Natural Fractals

(All underlines are links.)

in and around

Grand Canyon National Park

When something is ***fractal***…

…little parts resemble big parts, called

similarity…

…*substructure* is present: *similar* shapes that repeat on different scales…

…what shape the parts are depends entirely on the object.

- **Fractals possess *scale-invariance*:**

  scale-invariance implies a frame of reference is needed to determine size.

- **Fractals reveal *symmetry under magnification*:**

  zooming in on a fractal object leaves the shape approximately unaltered.

- **Fractals have strong intersections with *Chaos*:**

  some processes are fractal and not chaotic other processes are chaotic and not fractal, and some are both.

- **Fractals have *non-integer dimension*:**

  see an example related to galaxies.

- **It can be difficult to make distinctions between things that are fractals and:**

  "things that look like fractals but aren't."

Topics and other Pertinent Information:

All underlines in the presentation are links. On slides 5-11, *beneath* the title of each topic is a link to its respective slides, making it easy to jump between topics as an alternative to viewing the presentation in order. A word of caution: information is cumulative, with multiple references to previous slides.

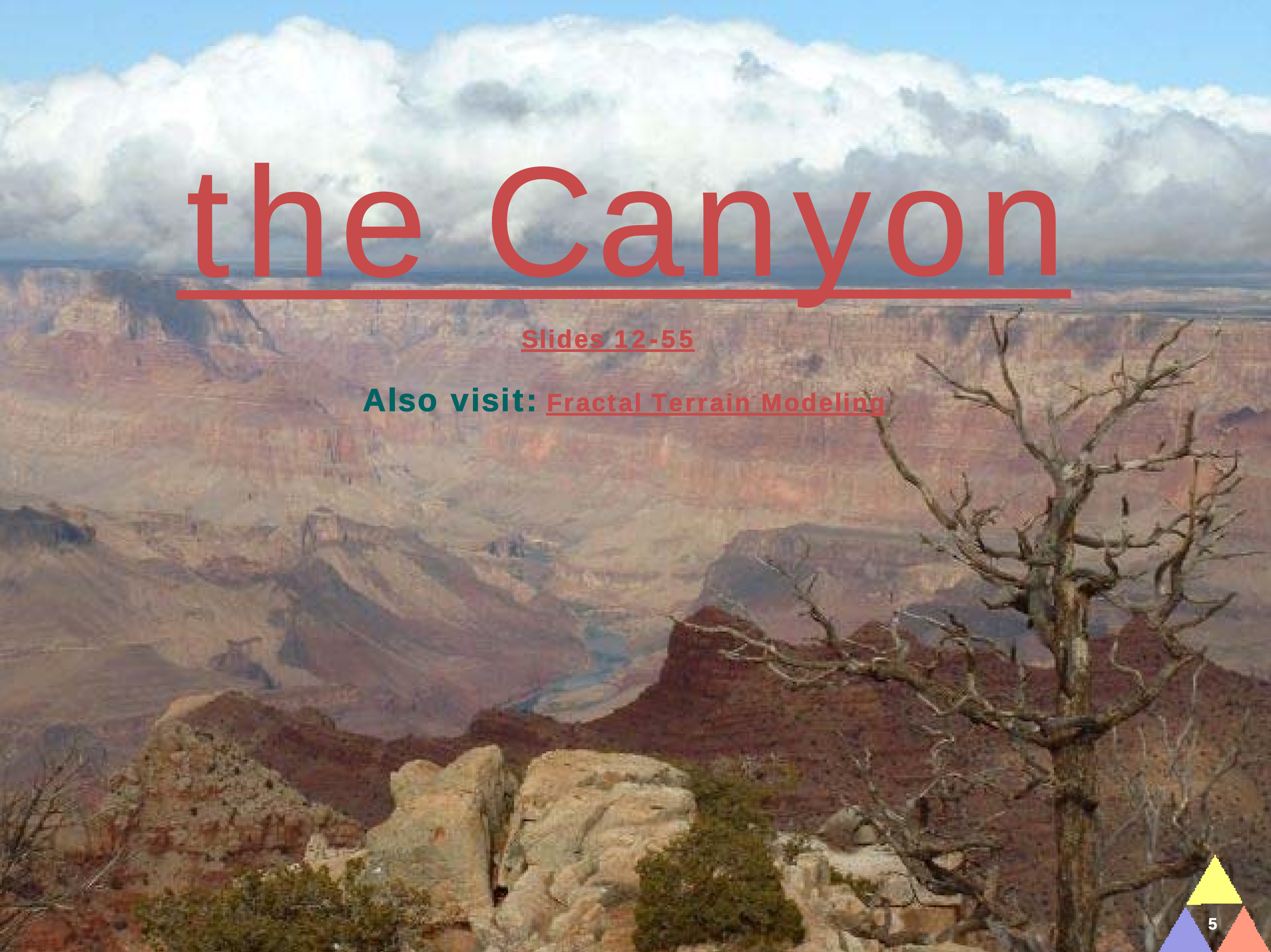
Slide notes pertaining to content on specific slides can be accessed by clicking on the Sierpinski triangle located in the bottom-right corner of every slide. Or, print them out ahead of time (about 30 pages).

In this Adobe Acrobat version of the presentation, only links are preserved. The PowerPoint version has the option of drawing on the slides and highlighting similarity in the images yourself. The Keynote version, available on Paul Bourke's website for Mac OS users, may have this option as well.

the Canyon

Slides 12-55

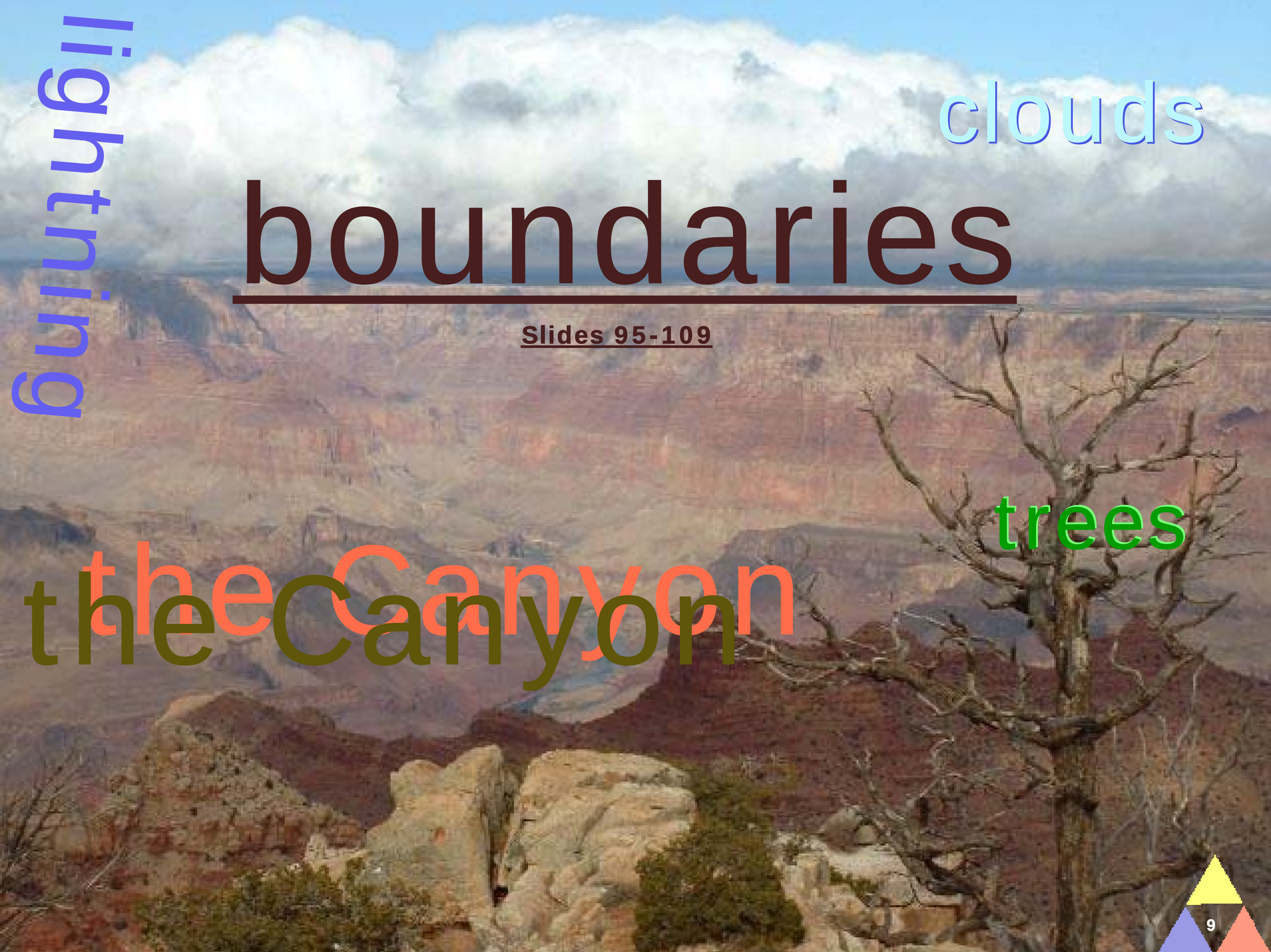
Also visit: Fractal Terrain Modeling




clouds
Slides 56-61
the Canyon
the Canyon


clouds
trees
Slides 62-90
the Canyon
the Canyon


clouds
lightning
Slides 91-94
trees
the Canyon
the Canyon


lightning
clouds
boundaries
Slides 95-109
trees
the Canyon
the Canyon

rocks

(frames of reference)

Slides 110-116

lightning

clouds

boundaries

trees

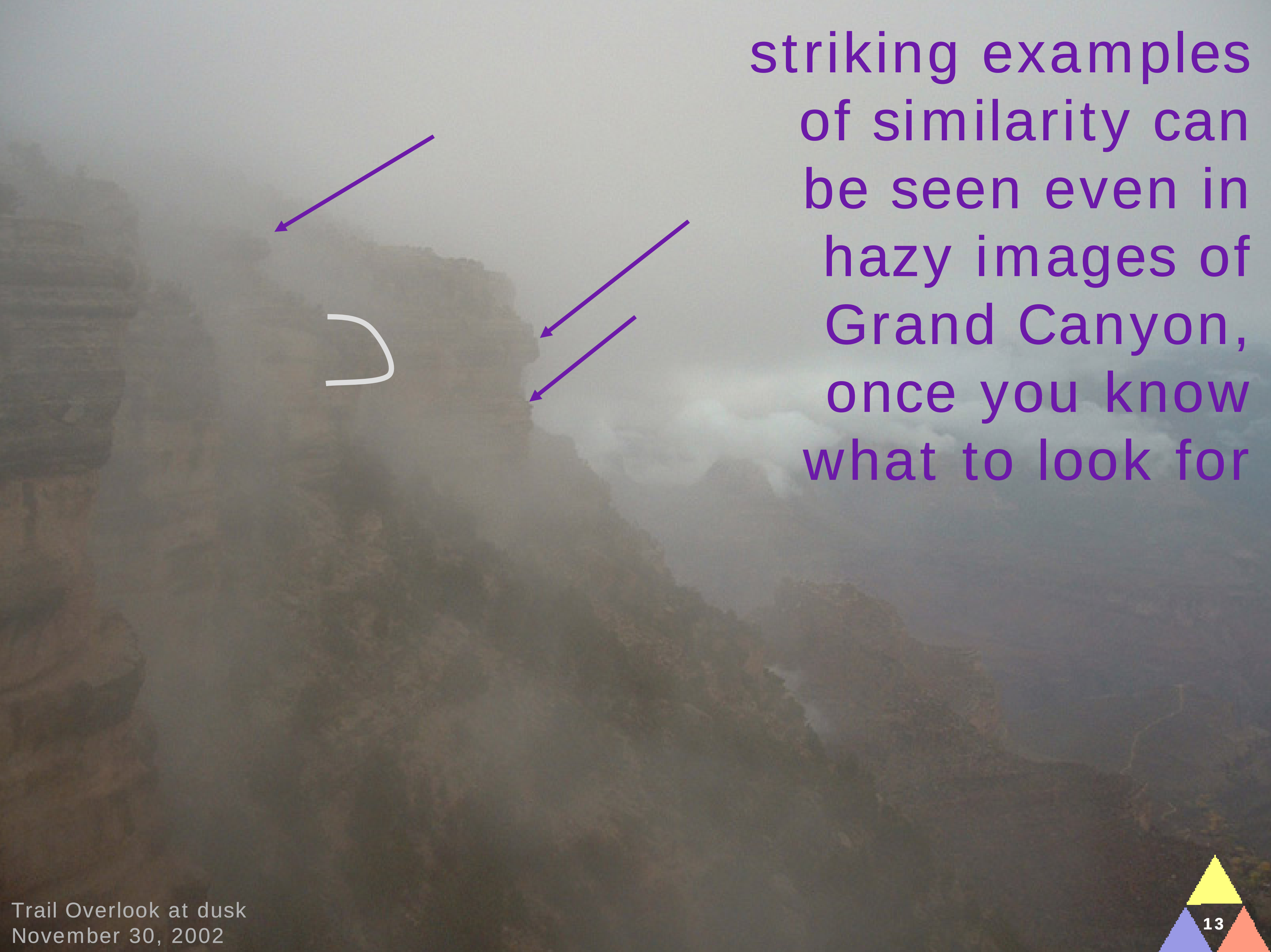
the Canyon

the Canyon


lightning
clouds
snowflakes
Slides 117-123
boundaries
trees
the Canyon
the Canyon
rocks
11


the Canyon

striking examples of similarity can be seen even in hazy images of Grand Canyon, once you know what to look for



Trail Overlook at dusk
November 30, 2002


look for shapes
within shapes

learn

to

recognize

similarity:

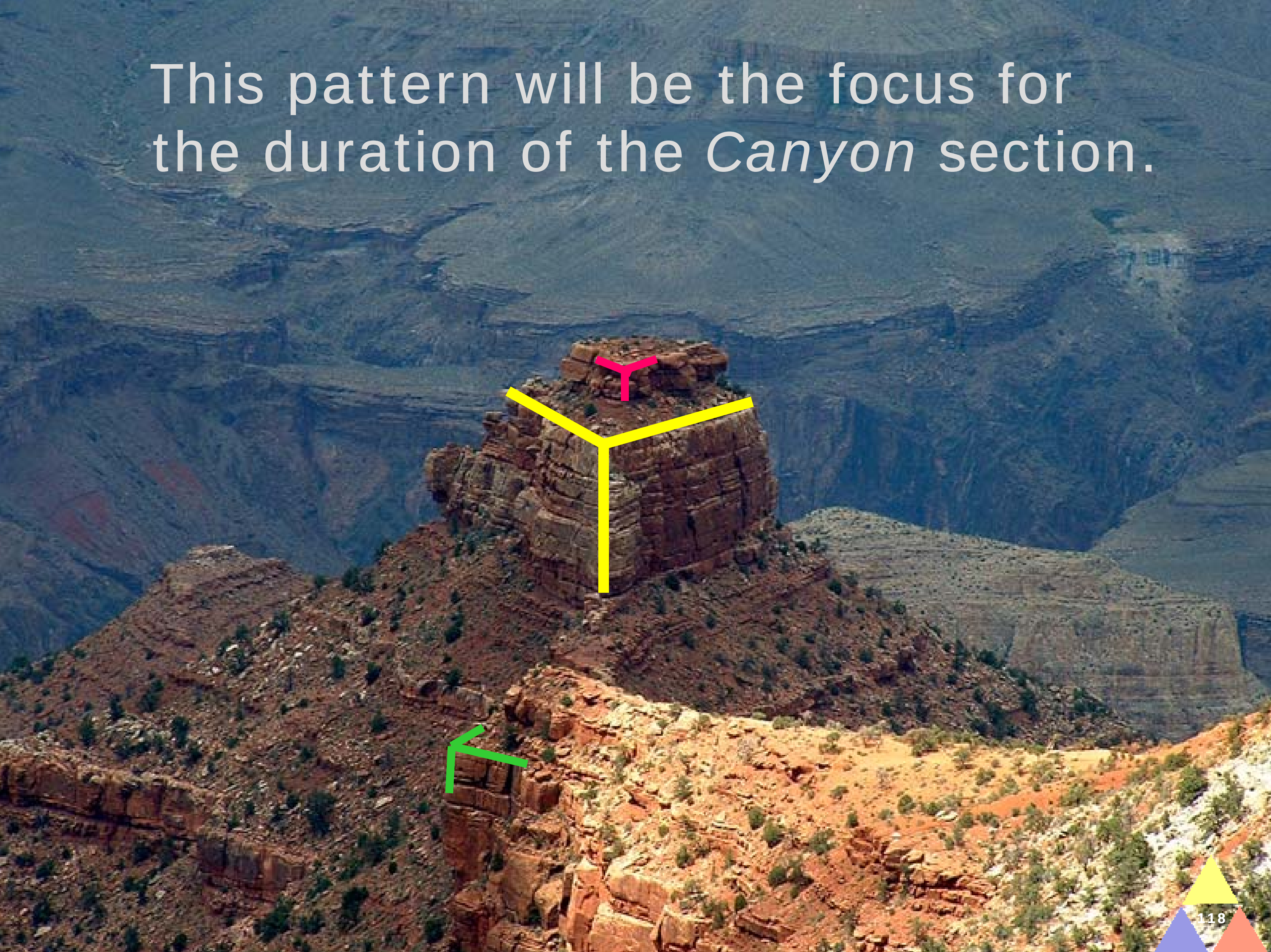
...in the Canyon

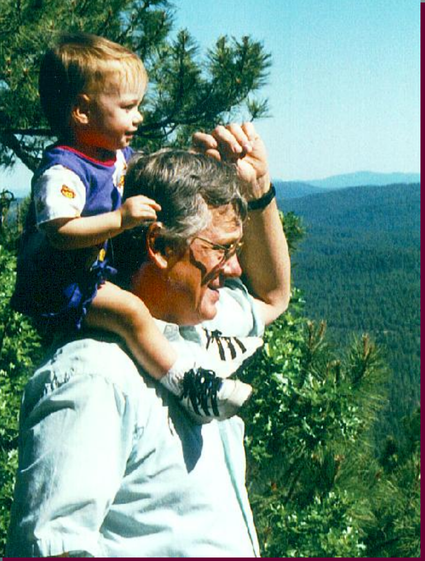
specifically

...in Nature

generally

This pattern will be the focus for the duration of the *Canyon* section.

