Investigation of Jura Mountain Range Formation
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California Institute of Technology
Summer Research Connection

Source: Jacek Photo

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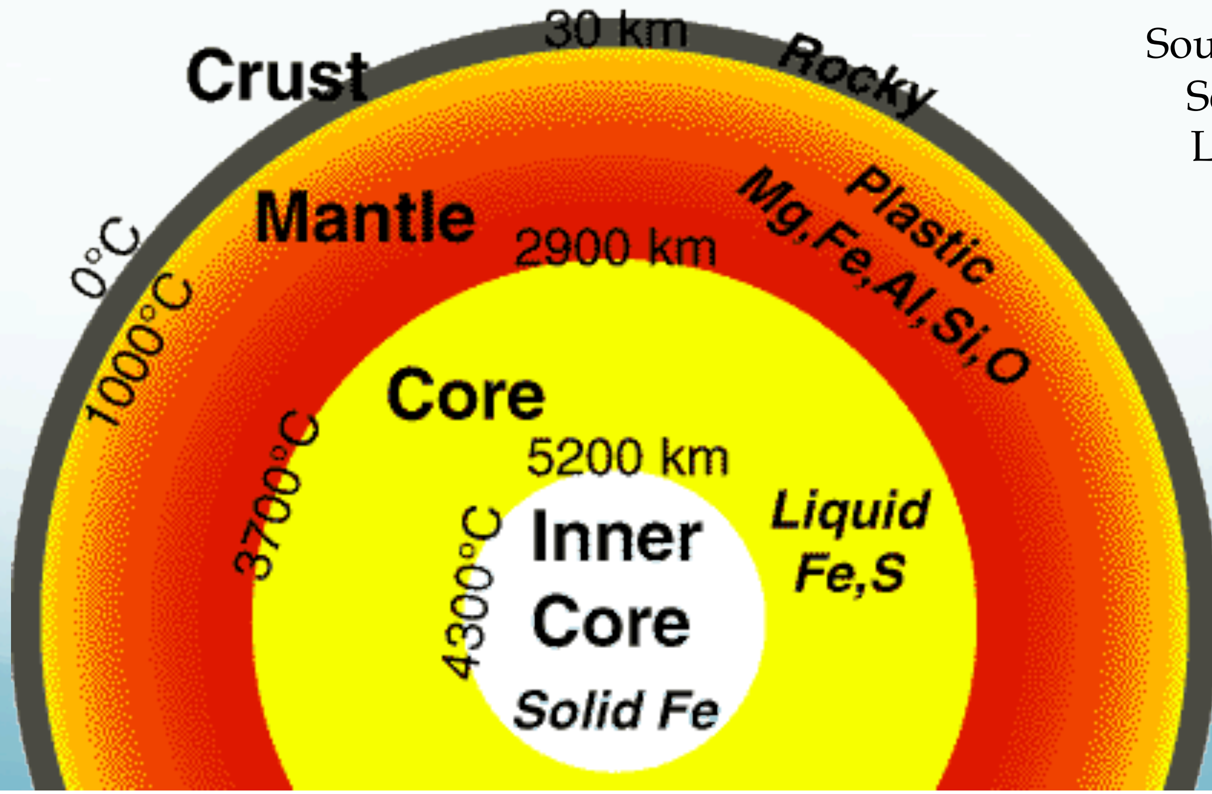
Theory of Plate Tectonics: Introduction

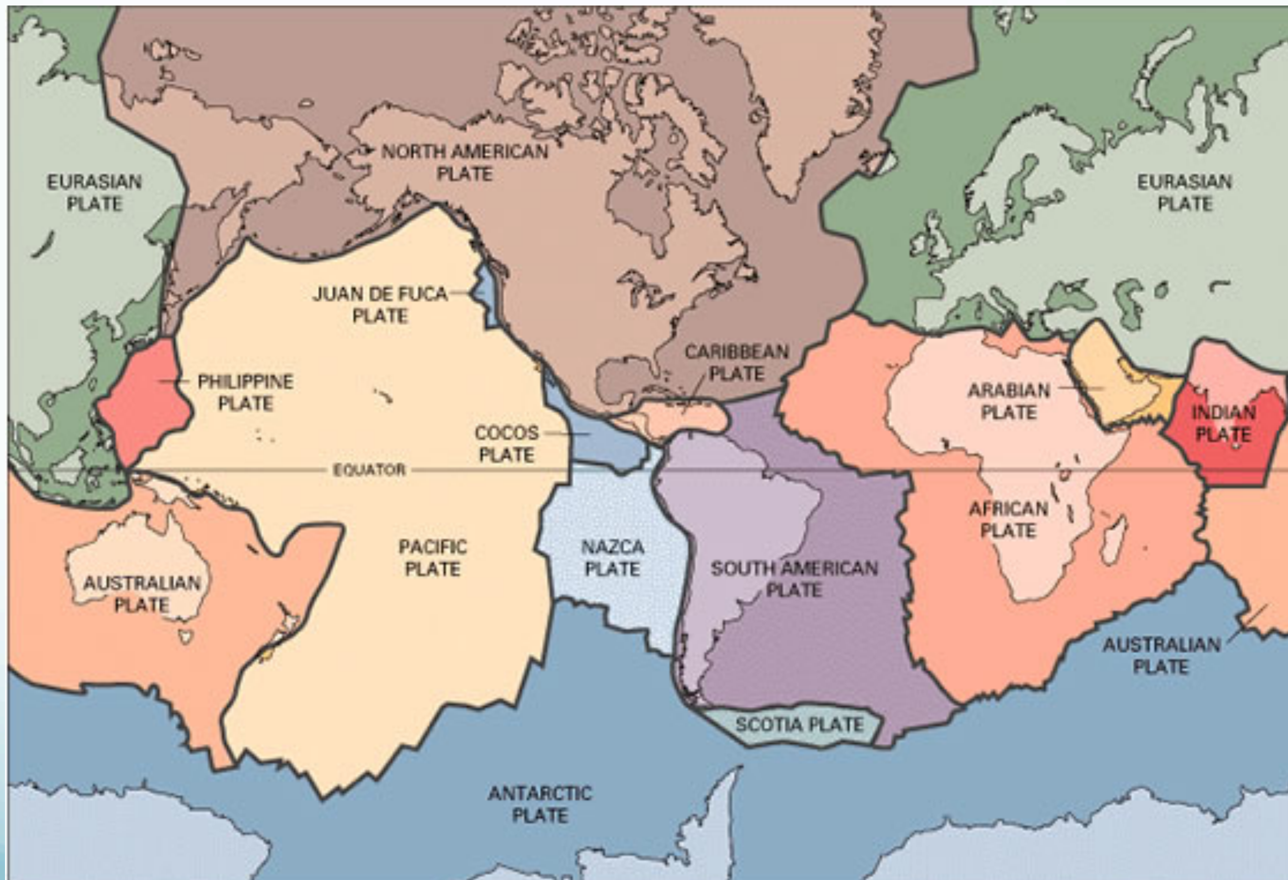
- Earth consists of three main layers: core, mantle and crust
- The crust is consisted of the lithosphere (the outer-most layer) and a section of the upper mantle.
- The crust is much more rigid than the mantle



Source: Nevada Seismology Laboratory

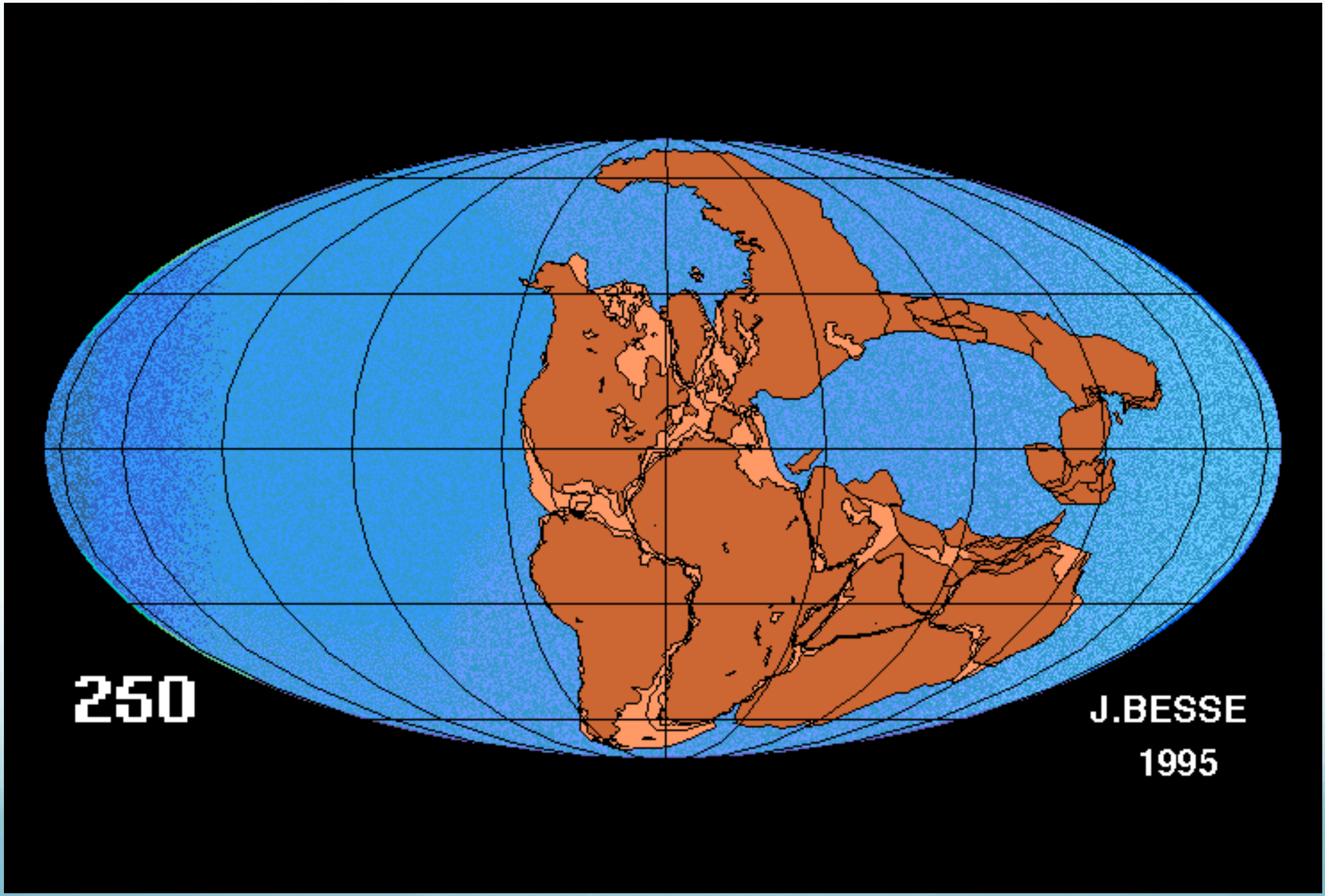
Theory of Plate Tectonics: World Map

- The crust is broken up into different pieces, called “plates”.
- These plates move independently of one another



