Sandbox Experiments

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Observing, Sketching and Synthesizing

Sometimes there is not much happening at the beginning of the experiment (especially under contraction) but then once things start, a lot happens at once. Once the faults and folds become apparent, students can sketch what they see at every few turns of the crank. These sketches will help them compare the deformation at different times of the fault system development.

After their sketches are completed, you can follow up by asking student to compare early and later sketches from one experiment and also sketches from different experiments. They can also write up their observations into a report of one or two paragraphs. Some questions that the students can consider as they write are:

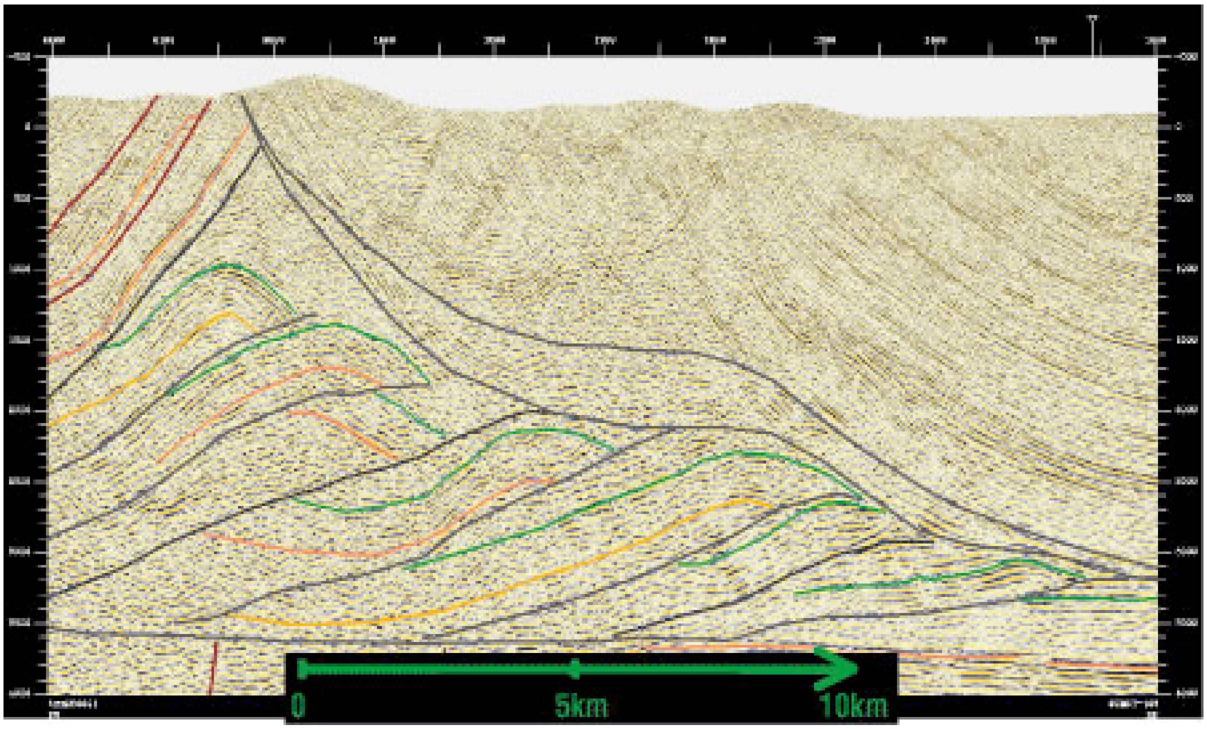
- Do 5 faults form at one time or do they develop one after the other?
- Does the newest fault always develop farthest from the movable wall?
- Did the pattern of fault development look the same under extension as it did under contraction?

This process of observing, sketching and then synthesizing is exactly the process that geologists use all the time in the field and in the laboratory. I recommend that students make their measurements and sketches in a lab notebook. Field-type notebooks are nice but even composition books work great. Then students can compare the new experimental results with previous results.

The Order of Fault Development

On each sketch, I ask students to highlight with red pencil the newest faults in the system. Then students can keep track of where new faults are developing.

