

# Teaching Geologic Time and Rates of Landscape Evolution with Dice, Sandboxes, & Cutting-Edge Thermochronology

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## Abstract

Debates over natural resource consumption and the validity of religious and scientific views of Earth history hinge on the public's conception of geologic time and rates of Earth change. Teaching these concepts effectively remains a challenge to educators in a variety of settings. We present labs designed to help students internalize these concepts using dice, sandboxes, stopwatches, and cutting-edge thermochronologic research to study landscape evolution, and illustrate how the basic models can be adapted to challenge students in grades 9-16 with kinematic, auditory and visual learning styles and diverse backgrounds.

Landscape evolution provides a convenient framework for understanding geologic time and rates because students can observe how processes like erosion and deposition shape their surroundings, even in urban settings. In order to describe landscapes qualitatively and quantitatively, students build 3-D sandbox models based on topographic maps and design and stage a "virtual adventure race."

Sandbox landscapes are used to illustrate erosional processes, the role of water in sediment transport, relief change, and how erosion exhumed rocks from depth, while local examples are used to discuss landscapes as transient or steady over different time- and length scales.

To convince students that the observed processes act over millions of years to shape Earth's surface, quantitative dating tools are introduced. Dice experiments illustrate radioactive decay and the shape of the age equation curve, and <sup>14</sup>C dating, geochronology and thermochronology are introduced as "stopwatches" that start when a plant dies, a crystal forms, or a rock nears the surface and cools to a certain temperature.

The sandbox model and thermochronometer "stopwatches" are combined to measure erosion rates at a point, uniform and spatially variable erosion, and rates of landscape change. Ultimately, model rates (cm/hour) calculated from stopwatch times on the order of seconds can be related to geologic rates (km/My) calculated from real million-year-old samples.

## Sandboxes & Topographic Maps

**What is Topography? What is Relief?**  
How do 2-D maps represent 3-D Landforms?

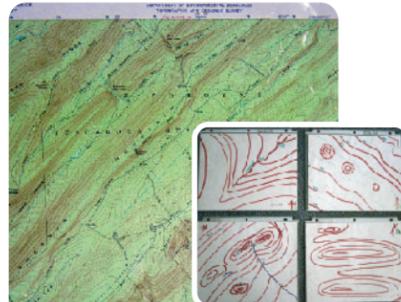
**Learning Goals:** Through the basic activities (SANDBOX, PLAY-DOUGH MODEL TESTS & ADVENTURE RACE), high school students should demonstrate mastery of map interpretation skills & landscape observation by 1) defining important terms, 2) describing, comparing, & mapping landscapes in 2- and 3-D, and 3) drawing topographic cross-sections.

The basic activities prepare college students to draw geologic cross sections, relate landscapes from field photos, stereo air photos, or field trips to maps, use compasses & triangulation in the field to locate themselves on a map, and eventually draw contacts to create geologic maps.

**Context:** For the initial sandbox landscape exploration activities, students need an introduction to reading map scales, contour lines, and orientation. Terms such as relief, slope, and gradient should be defined, and class should begin with a demonstration of how to make sandbox topography models based on a simplified topographic map accurately using vertical & horizontal scales.

**Materials:** Laminated topographic map & water-based marker, water-proof tray, sand, water, sandcastle-building tools, plastic rulers with pencil taped at right angles to them for measuring contours; home-made play dough, index cards.

**Activity & Evaluation I:** After demonstration, teams of students practice recreating 3-D topographic sand models from 2-D maps. Teams practice vocabulary and definitions and are evaluated for participation through informal question & answer with teacher, or mini in-class presentations of sand models that depict the topography of the area around a student's home.



Students practice recreating 3-D topography from topographic maps. Cut the model in half to check accuracy of cross-section diagrams based on topographic maps.



### Activity & Evaluation II:

#### 1. TOPOGRAPHIC MAP:

Teams draw topographic maps to include  
- Ridge - Two mountains - "River" valley  
- Harbor - Closed Depression - Contours  
- Compass Rose - Scale - Contour Interval

#### 2. MODEL:

Each team builds a "play-dough" model of the topography represented by their map. Map and model are assessed by teacher for accuracy, neatness, completeness, appropriate use of contours and scale, and orientation.

