# The Teacher-Friendly Guide to the GEOLOGY of the NORTHEASTERN U.S.

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Ithaca, New York

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# Preface

Geology is an inherently local subject. No two places share exactly the same sequence of geological events that led to the way they are today. In this sense, geology is a subject to be explored in one's own neighborhood, examining the detailed sequence of rocks for the history that has gone on under our feet. What is *not* possible from only one location is making sense of why this particular sequence of rocks formed when and where it did, particularly relative to sequences in other places around it.

The distribution of rocks and landforms can be explained by processes that shape areas covering thousands of kilometers, such as the volcanism, mountain building, and sedimentary basins that accompany converging tectonic plates. These processes link widely separated sequences in a common history.

Earth science educators at the Paleontological Research Institution, in working with teachers, have noted that no single source for educators exists that attempts to make sense of the disparate local features of the Northeastern United States in terms of a basic sequence of historical events and processes. Nationally distributed textbooks make few references specifically to the Northeast region. While a number of reasonably good resources exist for individual states, these do not take enough geographic scope into account to show how, say, the coals of Pennsyvlania are related to the Late Ordovician limestones of Upstate New York, or how the igneous intrusions into Maine are related to the dinosaur-footprint bearing rocks of the Connecticut River Valley. Further, these resources are not necessarily "teacher-friendly," or written with an eye toward the kind of information and graphics that a secondary school teachers might need in their classrooms. This guide is intended to fill this need for teachers.

Explaining *why* geological features occur when and where they do is the most effective way of providing students with a tool to remember and predict the nature of local geology. The 'Northeast' is of the right scale to discuss the evolution of signficant portions of mountain ranges and sedimentary basins, and to be illustrative of a wide spectrum of geological processes. The size of the region is, however, sufficiently limited that the distance between any two points is within a day's drive, and geological phenomena can be illustrated with examples in areas students and teachers are likely to have been to or at least heard of. Since regional rocks and landforms are relatively accessible, geology at this scale is an excellent subject for hands-on, inquiry-based teaching using real materials and examples. A transect across the Northeast in several places will reveal most major rock types that students need to know and will come into contact with over the course of their lifetimes.

The chapters chosen are by no means an exhaustive list of possible topics, but reflect especially the historical side of "solid Earth" geosciences. Each chapter starts with a Big Picture overview, then (in most chapters) a brief review, followed by a description of the geology of four *natural* geological regions within the Northeast. The activities at the end of each chapter are open-ended; they should be treated as suggestions in need of modification according to student background and curricular goals. Some activities depend on extra materials, but most can be done with appropriate geologic and topographic maps and a copy of the American Association of Petroleum Geologists Geological Highway Map of the Northeastern U.S. (see General Resources). There is a resource list at the end of each chapter, as well as a detailed list of specific resources for each state at the beginning of *The Guide*.

The second Saturday of each month in the exhibit space at PRI is a day the public brings fossils for identification by a paleontologist. When someone brings a fossil the first question we ask is "Where did you find it?" Knowing regional geology enables us to put the specimen in context. If the fossil-bringer said the specimen was from around Ithaca, perhaps slightly south, our response might be "ahh, so this must be Upper Devonian. It formed in a shallow delta-like setting... No, that couldn't be a feather — there were no birds around in the Upper Devonian. I think it must be a fairly rare fossil cnidarian called *Plumalina*." The reason we can make these estimations based on the locality is that many hundreds of geologists have helped piece together a coherent story of the geological history of the region. It is our hope that this book might present to teachers, and their students, a coherent "big picture" story that enables them to understand more deeply the meaning of their local geology and apply more easily theoretical concepts to the geology of their region.

*Robert M. Ross*
*Director of Education*
*The Paleontological Research Institution*

# Preface for the 2016 reprint

In 2000, *The Teacher-Friendly Guide to the Geology of the Northeastern U.S.* was published by the Paleontological Research Institution (PRI), to help teachers better integrate local and regional geology into their Earth science curriculum. The *Guide* was published with "seed" funds from the Arthur Vining Davis Foundations, under the commitment that PRI would use the published *Guide* to seek additional funding to develop six similar *Guides* for other regions of the country. The "*Northeast Guide*," as it became known internally, was produced over the course of a year with substantial input from teachers and geoscientists. At the suggestion of teachers, it was printed in a yellow three-ring binder to make it easy to photocopy pages or add new ones. Soon afterward, PDF copies of chapters were posted on PRI's website.

In the early 2000s funds were raised for a "*Southeast Guide*" from the Atlantic Philanthropies, Georgia Pacific, the River Branch Foundation, and the Childress Foundation. The *Southeast Guide* incorporated more content from authors outside PRI than had the *Northeast Guide*. Individual chapters were made available as PDFs on the website, and a limited number of internally printed copies in orange three-ring binders were made for workshops.

In 2005, PRI received "proof-of-concept" funds from the National Science Foundation to develop a new pedagogical model by which teachers could engage students in inquiry-based learning using real-world geology. This model became known as "Virtual Fieldwork Experiences." New online chapters on Virtual Fieldwork and Big Ideas in Earth Science were added to the *Northeast Guide*.

In 2007 PRI received a $1.8 M grant from NSF to create *Teacher-Friendly Guides*™ for the remaining five regions of the country and to offer teacher professional development on implementation of virtual fieldwork experiences in each of those regions. This grant funded the online versions of the new *Guides* and approaches, including new dedicated PRI websites, teacherfriendlyguide.org and virtualfieldwork.org. The *Northeast* and *Southeast Guides* were the first to be added to teacherfriendlyguide.org. In 2012 the *Southeast Guide* was redesigned for a bound printed version, inspired by but slightly different from the original *Guide*, and a glossary was added; this became a prototype for printed and PDF versions of the five new Guides.

To the new *Guides* we added chapters on energy, climate, soils, and Earth hazards, and expanded the lists of other printed and online resources useful to teachers. In the title we replaced "Geology" with "Earth science" to reflect the broader scope of the *Guides* and to acknowledge that the focal audience is Earth science teachers. The five new *Guides* were written by a combination of PRI staff and external writers with special knowledge of the regions and topics, and almost every chapter was reviewed by at least two external reviewers. The *Guides* were heavily edited to provide uniform treatment and writing style across the chapters and volumes, many new illustrations were added, and photographs were incorporated. A new cover design and logotype were created for the series. A 2$^{nd}$ edition of the *Southeast Guide*, with many revisions and additions, was also published. Six *Guides* -- five new regional *Guides* and the revised *Southeast Guide* -- were printed between October 2013 and September 2016.

As we undertook the national series of Earth science *Guides*, it became evident that the concept for *Teacher-Friendly Guides* – incorporating familiar, real-world examples into curricula – can be applied to other important topics in the natural sciences. Several new online *Teacher-Friendly Guides* were written as part of the outreach associated with colleagues' NSF research grants, including *Evolution using Bivalves as a Model Organism* (2011), *Evolution of Maize* (2011), and *Climate Change* (in preparation).

Though now 16 years old, the quality of the original *Northeastern Guide* has withstood well the test of time. While it does not contain all of the topics of the new *Guides*, and parts need updating, the original *Northeast Guide* remains a useful resource. Thus, as a symbol of completing the national series of regional Earth science *Guides*, we have produced a small number of reprints of the original *Northeast Guide*, with Big Ideas and Fieldwork chapters incorporated, bound in the manner of other volumes of the series.

Robert M. Ross,
Associate Director for Outreach, PRI
September 2016

# Table of Contents



## Geologic History of the Northeastern US



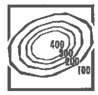
## Rocks of the Northeastern US



## Glaciers of the Northeastern US



## Fossils of the Northeastern US



## Topography of the Northeastern US

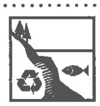


## Mineral Resources of the Northeastern US



## Non-Mineral Resources of the Northeastern US



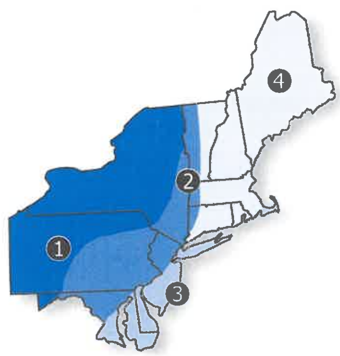


## Environmental Issues of the Northeastern US

# How To Use the Guide

The guide uses *four broad regions* based on natural geological divisions:

1. *Inland Basin*
2. *Appalachians &Piedmont*
3. *Coastal Plain*
4. *Exotic Terrane*




**Each Chapter Includes:**

- ***the BIG picture***: a brief summary of each region
- ***a brief review***: an overview of basic concepts
- ***the four regions:*** in-depth
- ***activities***
- ***resources***

***You do not have to read this guide from front to back!***

Each chapter is written to stand alone; there is built-in repetition of main concepts between chapters and regions to facilitate concentrating on a specific region or using different parts of the guide throughout the year. The chapters are conveniently cross-referenced to find more information about a concept or region.

Use the ***color Geologic Map*** and time scale *(found in the front pocket)* as a reference tool while you read the guide.

***The first and last chapters*** have a slightly different format. ***Geologic History*** gives you the big picture of geological processes in the Northeast region as a whole. ***Environmental Issues*** also looks at the entire Northeast, as these issues are not as closely tied to the bedrock geology of specific regions.

# General Philosophy of the Guide

- This is not a curriculum; incorporate ideas from the guide into your own existing curriculum.
- Introduce geologic history into your curriculum early. This guide is organized historically because regional history is responsible for and makes sense of rocks at the surface, topography and other regional geologic patterns.
- Try to understand your local geology in the context of the geologic history of the Northeast. The guide is intended to make sense of the detail of regional geology and provide the tools to understand your local geology.
- Using *real* geology is inherently open-ended; don't be intimidated by rocks that you don't recognize or the detail and language of geology.

# National Science Standards Matrix

based on *National Science Education Standards*, 1996, National Academy Press: Washington, D.C.

### Content Standards

| *Chapter* | *A* | *B* | *C* | *D* | *E* | *F* | *G* | *H* |
|---|---|---|---|---|---|---|---|---|
| Geologic History | ■ | ■ | ■ | | ■ | | | ■ |
| Rocks | ■ | ■ | ■ | | ■ | | | |
| Glaciers | ■ | ■ | ■ | | ■ | | | |
| Fossils | ■ | ■ | ■ | ■ | ■ | | | |
| Topography | ■ | ■ | ■ | | ■ | | | |
| Mineral Resources | ■ | ■ | ■ | | ■ | ■ | ■ | ■ |
| Non-Mineral Resources | ■ | ■ | ■ | | ■ | ■ | ■ | ■ |
| Environmental Issues | ■ | ■ | ■ | | ■ | | ■ | |

| | *Content Standards* | *k-4th grade* | *5-8th grade* | *9-12th grade* |
|---|---|---|---|---|
| A | *Unifying Concepts & Processes* | • *Systems, order and organization*<br>• *Evidence, models, explanation*<br>• *Change, constancy and measurement*<br>• *Evolution and equilibrium*<br>• *Form and function* | • *Systems, order and organization*<br>• *Evidence, models, explanation*<br>• *Change, constancy and measurement*<br>• *Evolution and equilibrium*<br>• *Form and function* | • *Systems, order and organization*<br>• *Evidence, models, explanation*<br>• *Change, constancy and measurement*<br>• *Evolution and equilibrium*<br>• *Form and function* |
| B | *Science As Inquiry* | • *Abilities necessary to do scientific inquiry*<br>• *Understanding about scientific inquiry* | • *Abilities necessary to do scientific inquiry*<br>• *Understanding about scientific inquiry* | • *Abilities necessary to do scientific inquiry*<br>• *Understanding about scientific inquiry* |
| C | *Physical Science* | • *Properties and changes of properties in matter*<br>• *Motions and forces*<br>• *Transfer of energy* | • *Properties and changes of properties in matter*<br>• *Motions and forces*<br>• *Transfer of energy* | • *Structure of atoms*<br>• *Structure and properties of matter*<br>• *Chemical reactions*<br>• *Motions and forces*<br>• *Conservation of energy and increase in disorder*<br>• *Interactions of energy and matter* |
| D | *Life Science* | • *Characteristics of organisms*<br>• *Life cycles of organisms*<br>• *Organisms and environments* | • *Structure and function in living systems*<br>• *Reproduction and heredity*<br>• *Regulation and behavior*<br>• *Populations and ecosystems*<br>• *Diversity and adaptation of organisms* | • *The cell*<br>• *Molecular basis of heredity*<br>• *Biological evolution*<br>• *Interdependence of organisms in living systems*<br>• *Behavior of organisms* |
| E | *Earth & space science* | • *Properties of Earth materials*<br>• *Objects in the sky*<br>• *Changes in Earth and sky* | • *Structure of Earth system*<br>• *Earth's history*<br>• *Earth in the solar system* | • *Energy in the Earth system*<br>• *Geochemical cycles*<br>• *Origin & evolution of the Earth*<br>• *Origin & evolution of the universe* |
| F | *Science & Technology* | • *Abilities of technological design*<br>• *Understandings about science and technology*<br>• *Abilities to distinguish between natural objects and objects made by humans* | • *Abilities of technological design*<br>• *Understandings about science and technology* | • *Abilities of technological design*<br>• *Understandings about science and technology* |
| G | *Science in Personal & Social Perspective* | • *Personal health*<br>• *Characteristics and changes in populations*<br>• *Types of resources*<br>• *Changes in environments*<br>• *Science and technology in local challenges* | • *Personal health*<br>• *Populations, resources and environments*<br>• *Natural hazards*<br>• *Risks and benefits*<br>• *Science and technology in society* | • *Personal and community health*<br>• *Population growth*<br>• *Natural resources*<br>• *Environmental quality*<br>• *Natural and human induced hazards*<br>• *Science and technology in local, national and global challenges* |
| H | *History & Nature of Science* | • *Science as a human endeavor* | • *Science as a human endeavor*<br>• *Nature of science*<br>• *History of science* | • *Science as a human endeavor*<br>• *Nature of scientific knowledge*<br>• *Historical perspectives* |

# Resources by State

## CONNECTICUT

**CT Geological and Natural History Survey**
The Department of Environmental Protection
79 Elm Street
Hartford, CT 06106-5127.
http://dep.state.ct.us/cgnhs/

Bell, Michael, 1997, ***The Face of Connecticut: People, Geology and the Land***, The State Geological and Natural History Survey of Connecticut: Hartford, Connecticut.

**Connecticut Geology**
http://www.wesleyan.edu/ctgeology/

**Colby College Field Trip to Hartford Basin of CT**
http://colby.edu/geology/Hartford.html

**Newark Basin and Connecticut River Basin**
http://everest.hunter.cuny.edu/bight/newark.html

**The Geology of Litchfield County**, CT with a Terrane Map of Connecticut
http://www.angelfire.com/ct/litchfield/geology.html

## DELAWARE

**Delaware Geological Survey**
University of Delaware, Delaware Geological Survey Building
Newark, DE 19716-7501
(302) 831-2833, fax (302)831-3579
http://www.udel.edu/dgs/dgs.html
*delgeosurvey@udel.edu*

Plank, Margaret O. and William S. Schenck, 1998, ***Delaware Piedmont Geology***, Delaware Geological Survey: University of Delaware, Delaware.

Sporljaric, Nedad, 1979, ***The Geology of the Delaware Coastal Plain***, *in eds., Kraft*, J. C. and W. Carey. Selected Papers on the Geology of Delaware, Volume 1, p. 115-134. Transactions of the Delaware Academy of Science: Delaware.

## MAINE

Maine Geological Survey
22 State House Station
Augusta, Maine, 04333
207-287-2801
http://www.state.me.us/doc/nrimc/mgs/mgs.htm
mgs@state.me.us

Caldwell, D.W, 1998, ***Roadside Geology of Maine***, Mountain Press Publishing Company: Missoula, Montana.

Loiselle, M.C. and W. B. Thompson, 1987, ***The Geology of Maine***, Rocks and Minerals, Volume 62, p.386-389.

Osberg, P., A. M. Hussey and G.M. Boon, eds., 1985, ***Bedrock Geologic Map of Maine*** *(Scale 1:500,000)*, Maine Geological Survey: Augusta, Maine.

Thompson, W. B., D. L. Joyner, R. G. Woodman, and V. T. King, 1998, ***A Collector's Guide to Maine Mineral localities***, *3rd ed.* Maine Geological Survey: Augusta, Maine.

**Generalized Bedrock Map of Maine**
http://www.state.me.us/doc/nrimc/pubedinf/factsht/bedrock/bedmap.gif

**Generalized Surficial Geologic Map of Maine**
http://www.state.me.us/doc/nrimc/pubedinf/factsht/surfical/surfmap.gif

**The Geology of Maine**
http://www.state.me.us/doc/nrimc/pubedinf/factsht/bedrock/megeol.htm

## MARYLAND

**Maryland Geological Survey**
2300 St. Paul St.
Baltimore, MD 21218
(410) 554-5500
http://mgs.dnr.md.gov/

Kent, B.W., 1994, *Fossil Sharks of the Chesapeake Bay Region*, Egan Rees & Boyer: Columbia, Maryland.

Kranz, Peter M., 1989, ***Dinosaurs in Maryland.*** Educational Series No. 6, p.34. Maryland Geological Survey: Baltimore, Maryland.

Reger, James P., 1987, ***Earthquakes and Maryland.*** Maryland Geological Survey; Baltimore, Maryland.

Schmidt, Martin F., Jr., 1993 ***Maryland's Geology.*** Tidewaters Publishers: Centerville, Maryland.

Vokes, H.E., 1957, ***Miocene Fossils of Maryland***, Maryland Geological Survey Bulletin 20.

1999, ***Highest and Lowest Elevations in Maryland's Counties***, Fact Sheet No. 1, Maryland Geological Survey, Baltimore, MD.

1988, ***The River and the Rocks: the geological story of Great Falls and the Potomac River Gorge***, Geological Survey Bulletin 1471, United States Geological Survey: Reston, Virginia.

Brezinski, David K., 1994, ***Geology of the Slideling Hill Road Cut.***
http://mgs.dnr.md.gov/esic/brochures/sideling.html

**Calvert Cliffs, Maryland**
http://mgs.dnr.md.gov/esic/brochures/ccliffs.html

## MASSACHUSETTS

**MA Department of Environmental Affairs**
251 Causeway Street, 9th Floor
Boston, MA 02114
(617) 626-1000, fax (617) 626-1181
http://www.magnet.state.ma.us/envir/eoea.htm

Grabau, A.W. and J.E. Woodman, eds., 1898, ***Guide to Localities Illustrating the Geology, Marine Zoology, and Botany of Boston***, Salem Press Co.: Salem, MA.

Oldale, Robert N., 1992, ***Cape Cod and the Islands, the Geological Story***, Parnassus Imprints: East Orleans, Massachusetts.

Skeehan, J., in press, ***Roadside Geology of Massachusetts***, Mountain Press Publishing Company: Missoula, Montana.

## NEW HAMPSHIRE

**NH Department of Environmental Services**
**6 Hazen Drive**
**P.O. Box 95**
**Concord, NH 03302-0095**
**(603) 271-3503**
http://www.des.state.nh.us/descover.htm

Van Diver, Bradford B., 1987, ***Roadside Geology of Vermont and New Hampshire***, Mountain Press Publishing Company: Missoula, Montana.

**New Hampshire Geological Society**
http://nhgs.org/NHGS/

## NEW JERSEY

**New Jersey Geological Survey**
29 Arctic Parkway, P.O. Box 427
Trenton, NJ 08625
(609) 292-1185, fax (609) 633-1004
http://www.state.nj.us/dep/njgs/index.html

Dooley, John H. and David P. Harper. 1996. ***New Jersey Rocks and Sediments.*** New Jersey Geological Survey; New Jersey.

Subitzkey, Semour, ed., 1969, ***Geology of Selected Areas in New Jersey and Eastern Pennsylvania***, Rutgers University Press: New Brunswick, New Jersey.

Sugarman, Peter, 1998, ***Sea Level Rise in New Jersey***, New Jersey Geological Survey: New Jersey.

Wolfe, Peter E., 1977, ***Geology and Landscape of New Jersey***, Crane Russak: New York.

Yotton, James S., ***Brownstone Industry of New Jersey***, Educational Series, New Jersey Geological Survey: Trenton, New Jersey.

**Earthquake Risk in New Jersey**
http://www.state.nj.us/dep/njgs/enviroed/eqrisk.htm

**Fossils of New Jersey**
http://www.home.earthlink.net/~skurth/

**Franklin Mineral Museum**
www.geocities.com/CapeCanaveral/Lab/6347

**Geology Field Trip: Hunterdon County, NJ**
http://www.hcrhs.hunterdon.k12.nj.us/science/geology/falltrip.html

**Geologic Map of New Jersey**
http://www.rci.rutgers.edu/%7Egeolweb/geomap.html

**Newark Basin and Connecticut River Basin**
http://everest.hunter.cuny.edu/bight/newark.html

**New Jersey Science Teachers Association**
http://www.rain.org/~rcurtis/njsta.html

**Sterling Hill Mining Museum**
http://sterlinghill.org

## NEW YORK

**New York State Geological Survey, NYS Museum**
State Education Department
Education Building
Albany, New York 12234
http://www.nysm.nysed.gov/geology.html

Isachsen, Y.W., E. Landings, J.M. Lauber, L.V. Rickard, and W.B. Rogers, eds., 2000, ***Geology of New York, A Simplified Account,*** New York State Geological Survey, New York State Museum Cultural Education Center: Albany, New York.

Jensen, D.E., 1978, ***Minerals of New York State,*** Ward press: Rochester, New York.

Schuberth, Christopher J., 1968, ***The Geology of New York City and Environs,*** Natural History Press: Garden City, New York.

Tesmer, L. H., ed., 1981, ***Colossal Cataract: The Geological History of Niagara Falls,*** State University of New York Press: Albany, New York.

Titus, Robert, 1993, ***The Catskills: A Geological Guide,*** United StatesGeological Survey, Purple Mountain Press: Fleshmanns, New York.

Von Engeln, O.D., 1961, ***The Finger Lakes Region: Its Origin and Nature,*** Cornell University Press: Ithaca, New York.

Van Diver, Bradford B., 1985, ***Roadside Geology of New York,*** Mountain Press Publishing Company: Missoula, Montana.

**Basic Geology and Neotectonics of the Adirondacks**
http://www.geo.wvu.edu/~tsattler/tectonics/adirondack/mountains.html

**Bedrock Geology of New York**
http://gretchen.geo.rpi.edu/roecker/nys/nys_edu.pamphlet.html

**Chimney Bluff**
http://www.oswego.edu/Acad_Dept/a_and_s/earth.sci/geo_geochem/geol/chimney.html

**Deposition of the Catskill Clastic Wedge: Middle and upper Devonian History**
http://www.stepahead.net/~schneller/devohist.htm

**Earth Science Program Innovation/Resources Team**
http://home.computer.net/~tmcguire/esprit.html

**Geology of the Catskills**
http://everest.hunter.cuny.edu/bight/catskill.html

**Geology and Geography of New York Bight Beaches**
http://www.geo.hunter.cuny.edu/bight/

**Geology of the Hudson Highlands**
http://everest.hunter.cuny.edu/bight/highland.html

**Geology of Westchester County, New York**
http://home.computer.net/~tmcguire/

**Long Islands's Natural Environment On-line**
http://www.journey.sunysb.edu/longis/

**New York State Academy of Mineralogy**
http://www.nysm.nysed.gov/nysam/

**New York State Museum Bulletins**
http://www.columbia.edu/dlc/nysmb/mb95/

**New York State Geological Association**
http://www.library.csi.cuny.edu/dept/as/geo/nysga.html

**New York State Geological Survey (unofficial)**
http://www.albany.net/~go/survey/

**New York Paleontology**
http://bingweb.binghamton.edu/~kwilson/home.htm

**New York Paleontological Society**
http://www.nyps.org/

**Overview: the Geology of Eastern New York**
http://www.hartwick.edu/geology/work/VFT-so-far/overview.html

**Overview of New York Geology**
http://gretchen.geo.rpi.edu/roecker/nys/nys_edu.pamphlet.html

**The Rochester Academy of Science Fossil Section**
http://www.ggw.org/ras/fossil/

## PENNSYLVANIA

**Pennsylvania Topographic and Geologic Survey**
P.O. Box 8453
Harrisburg, PA 17105-8453
(717) 787-2169
http://www.dcnr.state.pa.us/

Barns, John H., 1991, ***Rocks and Minerals of Pennsylvania,*** Educational Series 1, Pennsylvania Geological Survey: Harrisburg, Pennsylvania.

Barns, John H., and W. D. Sevon. 1996, ***The Geological story of Pennsylvania,*** *Educational Series #4*, Pennsylvania Geological Survey: Harrisburg, Pennsylvania.

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Van Diver, Bradford B., 1990, ***Roadside Geology of Pennsylvania,*** Mountain Press Publishing Company: Missoula, Montana.

**Pennsylvania Minerals**
http://www.pennminerals.com/

**Philadelphia Academy of Natural Science**
http://www.acnatsci.org/

**Delaware Valley Earth Science Society**
(field trips and fossil collecting)
www.dvess.org

## RHODE ISLAND

**Rhode Island Geological Survey**
**University of Rhode Island**
**Department of Geosciences**
**Kingston, RI 02881**
**(401) 874-2265, fax (401) 874-2190**
**rigsurv@etal.uri.edu**
http://nick.uri.edu/cels/gel/rigs.html

Miller, Clarence E., 1972, ***Minerals of Rhode Island,*** ed., Don O. Hermes, Department of Geology, University of Rhode Island: Kingston, Rhode Island.

## VERMONT

**Vermont Geological Survey**
**103 S. Main St., Laundry Building**
**Waterbury, VT 05671-0301**
**(802) 241-3608, fax (802) 241-3273**
http://www.anr.state.vt.us/geology/vgshmpg.htm

Baldwin, Brewster. 1982. ***Geology of Vermont,*** Volume 35, no. 3, American Geological Institute: Alexandria, Virginia.

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**Vermont Glaciers Virtual Field Trip**
http://geology.uvm.edu/geodept/ugradwww/glacier/index.html

**Vermont Historical and Geological Images**
http://geology.uvm.edu/morphwww/vtimages/index.html

**Vermont Landforms Virtual Field Trip**
http://geology.uvm.edu/vtlandforms/main.htm

**Vermont State Rocks and Minerals**
http://www.anr.state.vt.us/geology/news.htm

# General Resources

## *Maps*

American Association of Petroleum Geologists, 1995, *Geological Highway Map of the Northeastern Region,* Map no. 10.

*Geologic Map of the United States*, 1974, Scale 1:2500000, United States Geological Survey.

Topozone.com
http://www.topozone.com

National Geologic Maps Database
http://ngmdb.usgs.gov/ngmdb/ngm_catalog.ora.html

## *Internet*

American Museum of Natural History
http://www.amnh.org/

Ask-A-Geologist
http://walrus.wr.usgs.gov/docs/ask-a-ge.html/

Frank Potter's Science Gems
http://www.sciencegems.com/

Geology Labs On-Line
http://vcourseware3.calstatela.edu/GeoLabs/index.html

Geology Link
http://www.geologylink.com/

Learning From the Fossil Record
http://www.ucmp.berkeley.edu/fosrec/fosrec.html

Learning Web: Careers in Geosciences, activities and lessons
www.usgs.gov/education/index.html

The Virtual Geosciences Professor
http://www.uh.edu/~jbutler/anon/anonfield.html

A Geologist's Lifetime Field List:
http://www.uc.edu/geology/geologylist/

## *Field Guides*

Molitor, L. L., 1988, *Classic Field Sites for Teaching Geology in the Northeast,* Northeast Geology, Vol.10, No.1.

Roy, D. C., ed., 1987, *Northeastern Section of the Geological Society of America: Centennial Field Guide,* Volume 5, Geological Society of America: Boulder, Colorado.

*New England Intercollegiate Geological Conference field trip guidebooks*
found in New England university and public libraries.

## *Geological Organizations*

American Association of Petroleum Geologists (AAPG)
http://www.aapg.org/

American Geological Institute (AGI)
http://www.agiweb.org/

Association for Women Geoscientists (AWG)
http://www.awg.org/

Geological Society of America (GSA)
http://www.geosociety.org/

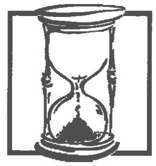
National Earth Science Science Teachers Association (NESTA)
http://www.soe.csusb.edu/NESTA

National Association of Geoscience Teachers (NAGT)
http://www.nagt.org/

The Paleontological Research Institution (PRI)
http://www.priweb.org/

United States Geological Survey (USGS)
http://www.usgs.gov/

# Geologic History of the Northeastern US: *the BIG picture*



*Geologic history is the key to this guide and to understanding the story recorded in the rocks of the region. The subsequent topics revolve around this central chapter. By understanding the historical context of the rocks and geologic processes observed in the Northeast region, we can make sense of geology. The rocks in your backyard fit into a much larger story of shifting plates and colliding continents. By knowing more about the geologic history of our region, you can better understand the type of rocks that are in your backyard and why they are there. Rather than focus on specific periods in geologic time, we will look at the history of our region as it unfolds: as a series of major events over the past one billion years and how those events created and shaped the Northeast. These events will act as the framework for the topics to follow and will shed light on why our region looks the way it does!*

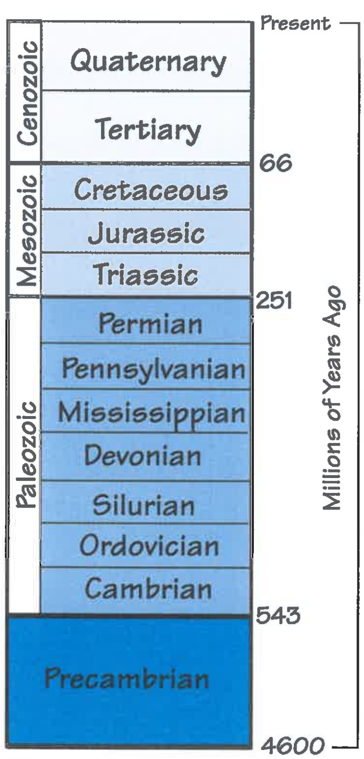



*Figure 1.1: Geologic Time Scale (not to scale).*

## Geologic time

*How did geologists come up with a timeline for the history of the Earth? Over the course of many years and through the combined work of geologists around the world, the Geologic Time Scale was developed (Figure 1.1). There is not a rock record in any one place that has the complete sequence of rocks from Precambrian to the present. Geology as a science grew as geologists studied individual sections of rock. Gradually evolutionary successions of fossils were discovered that helped distinguish the relative ages of groups of rocks. Rock units were then correlated with similarly-age rock units from around the world. The names you see for the different periods on the Geologic Time Scale have diverse origins. Time periods were named after dominant rock types, geography, mountain ranges and even ancient tribes like the Silures of England and Wales, from which the 'Silurian' Period was derived.*

# Mountain Building Part I: *the Grenville Mountains*

North America was not always the shape we see today. The continent was formed over billions of years, and geologic processes continue to shape it today. The Earth is estimated to be 4.5 billion years old. The ***oldest rocks*** that we know of are nearly 4 billion years old. Although these ancient rocks are found on almost every continent, none are found at the Earth's surface in the Northeast. In North America, these most ancient rocks are found exposed at the surface in many parts of Canada. These rocks make up the Precambrian shield, a stable continental landmass that is the core of North America. The dynamic plates of the Earth are constantly in motion, made of rigid continental and oceanic crust overlying the churning, plastically flowing ***asthenosphere*** *(Figure 1.2)*. Plates are pulling apart, colliding into one another, or sliding past each other with great force, creating strings of volcanic islands, new ocean floor, earthquakes, and mountains, melting rock and injecting magma into the overlying crust. As these plates move, the continents resting atop them are continuously shifting position. This not only shapes the land, but also affects the type of rocks and minerals, natural resources, climate and life present.

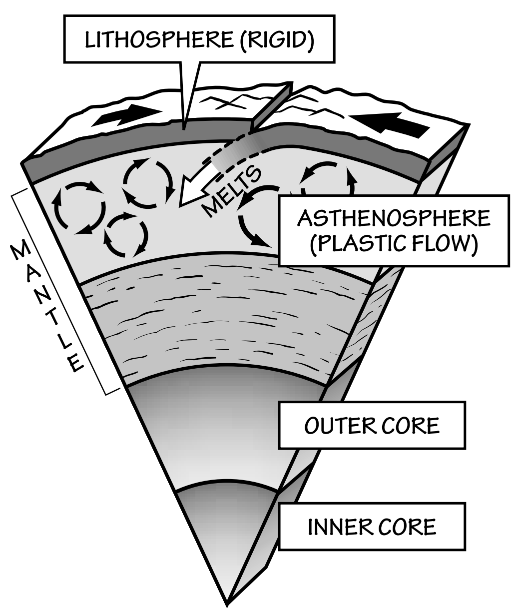



*Figure 1.2: The layers of the Earth include the rigid crust of the lithosphere, which is constantly moving over the plastically flowing asthenosphere.* Figure by J. Houghton.

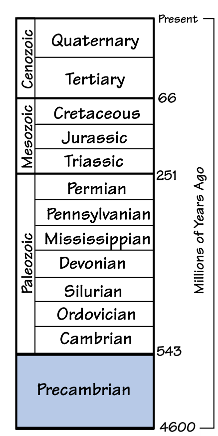
A series of additions of land to North America, compressions from colliding plates, stretching from the pulling apart of plates, and erosion have combined to slowly sculpt the form of the continent. The earliest positioning and shape we can reconstruct of North America dates back billions of years to the formation of continents. Narrow strips of land were smashed together to form the beginnings of North America and what is now the ***Precambrian shield.***

*The* **oldest rocks** *found on Earth date back 3.9 billion years. Ancient metamorphic gneiss from this time is found in South Africa, Antarctica, Greenland and Northwest Canada. Sedimentary rocks of the same age have been found in western Australia.*

### How do plates move?

*The* **lithosphere** *is the outermost layer of the Earth, a rigid crust and upper mantle broken up into many plates. The heat and pressure created by the overlying lithosphere, make the solid rock of the* **asthenosphere** *bend and move like metal when heated. The flowing rock in the asthenosphere moves with circular convection currents, rising when hot and falling when cool. The plates of the lithosphere move with the underlying asthenosphere, as much as 18 cm/yr (but normally much less.)*

*The* **Precambrian shield** *has had very little tectonic activity (faulting, folding) for millions of years. Shields are the stable cores of all continents, often covered by layers of younger sediments.*



# Geologic History

*'Proto-' North America refers to the ancestral landmass which gradually was shaped into the North American continent that we see today.*

*Many geologists believe that North America collided with* ***ancient Europe****, also called Baltica in the Precambrian.*

This ***proto-North America*** had sediment eroding off of its continental margins, into the adjacent oceans. The sediments deposited on the eastern margin of proto-North America are called the Grenville belt.

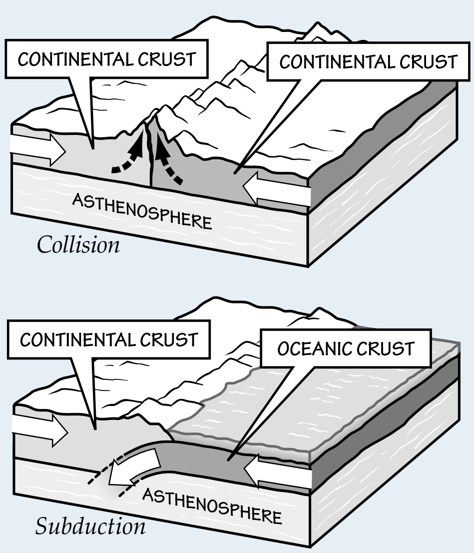
Over 1 billion years ago, proto-North America collided with ***another continent***. The Grenville belt of margin sediments was caught in between the colliding continents and was thrust up onto the side of proto-North America. The collision crumpled the crust, creating a tall mountain range that stretched from Canada to Mexico: the Grenville Mountains. These mountains are the earliest evidence of mountain building in our region, and the rocks remaining from that ancient mountain chain are the oldest rocks that we see exposed at the surface in the Northeast today.