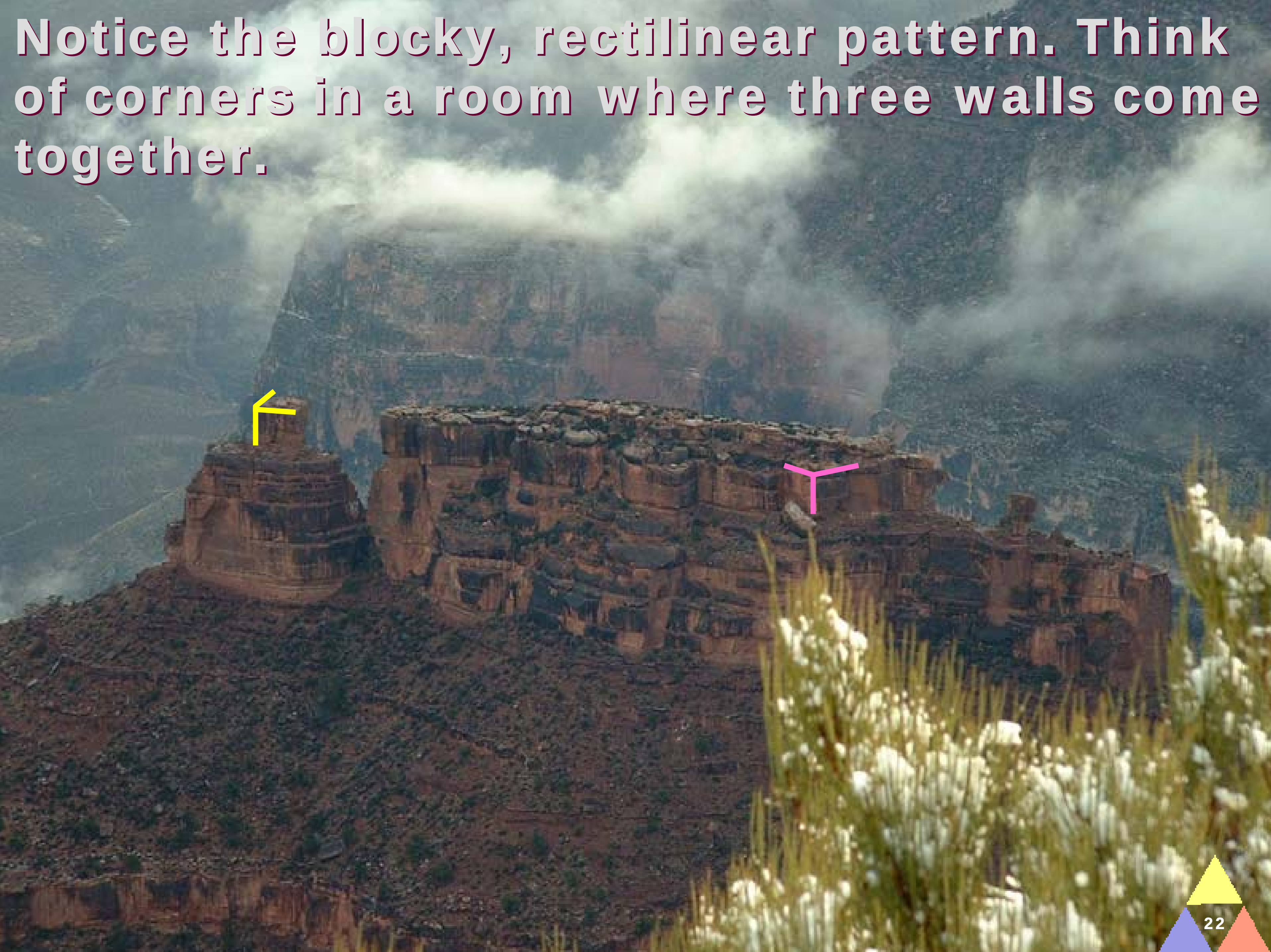


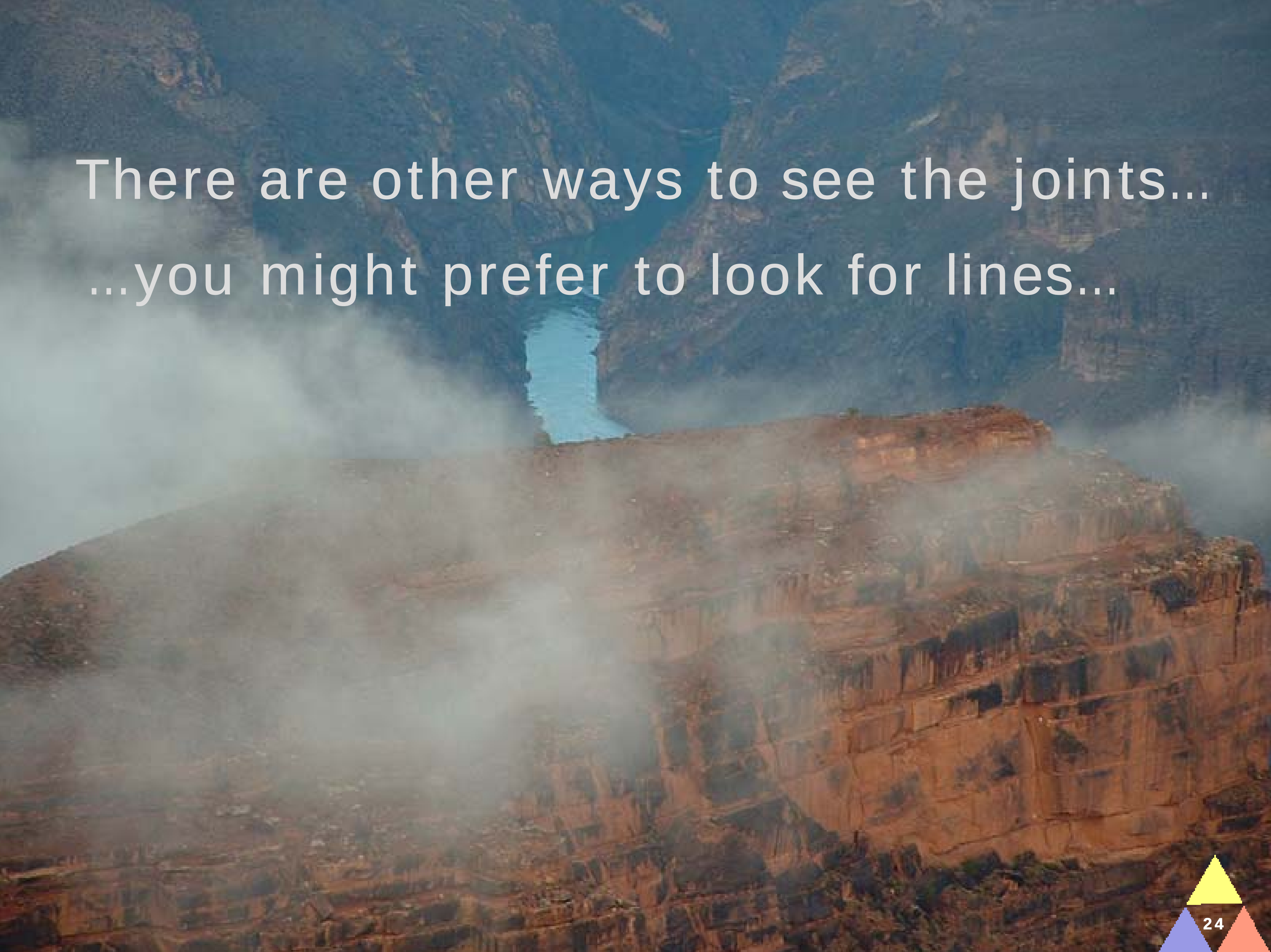


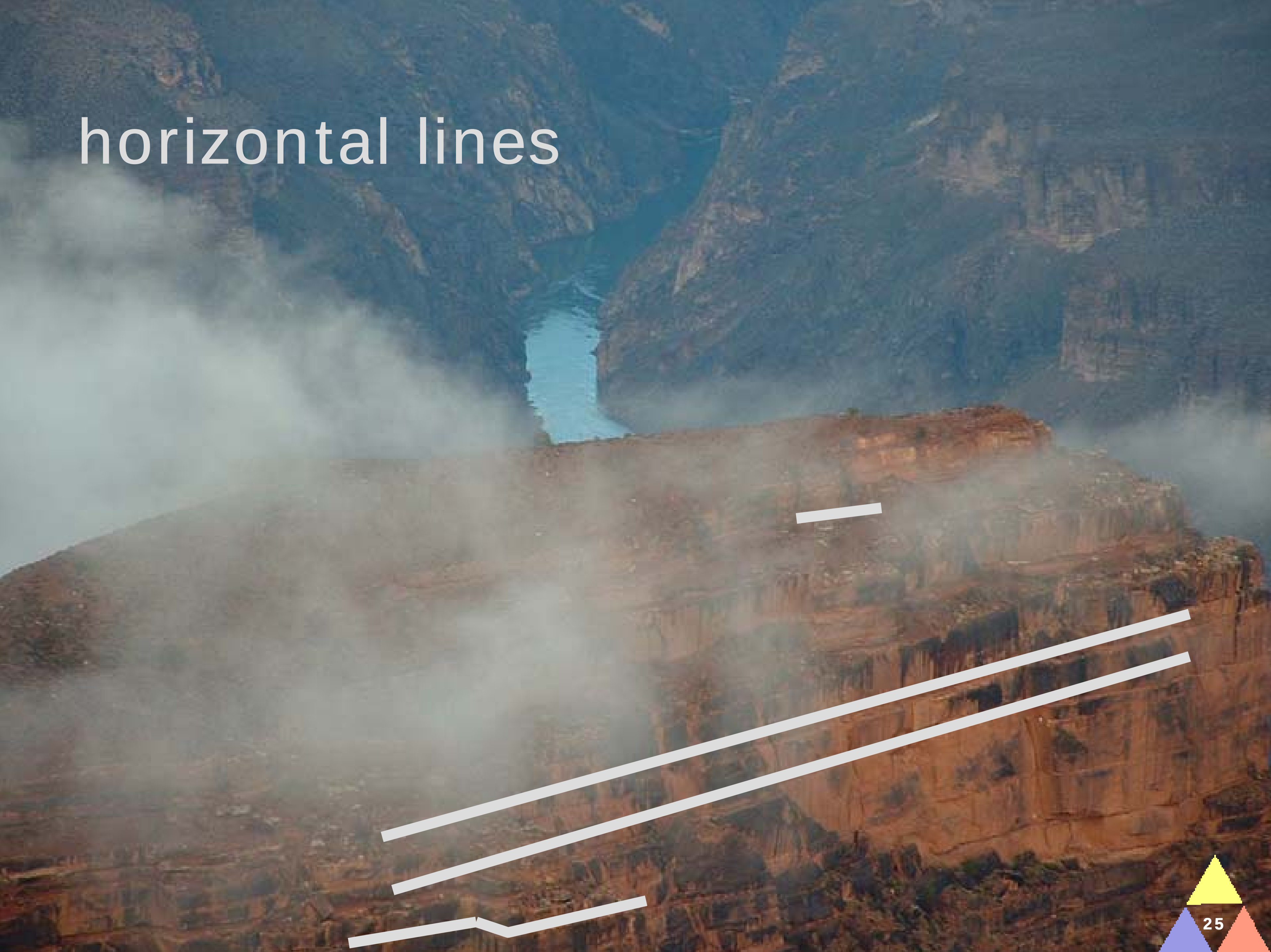
A pattern of **mutually orthogonal joints** runs throughout **Grand Canyon**, shown to me by Paul Knauth, Professor of Geology at Arizona State University.

The joints form cracks--revealed through weathering--that separate the rock into blocks, that reveal more cracks through weathering, that cause separation into more blocks, in an ongoing process.

Notice the blocky, rectilinear pattern. Think of corners in a room where three walls come together.