#### 3. STUDENT-PREPARED TEST (Makers):

Teams prepare note cards with scale, contour interval, compass direction, and five questions about the sculpted area to be graded by teacher & answered by classmates.

#### 4. STUDENT-PREPARED TEST (Takers):

Each student draws an accurate topographic map of two models made by other teams & answers questions about each model. Student teams evaluate their classmates' test maps and questions and answers using a rubric.

Advanced students can incorporate a triangulation exercise on the model topography, or answer questions regarding their "Rule of V's" & how water might flow over the topography

## Learning Landscapes: Virtual Adventure Race

### Activity & Evaluation III: The Peryliminator Virtual Adventure Race

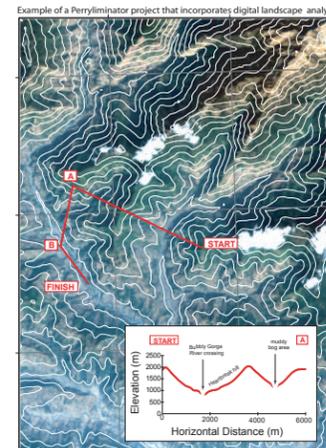
Your group has been nominated as event organizers for the 3rd ANNUAL SOUTHEAST-CENTRAL PENNSYLVANIA TRIATHLON (nicknamed the Peryliminator). Your task as organizers is as follows:

Plan out a 10-KM COURSE over the toughest, most treacherous terrain you can find on the Perry County quadrangle of your choice.

For this TRIATHLON, include 3 different challenges dealing with 1) water, 2) steep climbs and descents, and 3) flat runs! Include compass bearings for your contestants so they won't get lost. Make it fun and interesting!

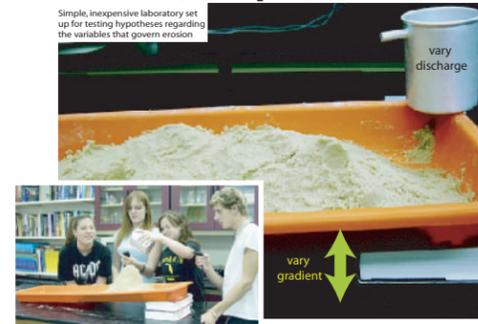
Draw your course on the laminated topographic map. Write a 1-page summary detailing to the planning committee the extent of your course's topography & the challenges it holds. Include the relief and % gradient of the steepest course component. As an added visual aid, draw a CROSS-SECTION of the most grueling part of the course.

- \_\_\_\_\_ (1) (4p) Latitude and Longitude of the Course Start and End
- \_\_\_\_\_ (1) (6p) Distance - requirement met (10 km) - accuracy of measure
- \_\_\_\_\_ (1) (6p) Distance between 3 course turning points noted
- \_\_\_\_\_ (1) (6p) Compass bearings accurate for changes of direction
- \_\_\_\_\_ (1) (2p) Steep slopes included (Up + Down)
- \_\_\_\_\_ (1) (2p) Water crossing included (at least one)
- \_\_\_\_\_ (1) (2p) Flat run included
- \_\_\_\_\_ (1) (10p) Steepest component
  - Relief calculation with Location
  - % Gradient calculation with Location
- \_\_\_\_\_ (1) (15p) Cross-section of most "interesting" course component
- \_\_\_\_\_ (1) Accuracy of Drawing (6) (1) Accuracy of Elevation Transfer (6)
- \_\_\_\_\_ (1) Label significant Features of course (3)
- \_\_\_\_\_ (1) (24p) Description of the Race Course
  - Complete: All components described (15p)
  - Grammar & Spelling (6p)
  - Neatness (3p)
- \_\_\_\_\_ (1) (13p) SIMPLIFIED LARGE SCALE TOPOGRAPHIC MAP
  - Make a simplified large scale topographic map of your racecourse
  - Map Accuracy: (1) Shape (1) Index Contours (1) Symbols
  - Scales Included: (1) R.F. Representative Fraction (1) Graphic



This activity can be used to introduce advanced students to GIS by requiring Digital Elevation Model (DEM) manipulation, point/time/polygon data addition, contouring & hillshading, hillslope & channel profiles, topographic swatch profiles, cross sections and more...