The Grenville rocks themselves have quite a story. The intense heat and pressure generated from the collision produced volcanic material, injected hot molten rock into the crust, and metamorphosed the sediments that had eroded from the margin of the Precambrian shield before the collision occurred. Evidence of this violent past is clear in the Grenville rocks, which are usually metamorphosed sedimentary rocks with igneous intrusions (from the hot molten injections) that have been folded and overturned by the collision-induced compression.

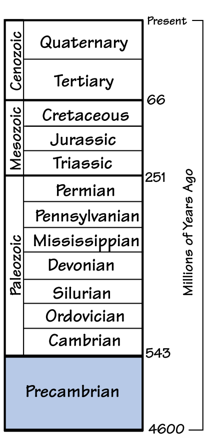
### Three types of rock

*Minerals are the building blocks of the three basic rock types: igneous, metamorphic and sedimentary. Igneous rocks form from cooling molten rock. Metamorphic rocks form by increasing the temperature and pressures on a pre-existing rock. Sedimentary rocks form by the compaction and cementation of sediment particles resulting from the breakup of pre-existing igneous, metamorphic and sedimentary rocks.*

### Continental and oceanic crust:




*The lithosphere has two types of crust: continental and oceanic. Continental crust is less dense but significantly thicker than oceanic crust. The higher density of the oceanic crust means that when continental crust collides with oceanic crust, the more dense oceanic crust will be dragged (or subducted) under the buoyant continental crust. Although mountains are created at these oceanic/continental crust collisions due to the compression of the two plates, much taller ranges are produced by continental/continental collisions. When two buoyant continental crusts collide, there is nowhere for the crust to go but up! The modern Himalayas, at the collision site of the Asian and Indian plates, are a good example of very tall mountains formed by a collision between two continental crusts.* Figures by J. Houghton.



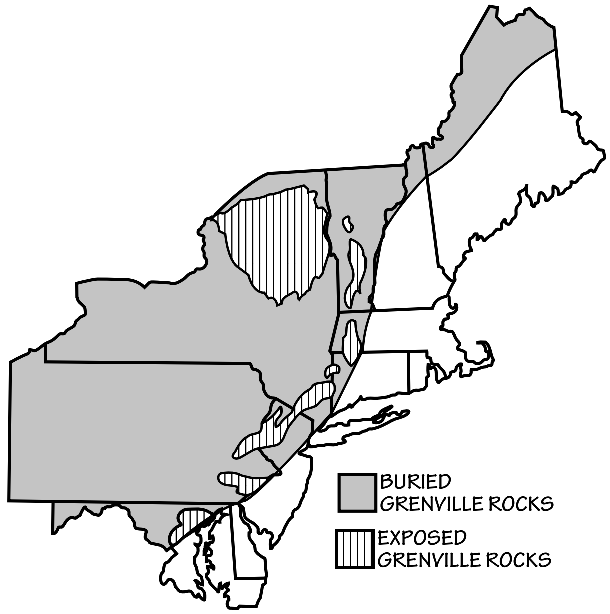



*Figure 1.3: Exposures of Grenville age rocks are found up and down the East Coast and Canada.* Figure by J. Houghton.

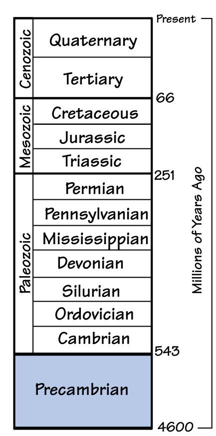
Over time, the Grenville Mountains ***eroded***, just as the Appalachians, Rockies and Himalayan Mountains are constantly being eroded today. By 600 million years ago, weathering and erosion had worn away the mountains, leaving exposed only their innermost cores. These ancient cores are the Grenville rocks that we see exposed today in the Northeast and eastern Canada *(Figure 1.3)*. The Grenville rocks are covered in many areas by younger rocks; however, exposures are found where overlying rocks have been worn away by erosion and the scraping action of glaciers. In the Northeast, the Grenville rocks are exposed in the Adirondacks, the Hudson and Jersey Highlands, Manhattan and Westchester in New York, the Green Mountains of Vermont, the Reading Prong of Pennsylvania, and the Berkshire Hills of Massachusetts.

During the erosion of the Grenville Mountains in the late Precambrian, the geography of the world looked nothing like today. North America was positioned on its side across the Equator, with today's east coast facing south. Sediments were eroding from the Grenville Mountains on either side. The ocean breaking on the shores of the east coast was known as the ***Iapetus*** or ***Proto-Atlantic Ocean***. Given the equatorial position of the continent, the

**Weathering and erosion** *are constants throughout the history of time. Rocks are constantly being worn down and broken apart into finer and finer grains by wind, rivers, wave action, freezing and thawing, and chemical breakdown. Over millions of years, weathering and erosion can reduce a mighty mountain range to low rolling hills.*

*If you could travel back in time to the Precambrian, you would not recognize the Northeast region. Parts of the Northeast were not added on until later and North America was not even in the same spot on the Earth! The Northeast region was just south of the Equator, making for much warmer weather.*

*The* **Proto-Atlantic** *is also known as the* **Iapetus Ocean***. In Greek Mythology, Iapetus was the father of Atlantis.*



Northeast was experiencing a warm climate. This is the earliest geography of the Northeast region that can be reconstructed. At this point in geologic time, all of New England east of the Berkshires and Green Mountains was not yet part of North America. New England was not assembled for several million more years.

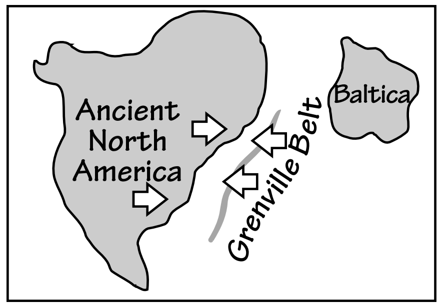
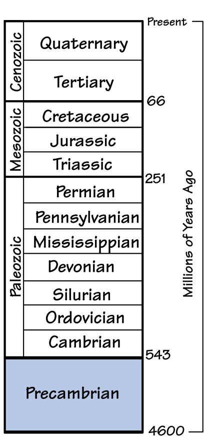



***Figure 1.4: Grenville Mountain Building***
*Baltica approaches and collides with North America*
*Grenville belt pushed onto side of ancient North America*
*Grenville Mountains erode away, only roots remain*
*North America straddles the equator*



# Mountain Building Part II: *the Taconic Mountains*

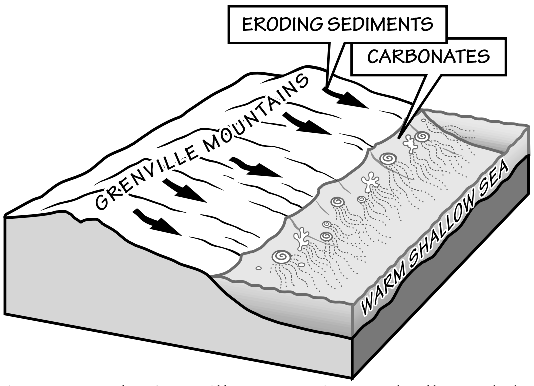



*Figure 1.5: The Grenville Mountains gradually eroded over millions of years, depositing sediments on either side of the range, becoming layered with carbonate rocks that were forming in the proto Atlantic Ocean along the margin of the continent.* Figure by J. Houghton.

The continental margin of North America was broad and flat as the Grenville Mountains were wearing down. Sea level at this time, the Cambrian period, was very high worldwide, and warm, shallow seas covered most of the Northeast. The Iapetus Ocean continued to widen during this time. Sediments from the eroding Grenville Mountains were still being deposited on the shoreline to the east, though in far lesser amounts *(Figure 1.5)*. In the Northeast, near the end of the Cambrian, sand deposits were gradually replaced by ***carbonates*** in the Iapetus Ocean. Carbonates were widely deposited on a broad flat shelf along the margin of North America.

Sometime during the middle of the Ordovician period, about 470 million years ago, the Iapetus Ocean began to close as two plates came together. The plate carrying ***Baltica (proto-Europe)*** approached the North American plate from the southeast *(Figure 1.6)*. Though Baltica did not collide with North America until several million years later, the convergence of the two plates created a whole new look for the eastern margin of North America. As the continents approached one another, the oceanic crust in the middle was forced under the Baltica plate. The friction and melting of the crust from the intense pressure of the colliding plates created a string of volcanic islands along the area where the plates converged (known as the subduction zone).

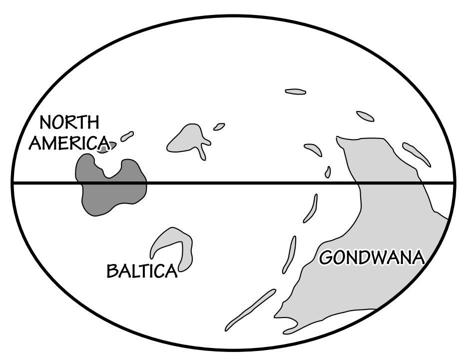
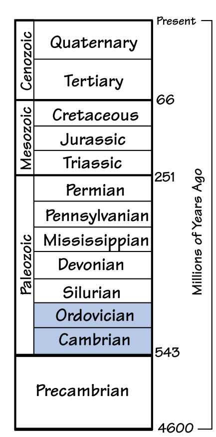



*Figure 1.6: Ordovician: 458 million years ago. Shaded areas represent land that was above water.*

**Carbonates** *include limestone and dolostone, formed by the accumulation of calcium carbonate ($CaCO_3$) shells and outer skeletons from aquatic organisms , such as corals, clams, snails, bryozoans and brachiopods. These organisms thrive in warm, shallow waters common to tropical areas. It is not surprising that modern carbonates are observed forming in places such as the Florida Keys and the Bahamas.*

### Ancient continents

*It has taken millions of years for the continents to take on the shapes we see today. To simplify ancient geography, geologists have given names to the proto-continents to distinguish them from their modern counterparts:* **proto-Europe** *(Northern Europe without Ireland and Scotland) is known as* **Baltica***; proto-North America is known as Laurentia; and Proto-Africa was part of a group of continents known as Gondwana.*



# Geologic History

The carbonates that had been deposited in the Iapetus Ocean were squeezed and pushed ahead of the ***volcanic islands*** up onto the margin of the continent along with deeper water silts, sands and clays *(Figure 1.8)*. These volcanic remnants may be found in a thin band of rocks in northernmost Vermont that extend through northern New Hampshire, and up the western and northernmost section of Maine.

As the Iapetus Ocean closed, folding, thrust-faulting, uplift, and intrusion occurred along the margin of the continent from the intense pressure of the colliding plates, causing another mountain chain to form in place of the worn-away Grenville Mountains. This mountain-building event is called the Taconic ***Orogeny.***

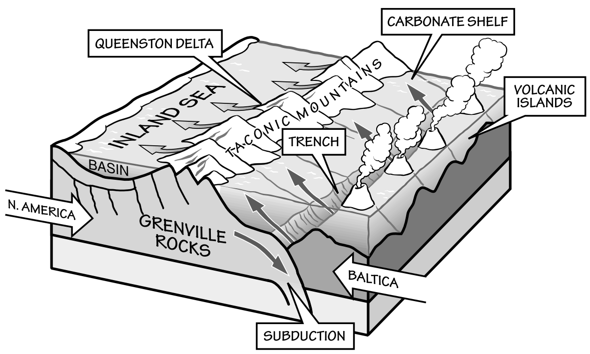



*Figure 1.7: Volcanic islands formed where the plates were forced together as the Iapetus Ocean closed. The compression crumpled the crust to form the Taconic Mountains and a shallow inland sea.* Figure by J. Houghton.

The compression induced by the collision of the two plates, caused a downwarp in the crust to the west of the Taconic Mountains. This sagging crust became a basin filled with a broad, shallow inland ocean and sediments from the eroding Taconic Mountains. As sediment was eroded from the western side of the Taconic Mountains, the Queenston ***Delta*** deposits formed a wedge of sediments spreading away from the Taconics through New York and Pennsylvania *(Figure 1.8)*. Some of the delta sediments settled in the shallow inland sea, gradually filling the basin. Sediments were also being eroded and deposited east of the Taconics into the

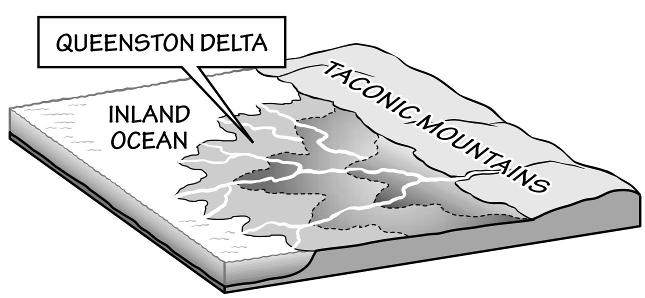


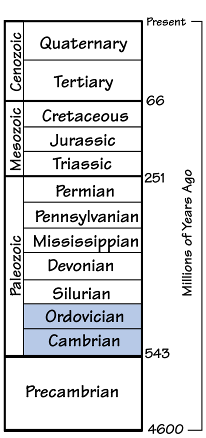

*Figure 1.8: The Queenston Delta formed as sediments eroded from the Taconic Highlands and were transported downward by streams, forming the characteristic wedge shaped delta deposits.* Figure by J. Houghton.

***Volcanic islands*** *are common at subduction zones between colliding oceanic plates. As the plates smash together, one plate is pulled under the other (or subducted). The friction between the plates generates enough heat and pressure to melt some of the crust. The molten rock rises upwards through the crust and creates a string of volcanoes along the edge of the plate.*

*The Aleutian Islands are a modern example of volcanic islands forming at a subduction zone.*

*An* ***orogeny*** *is a mountain-building event (like the formation of the Taconic or Grenville Mountains) caused by colliding plates and compression of the edge of the continents. Orogeny is derived from the Greek word, 'oro,' meaning mountain.*

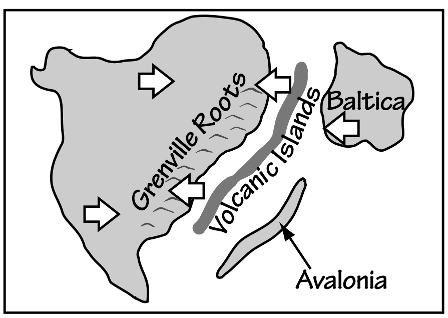
*A* ***delta*** *forms as sediment is eroded from mountains and transported downward by streams. Deltas typically form a wedge-shaped deposit as sediments fan out across the lower elevations.*



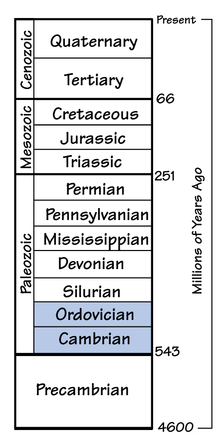
trench formed where the plates converged. Eventually, the Taconic Mountains eroded away to only the inner core, as had the Grenville Mountains previously.

The ***Taconic Mountains*** that we see today in eastern New York are not the ancestral Taconic Mountains. Further compression of the crust during the Taconic and Acadian mountain-building events thrust huge slabs of the ancestral Taconic Mountains westward from Vermont and Massachusetts. Thus older, more resistant rocks from the Taconics ended up on top of younger sedimentary rocks from the inland ocean. This is unusual in geology; usually the oldest sediments are on the bottom. The resistant blocks from the ancestral Taconic Mountains weathered much more slowly than surrounding rocks, eventually forming the Taconic Mountains of today.

*The rounded Berkshire Mountains of western Massachusetts are the roots of the original* **Taconic Mountains**. *Large segments of the Taconic Mountain mass (known as the Taconic Klippe) were thrust westward into eastern New York over younger rocks that had been deposited in the inland ocean.*




***<u>Figure 1.9: Taconic Mountain Building</u>***
*Baltica approaches North America after breaking away earlier*
*volcanic islands form over subduction trench*
*volcanic islands collide with North America, form Taconics*
*inland sea forms to the west of Taconics*
*Taconic Mountains erode*
*Queenston Delta deposited west of Taconics*



# Exotic Terranes:
## *the making of New England*

*Due to their origin from far away, 'exotic' places, **exotic terranes** have distinctly different geologic characteristics than the surrounding rocks.*

**Exotic terranes** *are not exclusive to New England. Florida is a good example of an exotic terrane, originating as part of Gondwana. Parts of the West Coast of North America (including Alaska) are also considered to be exotic terranes, sutured on to the coast and repositioned by strike-slip faults (shearing of blocks of crust).*

Until the Ordovician period, North America was missing most of what we know of today as New England. Formed over hundreds of millions of years, New England was slowly pieced together by the addition of several tiny strips of land to the proto-North American continent. These strips of land are called '***exotic terranes***,' small landmasses that originated from somewhere other than North America and were tacked on to the continent as plates converged. Cameron's Line marks the ancient suture line between proto-North America and the exotic terranes of New England. Over several million years, two exotic terranes were added to proto-North America: the Iapetus Terrane and the Avalonia Microcontinent Terrane *(Figure 1.10)*.

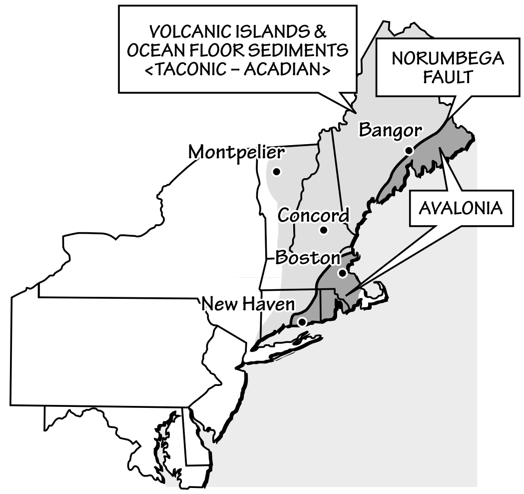
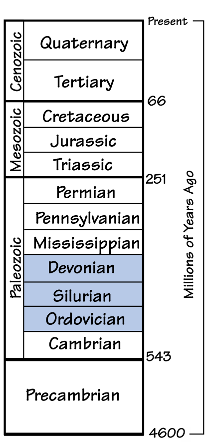



*Figure 1.10: New England was not always part of the North American continent. Slices of land known as exotic terranes, collided with North America during the Taconic and Acadian orogenies.* Figure by J. Houghton.

During the Taconic mountain-building event, volcanic islands had formed in the Iapetus Ocean, at the subduction zone of the plates carrying North America and Baltica. As the plates merged, the dense oceanic crust of the Iapetus Ocean was pulled down into the mantle where it melted. Some magma from the melting, subducting oceanic crust, rose back up through the plate to form the volcanic islands. Weathering and erosion of the volcanic islands produced sediments that were then deposited in the Iapetus Ocean. The volcanic islands drew closer and closer to proto-North America as the oceanic crust was subducted. Eventually, the volcanic islands were pushed onto the eastern margin of North America, along with sediments that had been eroded into the ocean basin from proto-North America and the volcanic islands. The Iapetus Terrane, including the string of volcanoes and associated



ocean basin sediments from the Taconic mountain-building event, added most of Vermont, New Hampshire, central Massachusetts, Connecticut and Maine to the Northeast.

The exotic terrane Avalonia was a microcontinent, originating from the African plate (Gondwana) in the south and traveling northwards on the moving plates to collide with North America. When the Iapetus Ocean closed in the Devonian, Avalonia was sutured to the East Coast in between the colliding continents of Baltica and North America. Avalonia tacked on the last main bits of New England, including eastern Maine, Connecticut and Massachusetts, and Rhode Island. Only Cape Cod, Long Island and smaller ***islands*** off the coast of New England were yet to be part of the Northeast.

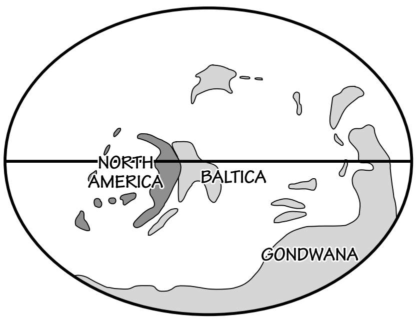


*Figure 1.11: Silurian: 425 million years ago.*

The Iapetus and Avalonia Terranes that make up New England were added to the Northeast over millions of years during the Taconic orogeny and the later Acadian orogeny (when North America collided with Baltica) from the Ordovician through the Devonian *(Figure 1.11)*. The terranes were squeezed, crumpled, deformed and intensely metamorphosed. This has made for some rather complex geology in the New England area. The intensity of deformation and metamorphism has made it difficult for geologists to distinguish the individual volcanic islands added to the margin of North America or the exact timing of exotic terrane collisions.

*The **islands** off the coast of New England did not form until millions of years later during the Cenozoic, as the Northeast was in the grip of the Ice Age. The enormous amounts of material dumped by glaciers as they melted and retreated North created these island landmasses.*

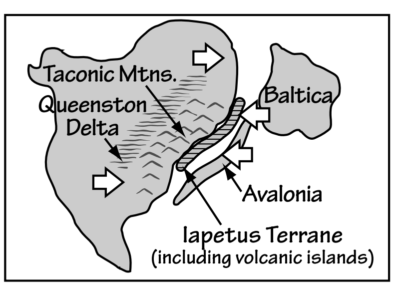
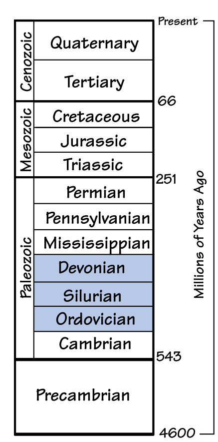


***Figure 1.12: Exotic Terranes***

*Taconic volcanic island arc collides with North America*
*Iapetus Ocean sediments collide with North America*
*Avalonia (origin uncertain) collides with North America*



# Mountain Building Part III: *the Acadian Mountains*

When Baltica (proto-Europe) finally collided with North America around 380 million years ago in the middle Devonian, the exotic terranes making up New England were in between the colliding continents. The terranes (and the eastern margin of North America) were squeezed, folded, metamorphosed and intruded by magma. This collision with Baltica and North America formed yet another tall mountain chain, the Acadian Mountains, along the eastern margin of North America.

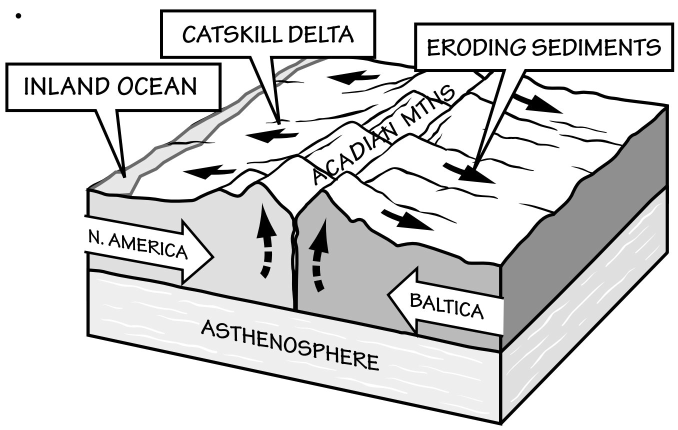



*Figure 1.13: North America and Baltica collided finally in the mid Devonian, crumpling the crust to form the Acadian Mountains. Sediments eroded from the highlands formed*

The Acadian mountains were similar to the Taconic and Grenville mountains of the past which had since eroded *(Figure 1.13)*. Just as in the Taconic mountain-building period, compression from the Acadian continental collision warped the crust downward, reinforcing the inland ocean. The ***Queenston Delta*** was buried by new sediments eroding from the western side of the Acadian mountains. These sediments, known as the ***Catskill Delta***, created a new wedge of sediments stretching into a shallow inland sea.

During this time, North America gradually began to move closer to its present geography and assume the north-south alignment we see today. At the time of the Acadian mountain building and subsequent erosion during the Devonian, the Northeast was at the

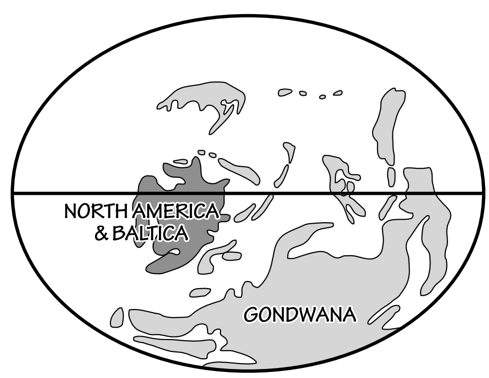
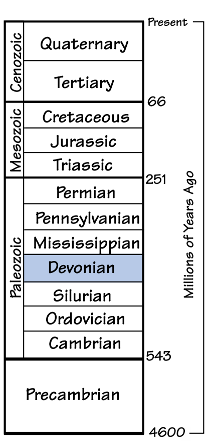



*Figure 1.14: Devonian: 390 million years ago.*

*The **Queenston Delta** formed from sediments eroding off of the Taconic highlands. With the rise of the Acadian Mountains, erosion of sediments was renewed and the Catskill Delta deposits covered over the Queenston delta.*

*The Mississippi Delta is a modern delta that is dumping sediment from the Mississippi River into the Gulf of Mexico. Looking at the Mississippi Delta from above, the characteristic wedge shape of a delta is evident.*

*The sediments of the **Catskill Delta** are over 1.2 km thick in some places, indicating intense erosion and the enormity of the Acadian Mountains. Close to the source of erosion (the Acadian highlands) the delta sediments are coarser grained and thicker. As the sediments spread west across New York and Pennsylvania, they became finer grained and thinner deposits.*



Equator and experiencing the associated tropical climate *(Figure 1.15)*. Baltica (proto-Europe) and North America were united as one larger landmass. Africa, South America, India, Australia, Antarctica and Florida were all combined as one continent (Gondwana) in the southern hemisphere. The continents were gradually merging to become one.

**Pangea**, *meaning 'all Earth,' formed over 250 million years ago and lasted for almost 100 million years. All of the Earth's continents were literally joined as one to form a giant super-continent.*

### Between mountain-building events: *deposition in the inland ocean*

*The Northeast was not continuously experiencing dynamic mountain-building events. There were quieter times as well between the rise of great mountains and crushing crusts of colliding plates. The quiet times were marked by erosion of the highlands and very little plate movement and compression within the Northeast region. The building of the Taconic Mountains was over by the late Ordovician. Throughout the following Silurian period, the Northeast experienced a quiet time in which erosion from the Taconic highlands and deposition in the inland sea were the main events. Huge thicknesses of sedimentary rocks accumulated in and on the margins of the inland sea during part of the Silurian. The inland ocean, which spread across much of New York, Pennsylvania and western Maryland, was similar to the modern Persian Gulf, becoming very salty because of the shallow water, high rates of evaporation and poor circulation.*

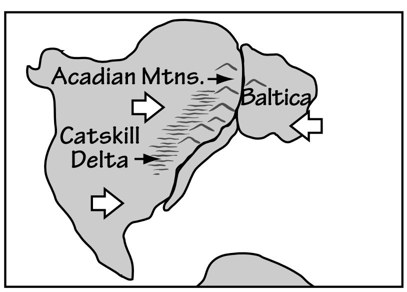
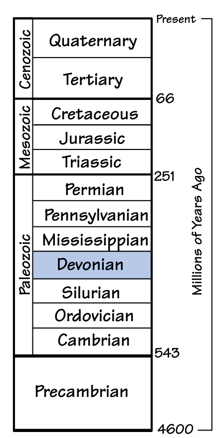



***Figure 1.15: Acadian Mountain Building***
*Baltica collides with North America*
*Acadian Mountains form (northern Appalachian Mountains)*
*similar to Taconic mountain building*
*inland sea forms west of Acadian Mountains*
*Acadian Mountains erode*
*Catskill Delta deposited west of Acadian Mountains*



### Why are the Appalachians still here?

*Although the Appalachian Mountains were formed over 250 million years ago, they are still around today. The forces of erosion and weathering have worn down the Appalachians over time; periodic uplift of the range, however, has prevented them from completely eroding away.*

# Mountain Building Part IV: *the formation of Pangea and the Appalachian Mountains*

Today's Appalachian Mountain chain formed 470 million years ago at the time of the Taconic mountain-building event, with the initial squeeze of the margin of North America. The Acadian mountain-building, 380 million years ago, crunched the crust of North America a bit more. Finally, approximately 250 million years ago, the Alleghanian mountain-building event occurred as ancestral Africa collided with North America to create the central and southern Appalachians during the Permian *(Figure 1.16, Figure 1.17)*. The Acadian orogeny helped to shape the northern Appalachian Mountains, but the Alleghanian orogeny gave the final squeeze to the margin of the continent to form today's Appalachian Mountain chain, extending from Alabama to Maine and beyond into Canada. From the time of the Acadian mountain-building event until the Triassic, the Appalachians were continuous with the Caledonide Mountains of northwestern Europe and Greenland.

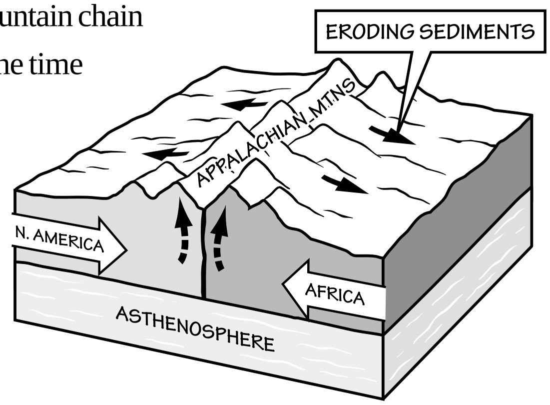



*Figure 1.16: When ancestral Africa collided with North America, the Appalachian mountains were formed.* Figure by J. Houghton.

The Appalachian Mountains that we see today, however, are merely the worn down remnants of the Appalachians created millions of years ago. At one time the Appalachians were probably as tall as the modern Himalayas, but today the Appalachians are the

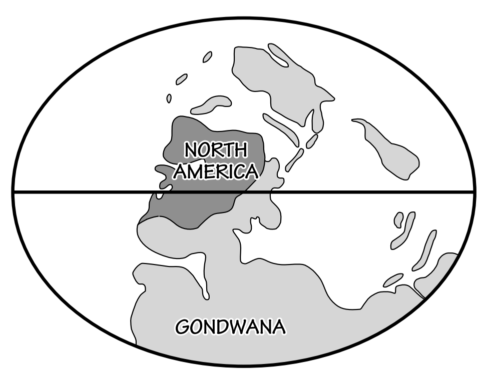
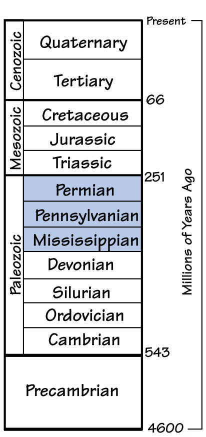



*Figure 1.17: Late Pennsylvanian: 306 million years ago.*



rounded, weathered and aged peaks of a more mature mountain range that has seen millions of years of erosion and uplift.

The direct cause of the creation of the Appalachian Mountains was the merging of all continents into the supercontinent Pangea as the Iapetus Ocean closed 290 million years ago. Baltica and North America had merged to form one continent during the Acadian mountain-building period in the Devonian, effectively creating the ancestral northern Appalachians. In the meantime, through the Mississippian and Pennsylvanian periods, ancestral Africa (already joined to other continents as Gondwana) drifted closer to North America and Baltica. The Iapetus Ocean narrowed as the oceanic crust was subducted under the North American continental crust. When ancestral Africa finally collided with North America during the Permian, the continental crusts were too bouyant to be subducted like dense oceanic crust. Instead, the crusts crumpled together to create a tall range of mountains. Sediments from the proto-Atlantic ocean basin and the continental shelf and slope of North America, were pushed upwards and squeezed along with the crust.

*Though the Appalachian Mountains do not look as tall and rugged as the Himalayas of India, the Appalachians formed through esentially the same geologic processes. The collision of the Indian and Asian plates that is taking place today is raising the Himalaya Mountains, similar to the collision over 250 million years ago between Africa and North America created the Appalachian Mountains.*

### Evidence For Pangea

*How do we know that Pangea existed 250 million years ago? Fossil evidence and mountain belts provide some of the clues. The Permian-age fossil plant,* Glossopteris *had seeds too heavy to be blown across an ocean. Yet* Glossopteris *fossils are found in South America, Africa, Australia, India and Antarctica! The mountain belts along the margins of North America, Africa and Europe line up as well and have similar rock types, indicating that the continents at one time were joined as Pangea. The discovery of* Glossopteris *and the evidence in the rocks helped geologists to formulate the theory of Continental Drift, which, when the processes of continental movement were later discovered, was reformulated under the modern theory of Plate Tectonics.*

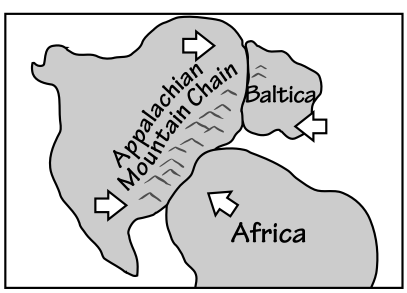
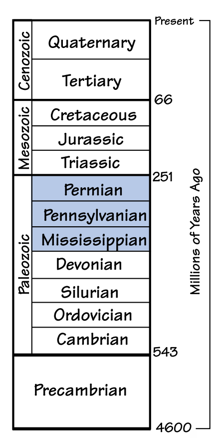
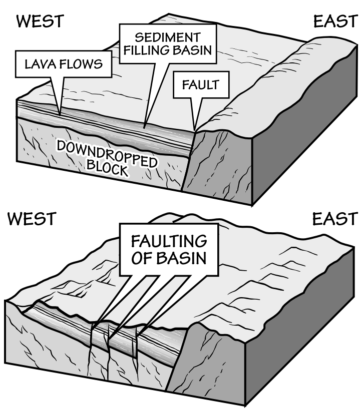



***Figure 1.18: Alleghanian Mountain Building***
*Africa collides with North America*
*central/southern Appalachians form*
*Pangea assembled, one supercontinent on Earth*



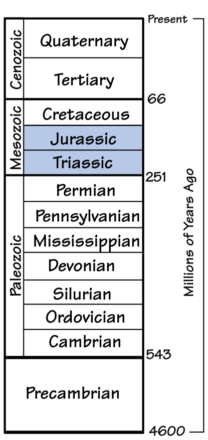
**Rifts** *are breaks or cracks in the crust which can be caused by tensional stress as a landmass breaks apart into separate plates.*

*The same processes that are today tearing apart* **East Africa**, *were tearing apart Pangea 180 million years ago. In East Africa, the African plate is pulling away from the Arabian plate, stressing the crust to the point of breaking apart.*




*Figures 1.19 and 1.20: As rifting occurred, blocks of crusts slid down faults to form a basin. The basin was filled with sediments and lava flows. Eventually, the entire basin was tilted and faulted.* Figure by J. Houghton.

*The long, narrow* **Triassic rift basins** *formed through the Triassic and early Jurassic periods.*




# The Breakup:

## *Pangea comes apart*

The super-continent, Pangea, lasted 100 million years. But, as we have seen, the Earth's crust is not static. The direction of plate movement shifted over time and the continents began to pull apart rather than converge. ***Rifts*** developed in the crust, eventually breaking completely through the crust and leading to the breakup of the supercontinent. Modern day rifting can be observed in the ***East African*** Rift Valley. Tension (two forces pulling in opposite directions) slowly began to pull North America away from the other merged continents. As the crust was pulled apart, it stretched, thinned and uplifted to the point of breaking.