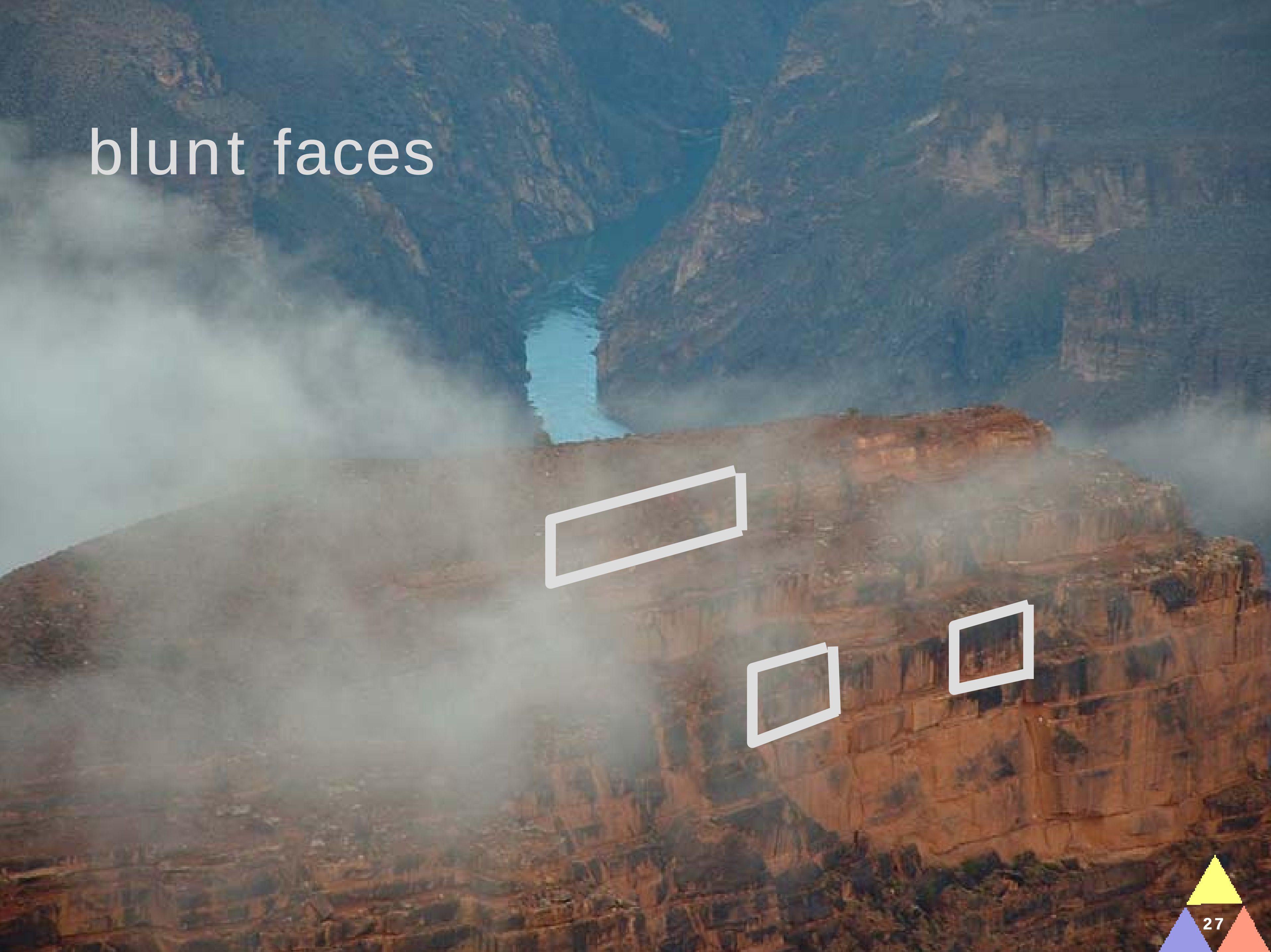


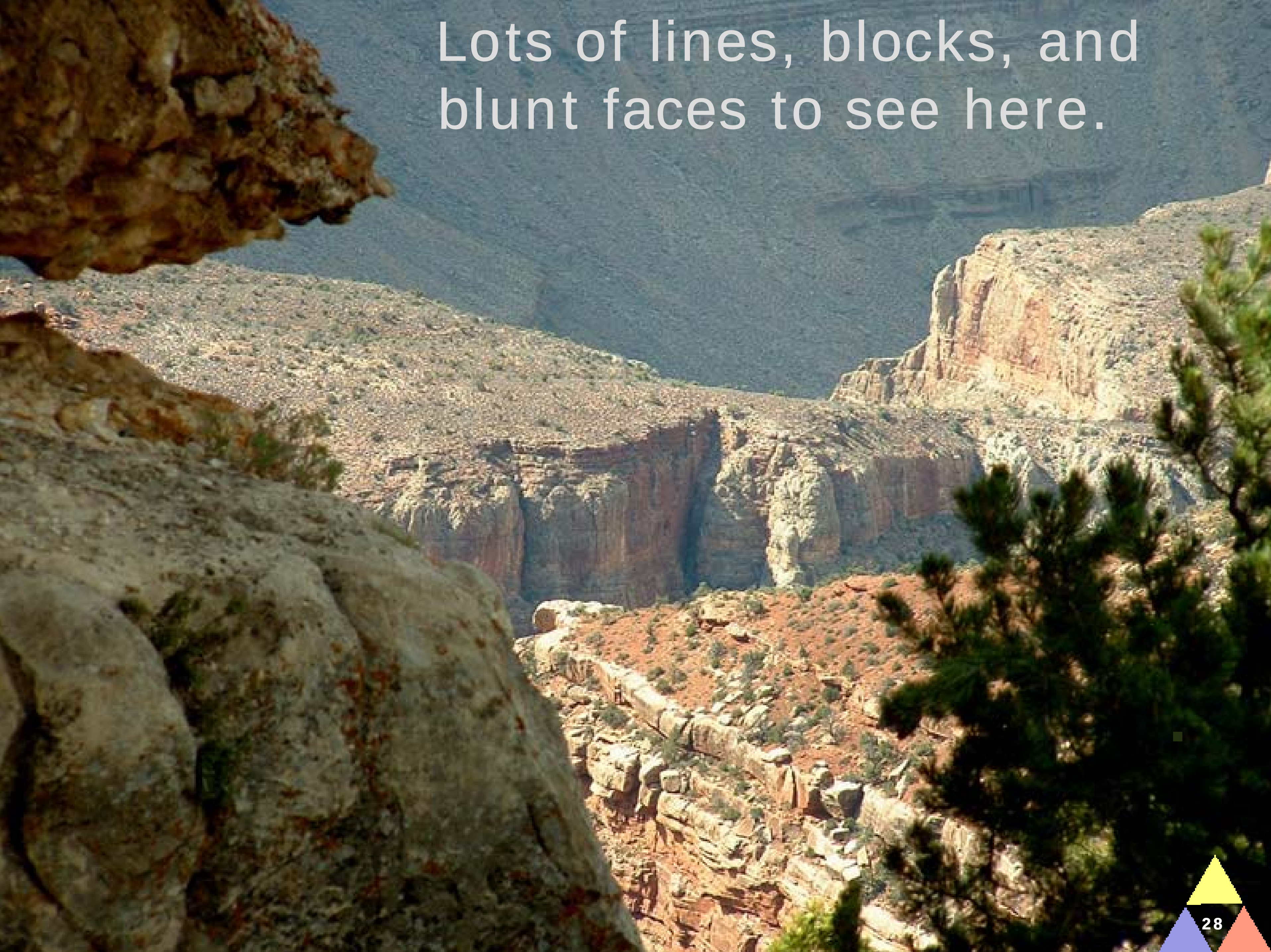

There are other ways to see the joints...
...you might prefer to look for lines...

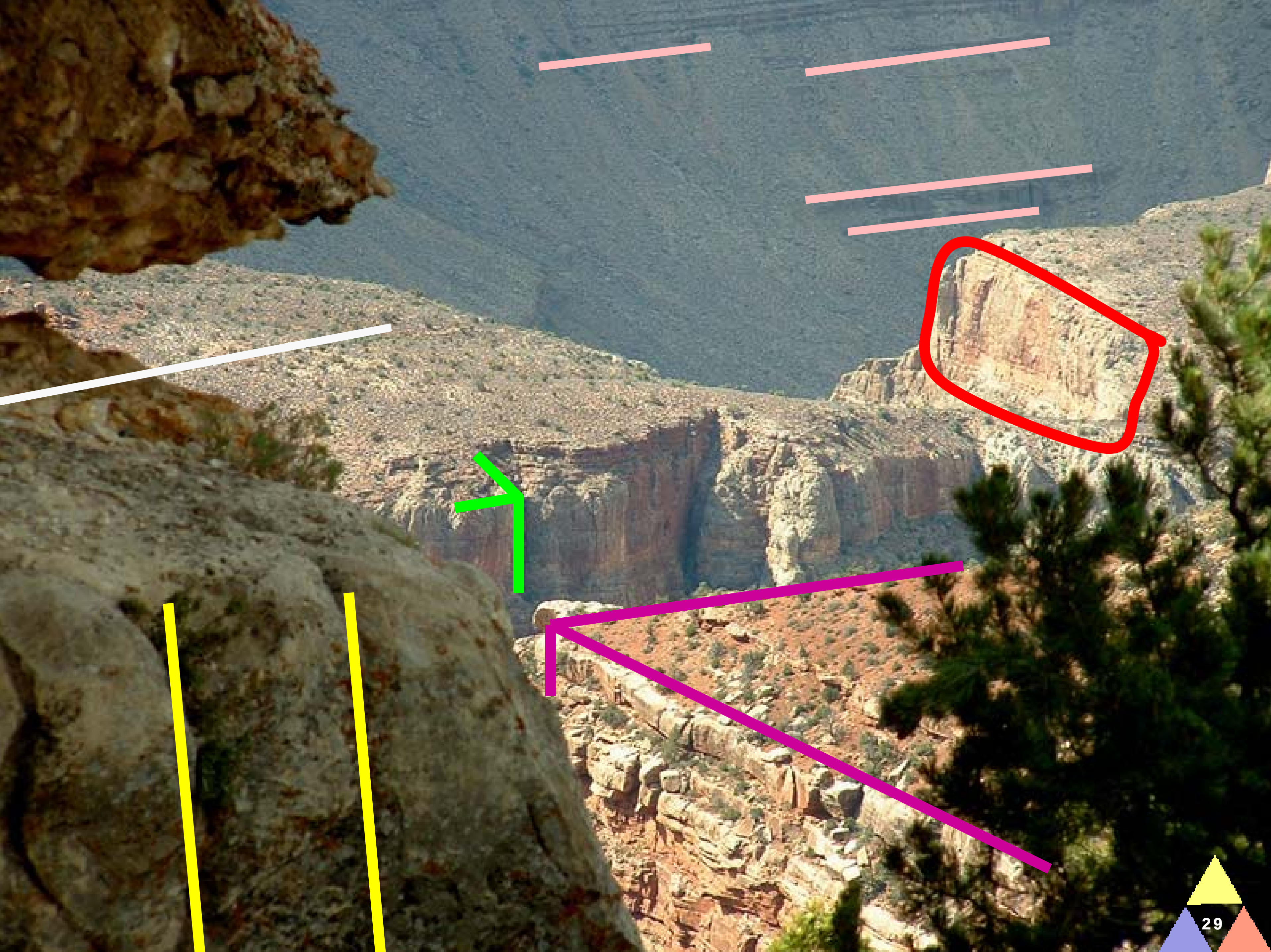

horizontal lines


vertical lines

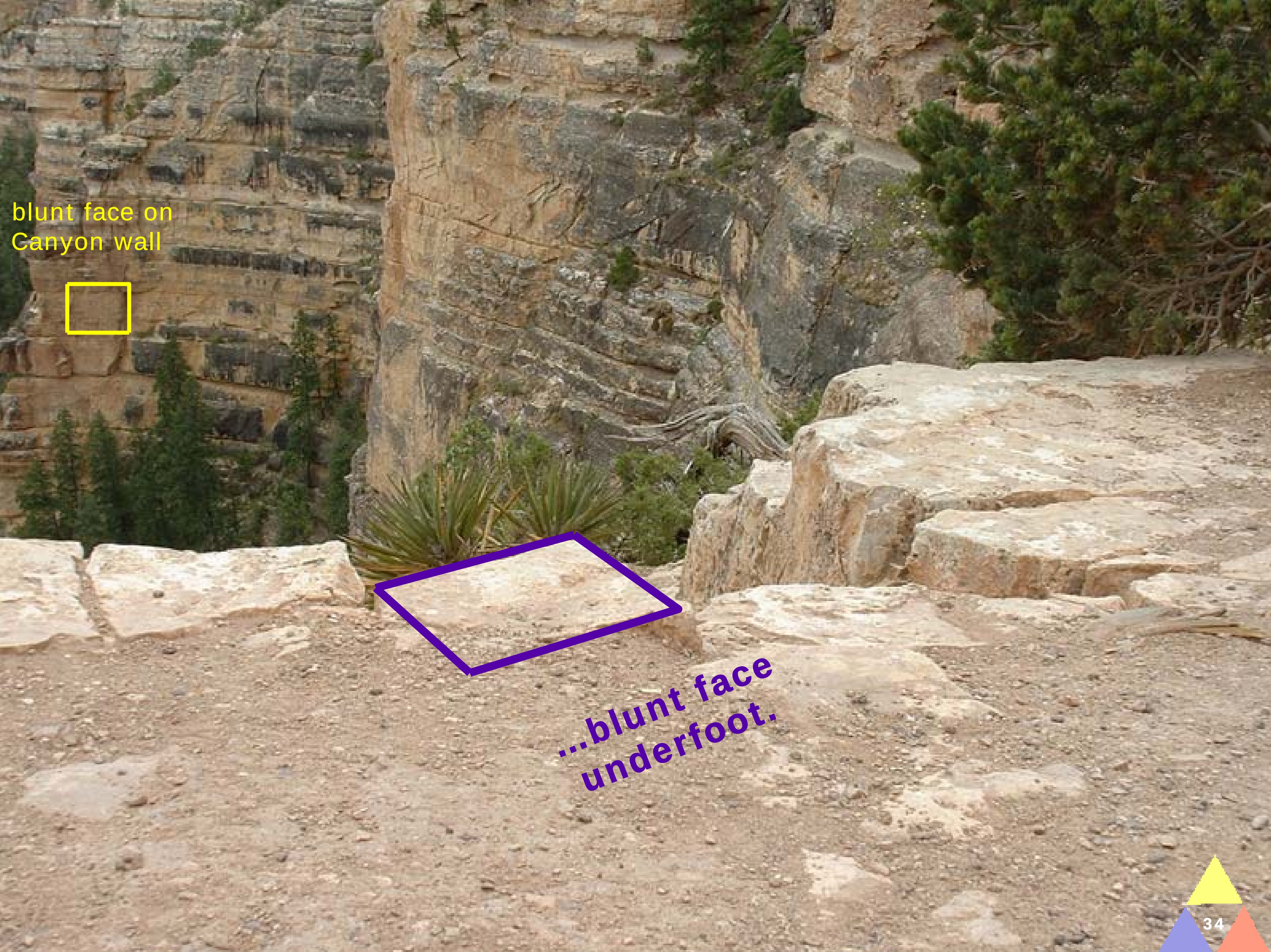
blunt faces

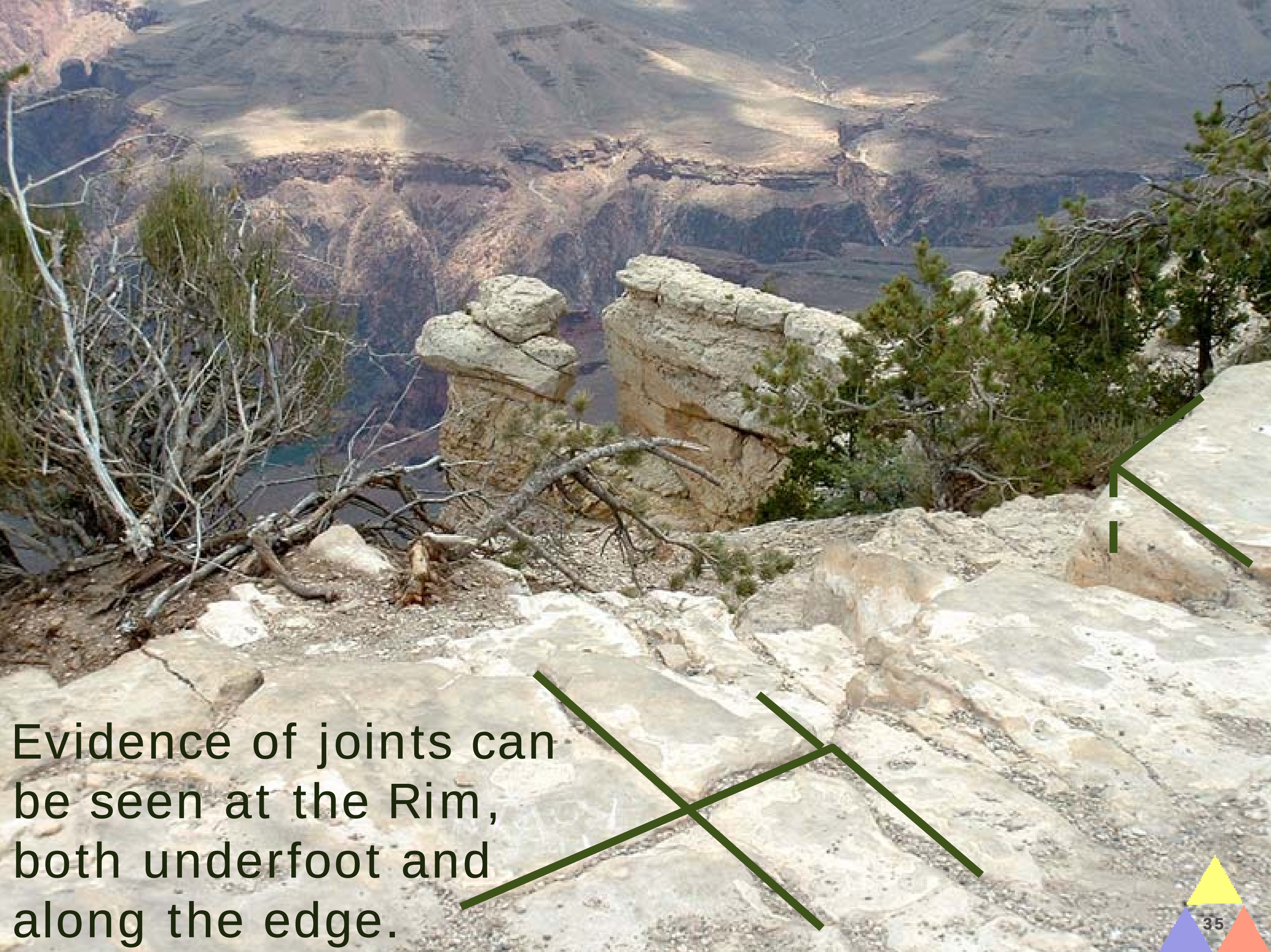



Lots of lines, blocks, and
blunt faces to see here.