Source: U.S. Geological Survey

Plate Tectonics: A History

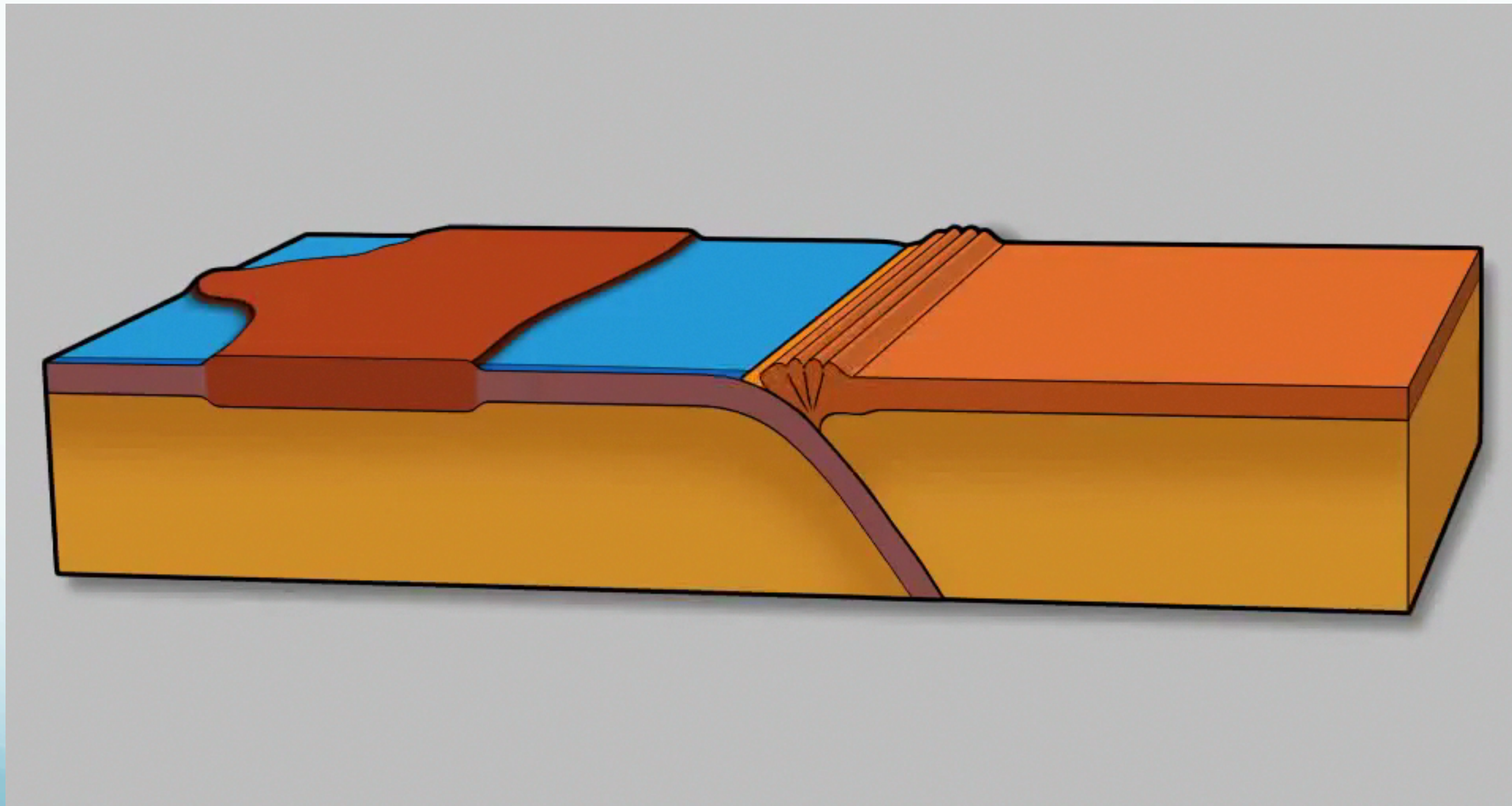


Source: Jean Besse, Institut de Physique du Globe de Paris

Plate Tectonics: Convergent Boundaries

- Plates consist of continental and/or oceanic crust

- Oceanic crust is the denser of the two



Credit: Tectonics Observatory, Caltech

Plate Tectonics: Convection

Source: National Geographic

Faults and Folds

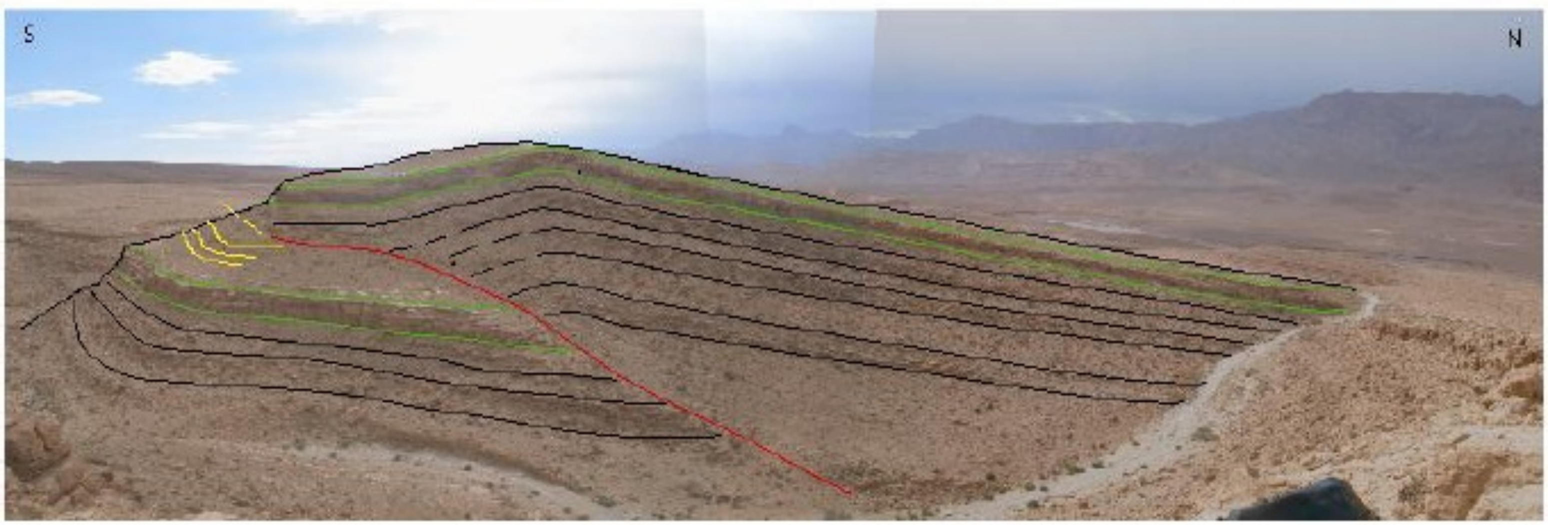
• When collisions occur between two plates, two different types of results can occur

• Faults occur when the crust "breaks"- the different layers of sand don't align

• Folds occur on the surface, causing bends in the crust

• These faults and folds, at a convergent boundary, accumulate to form mountains

Faults



Folds

Syncline Fold (Downwards)

http://4.bp.blogspot.com/_u8RzBC9dWv0/SDh1Q38mdVI/AAAAAAAAAXQ/zE-GiMjX778/s400/DSC01517+Barstow+syncline+c.jpg

Anticline (Upwards)

http://flickrfanstan.files.wordpress.com/2009/10/dramatic-folds-faults.jpg

Goals: Create Scale Model of the Jura Mountain Range

- - Test the hypothesis of the formation of the Jura Mountain Range through a sandbox experiment
- - Run several control sandbox experiments with varying friction and analyze resulting faults, folds, and deformations
- - Use quantitative and qualitative data from control experiments to find ideal parameters to simulate Jura Mountain Range

Significance of Scale Model Reproduction

- Understand topographic formations, such as mountain ranges
- More accurately validate mechanical predictions and test hypotheses to understand the influence of geometrical and physical parameters
- **Produce a portable model that can educate elementary and high school students about mountain formation**

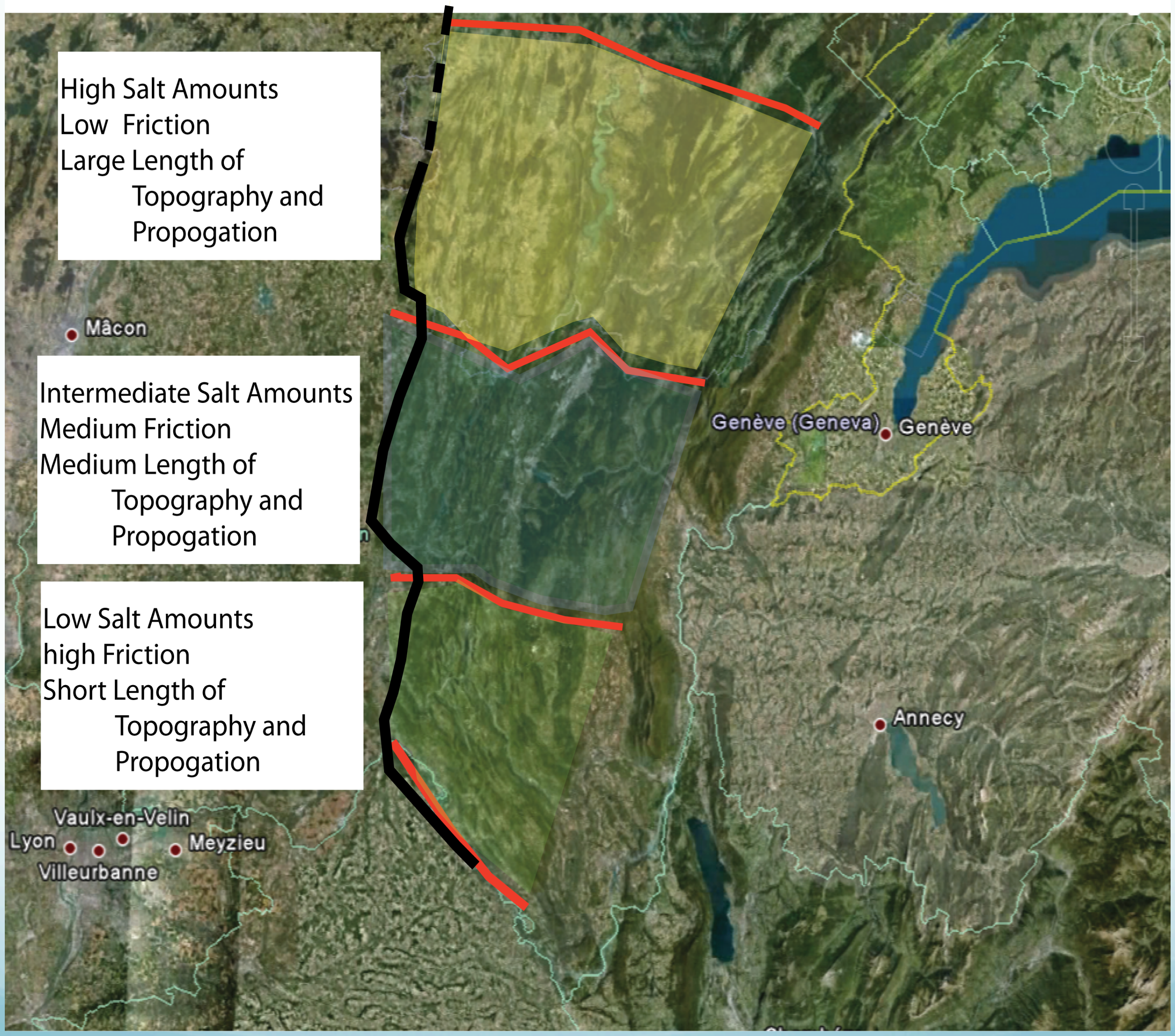
Why the Jura Mountain Range?

