Why Are the Appalachian Mountains So High?

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Adirondacks from Mt. Marcy, NY

Steep Topography
(30 m at Lake Champlain)

High elevation
(1630 m at summit)

Old Rocks from deep crust
(1200 Ma Anorthosite, crystallized at 15-20 depth)

Photo by Jef Renaud
Eastern North America Topography

From Geological History of Jamestown, Rhode Island web site
Earth’s Interior

- Pressure at center is 350 Gpa (3,500,00 atmospheres)
- Temperature at center: 5430 °C (9800 °F)

UC Berkeley Seismo Lab
Continents v. Oceans

Continental crust
• Light granite: “floats” on surface
• Formed by continental collision
• Old (4000 My) to very young

Oceanic crust
• Heavy basalt: subducts into mantle
• Formed at mid-ocean ridges
• Young <185 My to right now!

Rigid & elastic
• Continental Drift was first proposed by Alfred Wegner in 1912

• Strong geological evidence for drift, but no physical mechanism for moving the continents through the oceans

• Modern theory of sea floor spreading /Plate Tectonics developed in 1950s - 1970s
Plate Map

Earth’s Dynamic Systems /W. Kenneth Hamblin and Eric H. Christiansen
Plate Boundaries

CONVERGENT PLATE BOUNDARY
TRANSFORM PLATE BOUNDARY
DIVERGENT PLATE BOUNDARY
CONVERGENT PLATE BOUNDARY
CONTINENTAL RIFT ZONE (YOUNG PLATE BOUNDARY)

ISLAND ARC
TRENCH
SHIELD VOLCANO
OCEANIC SPREADING RIDGE
TRENCH

LITHOSPHERE
ASTHENOSPHERE
HOT SPOT
OCEANIC CRUST
SUBDUCTING PLATE
CONTINENTAL CRUST

Virtual Upper Mantle of the Earth web site
Hawaiian Hot Spot

Figure 3. — A schematic cut-away view along the island chain, showing the inferred mantle plume that has sustained the Hawaiian hotspot on the overriding Pacific plate. The geologic ages of the oldest volcano on each island are progressively older to the northwest, consistent with the hotspot model for the origin of the Hawaiian Ridge-Emperor Seamount Chain. View prepared by Joel E. Robinson (USGS).

Subduction zones

(A) The Philippine Islands represent the convergence of two oceanic plates.

(B) South America represents the convergence of an oceanic plate and a continental plate.

(C) The Himalaya Mountains represent the convergence of two continental plates.
Wilson cycle

A - Stable Craton

B - Early Rifting
   Continent in two pieces; new ocean basin opening

C - Full Ocean Basin
   Continents widely separated

D - Subduction Zone
   Ocean basin begins to close

E - Closing Remnant Ocean Basin
   Ocean basin almost closed; collision about to occur

F - Collision Orogeny
   Right continent overrides left continent; ocean basin closed

G - Penetrated Mountain
   Mantle is eroded to sea level; tectonic stability again

Lynn S. Fichter/James Madison University
Building the Appalachians: Precambrian to Paleozoic
Geology of North America

Michael L. Ziertek and Greta J. Orris
USGS Open File report 2005-1294A
Geologic Map of Eastern North America

USGS
“Suspect” Terranes

Hibbard et al, 2006
Rodinia - 700 My

Paul Hoffman, Science, v. 252, p. 1409

After Hoffman, 1991
Passive Margin
Early Cambrian - 550 My

- Maps from Ron Blakely
- Cross-sections from Virginia Geology web site and USGS
Taconic Orogeny
Ordovician - 450 My

Ron Blakely and USGS
Acadian Orogeny

Devonian - 385 My

Ron Blakely and USGS
Alleghany Orogeny
Pennsylvanian & Permian - 290 My

The Paleozoic Appalachians were probably similar to today’s Himalaya Mountains

Ron Blakely and USGS
Rifting of Pangaea
Triassic - 195 My

North America
Africa

Ron Blakely and JMU
Triassic rifting: Opening of the Atlantic

~200 My

(A) Continental rifting begins when the crust is uparched and stretched, so that block faulting occurs. Continental sediment accumulates in the depressions of the downfaulted blocks, and basaltic magma is injected into the rift system.