The rifts occurred along a series of cracks in the Earth's crust roughly parallel to the present coastline. Along a series of faults, blocks of crust slid down the faults to form down-dropped basins bounded by tall cliffs that came to be known as ***Triassic rift basins*** *(Figures 1.19 and 1.20)*. The eroding cliffs filled the adjacent basins with poorly sorted, red-colored sandstones and shales. These basin deposits are part of a sequence of rocks known as the Newark Supergroup, with thicknesses reaching up to 6 km in some places. Deposits are found in the Connecticut Valley of Massachusetts and Connecticut, and in the Newark Basin, which stretches from southeastern New York across New Jersey, Pennsylvania and Maryland. There are more Triassic Rift Basins located off the east coast that are buried by continental shelf sediments *(Figure 1.21)*. During the Jurassic, the final break between the plates of North America, Africa and Baltica occurred many kilometers to the east of today's coastline at what is now the Mid-Atlantic Ridge. Other fragments of Pangea gradually broke into the modern continents, slowly moving into their present positions over the next several hundred million

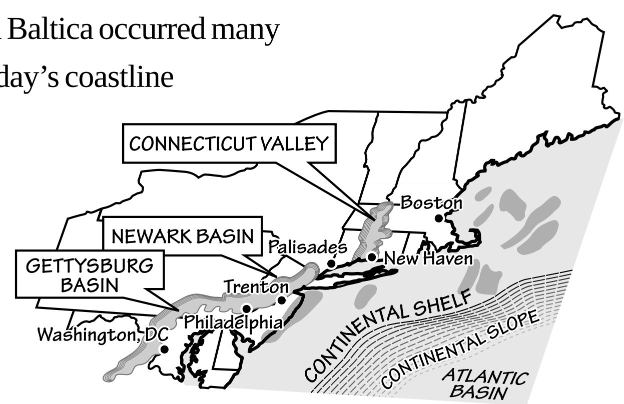



*Figure 1.21: The Triassic Rift Basins of the Northeast formed as North America broke away from Pangea during the Triassic and Jurassic.* Figure by J. Houghton.

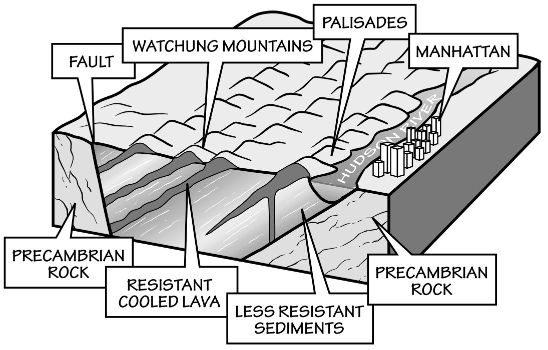



*Figure: 1.22: The softer sediments of the Newark Rift basin were quickly worn away, forming valleys between the more resistant ridges of hardened lava flows.* Figure by J. Houghton.

years.

The tension released by the pulling apart of plates, resulted in numerous faults and volcanoes. Alternating with the sandstone and shale being deposited in the basins were deposits of ash and lava flows originating from volcanoes along the rift area. The flat-lying beds of the Newark and Connecticut Valley basins were eventually faulted again and tilted, exposing the edges of the layers of sediment and cooled lava. The hardened lava was more resistant to erosion than the sediments in the basin, so ridges of cooled lava were left standing as the sediments around them wore away *(Figure 1.22)*.

As the supercontinent gradually broke apart, the continents moved into the geographic positions we see today *(Figures 1.23 and 1.24)*. The Atlantic Ocean began to widen. The east coast of North America no longer experienced the strong tectonic activity associated with the compression and rifting of a plate margin. Instead, the tectonic activity gradually moved with the Mid-Atlantic Ridge hundreds of kilometers off the coast in the Atlantic Ocean. The Northeast, remaining a 'passive margin' through to the present, began a long period of erosion that would continue through the Cretaceous and into the Tertiary.

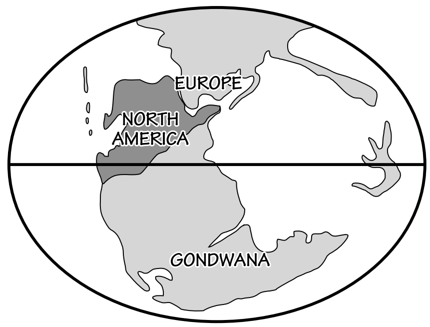



*Figure 1.23: Triassic: 237 million years ago.*

### Rocks that form ridges

*Some rocks wear down relatively quickly, while others can withstand the power of erosion for much longer. Softer, weaker rocks such as shale and poorly cemented sandstone and limestone are much more easily worn away than hard, crystalline igneous and metamorphic rocks, or well cemented sandstone and limestone. Harder rocks are often left standing alone as ridges because surrounding softer, less resistant rocks were quickly worn away.*

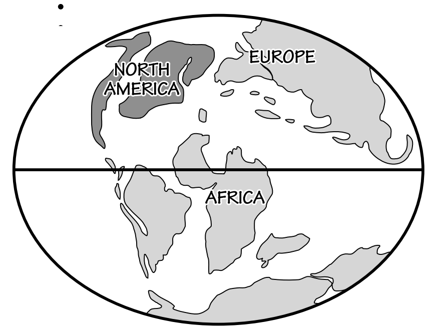



*Figure 1.24: Cretaceous: 94 million years ago.*

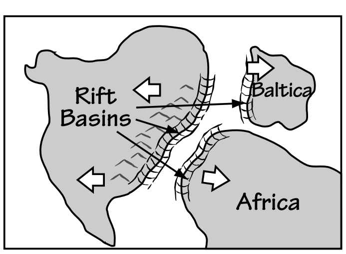
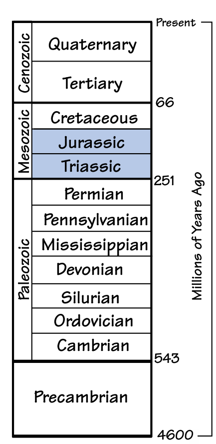



***Figure 1.25: Pangea Breaks Up***
*Pangea begins to split*
*rifts are created in the crust*
*Triassic/Jurassic Rift Basins form*
*Rift Basins filled with sediments and lava flows*
*Rift Basins later tilted, faulted and eroded*
*long period of erosion*



# The Ice Age:
## *mountains of ice*

Although today the plates are still drifting and the Atlantic Ocean continues to widen, the dynamic plate tectonic activity of the geologic past has temporarily quieted along the east coast. However, despite the minimal tectonic activity in the Northeast throughout the Cenozoic (with the exception of periodic uplift and movement of faults), the face of the land continued to change due to erosion and a series of advances and retreats of glacial ice.

A cooler climate contributes to the growth of continental glaciers. The continental glacier that repeatedly covered parts of North America during the Quaternary, had its origin in northern Canada. As the climate cooled, more snow fell in the winter than melted in the summer, causing the snow to pack into dense glacial ice.

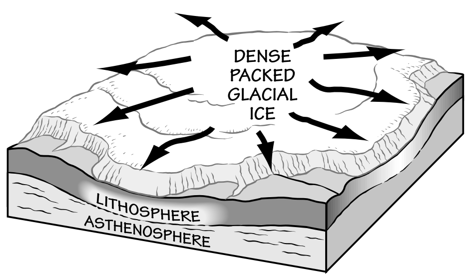



*Figure 1.26: As dense glacial ice piles up, a glacier is formed. The ice begins to move under its own weight and pressure.* Figure by J. Houghton.

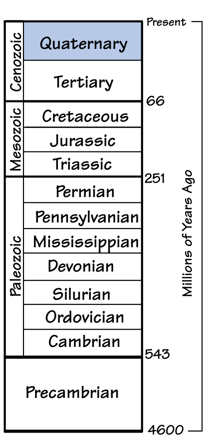
As more snow and ice accumulated on the glacier (and less melted), the ice began to move under its own weight and pressure. The older ice on the bottom was pushed out horizontally by the weight of the overlying younger ice and snow. Glacial ice then radiated out from a central point, flowing laterally in every direction away from the origin *(Figure 1.26)*. And thus, a continental glacier originating in far Northern Canada began to move south towards the northeastern U.S *(Figure 1.27)*. The ice sheet crept slowly forward, scraping off the loose rock materials and gouging the bedrock beneath the ice as it advanced.

*Figure 1.27: The movement of the ice sheet over North America.* Figure by J. Houghton.

Nearly two million years ago, the

### What happened between the breakup of Pangea and the ice age?

*The Northeast gradually rifted away from the rest of Pangea during the Mesozoic. Throughout the Tertiary period (which followed the breakup of Pangea) a warm climate promoted chemical weathering and erosion of rocks of the Northeast. Periodic uplift and significant erosion of the land shaped much of the topography of the Northeast. Though Tertiary deposits are thick along the continental shelf and parts of the Coastal Plain (evidence of significant erosion during this time), there are very few Tertiary deposits on much of the Northeast coast. This is because as the climate began to cool and the ice age set in, glaciers scraped up most of the sediments deposited during the Tertiary and pushed them southward. Uplift during the Tertiary created the Adirondack Mountains of New York.*



Earth's climate shifted towards ice age conditions. Since that time, there have been several dozen intervals of glaciation separated by warmer intervals not unlike the present. The most recent glacial advance reached its maximum extent 25-20,000 years ago and lasted until 10,000 years before the present. Though the glaciers are long gone from the Northeast, they have left behind evidence of their advances and retreats, smoothing over the mountains and blanketing the surface with glacial deposits. The Northeast owes a large share of its present topography and drainage patterns to the last glacial advance.

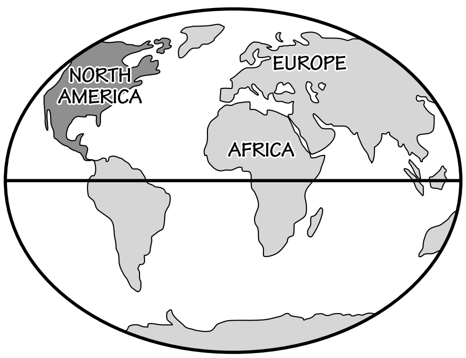



*Figure 1.28: Modern geography.*

Although the entire Northeast region was affected by the cooling climate during the last advance of the ice sheet, the glaciers only extended as far south as northern Pennsylvania and Long Island. Today, the Earth is technically in an interglacial time, as the ice sheets have retreated for now. There is every reason to believe, however, that the Earth will return to a glacial maximum unless ***global warming*** resulting from human activities pulls the Earth from another ice age.

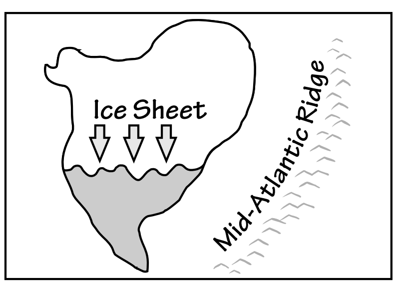
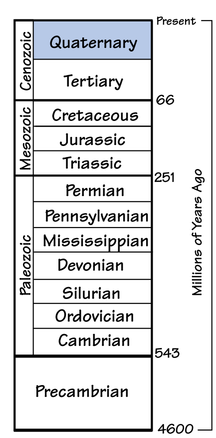



***Figure 1.29: Ice Age***
*Northern Canadian ice sheet forms*
*repeated advances and retreats of ice sheet over the Northeast*
*put the finishing touches on the topography of the Northeast*

*Throughout the Earth's history, the continents have been periodically plunged into an ice age, dependent upon the climate and position of the continents. Over the last million years, North America has experienced glaciation approximately* **once every 100,000** *years and once every 40,000 years during the previous two million years.*

*With the coming of the Industrial Age and exponential increases in human population, large amounts of gases have been released to the atmosphere (especially carbon dioxide) that contribute to* **global warming.**

*see Glaciers, p.57*



# The Last One Billion Years

Figures by J. Houghton; Paleogeography figures after
C. Scotese, Paleomap Project, 2000,
http://www.scotese.com/

***Grenville Mountain Building***
-Baltica approaches and collides with North America
-Grenville belt pushed onto side of ancient North America
-Grenville Mountains erode away, only roots remain
-North America straddles the equator

**Precambrian (4500-544 mya)**

***Taconic Mountain Building***
-Baltica approaches North America after breaking away earlier
-volcanic islands form over subduction trench
-volcanic islands collide with North America, form Taconics
-inland sea forms to the west of Taconics
-Taconic Mountains erode
-Queenston Delta deposited west of Taconics

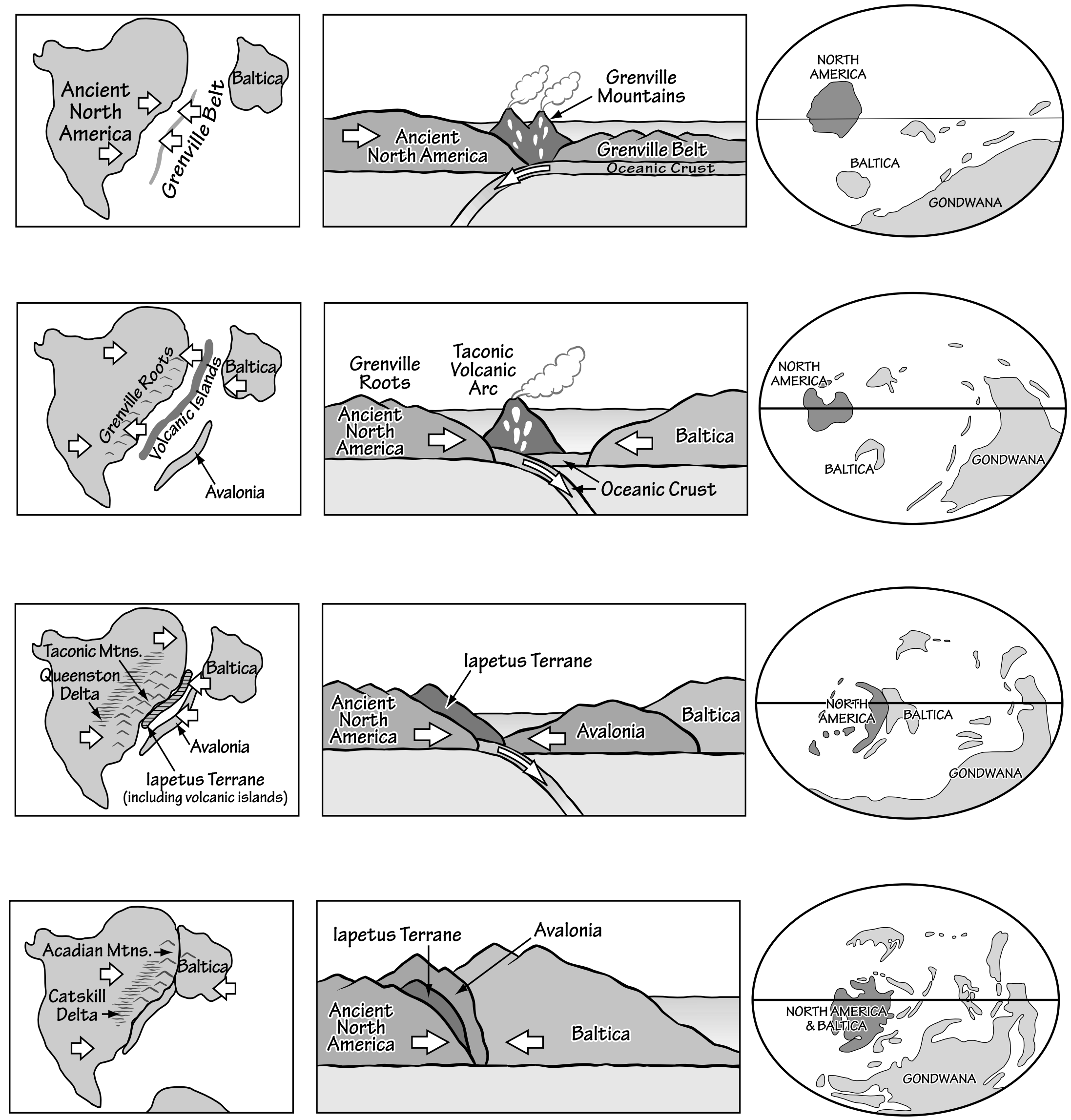
**Cambrian/ Ordovician (544-440 mya)**

***Exotic Terranes***
-Taconic volcanic island arc collides with North America
-Iapetus Ocean sediments collide with North America
-Avalonia (origin uncertain) collides with North America

**Silurian/ Devonian (440-360 mya)**

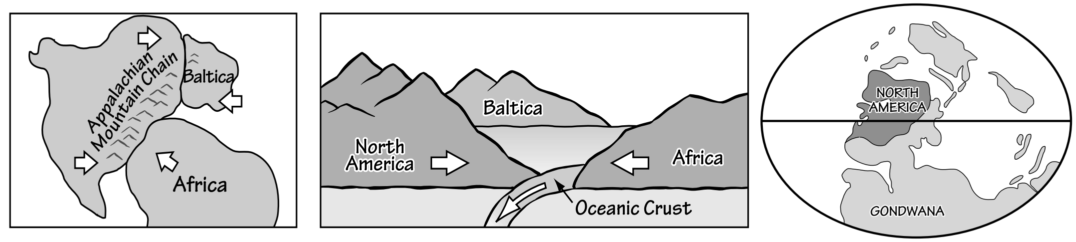
***Acadian Mountain Building***
-Baltica collides with North America
-Acadian Mtns form (northern Appalachian Mtns)
-similar to Taconic mountain building
-inland sea forms west of Acadian Mountains
-Acadian Mountains erode
-Catskill Delta deposited west of Acadian Mountains

**Devonian (410-360 mya)**



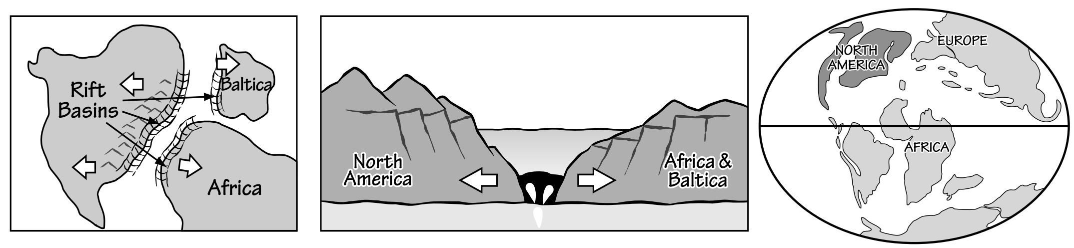
**Alleghanian Mountain Building**
*-Africa collides with North America*
*-central/southern Appalachians form*
*-Pangea assembled, one supercontinent on Earth*

**Mississippian**
**Pennsylvanian**
**Permian**
**(360-245 mya)**



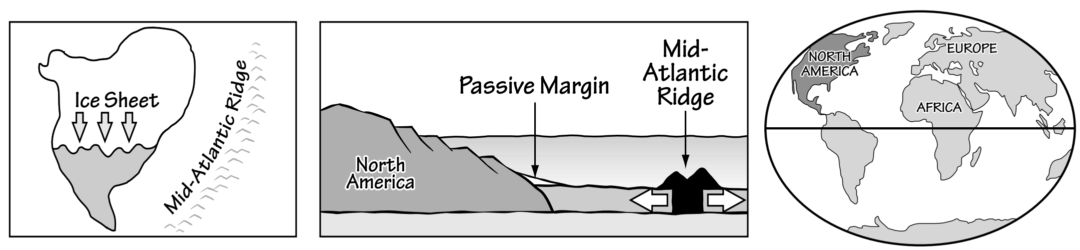

**Pangea Breaks Up**
*-Pangea begins to split*
*-rifts are created in the crust*
*-Triassic/Jurassic Rift Basins form*
*-Rift Basins filled with sediments and lava flows*
*-Rift Basins later tilted, faulted and eroded*
*-long period of erosion*

**Triassic/ Jurassic**
**Cretaceous**
**(245-65 mya)**




**Ice Age**
*-Northern Canadian ice sheet forms*
*-repeated advances and retreats of ice sheet over the Northeast*
*-put the finishing touches on the topography of the Northeast*

**Quaternary**
**(1.8 mya-present)**



# Activities

1. As part of an experimental program to bring together arts and sciences at your school, you are requested to create an art piece that shows in three dimensions — through drawings, sculptures, computer animations, or other forms — the sequence of geologic events that took place in the Northeast United States over the past billion years. It is thought that the sequence of events, represented in different colors and changing shapes, may give an interesting art form as well as illustrating geologic history.

*Create your own artistic piece, of the history of the Northeast, showing:*
(1) the Grenville passive margin,
(2) the Taconic converge,
(3) the Acadian convergence,
(4) the rifting apart of Pangea, and
(5) the Coastal Plain passive margin.

2. Your art piece is selected to go on display in your local art museum. The Director of Exhibits there asks if you could create another three dimensional piece that represents a stack of rocks of various ages from just your own area. This will help show people at a local scale the influence of these geologic events on the rocks under their feet. You are asked to please use colors consistent with the first piece, so that the two pieces are complementary.

*Create a second artistic piece, representing local rocks through time, consistent with (1).*

3. You have another creative idea. You apply for and receive a grant to create three more pieces for local geology as in (2), each of them in a different place that, all together, can help tell the large-scale story of number (1).

*(a) Create three more art pieces for areas of the Northeast that are each geologically different from each other, so that altogether they represent how large scale geologic events have affected local rocks. You choose the locations. Create an artwork representing the series of rocks present at each location.*

You decide each piece of art should somehow include actual specimens of rocks representing each event or geological period. Though it is clear that you can go to the three places and find rocks at the surface, the rocks under the surface from previous geologic periods will be buried; you reason that you can find rocks of similar age and origin exposed at the surface elsewhere. Fortunately you had the foresight to see that you'd need to do some field work, and have a modest travel budget as part of your grant.

*(b) Describe in highway travel the most efficient way to collect appropriate samples that represent the subsurface samples you need. Create a travel report listing each segment of the trip, what you collected, how many miles you traveled, and what your travel costs were.*

# For More Information...

## *Books*

Bain, George W. and Howard A. Meyerhoff, 1976, *The Flow of Time in the Connecticut Valley*, Connecticut Valley Historical Museum: Springfield, Massachusetts.

McPhee, John, 1983, *In Suspect Terrain*, Farrar, Straus, Giroux: New York, New York.

Raymo, Chet and Maureen E. Raymo, 1989, *Written in Stone*, The Globe Pequot Press: Old Saybrook, Connecticut.

Redfern, Ron, 1983, *The Making of a Continent*, Times Books: New York, New York.

## *Internet*

Basic Geology and Neotectonics of the Adirondacks
http://www.geo.wvu.edu/~tsattler/tectonics/adirondack/mountains.html

Deposition of the Catskill Clastic Wedge
http://www.stepahead.net/~schneller/devohist.htm

Geologic Time
http://www.ucmp.berkeley.edu/help/timeform.html

Newark Basin and Connecticut River Basin
http://everest.hunter.cuny.edu/bight/newark.html

Paleomap Project
http://www.scotese.com/

USGS Information on Plate Tectonics
http://geology.er.usgs.gov/eastern/tectonic.html

USGS The Story of Plate Tectonics
http://pubs.usgs.gov/publications/text/dynamic.html

## *Other Resources*

***used in compiling this chapter***

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Dott, R.H., Jr. and D.R. Prothero, 1994, *Evolution of the Earth*, 5$^{th}$ edition, McGraw-Hill, Inc.: New York, New York.

Hatcher, R.D., Jr., W.A. Thomas, and G.W. Viele, eds., 1989, *The Decade of North American Geology: The Appalachian-Ouachita Orogen in the United States*, Volume F-2, the Geological Society of America: Boulder, Colorado.

Rodgers, J., 1971, *The Taconic Orogeny,* The Geological Society of America, Volume 82, p.1141-1178.

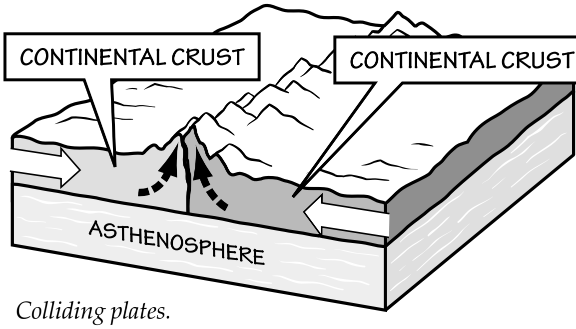
Roy, D. C., ed., 1987, *Northeastern Section of the Geological Society of America: Centennial Field Guide,* Volume 5, Geological Society of America: Boulder, Colorado.

Zen, White, Hadley and Thompson, eds., 1968, *Studies of Appalachian Geology,* Inter Science Publishers: New York, New York.

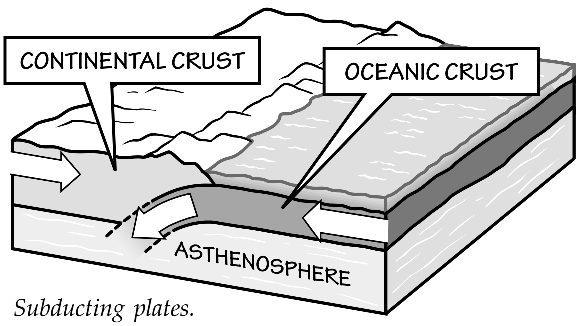
*Special thanks to Robert Hatcher, Bob Darling, and Bosiljka Glumac for information and resources regarding geologic history.*

# Selected Figures

## *for overheads & handouts*




*Colliding plates.*




*Subducting plates.*

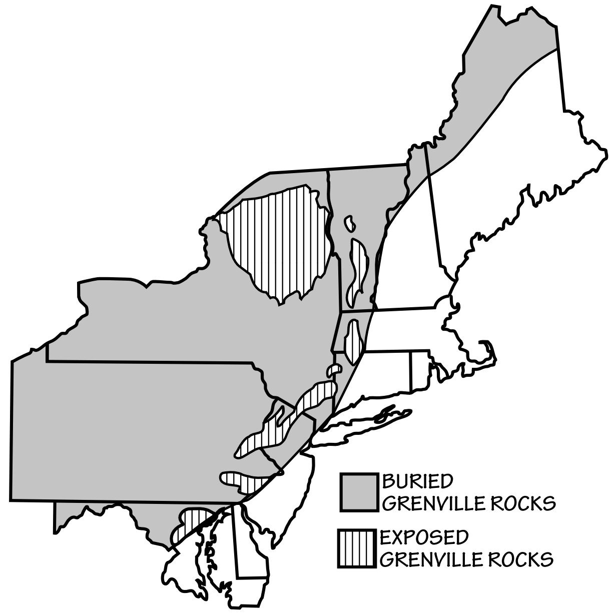



*Figure 1.3: Exposures of Grenville age rocks are found up and down the East Coast and Canada.* Figure by J. Houghton.

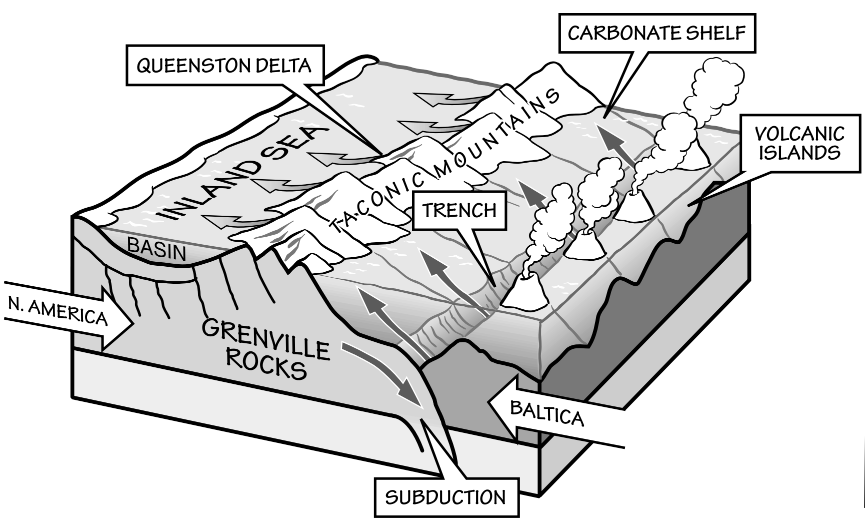



*Figure 1.8: Volcanic islands formed where the plates were forced together as the Iapetus Ocean closed. The compression crumpled the crust to form the Taconic Mountains and a shallow inland sea.* Figure by J. Houghton.

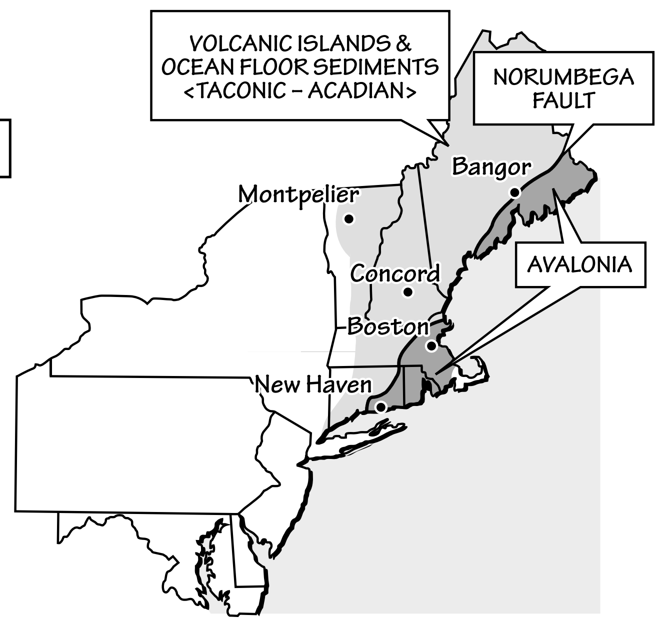
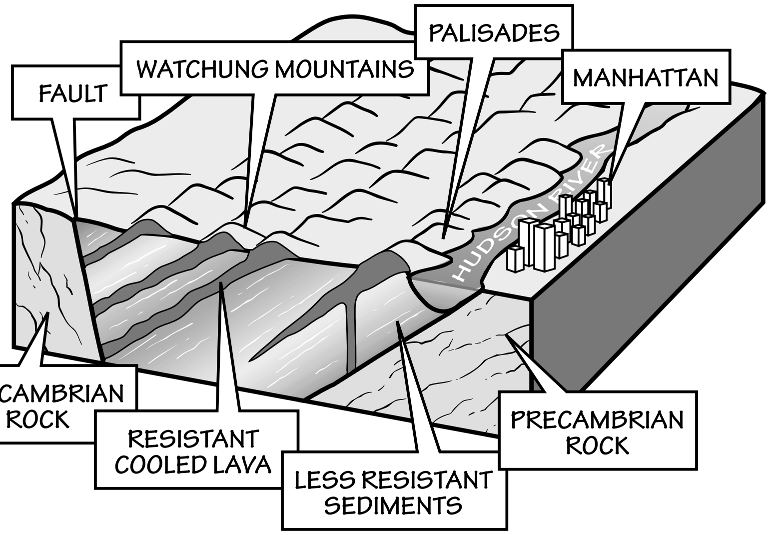



*Figure 1.11: New England was not always part of the North American continent. Slices of land known as exotic terranes, collided with North America during the Taconic and Acadian orogenies.* Figure by J. Houghton.

Figure: 1.22: The softer sediments of the Newark Rift basin were quickly worn away, forming valleys between the more resistant ridges of hardened lava flows. Figure by J. Houghton.



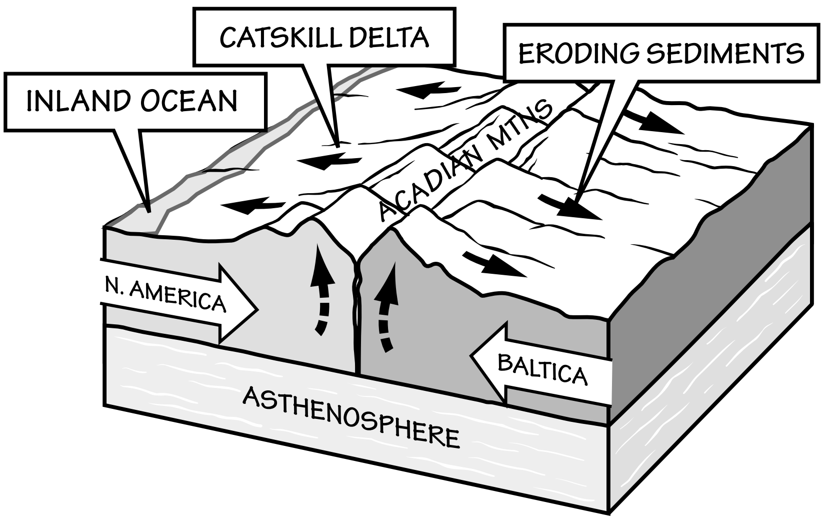




*Figure 1.14: North America and Baltica collided finally in the mid Devonian, crumpling the crust to form the Acadian Mountains. Sediments eroded from the highlands formed the Catskill delta.* Figure by J. Houghton.

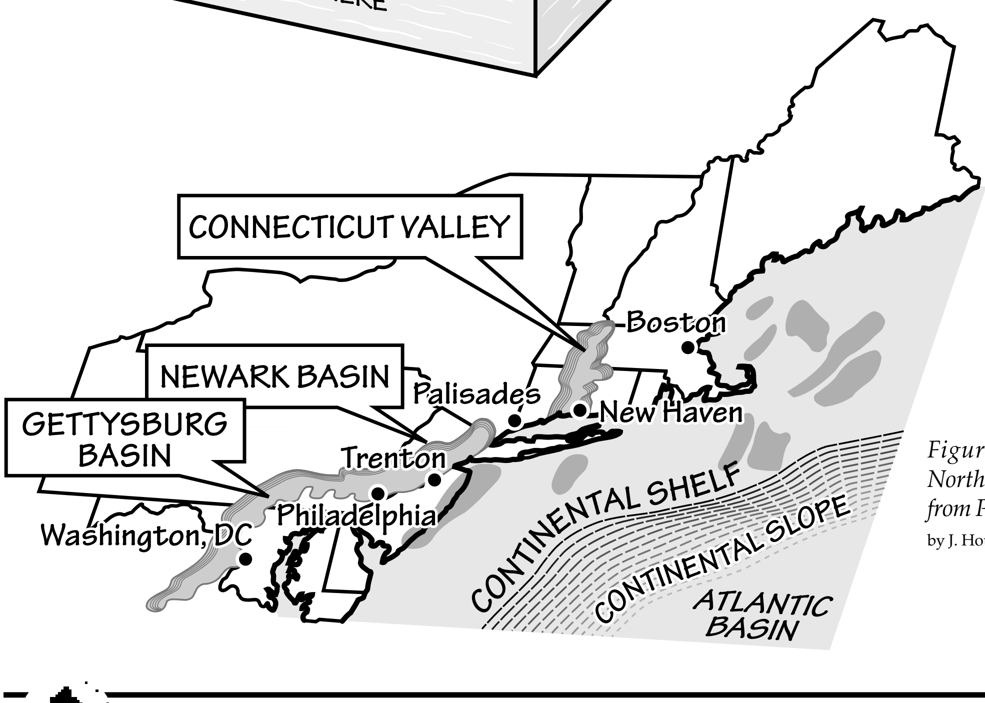
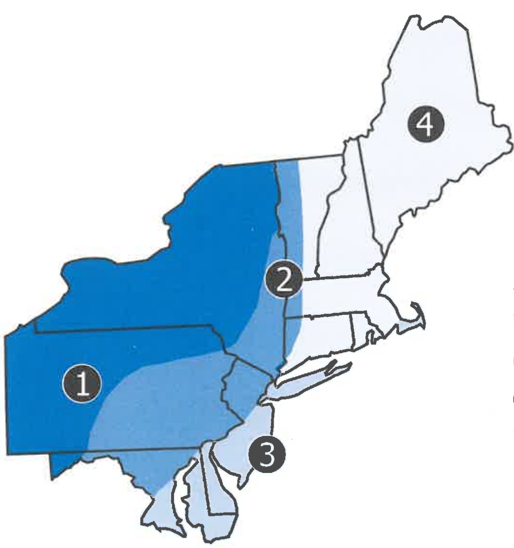



*Figure 1.21: The Triassic Rift Basins of the Northeast formed as North America broke away from Pangea during the Triassic and Jurassic.* Figure by J. Houghton.

