, yeah

Randy: Clear shearing that's going on in there. The question is, is it, is its origins. Right? And it's like, it's another thing we talked about yesterday. Like broadly there's three mechanisms for a gouge, right? Either you're dragging it and moving it along from a bed, or you're mobilizing or injecting it, or squeezing it in, or it's, it's ground-up rock around it and a combination of authigenesis creating those clays.

Terry: Right.

Randy: So of those three things, I, I would go pretty firmly with the first one at this point. Like it's being moved up from - (cut off cross talk)

Cristina (off-camera): What about the, what about the big sand though, the big chunks of sand? I thought the -

Randy: Well I don't think that's a problem personally if you're thinking about dragging it up from depth, along a fault

Cristina (off-camera): Uh huh

Randy: Like I would actually expect it to pick up some bits of sand along the way, or even

Terry: In fact I would even

Cristina (off-camera): Bits, but big like? (gestures behind Randy)

Terry: But that would be -

Randy: even big things

Cristina (off-camera): Okay

Terry: to me that would be my justification for the hypothesis that the-

Cristina (off-camera): Oh the fact that the sand is -

Terry: -the Palm Spring is depositional on this, and then continued motion, slices and dices that material a little bit

Cristina (off-camera cross talk): Ahhh.

Randy: Oh, oh okay.

Terry: a little bit of motion vertically brings those together again.

Randy: Got it. So you've -

Terry: And another, as it keeps bringing it up, and you just erode away

Cristina (off-camera): Mhmm

Terry: the rest of it.

Randy: Yeah. It does get weird with the sand bodies we saw yesterday. Yeah. We should go look.

Cristina (off-camera): Yeah.

Terry: Oh, okay, so I have -so that's the ones we skipped?

Randy: Yeah we should, we should-

Cristina (off-camera): Well this was nice though. I'm not a geologist but I buy it. So let's go see if the sand ruins it.