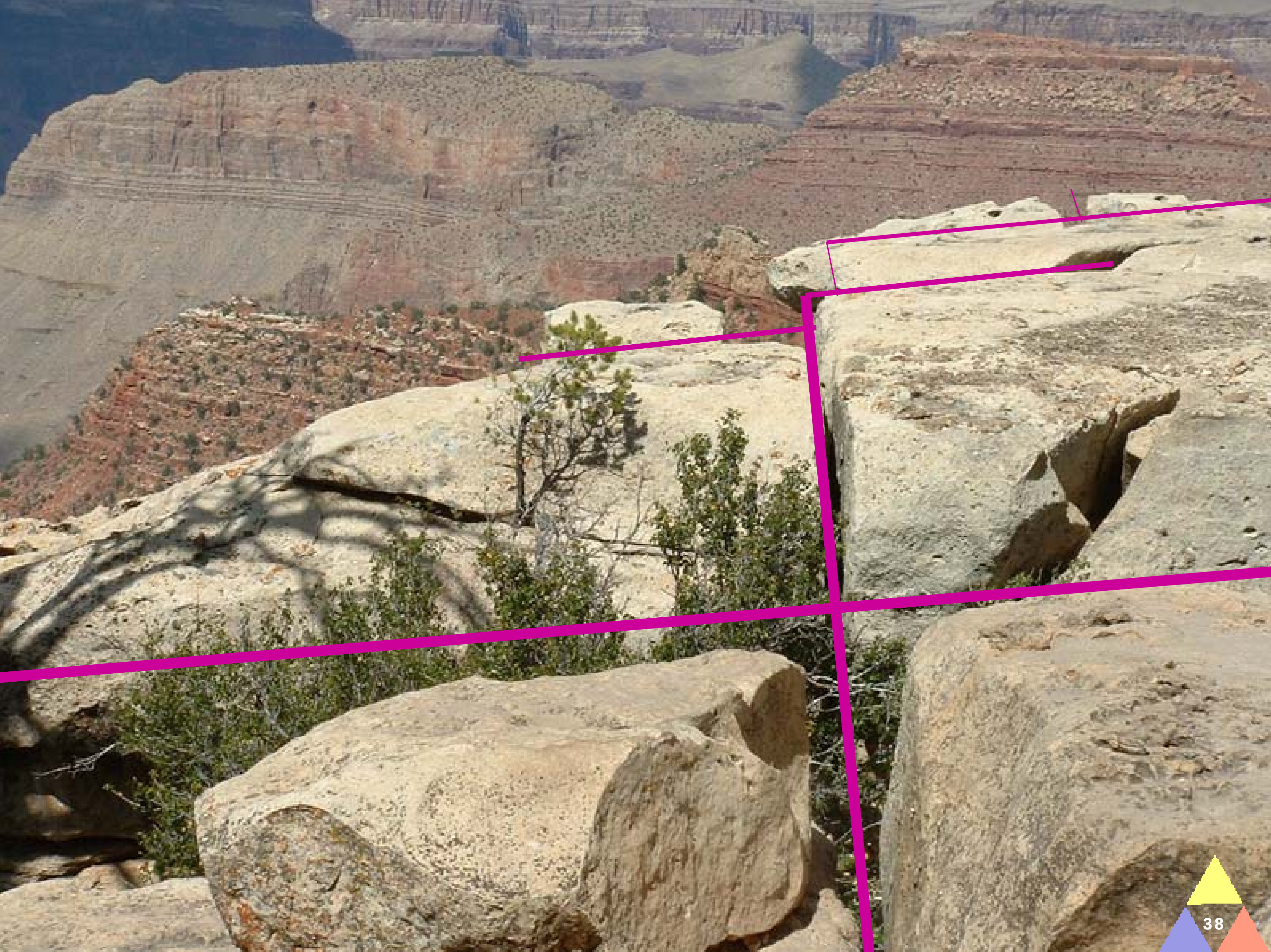



Someday, this section will break off, probably right around this spot, following the blunt pattern seen throughout the Canyon.

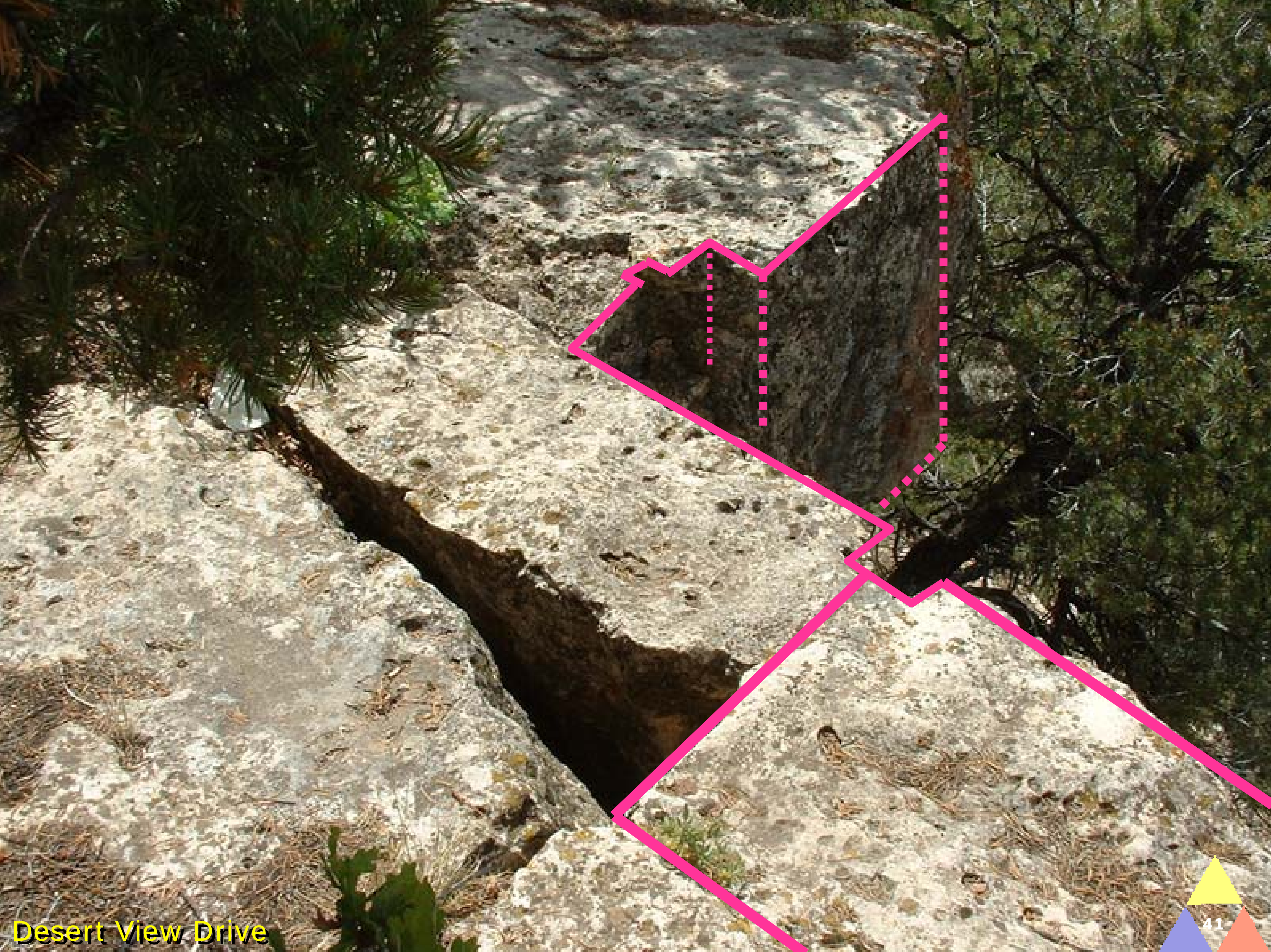

blunt face on
Canyon wall
...blunt face
underfoot.



Evidence of joints can be seen at the Rim, both underfoot and along the edge.



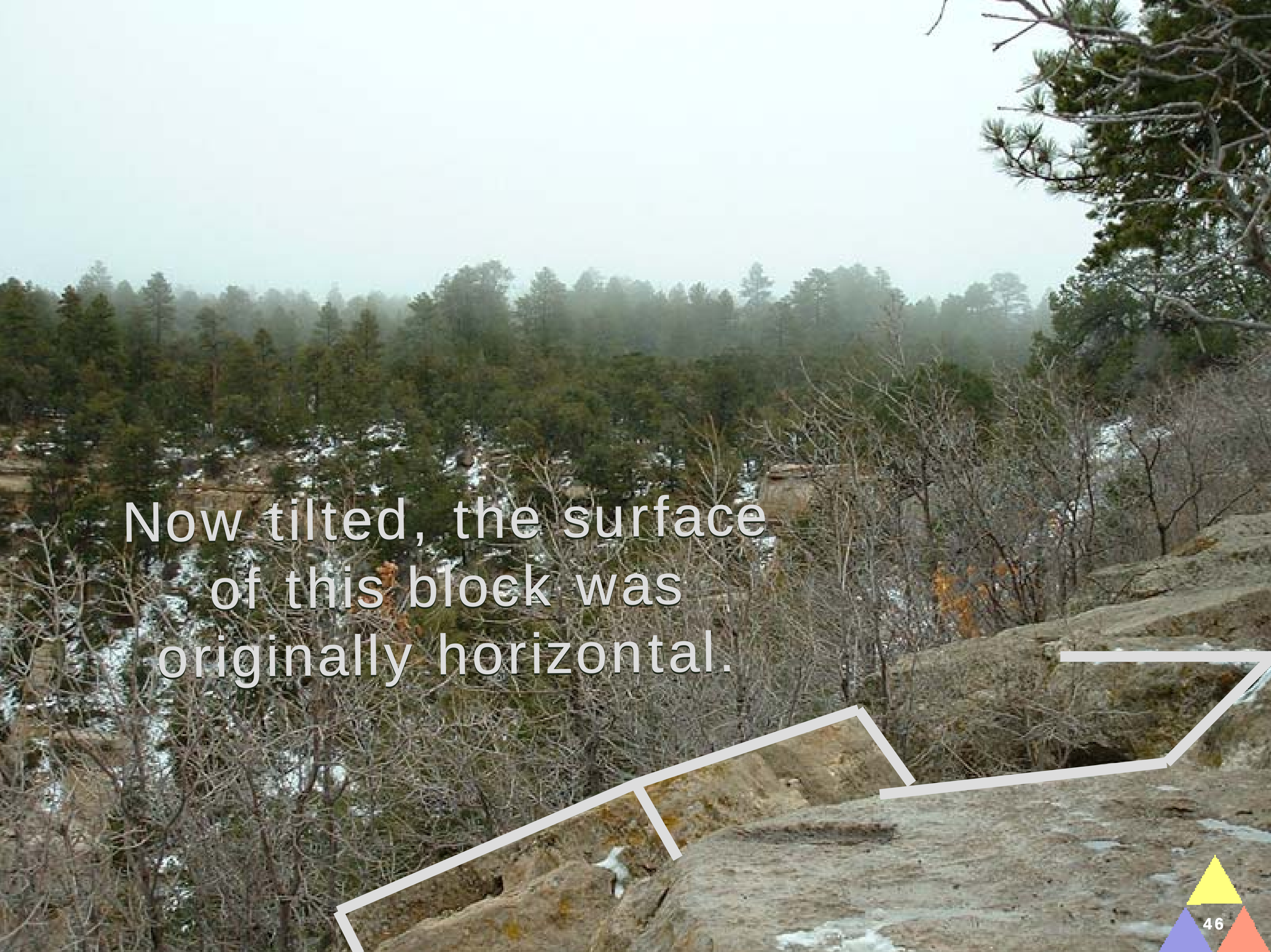

many lines are at off-angles as well
39


Desert View Drive

...in big views of the Canyon,
seek out repeating shapes...

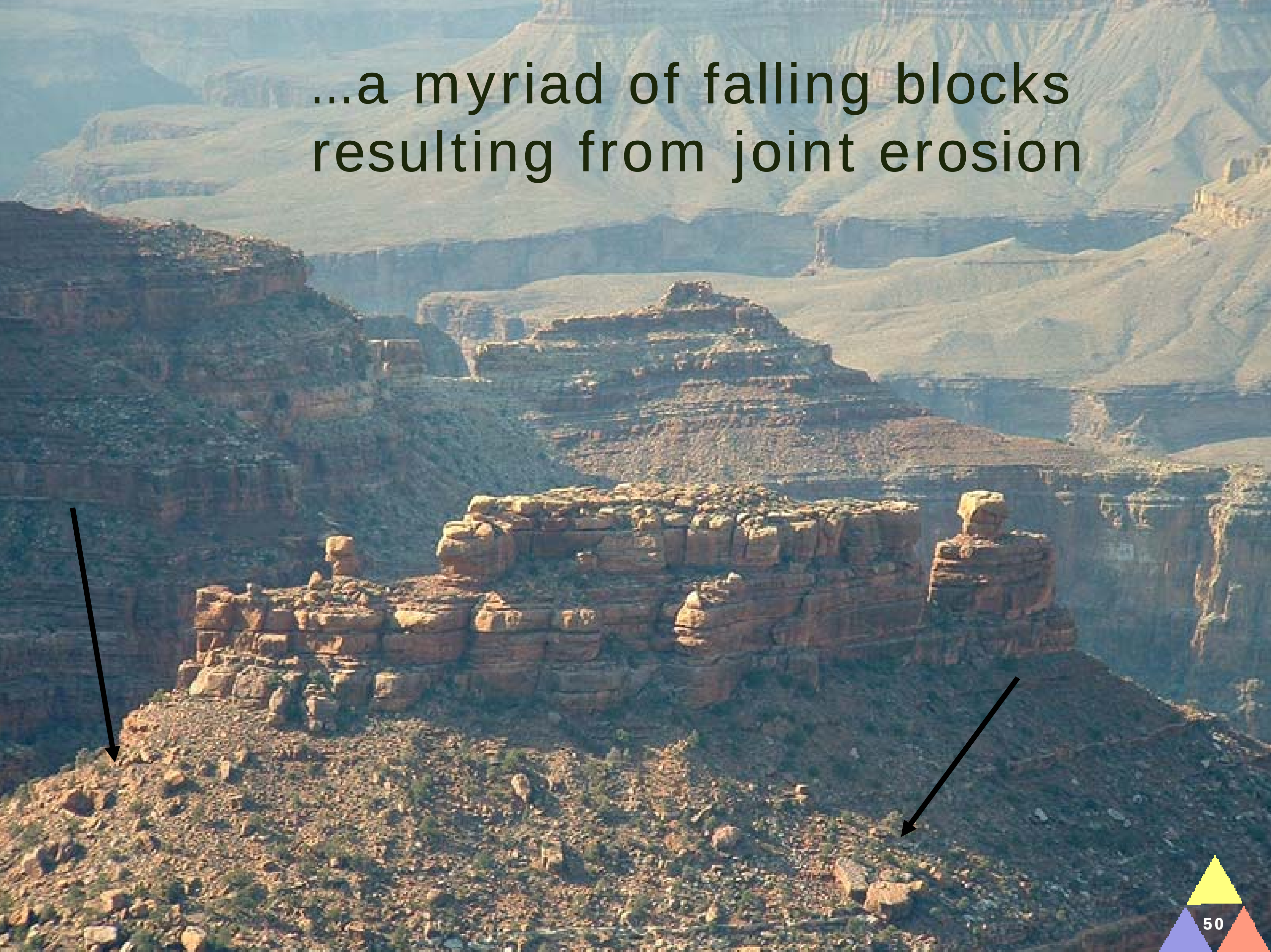

…for instance, rectangles


...take a look at this loose block


Now tilted, the surface
of this block was
originally horizontal.