# Rocks of the Northeastern US:
# *the BIG picture*

## ❶ Inland Basin

*Sedimentary rocks are very abundant in the Inland Basin. During the Silurian and Devonian, approximately 400 million years ago, much of this area was a shallow inland sea, the perfect environment for the deposition of thick layers of sand, silt and clays to form sandstone, siltstone, and shale. The shells of abundant sea life were deposited to form limestone. Sediments eroded from the Taconic and Acadian highlands which lay to the east, and formed thick deltaic sequences stretching toward the west across the basin. Precambrian igneous and metamorphic Grenville rocks lie exposed in the Adirondack region because of uplift and erosion of the overlying cover of younger sedimentary rocks.*




## ❷ Appalachian/ Piedmont

*Exposed in the Appalachian and Piedmont region are the remains of ancient mountains that preceded the Appalachians (the Taconic, Acadian and underlying Grenville Mountains), sedimentary rocks formed by erosion of the highlands, and igneous and metamorphic rocks formed during the crunch caused by the Taconic, Acadian and Alleghenian mountain building events. In the Appalachian/Piedmont area, Triassic Rift Basins filled with sedimentary rock (red beds) and basalt flows mark the break up of Pangea.*

## ❸ Coastal Plain

*Loose sediments that have not solidified to become rock dominate the geology of the Coastal Plain. Gravel, sand, silt and clay transported from inland form a wedge that thickens oceanward towards the continental slope at the edge of the continent.*

## ❹ Exotic Terrane

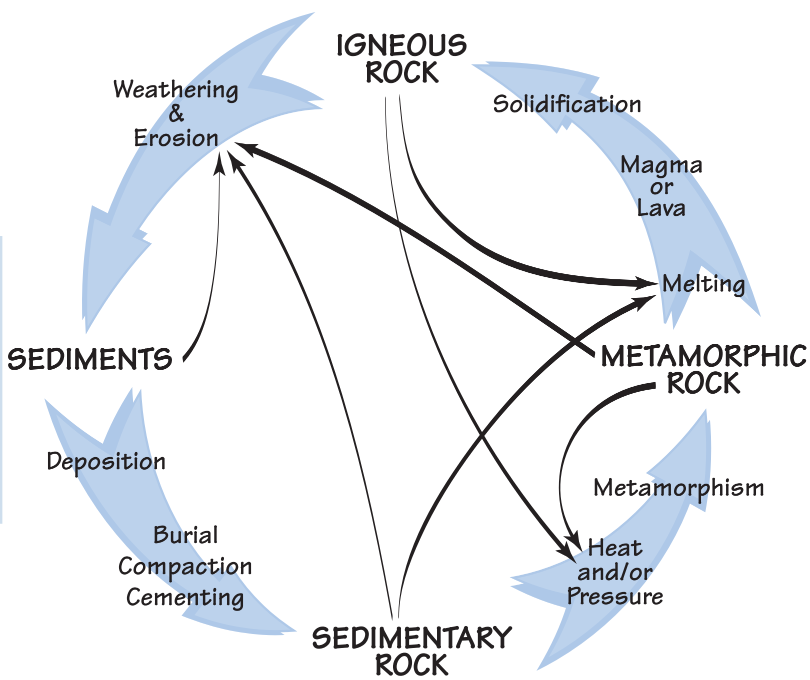
*Igneous and metamorphic rocks dominate the Exotic Terrane region. New England was formed by the addition of small slices of land (exotic terranes) that collided with North America millions of years ago during the Taconic and Acadian orogenies. The intense heat and pressure of the collisions created large igneous intrusions and metamorphosed the exotic terranes and adjacent crust.*

# Rocks of the Northeastern US:
## *a brief review*

There is an amazing diversity of rocks exposed at the surface in the Northeast. The rocks record a 1 billion year history of colliding plates, inland oceans, deposition, erosion, uplift, igneous intrusions and extrusions and glacial activity. The different rock types of the region influence the topography and tell us where to look for certain fossils and natural resources. The rocks exposed on the surface in the Northeast are there because of the unique geologic story of the region. Each type of sedimentary, igneous and metamorphic rock forms in a particular environment under particular conditions *(Figure 2.1)*.

**Igneous Rocks of the Northeast**

*granite, anorthosite, basalt, pegmatite, diorite, diabase, gabbro*




**Sediments of the Northeast**
(not consolidated into rocks)

*gravel, sand, silt, clay*

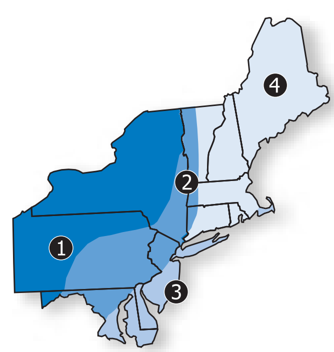
**Metamorphic Rocks of the Northeast**

*slate, schist, marble, serpentinite, phyllite, gneiss, quartzite*

**Sedimentary Rocks of the Northeast**

*limestone, sandstone, shale, coal, dolomite, siltstone, conglomerate*

*Figure 2.1: The rock cycle.*



# Rocks

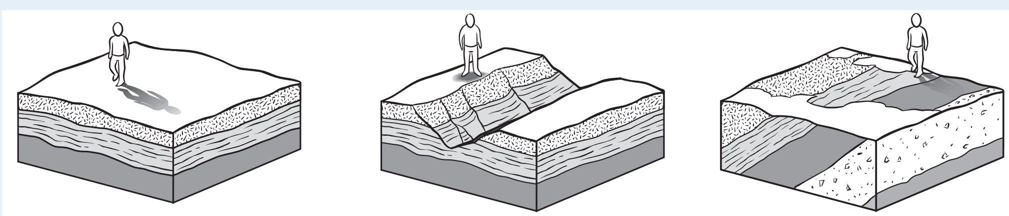
Sedimentary rocks form from the breakup of pre-existing rocks. Weathering and erosion by wind, water or chemical action breaks up sedimentary, igneous and metamorphic rocks to form loose sediments. Sediments are transported downstream by rivers and dumped into the ocean or are deposited somewhere along the way. Compaction of the sediments usually happens through burial by more sediments. As fluids work their way through the spaces between the sediments, cementing-minerals are left behind to form hardened sedimentary rocks: sandstones, siltstones and shales. Sedimentary rocks may also form by evaporation of water, leaving behind deposits of evaporites such as halite and gypsum. Deposits of calcium carbonate, usually formed through the accumulation of calcium carbonate skeletal material (such as clams and corals), create the sedimentary rocks limestone and dolostone.

| Sediments | | Sedimentary Rocks |
|---|---|---|
| *gravel* | → | *conglomerate* |
| *sand* | → | *sandstone* |
| *silt* | → | *siltstone* |
| *clay* | → | *shale* |
| *calcium carbonate* | → | *limestone* |
| *calcium magnesium carb* | → | *dolostone* |

(↓ Finer Grain Size: conglomerate → shale)

### Why do we see different kinds of rocks at the surface?

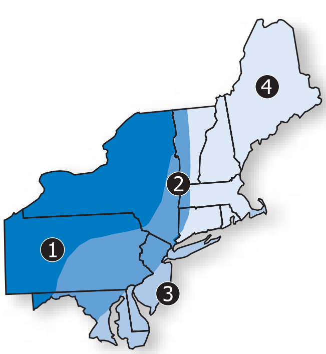
*As you walk across the surface of the Earth, you will observe an amazing variety of rock types. If all rocks were flat-lying layers and there was no erosion, then we would only see one type of rock exposed on the surface. Often, though, rocks have been worn away (eroded) and now underlying layers are exposed at the surface. Layers of rock may also be tilted, folded or faulted to reveal underlying rocks at the surface.* Figures by J. Houghton.



*When rocks are flat-lying layers and there is no erosion, folding or faulting, the person walking across the surface sees only one rock type.*

*When rocks are worn away (often by streams), the person walking across the surface sees the underlying layers of rock exposed.*

*When rocks are folded or tilted, the person walking across the surface sees several layers of rock exposed.*




**Igneous rocks** form from the cooling of hot molten rock. If the molten rock is below the surface, it is called magma. Rocks with large crystals indicate there was plenty of time for the crystals

**Igneous Rocks**

| Magma *(large crystals)* | | Lava *(fine crystals)* |
|---|---|---|
| *granite* | | *rhyolite* |
| *diorite* | *diabase* | *andesite* |
| *gabbro* | | *basalt* |
| *anorthosite* | | |

(↓ *more iron & magnesium*)

to grow as the magma cooled slowly below the Earth's surface. Molten rock that breaks through the crust to the surface (usually through a volcano) is lava. Lava cools quickly as the heat escapes to the atmosphere, producing igneous volcanic rocks with very tiny crystals or no crystals at all.

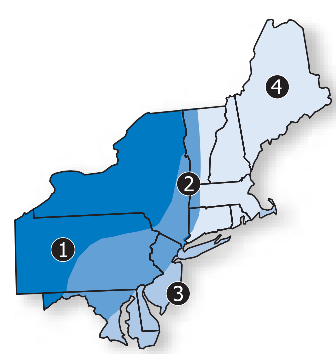
Metamorphic rocks form from pre-existing sedimentary, igneous and metamorphic rocks that are exposed to increases in temperature and pressure. This can occur from plate movements, very deep burial, or contact with molten rock. The minerals within the rock recrystallize and realign, forming a much harder rock. Some examples of metamorphic rocks are given below:

| Parent Rocks | | Metamorphic Rocks |
|---|---|---|
| *shale* | → | *slate* |
| *slate* | → | *phyllite* |
| *phyllite* | → | *schist* |
| *peridotite* | → | *serpentinite* |
| *sandstone* | → | *quartzite* |
| *limestone* | → | *marble* |
| *anorthosite* | → | *metanorthosite* |
| *gabbro* | → | *metagabbro* |
| *granite* | → | *gneiss* |
| *shale/sandstone* | → | *gneiss* |

As you read through this chapter, keep in mind that you should be able to predict the type of rocks in any given region by understanding the events in geologic history that have affected the area. When the plates collided, the compression and friction melted the crust. The rising magma formed igneous intrusions that crystallized below the surface, producing igneous rocks with large crystals such as granite. The rising magma may have broken through the surface as volcanoes, creating volcanic rocks such as basalt. The colliding plates buckled the crust (creating metamorphic rocks), forming an ocean basin to the west of the mountains. The basin filled with shedding sediment from the newly-formed mountains, producing thick sequences of sedimentary rock. Where the plates diverged, as in the Triassic period when Pangea separated, the crust rifted in many places, creating basins filled with sediment that became sedimentary rock. The rifting gave rise to volcanic activity, creating volcanic rocks.

**Bedrock vs. Surficial Sediments**

*The bedrock of the Northeast is covered with a thin layer of recently deposited sediments and soil. This chapter deals mainly with the older bedrock, formed over the last billion years. The bedrock links more closely with the events in geologic history discussed in the preceding chapter. Surficial deposits are discussed in more detail in the next chapter (Glaciers).*



# Rocks of the Inland Basin

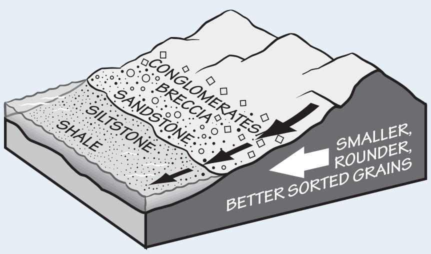
## *Region 1*

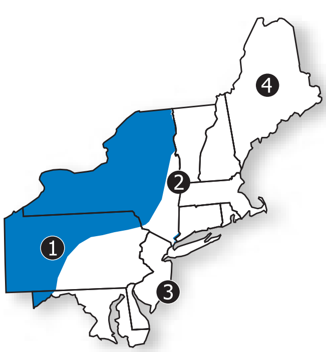
*see Geologic History, p. 7 and 12 for* **Taconic** *and* **Acadian** *events.*

Sedimentary rocks dominate the Inland Basin because the area was covered by the ocean for tens of millions of years: first in the Cambrian when global sea level was high and the ocean stretched far inland over most of the Northeast, and later during the ***Taconic*** and **Acadian** mountain-building periods (Ordovician through Devonian) when an inland ocean existed west of the new mountain ranges. The basin of the inland sea formed by the buckling of the crust from the compression of plates during the mountain-building events. Conglomerates, sandstones, siltstones, shales, limestones and dolostones are common rocks formed in these oceans and the bordering environments such as deltas, swamps, mud flats and tidal areas.

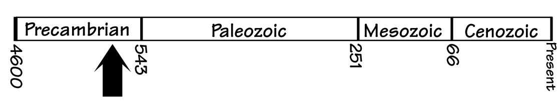
### Why are there different sedimentary rocks in different environments?

*As mountainous highlands erode, sediments are transported down the mountain by gravity and streams. The sediments that have only been transported a short distance and have not undergone considerable weathering, form conglomerates when compacted and cemented. Conglomerates are made of poorly sorted sediments, containing large pebbles of rock as well as finer sediments in between, typical for a deposit that occurs close to the source of erosion. If the sediments are transported a bit farther before being deposited and undergo more wearing down along the way, the sediments become rounded, smaller, and better sorted, as all of the larger grains drop out of the slowing water. If you examine sediments from the beach out to deep ocean, you will notice that beach deposits (and river deposits) are mainly sandy, followed by finer grained silts in deeper water, and very fine-grained clay in the deepest water above which currents may be slow enough to permit such small particles to settle. Limestones tend to accumulate where the rate of sediment being eroded from the highlands is low enough not to dilute accumulation of the calcium carbonate shell material that forms limestone. Many organisms that secrete calcium carbonate shells thrive ecologically in the clear water. In a shallow continental sea, low rates of sedimentation and clear water may be reached further from shore where sediment derived from land has settled out. Thus, the typical sequence of rocks formed across a shallow continental basin at any given time begins with conglomerate near the source, and sandstone, siltstone, shale and reefy limestone forming farther out.* Figure by J. Houghton.




### *Precambrian Adirondack Rocks:*




The Adirondack region of New York is composed of many types of billion-year-old rocks, all of which were metamorphosed as a result of the Grenville Orogeny. These ancient metamorphosed rocks are an anomaly in the basin region, which is dominated by sedimentary rocks. Grenville-aged rocks that were originally sandstones, limestones and shales deposited in a warm, shallow ocean at the eastern margin of proto-North America, make up the bulk of the resistant rocks of the Adirondacks *(Figure 2.2)*. These are the oldest rocks found at the surface in the Northeast. As Baltica approached North America for the first time (in the Late Precambrian), the Grenville belt of sedimentary rocks was squeezed and pushed up onto the margin of proto-North America, forming the Grenville Mountains. During the intensity of the squeeze, the sedimentary rocks were metamorphosed. Sandstone became quartzite, gneiss or schist; limestone became marble; and shale became gneiss and schist.

There are other types of rocks exposed in the Adirondack region as well. During the Grenville mountain-building event, magma created by the friction between the converging plates was rising up into the overlying crust. The blobs of magma rose higher, pushing through overlying sedimentary rocks. The blobs eventually cooled and crystallized, forming igneous rocks such as granite, ***anorthosite*** and, less commonly, gabbro. As the Grenville Orogeny continued, the cooled igneous blobs and the sedimentary rocks of the Grenville Belt were buried under as much as 30 kilometers of crust! With that much crust overhead, the pressure and temperature on the buried rocks was extremely high, causing further **metamorphism**. The granites became gneiss; gabbros became metagabbro; and the anorthosite became metanorthosite. The intensity of the Grenville mountain-building event also sheared the rock as blocks of crust slid past each other in opposite directions. This is most evident in a band of rocks called mylonites in which minerals were compressed and recrystallized upon shearing.

For millions of years following the Grenville mountain-building event, the Grenville Rocks that stretch from Canada to Mexico were worn down and buried by layers of sedimentary rock. Grenville-age rocks are present in many other parts of the Northeast, but are generally deeply buried by younger overlying sedimentary rocks. In the Adirondack region, the Grenville rocks are exposed because of an uplift of the crust that occurred only 10-20 million years ago during the Tertiary period.

The Adirondacks, though composed of billion-year-old rocks, are actually relatively young as mountains. Their exact mode of formation is still debated. Some geologists think that the crust was uplifted because of a hot spot beneath the crust caused by plumes of magma rising from the asthenosphere. As the magma rose, the crust was pushed upwards, forming a dome. The softer

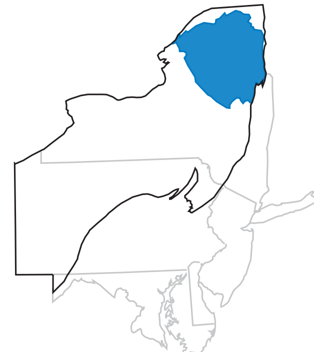
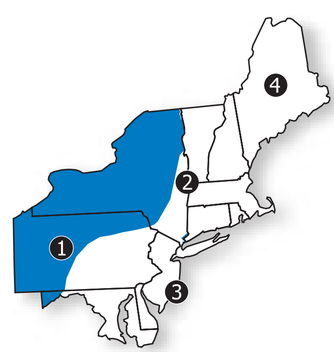


*Figure 2.2: Precambrian Adirondack rocks exposed in the Inland Basin.*

**Anorthosite** *is an igneous rock made almost entirely of the mineral feldspar.*

### What happens to a rock when it is metamorphosed?

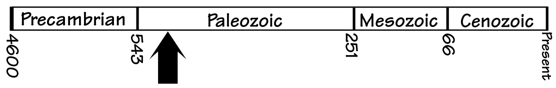
*When sedimentary or igneous rocks are subjected to increased temperatures and pressures, they are altered to become metamorphic rocks and exhibit characteristic metamorphic textures such as foliation and recrystallization. As pressure increases, usually by the weight of overlying layers or the compression of colliding plates, foliation occurs whereby minerals in the rock align themselves to the pressure, creating parallel layering. Foliation is obvious in rocks such as gneiss and schist. Recrystallization of rocks is seen in marble and quartzite, as the rock is heated to high temperatures. Individual grains of sediment making up the original rock recrystallize to form a more solid rock with interlocking crystals.*



*Many of the Grenville igneous and metamorphic rocks are resistant and are being eroded very slowly. In fact, the Adirondack region is still being uplifted today about 2 mm/yr, a rate faster than the mountains can erode in some places.*

sedimentary rocks on top of the dome were uplifted, fractured, and eroded away quickly, exposing the underlying Grenville rocks.

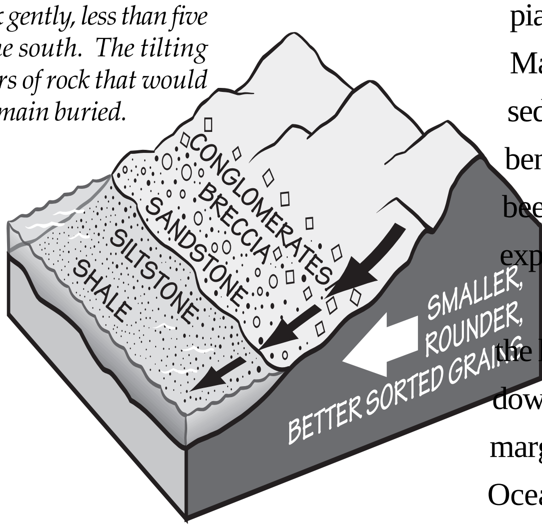
## *Cambrian-Ordovician Rocks*



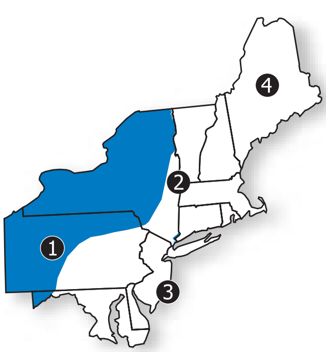

The remaining rocks exposed in the Inland Basin are sedimentary rocks. As you move from north to south on the geologic map of the basin, you will notice that the exposed surface rocks become younger *(Figure 2.3)*.

Cambrian and Ordovician rocks are exposed in northernmost New York and in patches around the Adirondack dome, followed by a thin stripe of Silurian rocks to the south. Most of the southern tier of New York and northern Pennsylvania exposes Devonian sedimentary rocks, followed by exposures of Mississippian, Pennsylvanian and Permian rocks continuing south into Maryland. These rocks were at one time flat-lying layers of sedimentary rock, with the Cambrian rocks lying unseen beneath overlying younger rocks. The layers, however, have been tilted very gently a few degrees to the south and eroded, exposing the underlying older rocks.

*Figure 2.3: The east-west stripes of rocks in the Inland Basin occur because of the shallow angle of the rock layers. Regional compressional stress from mountain building tilted the layers of sedimentary rock gently, less than five degrees to the south. The tilting exposes layers of rock that would otherwise remain buried.*




When the Grenville mountain building finally subsided in the late Precambrian, a period of erosion followed that wore down the ancient Grenville Mountains, which stretched up the margin of North America. During this period, the Iapetus Ocean opened and widened as Baltica separated once again from North America. Rifts developed in the crust during this separation, creating small basins of down-dropped blocks of crust. Cambrian sedimentary rocks from the eroding Grenville highlands are preserved in the rift basins. The rift basins appear in patchy areas around the Adirondack dome. Globally, sea level rose during the late Cambrian, covering most of the Northeast with a shallow ocean *(Figure 2.4)*. Sedimentary rocks



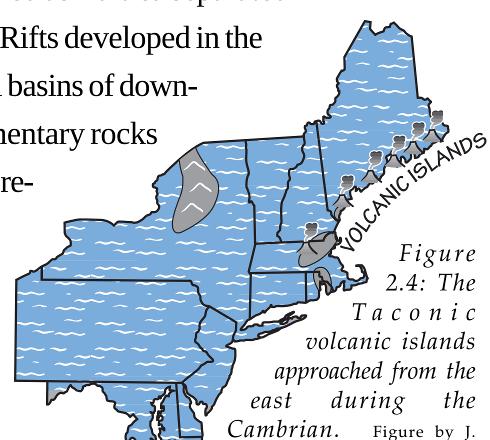




*Figure 2.4: The Taconic volcanic islands approached from the east during the Cambrian.* Figure by J. Houghton, after *Geological Highway Map of the Northeastern Region, no. 10*, American Association of Petroleum Geologists, 1995.

formed from the sediments eroded from land to the west.

Most of the early Ordovician produced similar deposits to the Cambrian *(Figure 2.5)*. Sea level remained high and the rocks formed were predominantly limestone and dolostone, common in warm, shallow, sediment-starved seas. As sea level dropped later in the Ordovician, these sedimentary rocks were subjected to intense erosion.

*Figure 2.5: Cambrian and Ordovician rocks exposed in the Inland Basin.*

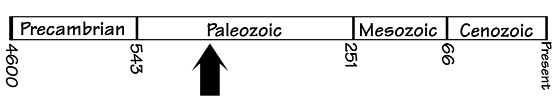

*Figure 2.6: The Taconic volcanic islands collided with the margin of North America, forming an inland ocean.* Figure by J. Houghton, after *Geological Highway Map of the Northeastern Region, no. 10,* 1995.

Towards the end of the Ordovician, volcanic islands that had formed along the subduction zone between North America and Baltica, moved towards the margin of North America. Layers of ash resulting from the volcanic activity to the east were deposited in the basin and can be seen today preserved within the rocks of the Inland Basin. The volcanic islands collided with North America to form the Taconic Mountains and buckled the crust to the west of the mountains, forming an ***inland*** ocean.

*For millions of years during the Paleozoic, an* **inland ocean** *existed on the eastern half of North America as an extension of the Iapetus Ocean, filling the basin formed by the mountain-building events with sea water. The inland ocean was separated from the Iapetus Ocean by the Taconic and Acadian Mountains.*

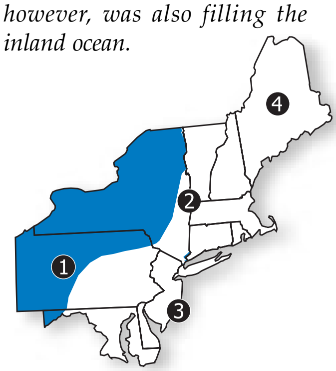
Sediment tumbled down the mountain flanks carried by streams westward into the inland ocean, forming the Queenston Delta *(Figure 2.6)*. Close to the highlands, conglomerates formed. Deltaic streams brought sandy, muddy sediments downstream towards the inland ocean basin to form sandstone, siltstone and shale. Settling within the inland ocean, sediments were compacted and cemented to become sedimentary rocks that stretch across to the western border of New York and Pennsylvania.

## *Silurian Rocks*




The Silurian rocks exposed east to west across the middle of New York record the continuing story of the inland ocean. Sedimentary rocks were still forming with the rise and fall of ***sea level*** in the inland ocean. During the late Silurian, the ocean became extremely shallow in the Northeast. Sediments in the ocean were exposed as mudflats and rapid evaporation of the shallow seas led to

**Sea level** *rose and fell in the inland ocean during the Paleozoic, in part because the convergence of the plates carrying North America and Baltica continued to buckle the inland basin, deepening the ocean. Sediment eroded from the mountains, however, was also filling the inland ocean.*



the formation of evaporites *(Figure 2.7)*.

Much of the sediments deposited in the earlier Silurian were quickly eroded away when exposed above sea level. The rate of deposition of sediments was also slower during the Silurian because the majority of the Taconic Mountains had already been worn down by this time. As a result, relatively little sediment was preserved as rock in the Silurian, and they are therefore represented by only a thin stripe on the geologic map *(Figure 2.8)*.

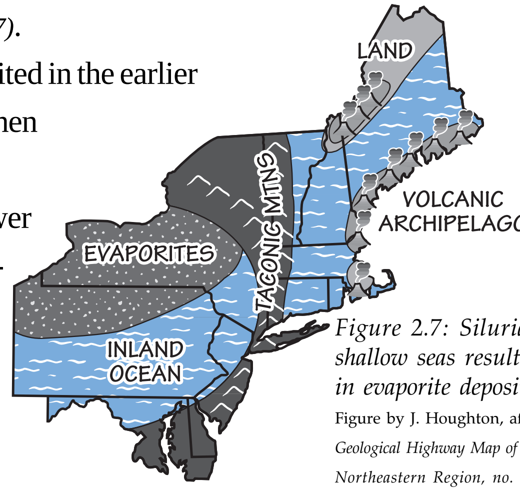
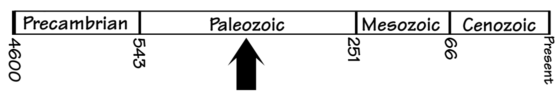



*Figure 2.7: Silurian shallow seas resulted in evaporite deposits.* Figure by J. Houghton, after *Geological Highway Map of the Northeastern Region, no. 10*, 1995.

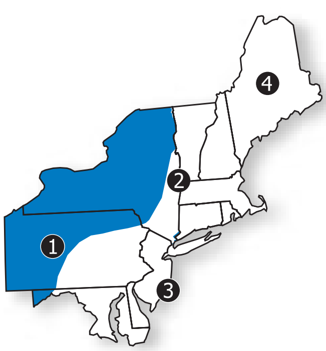
*Figure 2.8: Silurian rocks exposed in the Inland Basin.*

## *Devonian Rocks*




Devonian-aged rocks are exposed across southern New York and northern Pennsylvania *(Figure 2.9)*. These sedimentary rocks record the Acadian mountain-building event as North America collided with Baltica. The formation of the Acadian Mountains was similar to the formation of the Taconic Mountains. Just as the Taconic mountain building during the Ordovician had formed an inland ocean and the westward spreading Queenston Delta, Acadian mountain building renewed the inland ocean by buckling the crust downward and forming a westward spreading Catskill Delta *(Figure 2.10)*. As one would expect, the rocks of the Devonian period produced during the Acadian orogeny are similar to the rocks of the earlier Ordovician period produced during the Taconic orogeny. Conglomerates were formed close to the Acadian highlands, and finer grained sediments spread westward to form sandstone, siltstone and shale. At times, when the amount of sediment being deposited from

*Figure 2.9: Devonian rocks exposed in the Inland Basin.*



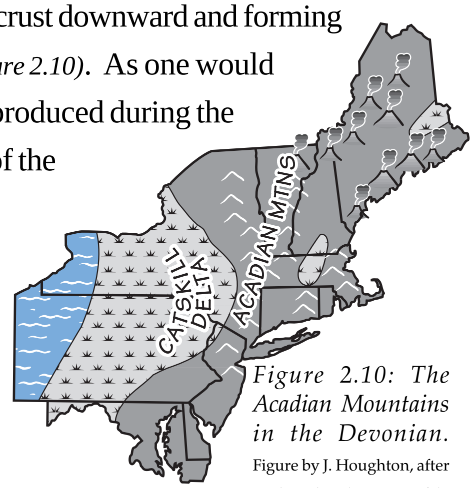
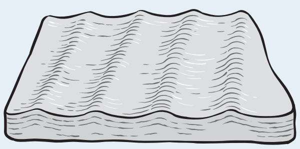




*Figure 2.10: The Acadian Mountains in the Devonian.* Figure by J. Houghton, after *Geological Highway Map of the Northeastern Region, no. 10*, 1995.

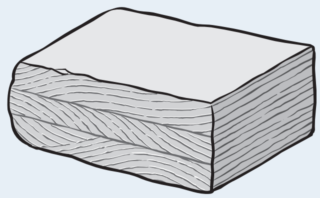
the highlands decreased, limestone and dolostone formed as well. The Acadian highlands eroded rapidly, providing huge amounts of sediments to be deposited on the Catskill delta and into the inland ocean that were preserved as a thick sequence of Devonian-age sedimentary rocks.

### Sedimentary Structures

*Upon close examination, the Devonian rocks of the Inland Basin often reveal the type of environment in which they formed by the presence of sedimentary structures within the rock. Sedimentary structures include ripple marks, cross-beds, mud cracks, and even rain drop impressions. Consider the type of environment in which you see these sedimentary structures today in the world around you.* Figures by J. Houghton.

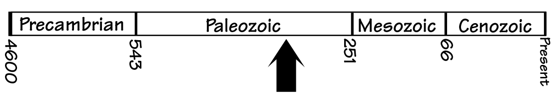


*Ripple marks suggest the presence of moving water (though wind can also create ripples and even dunes). Mudcracks indicate that the sediment was wet but exposed to the air to dry and crack.*



*Cross-beds form as flowing water pushes sediment downstream, creating thin beds that slope gently in the direction of the current as migrating ripples. The downstream slope of the ripple may be preserved as a thin layer dipping in the direction of the current, across the natural flat-lying repose of the beds. Another migrating ripple will form another layer on top of the previous.*

## *Mississippian Rocks*




During the Mississippian and Pennsylvanian period, the Inland Basin region was still an inland sea environment, with sediment being shed into the basin from the Acadian highlands in the east *(Figure 2.11)*. Gradually, the amount of incoming sediment into the basin declined. The shoreline of the inland sea moved back and forth across the basin as sea level rose and fell during this period. The fluctuating water levels created alternating sequences of marine and non-marine sedimentary rocks, characterized by red and gray colors *(Figure 2.12)*. Limestones were also forming in the inland sea in areas receiving very little sediment. The Northeast was still located along the equator at this time, so the warm climate created lush vegetation. Large swamps covered the shoreline areas of the inland sea. Plant material in the swamps died and accumulated as thick piles of peat.

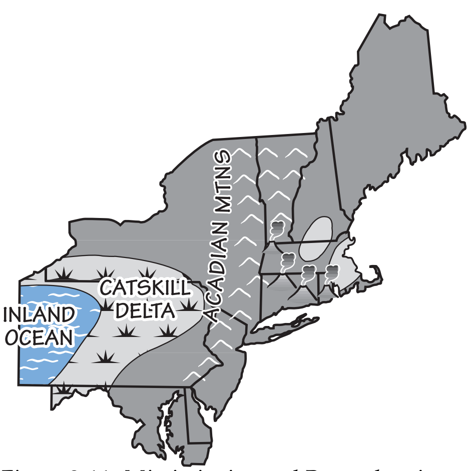



*Figure 2.11: Mississippian and Pennsylvanian Northeast landscape.* Figure by J. Houghton, after *Geological Highway Map of the Northeastern Region, no. 10,* 1995.

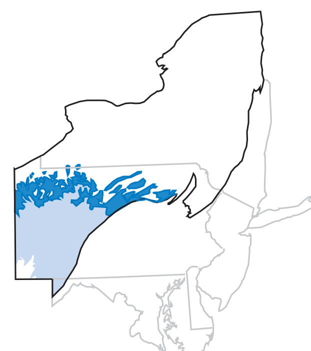
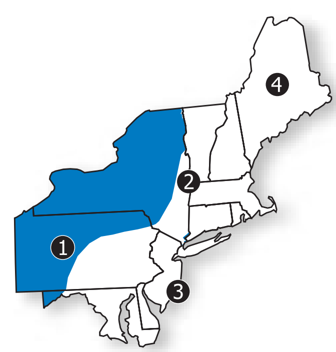


*Figure 2.12: Mississippian (dark) and Pennsylvanian (light) rocks exposed in the Inland Basin.*



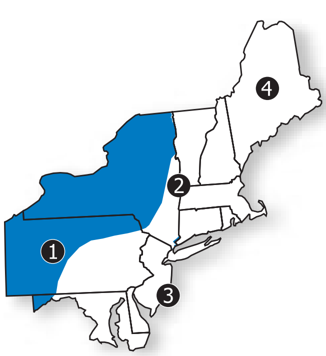
**Mississippian rocks** *are also exposed in small patches at the surface in the Inland Basin in southwestern New York.*

*see Non-Mineral Resources, p.154 for more on the formation of* **coal.**

*see Fossils, p.90 for more on the composition of* **coal.**

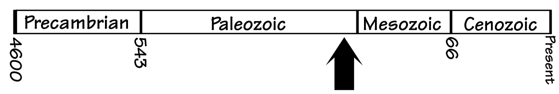
*Figure 2.13: Permian rocks exposed in the Inland Basin.*

*Though Permian-age rocks have some thin bands of coal, they have nowhere near the abundance of coal seen in the Mississippian and Pennsylvanian rocks.*




Buried by waves of sediment and more vegetation, the peat was compressed. Over time and continued burial, the peat was transformed to layers of coal. Thus, the Pennsylvanian and ***Mississippian rocks*** of the Inland Basin region, found primarily in Pennsylvania, are repeating sequences of alternating sedimentary rock and bands of ***coal*** formed because shifts in sea levels allowed lush vegetation to develop in swampy areas.

## *Permian Rocks*




Exposed at the surface in the Pennsylvania and Maryland Inland Basin region are Permian-age sedimentary rocks *(Figure 2.13)*. At this time in geologic history, the continents had united to form one giant landmass known as Pangea. North America was sutured to Pangea by the collision of Africa with the east coast of North America during the Alleghanian mountain-building event, forming the Appalachian Mountains. The unification of Pangea signaled the closing of the Iapetus Ocean as well as the last time the inland sea invaded eastern North America. Though sea level fluctuated for a time, the inland ocean gradually retreated, leaving behind river sediment deposits rather than marine deposits. River sediments generally form coarser grained and more poorly sorted sedimentary rocks. With the closing of the Iapetus, the climate in the Northeast became significantly drier as the Northeast was near the center of Pangea. The lush coal swamps of the Mississippian and Pennsylvanian periods gradually disappeared as more arid conditions developed in the area. With the absence of organic-rich swampy areas, very little coal could be formed, accounting for the much smaller amounts of coal in the Permian rock record.

### Missing time in the Inland Basin

*Where are the rocks representing the Triassic, Jurassic, Cretaceous and Tertiary periods in the Inland Basin? The absence of rocks deposited during certain time periods in regions of a geologic map does not mean that there were no rocks forming during that time. It may mean, however, that very little sediment was deposited, that the sediment was eroded away, or that the rocks are buried beneath the surface. There is no single place on Earth that has a complete sequence of rocks from the Precambrian to the Quaternary. Erosion and weathering over time have removed many meters (and in some cases kilometers) of rock from the surface of the Northeast.*

# Rocks of the Appalachian/Piedmont
## *Region 2*

The folded, deformed rocks of the Appalachian/Piedmont region record the successive mountain-building events that folded the land into narrow ridges in this area. The rocks of this region were originally sandstone, siltstone, shale and limestone, formed as sediments eroded from the Taconic and Acadian Mountains into the inland ocean basin. Much of the Appalachian/Piedmont rocks are similar to those of the Inland Basin region because they were deposited in the same inland basin, though much closer to the mountains. Many of the sedimentary rocks, however, from the Appalachian/Piedmont Region are no longer sedimentary rocks. They have been squeezed, pushed, faulted and severely deformed in many places because this region was, at various times through geologic history, either the suture area for converging plates or directly adjacent to the uplifting mountains. The Appalachian/Piedmont Rocks were closer to the mountain building than rocks further west, and so felt the effects of the immense pressures of colliding plates much more severely. The northeast-southwest trending narrow ridges and valleys, and the rolling hills of the Piedmont are a result of the stress caused by the intense compression of plates of crust *(Figure 2.14)*.