- Jura consists of a sequence of faults and folds
- Jura is the Front of the Alps
- Only theoretical (not much physical) analysis has been done here
- The Jurassic Era was named for the Jura mountains by Alexander von Humboldt
- Constant tectonic plate movement is pushing the range higher

Why the Jura Mountain Range?

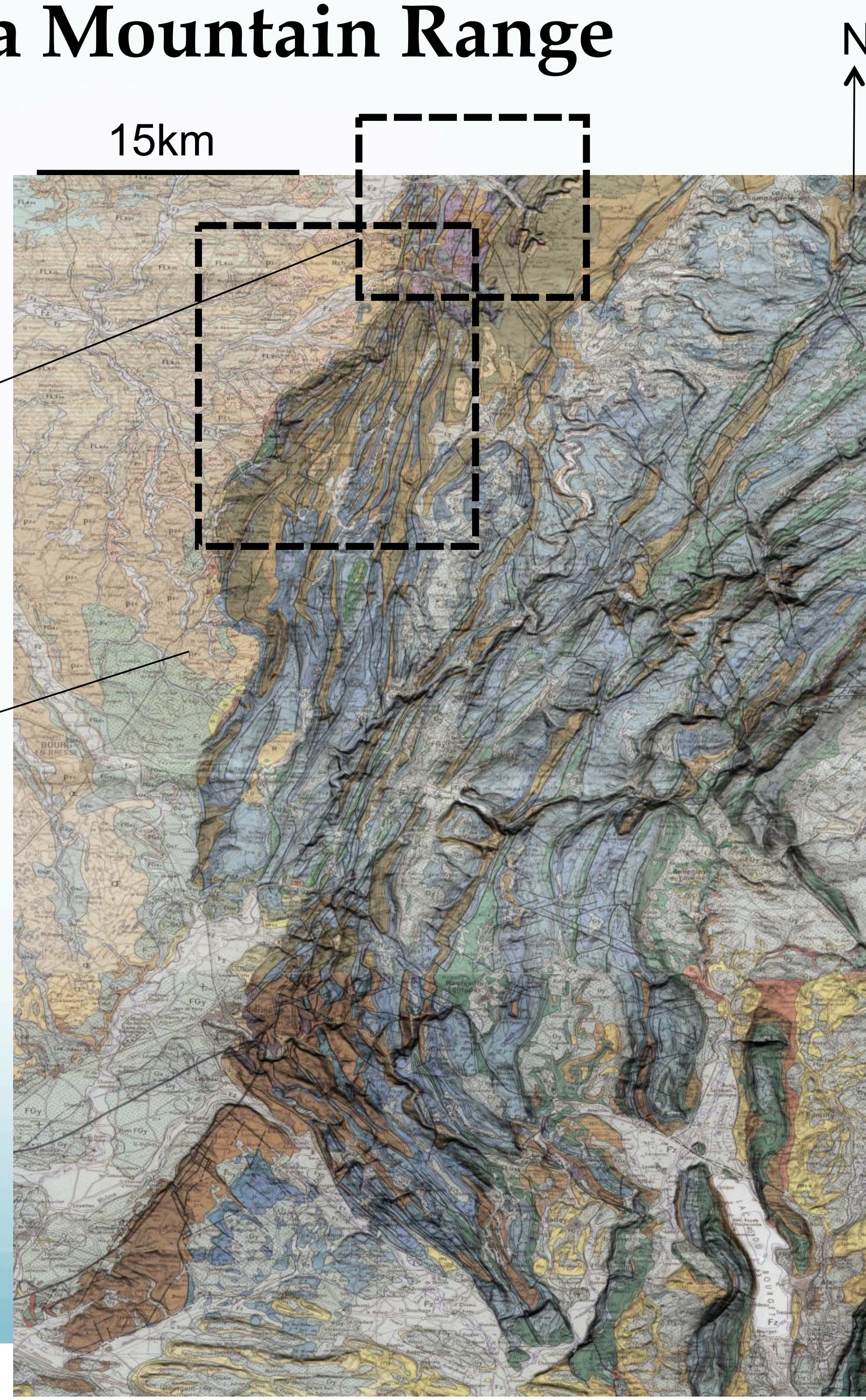
Source: Google Earth

Sections of the Jura Mountain Range



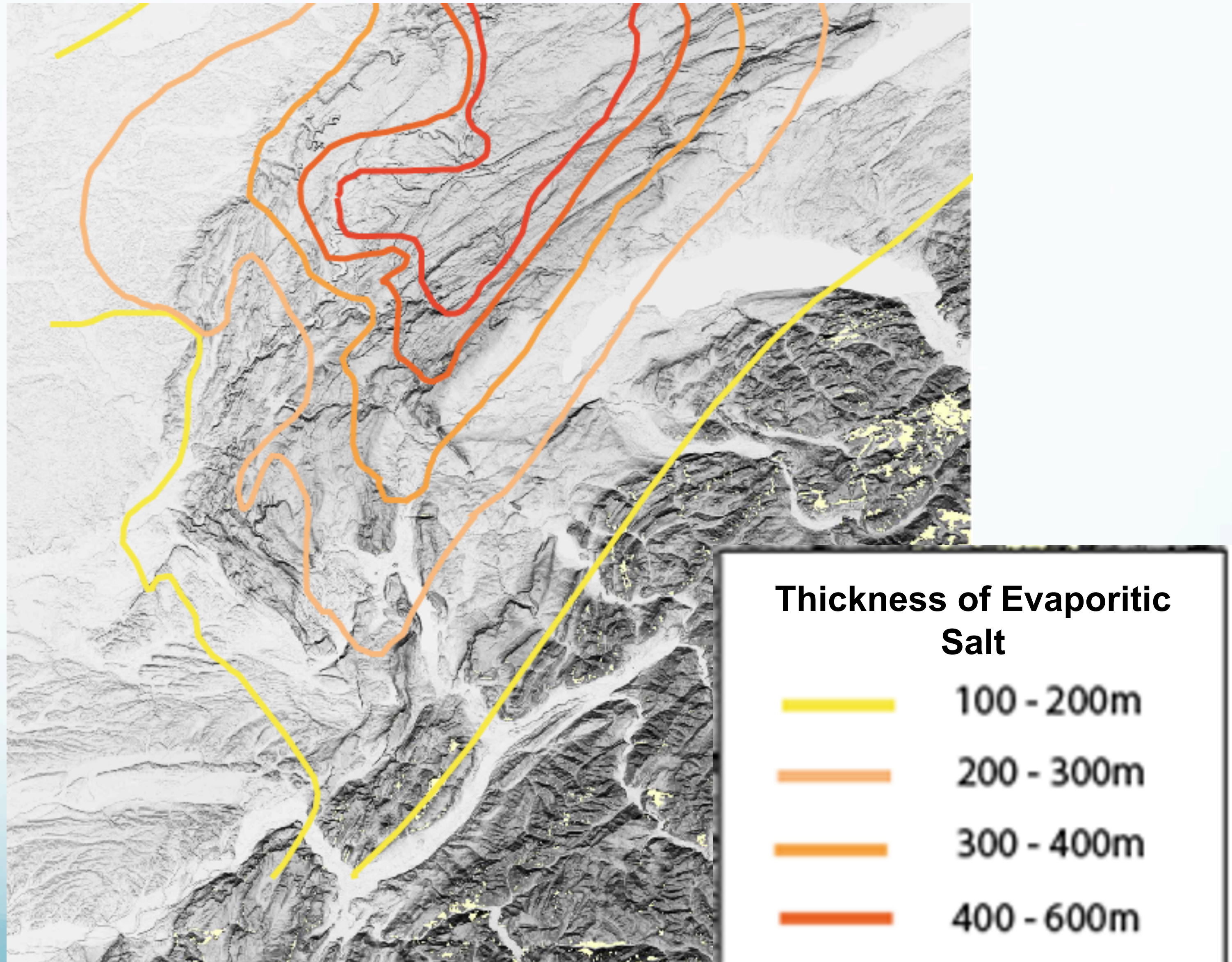
Source: Google Earth

Sections of the Jura Mountain Range



Salt Thickness of Jura

Geometry of the fold and thrust belt is directly related to friction properties of the basement

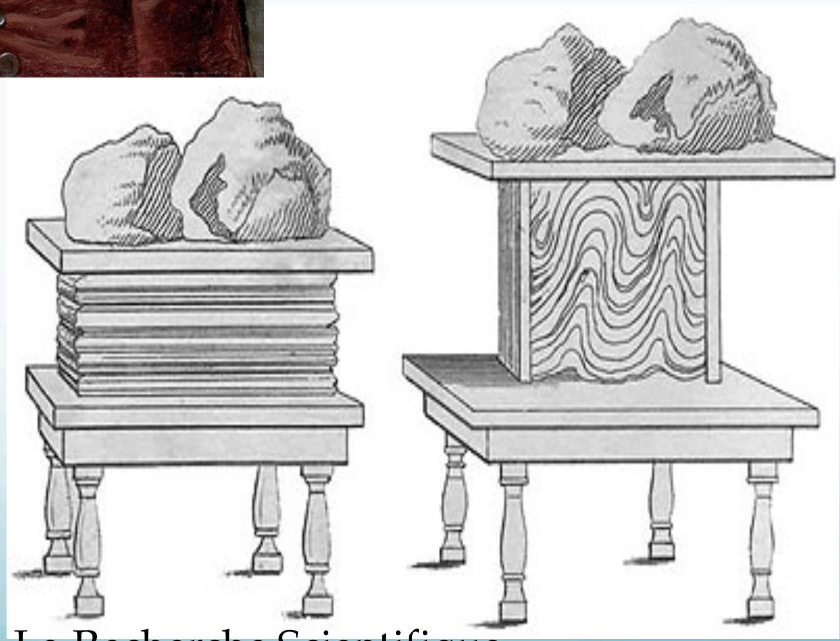


History of Sandbox Experiments

James Hall

-Founder of the experimental geology

-In 1815 he discovered that a horizontal force is necessary in order to form mountains