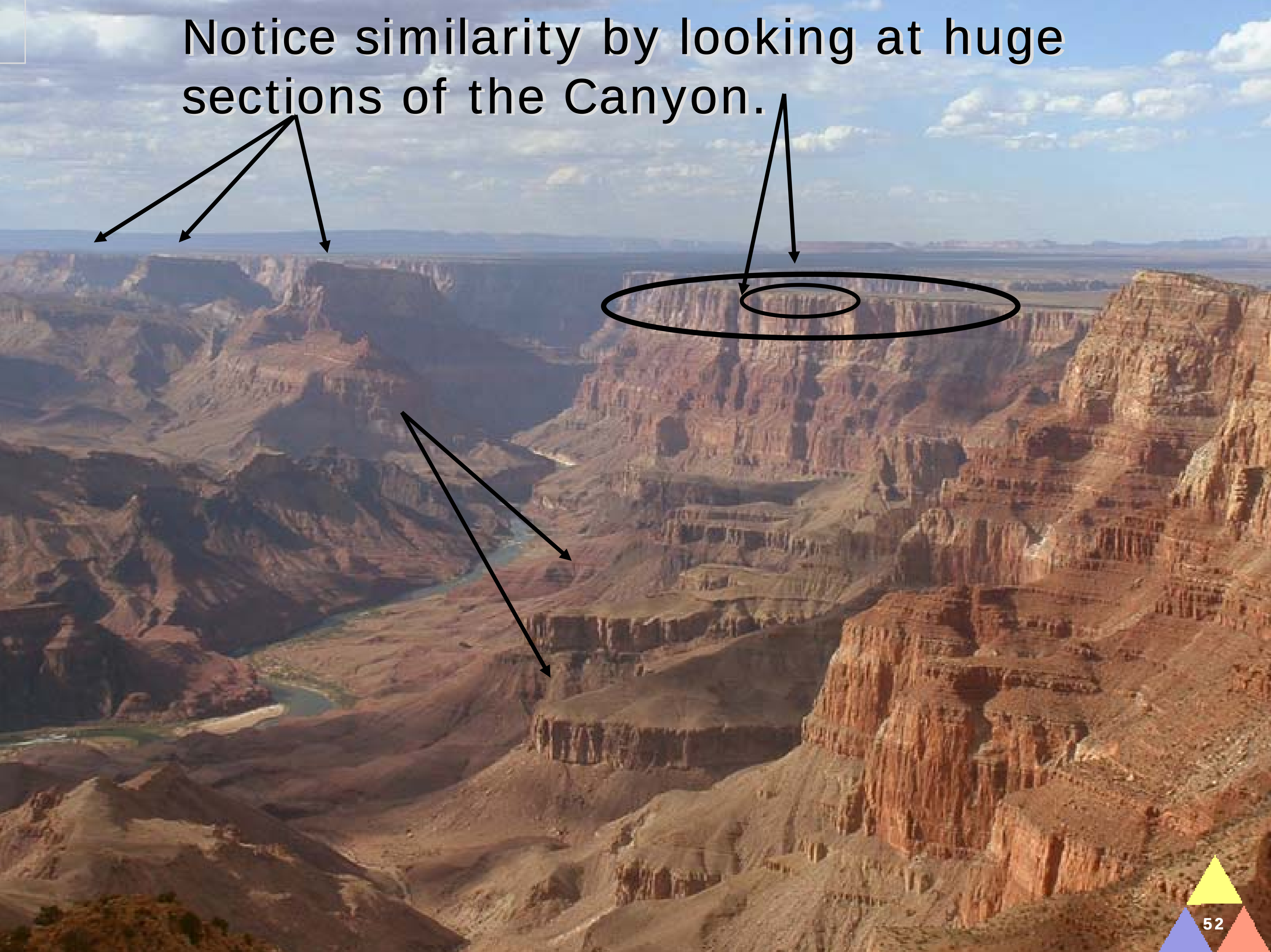
Look for evidence of falling (and fallen) blocks

...a myriad of falling blocks resulting from joint erosion

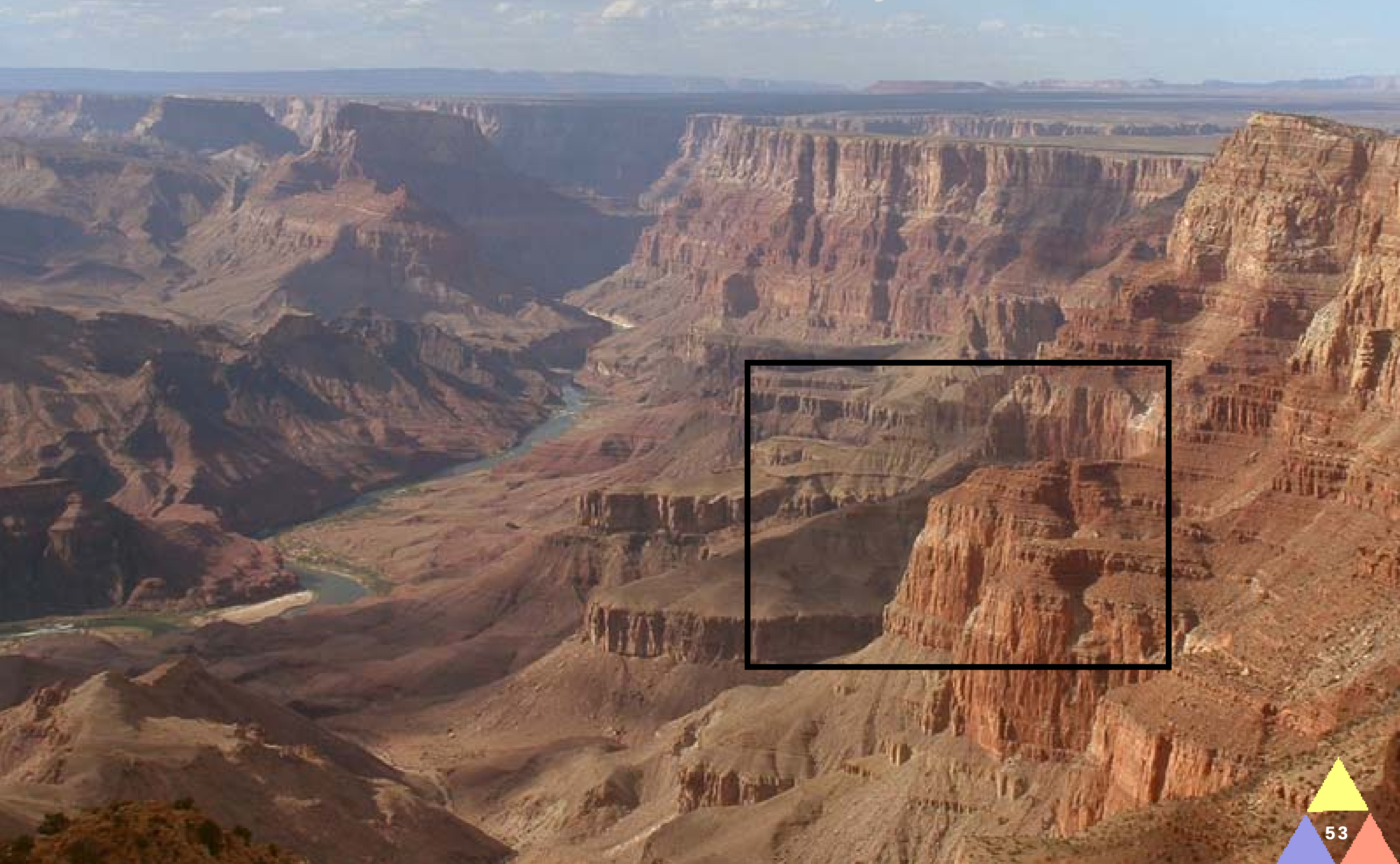



a field of fallen blocks

Notice similarity by looking at huge sections of the Canyon.



or zoom in to smaller and smaller sections of Canyon.



The beautiful East Rim in late afternoon...

Clouds

break apart to form smaller clouds
and merge to form larger clouds

Aside: The Sierpinski tetrahedron is seen in several images in this presentation (not to imply that there are triangles and tetrahedrons in nature, the connection is repeating patterns on different scales). It is a geometric fractal that grows in powers of 4. Patterns that repeat on different scales are often easier to see in geometric fractals than in natural fractals, because the repetition is exact. The repetition in natural fractals tends to be more subtle. There are a lot of things happening in natural systems at the same time, of which approximate, fractal-like repetition is only a part.

back to clouds...

Clouds are scale invariant. Without a frame of reference, it is hard to tell what size they are.

Powell Memorial at dawn
December 1, 2002.

Take a moment to enjoy the elegance of these snowy branches.

Trees

little branches
resemble
big branches

Desert View Drive
December 1, 2002

Bare tree limbs are one of the easiest things to observe similarity in.

Hermit's Route
October 25, 2003.
The haze is smoke
from a nearby fire.

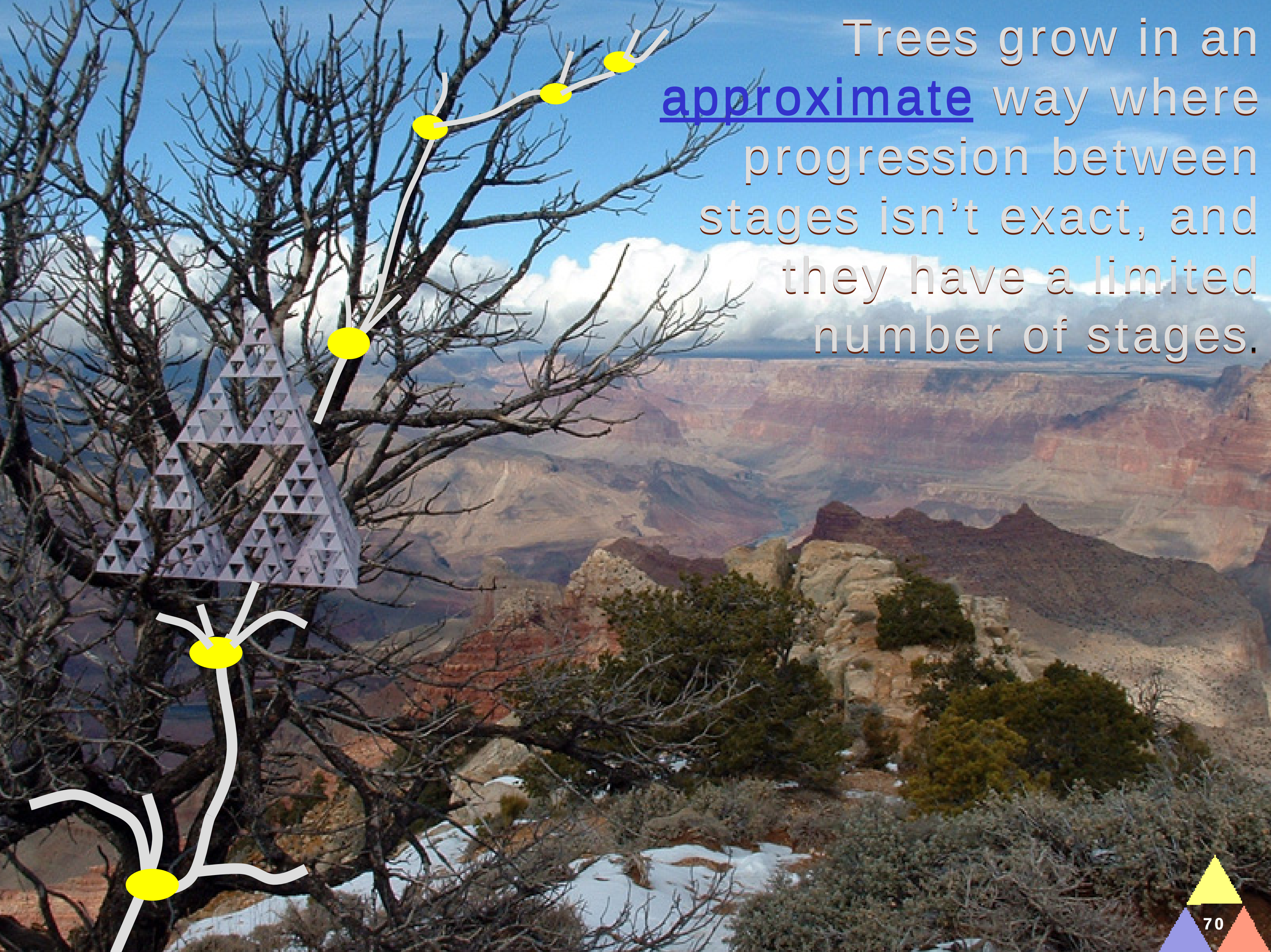
Also notice the curliness of limbs throughout this tree.

This slide compares the growth of the geometric fractal Sierpinski's tetrahedron with the growth of a tree.

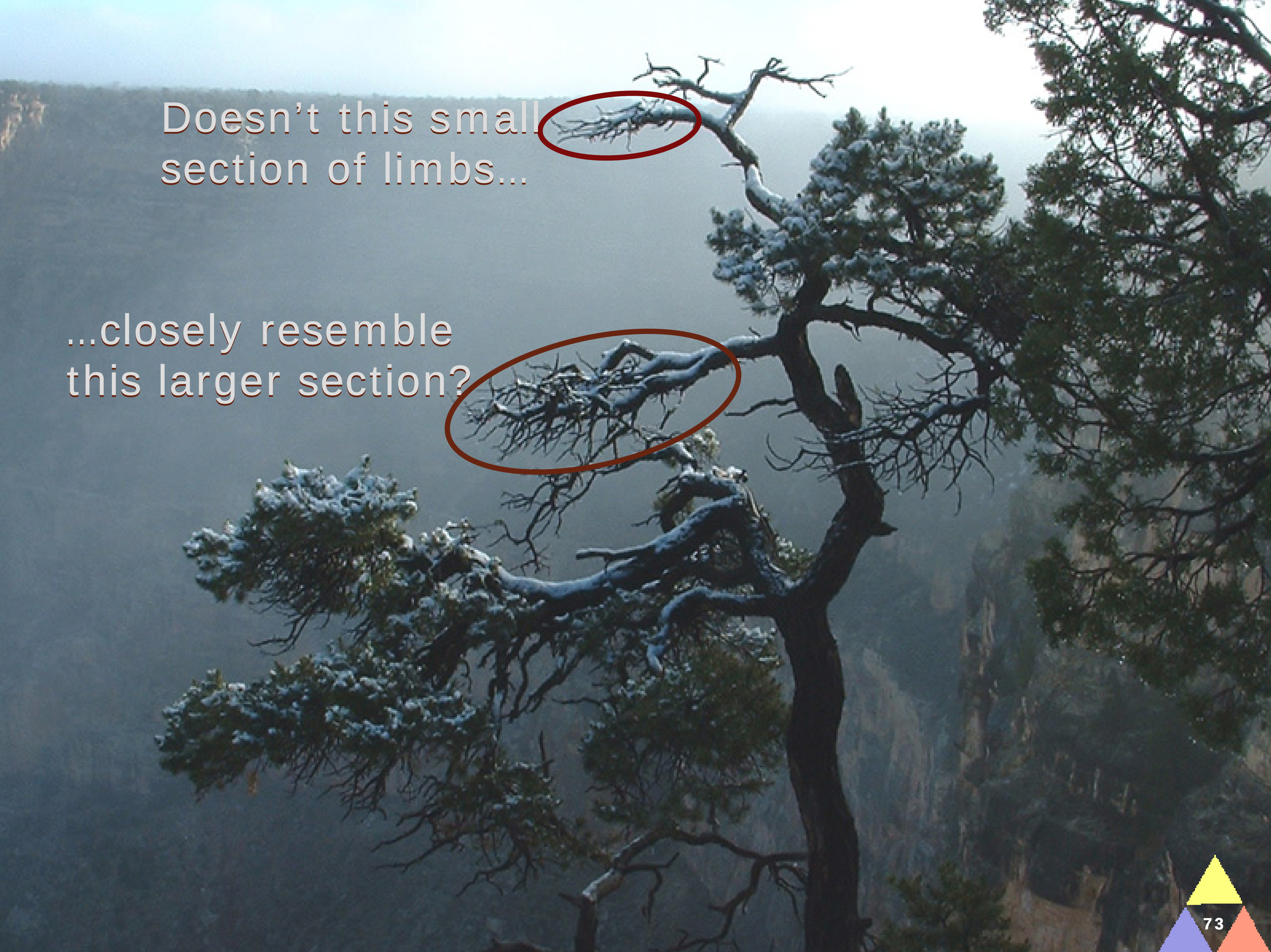

We will follow a path
of growth through the
Sierpinski tetrahedron
and the tree.

