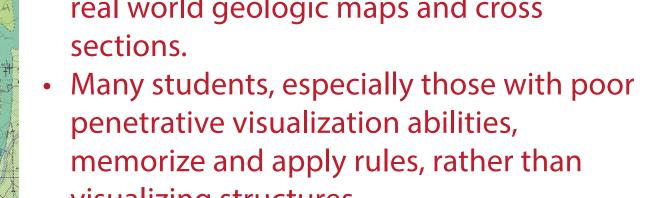


and techniques and, at the same time, translate the block models and 2D diagrams that we typically use in class to real world geologic maps and cross



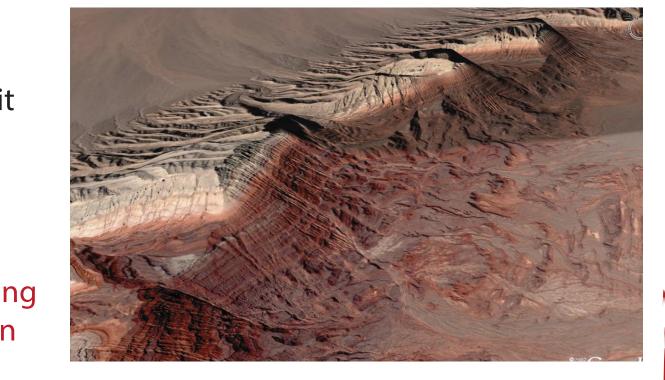


## Google Earth to the rescue



Imagery is high resolution and seamless. It's free, and every student can work with it on his/her own computer.

- Areas with strong color contrast among units already look like geologic maps.
- Google Earth has interactive, 3D terrain "tilt-and-fly" viewing, which is key to helping tudents visualize the connection between nap patterns and structures.

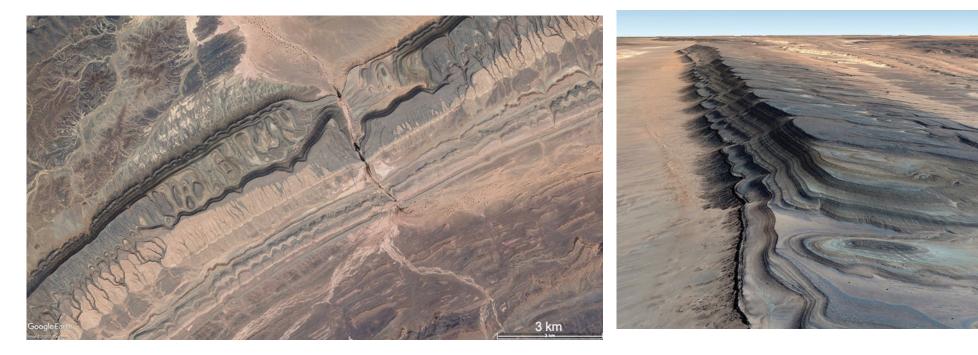


The level of detail in the 3D View is extraordinary

For all activities: it is critically important that each student is "at the wheel" controlling the tilt and viewing angle on his/her own computer. Watching someone else's screen (or the instructor's screen via a data projector) is not the same visualization experience. Also Also – Terrain MUST be turned on in Google Earth!!

## Starting with visualizing dipping contacts

Google Earth has many fabulous areas that can be used to help students visualize that the color bands in both satellite imagery and geologic maps are not just 2D "paint stripes" but are actually tilted and eroded layers that extend below the ground.



Using the tilt and fly through capability of Google Earth, students can see layering and contacts between layers almost as well as if they were in the field.

- Using "dip" and "dipping", rather than "inclined" is critically important. Although we talk about "inclined units", many students visualize inclined as being upward because an incline, is a ramp that slopes upward (i.e., they would describe a contact that dips SE as "inclined to the NW").
- Many students intially have trouble drawing the distinction between the direction that the ground slopes and the direction that contacts dip. Fly-throughs are useful for helping students develop criteria for distinguishing the difference between slopes that are quasi-parallel to contacts (dip slopes) and slopes that cut across contacts.