Source: Centre National De La Recherche Scientifique

History of Sandbox Experiments

Henry Cadell

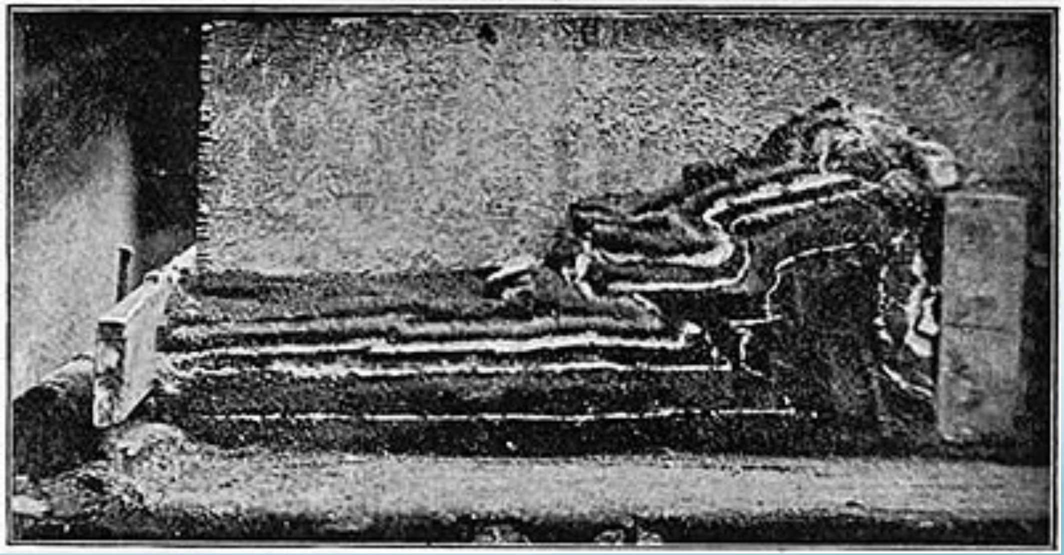
- Conducted the first sandbox experiment in 1893

- Used sand and plaster to simulate the construction of a mountain

- Discovered that the pushing of sand creates a wedge shape formed by faults and folds, as seen in mountains

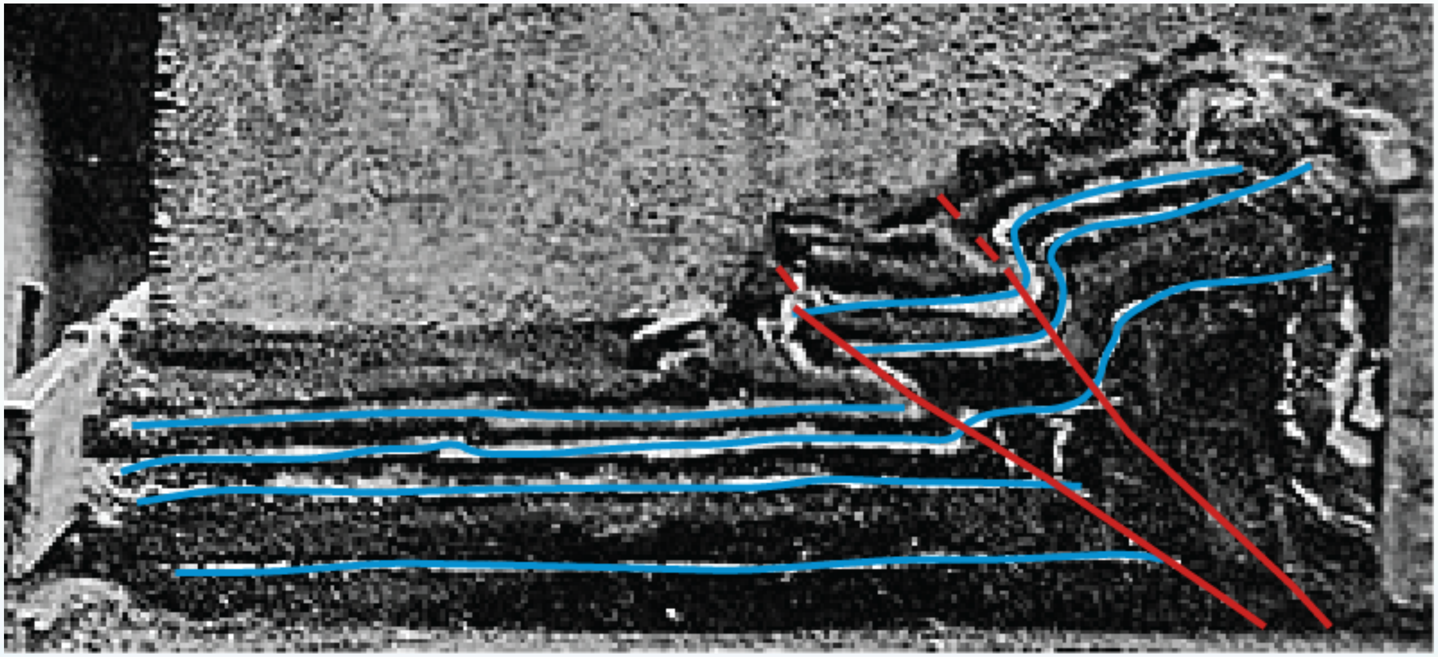
Source: Centre National De La Recherche Scientifique

History of Sandbox Experiments



Source: Centre National De La Recherche Scientifique

History of Sandbox Experiments



Source: Centre National De La Recherche Scientifique

How to Create a Scalable Model

Mountain range : 200km x 200km x 8km

Sandbox : 30cm x 40cm x 15mm

1) Length, width, height
2) Density
3) Viscosity
4) Stress
5) Deformation
6) Time
7) Velocity

How to Create a Scalable Model

Dimensions

Length: $L^*=L_b/L$

Width: $W^*=W_b/W$

Height: $H^*=H_b/H$

$L_{b,}$ W_b ,H_b are dimensions of the box

Mountain range : 200km x 200km x 8km
Sandbox : 30cm x 40cm x 15mm

Strain Rate

$$\Sigma^* = \sigma^*/\eta^*$$

σ* stress ratio

η* viscosity ratio

Stress

$$\sigma^* = p^* g^* L^*$$

p*=density ratio; g*=gravity ratio=1

Density of Sedimentary Rocks: 2550 kg/m^3

Density of Sand: 1500 kg/m^3

Sandbox v. Jura Mountain Range

	Sandbox	Jura Mountains	Ratio
Length	40 [cm]	200 [km]	2.0×10^{-6}
Width	30 [cm]	200 [km]	1.5×10^{-6}
Height	15 [mm]	8 [km]	1.9×10^{-6}
Density of Crust	1,500 [kg/m^3]	2,550 [kg/m^3]	0.59
Gravity	9.8 [m/s^2]	9.8 [m/s^2]	1
Stress*	5880 [N/m^2]	5.0×10^9 [N/m^2]	1.17×10^{-6}
Viscosity+	200 [$Pa \cdot s$]#	10^{18} [$Pa \cdot s$]	2.0×10^{-16}
Deformation*	N/A	N/A	5.88×10^9
Time	7.44 Hours	5 [Ma]	1.7×10^{-10}

* Calculated value (not measured)
+ Ratio/Value only needed when using viscous material
# Viscosity of peanut butter