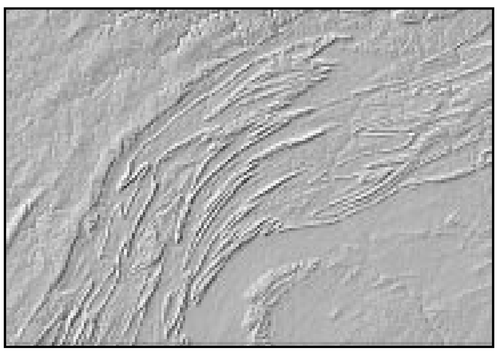
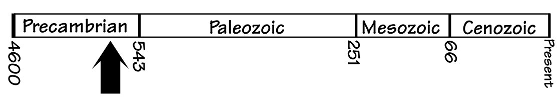


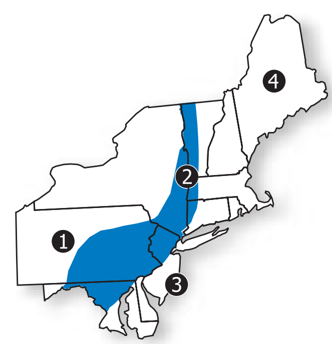
*Figure 2.14: Shaded-relief map of the Appalachian-Piedmont Valley and Ridge in Pennsylvania.* Image provided by Ray Sterner, Johns Hopkins University.

*The rocks of both the Appalachian/ Piedmont Region and the Inland Basin got their final squeeze during the Alleghanian mountain-building event. The rocks at the surface today were once buried under kilometers of sediment. They have been exposed over time by erosion and weathering.*

### *Precambrian Rocks*




The oldest rocks of the Appalachian/Piedmont region record the deposition of sediments on the ancient North American coastline more than one billion years ago as sediments eroded from the Grenville Mountains. There are several areas in which Precambrian rock is exposed within the Appalachian/Piedmont Region: the Green Mountains of Vermont; the Berkshire Mountains of Massachusetts stretching south into northern Connecticut; the Hudson Highlands and

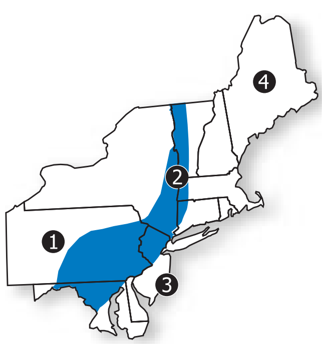


*The Manhattan, Reading and Trenton exposures of Precambrian rock are called* ***prongs*** *because of their elongated, narrow outcrops that resemble a prong. In New York City, the Manhattan Prong is actually Precambrian Grenville Fordham gneiss, and the Cambrian Inwood Marble and Manhattan Schist.*

*see Geologic History, p. 3, for more on the* ***Grenville*** *rocks.*

### Recrystallization of rocks

*As temperature and pressure increases during metamorphism, individual grains of sediment making up the original rock are melted slightly and recrystallize. The crystals are more tightly interlocked than an unmetamorphosed rock. The spaces between grains (pore space) in a sedimentary rock are easy paths for fractures and splitting. Elimination of pore space through recrystallization during metamorphism strengthens the overall structure of the rock. Thus, sedimentary rocks in general are an easier target for erosion and weathering than the more resistant interlocking crystals of metamorphic rocks.*




Manhattan ***Prong*** of New York; the Reading Prong; the Trenton Prong; the Baltimore Gneiss; South Mountain and the Catoctin Mountains *(Figure 2.15)*. At each exposure, metamorphosed sedimentary rocks are visible, including gneiss, quartzite, schist and marble. Remember, though, that these metamorphic rocks were once sands, silts, muds and limestone deposited in the warm, tropical Iapetus Ocean from the Grenville Mountains. They were repeatedly subjected to enormous pressures and high temperatures from the colliding continents, ***recrystallizing*** to become metamorphic rocks. The Precambrian rock is visible at the surface only because of intense folding of the Appalachian/Piedmont region, which has uplifted layers of rock that were once buried beneath kilometers of crust, and erosion.

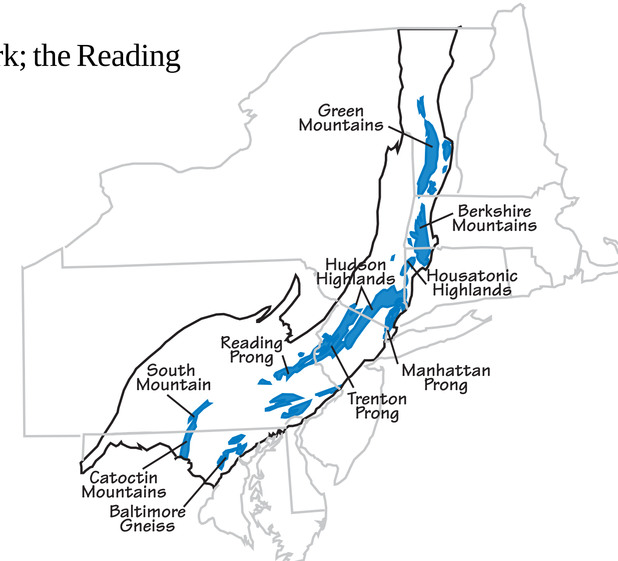



*Figure 2.15: The Precambrian rocks of the Appalachian/Piedmont occur in a nearly north-south line, forming the many ridges of the Appalachian Mountains and revealing the location of the ancient Grenville Mountains (though in some places the Precambrian rock has been thrust westward from its original position).*

Indeed, the erosion-resistant Precambrian rocks have become the 'backbone' of the range, helping the mountains resist being worn completely flat. The Precambrian rock and overlying younger sedimentary rocks have been compressed by the collisions of the continents into a giant upward fold. The softer sedimentary rocks were eroded away at the peak of the fold, exposing the resistant Precambrian rocks at the center. The Green Mountains of Vermont clearly expose this backbone of Precambrian gneiss and quartzite. The Hudson Highlands, extending into Pennsylvania as part of the Reading Prong, the Berkshire Mountains, Manhattan Prong and the Trenton Prong, follow the same line of resistant ridges of Precambrian rock.

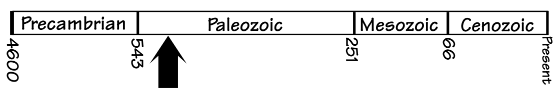
The Precambrian Baltimore Gneiss, near Baltimore, Maryland, is actually a series of domes. The domes have Precambrian gneiss in the middle, surrounded by rings of quartzite and marble. These domes are not simple upwarps of the crust. The rocks of this region have been squeezed so tightly and have been so complexly deformed, that the folds have overturned, folded again, and later eroded to expose the Precambrian gneiss. The ***gneiss*** is a hard, resistant metamorphic rock that has remained a highland, while surrounding softer rocks have worn away.

Basalts, rhyolites and other Precambrian volcanic rocks, as well as Precambrian gneiss and quartzite, are found stretching across the Pennsylvania-Maryland border along the north-south line of Precambrian rock. South Mountain of Pennsylvania and Maryland's Catoctin Mountains record the rifting of North America and Baltica in the Cambrian. As North America moved away from Baltica and the Iapetus Ocean opened up, cracks in the crust occurred that were similar to the younger Triassic rifts from Pangea. The ***rifts*** and fractures in the crust made pathways for emerging lava to pour out across the surface, forming the volcanic rocks seen today.

**Gneiss** *is a metamorphic rock that forms by subjecting rocks to high degrees of metamorphism. Gneiss can either form from granite or layered sedimentary rock such as sandstone or siltstone. The result is very similar: parallel bands of light and dark minerals give gneiss its foliated texture.*

*see Geologic History, p. 7 and 16, for more on the* ***rifts****.*

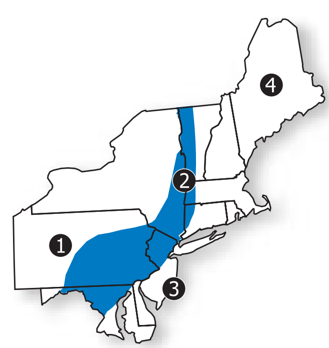
## *Cambrian-Ordovician Rocks*




The Cambrian and early Ordovician sediments record the ancient North American shelf and slope ***sediments***. Sandstone and shale were the dominant rocks formed from the eroding sediments of the continental highlands and limestone was formed from the abundant shelled organisms in the inland ocean. With the collision of the Taconic volcanic islands, the original limestone, sandstone and shale were metamorphosed in many areas, forming the marble, quartzite and slate that make up the bulk of the Appalachian/Piedmont region. The Cambrian and Ordovician rocks underlie the Champlain Valley of Vermont, the Taconic Mountains and highlands of western New England and eastern New York, and the prominent ridges and valleys further south in Pennsylvania, New Jersey and Maryland. In some areas, particularly the Marble Valley of western Massachusetts, Connecticut and southern Vermont, the less resistant ***marble*** is extensively exposed at the surface, forming a wide valley of fine marble that was once vigorously quarried for buildings and monuments.

*These* **sediments** *were part of a wide bank of carbonate rocks that formed along the margin of the continent while the eroding sediment supply dwindled from the nearly worn-down Grenville Mountains. As the Taconic volcanic islands approached North America during the later Ordovician, sediments were also eroded from the uplifted crust into the inland ocean to the west.*

*see Non-Mineral Resources, p.161, for more on* **marble**.




The Taconic Mountain rocks are unusual because older Cambrian rocks (which should be *beneath* younger rocks) are overlying younger Ordovician rocks. This unusual situation occurs because the sediments deposited on the

*Unless rock layers are overturned, older rocks are found at the bottom and younger rocks are found at the top of a sedimentary sequence. This is known as the Law of Superposition.*

continental shelf and slope of ancient North America were shoved and stacked up onto the coast. Older rocks from the continental shelf and slope were thrust on top of younger rocks from the Inland Basin, causing no small amount of confusion when geologists first tried to unravel the history of the area. The older Cambrian rocks are a resistant cap atop the less resistant Ordovician sedimentary rocks, forming the ridge of the Taconic Mountains *(Figures 2.16 and 2.17)*.

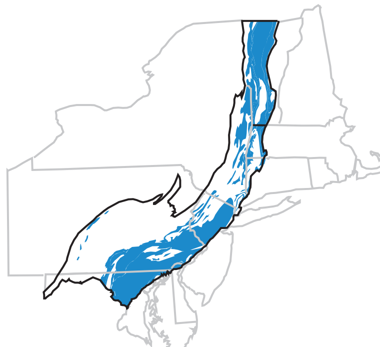


*Figure 2.16: Cambrian rocks exposed in the Appalachian/ Piedmont.*

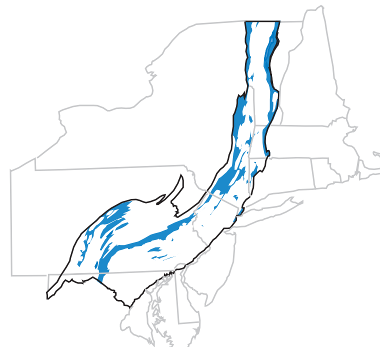


*Figure 2.17: Ordovician rocks exposed in the Appalachian/Piedmont.*

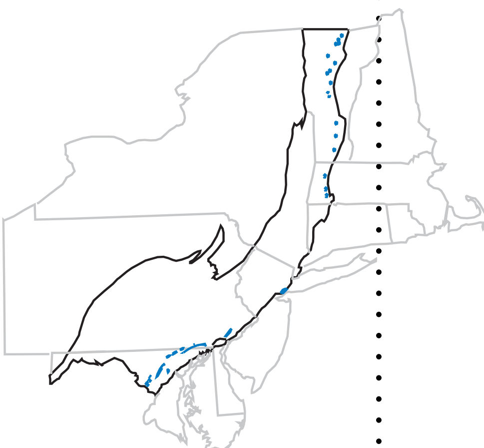
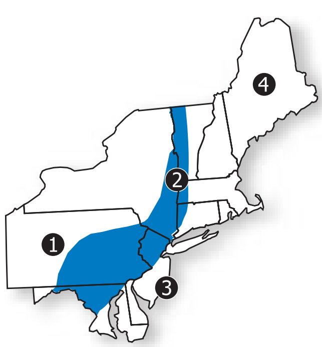


*Figure 2.18: The Serpentine Belt exposed in the Appalachian/ Piedmont.*

Along a line from the middle of Vermont through western Massachusetts and Connecticut, southeastern New York, Pennsylvania and Maryland are small exposures of very unusual dark rocks that are part of ophiolite sequences *(Figure 2.18)*. Ophiolites are made of deep-sea sediments, oceanic crust and upper mantle material that are rarely seen at the Earth's surface. The line of ophiolite exposures is located along the ancient suture line between North America and the volcanic island terranes of the Taconic mountain building in the Ordovician period. These igneous rocks, known as the Ultramafic Belt, are very rich in magnesium and iron, but very low in silica, typically forming basalts, gabbros and peridotite. The peridotite, derived from the upper mantle, is often altered slightly through metamorphism to a greenish rock called serpentinite.

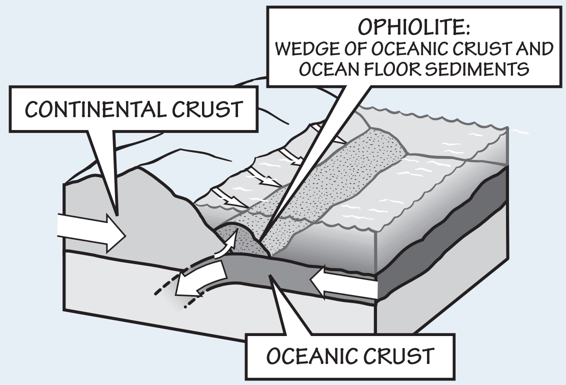
***Ophiolites*** are recognized by their particular sequence of rocks that are not usually found at the surface. The sequence includes sedimentary rock from the ocean floor underlain by flows of pillow basalt. The pillow basalts form as lava pours out of cracks in the oceanic crust and cools very quickly in the seawater, creating a pillow-shaped mass of lava. Beneath the pillow lavas are sills of gabbro, a dark igneous rock formed from cooling magma beneath the



surface. The lowest layer in the ophiolite sequence is composed of peridotite, a rock formed from the upper mantle layer of the Earth that is rarely seen at the surface. The subduction of the oceanic plate also caused igneous intrusions beneath the volcanic islands.

### Ophiolites

*When North America was on its collision course with Baltica, the oceanic crust in between the continents was being pushed beneath the continental crust of the approaching North America. As the oceanic crust was subducted, some of the deep-sea sediments overlying the crust, the oceanic crust itself, and perhaps rock from the upper mantle, were scraped off the descending plate and did not get shoved back down into the mantle. Instead, the scraped off ophiolite was left stuck on the continental crust. Subsequent erosion exposed this odd group of rocks that is so unlike the surrounding rock of the continental crust. The ophiolites are significant in the geology of the Northeast because they record the subduction of the oceanic plate beneath the Taconic volcanic islands as they collided with North America.* Figure by J. Houghton.

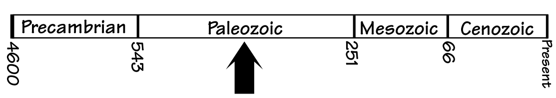



During and after the Taconic mountain-building event, sediments were deposited into the Iapetus Ocean basin and the inland ocean basin east and west of the mountains, mixing with and then covering the limestones that had been building up along the margin of North America prior to mountain building. Volcanic ash within these rock layers indicates volcanic activity occurring as the volcanic islands collided with the continent. The sediments of the Queenston Delta record the deposition of eroding sediment from the Taconic Highlands as well as the changing shoreline as the basin filled.

### Light-colored vs. dark-colored igneous rocks

*Dark-colored igneous rocks generally come from either mantle magma or melting oceanic crust at a subduction zone. Oceanic crust is already dark, dense and rich in iron and magnesium. The dark color originates from the iron and magnesium as well as a relatively low percentage of silica, and characterizes rocks such as basalt and gabbro. Light-colored rocks are formed from continental crust that is melted from the pressure of overlying rock or friction from colliding plates. Continental crust-derived sediments may also form light-colored rocks. Light-colored igneous rocks are very rich in silica and lack significant amounts of iron and magnesium, and include rocks such as granite. The abundance of silica also makes light-colored igneous rocks less dense than oceanic crust. Thus, continental crust, with a density of 2.7 g/cm$^3$, is rarely subducted when plates collide because it is too buoyant to be pulled under another plate. Oceanic crust on the other hand, with a density of 3.2 g/cm$^3$, is very dense and more easily pulled under an approaching plate.*

## *Silurian-Devonian Rocks*



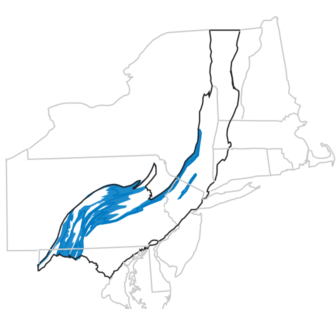
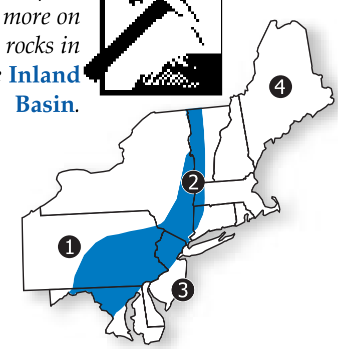



*Figure 2.19: Silurian and Devonian rocks exposed in the Appalachian/Piedmont.*

Silurian and Devonian rocks are found primarily in the southwestern-most part of the Appalachian-Piedmont region *(Figure 2.19)*. These rocks are very similar to the Silurian and Devonian rocks of the adjacent ***Inland Basin***. They record deposition in the inland ocean and the collision of Baltica with North America, which formed the Acadian

*see Rocks, p.35 for more on similar rocks in the* **Inland Basin**.



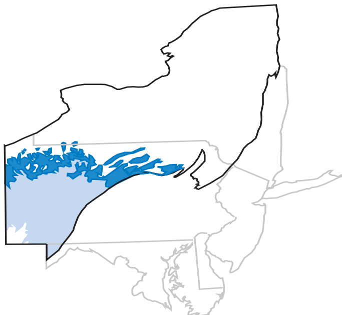


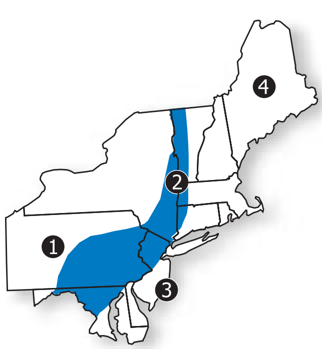
Figure 2.20: Mississippian, Pennsylvanian and Permian rocks exposed in the Appalachian/ Piedmont.

see *Rocks*, p.37.

see *Non-Mineral Resources*, p.162, for more on the formation of **coal**.

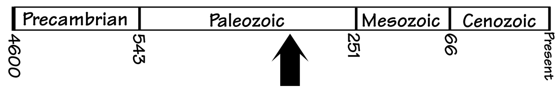
see *Rocks*, p.52, for more on rift basin rocks.

see *Geologic History*, p. 16, for more on the formation of **rift basins.**



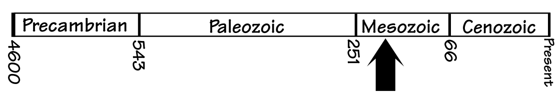

Mountains and renewed deposition in the inland ocean. The main distinction between the Silurian and Devonian rocks of the Appalachian/Piedmont region and the Inland Basin region is the compression and metamorphism of the Appalachian Piedmont rocks.

## *Mississippian-Pennsylvanian-Permian Rocks*




The rocks of the Mississippian, Pennsylvanian and Permian periods of the Appalachian/Piedmont are also only found in the southwestern area of the region *(Figure 2.20)*. Again, these ***rocks*** are very similar to exposures of the same age in the adjoining Inland Basin, recording the lush vegetation and swampy deposits of the receding inland ocean shoreline and deeper-water sediments. However, the rocks of the Appalachian/Piedmont were metamorphosed in many places. The soft coal seen in the Inland Basin is present as very hard anthracite ***coal*** in the Appalachian/Piedmont region.

## *Triassic-Jurassic Rocks*




Dissecting the southeastern tip of New York, northern New Jersey, eastern Pennsylvania and Maryland, are two connecting basins filled with rocks dating back to the Triassic and Jurassic *(Figure 2.21)*. The northernmost of the two is called the Newark Basin, and the southern is called the Gettysburg Basin. In the adjoining Exotic Terrane region, a similar basin occurs in Massachusetts and Connecticut known as the Connecticut Valley ***rift basin***. In Connecticut, there are a few other mini-versions of the large rift basins, where smaller faults formed tiny basins that preserved Triassic- and Jurassic-aged sediments.

The basins formed as blocks of crust slid down the fault planes (rifts) during the late Triassic and early Jurassic when Pangea was breaking apart. The basins that formed expose characteristic reddish-brown sedimentary rocks and ridge-forming basalt, an igneous volcanic rock also known locally as 'traprock'. Periodically the basins were filled with water, forming shallow lakes and depositing thin, dark layers of sediment typical of lake deposits.

The rift valley igneous rocks were formed when magma pushed up through fractures in the crust and either poured out on the surface of the basin as flows of lava, or cooled and crystallized as igneous intrusions before reaching the surface *(Figure 2.22)*. The igneous intrusions, typical within the rift basins, formed rather shallow within the crust. The relatively cold temperatures of the upper crust forced the ***magma*** to cool quickly.

The same magma that formed the **Palisades Sill** continued to rise towards the surface. The rising magma cut through the overlying layers and burst out onto the surface, spreading basaltic lava over the basin. These lava flows are recorded by the Wachtung Mountains of New Jersey, left standing because of the resistance of the tilted lava beds in comparison to the weaker sedimentary rocks above and below.

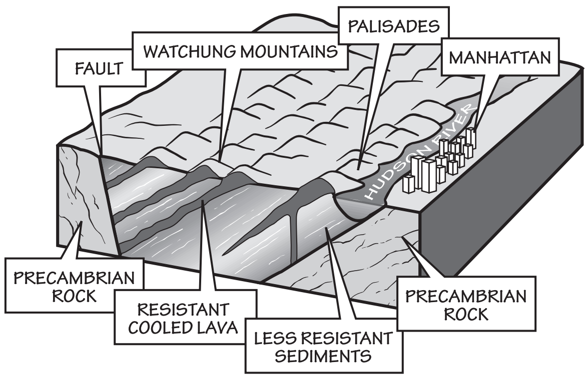



*Figure 2.22: The Palisades Sill is an igneous intrusion; the Wachtung Mountains are a volcanic extrusion of lava.* Figure by J. Houghton.

## Colors of sedimentary rocks:
***what do they tell us about the environment?***

*Color in rocks may be an important indicator of the type of environment in which the rocks were formed. The red-brown color so common in the rift basins of the northeast is present because of iron within the rock that has been oxidized (rusted!), which tells us that the rock formed in a seasonally hot and dry climate on land, where the iron could be exposed to the air and oxidized. Red sedimentary rock is also found in the Silurian rocks of the Inland Basin, reflecting a time of shallow seas in which the ocean floor sediments were often exposed above water and allowed to oxidize. In some marine environments, where iron is reduced rather than oxidized, rocks may take on a greenish hue. However, in well-oxygenated, deep marine conditions, red clays may form.*

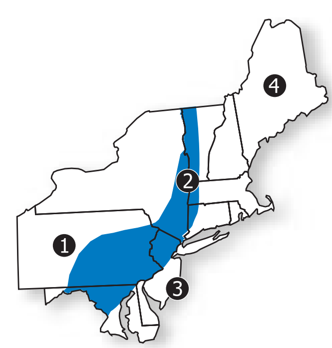
*In contrast, most shales are gray or black in color, reflecting the abundance of organic material that can accumulate in quiet-water settings and preserve in fine-grained rocks that are relatively impermeable to oxygen-rich pore water. Shales are most commonly formed in quiet waters where tiny particles have time to settle out to the sea or lake floor, where there is very little oxygen to aid in the decomposition of the organisms, so the sediments retain a black color from the carbon of organic material. The darker the shale, the more organic material that is preserved within! The presence of certain minerals may also affect the color and aid in the interpretation of the environment of deposition. Green sedimentary rocks may indicate the presence of the mineral glauconite, found only in marine environments.*

*Figure 2.21: Triassic-Jurassic rift basins exposed in the Appalachian/ Piedmont.*

**Magma** *cooled quickly has little time to crystallize, and therefore microscopically fine-grained igneous rocks such as basalts are often produced in rifts.*

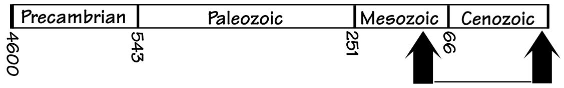
## What is a sill?

*A sill occurs when rising magma forces its way between layers of rock, spreading out parallel to the layers and creating a flat intrusion like the Palisades along the Hudson River in New York. The* **Palisade Sill** *is composed of an igneous rock called diabase. The texture of diabase is a medium-size crystalline texture, between that of a basalt (finely crystalline) and a gabbro (coarsely crystalline). Diabase cools more slowly than basalt because it is not above the surface, yet it cools more quickly than gabbro because it is closer to the surface.*



# Rocks of the Coastal Plain

## *Region 3*




The Coastal Plain region has fairly straightforward geology. The rocks here are actually not yet rocks! Instead, there are usually unconsolidated sediments that have not been cemented or compacted. The sediments are geologically very young, ranging in age from the Cretaceous to the Quaternary. The sediments include gravel, sand, and silt; it may take tens or hundreds of millions of years before these sediments are turned to rock. Overlying the Paleozoic rocks, the Coastal Plain sediments form a wedge of nearly flat-lying layers of sediment that thicken eastward onto the continental shelf and slope and then thin again further to the east.

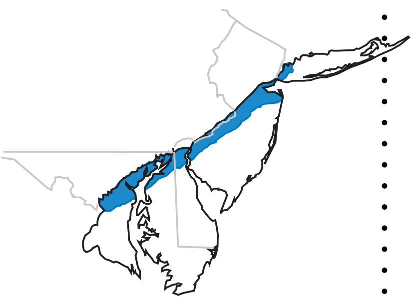
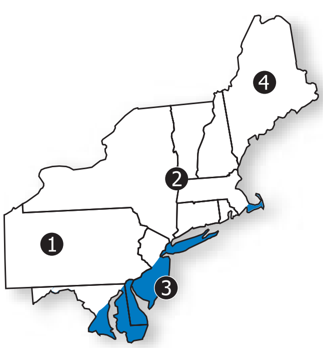


*Figure 2.23: Cretaceous sediments exposed in the Coastal Plain.*

Consider the geologic events between the Cretaceous and the Quaternary: the Northeast was experiencing a relatively quiet time tectonically and the east coast of North America had become a passive margin (there were no longer converging or diverging plates right at the margin of the continent). In this time of tectonic quiet, significant erosion of the Appalachian highlands occurred. The sediment deposits were similar to the formation of the ***Queenston*** and ***Catskill Deltas*** of the Taconic and Acadian mountain building millions of years before. Rivers draining from the mountains brought sediment down to the coast. The oldest deposits seen on the Coastal Plain (Cretaceous) record the story of eroded sediments transported by rivers to the coast and are found along the inner edge of the region *(Figure 2.23)*. Cretaceous sediments are also found on Martha's Vineyard at Gay Head Cliff, uplifted and pushed forward by the ice sheet during the Quaternary .

*Unlike the Queenston and Catskill Deltas, which have been cemented and compacted to become thick sequences of sedimentary rock, the sediments being transported from the Appalachians have not yet become sedimentary rocks.*




Throughout the Tertiary and Quaternary periods, the Northeast repeatedly experienced rise and fall of sea level, in part due to the build-up and melting of glaciers. Overlying the older river deposits of the Cretaceous, Tertiary marine sediments record the rise and fall of sea level over greater than sixty million years *(Figure 2.24)*. 'Greensand' is common in marine Tertiary sediments because marine deposits often contain the green mineral, glauconite, lending the sediment a greenish tinge.

The Quaternary is recorded in the youngest sediments of the Coastal Plain *(Figure 2.25)*. Long Island, Cape Cod and the several smaller islands off the coast of New England (Block Island, Nantucket, Martha's Vineyard) are testaments to the advance and retreat of an enormous ice sheet over the continent. The islands are actually formed from glacial outwash: gravel, sand and silt that piled up in front of the glacier as it melted. The islands represent the maximum extent of the most recent glacial advance over 20,000 years ago. The glaciers never advanced further south than Long Island and northern Pennsylvania. Where the glacier stood still (neither advancing nor retreating for some time) huge ***deposits*** of outwash built up in front of the glacier. This feature is known as a terminal moraine. There are a series of terminal moraines in the Northeast that represent the retreat of the glacier toward the north.

While the continental ice sheet never made it as far south as New Jersey, Delaware, Maryland, or southern Pennsylvania, the glaciers still left their mark on the area. Melt water streaming off the retreating glaciers brought gravel, sand, silt and clay that had been carried along by the glacier downstream to the Coastal Plain. Quaternary deposits make up most of the sediments you see immediately adjacent to modern estuaries and streams because they are relatively recent deposits.

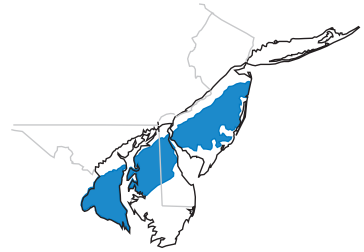
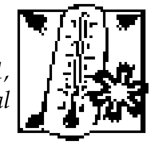


*Figure 2.24: Tertiary sediments exposed in the Coastal Plain.*

*see Glaciers, p. 61, for more on glacial* **deposits**.



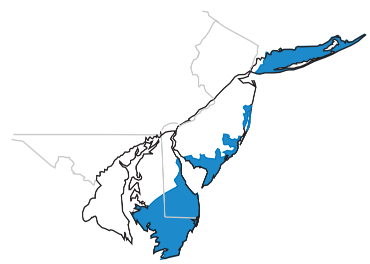
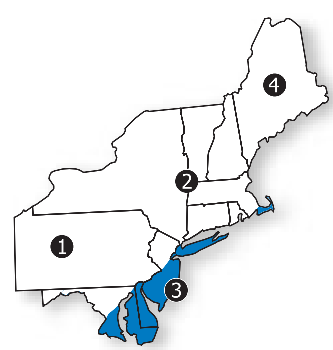


*Figure 2.25: Quaternary sediments exposed in the Coastal Plain.*



# Rocks of the Exotic Terrane

## *Region 4*

see *Geologic History*, *p. 10, for more on exotic* **terranes.**

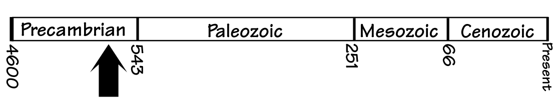
There are two basic divisions of the Exotic Terrane region of New England: the Iapetus Rocks, recording the sediments deposited in the ancient Iapetus Ocean, and the Avalonia Rocks, recording the distinctive rocks of the Avalonia microcontinent, which were caught in the middle of the collision between North America and Baltica. The Iapetus and Avalonia Rocks were not originally part of North America. Indeed, the rocks have distinctly different geologic characteristics than the bulk of North America. The Exotic Terrane region is dominated by igneous and metamorphic rocks. Both the Iapetus ***Terrane*** rocks and the Avalonia ***Terrane*** rocks are cut through with igneous intrusions that formed as magma cooled within the compressed crust, and volcanic rocks that formed from volcanoes as lava broke out of the crust. The remaining rocks of the Exotic Terrane region are metamorphosed sedimentary rocks that originated as sediments on the continental shelf of North America, the floor of the closing Iapetus Ocean basin, and shed off of the approaching volcanic islands. In some places, especially northern Maine, the sedimentary rocks were only weakly metamorphosed and still retain much of their original character.

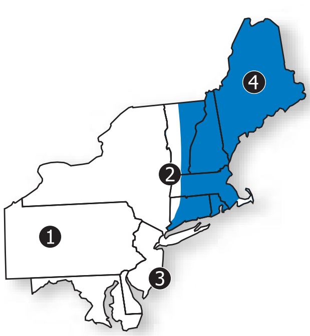
**The origins of metamorphic rocks**

*The type of rock produced during metamorphism depends on the composition of the original rock as well as the degree of higher temperatures and pressure. For example, when the sedimentary rock shale is weakly metamorphosed, it becomes slate. Though slate retains much of the original character of the shale, the minerals within the slate have become aligned as the original clays are changed to micas through the pressure of metamorphism. Increased metamorphism produces a phyllite. Finally, with the highest degree of metamorphism, schist is formed as the micas become large, easily observed crystals. Thus, the type of rock in a given area can indicate the degree of metamorphism.*

| *original rock* | *weakly metamorphosed* | → | *strongly metamorphosed* | |
|---|---|---|---|---|
| *shale* | *slate* | *phyllite* | *schist* | *gneiss* |

### *Precambrian Rocks*




Precambrian rock in the Exotic Terrane region is found in eastern Massachusetts, Rhode Island, and Connecticut, and northwestern Maine *(Figure 2.26)*. Eastern Massachusetts, Rhode Island and Connecticut were the Avalonia rocks that collided with North America during the Acadian mountain-building event. Though it is gneiss, the Avalonia gneiss is not the same as the Precambrian Grenville gneiss. The Avalonia rocks were far to the southeast of

North America during the Precambrian.

In northwestern Maine, the mountainous Chain Lakes Massif gneiss stands out as distinctly different from the surrounding rocks. Geologists continue to debate the origin of the Chain Lakes Massif, which is puzzling because of the intensely metamorphosed rocks. It is possible that this mass of gneiss was part of the Grenville belt of sediments.

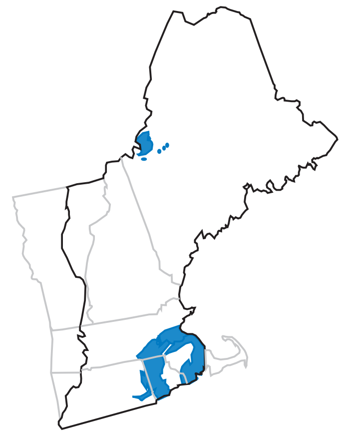


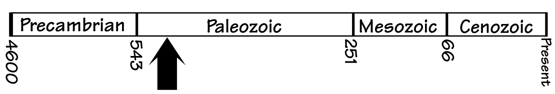
*Figure 2.26: Precambrian rocks exposed in the Exotic Terrane.*

### The Boston Basin

*Near the close of the Precambrian, Avalonia was breaking away from Africa, and on a collision course with North America. A rift within the Avalonia rocks created a basin, similar to the rift basins that formed in the Triassic when Pangea began to break apart. The basin filled with Precambrian-and Cambrian-age volcanic and sedimentary rocks. In the Devonian, millions of years later, Avalonia collided with North America to form eastern Massachusetts, Rhode Island, Connecticut and Maine. The rift basin created in the Avalonia rocks during the Precambrian, known as the Boston Basin, is still visible today as the foundation of eastern Massachusetts. The basin may actually extend several kilometers farther east under the Atlantic Ocean. Within the basin is the Braintree Slate, famous for its preservation of an unusually large species of trilobite,* Paradoxites.

*see Fossils, p.96, for more on the* **Boston Basin.**

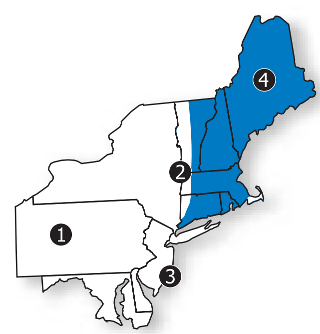
## *Cambrian-Ordovician Rocks*




Close to the Chain Lakes Massif of Maine are several occurrences of ophiolites. Geologists believe that the ophiolites were scraped off a subducting oceanic plate and welded onto the Chain Lakes Massif sometime during the Ordovician.