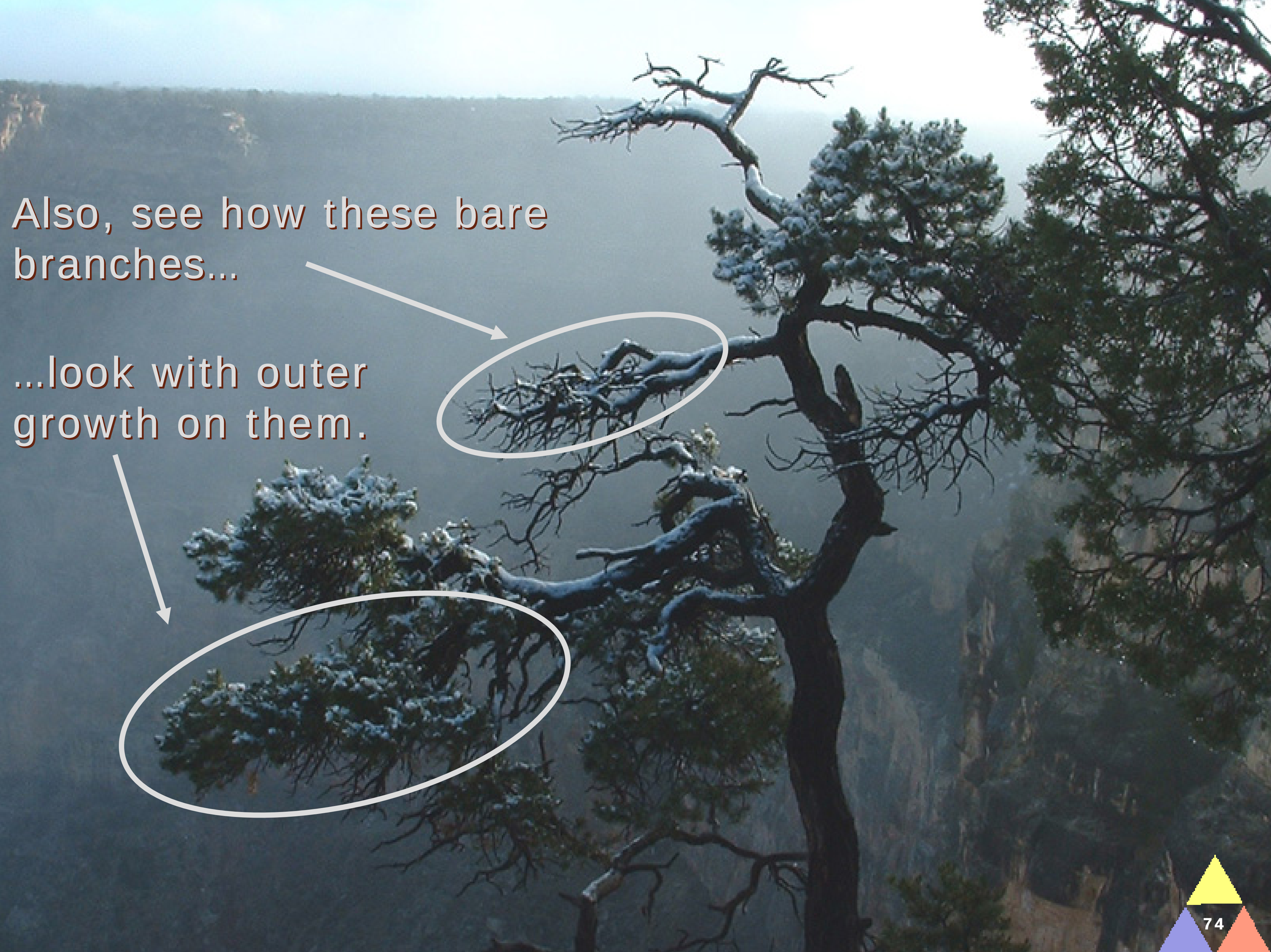

Count the number of different sizes of openings to determine the level of growth.


Geometric fractals can feasibly keep growing forever, to a place we refer to as infinity, where self-similarity is achieved.
4
3
2
1


Trees grow in an approximate way where progression between stages isn’t exact, and they have a limited number of stages.


There are around eight intersections on a path to the top of this tree (two intersections at the top of the tree were too small to outline).
1
2
3
4
5
6
71


Doesn’t this small
section of limbs…
…closely resemble
this larger section?


Also, see how these bare branches...
...look with outer growth on them.

W L
HIDE
E A
N V
E
BRANCHES

Bright Angel
November 29, 2002

W L
HIDE
E A
N V
E
BRANCHES

W L
HIDE
E A
N V
E
BRANCHES


Trail Overlook
November 29, 2002


this
tree
has
brushy
oval
features

almost all
branching in
nature is fractal

however

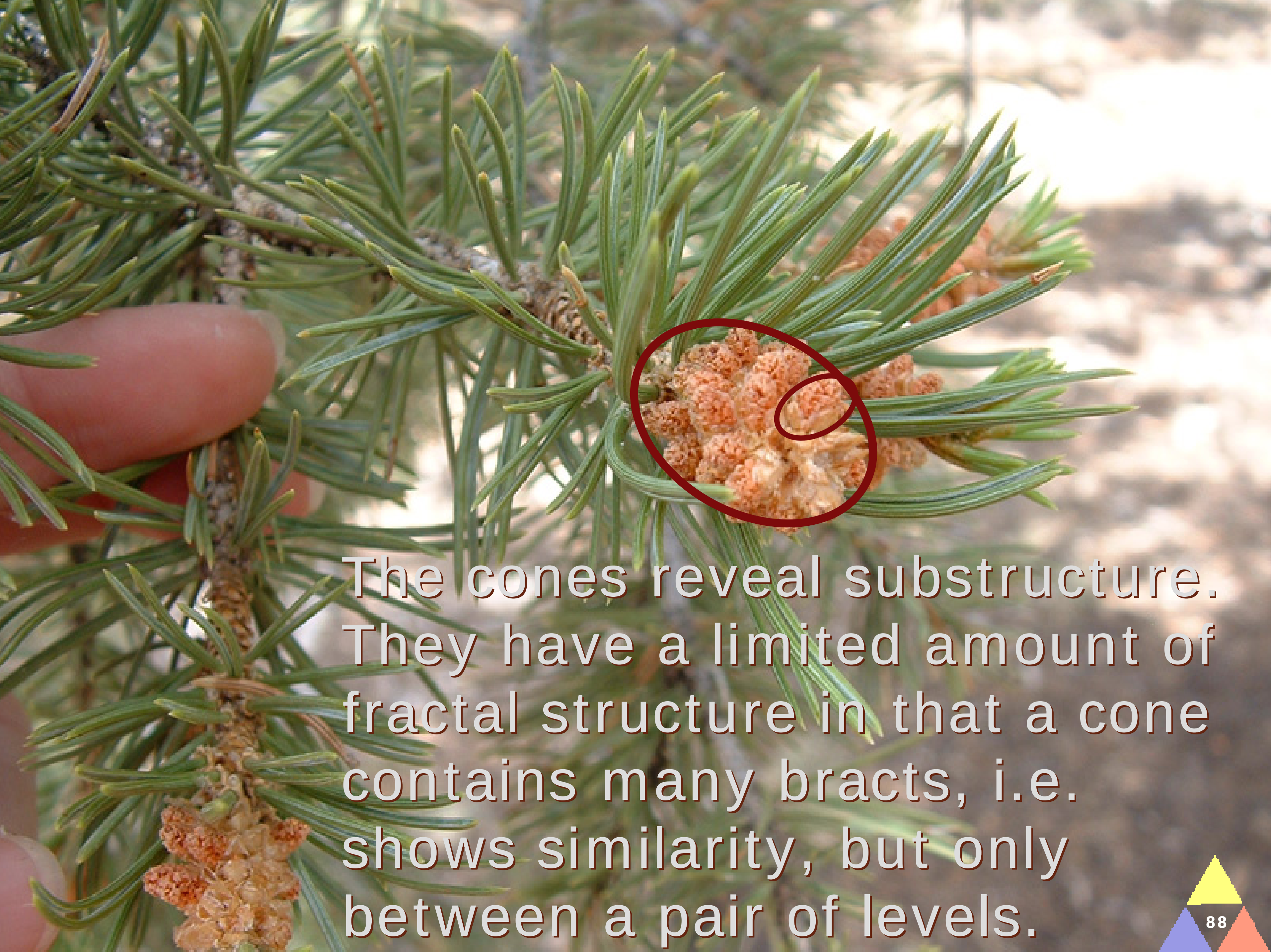
outer foliage
is generally not fractal
(since leaves are <u>terminal organs</u>, they do not reproduce little copies of themselves as do stems, roots, and many other reproductive structures)


Grand Canyon School
March 14, 2004

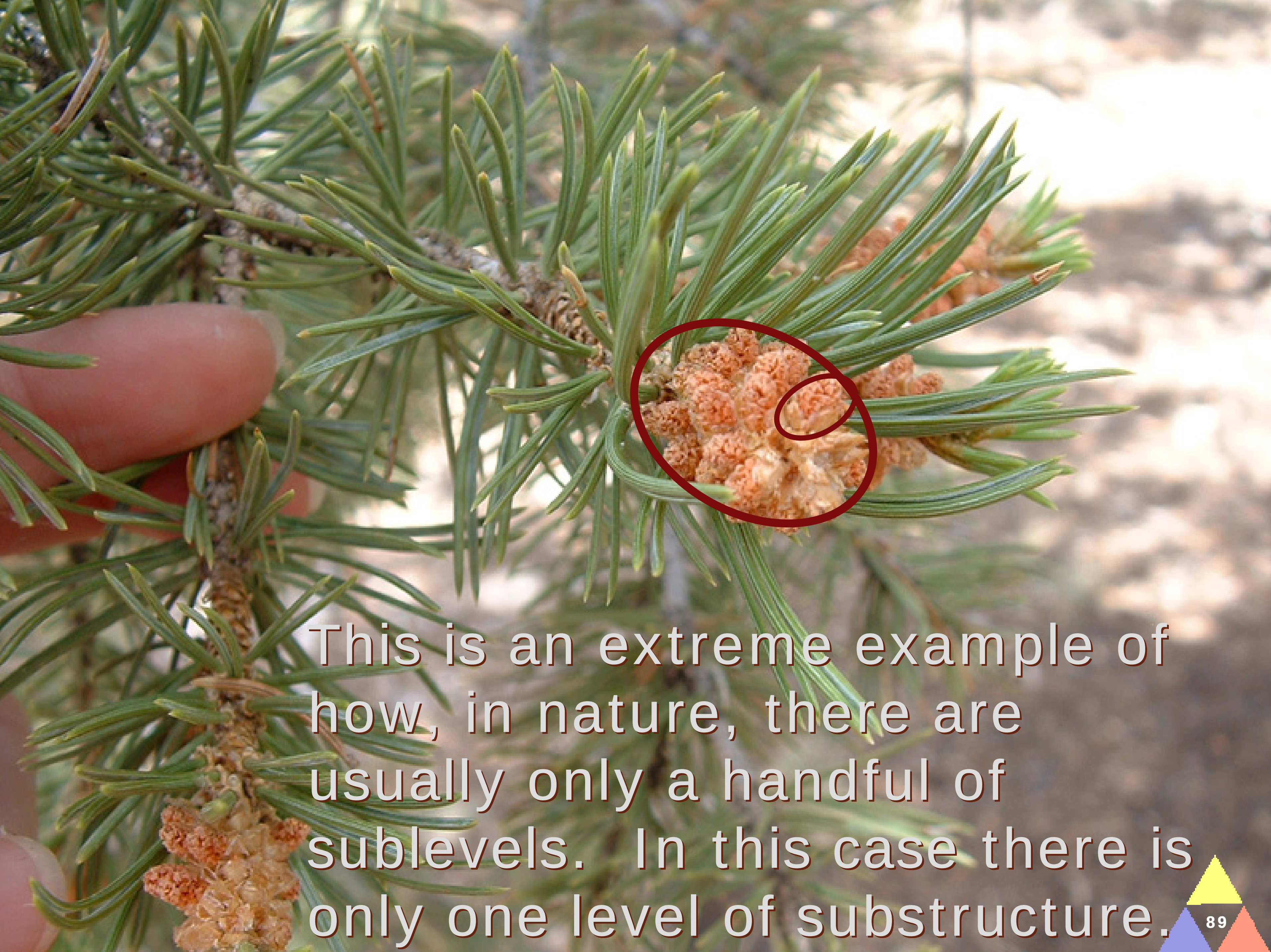

The needles on this tree
reveal no substructure.

(Why not?—because they are
terminal organs.)

Now consider these male cones ('**microstrobili**' containing bracts known as '**microsporophyls**' which hold the pollen sacs).



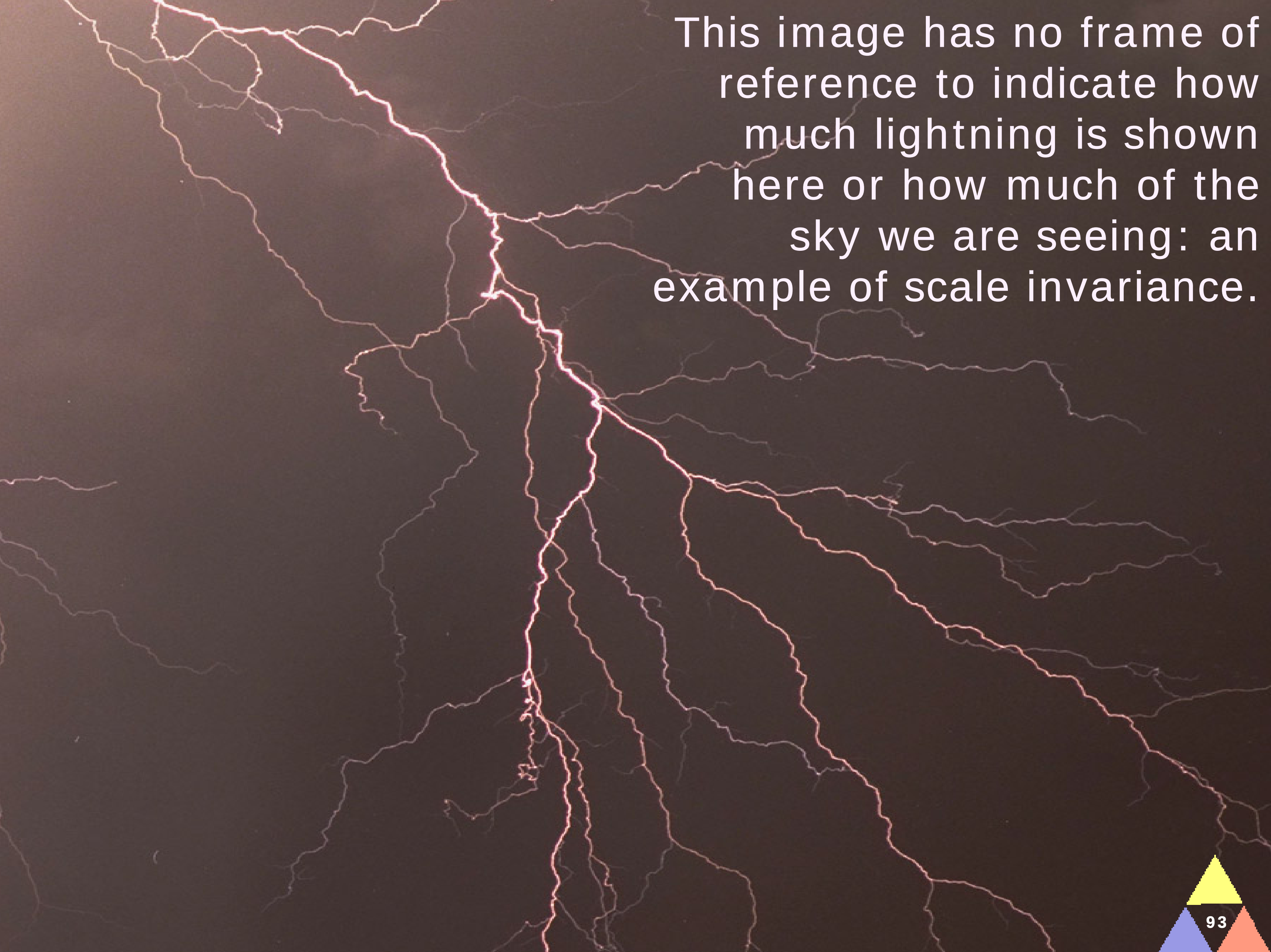
The cones reveal substructure. They have a limited amount of fractal structure in that a cone contains many bracts, i.e. shows similarity, but only between a pair of levels.