Sandbox Experiment Outline

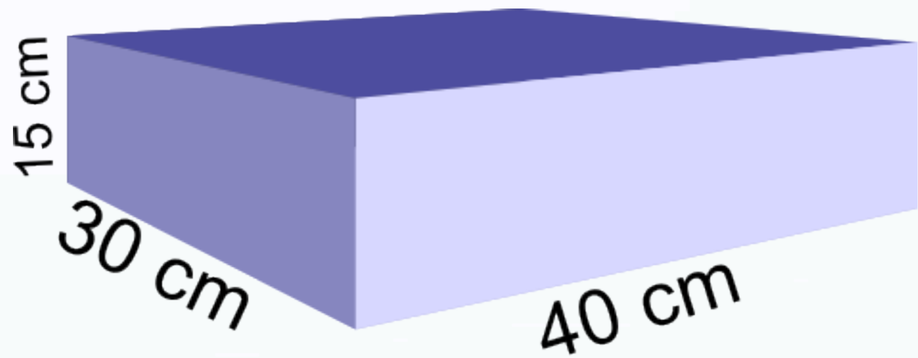
1. Sandbox Design

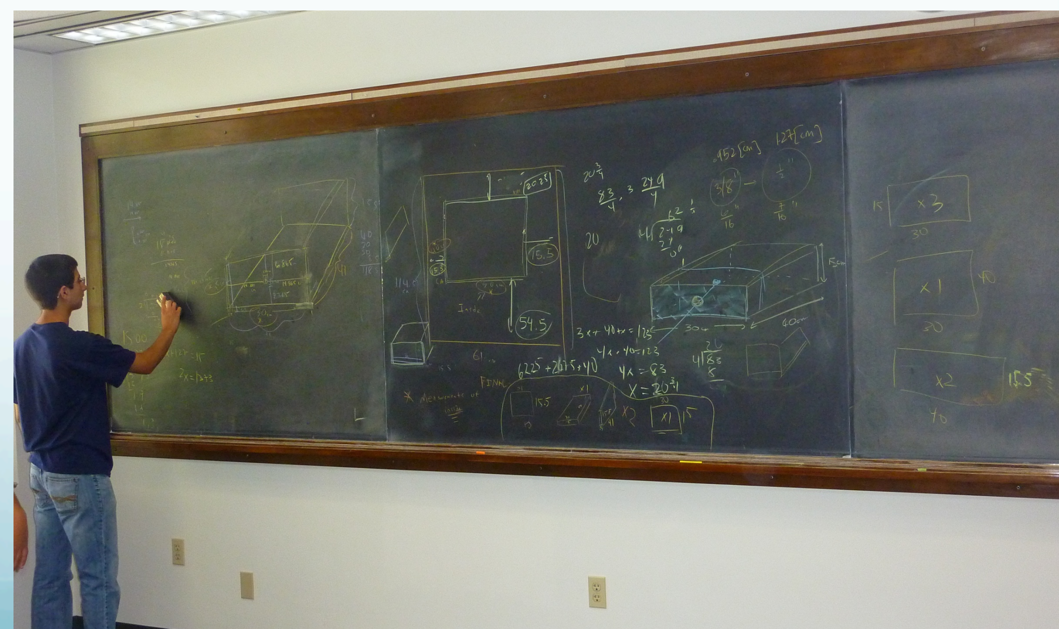
2. Horizontal Force

3. Internal and Basal Friction

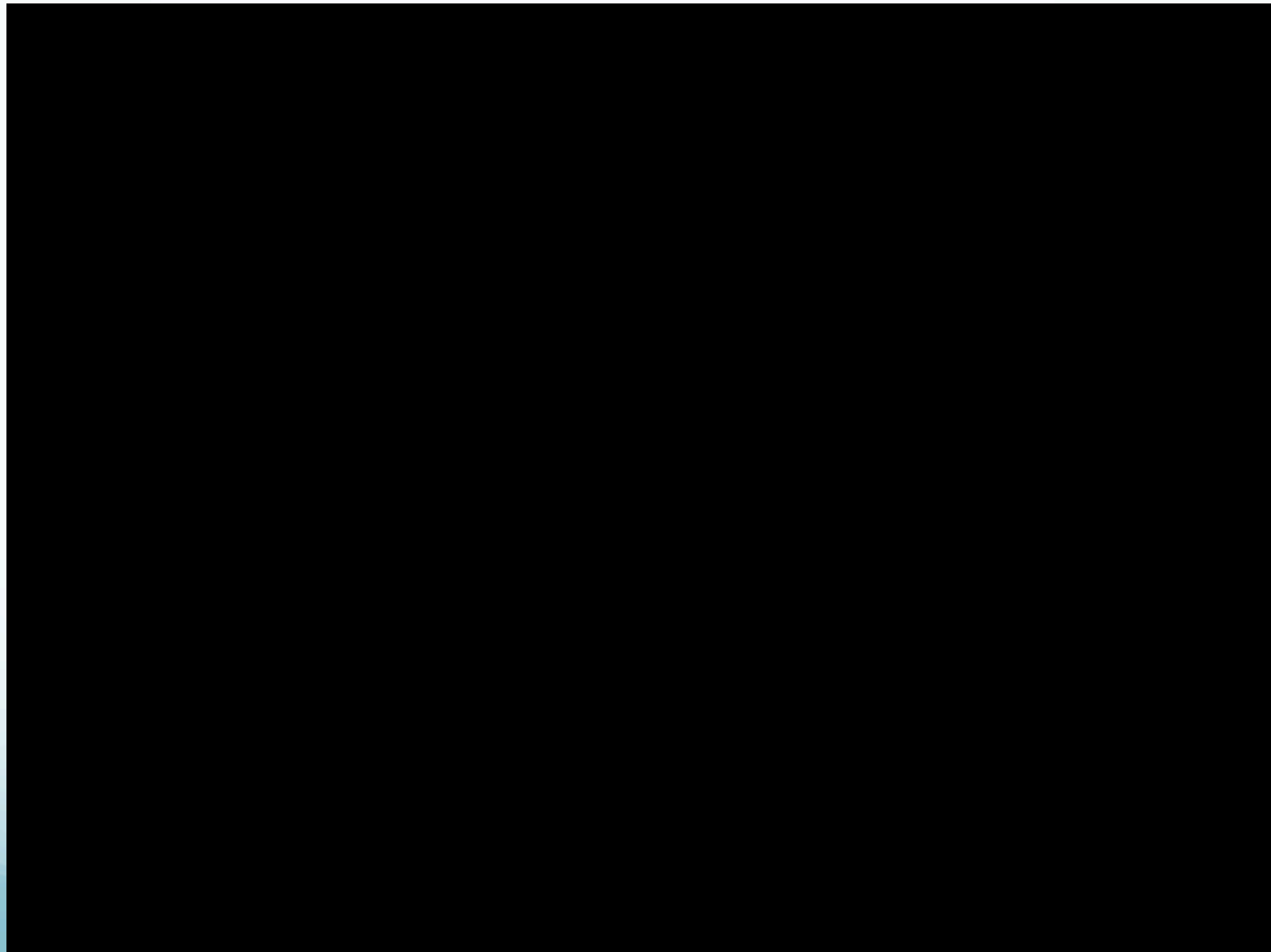
4. Control Experiments

5. Cross-Section Analysis





Constructing a Plexiglass Box



Sandbox Experiment Outline

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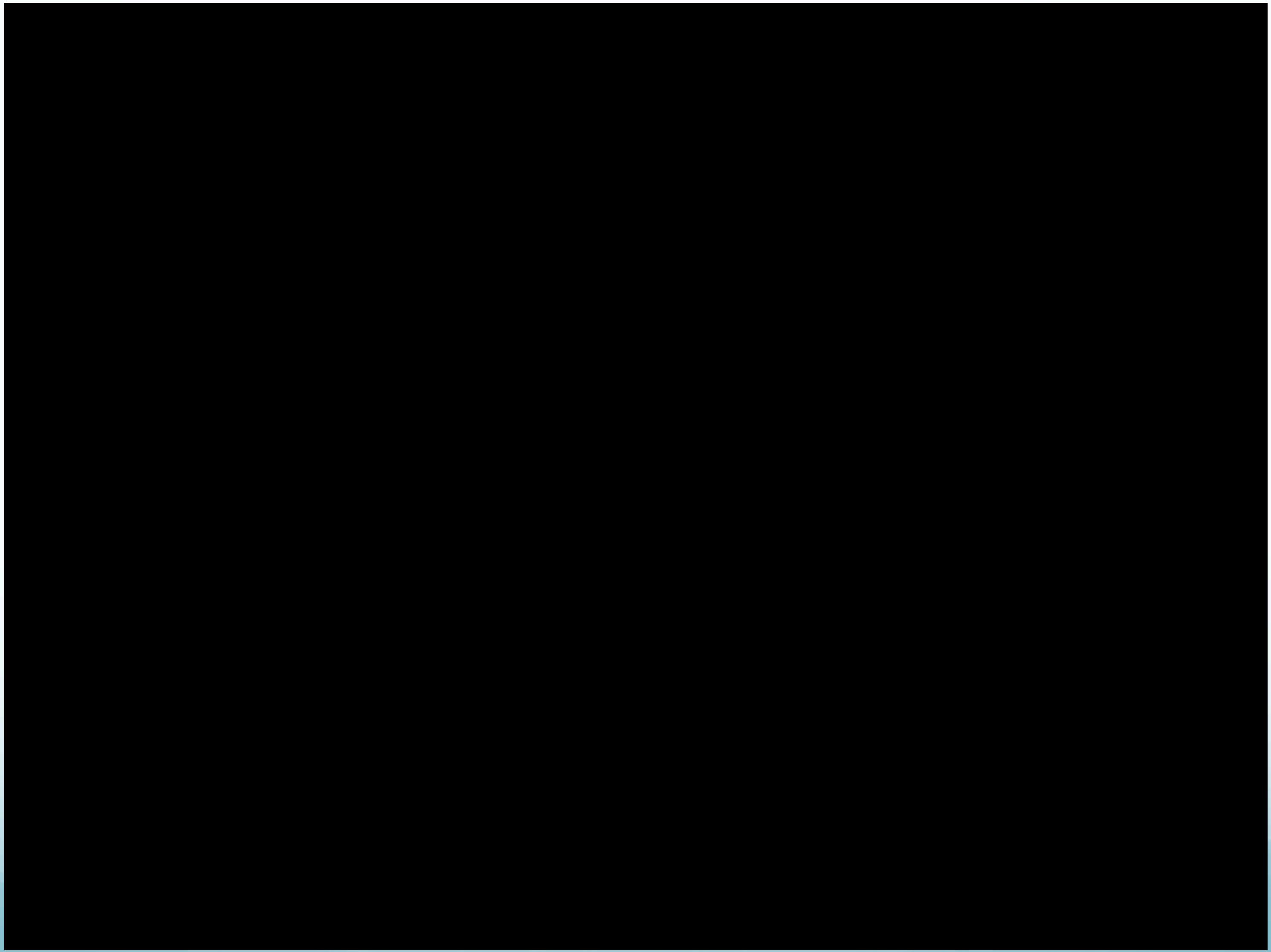
Final Horizontal Force Design



Sandbox Experiment Outline

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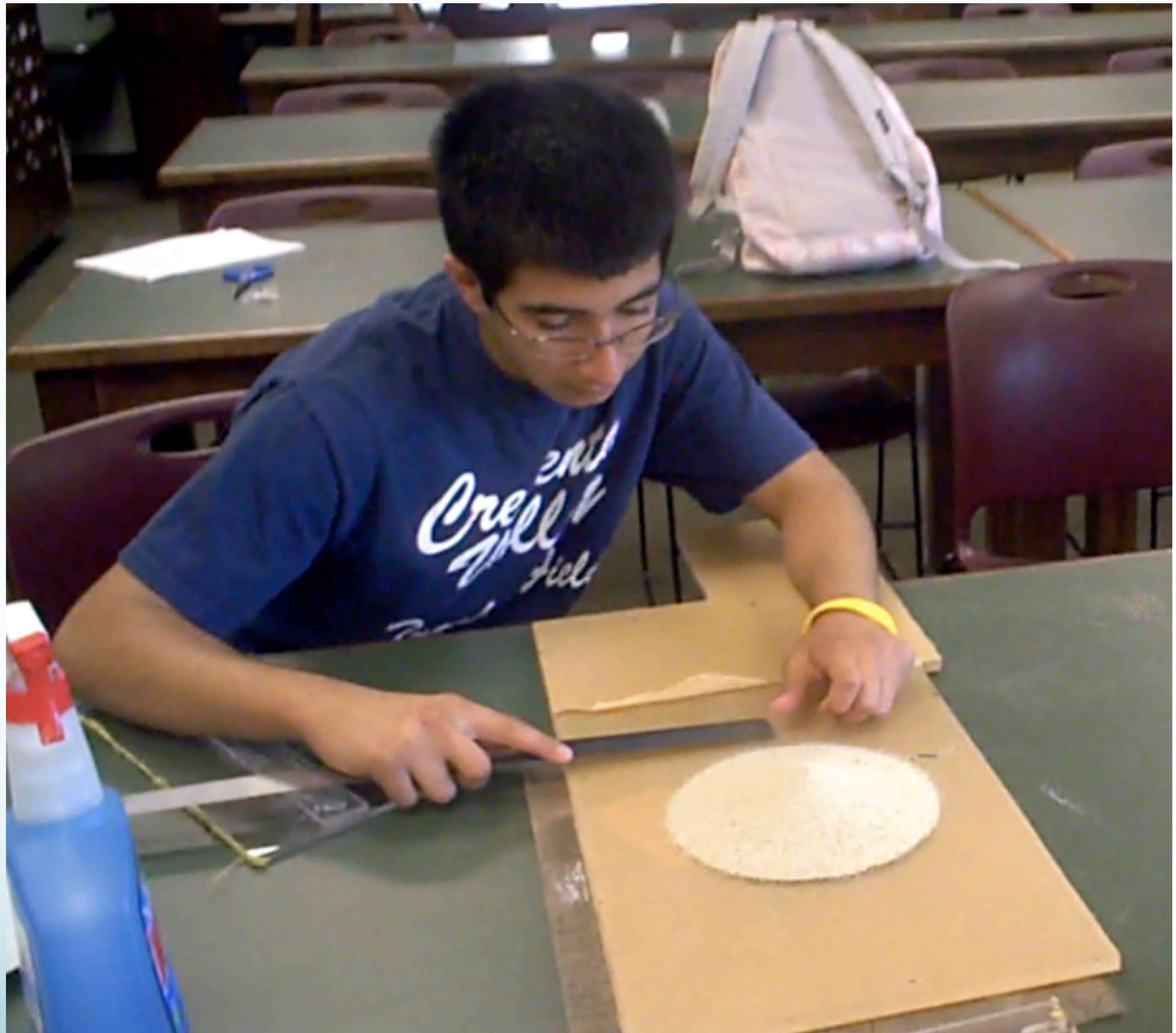
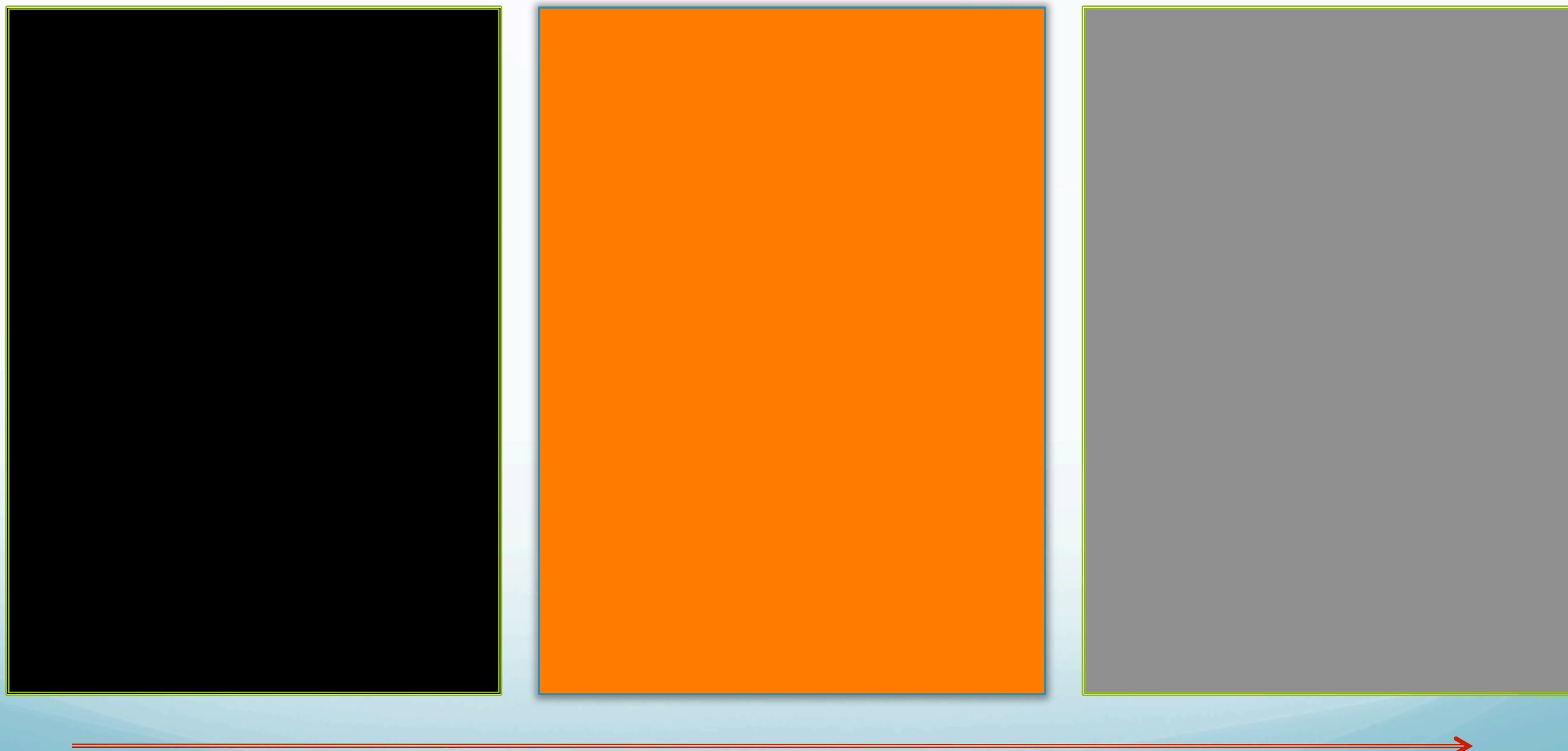