Under contraction, the newest faults will form at or in front of the toe of the wedge. This process leaves older faults abandoned within the body of the wedge. Within the seismic line below of a South American fold and thrust belt (taken from AAPG Explorer May2004) the youngest faults are at the right and the older faults are at the left. The old ones have been rotated and steepened by slip on the younger faults. These old faults are no longer active. The sandbox wedge show similar pattern of old fault abandoned and new fault development in front of the wedge. This is sometimes called ‘piggy-back’ thrusting because the old thrust rides piggy-back on the newer faults.



Sometimes a backthrust can be observed within the contractional systems. If your glass window is clean and slippery you might see a fault develop in the back part of the wedge that dip towards the front of the wedge, this is a backthrust. Geologists often observe backthrusts in mountain belts.

In extension, the fault system behaves quite differently. Instead of one active fault at a time, the model simultaneously develops many small faults. These small faults can often be best observed with the aid of low angle lighting. The largest faults usually develop at the far edges of the rubber sheet. This is similar to the basin and range province where the largest normal faults are along the Sierra Nevada in California and along the Wasatch Mountains in Utah. All the normal faults within Nevada are smaller than those two. For extensional experiments, I find it most useful for students to sketch the faults in map view. Unless the glass is very slippery, normal faults can be quite difficult to see in the window. This happens because while stretching, the rubber at the base of the sand pack is also necking in the orthogonal direction. Therefore, the sand is no longer constrained at the window panel and starts flowing at the glass interface, spoiling the geometry of growing faults.

Measuring Fault Geometry

The orientation of geologic faults is described by taking two measurements, the ‘strike’ of the faults, which describes their trend/orientation, and the ‘dip’ of the faults, which describes their attitude. In sandbox experiments the strike of the faults will parallel the moveable wall. This won’t change under extension or contraction. The dip of the faults (i.e. how steep or shallow the faults are) will change with different extensional or contractional loading conditions (see also Ups and Downs of the Earth file downloadable at: http://www.geo.umass.edu/structure/cooke/FSE-SOARhigh/AnalogModels/AnalogModels.html).

At each stage where students are making a sketch the students can use a protractor to measure the angle between the horizontal and the fault planes. Vertical faults have a dip of 90˚ and horizontal faults have a dip of 0˚. You can ask students if each of the newest faults at each stage has the same dip. Does the dip of the old faults stay the same or do these faults rotate a bit during the deformation?

A nice comparison is the dip of faults under contraction and the dip of faults created under extension. Faults created under contraction usually form with dips around 30˚ whereas fault under extension form at 60˚ dips. This might vary a little but this finding should be consistent in all of your experiments. Does this mean that physics of fault formation are different under contraction and extension? Not at all!

The physics of fault formation are that the faults form at around 30˚ from the direction of maximum compression in sand. Under contraction, the maximum compression is horizontal so that faults dip 30˚. Under extension, the sand is in tension along the horizontal direction so the faults do not form with 30˚ dip; instead they form 60˚ from the maximum tension. The maximum tension is perpendicular to the maximum compression (30˚ + 60˚ = 90˚).

The problem with doing this comparison of contraction and extension is that as the rubber sheet stretches, it necks inward from the sides of the experiment and so extensional faults are not well exposed at the sides of the sandbox. One way around this is to run extensional experiments with just a base plate and no rubber sheet; the deformation will be much more localized but faults will show up along the sides.

In nature, we general observe that thrust faults, which form under contraction, are shallow dips and normal faults, which form under extension, have steep dips. However, exceptions to this trend arise all the time when a region is extended or contracted that already has pre-existing faults.

Reactivation of Pre-existing Faults

The Big Horn basin of Wyoming is an area where old Precambrian normal faults were reactivated during contraction of the Laramide Orogeny. The mountains are uplifted along steep thrust faults (steep thrust faults are also called reverse faults, see figure next page).

Students can introduce pre-existing faults into the model prior to deforming the sandbox. The faults may be introduced by cutting into the sand with a knife or thin metal sheet. The knife or metal sheet pushes the sand grains aside and creates a zone of dilation, the sand is looser in that area where the fault was cut. Because the sand is not so tightly packed there, this is a region of weakness that could slip upon deformation.

Sheep Mountain Anticline. A fold overlying a reverse fault within the Big Horn basin.