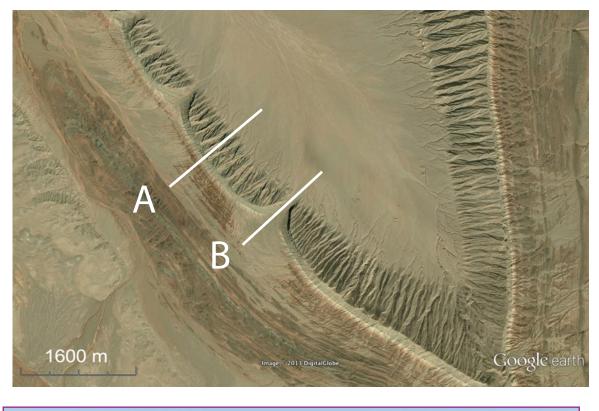
 Fly-throughs are also useful for helping students distinguish the patterns that are characteristic of resistant and non-resistant bedrock units.

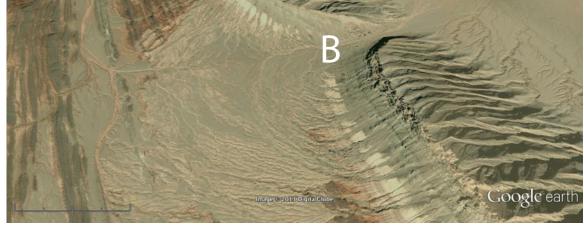
 Fly-throughs also help students work out where rock units "go" (do they just end??) where they intersect surficial deposits, which is critically important for previsualization before tackling a cross

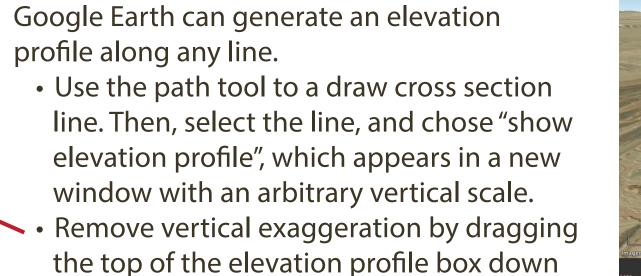
## Cross sections and elevation profiles

Good geologic cross sections show a geologist's interpretation of what lies below ground and what has been eroded away. Good cross sections cannot be constructed purely mechanically by applying rules. Teaching students how to make good cross sections not only requires an understanding of structures but also an ability to previsualize the 3rd dimension before starting a cross section. Tilting and flying through in Google Earth helps students previsualize because they can actually see some of the 3rd dimension.

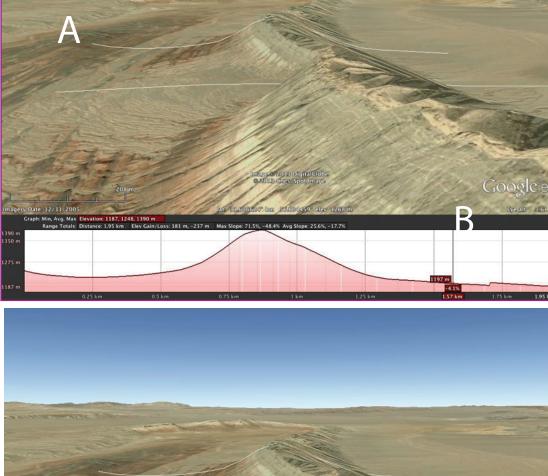
Areas such as the one below are great for having students draw geologic cross sections: units at A and B have similar dip but very different elevation profiles. Students have to work out 1) that the geology in the cross sections is the same, even though the ground surface is quite different and 2) that the layers are actually continuous in the subsurface and are only thinly mantled by surficial deposits (at B below).

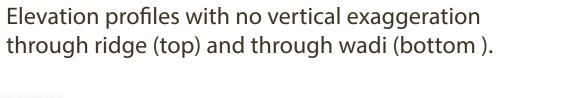


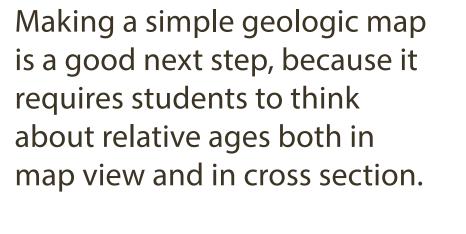


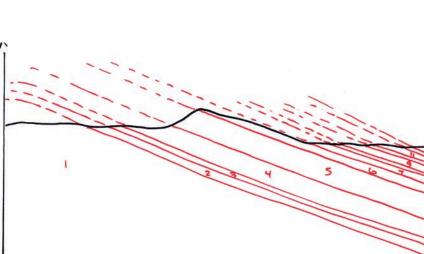


to equalize vertical and horizontal scales.