This is an extreme example of how, in nature, there are usually only a handful of sublevels. In this case there is only one level of substructure.

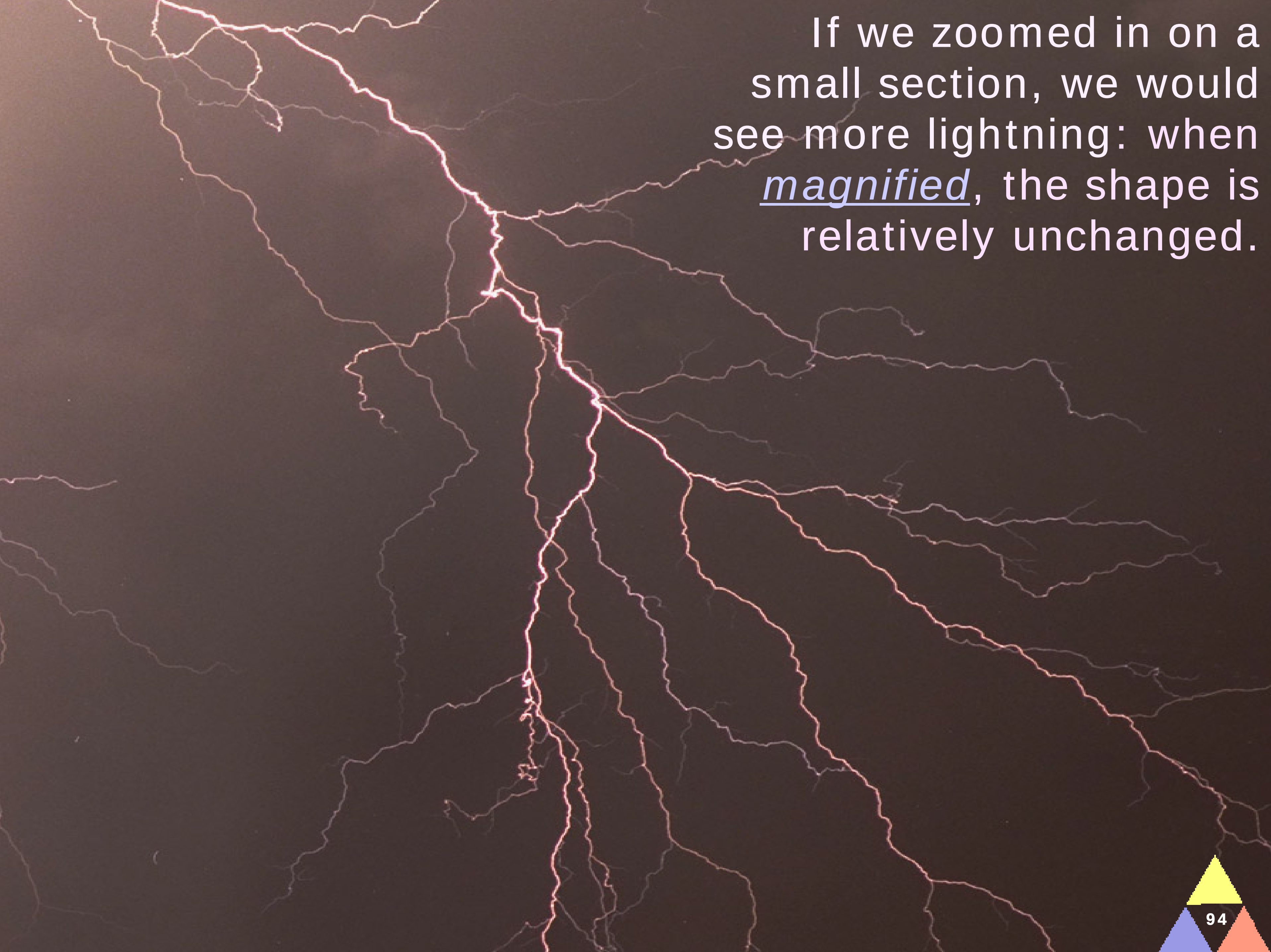
Lightning

Photo taken by Peter Ledlie
http://members.aol.com/PSLedlie/myphotos.htm


notice the beautiful
fractal branching


This image has no frame of reference to indicate how much lightning is shown here or how much of the sky we are seeing: an example of scale invariance.

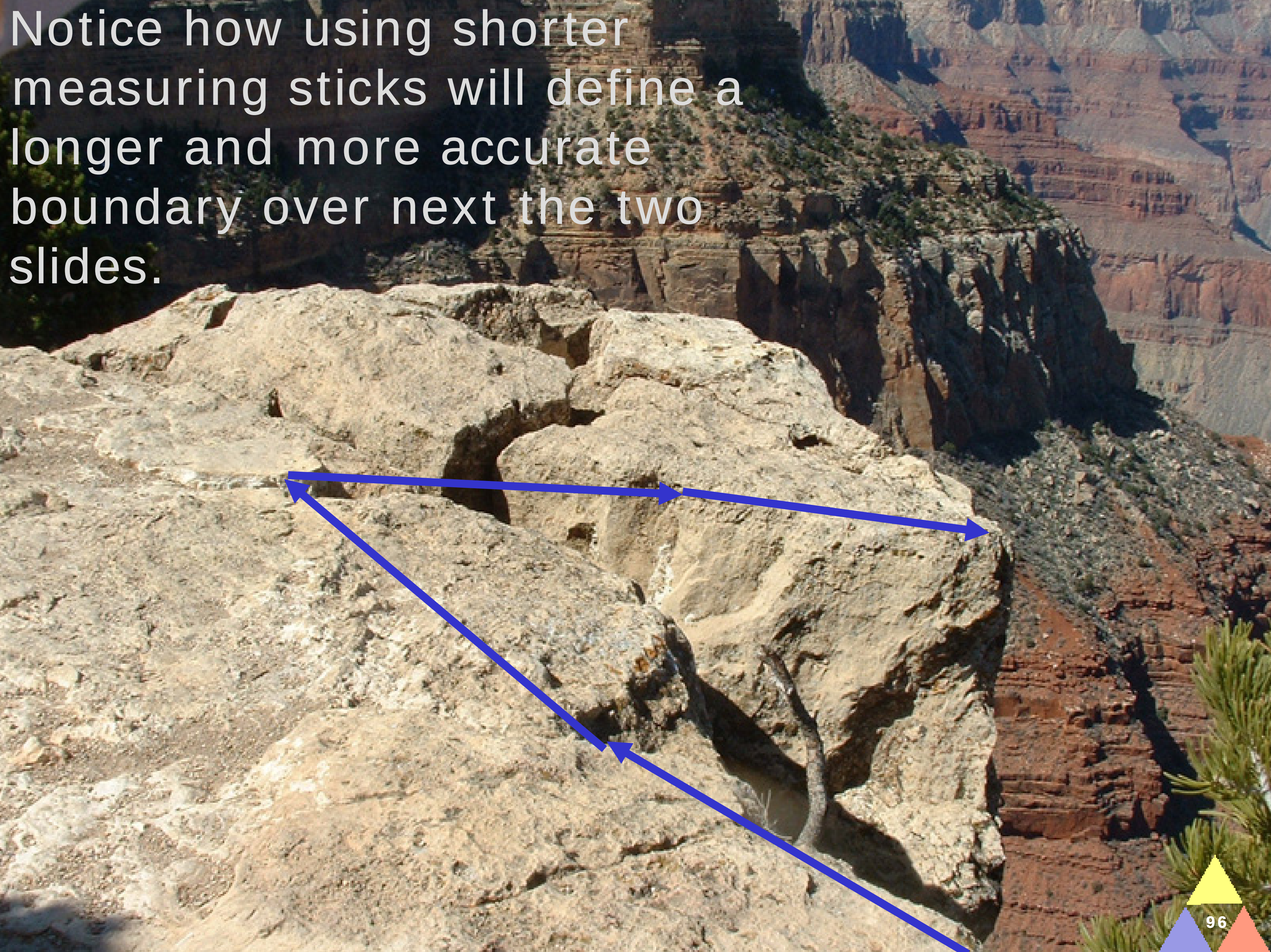
If we zoomed in on a small section, we would see more lightning: when *magnified*, the shape is relatively unchanged.

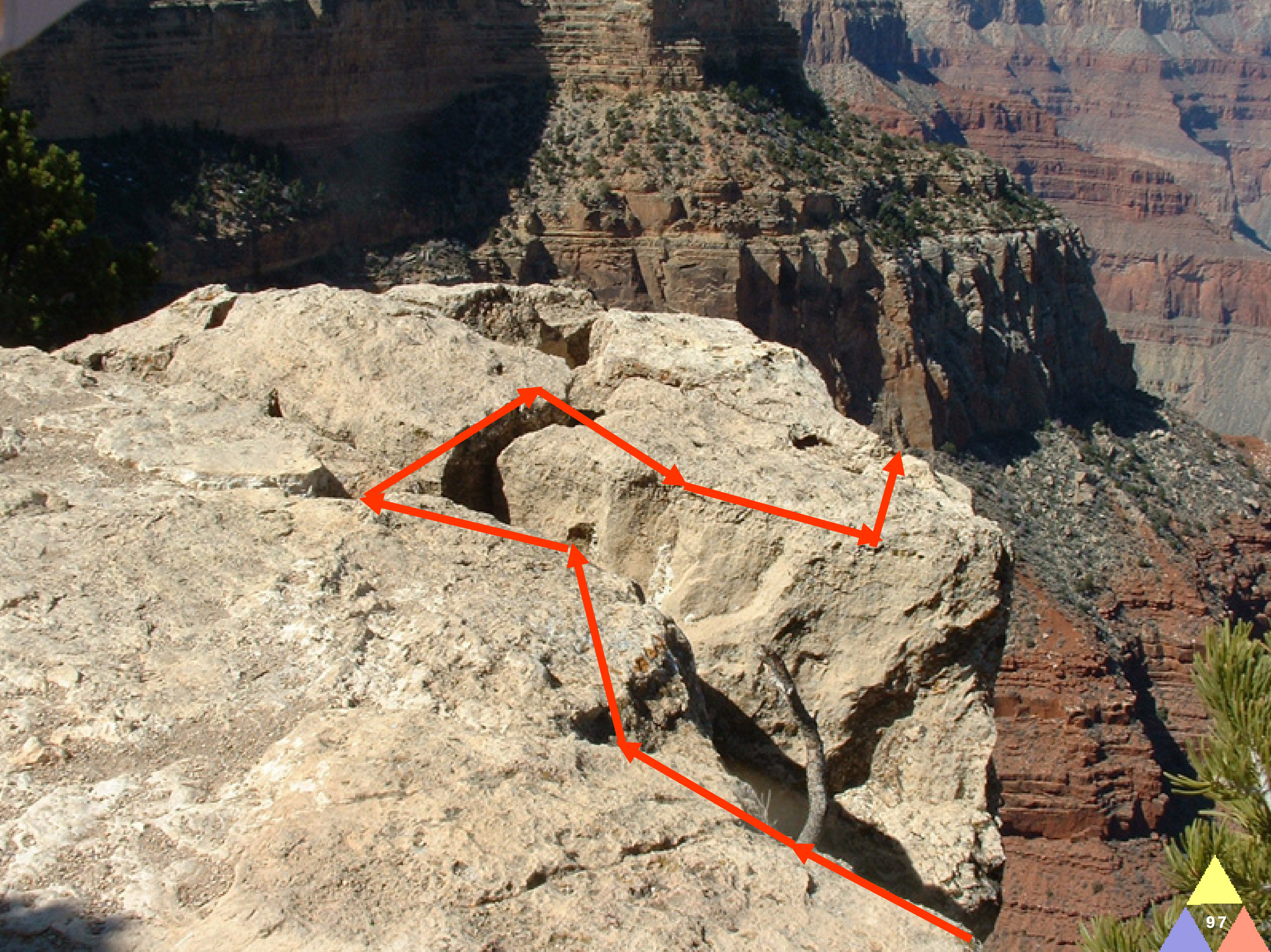


Fractal Boundaries

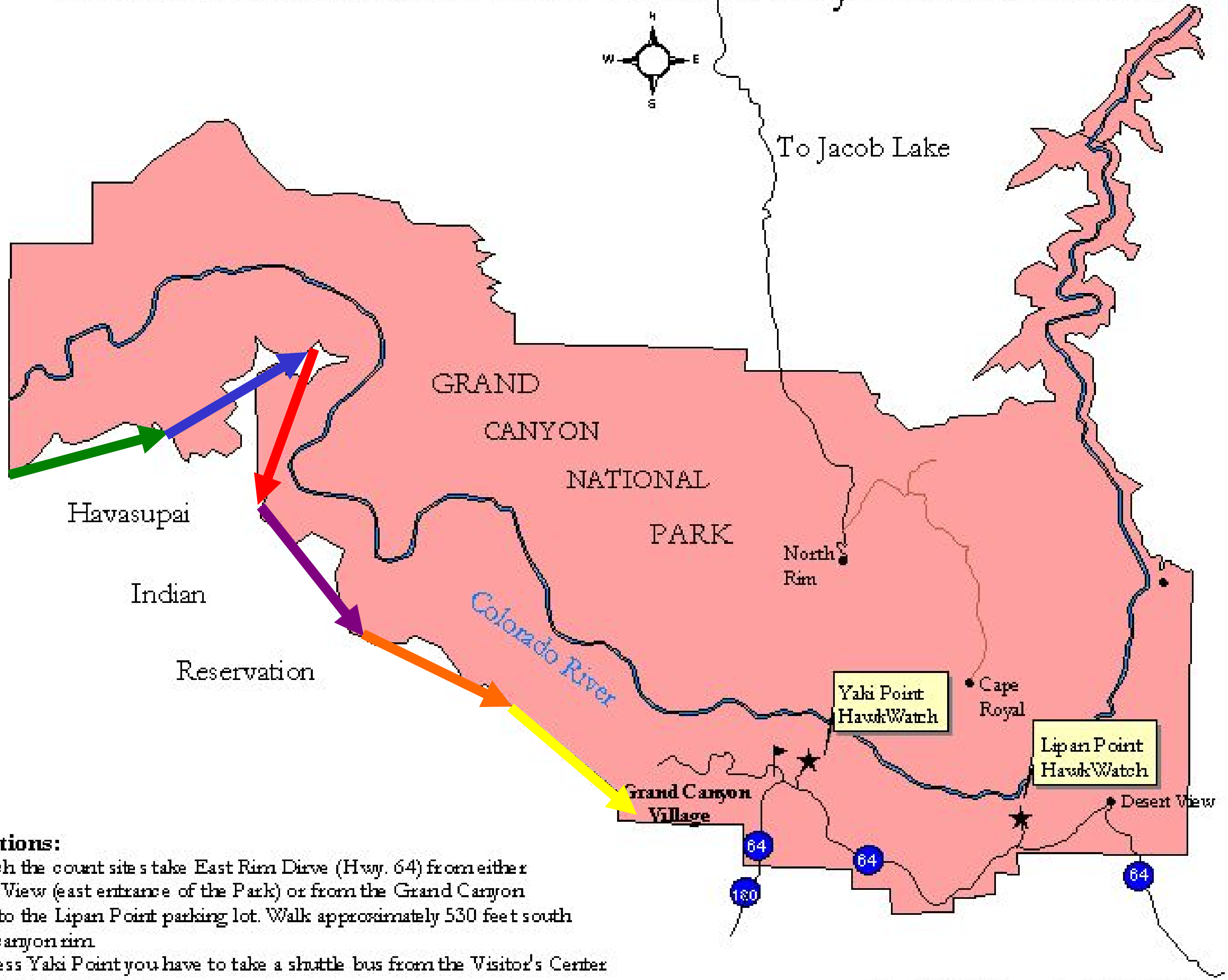
shorter measuring sticks produce longer boundaries

Notice how using shorter measuring sticks will define a longer and more accurate boundary over next the two slides.





HawkWatch International Grand Canyon Research Sites



Directions:

To reach the count sites take East Rim Dirve (Hwy. 64) from either Desert View (east entrance of the Park) or from the Grand Canyon village to the Lipan Point parking lot. Walk approximately 530 feet south to the canyon rim.

To access Yaki Point you have to take a shuttle bus from the Visitor's Center in Grand Canyon village.

Look for HawkWatch educators and observers near the canyon rim at either site.

HawkWatch International 1800 S. West Temple #226
SLC, Utah 84115 801-484-6808 www.hawkwatch.org

Famous problem: How long is the Coast of Britain?