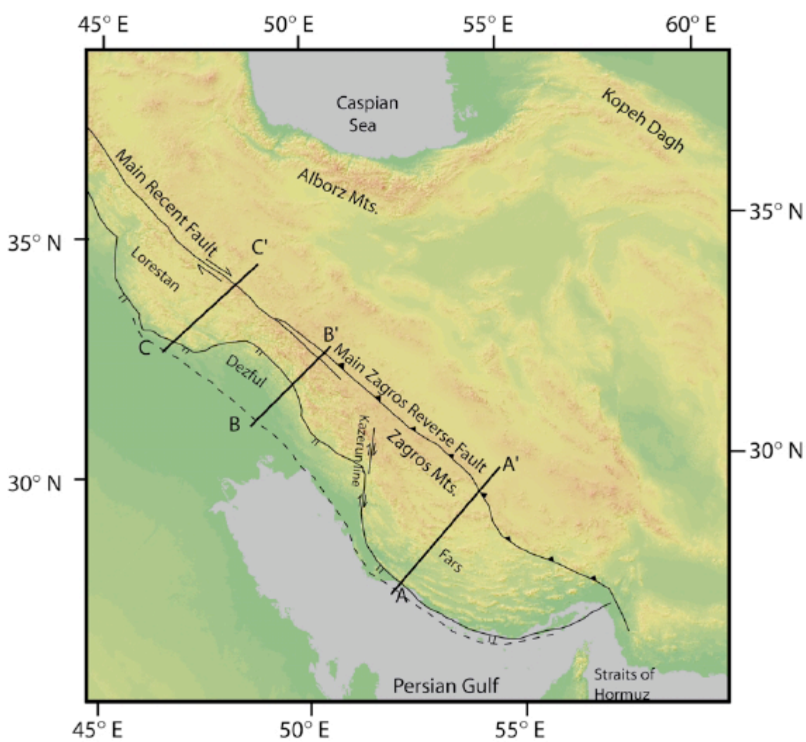
Students can explore a variety of topics related to faults being favorably or unfavorably oriented for slip. What happens if you cut a fault that is at angle to the direction of extension, will this fault slip or a new fault form that is perpendicular to the extension direction? Does the same thing happen in contraction? The same questions can be asked if a fault is cut that is steeper or shallower than the favored direction.

Note: Introducing faults in this way within sand only creates a slight preference for reactivation along the created fault because the sand grains compact due to gravity and easily ‘erase’ the fault. Within the Earth, an existing fault often provides a significantly easier way to accommodate deformation than creating a new fault. At UMass we are exploring these issues with experiments in wet clay. Within clay, the faults reactivate more readily.

Measuring Wedge Height and Length under Contraction

Another interesting measurement is the ratio of contraction wedge height to length. During contraction, the wedge will grow in height and also grow in length. As long as the friction of the bottom of the sandbox is uniform and no erosion takes place (see Mountain Building and Erosion exercise description downloadable from http://www.geo.umass.edu/structure/cooke/FSE-SOARhigh/AnalogModels/AnalogModels.html), the ratio of height to length will stay the same. The wedge grows in equilibrium with the frictional forces along the base of the sandbox.

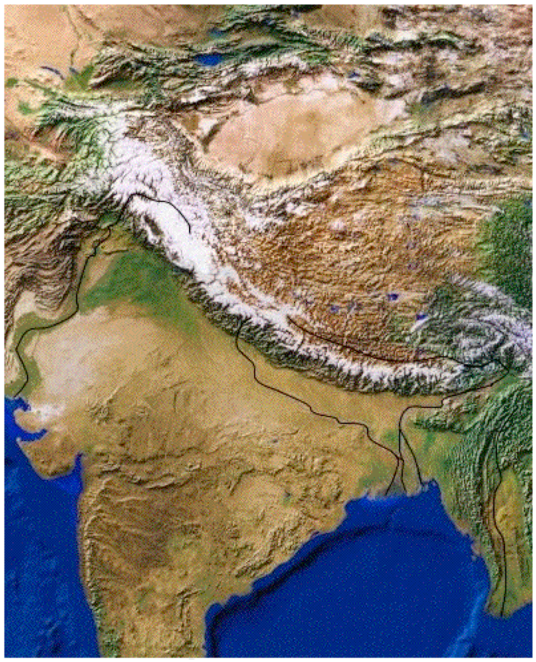
An interesting experiment is to set up half of the sandbox with regular wood under the sliding metal plate and the other half with sandpaper. The higher friction of the sandpaper will produce a higher and shorter wedge than the normal wood base of the sandbox. This can lead students to think about how different rock layers present in the world might influence deformation. In the figure below the front of the thrust belt is not straight and is quite sinuous. The rocks in the region where the thrust belt jumps way out in front are sliding along a layer of rock salt, which is a very weak type of rock. The salt has low friction and so the leading thrust fault slides far from the back of the wedge producing a low ratio of wedge height: length.