## Erosion, Deposition, & Landscape Evolution



### Activity I: List variables (gradient, discharge, sediment size, channel width, vegetation, erosion) & discuss as a class which can be varied in experimental setup. Hypothesize what effect on erosion increasing each variable will have, and design and perform experiments to test hypotheses. Devise ways to measure erosion rate (volume/time or depth over area per time).

### Activity II: Use sandbox models to show mechanics of relief change driven by each geologic situation. For example, measure initial maximum relief in sandbox. Then tilt sandbox to uplift mountain, and allow water to erode valleys as channels steepen. Measure increased relief after erosive period.

Students devise ways to measure flow velocity, cross-sectional area, and discharge in the field

Low-relief Appalachian landscape

High-relief Himalayan landscape

Deeply incised low-relief Andean plateau

**How does water shape landscapes?**  
**What drives relief change?**  
**How does erosion exhume rocks from depth?**

**Learning Goals:** Students should be able to explain 1) how channel gradient, water discharge, sediment size, and vegetation influence stream power for sediment transport, and 2) how uplift, base-level change, & precipitation can drive relief change.

**Context:** Builds on previous topographic map & landscape study activities. Should be accompanied by discussion of erosion, deposition, & relief motivated by slides or images of real landscapes to compare/contrast with local landscape. Students should be familiar with the concept of independent variables, dependent variables, hypothesis, & control, and steady vs. transient landscapes.

**Materials:** Sandbox setup with sand, water inlet & outlet, adjustable gradient; small pebbles, net or baffle to simulate vegetation; overhead transparency sheets to set channel width; stopwatch and sediment trap can also be used to measure erosion rates.

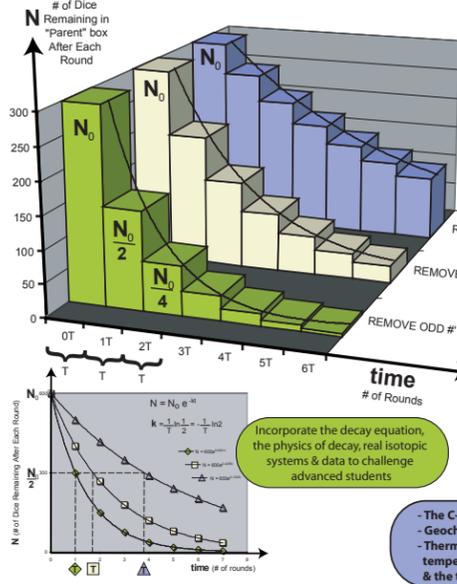
For advanced students, these activities serve to introduce the Stream Power Law, & learn concepts that can be explored in a seminar setting based on research paper readings.

**Activity III:** Use a straight, vertical cut through the sandbox model to create a cross section. Stick a marble in the sand in the plane of the cut, but 3 cm below the surface. Erode sand from the top until the marble is exhumed. Discuss qualitatively how faster erosion exhumed a marble buried at a given depth more rapidly than slower erosion.

**Evaluation:** 1) Students take a photo of a local river & describe how it's gradient, discharge, sediment size, width & vegetation affect the flow, and devise ways to measure these characteristics.

2) Students write essay about how one aspect of the landscape in the photograph is transient or steady, and specify the appropriate length & time scale for their observation.

## Dice & Dating with Geologic "Stopwatches"



**How do we measure rates of landscape evolution? How can Radioactive Decay tell us when dinosaurs lived, a volcano erupted, or the Earth formed?**

**Learning Goals:** 9th-graders should be able to 1) plot and interpret experimental data and trends in an x-y graph, 2) describe the concepts of radioactive decay and half-life, 3) describe how Parent and Daughter abundances are used to calculate relative ages for isotopic systems or "geologic stopwatches" with different half-lives, 4) describe what measured dates for the C-14 system, a geochronometer, and a thermochronometer represent.

**Context:** For the basic activity, students should understand how to construct bar graphs and x-y plots

**Materials:** Blackboard, large number of dice (donated free by a casino), boxes labeled "Parent" and "Daughter." Optional: Excel spreadsheet or graphing calculator.

**Basic Activity:** For each round, shake "Parent" box with all dice in it and have students remove the odd-numbered dice and put them in the "Daughter" box. Plot the Round # vs. the number of dice remaining in the "Parent" box. Plot trend of data, and find the number of Rounds equal to a half-life from the plot (~1 round in this case). Repeat for other "isotopic systems" with different half-lives.