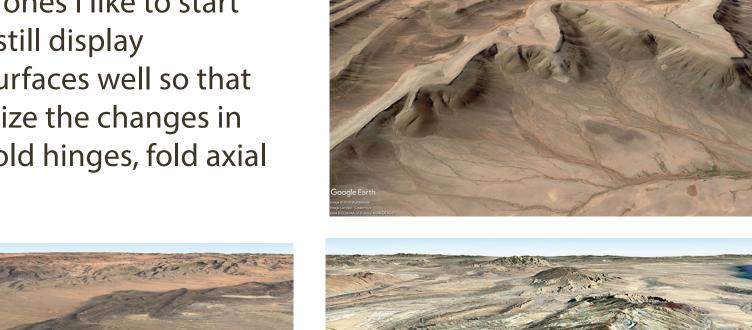


## Visualizing folded contacts and their outcrop traces

Folded contacts are just a special case of dipping contacts, so I have students work with folds and make cross sections before we get to the outcrop patterns of vertical and horizontal contacts. It is also an opportunity to introduce planar vs. non-planar contacts, plus fold terminology and symbology.



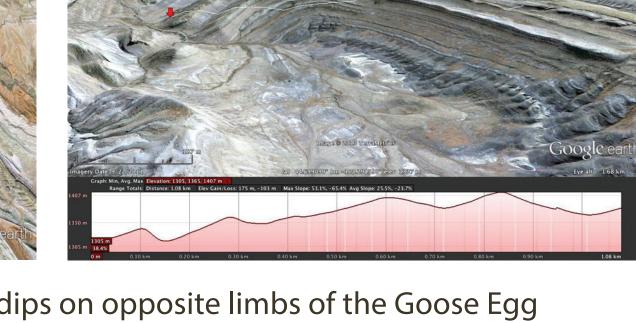
There are lots of fabulous areas for students to have their first experience with folds, but the ones I like to start with are folds that still display ndividual folded surfaces well so that students can visualize the changes in dip direction, the fold hinges, fold axial urface traces, etc.







A fold like the "Goose Egg" NW of the Alkali Anticline in Wyoming is a particularly good type of structure for students to work with because, unlike the folds illustrated above, the Goose Egg is actually *lower* topographically in the core due to erosion. This helps address the misconception that students have topographically higher in the



Students begin by mapping strikes and dips on opposite limbs of the Goose Egg (above) and then fly around the area to work out what the structure is like. Students then fly to a vantage point (look direction shown with red arrow above left) to draw a cross section along a line across the structure (above right).



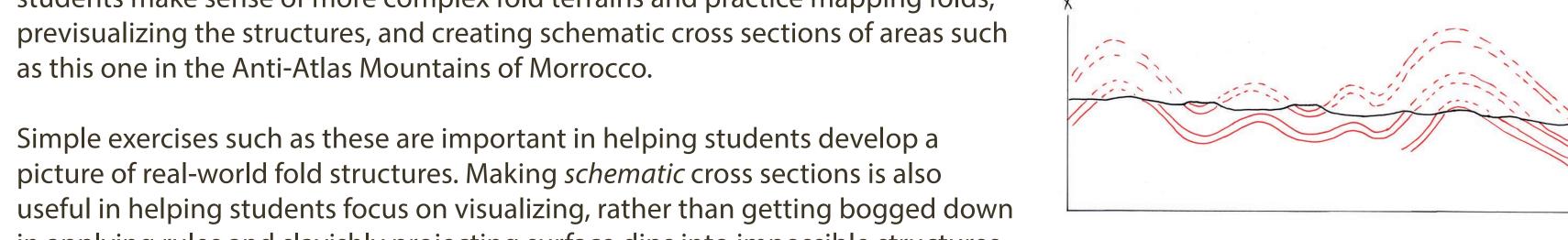
as this one in the Anti-Atlas Mountains of Morrocco.

above and below the ground surface.