Three Types of Sandpaper

600 Grit | **220 Grit** | **60 Grit**

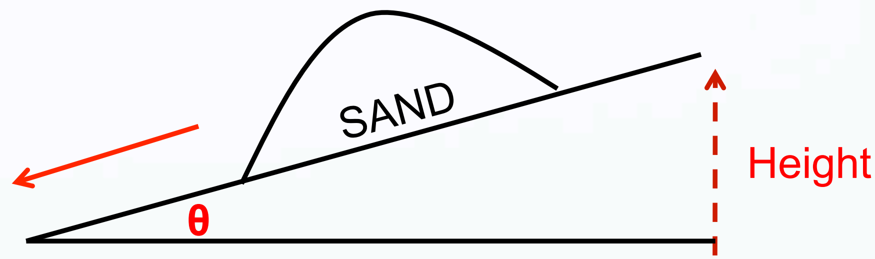


increasing friction

Basal and Internal Friction

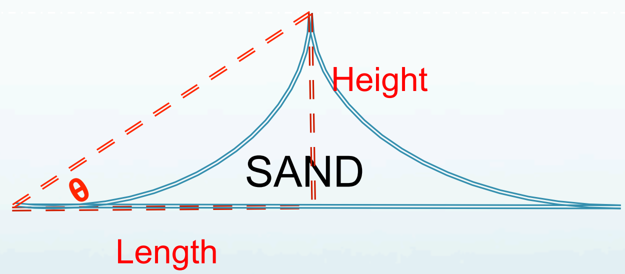
•Basal friction refers to the amount of friction of the sand against the base of the box (ie. Plexiglas)

- •Measured through:



•Internal friction refers to friction of sand against sand

- •Measured through:



How to Measure Friction

Sandbox Experiment Outline

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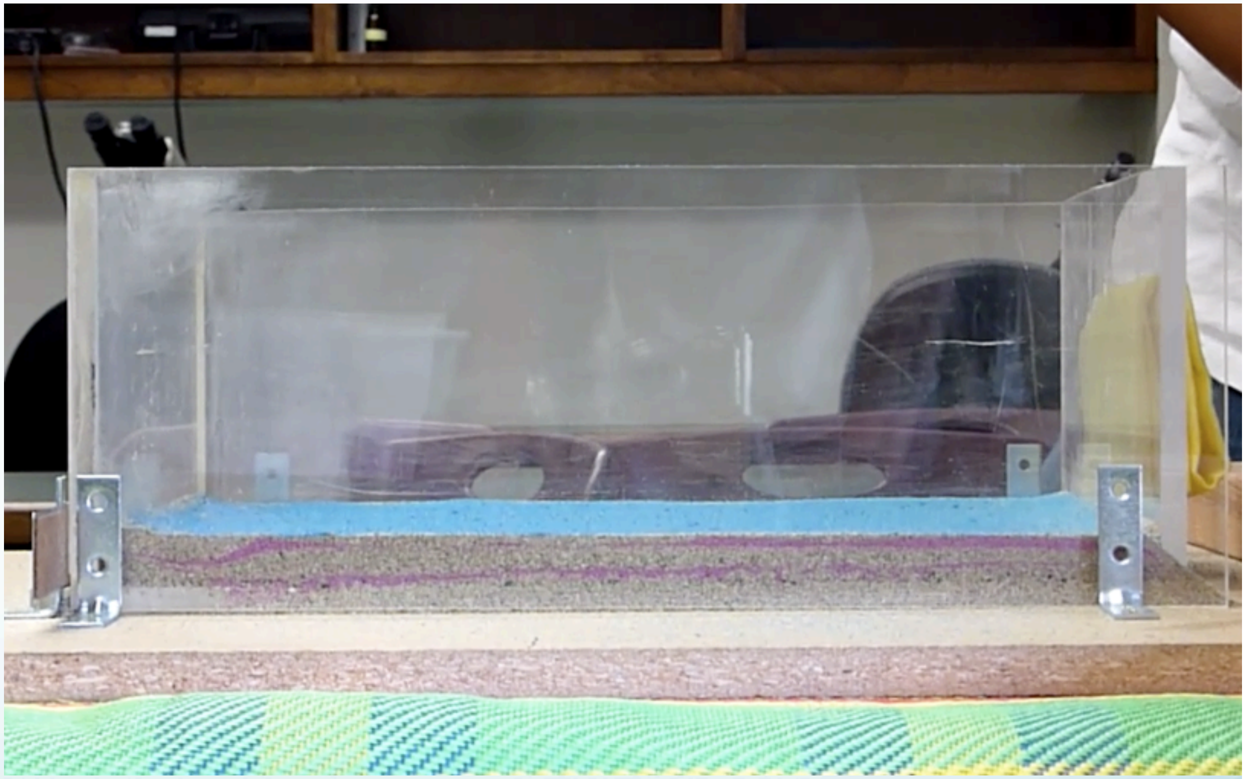
5. Cross-Section Analysis



Video Summary of Experiments

Sandbox Experiment Outline

1. Sandbox Design

2. Horizontal Force

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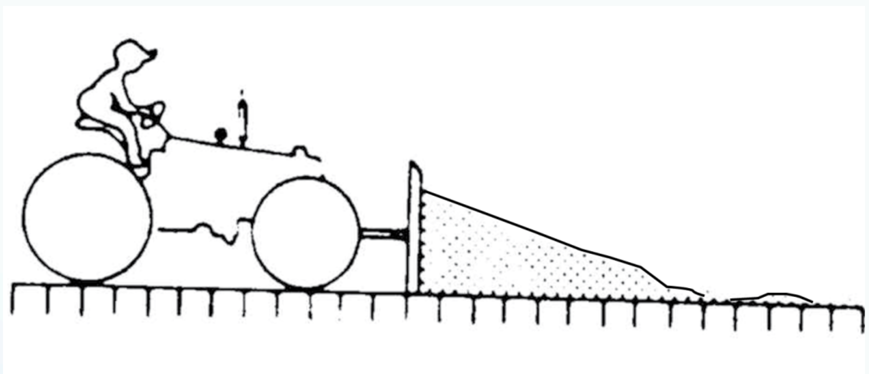
How to Create a Cross-Section for Analysis

Critical Taper



- The Critical Taper is the angle of topographic slope
- Critical Taper =

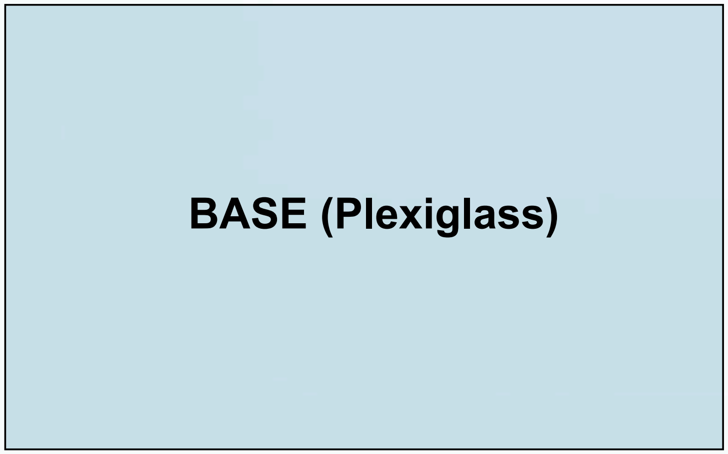
$$\frac{\tan(\theta\ b)}{1+ f(\tan(\theta))}$$