*see Geologic History, p. 7, for more on the* **Taconic events.**

During the late Ordovician, as the ***Taconic*** volcanic islands approached North America, slices of crust were stacked and squeezed like a collapsing telescope across the Exotic Terrane and Appalachian/Piedmont regions. In the Exotic Terrane region, we see the remains of the volcanic island chain that caused the stacking. Though it is difficult to distinguish individual volcanic islands and slices of crust, there is evidence of the volcanic islands and sediments associated with the volcanic activity of the Taconic mountain building period. Ordovician-age metamorphosed sedimentary ***rock*** that originated



*These* rocks *are all part of the Iapetus Terrane.*

*Figure 2.27: Cambrian and Ordovician rocks exposed in the Exotic Terrane.*

from the Taconic volcanic islands are interwoven with volcanic rocks, including basalt and rhyolite, which form many of the ridges up and down the central New England area *(Figure 2.27)*.

Ordovician-age igneous ***intrusions***, generally granites, are located up and down the volcanic island suture area in and around the sedimentary and volcanic rocks *(Figure 2.28)*. These intrusions are the cooled remains of the magma chambers that formed the Taconic volcanic islands as well as magma formed as the crust compressed during the collision.

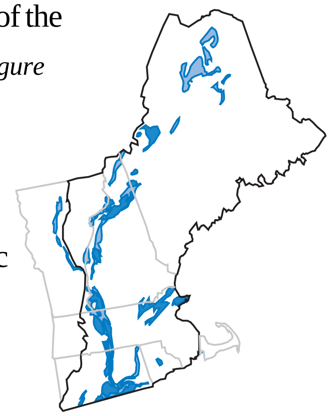


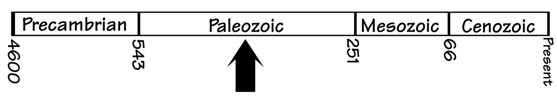
*Figure 2.28: Ordovician-age igneous intrusions exposed in the Exotic Terrane.*

**Volcanic vs. intrusive rocks**

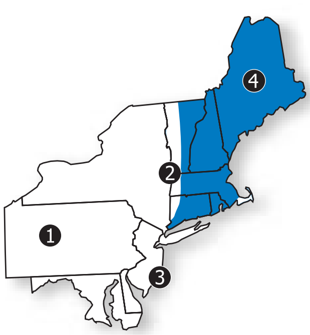
*What is the difference between volcanic igneous rocks and intrusive igneous rocks? Hot, molten rock beneath the Earth's crust is called magma. As magma rises, pushing through overlying layers of rock, it will begin to cool. The cooling magma may crystallize and harden to become an* intrusive *igneous rock. If, however, the magma rises to the surface without cooling enough to crystallize, the magma may be able to break through the crust at the surface forming a volcano or basalt flow. Geologists call volcanic magma 'lava'. Lava cools much more quickly than magma because it is at the surface and exposed to the atmosphere or ocean water where temperatures are much cooler. Lava thus has less time to crystallize than magma. Though the composition of a magma may be the same as a lava, the texture (mineral crystal size) of the rocks will be quite different. It is because of this difference in genesis that geologists are able to make the distinction between volcanic and intrusive igneous rocks when encountered at an outcrop at the Earth's surface.*

| | *high* iron & magnesium | *low* iron & magnesium |
|---|---|---|
| **Volcanic:** | *basalt* | *rhyolite* |
| **Intrusive:** | *gabbro* | *granite* |

## *Silurian-Devonian Rocks*

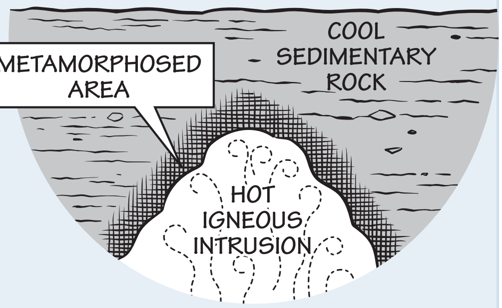



Central New England is predominantly composed of the remnants of the sediments deposited during the Silurian and Devonian in the Iapetus Ocean *(Figure 2.29)*. These rocks were originally sand, silt and mud deposited on the floor of the Iapetus Ocean following the Taconic mountain-building event. The sedimentary rocks were later squeezed tight, folded and metamorphosed during the Acadian and Alleghanian mountain-building events. The metamorphosed sedimentary rocks are now the schists and gneiss of central Vermont, New Hampshire and southern Maine, the region where the temperature and pressure were highest.




Though the degree of metamorphism varies throughout New England, in general the rocks in the west experienced lower degrees of metamorphism than rocks in the east. Likewise, rocks in Northern Maine experienced far less metamorphism because they were not directly affected by the later Alleghanian mountain-building event. Mild metamorphism in the less-stressed areas formed slates and phyllites. Central Maine is known as the Slate Belt because of the weak metamorphism that affected the Silurian and Devonian sedimentary rocks of the area, which were mainly shales. Intrusions of magma pushing up through the crust during the Acadian mountain-building event also played a role in metamorphosing rocks.

### Regional and contact metamorphism




*The intense heat of intruding magmas often metamorphoses the rocks into which they are intruded. This is known as contact metamorphism. Shale, rather than becoming slate or phyllite or schist (in which the minerals become aligned through pressure), is often simply baked by an intrusion to become hardened shale known as hornfels. Regional metamorphism, on the other hand, refers to metamorphism induced through increased pressure as the crust is squeezed together and folded when plates collide. The Taconic, Acadian and Alleghanian mountain-building events all produced regional stress on the rocks surrounding the collision zones. In this way, the sedimentary rocks of the Exotic Terrane region and parts of the Appalachian/Piedmont region have been regionally metamorphosed.* Figure by J. Houghton.

The eastern section of the Exotic Terrane Region consists of the rocks of the Avalonia microcontinent. They include most of coastal Maine as well as Rhode Island, eastern Massachusetts and Connecticut *(Figure 2.30)*. In the late Devonian, when the microcontinent Avalonia was caught in the middle of the collision between North America and Baltica, numerous igneous intrusions occurred throughout Vermont, New Hampshire, Maine, Massachusetts and the Avalonia Rocks themselves *(Figure 2.31)*. These intrusions are known as the New Hampshire ***Plutonic*** Series.

Intrusions related to this series occur throughout New England and are responsible for several high peaks as the hard granite generally resists erosion better than sedimentary rocks. The famed ***Barre Granite*** of Vermont, commercially valuable for building and monument stone, is also part of the New Hampshire Plutonic Series.

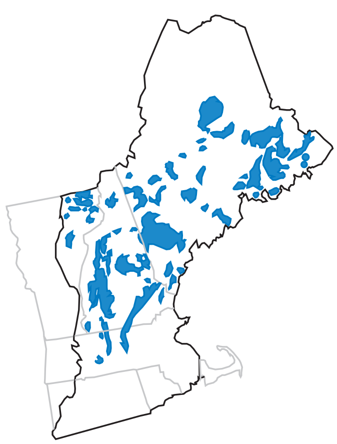


*Figure 2.31: Devonian igneous intrusions in the Exotic Terrane.*

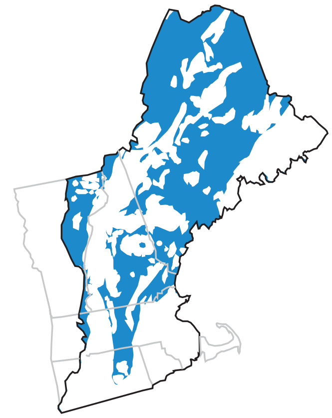


*Figure 2.29: Silurian and Devonian rocks exposed in the Exotic Terrane.*

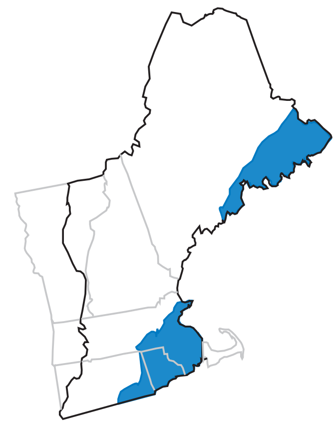
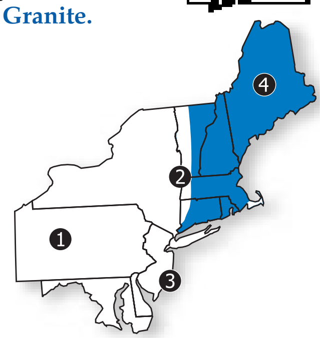


*Figure 2.30: Avalonia rocks exposed in the Exotic Terrane.*

**Pluton** *is another name for a large intrusion. The term is derived from Pluto (Hades), the ancient Greek god of the underworld.*

*see Non-Mineral Resources, p.166, for more on* **Barre Granite.**

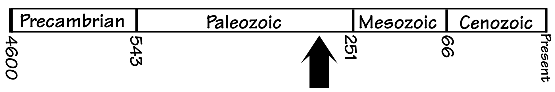


see *Minerals*, *p. 144, for more on* **pegmatites.**

### Pegmatites

*Pegmatite dikes are frequently found near the Taconic and Acadian igneous intrusions. Hot, molten magma rising through the crust from deep magma chambers (which eventually formed igneous intrusions) put significant pressure on the overlying rocks. The pressure caused the crust to crack in many places, creating additional pathways for magma to intrude and crystallize in dikes. The heat from the rising magma also partially melted some of the overlying crust. Partial melting and the escape of volatiles from slow cooling of continental crust created a unique rock type rich in rare elements: a pegmatite. Their very large crystals, which range anywhere from 2 cm to as much as 5 meters across, easily distinguish pegmatites!*

## *Pennsylvanian Rocks*




The youngest rocks of the Paleozoic era in the Exotic Terrane Region, approximately 315 million years old, are found in basin deposits of Massachusetts and Rhode Island. The basins formed as Avalonia collided with North America and the compression downwarped the crust slightly. The basins preserve Pennsylvanian-age sedimentary rocks including sandstone, conglomerate, and siltstone, all of which have experienced varying degrees of metamorphism. They also have layers of coal, which were mined in the past for steam engines and heating homes. The Narragansett Basin, the largest of the Pennsylvanian basins, has layers of anthracite coal up to 12 meters thick and the greatest number of plant fossil species than any other coal basin worldwide. Several smaller basins are found close by, including the Norfolk, Woonsocket, and Northern Scituate Basins *(Figure 2.32)*.

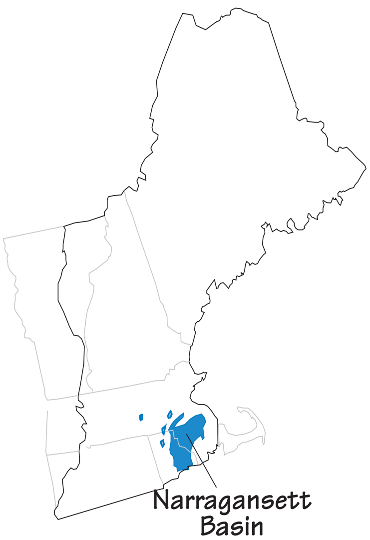
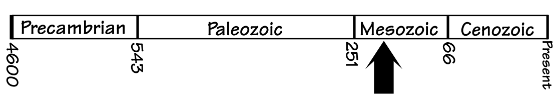



*Figure 2.32: Pennsylvanian-age basins in the Exotic Terrane.*

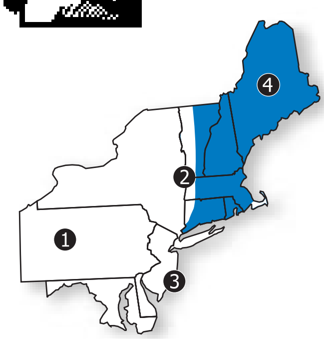
see *Geologic History*, *p. 16, for more on* **rift basins.**

see *Rocks*, *p.44, for more on* **rift basins**.

## *Triassic-Jurassic Rocks*




Similar to the Triassic ***rift basin*** of the Appalachian/Piedmont, there is a rift basin that cuts through the Exotic Terrane Region as well, known as the Connecticut Valley Rift Basin. This basin, which cuts through the Iapetus Terrane of the Exotic Terrane region, may have once been continuous with the Newark Rift Basin. The process of formation of the two basins was the same, occurring as the continents of Pangea separated and North America pulled apart from Africa. Likewise, the rocks of the basins are similar, consisting of



ridges of basalt and reddish-brown sedimentary rocks *(Figure 2.33)*.

In New Hampshire and southern Maine, late Triassic through Cretaceous igneous intrusions are exposed in a curious arc that extends up into Canada *(Figure 2.34)*. Known as the White Mountain Series, these intrusions are not related to the Rift Basin lava flows, which produced quickly cooled basalts. Rather, these intrusions formed deep within the crust as plumes of magma rose from the mantle. The magma originated at what some geologists think may have been a ***hot spot***. As the plate moved over the hot spot, magma pushed upwards through the crust to form the string of plutons visible at the surface today through erosion. The intrusions form the core of certain mountains in central New Hampshire.

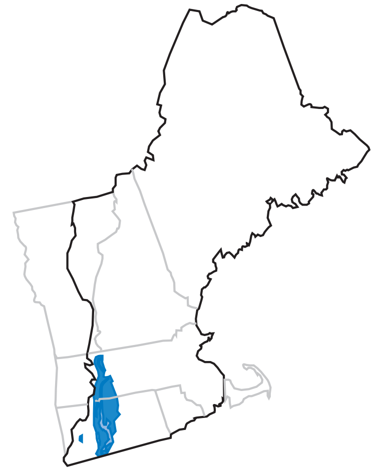


*Figure 2.33: Triassic rift basin in the Exotic Terrane.*

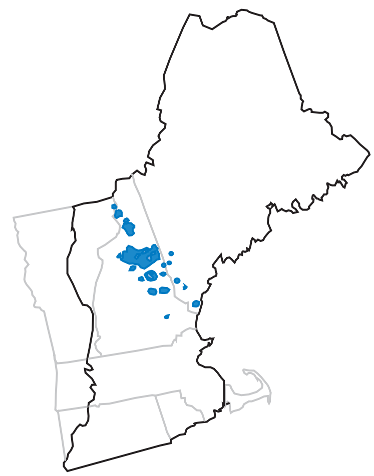
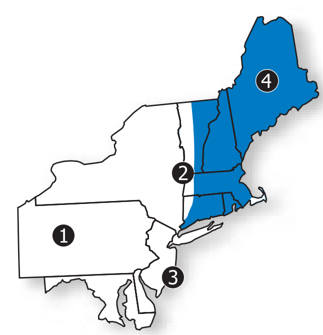


*Figure 2.34: The White Mountain Series intrusions in New Hampshire and Maine.*




## Hot Spots

*Hot spots form from plumes of magma rising off the mantle. Though the hot spot remains fixed, the plates of the lithosphere are moving above it. Magma from the hot spot pushes its way up through the crust, creating an igneous intrusion and sometimes a volcano. As the plate continues to move over the hot spot, magma pushes up next to the previous volcano to form another intrusion or volcano. This gradually produces a chain of volcanic islands such as the Hawaiian Islands or a series of plutons as in New Hampshire (Figure A). Erosion of the volcanoes may eventually wear down the crust to reveal the igneous intrusions that were the magma chamber of the volcano (Figure B). This is one of the proposed explanations for the exposures of the White Mountain Series.*

Figures by J. Houghton.

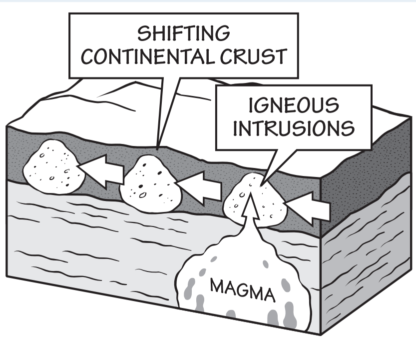



*Figure A*

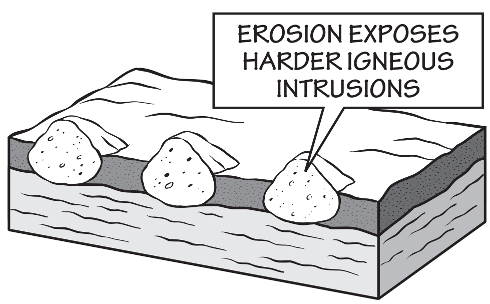



*Figure B*

# Activities

As part of a new program to give students work experience, the school district has hired you to run the Geological Heritage Project for your school district. The "GHP," as it is known, will become the basis for an Earth science exhibit that will rotate among district schools.

1. You decide the thing to do is describe the variety of rock types that give evidence to the sequence of events in plate tectonic history of the Northeastern U.S. You realize that you must be sure you know what kinds of rocks are found in various parts of any average place where two plates meet each other, before you go looking for rocks that represent historical plate tectonic events in the Northeast. You also realize that you will need to learn where to find the most important rocks that represent the history of plate tectonic events.

a) *Draw a cross-section of an area in which two tectonic plates are converging, and another in which there is a passive margin west of a mid-ocean ridge. Label all the rocks (for example, granite, basalt, rhyolite or andesite, schist, gneiss, shale, sandstone, conglomerate, and limestone) and sediment types (mud, sand, gravel) one might expect to find across these settings.*

b) Now that you've done (a), you decide to document the existence of as many of these rock types as possible from past geologic events in the northeast. You ambitiously get funding from a local supermarket to send out an expeditionary team of fellow students to collect sets of geological samples from each historical event (but you need to keep costs down).

*Naming the rocks, ages, and localities, find the shortest highway route your fellow students should take to collect rocks from the sedimentary basins associated with:*

(1) Greenville passive margin
(2) Taconic convergence
(3) Acadian convergence
(4) rifting apart of Pangea
(5) Coastal Plain passive margin

2. The Discovery Channel hears about the incredible work you've done with the exhibit, and decides that making a rockumentary — in this case the history of the rocks at some particular point — would make a fascinating television special. What better, they suggest, than to feature the history of the rocks in your area. You will be the star of the show. Although you've learned the sequence of events in the Northeast, you realize that you don't know the detailed sequence of rock types right in your own neighborhood.

*Draw a likely geologic section of the types and ages of rocks under your home down to the Precambrian basement and associate them with the major events in the geologic history of the northeast.*

3. A tour developer watching the Discovery program realizes that there's a new business opportunity for her. Instead of human history tours, take advantage of the growing popularity of nature tourism and give geological history tours.

*She'll let you in on the profits if you'll get her started — choose three different areas with rather different geological histories and describe the history of each of them, and what evidence in rock types can be seen of that history at the surface. These will become the tour destinations.*

Teacher tip: *The American Association of Petroleum Geologists has a map for the Northeast United States with both cross sections and geological map that may suit your needs. Students may be able to find some information on the Web that gives geological maps and cross sections.*
*Also see General Resources at the front of the guide.*

ACTIVITIES

# For More Information...

## *Books*


Caldwell, D.W, 1998, *Roadside Geology of Maine*, Mountain Press Publishing Company: Missoula, Montana.

Isachsen, Y.W., E. Landings, J.M. Lauber, L.V. Rickard, and W.B. Rogers, eds., 2000, *Geology of New York, A Simplified Account*, New York State Geological Survey, New York State Museum Cultural Education Center: Albany, New York.

*New England Intercollegiate Geological Conference field trip guidebooks*, found in New England public and university libraries.

Schmidt, Martin F., Jr., 1993 *Maryland's Geology*. Tidewaters Publishers: Centerville, Maryland.

Van Diver, Bradford B., 1990, *Roadside Geology of Pennsylvania,* Mountain Press Publishing Company: Missoula, Montana.

Van Diver, Bradford B., 1987, *Roadside Geology of Vermont and New Hampshire,* Mountain Press Publishing Company: Missoula, Montana.

Van Diver, Bradford B., 1985, *Roadside Geology of New York,* Mountain Press Publishing Company: Missoula, Montana.


## *Internet*


Atlas of Igneous and Metamorphic Rocks, Minerals and Textures
http://www.geolab.unc.edu/Petunia/IgMetAtlas/mainmenu.html

State Geologic Maps
http://geology.er.usgs.gov/eastern/stgeomap.html


## *Videos and Maps*

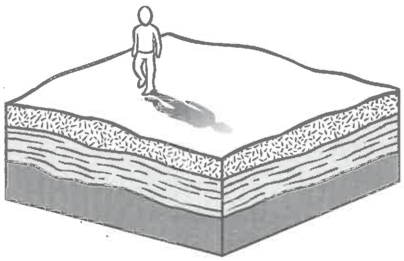

Allmon, Warren D., 1998, *Round Rocks: Teaching Earth Science as a Process of Discovery,* video and teacher guide, The Paleontological Research Institution: Ithaca, New York.

Reusch, Douglas N., 1993, *In Search of the Missing Iapetus Ocean: a Geotraverse Across New England,* video study guide, Department of Conservation, Maine Geological Survey: Augusta, Maine.

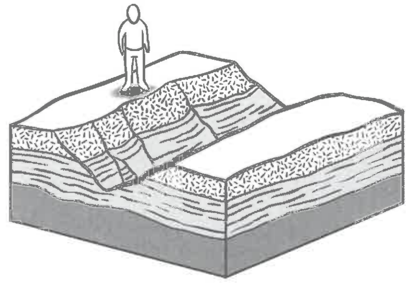
American Association of Petroleum Geologists, 1995, *Geological Highway Map of the Northeastern Region,* Map no. 10.

*Geologic Map of the United States,* 1974, Scale 1:2500000, United States Geological Survey.

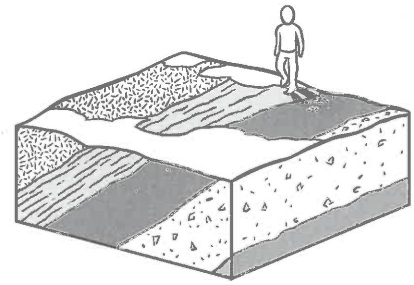
# Selected Figures
## *for overheads & handouts*



*When rocks are flat-lying layers and there is no erosion, folding or faulting, the person walking across the surface sees only one rock type.*

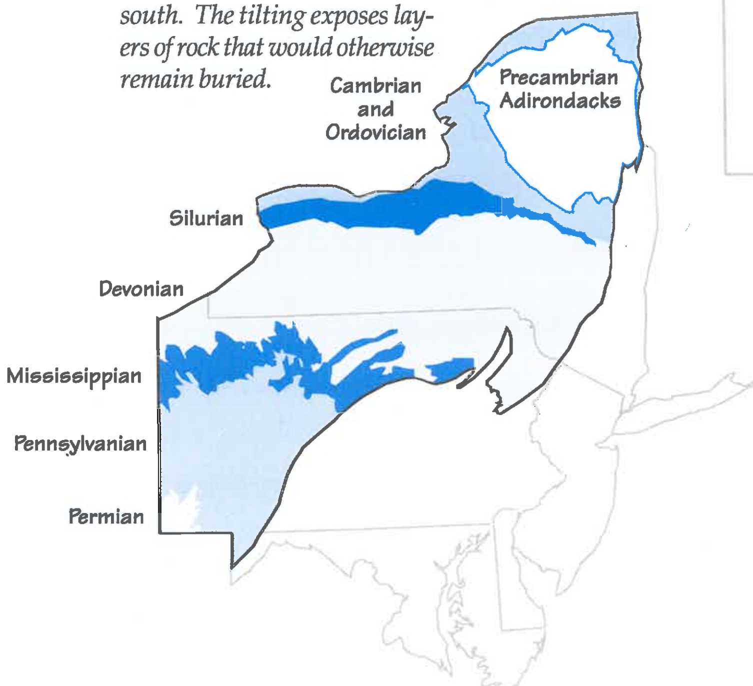


*When rocks are worn away (often by streams), the person walking across the surface sees the underlying layers of rock exposed.*



*When rocks are folded or tilted, the person walking across the surface sees several layers of rock exposed.*

*Figure 2.3: The east-west stripes of rocks in the Inland Basin occur because of the shallow angle of the rock layers. Regional compressional stress from mountain building tilted the layers of sedimentary rock gently, less than five degrees to the south. The tilting exposes layers of rock that would otherwise remain buried.*



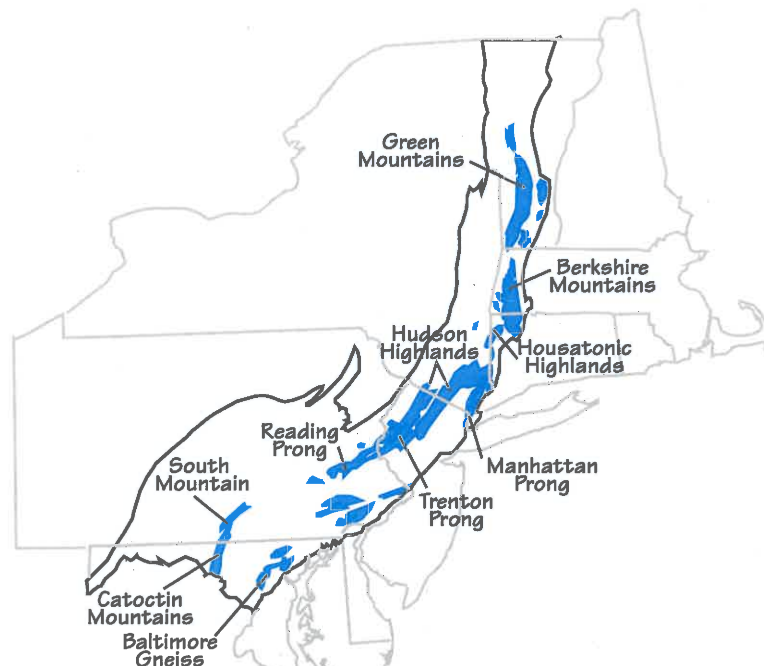




*Figure 2.15: The Precambrian rocks of the Appalachian/Piedmont occur in a nearly north-south line, forming the many ridges of the Appalachian Mountains and revealing the location of the ancient Grenville Mountains (though in some places the Precambrian rock has been thrust westward from its original position).*

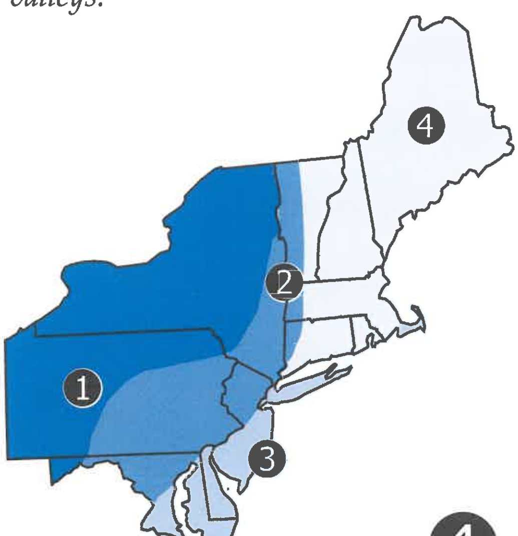
# Glaciers of the Northeastern US:
## *the BIG picture*

### 1 Inland Basin

*There are several significant and spectacular examples of glacial features in the Inland Basin, though only New York and northern Pennsylvania were covered by the ice sheet. Glacial scour features in the Inland Basin include the Great Lakes and Finger Lakes. Glacial deposits include lake bottom sediments and drumlins, and moraines that drastically affected the drainage patterns of the region. Periglacial features, found in Pennsylvania and Maryland, include solifluction, patterned ground and boulder fields. Post-glacial erosion features include gorges where streams flowing over waterfalls into glacially cut basins (such as the Finger Lakes of central New York) eroded back up their valleys.*

### 2 Appalachian/ Piedmont

*Glacial scouring in the Appalachian/ Piedmont region is evident in potholes, and the deepening and widening of lake basins such as Lake Champlain and glacial Lake Albany. Significant glacial deposits include the moraines that stretch across Pennsylvania and New Jersey. Periglacial features in the Appalachian/Piedmont region include numerous boulder fields, ice wedge casts and solifluction.*




### 3 Coastal Plain

*Though the glaciers did not cover the Coastal Plain, several features of the region are closely linked to the most recent ice age. The northern Coastal Plain, including Long Island and Cape Cod, was formed entirely by the moraine deposits of the melting ice sheet. Periglacial features include deformation of the Coastal Plain sediments by frost action. Sea level changes caused by the forming and melting glaciers affected the Coastal Plain exposure and thus erosion and sedimentation.*

### 4 Exotic Terrane

*The entire Exotic Terrane region was covered by the ice sheet during the most recent ice age, leaving a variety of glacial scour and deposit features. Scour features include the erosion of the highlands and cirques still seen on many New England peaks. Glacial deposits include moraines, wind deposits on drained lake bottoms, kettle lakes, drumlin fields, and eskers; marine clay deposits occur in Maine from the post-glacial rise of sea level. There are no periglacial features in the Exotic Terrane region because the whole area was under ice.*

# Glaciers of the Northeastern US:
## *a brief review*

The Quaternary period began 1.8 million years ago and was marked by a series of advances and retreats of successive enormous ice sheets that originated in the Hudson Bay area of Canada. The Quaternary period is divided into two epochs: the Pleistocene and Holocene *(Figure 3.1)*. The Pleistocene is simply the equivalent of the Quaternary minus the most recent (and current) interglacial interval, the Holocene. Ice age conditions existed when the ice sheet advanced over the North American continent; interglacial or warming periods existed when the ice sheet retreated north. Advances of the ice sheet over the northern United States occurred several dozen times over the course of the Pleistocene epoch of the Quaternary.

The most recent glacial advance reached its maximum extent 25-20,000 years ago and had an enormous impact on the Northeast. The glaciers blanketed much of the region with glacial deposits, challenging agriculture with rocky fields; limestone ridges, however, were ground and spread, increasing soil quality south of limestone outcrops. The topography was sculpted and drainage patterns shifted by the scouring action and deposits of the glacier. Abundant and easily mined sand and gravel also resulted from glacial deposits. Marks left behind by the glaciers on the high peaks of the Adirondacks and New England mountains tell us that the ***glaciers*** reached a thickness of between 1 and 2 kilometers, covering the tallest peaks in the Northeast. By 10,000 years ago, the ice had fully retreated from the Northeast. This ice-free interval, which we are in currently, is called the Holocene or Recent. Although all glacial advances had impacts on the surface of the Northeast, the effects of only the last ice sheet are well documented, since each succeeding glacial advance erodes and smears the record of the previous advance.

The ice sheets are a form of glacial ice. As snow falls and is compacted, individual snowflakes become smaller, rounder and thicker, changing to granular snow. Upon further burial, compaction and cementation from recrystallized meltwater, the granular ice is changed to ***firn***. When the firn has been buried to a depth greater than 30 meters, ice flow occurs, causing subsequent deformation. The firn recrystalizes to glacial ice, forming interlocking ice crystals, just as

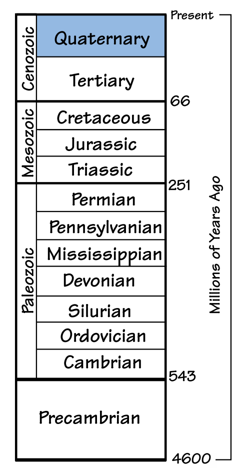
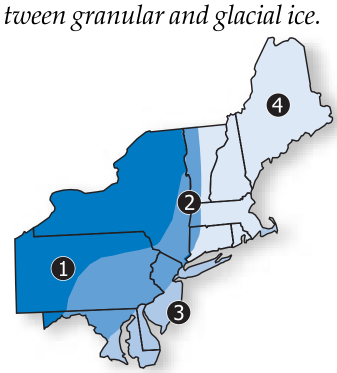



*Figure 3.1: Geologic Time Scale (not to scale).*

**Glaciers** *are a build-up of snow, firn and ice, partially or wholly on land, which move downhill under their own weight.*

**Firn** *is a transitional form between granular and glacial ice.*



# Glaciers

*see Rocks, p.29, for the **rock** cycle.*

sedimentary rocks are recrystalized to form metamorphic ***rocks***. As snow accumulates, packs down, and is converted to glacial ice, the weight of the accumulating snow causes the underlying glacial ice to flow out in all directions from the center. Like water, ice flow is driven by gravity, and moves downhill.

There are two types of glaciers: smaller-scale valley glaciers and large-scale ice sheets. Found in mountainous regions at high altitudes, valley glaciers form by erosive action in bowl-shaped scours called cirques and flow down pre-existing valleys on high altitude mountains. Ice sheets occur on a much larger scale, spreading from a central point outward in all directions across a continent. ***Greenland*** and ***Antarctica*** currently have ice sheets similar to the one that stretched over North America 20,000 years ago.

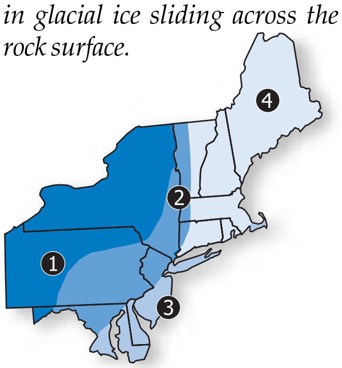
*The **Greenland** and **Antarctica** ice sheets make up 95% of all the current glacial ice on the planet.*

Glaciers will only form in specific environments. They require adequate snowfall so that each year more snow is accumulating than melting. This allows for the build-up and compaction of snow that will gradually become glacial ice. Thus, cold climate and sufficient moisture in the air for the precipitation of snow are both necessary for the formation of a glacier. Cold climate conditions exist at high altitudes and high latitudes. It is not surprising that the ice sheets of today are in the high latitude polar regions of Greenland and Antarctica, where temperatures are low. For continental ice sheets to occur, there must be landmasses over the high latitudes, since flowing ice will not form over open water.

*Very fine sediments and clay resulting from the grinding action of glaciers is called **rock flour**.*

*Meltwater from the glacier enters cracks in bedrock beneath the ice sheet and freezes, expanding the cracks and breaking up the bedrock. The glacier then **plucks** the sediments from the bedrock.*

*Long, parallel **scratch** marks that look like pinstripes on a rock are called striations. Striations result from the grinding sediments in glacial ice sliding across the rock surface.*




## *Glacial Scouring*

The ice sheet left its mark in many ways on the Northeast, resulting in many noticeable topographic features. As the 1-2 kilometer thick glacier advanced forward, flowing under its own weight from the center of accumulation, it scraped and scoured the crust beneath. Boulder- to clay-sized sediments were ***plucked*** from the underlying bedrock and soil. The glaciers incorporated this sediment into the glacial ice or bulldozed it forward in front of the advancing ice. Sediments in the glacial ice acted like coarse sand paper, scouring and scraping the bedrock beneath. Sediments and less resistant sedimentary rocks over which the glacier moved were often eroded and ground-up into very fine sediment and clay (called **rock flour**). More resistant igneous and metamorphic rock was often polished and ***scratched*** by the grinding action of the sediments in the glacial ice. Knobs of resistant rocks, polished by the glaciers, are common in the

Northeast. Streams of meltwater from the glacier, frequently gushing and full of sediment, caused significant amounts of scour as well. The abrasive sediments in the flowing water created ***potholes*** in the bedrock and ***plunge pools*** at the base of waterfalls.

Valley glaciers, flowing from the high mountains in the Adirondacks, Catskills and New England, originated near the peaks in bowl-shaped scours called ***cirques***. Though the mountains are now free of glacial ice, the distinctive scoop-like cirques are still visible in some peaks in the Northeast. (Tuckerman's ravine in New Hampshire is a cirque.) Scouring by the valley glaciers and the ice sheet that covered the mountains eroded a great deal of bedrock, rounding out and shortening the mountains, sometimes by hundreds of meters.