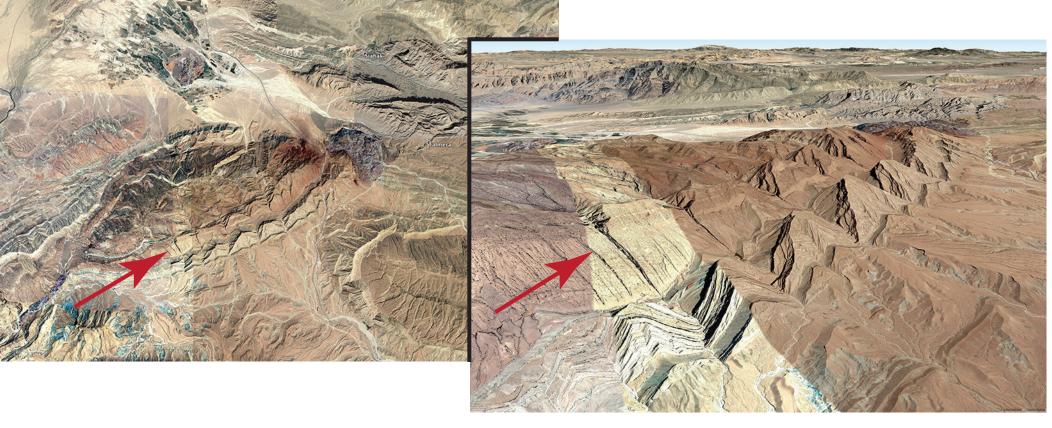
that anticlines are always







## Erosion of dipping layers and visualizing structure contours



The tilt, pan, and rotate features in Google Earth are instrumental in helping

Simple exercises such as these are important in helping students develop a

picture of real-world fold structures. Making schematic cross sections is also

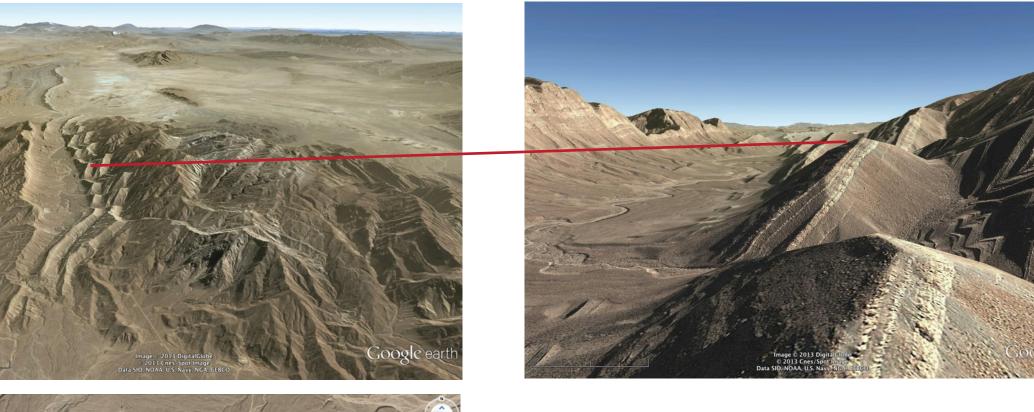
in applying rules and slavishly projecting surface dips into impossible structures

previsualizing the structures, and creating schematic cross sections of areas such

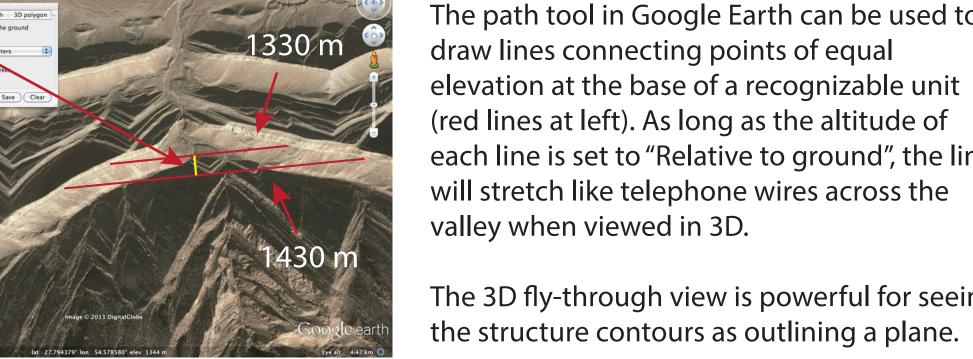
This area at left in the Zagros is fabulous for illustrating the progressive dissection of a dipping

At the SW end of the dipping layer (red arrow), the layer is nearly continuous along strike and is dissected only by slot canyons eroded parallel to a prominent joint set. Although more extensive erosion along the ridge to the NE has produced flatirons instead of slot canyons, it is easy to see the progression, and the evolution from a once-continuous layer is easy to visualize.

Once students have a good visual grasp of dipping units and contacts, they explore the north flank of a spectacular whaleback anticline near Kourdeh, Iran (below). Students use what they have learned about erosion of dipping layers to visualize structure contours. NOTE: It turns out that the local relief in the area I've shown below combines perfectly with the resolution of the elevation model in Google Earth to make this visualization of structure contours. This does not work well everywhere.