- ↑ critical taper = more topography

  ↓ critical taper = less topography

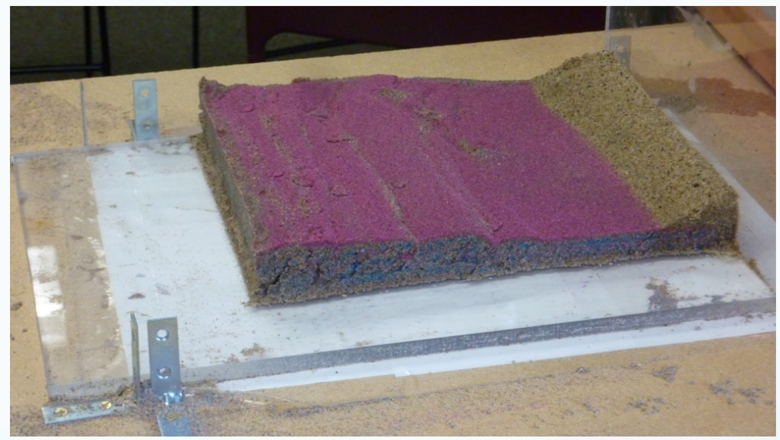
Plexiglass Only Experiment

Schematic of Base



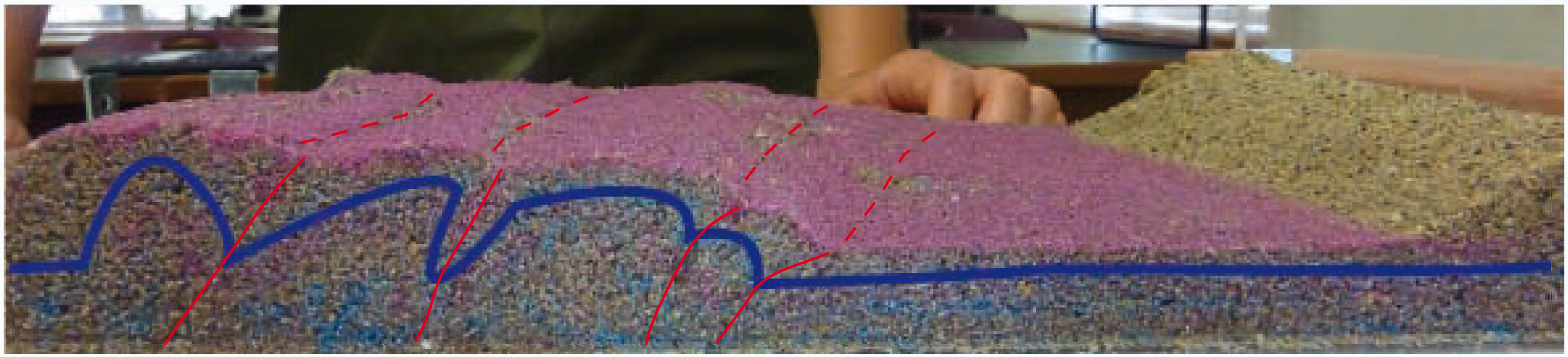
Picture of Base

Top View of Deformation



Plexiglass Only Experiment

Cross-Section of Sandbox

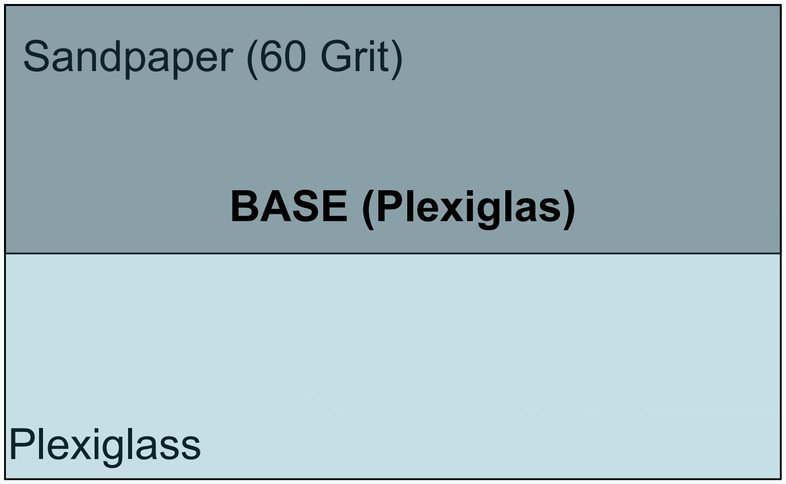


Results

Internal Friction: 18.5 °
Basal Friction: 19.9 °
Critical Taper: 7.43 °

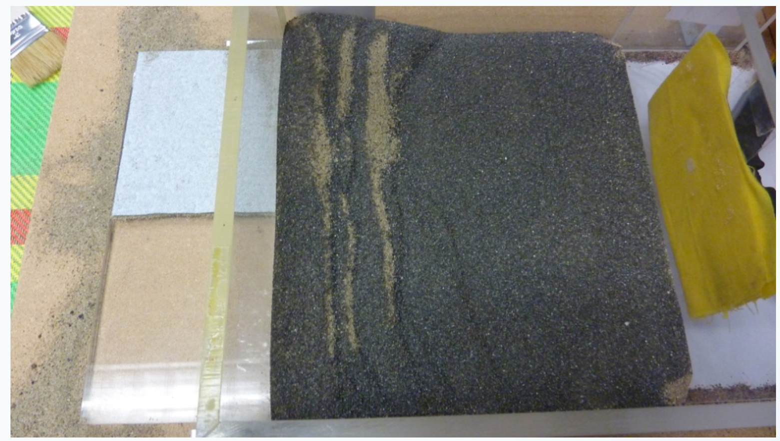
Half Plexiglass, Half 60 Grit Experiment

Schematic of Base



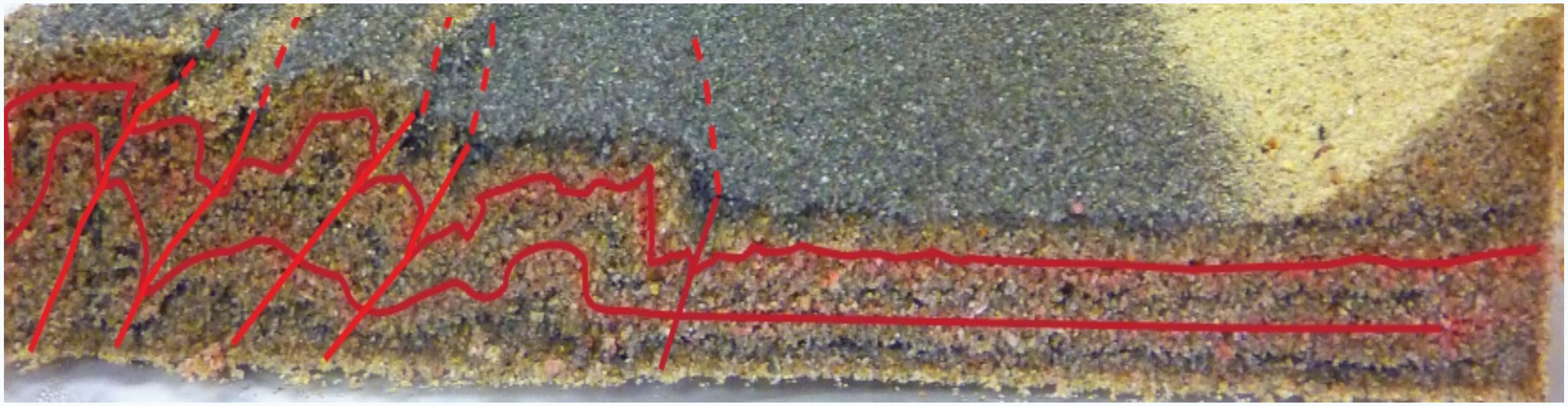
Picture of Base

Top View of Deformation



Half Plexiglass, Half 60 Grit Experiment

Cross-Section of Sandbox

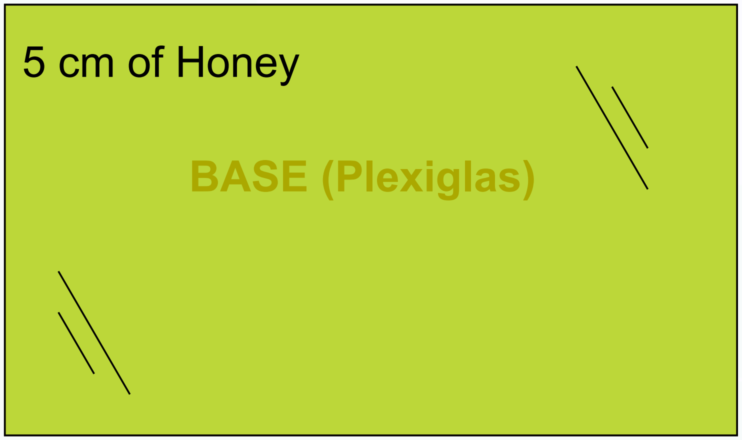


Results

Internal Friction: 18.5°
Basal Friction: 27.0°
Critical Taper: 17.79°

Honey Only Experiment

Schematic of Base

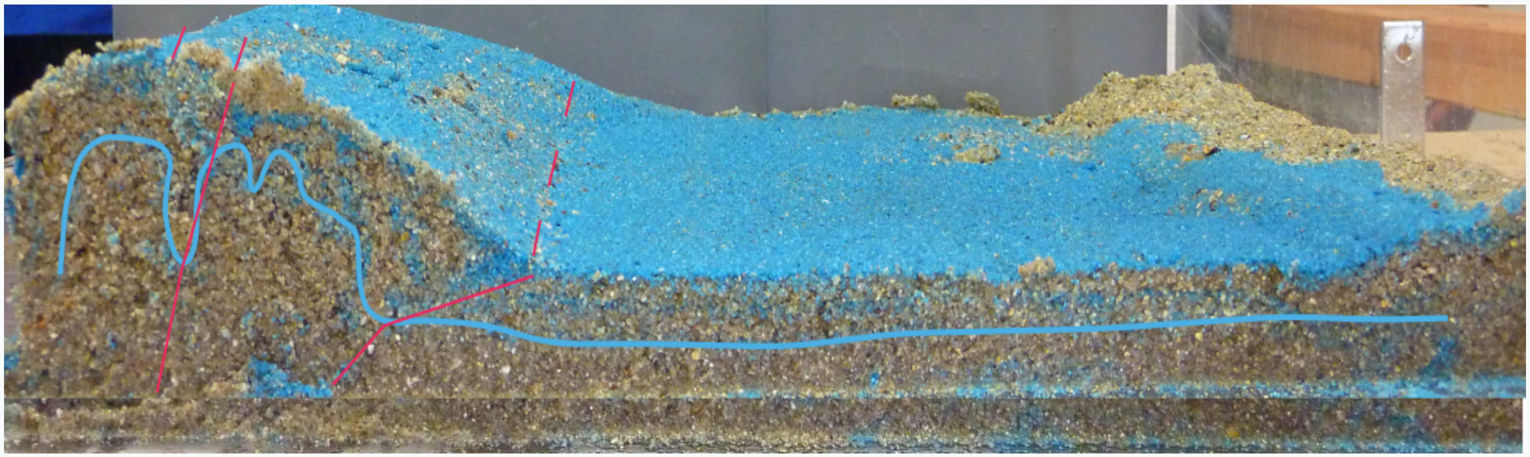


Picture of Base

Top View of Deformation

Honey Only Experiment

Cross-Section of Sandbox

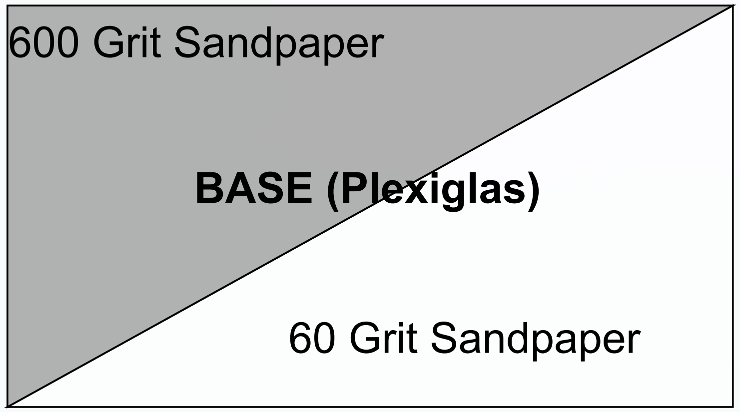


Results

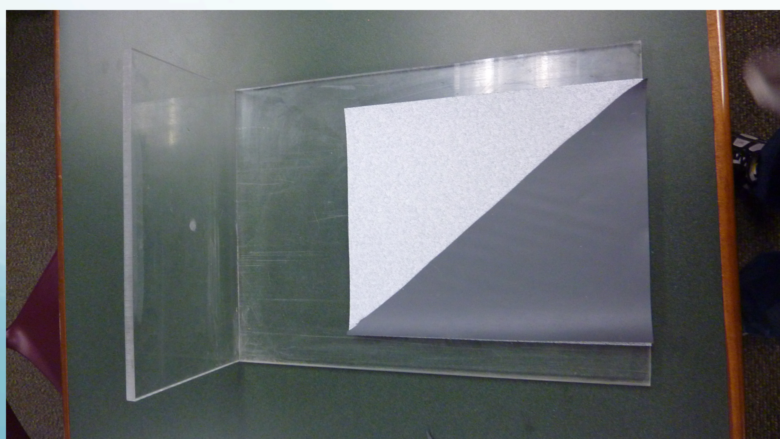
Internal Friction: 18.5°
Basal Friction: N/A
Critical Taper: 20.43°