500 km compass setting → 2600 km coastline length
100 km compass setting → 3800 km coastline length
54 km compass setting → 5770 km coastline length
17 km compass setting → 8640 km coastline length
(1 km = 0.621371192 miles)

Peitgen, H.-O., Jurgens, H., Saupe, D., *Chaos and Fractals: New Frontiers of Science,* Springer Verlag, Inc., New York, 1992, 192-198

Smoky Grand Canyon at Hopi Point at Sunset on October 25, 2003.


Shorter units of measure
define a longer coastline.
102

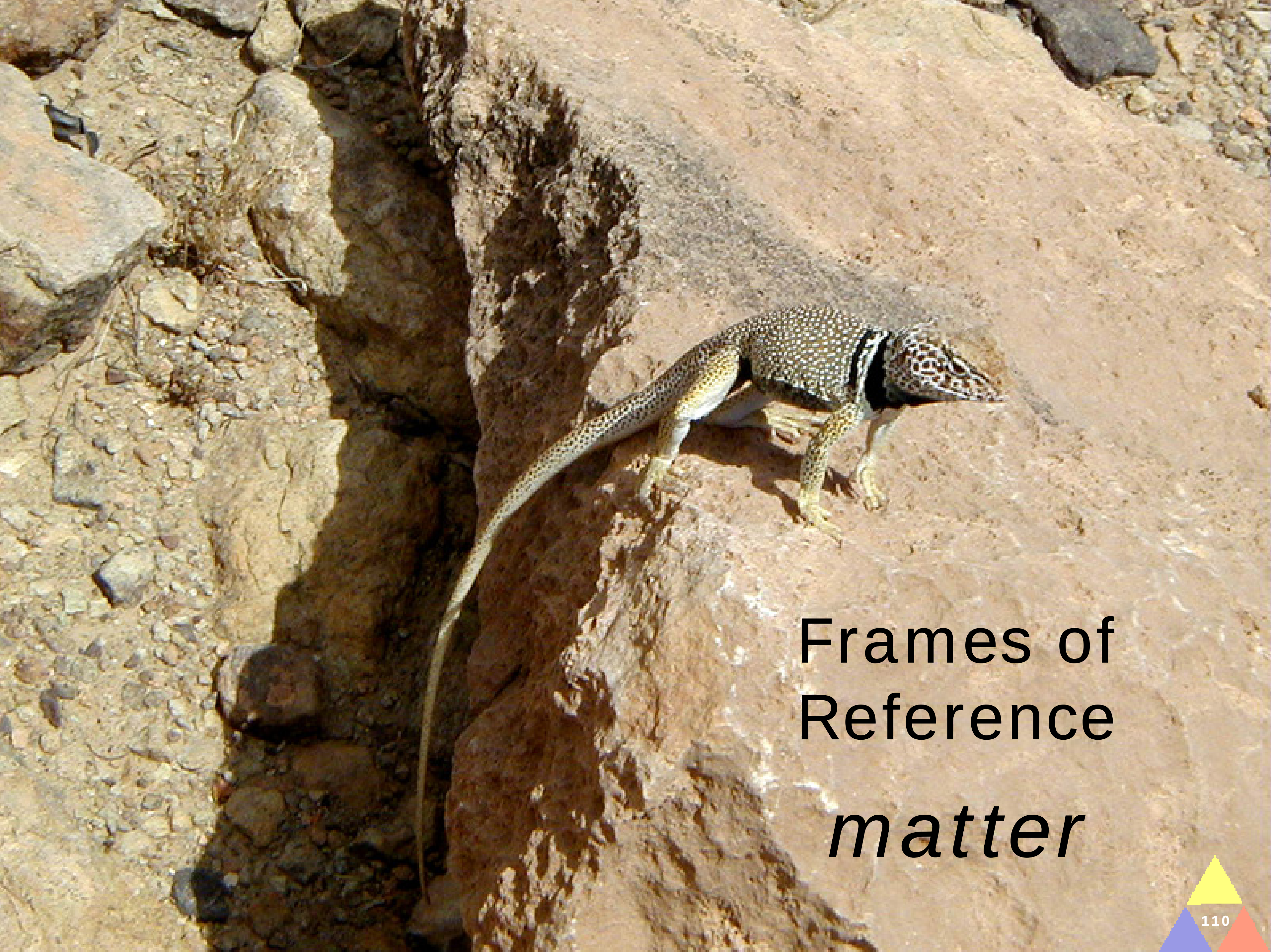

Consider the surface roughness of this tree trunk.
Harry Gensler, a philosopher from John Carroll University in Cleveland, Ohio, took this image and the two upcoming lizard images at the bottom of the Canyon.


The shorter the legs of an insect, the longer the distance around the trunk.


(All the lizard images
are Harry Gensler's.)

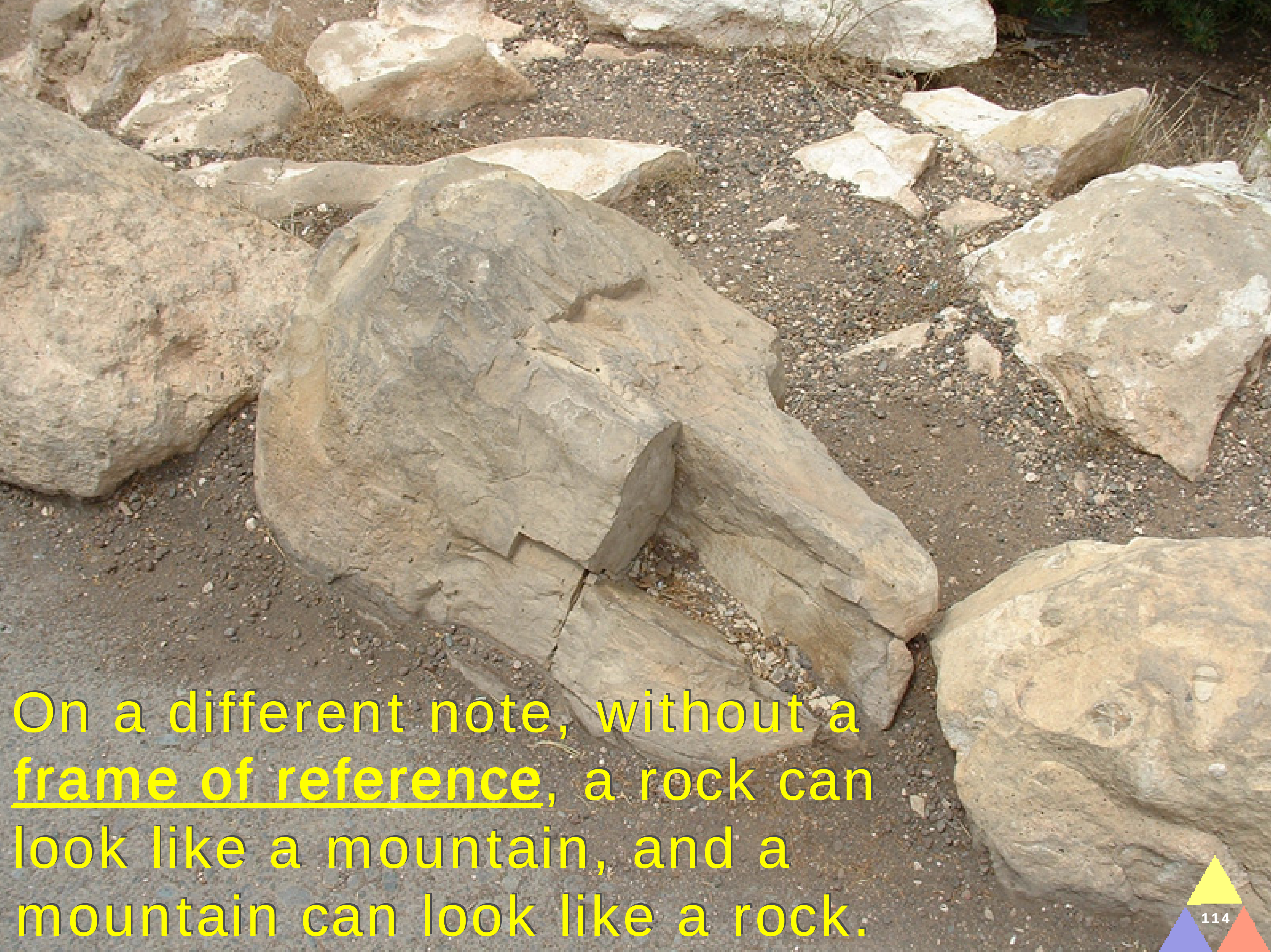
This trunk isn't quite as rough as the last one. It will have a smaller fractal dimension.


(second lizard)


Frames of
Reference
matter


Given an approximate idea of the size of this lizard, we can make a fair determination about the size of the rock.


Look for frames of
reference in this picture
that give a sense about
the size of the rocks.


On a different note, without a
frame of reference, a rock can
look like a mountain, and a
mountain can look like a rock.


Rocks and mountains
are natural fractals.


Also notice the familiar joint
pattern visible in this rock.

Snow

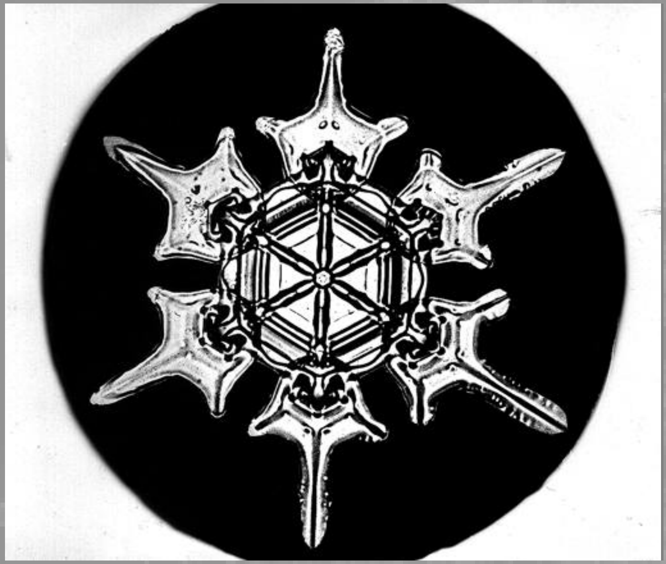

This section will address individual snowflakes.

Snow—An Explanation of the Shape

(ctrl+click to follow link to this page)

Yale Fractals Page

(ctrl+click to follow link to their main page)



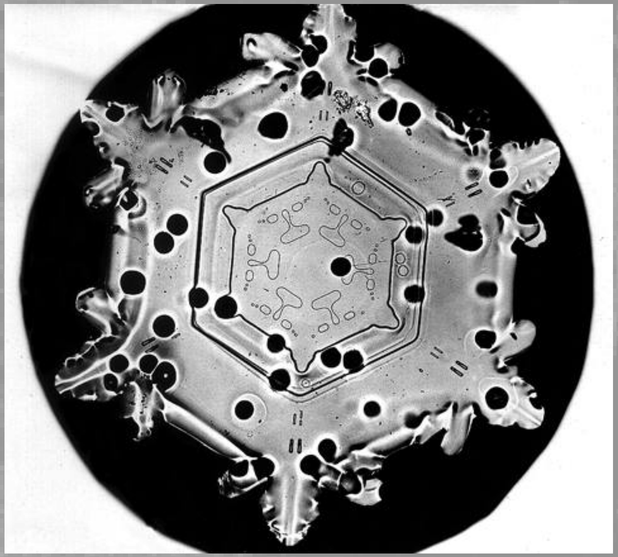
Snowflake images from **Wilson Bentley's** book "Snow Crystals"

From a small seed, tiny bulges form in the six directions preferred by the crystal.

These grow into needle-shaped arms, the arms in turn develop bulges from which side branches grow, the side branches themselves sprout tiny side branches, and so on.

The specific branch thickness and spacing are very sensitive to small changes in *temperature*, *humidity*, and *pressure*.

Since these conditions are almost constant over the size of a snowflake, its six branches grow in a nearly identical fashion.



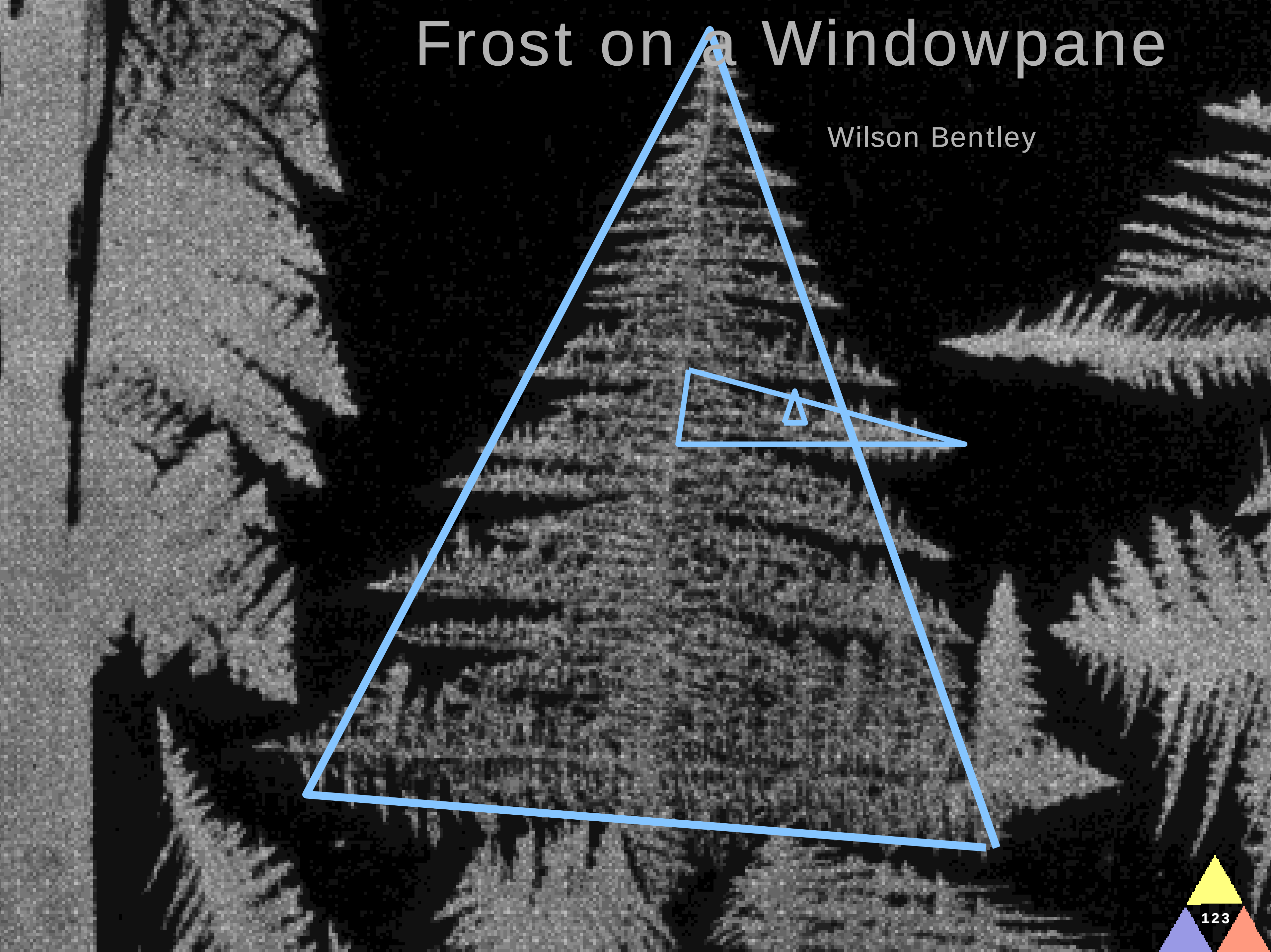
The atmosphere in a snow cloud is turbulent over the scale of meters, so each flake takes a different route through the cloud and encounters different sequences of conditions for its growth.

If we knew how to read it, each snowflake contains a record of the sequence of conditions through which it grew.

(Snowflakes are an instance of a fractal process called DLA--Diffusion Limited Aggregation)

Frost on a Windowpane

Wilson Bentley



Fractal geometry has a heightened presence in Grand Canyon, and it is also present in our everyday lives, wherever we call home.

Learning about fractals hasn't changed trees and clouds, but we can look at them with a greater understanding than before, and there have been resulting leaps in scientific discovery.

Acknowledgments