As long as vertical exaggeration is set to 1 in Google Earth Preferences (Tools, PC), students can tilt the view to very low angle, look along the row of flatirons, and use a protractor to estimate dip angle. In the row of flatirons at left, the measured dip is about 40°.



The path tool in Google Earth can be used to draw lines connecting points of equal elevation at the base of a recognizable unit (red lines at left). As long as the altitude of each line is set to "Relative to ground", the lines will stretch like telephone wires across the valley when viewed in 3D. The 3D fly-through view is powerful for seeing



Students then use trig to calculate the dip of the "filled in" surface, using the measure tool to get the perpendicular map distance between any two structure contours (above left). For this example, the calculated dip is about 40°, which nicely matches the dip amount that students measured with a protractor in "fly-through" view.

# Using Google Earth for More Effectively

# Hamilton Teaching Undergraduate Structural Geology

Barbara J. Tewksbury, Hamilton College, Clinton, NY, USA

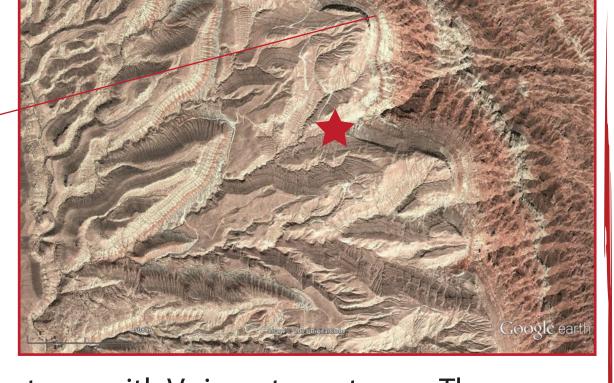


## Generating the "Rule of Vs"

At this point, students have seen enough that they can generate the Rule of Vs entirely on their own.

In fact, at some point prior to this, at least a couple students in the class will have noticed that it's possible to tell the way a contact dips by the pattern that the outcrop trace makes when the contact is eroded and that you don't need to have a 3D model in Google Earth to help you.





Students typically confuse Vs in topo contours with Vs in outcrop traces. The area at right is an excellent place to have students see that the Vs in the outcrop traces point downstream SW of the star and upstream NE of the star, even though the dip direction remains consistently SW.

## Vertical and horizontal contacts and their outcrop traces

The outcrop pattern of vertical contacts is just a special case of the outcrop pattern of dipping contacts. Although it seems backwards to start with the harder concept of dipping contacts, students seem to benefit from spending more time on dipping contacts first. Then, using Google Earth, they breeze through vertical and horizontal contacts and their outcrop patterns.



Vertical dikes radiating from the Spanis Peaks in Colorado are outstanding for visualizing vertical contacts.

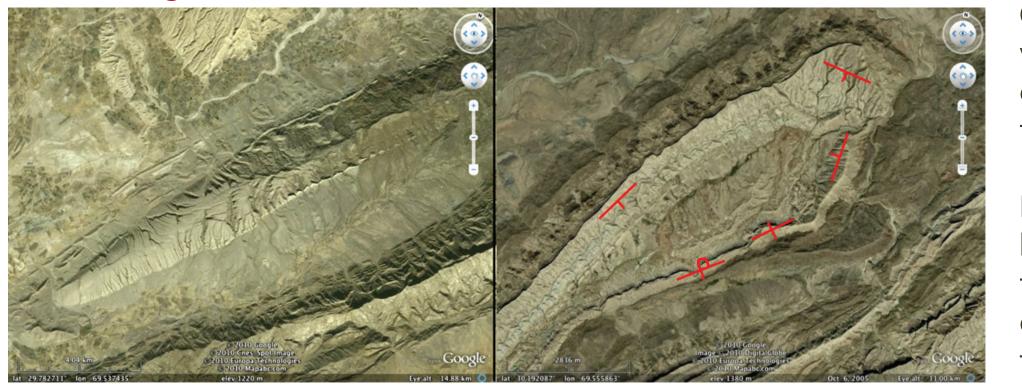


pattern shows up beautifully in Google Earth (above center).



is, in fact, eroded but maintains a straight line outcrop pattern because the contacts eroded directly away from the viewer in map view.