### How do we know the mark of glaciers?

*How do we know that striations, polish, scoured basins, U-shaped valleys and the variety of deposits attributed to glaciers are in fact a result of glacial action? Before the modern understanding of the ice ages, many believed that the features now attributed to glaciers were the result of a great flood similar to the story of Noah and the Ark in the Bible. By studying modern glaciers, however, geologists have come to understand the resulting features of glacial scour and deposition that are readily identified in much of the Northeast. Modern glaciers include the large-scale ice sheets in Greenland and Antarctica as well as the small-scale valley glaciers found in mountain ranges in places such as Alaska, Canada and the Alps.*

## *Glacial Deposits*

In an action similar to a bulldozer, the glacier plowed over the land. As it moved forward, the glaciers scraped up earth and pushed ahead piles of sand, gravel and broken rock to form characteristic glacial deposits *(Figure 3.2)*. The unsorted mixture of boulders, gravel, sand, silt and clay picked up and later deposited by glaciers is called ***till***. Where the bulldozing glacier stopped its advance for a time and then melted back, the ridge of till that had been pushed in front of the glacier was left behind, marking the end or terminus of the glacial advance. The ridge of till is called a ***moraine*** and ranges in length from hundreds to thousands of meters. Till that has been molded and reshaped by the underside of an advancing glacier into a streamlined, elongated hill is called a drumlin. This is till that has been trapped underneath the glacier, and has thus been deformed by the ice flowing above. The elongated shape of a drumlin is parallel to the direction of ice flow, and thus an excellent clue to determine the flow of the ice sheet

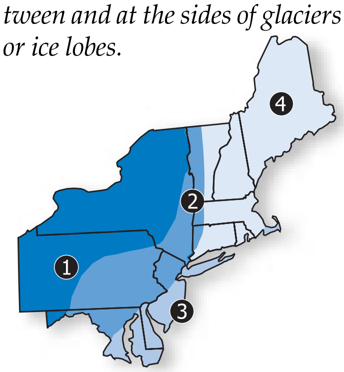
*When sediment-laden water wears away bedrock in swirling eddies it forms* **potholes** *and* **plunge pools** *at the base of waterfalls.*

### Valley shapes

*A river cutting through bedrock tends to make a V-shaped valley, as it erodes deeper and deeper towards sea level. A glacier, on the other hand, makes a U-shaped valley as a tongue of ice cuts through bedrock. Often, glaciers flow down pre-existing river valleys, reshaping them to broader, deeper, U-shape valleys. Unlike a river that erodes to sea level, a glacier may form valleys that are deeper than sea level.*

*The term* **till** *originated with farmers living in glaciated areas who were constantly removing rocks from their fields (and building the famous stone walls of New England.) The rocks are deposits of cobbles and gravel left by the glaciers that made it more difficult to farm parts of the Northeast.*

*Many* **moraines** *mark the terminus or edge of the glacier. Lateral moraines may also occur in between and at the sides of glaciers or ice lobes.*



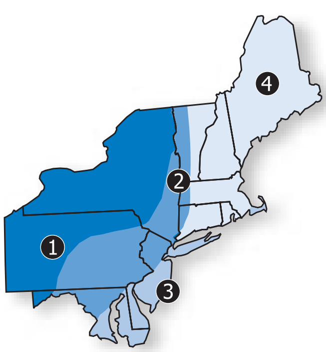
# Glaciers

**Well-sorted** *deposits have relatively uniform grain size.*

*A* **braided stream** *carries more sediment than a typical stream, causing the formation of sandbars and a network of crisscrossing streams.*

**Eskers** *are sinuous, elongated ridges of sand and gravel. They are found in many parts of the glaciated Northeast, and are often mined for their well-sorted sand and gravel.*

**Erratics** *are often distinctive because they are a different type of rock than the bedrock in the area to which they've been transported. For example, boulders and pebbles of igneous and metamorphic rocks are often found in areas where the bedrock is sedimentary; it is sometimes possible to locate the origin of an erratic if its composition and textures are highly distinctive.*




during its most recent advance.

Meltwater flowing off the glacier also left behind deposits. Unlike till deposits, meltwater deposits are ***well sorted***, just as other rivers and streams have well sorted layers of sediment. As the glacier melted, streams of sediment-laden meltwater poured off the ice, often creating networks of ***braided streams*** in front of the glacier. Streams of meltwater flowing under the glacier deposited sand and gravel. When the ice sheet retreated, these ridges of meltwater stream deposits, known as ***eskers***, were left standing.

Other glacial features include kettles, kames and erratics. Kettles are ponds or depressions left behind by the melting glacier. Blocks of ice broken off from the glacier often were buried or surrounded by meltwater sediments *(Figure 3.3)*. When the ice eventually melted, the overlying sediments had no support, collapsing to form a depression that often filled with water to become a lake. Many kettle lakes and ponds are found throughout the glaciated Northeast. Kames are mound-like deposits of sediment from the melting glacier. ***Erratics*** are rocks that the ice sheet picked up and transported further south as it moved over the continents.

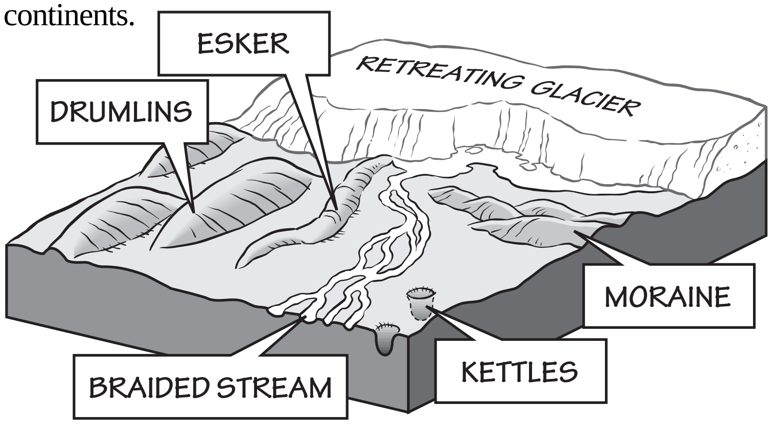



*Figure 3.2: Glacial deposits.* Figure by J. Houghton.

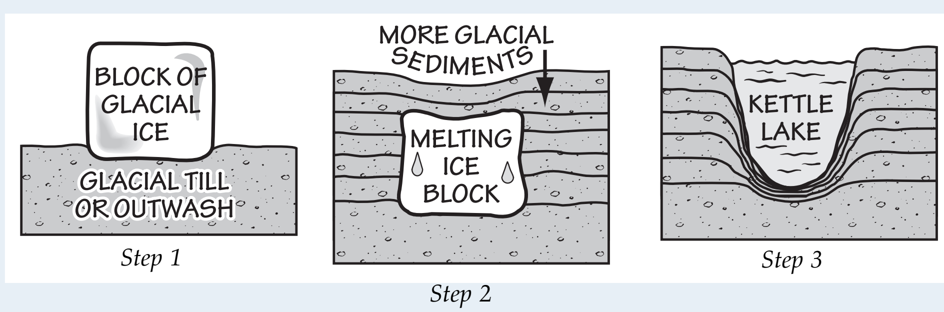



*Figure 3.3: Formation of a kettle lake.* Figures by J. Houghton.

## *Periglacial Environments*

Though not all of the Northeast was covered by the ice sheet, the entire region felt its effects. The region covered by the ice sheet was scoured and covered with glacial deposits; the region south of the ice sheet has its own distinctive landscape and features because it was next to the ice margin. This unglaciated but still affected zone south of the ice sheet is called the ***periglacial*** zone.

There are a variety of features associated with a periglacial zone that also provide clues to the extent of the most recent ice sheet. In the tundra-like environment of a periglacial zone, ***eolian*** deposits are common. Sand dunes and wind-transported sediments are found in former periglacial areas and in glacial lake bottoms of the Northeast. The permafrost associated with the periglacial area, in which the ground is frozen much of the year, can cause mass movement of sediment. When the surface layer of the permafrost ground thaws, it is full of moisture. This water-heavy layer of soil may move rapidly down a hill in a process called ***solifluction***. ***Physical weathering*** of the bedrock is magnified in the periglacial environment because of the freeze-thaw cycles associated with permafrost. When water enters the cracks and fissures in the ground and subsequently freezes, the ice wedges the cracks further and further apart *(Figure 3.4)*. Because ice takes up more space than water, the pre-existing cracks and fractures are widened when the water freezes. Along ridges, rocks are eventually broken off as ice wedges continue to expand in joints and fractures. The boulders and blocks of bedrock roll downhill and are deposited along the slope or as fields of ***talus.*** Especially in the Appalachian/Piedmont region, talus blocks are carried far down slope and are found as fields of boulders. Frost action also brings cobbles and pebbles to the surface to form nets, circles, polygons and garlands of rocks. These unusual patterns of sorted rock are known as ***patterned ground.*** Solifluction and ice wedging are found exclusively where the ground remains perennially frozen, yet is not insulated by an ice sheet. Such conditions only occur in areas adjacent to ice sheets.

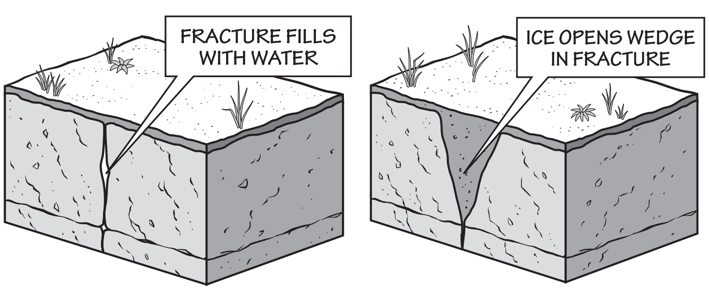



*Figure 3.4: Physical weathering from freeze-thaw cycles.* Figures by J. Houghton.

*The average annual air temperature in a* **periglacial** *area is between* $-12^{\circ}$ *and* $3^{\circ}$*C. Though the surface of the ground may melt in the summer, it refreezes in the winter. When the ground surface has remained frozen to a certain depth for most of the year, it is called permafrost.*

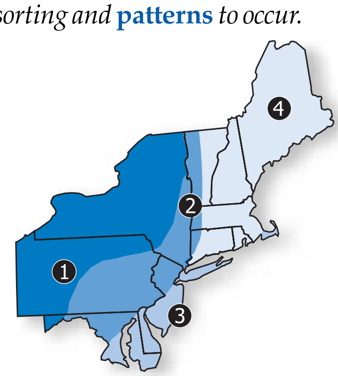
**Eolian** *means wind. Sediments that have been* wind transported *are often polished, giving them a 'frosty' appearance.*

**Solifluction** *is similar to a landslide or mudslide (which are triggered by things other than permafrost).*

**Physical weathering** *is the break-up of rock due to physical processes (such as erosion by wind, water and ice) rather than chemical processes.*

**Talus***, or block-fields found on the sides of steep slopes, are common in periglacial environments.*

*As the ground freezes and thaws, the rocks and pebbles in the soil are repeatedly heaved upwards and then settled. This movement of the material in the soil causes sorting and* **patterns** *to occur.*



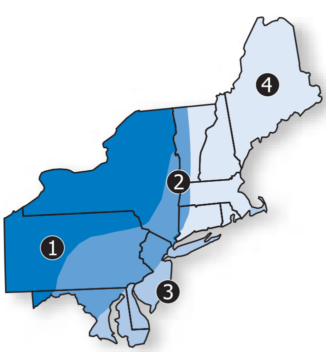
# Glaciers

### Why was there an ice age?

*Scientists continue to debate the causes of the glacial advances and retreats in North America over the last 2 million years. Movement of the Earth's plates may have been a direct or indirect cause of the glaciation. As plates shifted, continents moved together and apart, changing the size and shape of the ocean basins. This altered the oceanic currents and subsequent wind currents. Mountain building, occurring when continents collided, put up obstacles to prevailing winds and changed moisture conditions.*

*An ice* **dome** *is the spreading center for an ice sheet. Glacial ice flows outward from the ice dome, where snow continues to accumulate, like pouring pancake batter into a frying pan.*

**Calving** *refers to the breaking of chunks of ice from the ice sheet into the ocean.*




## *The Pleistocene*

Whatever its cause, a cooling climate triggered the start of a series of ice ages shortly before the Pleistocene began. The most recent ice age before the present interglacial period began 65,000 years ago and affected the Northeast until 10,000 years before the present. Initially, the ice was spreading from a single ***dome*** located in northern Canada over the Hudson Bay. Twenty thousand years ago, this ice sheet reached its maximum extent, as far south as Long Island and northern Pennsylvania in the Northeast.

The formation of glaciers comes from precipitation of water originating from evaporation of ocean water. Thus, significant glacial build-up ties up water in ice sheets, causing a sea level drop. During the Pleistocene glacial advances, sea level dropped an estimated 110 meters! The coastline of the east coast was an estimated 100 kilometers east of its present location 20,000 years ago *(Figure 3.5)*.

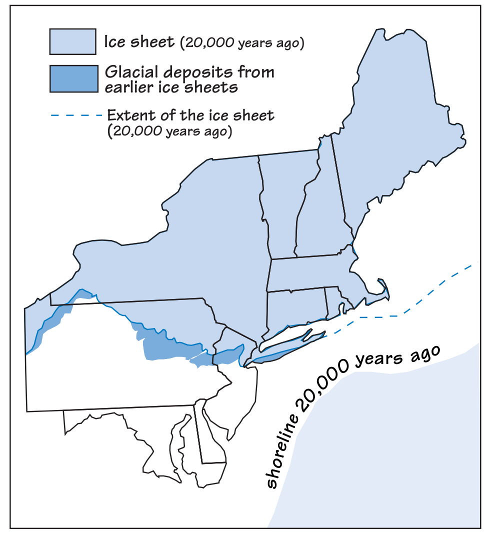



*Figure 3.5: The approximate position of the ice sheet 20,000 years ago.* After Hughes, T., et al, 1985.

By 18,000 years ago, the ice sheet was in retreat because of a slight warming of the climate *(Figure 3.6)*. Melting ice caused the ice sheet to begin ***calving*** into the St. Lawrence River and the Gulf of Maine, raising sea level. Though the ice sheet alternately moved forward and melted backward, overall it was on the retreat. Even during full glacial times, the glacier was always melting at its fringes. During times of glacial retreat, the ice sheet was not flowing backwards. The glacier continued to flow forward, but it was melting faster than it was advancing.

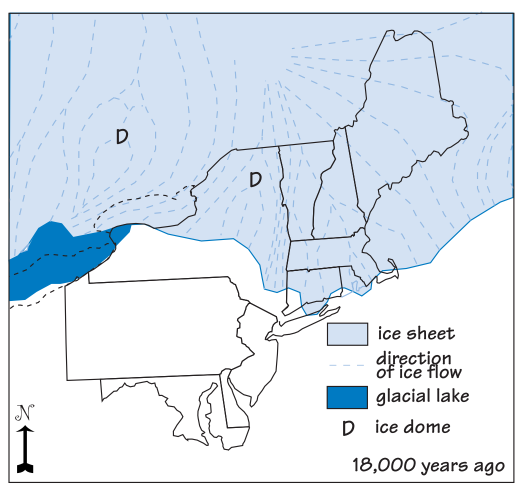



*Figure 3.6: The approximate position of the ice sheet 18,000 years ago.* After Hughes, T., et al, 1985.

By 14,000 years ago, sea level had risen so high that the ocean flooded the St. Lawrence River. The formation of the ***St. Lawrence Seaway*** cut off the glacial ice that covered much of Maine. Continued melting left the Northeast free from the ice sheet 10,000 years ago. Though the crust was ***rebounding*** now that the heavy glacial ice was gone, continued melting of the ice sheet caused sea level to rise faster than the crust.

Sea level rise and the slowly rebounding crust caused the Northeast coastline and inland lakes to be flooded. Lake Champlain, many times larger than it is now, was flooded by ocean water to become the Champlain Seaway. The basins scoured by the glaciers to form the ***Great Lakes*** were flooded by meltwater and formed lakes with boundaries much larger than today *(Figure 3.7)*.

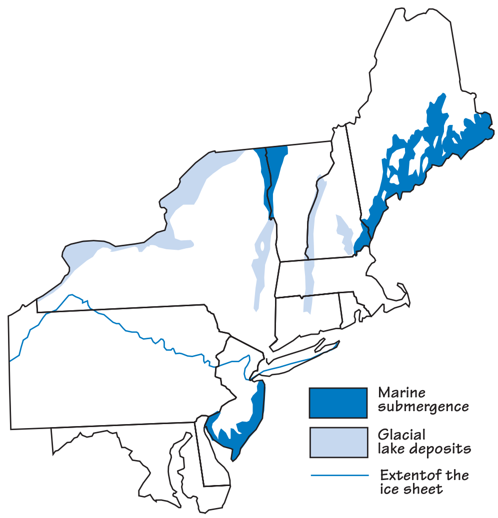



*Figure 3.7: The approximate position of the ice sheet 12,000 years ago.* After Hughes, T., et al, 1985.

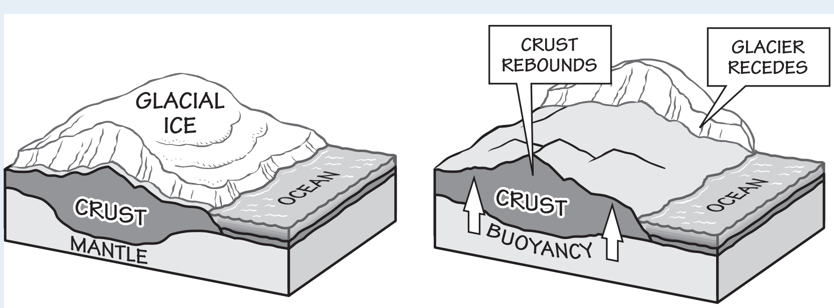
*When the melting ice sheet uncovered the St. Lawrence River, the river valley was flooded with ocean water from rising sea level and became the* **St. Lawrence Seaway.** *Maine was left with its own local icecap and spreading center from which ice flowed in all directions (even, strange as it may seem, north!). Though the ice sheet continued to radiate from the Hudson Bay ice dome, there were several other smaller ice domes throughout the ice sheet from which glacial ice flowed as well.*

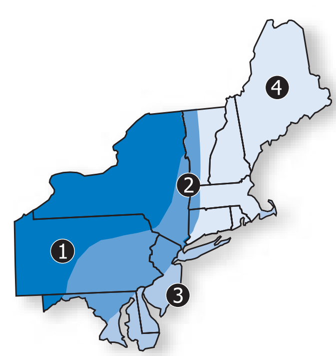
*Prior to glaciation, the* **Great Lakes** *were river valleys that had been scoured and deepened repeatedly by the many ice advances during the Quaternary period. Many sizable glacial lakes were formed at the edge of the melting glacier that no longer exist today or have significantly shrunk in size.*

## *Glacial Scouring*

### Rebounding of the crust

*A 2 kilometer thick ice sheet can weigh quite a bit. The enormous weight of the ice sheet over the continent depressed the crust into the asthenosphere just as the weight of a person in a canoe causes the boat to ride lower in the water. When the person steps out of the canoe, the buoyancy of the canoe allows it to once again rise. When the ice sheet retreated from the Northeast during the most recent ice age, the crust rebounded and continues to do so today. However, the crust could not rebound as fast as sea level was rising from the melting glaciers. The result was flooding of the coast and glacial lakes. The rebound of the crust when it is freed from overlying ice is known as* isostasy. Figures by J. Houghton.



# Glacial Features of the Inland Basin

## *Region 1*

Excellent examples of glacial scouring are found in the Inland Basin region of the Northeast. Lakes Ontario and Erie were formed by the scouring action of glaciers. The broad, deep basins of Lakes Ontario and Erie, former river valleys, were scooped out by tongues of ice as the glacier advanced over North America. When the glacier began its retreat, meltwater flooded lake basins. Lakes Ontario and Erie were both much larger than today. Glacial meltwater poured into these basins, and the ice blocked drainage that would eventually flow to the northeast via the St. Lawrence River. The Erie and Ontario Lowlands, as well as the once-flooded Mohawk River Valley south of the Adirondacks, are the remains of the much larger lakes. Flat, lowland topography and characteristic lake bottom sediments are found in the areas where the lakes once reached.

The Finger Lakes region of New York was also formed by glacial scouring *(Figure 3.8)*. The Finger Lakes were pre-existing river valleys before the tongues of ice covered the area and widened and deepened the valleys. The stream valleys were dammed at their southern end by glacial till and flooded to form the Finger Lakes when the ice sheet retreated. Whereas streams only erode as far down as sea level, glaciers are able to erode more deeply. The bottoms of two of the Finger Lakes (Lakes Seneca and Cayuga) are actually below sea level.

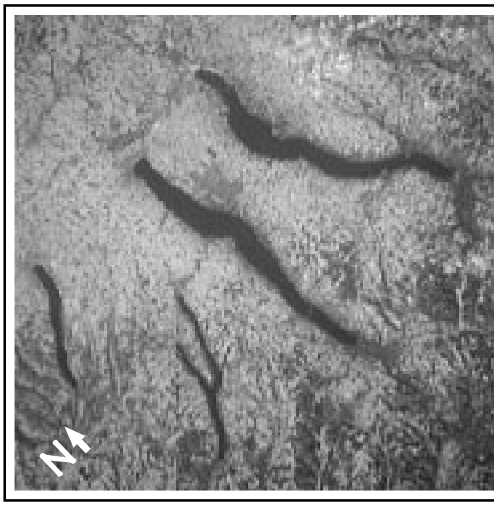
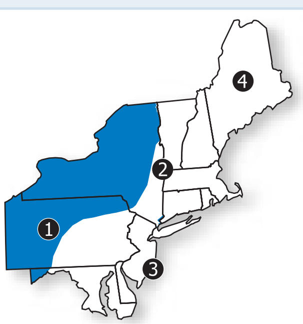



*Figure 3.8: A view of the Finger Lakes region glacially carved lakes from the Space Shuttle.*
Image courtesy of Alan Spraggins, NASA, JPL, Houston.

The Finger Lakes region is famous for its numerous gorges, which also resulted indirectly from the glaciers of the Laurentide ice sheet. After the glaciers retreated, or began retreating, tributary streams began running into the Finger Lake Valleys. The erosive force of the glaciers, however, considerably deep-

*The bottoms of Seneca (193 meters deep) and Cayuga (132 meters deep) Lakes are deeper than sea level.*



ened these valleys. Thus, tributary streams were left hanging far above the lake surface, forming a series of waterfalls and cascades all along the Finger Lake Valleys. These stream valleys are called ***hanging valleys*** *(Figure 3.9)*. In a matter of only several thousand years, deep erosion by the tributary streams has moved many of the waterfalls hundreds of meters back away from the edge of the Finger Lake Valleys and created beautiful long, narrow gorges *(Figure 3.10)*. It is possible, though not always easy, to document that some gorges were formed during one or more previous glacial advances and simply re-excavated and further eroded since the last glacial event; some gorges formed during previous glacial advances were buried by sediment (till) in the most recent glacial advance and have not been re-excavated.

*The tributary streams rapidly eroded the valley trying to reach the new base level in the Finger Lake Valleys. Resistant rock units have temporarily slowed the stream erosion, and the waterfalls remain.*

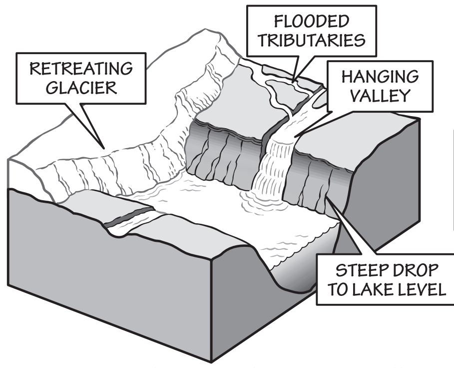



*Figure 3.9: Development of a hanging valley following glacial retreat.* Figure by J. Houghton.

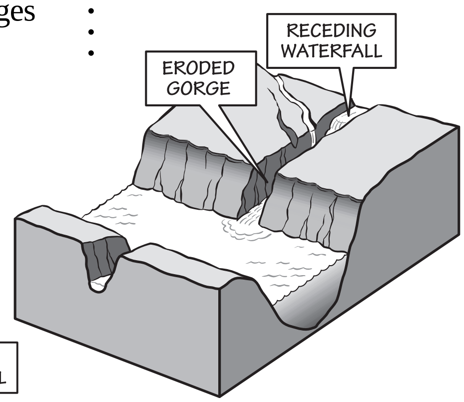



*Figure 3.10: Development of a post-glacial gorge as in the Finger Lakes of central New York.* Figure by J. Houghton.

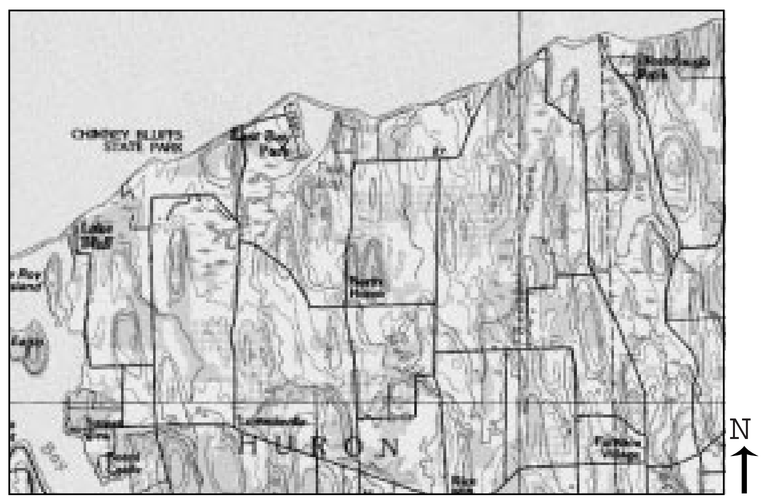
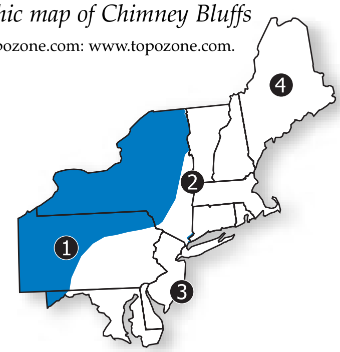



*Figure 3.11: Drumlins on the topographic map of Chimney Bluffs State Park, New York.* Image provided by Topozone.com: www.topozone.com.

## *Glacial Deposits*

In addition to a blanket of till over the region, glacial deposits in the Inland Basin Region include abundant drumlins and moraines south of the Finger Lakes *(Figure 3.11)*. Between Rochester and Syracuse in the Ontario Lowlands are more than 10,000 drumlins. The drumlins are an important clue in determining the direction of flow of the most recent advance of the ice sheet. The Ontario Lowland drumlins are all generally oriented north to south, providing solid evidence that the glaciers flowed south over the landscape.

The terminal moraines in the Inland Basin include the Kent and Olean Moraines in Pennsylvania and the Valley Heads Moraine in New York *(Figure 3.12)*. The Valley Heads Moraine is significant because it divides the St.



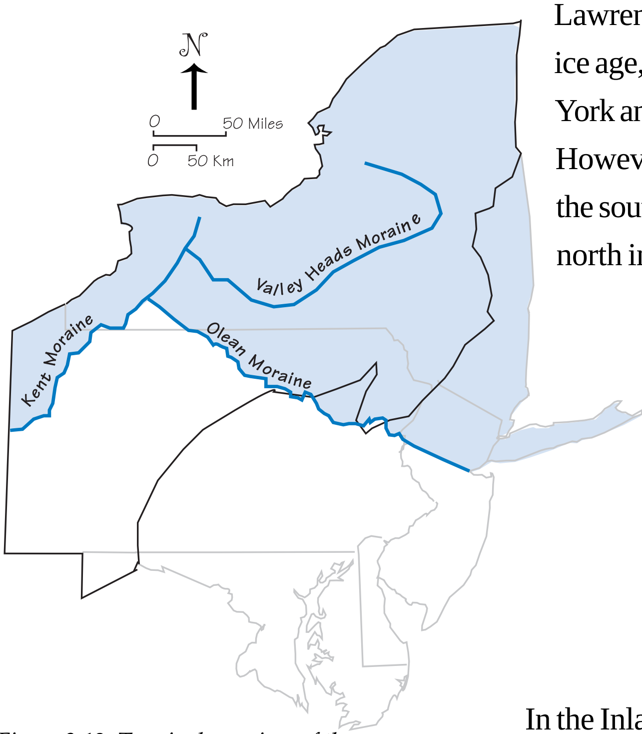



Figure 3.12: Terminal moraines of the Inland Basin. Light blue represents the maximum extent of the most recent ice sheet.

Lawrence and Susquehanna drainage basins. Before the most recent ice age, many streams of the Inland Basin region (especially in New York and Pennsylvania) flowed south into the Susquehanna River. However, the Valley Heads Moraine, blocked the flow of water to the south, damming the Finger Lakes and forcing streams to drain north into the St. Lawrence River Valley *(Figure 3.12)*.

**Varves:**
***glacial lake deposits***
*Thinly bedded, very fine-grained sediments or clay characterize the deposits of glacial lakes that have shrunken considerably or disappeared. Coupled laminations of light and dark sediments, called varve deposits, are common lake-bottom features. The light bands represent summer deposits in the lake, whereas the dark layers represent winter deposits. The dark color in varved layers is attributed to an abundance of organic material.*

## *Periglacial Features*

In the Inland Basin, a small area of southern New York, most of Pennsylvania and all of Maryland were left ice-free. Much of this region not covered by the ice sheet was periglacial, showing characteristic features of permafrost *(Figure 3.13)*. Throughout Pennsylvania and parts of Maryland are evidence of solifluction (permafrost-area mudslides), patterned ground and boulder fields.

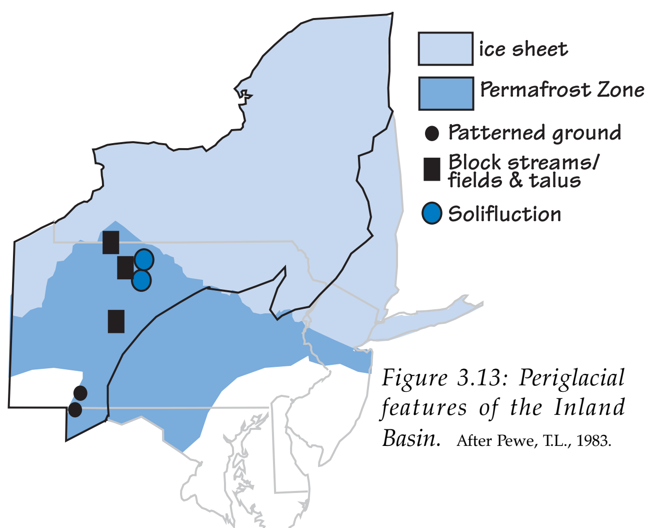
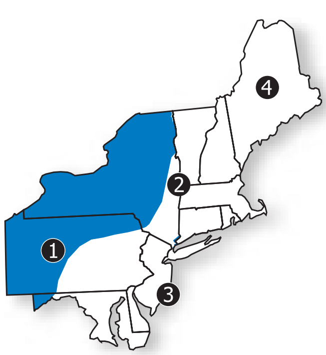



Figure 3.13: Periglacial features of the Inland Basin. After Pewe, T.L., 1983.



# Glacial Features of the Appalachian/Piedmont

## *Region 2*

### *Glacial Scouring*

Glacial scouring, resulting from the scraping action of the glacial sediments, have formed two classic glacial features in the Appalachian/Piedmont region: potholes and lake basins. Archbald Pothole State Park near Scranton, Pennsylvania is one of the largest glacier-scoured ***potholes*** in the world, measuring approximately 13 meters wide and 12 meters deep. While not always caused by glacial runoff, smaller potholes are found throughout the once glaciated areas of the Appalachian/Piedmont as well as other regions of the Northeast.

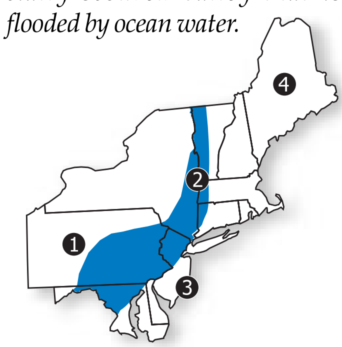
*In order to form such an enormous* ***pothole****, scouring conditions must last for quite some time.*

In the Appalachian/Piedmont, the glaciers of the Laurentide ice sheet scoured and the meltwater flooded two major lake basins: Lake Champlain and the former glacial Lake Albany. The edge of Lake Champlain was 15-30 kilometers east of its present shoreline during the ice age. The shoreline once extended as far east as the Green Mountains (and in some areas even beyond). Examination of the ancient shorelines left by the glacial Lake Champlain shows clear evidence for rebound of the land after the removal of the ice sheet. More than 150 meters of rebound is evident by looking at the once horizontal shorelines of glacial Lake Champlain. The Champlain Lowlands, with their low elevation and minimal relief, show the extent of the glacial Lake Champlain. Fourteen thousand years ago, the receding glaciers caused a rise in ocean levels. Because northern New England was just becoming ice-free, the crust was still depressed, not having had enough time to rebound. As a result, the St. Lawrence Seaway and Lake Champlain were flooded with encroaching ocean waters. Thus, it is not surprising that marine ***fossils*** were found in the lakebed sediments, such as Vermont's state fossil, the Charlotte Whale.

*see Fossils, p.98, for other ice age* ***fossils.***

The Hudson River Valley, also deepened and broadened by the ice sheet advance, was likewise flooded when the glaciers began to melt. Glacial Lake Albany was formed when the lowlands flooded, though the lake does not exist today. *Evidence* of the lake does exist, however. The glacially scoured, narrow and deep Hudson River is a ***fjord,*** similar to the fjords of the Netherlands. Ocean water extends up the river valley with the tides as far north as Poughkeepsie, New York.

*A* **fjord** *is a deep and narrow, glacially scoured valley that is flooded by ocean water.*



## Glacial Deposits

The most significant glacial deposits in the Appalachian/ Piedmont region are the moraines that stretch across northern Pennsylvania and New Jersey *(Figure 3.14)*.

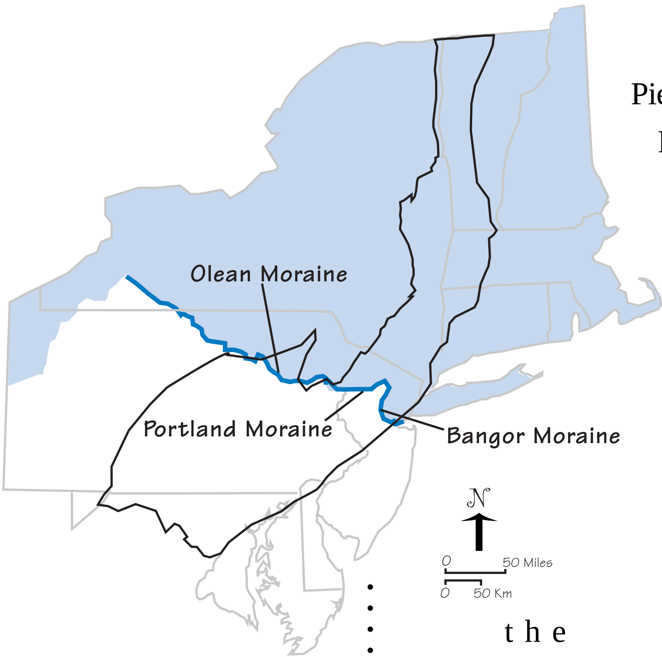


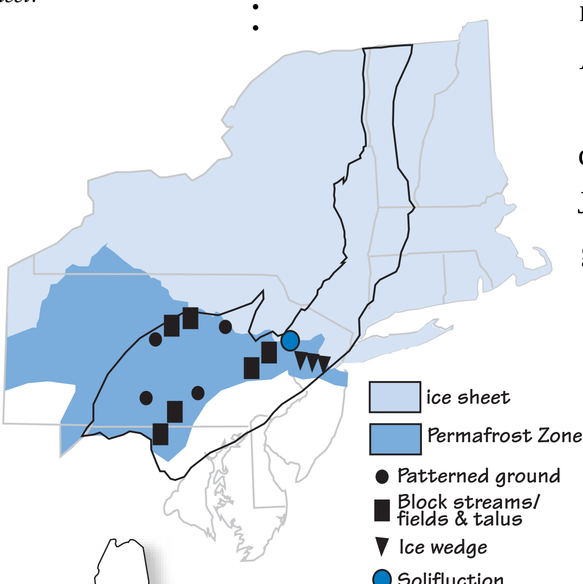

*Figure 3.14: Terminal moraines of the Appalachian/Piedmont. Light blue represents the maximum extent of the most recent ice sheet.*

## Periglacial Features

The steep, mountainous topography of the Appalachian/Piedmont aided the glaciers in speeding up physical weathering of the rocks in the periglacial region *(Figure 3.15)*. Boulder fields, some deeper than 3 meters, formed when blocks of rock from nearby ridges were loosened by freezing and thawing water in fractures and cracks. The boulders tumbled down slope and were left as fields of rocks. The majority of boulder fields occur in the periglacial Appalachian/Piedmont region of Pennsylvania and Maryland. Some of the best examples of boulder fields in Pennsylvania include Hickory Run in Carbon County; Blue Rocks in Berks County; Ringing Rocks in Bucks County; and Devils Race Course in Dauphin County. There are many smaller boulder fields as well throughout the Appalachian/Piedmont in Maryland and Pennsylvania.