Half 600 Grit, Half 60 Grit Experiment

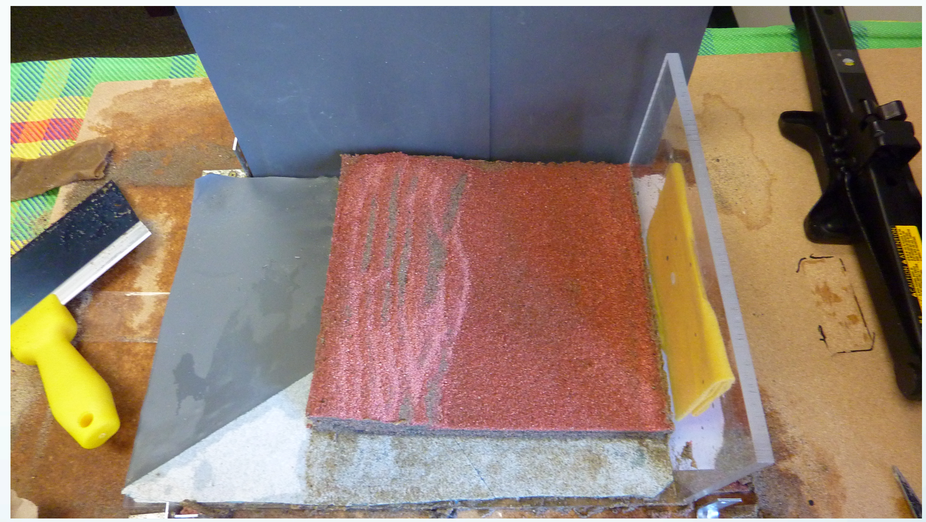
Schematic of Base



Picture of Base

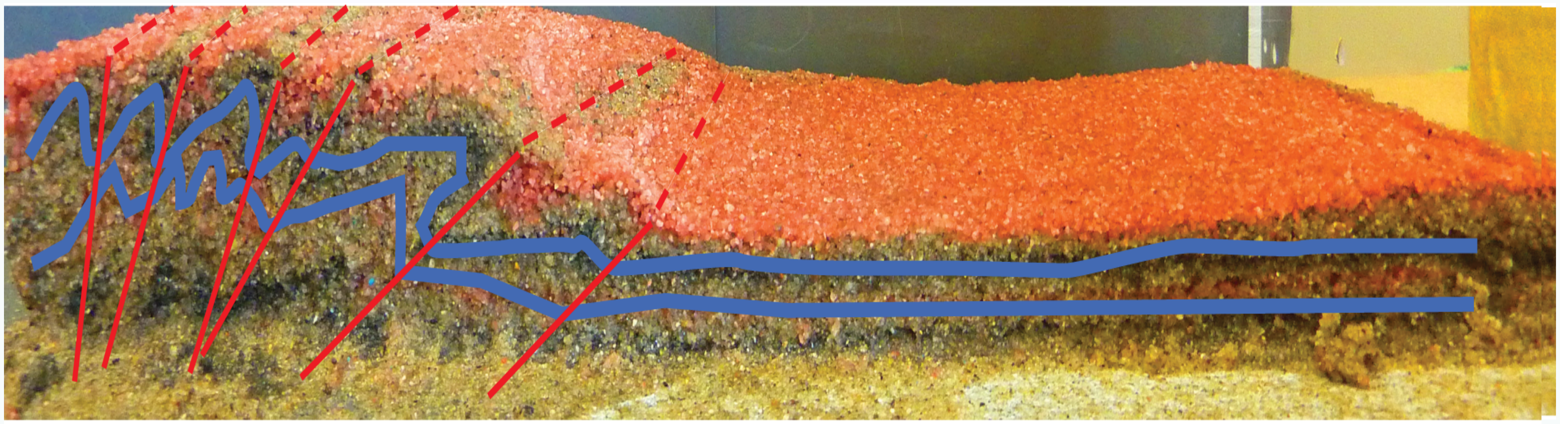


Top View of Deformation



Half 600 Grit, Half 60 Grit Experiment

Cross-Section of Sandbox



Results

Internal Friction: 18.5°
Basal Friction: 23.7°(600 G)
Basal Friction: 27° (60 G)
Critical Taper: 10.16° (600 G)
Critical Taper: 17.79° (60 G)

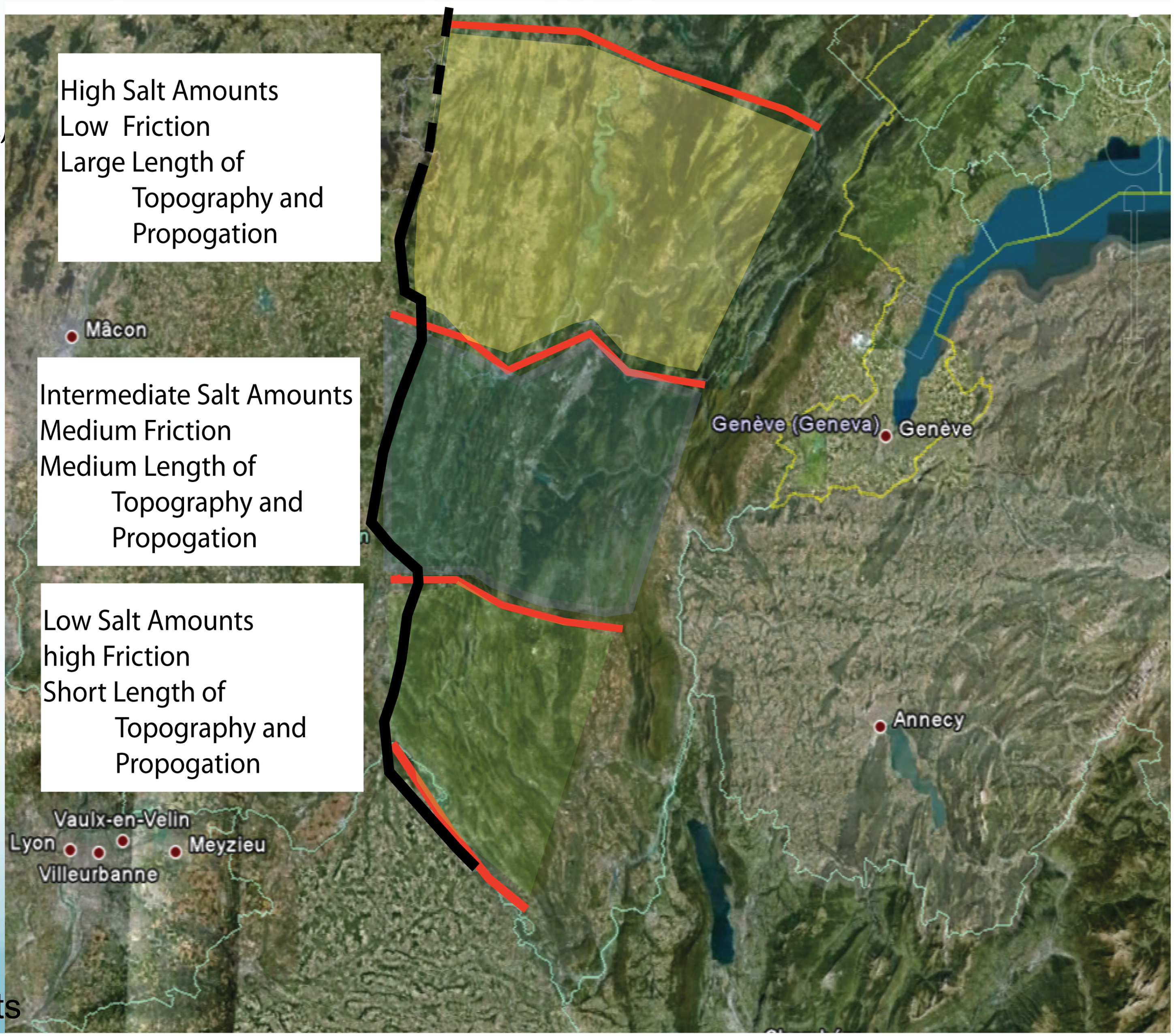
Final Words-What did we learn?

- Experiments with plexiglass base have large propagations and small critical tapers ~7 degrees.
- Experiments with sand paper have less propagation and large critical tapers; as well as less faults
  - The average taper for 60 Grit was ~17 degrees
  - The average taper for 600 Grit was ~10 degrees

Final Words (con.)

- Plexiglass results (smooth, less friction) symbolize Northern regions
- 600 Grit (medium friction) results symbolize Middle regions
- 60 Grit (most friction) results symbolize Southern regions

*Qualitative; best results

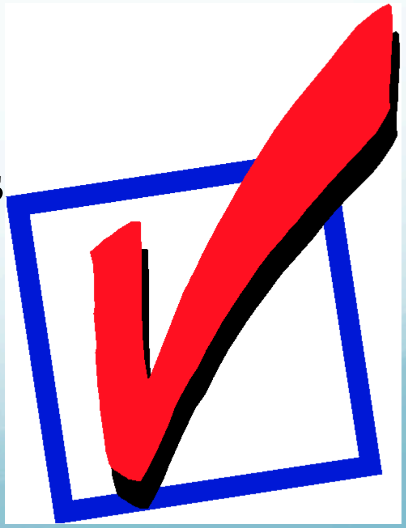


Final Words (cont.)

- In other words, we have proven that the friction conditions and geology of the region did in fact influence the way the Jura Mountains were created

Future Directions

- Create a machine automated sandbox with greater precision
  - Perform sandbox compressions in scaled times
  - Continue testing more types of base materials with different grits of sandpaper
  - Use high-quality viscous material such as silicone
  - Perform experiments of greater accuracy and specificity regarding the Jura Mountains
  - Find a way to measure stress and strain forces with electronic sensors to compare to mechanical prediction
  - Prototype for future large scale experiments
  - Educational outreach programs



Acknowledgements

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Thank you for your time!

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