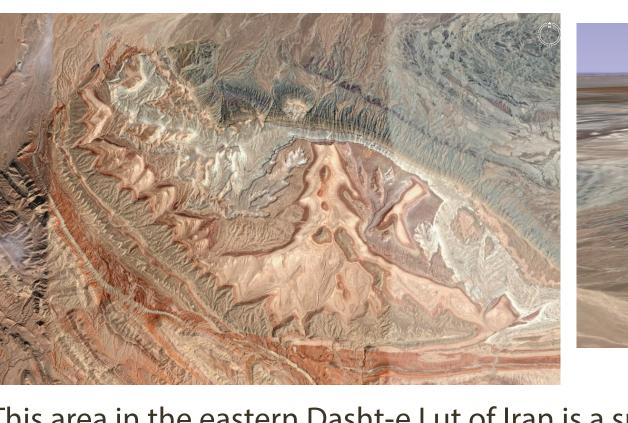
### Visualizing overturned folds

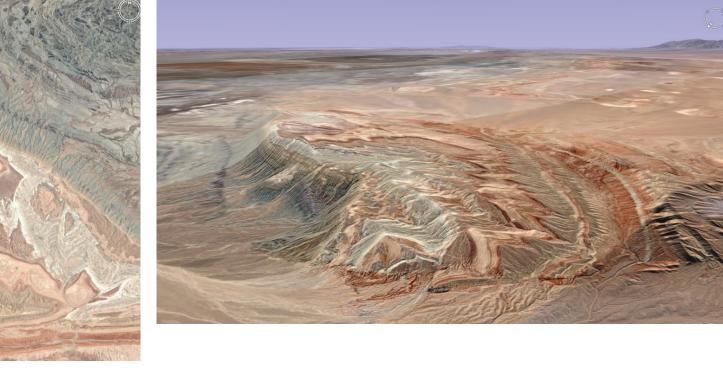


Once students are able to recognize the outcrop patterns of vertical contacts, they can tackle overturned folds and contrast the patterns of dips in an upright fold (far left) with those in an overturned fold (near left).

Flying in Google Earth around the overturned syncline, near left, in the Suleiman Fold Belt in Pakistan, allows students to trace the NW right-side-up limb as it wraps around the nose of the fold, rolls through vertical, and flips upside down to form the SE limb of the fold.

### Once students have a good visual grasp of dipping and vertical contacts, horizontal contacts are simple.





The US Geological Survey has developed

an online map interface for USGS maps

that date back to the 19<sup>th</sup> century. Maps

are available as high resolution .tifs and,

quickly in Google Earth because they

have been pyramided. The map interface

for many maps, kmz files that load

is shown at right, and the URL can be

accessed using the QR code at left

Flying through the terrain in

topography in the area. Look

direction is shown by the red

Google Earth reveals the

arrow at left.

This area in the eastern Dasht-e Lut of Iran is a spectacular area for students to explore the transition between dipping contacts and horizontal contacts. The area also illustrates that dipping contacts have straight-line outcrop patterns where there is no topographic relief along the outcrop trace.

USGS Geologic maps and Google Earth

The National Geologic Map

veloping a distributed archive of standard

geoscience information for the nation

The Google Earth image above shows

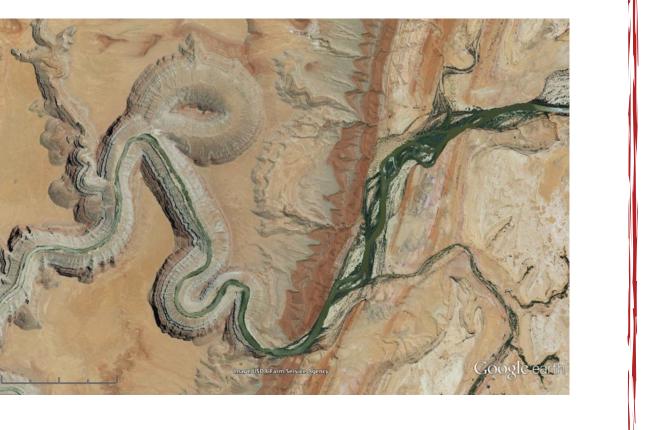
the footprint of a kmz overlay for the

Series geologic maps for the Castle

Miscellaneous Investigation (MI)

Reef and Sawtooth Mountain,

Montana 7.5' quadrangles.



The area of the Comb Ridge monocline and the San Juan River Canyon to the west in Utah (right) is another wonderful area for students to explore the change in outcrop pattern as contacts transition from ESE-dipping in the monocline to horizontal in the canyon region.