(from McQuarrie, 2004)

Indentor

Rather than straight, many mountain belts have large curves along their fronts (see front of the Himalayas below). This can be due to different slipperiness of underlying rocks and it can also be due to the shape of the tectonic front. This can be simulated within the sandbox by introduce a rigid ' indentor' along the moveable wall, which contracts the sand in a non-uniform way.



Students can develop ideas for the patterns they expect to see with differently shaped indentors. How far from the indentor will the deformation mimic the shape of the indentor?

Seismic hazards

If you set up monopoly houses on the surface of the sandbox prior to the experiment students can explore the ideas of the vulnerability of structures to ground rupture and deformation (see also Why do faults matter and Seismic hazards downloadable at: http://www.geo.umass.edu/structure/cooke/FSE-SOARhigh/AnalogModels/AnalogModels.html).

Data Collection

Collect measurements every 10 turns of the crank. Make cross-sectional sketches in notebooks every 20 turns of the crank. Make map sketches at 40 turns and at the end of the experiment. You may want to end at 60 turns and not go all the way to 80.

Annotate your sketches to show where you see the faults and folds. Using colored pencils can help delineate the different features that you see.

The following chart shows how students can organize information within their lab notebooks.

Contraction information set up

Turns of the crank	cm of movable wall disp.	Max. Wedge Thickness	Length of the Wedge	Number of faults	Dip of youngest fault	Dip of the fault that was youngest at previous sketch
10			0	0	-----------	-------------
20						-------------
30						
40						
50						
60						
70						
80						

For experiments with one side high friction and one side low friction I use the following chart.

		HIGH FRICTION SIDE (sandpaper base)		LOW FRICTION SIDE (wood base)	
Turns of the crank	Displacement (cm)	Max Wedge Thickness (cm)	Wedge Length (cm)	Max Wedge Thickness (cm)	Wedge Length (cm)

Here are some questions that I ask my students to explore for contraction
Turn in the measurements and sketches that you made in lab.

1. Graph the following versus cm of moveable wall displacement
    a. The number of faults
    b. Maximum thickness and length of the wedge

2. Is the wedge deformation constant in time? Why or Why not?

3. Where do the new faults develop? In an active mountain belt like the Andes, where would you expect the youngest and most active faults?

4. Using your last map-view sketch, develop a landuse plan for the region that will mitigate the vulnerability of the region to future active deformation.

    a. What areas are most likely to experience future deformation?

    b. Where should the nuclear power plant go? Where could soccer fields go? Hospitals? Residential communities? Downtown?

For extension with a rubber sheet at the base, the faults will not be visible in cross-section and students will recognize them by seeing the ‘bumps’ developing on the surface. Take measurements every 5 turns and sketch map views in your notebook every 10 turns of the crank.

Extension information set-up

Turns of the crank	cm of movable wall displacement	Depression depth	Depression width	Number of faults
0		0	0	0
5				
10				
15				
20				
25				
30				
35				
40				

At some point the duct tape will fail and the rubber sheet will ‘scoot’ over ending the experiment. This has happened for us around 30 turns.

Here are some questions that I ask my students to explore for extension

5. Turn in the measurements and sketches that you made in lab.

6. Graph the following versus cm of moveable wall displacement
   a. The number of faults
   b. Maximum thickness and length of the depression

7. Is the deformation constant in time? Why or Why not?

8. Does the pattern of deformation overlying the rubber sheet look more like the extension of the Basin and Range of the US (Nevada) or the extension of the East African rift valley? (use images from the exsension.ppt file) What might this mean about the nature of the deep crust below Nevada?

9. Using your last map-view sketch, develop a landuse plan for the region that will mitigate the vulnerability of the region to future active deformation.

   a. What areas are most likely to experience future deformation?

   b. Where should the nuclear power plant go? Where could soccer fields go? Hospitals? Residential communities? Downtown?