**Evaluation:** Students use in-class graphs to rank relative age for different combinations of Parent and Daughter abundances and half-lives. Students synthesize ideas from marble exhumation activity & thermochronometer stopwatches to measure erosion rates (distance over some area per time)

- The C-14 "stopwatch" starts ticking when a plant dies  
- Geochronology "stopwatches" record time since a mineral crystallized  
- Thermochronology "stopwatches" start when a buried rock cools below a certain temperature as erosion removes overlying rocks & brings it closer to Earth's surface, & the time it takes to cool depends on the erosion rate

## Measuring Rates of Landscape Evolution

**How do millions of years of erosion & mountain building shape Earth's surface?**

**Learning Goals:** Students should be able to explain how erosion rates can be calculated in (volume/time) measurements & (distance over area/time), carry out these measurements on model landscapes, and explain how rates are determined for real landscapes. Students should be able to give examples of how the cumulative effects of gradual processes acting over large distances and geologic time shaped landscapes near their homes, and in some interesting locations around the world.

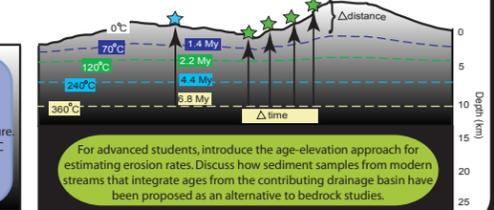
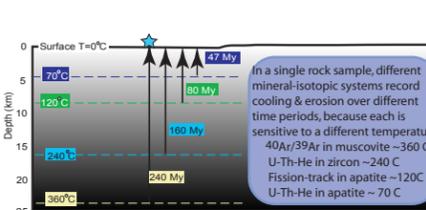
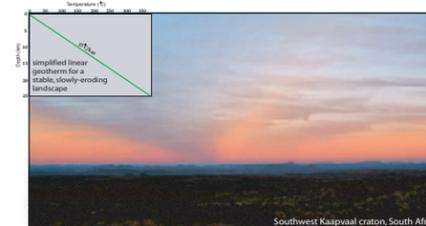
**Context & Materials:** Builds on knowledge of erosional & depositional processes, erosion rate measurements, and quantitative thermochronology, and uses same setup as previous activities.

**Activity I:** Use sandbox model & thermochronometer "stopwatches" to measure erosion. a) 3 students each bury a marble to a different depth beneath sand pile of uniform thickness. Marble travel time to the surface is measured with stopwatches as sand is "eroded" in a spatially uniform way (e.g. using water or paintbrushes). Use initial depth & time to calculate rates - analogous to using multiple thermochronometers on a single rock sample. b) Students bury multiple marbles at the same depth beneath "mountainous" topography, then "erode" the model landscape in a non-uniform fashion (e.g., increase relief through incision). Calculate how erosion rate varies on ridges & in valleys - analogous to using one thermochronometer over a large area.

**Evaluation I:** Students interpret cooling age distributions on simplified topographic maps in terms of erosion rates.

**Activity & Evaluation II:** Integrate with cutting-edge research: After lab groups model rates (cm/hour) over the area of the landscape model, and volume eroded from model (per time), individual students relate these rates to geologic rates (km/My) for case studies in the Nepal Himalaya, the Southeast US Appalachians, and the Kaapvaal craton in South Africa, using real sample ages for a particular thermochronometer & temperature and an assumed geothermal gradient.

Advanced students discuss geothermal gradients & use journal articles to learn about influence of thermal parameters, erosion, topography, and faulting on the thermal structure beneath the surface, & how scientists use thermochronology to study these effects



In a single rock sample, different mineral-isotopic systems record cooling & erosion over different time periods, because each is sensitive to a different temperature: <sup>40</sup>Ar/<sup>39</sup>Ar in muscovite ~360 C, U-Th in zircon ~240 C, Fission-track in apatite ~120C, U-Th in apatite ~70 C

For advanced students, introduce the age-elevation approach for estimating erosion rates. Discuss how sediment samples from modern streams that integrate ages from the contributing drainage basin have been proposed as an alternative to bedrock studies.