The fabulous thing about the kmz map overlay in

Google Earth is that it drapes over topography. This

allows students to visualize the correlation between

the bedrock geology and the topography to help them

interpret the map patterns of contacts and the relative

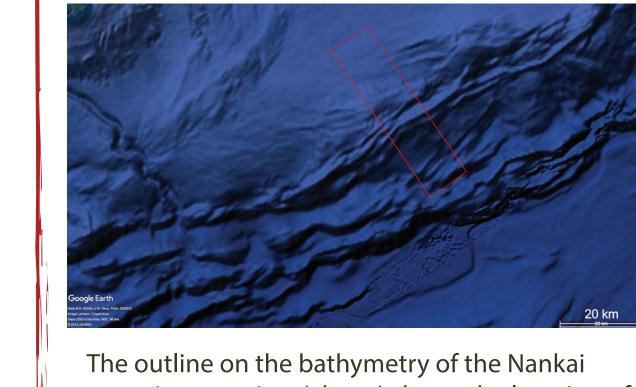
resistance of different rock units and to assess, in 3D,

why the same sequence of units is repeated.

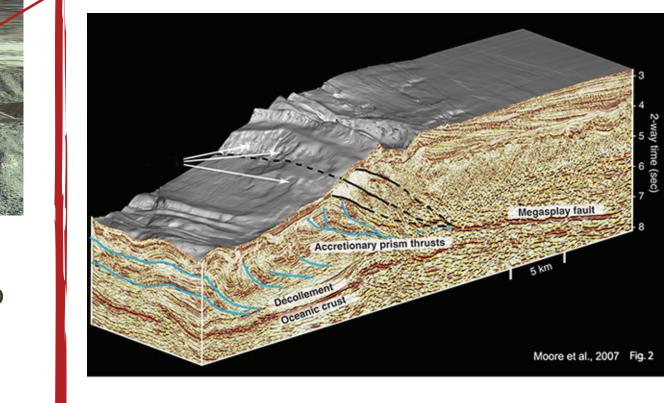
## Google Earth and submarine structures

structures can show up beautifully in Google Earth. 1 see them well, be sure to turn off "Water Surface"!

The Google Earth image at right shows the trenches at the convergent plate boundaries where the Pacific and Philippine plates are



accretionary prism (above) shows the location of the 3D seismic survey shown below.



accretionary prism (left) matches

Additional data sets, such as this 3D

seismic survey, can help students

visualize the connection between

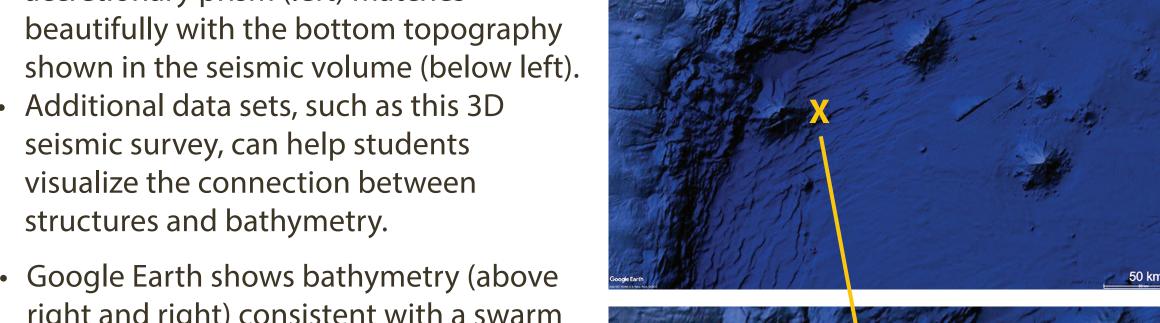
Kuril trenches, and bathymetry

south of the bend.

structures and bathymetry.