~185My

(B) As the continents separate, new oceanic crust and new lithosphere are formed in the rift zone, and the ocean basin becomes wider. Remnants of continental sediment can be preserved in the down-dropped blocks of the new continental margin.

FIGURE 17.15 Divergent plate boundaries are found in the ocean basins and continents. The midocean ridge is one type of divergent plate boundary and has abundant normal faults, shallow earthquakes, and basaltic magmatism.

Earth’s Dynamic Systems / W. Kenneth Hamblin and Eric H. Christiansen
“How many years can a mountain exist
Before it's washed to the sea?”

- Bob Dylan, *Blowin’ in the Wind*
The Last 200 My

• Eastern North America is a “passive” margin
  – Sedimentation along the Atlantic coast
  – Far from active plate boundaries

• Passage over the Great Meteor hotspot 125-90 My

Unsolved question is the persistence of high Appalachian topography to the present
Great Meteor Hotspot Track

McHone, 1996

Hot spot in New England 125-100 My
North America 115 My ago

Map by Ron Blakely
Evidence for Hotspot Uplift

Devonian sediments are truncated

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Figure 3. Isopach and lithofacies relations for Middle Devonian sediments in Appalachian basin south of hotspot track (from Sloss and others, 1960). Contours of sediment thickness (in feet) are not drawn where Middle Devonian sediments are exposed at surface and eroded. Patterns indicate ratio of clastic to nonclastic sediments. These deposits once extended farther north, and there is no indication of northern cratonic source area.

Crough, 1981
Thermochronology

Apatite grain w/tracks

Apatite fission track (AFT) ages tell when a rock cooled through approximately 100 °C, or about 4-5 km depth.

Assumed geothermal gradient converts temperature to depth

Stanford University

New England AFT ages

Roden-Tice and Tice, 2005
Offshore sediments

Fig. 85 from USGS, Geology of New York City area
Sediment Supply to Atlantic Basins

Pulse in sedimentation (& uplift?) ~15 My

Total Flux Due To Mechanical Erosion

Flux of Eroded Rock

(10^3 km^3 of rock/m.y.)

Pazzaglia and Brandon (1996)
Poag and Sevon (1989)
Seismic structure of the Earth

Stephen A. Nelson, Tulane University
S-wave velocities in New England

Li et al (2002)

Remnant of Great Meteor hot spot?
Structure of North American mantle constrained by simultaneous inversion of multiple-frequency $SH$, $SS$, and Love waves

Tian, Yue, Ying Zhou, Karin Sigloch, Guust Nolet, and Gabi Laske (2011)
Farallon plate beneath North America

High S velocity =
- low temp
- high density

Grand et al, 1997
IRIS Earthscope TA Stations

Incorporated Research Institutions in Seismology
The “Great” Unconformity near Alexandria Bay, NY

Chris Murray, Thousand Islands Life web site
Saga of the Potsdam sandstone
Questions?
Further Reading

• Mountain Press Roadside Geology Series
  – Fr. James Skehan, S.J.: MA and CT/RI
• USGS Geology of the New York City Region
• Geological Evolution of Virginia and the Mid-Atlantic Region – Lynn S. Fichter/James Madison University
  – http://csmres.jmu.edu/geollab/vageol/vahist/
• Geological History of Jamestown, Rhode Island
  – http://www.jamestown-ri.info/northern_appalachians.htm
• PhysicalGeography.net
  – http://www.physicalgeography.net/
• Ron Blakely Paleogeographic Maps
  – http://cpgeosystems.com/paleomaps.html
Bibliography