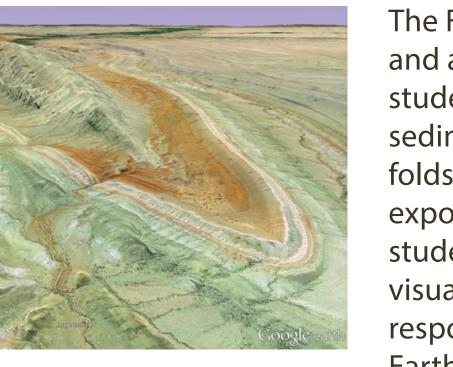


Google Earth bathymetry of the Nankai beautifully with the bottom topography

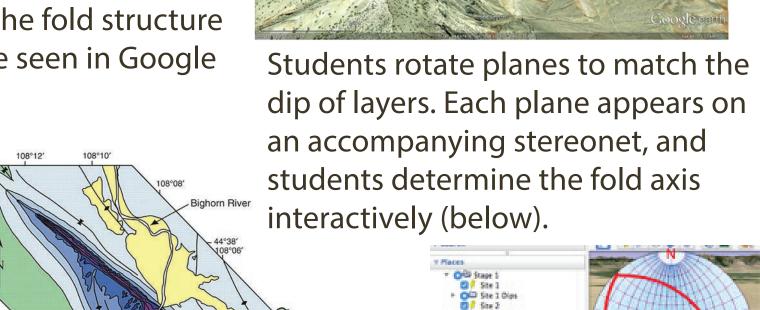




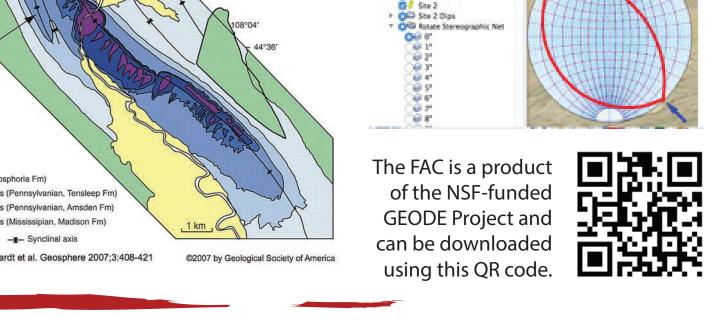
The GEODE Project and the Fold Analysis Challenge (FAC)



and a customized Google Earth interface to help students visualize the orientations of eroded dipping sedimentary layers and visualize the geometries of folds in layered rocks. The FAC uses spectacularly exposed layers at Sheep Mountain, Wyoming and takes students through a variety of activities to help them visualize the shape and orientation of the fold structure responsible for the patterns that can be seen in Google Earth at Sheep Mountain.



Students raise and lower folded surfaces in order to visualize how interaction of the folded surface and topography produces the patterns on the geologic map.



## Insights, surprises, and cautionary tales

Interactive classroom strategies that involve listening to your students, including using Google Earth as described in this poster, are incredbly useful for daylighting and tackling the issues described here that cause students confusion.

When we use terms such as horizontal, vertical, above, below, up, down before, and after, many students aren't visualizing what we expect, because they have different (and deeply ingrained) personal definitions for these words that are at odds with ours. For example:

- When asked to define horizontal and vertical, at least 1/4 of my structural geology students at the beginning of the semester define horizontal as something that is east-west and vertical as something that is north-south. This clearly stands in the way of students visualizing an accurate and meaningful picture of the orientations of structures. This is also a very difficult visual misconception to dislodge even when students have learned to write accurate definitions of the terms.
- Many students also use *horizontal* as a relative term and describe something as horizontal to something else (confusing it with parallel to) or vertical to something (confusing it with perpendicular to).
- Many students use *above* to mean *to the north of* and *below* to mean to the south of
- Many students think of inclined as being upward rather than downward and would describe units that dip to the SE as being inclined to the NW.
- When asked about stratigraphic order, some students will say that "the Cambrian units are after the Ordovician units". Whereas we use *after* in a temporal sense, some students use *after* in a "list" sense - they read a strat column from top down and get to the Cambrian units after the Ordovician ones.

In all of these terminology issues, students know what they mean, but either 1) we misinterpret their answers or 2) they visualize inaccurately when we use terminology because their internal definitions do not match ours.

We also need to remember that students, as novices, do not actually see what we see. The first thing I ask students to do in Google Earth is to fly to a vantage point that shows fabulously exposed dipping layers. I ask students to describe what they see from the vantage point. Only the students who have had a lot of field experience actually see the layers in the bedrock geology that are so obvious to me. The others see only hills, valleys, rivers, and vegetation.

Making sense of patterns (temporal, spatial, geometric) is at the heart of geologic map interpretation and geologic mapping. When I ask students, "What kinds of patterns do you see in this map/area/satellite image?", many students don't know what I mean. It's useful to give students some practice in describing patterns of various kinds (e.g., using fabrics, graphics, etc.) before tackling geologic patterns.

ResearchGate page, where you can download this entire poster plus a kmz file containing placemarks for all the locations on this poster, plus a boatload of other places that show faulous structural features that you can use with your students, including a set that I've used for training incoming NASA astronauts.

Scan this QR code to take you to my