Another periglacial feature found in the Appalachian/Piedmont region are ice wedges. In northern New Jersey, ice wedge casts created polygonal patterns in the ground. The polygons range in diameter from 3-30 meters. When the ice melted, the wedges filled with sediment from glacial meltwater. The sediments in the cracks are able to hold more moisture, and thus are a better medium for plant growth. The polygon patterns were first recognized in agricultural fields because the crops grew much better in the wedge sediments than the surrounding sediments.

The Appalachian/Piedmont periglacial region also has evidence of solifluction. Becoming increasingly heavier with water from thawing in the periglacial environment, soils began to flow rapidly down slope in many areas.



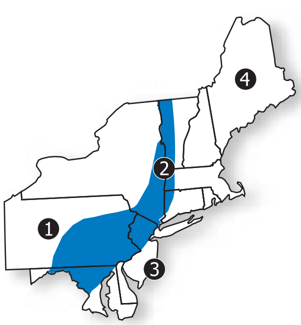




*Figure 3.15: Periglacial features of the Appalachian/ Piedmont.* After Pewe, T.L., 1983.

# Glacial Features of the Coastal Plain

## *Region 3*

### *Glacial Deposits*

Long Island, Cape Cod, Martha's Vineyard, Block Island and other islands off the New England coast are end moraines deposited during the most recent ice age that mark the maximum extent of the ice sheet 20,000 years ago. When the ice sheet paused in its advance over the Northeast, the melting ice deposited massive quantities of sand and gravel at its terminus *(Figure 3.16)*. Long Island serves to buffer the Connecticut coastline from storms, creating calmer water behind the island. The Ronkonkoma Moraine runs the length of Long Island and forms many of the smaller islands off the coast. The Harbor Hill Moraine stretches across northern Long Island and upwards to form the coast of Rhode Island and Cape Cod. As there is no buffering island for the Rhode Island coast, it is more severely affected by storms and high waves than the coast of Connecticut. There are no skyscrapers on Long Island because of the loose, unconsolidated glacial till that makes up the island. Till is not stable enough for very tall buildings. Not far away, however, tower the skyscrapers of Manhattan, such as the Empire State Building, built on the very resistant, metamorphosed Precambrian and Cambrian rocks of the Manhattan Prong.

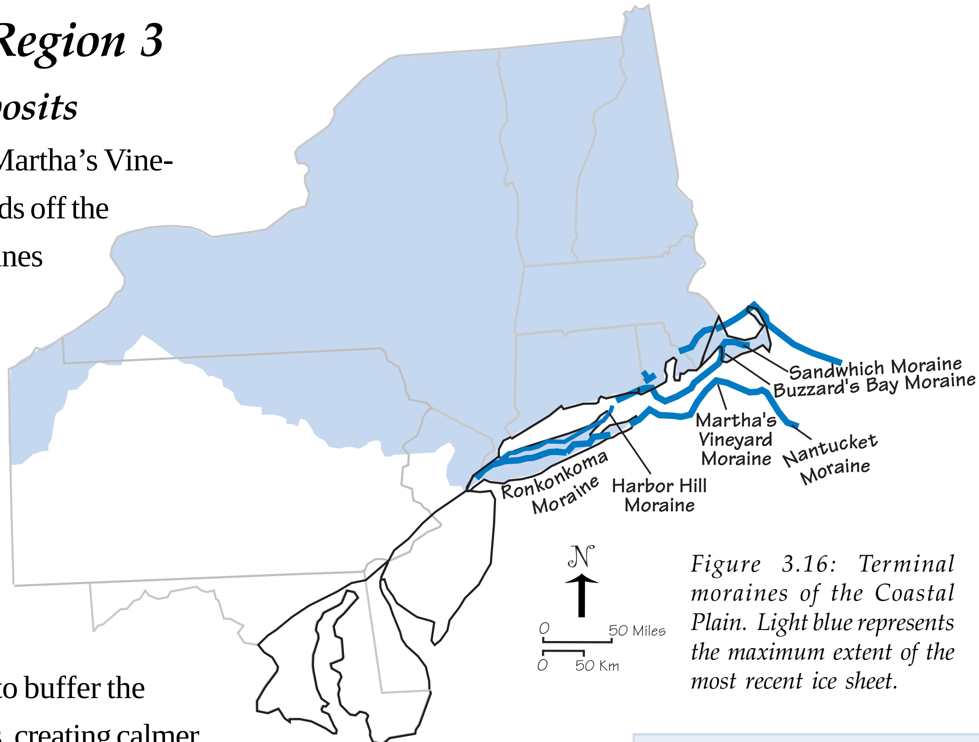


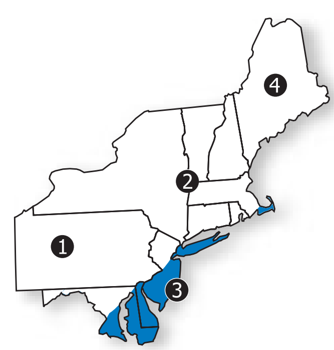

*Figure 3.16: Terminal moraines of the Coastal Plain. Light blue represents the maximum extent of the most recent ice sheet.*

**Sea level changes**

*At the beginning of the ice age, sea level dropped about 100 meters because of the formation of the vast ice sheets. The drop in sea level caused rivers and streams to incise deep channels into the Coastal Plain sediments, eroding to the new sea level. These deep channels and canyons are now underwater because the melting of the glaciers caused sea level to rise. Flooding of river valleys such as the Chesapeake Bay resulted from the rising sea level.*

### *Periglacial Features*

The unconsolidated, loose nature of the Coastal Plain sediments made them particularly susceptible to movement during the freeze and thaw cycles of the periglacial environment. As the surface thawed in the summer and then refroze in the winter, the sediments in some areas were repeatedly settled and heaved upward. Though not covered by the ice sheet, some surficial layers of periglacial Coastal Plain sediment were thus still affected by the ice age.



# Glacial Features of the Exotic Terrane

## *Region 4*

### *Glacial Scouring*

The most evident glacial scour features in the Exotic Terrane region are ***cirques***, scoop-shape bowls where valley glaciers have originated at high altitudes. At Mt. Washington in New Hampshire, and Sugarloaf Mountain, Mt. Katahdin and other Baxter Park peaks in Maine, cirques are visible today. The intense erosion by the glaciers removed many meters of bedrock from the New England mountains.

### *Glacial Deposits*

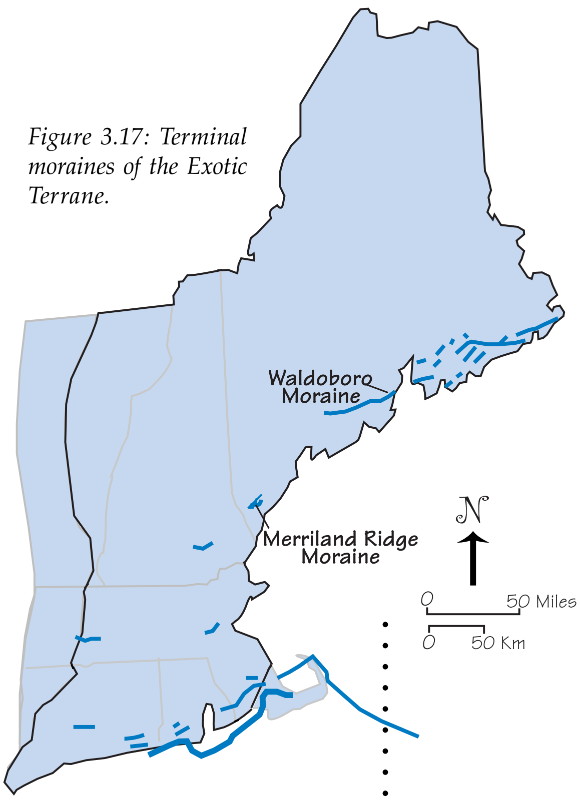
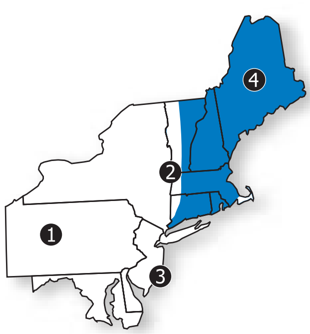



*Figure 3.17: Terminal moraines of the Exotic Terrane.*




On average, the moraines found in the Exotic Terrane region show approximately 30 meters of relief. Southeastern Maine in particular has hundreds of moraines formed where the ice sheet met the Atlantic Ocean *(Figure 3.17)*. The Connecticut Valley became a lake when an end moraine dammed the valley and blocked drainage. When the moraine-dam was broken, the 160-mile long lake drained away. The lake bottom sediments dried up and blew around, forming thick dune deposits of blown sand. Eventually these wind-blown deposits became vegetated to form the floor of the valley.

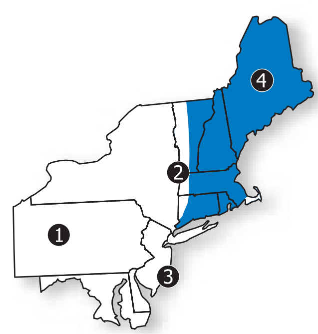
Common throughout the Northeast are kettle lakes or the lakebed deposits of kettle lakes. Thoreau's Walden Pond in Cambridge, Massachusetts is actually a kettle pond, formed when a buried block of glacial ice melted and overlying sediments collapsed to form a depression that filled with lake water.

An enormous field of drumlins is found in southern New Hampshire and northern Massachusetts. These elongated, glacially sculpted hills of till were formed as the ice sheet moved over mounds of glacial sand and gravel. The orientation of drumlins is an excellent clue in deciphering the direction in which the ice sheet flowed. Also common in the Exotic Terrane region, particularly in Maine, are eskers. These features were deposited by streams of meltwater flowing under the glacier. Well-sorted sand and gravel were left behind as sinuous ridges, or eskers, when the ice sheet receded. The abundance of sand and gravel that forms eskers has made them an easy target for mining. Many eskers no longer exist because the sand and gravel has been removed and sold. As it turns out, Maine has the longest eskers in the world.

Sea level rise due to the melting ice sheet greatly affected the Exotic Terrane region. As the ice sheet began to retreat northwards, sea level rose faster than the crust was able to rebound from the weight of the glaciers. The result was a dramatic change in the shoreline of the Northeast, from one in which the continental shelf was exposed or ice covered to one in which the shelf was under water, with the coast even more covered by sea water in some places than it is presently. Coastal river valleys, such as Rhode Island's Narragansett Bay. The whole coast of Maine, however, was flooded beyond its present shoreline, leaving a blanket of clay deposited by the ocean waters inland and along the present day coast. The clays are known as the Presumpscot Formation, filled with a variety of ***fossil*** marine organisms that are clear evidence of the marine submergence.

*see Non-Mineral Resources, p.167, for more on glacial deposit resources.*

*see Fossils, p.98, for more on ice age fossils.*



# Activities

1. Discussion with some of your school friends who are not taking Earth science reveals that they cannot imagine a 2 kilometer-thick sheet of ice, nor do they see evidence that such ice sheets covered the northern Northeast. The school newspaper editor suggests you write a persuasion piece, showing the evidence for glaciation. You bring this topic up with your teacher, who explains that Louis Agassiz, a Harvard professor originally from Europe, had to undertake a similar challenge in the mid-19th century when he suggested that features left behind by glaciers he'd seen in Europe caused features he saw in New York State.

*Compile evidence for glaciation in the Northeastern United States. How do glacial features vary from place to place? Suggest a travel route for interested individuals to see glacial features in the northeast.*

2. Someone from the local newspaper, seeing your article, was sufficiently intrigued to suggest that you write an article for their newspaper. He suggested that you focus your article on features that can be seen relatively locally, within about an hour's drive of your home.

*Write another article, this time to the local newspaper referring to specific local evidence.*

3. USA Today, taking note of your fine article, asks that you write an article with national appeal.

*They suggest you contrast three areas of the northeast: northern areas that have been "flattened" by lake sediments, features along the margin of the glacier, and areas south of the glacier. Choose three localities and write an article describing what is going on in each of the three localities through time, starting with*

(1) the maximum extent of the last glaciation,
(2) the receding of the glacier and what it leaves behind, and
(3) what influences we see at the surface today (especially as they relate to the settlement and economy of people living there.)

# For More Information...

## *Books*

Allmon, W.D., and Robert M. Ross, 1999, *Ithaca is Gorges*, The Paleontological Research Institution: Ithaca, New York.

Oldale, Robert N., 1992, *Cape Cod and the Islands, the Geological Story,* Parnassus Imprints: East Orleans, Massachusetts.

Von Engeln, O. D., 1961, *The Finger Lakes Region: Its Origin and Nature*, Cornell University Press: Ithaca, New York.

## *Internet*

All About Glaciers
http://nsidc.org/glaciers/

Vermont Glaciers Virtual Field Trip
http://geology.uvm.edu/geodept/ugradwww/glacier/index.html

## *Other Resources*

***used in compiling this chapter***

Pewe, T.L., 1983, *The Periglacial Environment in North America During Wisconsin Glacial Time* in Porter, S.C., ed., *Late-Quaternary Environments of the United States*, vol. 1, University of Minnesota Press: Minneapolis, Minnesota.

Hughes, T., H.W. Borns, Jr., J.L. Fastook, M.R. Hyland, J.S. Kite, T.V. Lowell, 1985, *Models of Glacial Reconstruction and Deglaciation Applied to Maritime Canada and New England,* Geological Society of America Special Paper 197.

*Special thanks to Pete Nester for providing additional content on this chapter.*

RESOURCES

# Selected Figures

## *for overheads & handouts*

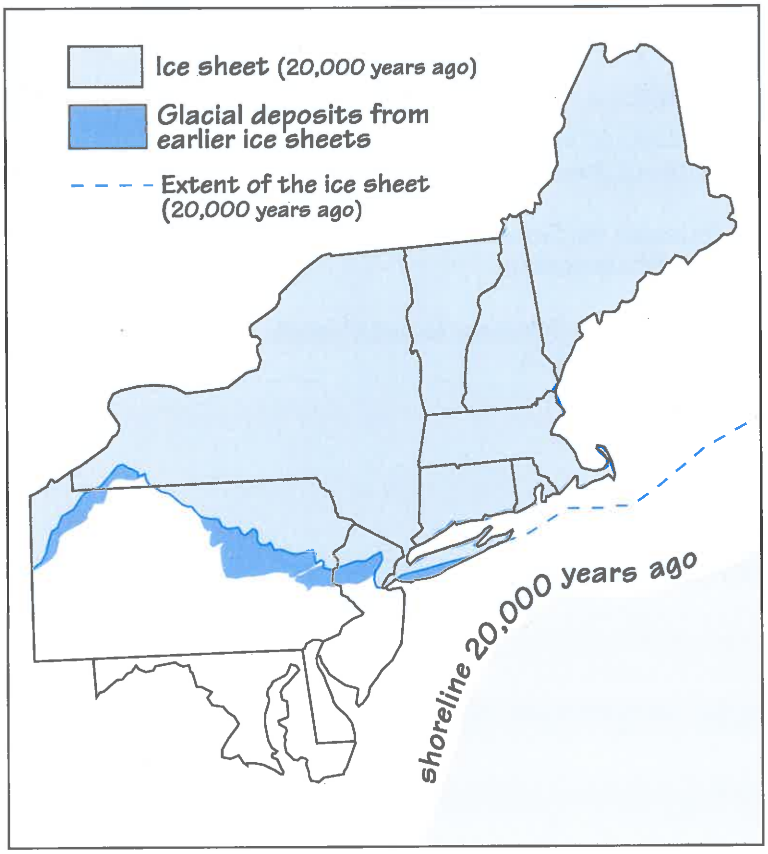
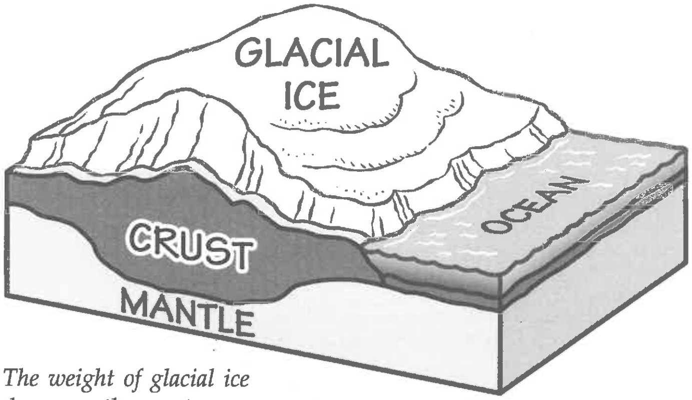
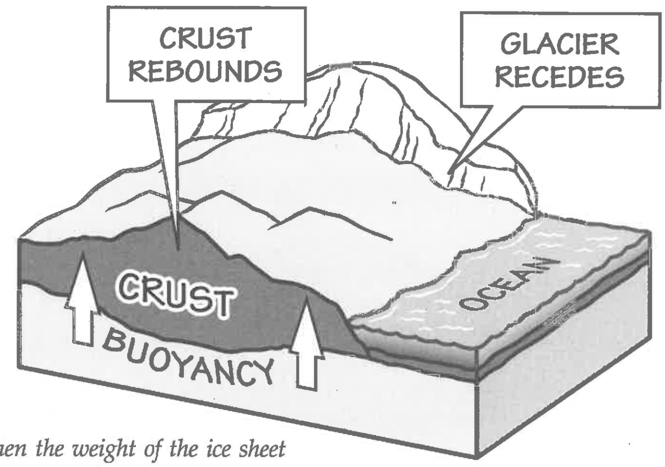



*Figure 3.5: The approximate position of the ice sheet 20,000 years ago.* After Hughes, T., et al, 1985.


*Figure 3.7: The 12,000 years ago.* After Hughes, T., et al, 1985.




*The weight of glacial ice depresses the crust.*




*When the weight of the ice sheet is gone, the crust is uplifted..*

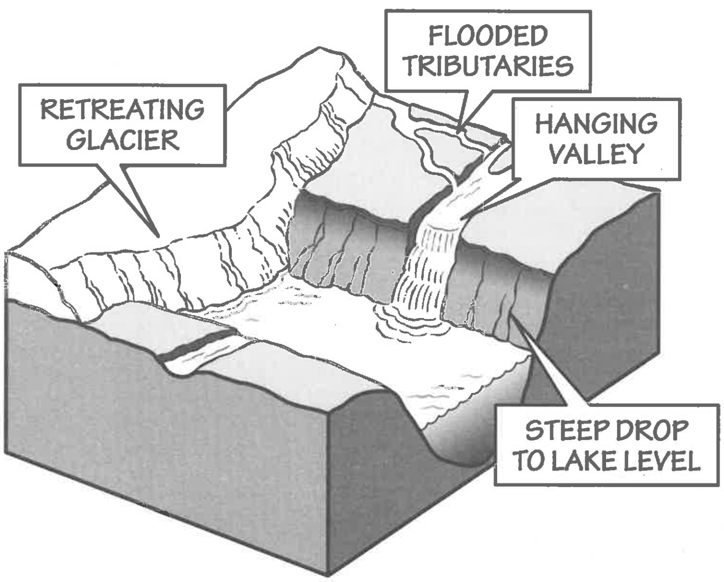



*Figure 3.9: Development of a hanging valley following glacial retreat.* Figure by J. Houghton.

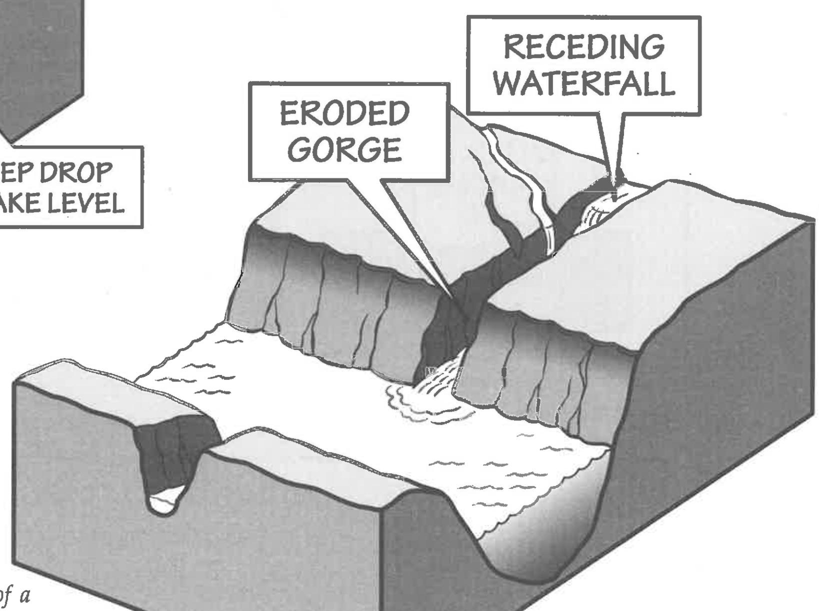



*Figure 3.10: Development of a post-glacial gorge as in the Finger Lakes of central New York.* Figure by J. Houghton.

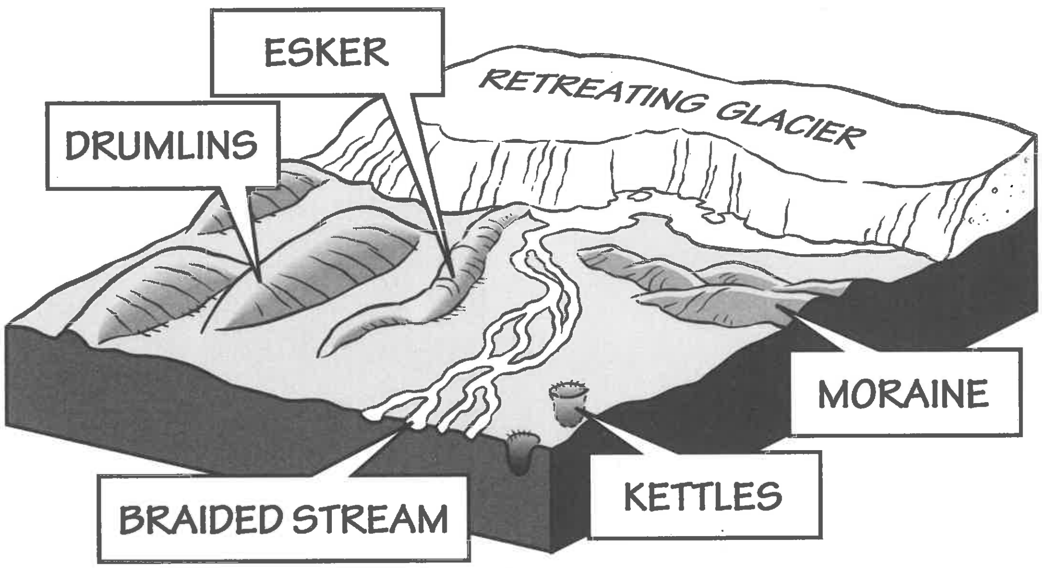



*Figure 3.2: Glacial deposits.* Figure by J. Houghton.

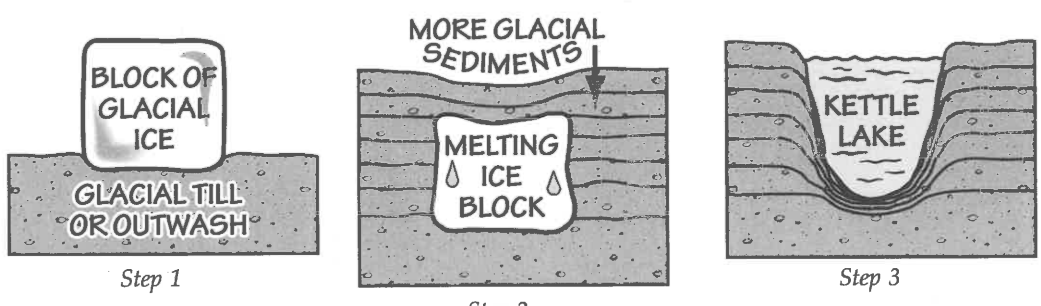
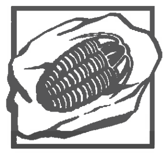


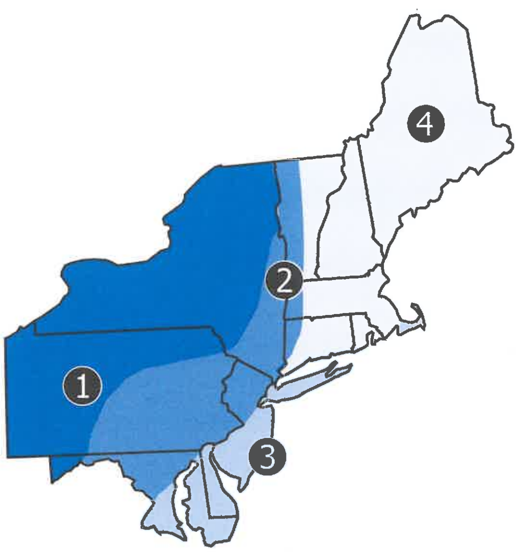

*Figure 3.3: Formation of a kettle lake.* Figures by J. Houghton.

# Fossils of the Northeastern US:
## *the BIG picture*



## ❶ Inland Basin

*The Inland Basin has many fossil-rich rocks, particularly in the Cambrian through Pennsylvanian. These rocks preserve shallow marine organisms characteristic of the diversification of marine life that occurred in the early and mid-Paleozoic. Some of the most common fossils include brachiopods, trilobites, bivalves, crinoids, and corals. In the vicinity of the coal layers found in Pennsylvania and Maryland, there is an excellent record of Pennsylvanian-age plants.*




## ❷ Appalachian/Piedmont

*Similar to the Inland Basin, the Appalachian/Piedmont also contains a rich fossil record of Paleozoic sea life. However, in most cases, the fossils are not as well preserved because of the deformation and alteration of the Appalachian/Piedmont rocks by stress from the mountain-building events. Additionally, the Triassic and Jurassic rift basins that formed in this region during the breakup of Pangea preserve land animals such as dinosaurs, and freshwater organisms from lakes within the basins.*

## ❸ Coastal Plain

*The Coastal Plain sediments contain a rich record of Cretaceous and Tertiary continental shelf marine life. These marine organisms are an interesting contrast to the Paleozoic marine fossils of the Inland Basin and are evidence of the significant changes in sea life over the last several hundred million years. The most common fossils include mollusks (clams, snails and cephalopods), corals, barnacles, and sharks' teeth. The degree of preservation of Coastal Plain fossils varies widely, with many looking much like modern shells.*

## ❹ Exotic Terrane

*The Exotic Terrane region is generally not fossil-rich because of the deformation and extent of igneous and metamorphic rocks caused by mountain-building events in the Paleozoic. There are, however, early Paleozoic fossil animals strikingly different from those found elsewhere in the Northeast. These fossils are quite similar to organisms found on the north coast of Africa, and are among the kinds of evidence that this area is a chunk removed from land on or near Africa.*

# Fossils of the Northeastern US:
## *a brief review*

Fossils are found almost exclusively in sediment and sedimentary rocks. Igneous rocks, which form from cooling magma or lava, would not normally be expected to preserve fossil material or be likely to have any. The elevated temperature and pressure necessary to form a metamorphic rock likewise would destroy any fossil material within the rock, unless it is only weakly metamorphosed. Fossils usually are the mineral skeleton of an organism, such as the shell, bones or some kind of impression. Most shells and bones never become fossils, but instead are broken to tiny bits or dissolved. In order to become a fossil, the skeletal material must be buried before it is destroyed. Often, the shells or bones leave fossil impressions or casts of their shape in the sediment in which they are buried. Records of the movement of animals in the rock are also fossils; these are known as ***trace fossils***.

Fossils are especially useful in geology because of where they occur. Particular kinds of rocks are formed as a result of processes that are not unique to time or space. A sandstone formed in the Devonian in the Northeast, for example, may look very similar to a sandstone formed in another time period or another region. Fossils, on the other hand, are unique to particular times and places because the organisms preserved as fossils have evolved through time, and live in specific geologic areas and environments. There are, however, important generalities about the distribution of groups of organisms in the Northeast with respect to age and types of rocks in which they are found.

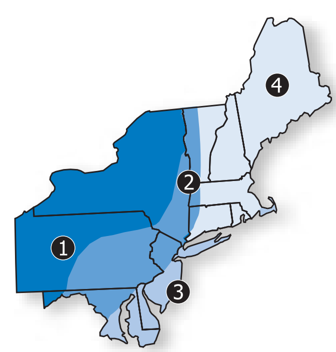
**The Northeast preserves an excellent record of:**

- *the* **shallow marine realm of the inland ocean** *that existed in the early and mid-Paleozoic. Brachiopods, trilobites, corals and sea lilies are especially numerous.*
- **Devonian, Mississippian** *and* **Pennsylvanian plants** *that accumulated in swampy coastal wetlands bordering the inland ocean.*
- *organisms that lived in the lakes that existed in parts of the* **Triassic/ Jurassic rift basins** *and on the land during the same period.*
- **Cretaceous and Tertiary shallow marine organisms**, *mostly clams and snails, in Coastal Plain sediments.*
- *and* **late Pleistocene land, freshwater, and marine animals** *that lived during the most recent ice age.*

*see Rocks, p.5*

*The soft parts of an organism, including the skin and internal organs, tend to rot away and are not normally preserved in the fossil record. The exceptions to the rule occur when minerals replace soft parts before they rot away, such as petrified wood, or where the oxygen content is low enough that rotting is slowed down to near zero, such as leaves in swamp sediments or insects preserved in amber.*

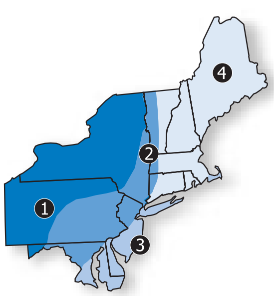
**Trace fossils** *do not preserve shell or bone material. Rather, they preserve the evidence of the movement of an organism, such as a footprint, burrow, trail or trackway. Trace fossils cannot always be linked to a particular species, but they can often be associated at least with a group of organisms or way of life. The first trace fossils appear a couple hundred million years before the first animal fossils, and burrows through sediment seem to become deeper from the Paleozoic through the Cenozoic.*



# Fossils

### Mass Extinctions

*Most species have a lifetime of several million years before going extinct; rarely do species live longer than 10 million years. The extinction of a species is a normal event within the history of life. There are, however, intervals of time in which extinction rates (the number of species going extinct within a given time interval) are relatively high, in some cases at a rate 10 or 100 times the normal rate. These intervals are known as 'mass extinctions'. There were five particularly notable mass extinctions in geologic history. These largest mass extinction events, probably due to unusual ecological events, have helped to shape life through time. The largest known extinction occurred at the Permian-Triassic boundary, in which over 90% of the species worldwide became extinct. Trilobites, rugose and tabulate corals, and most other taxonomic groups prevalent in the Paleozoic disappeared. Clams, snails, ammonoids, a new group of corals (scleractinians), crustaceans, and bony fish became the dominant ocean animals during the Mesozoic.*




Different plant and animal fossils are found in different places in the Northeast because differently aged rocks occur at the surface in different areas. Further, particular fossil organisms lived only in certain environments and these environments did not exist continuously through time, nor were these environments necessarily preserved in the rock record. Thus the fossil record is very closely tied to the historical geologic events over the last billion years, the rock record formed through those events, and the rocks exposed at the surface today in the Northeast *(Figure 4.1)*.

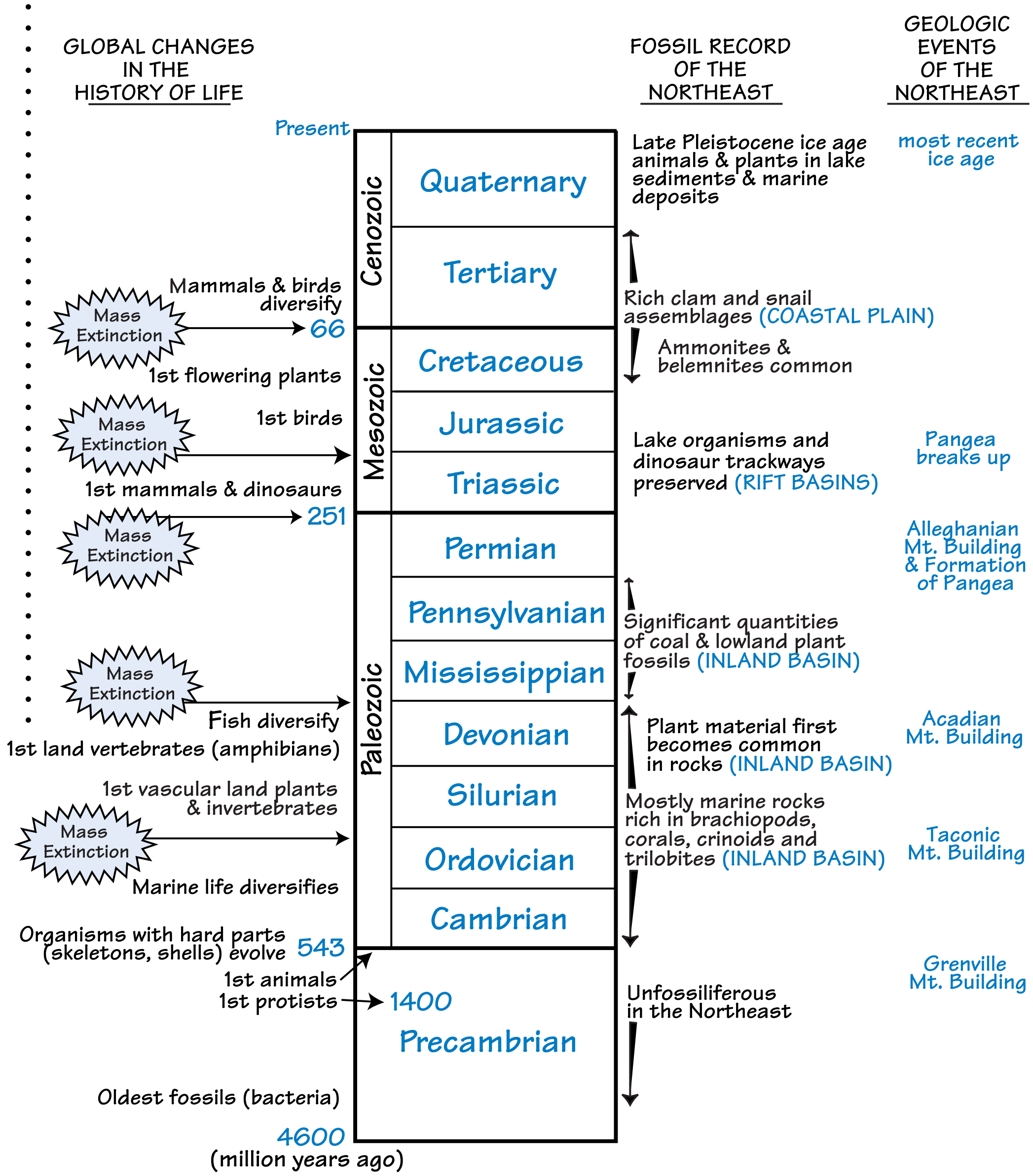



*Figure 4.1: The history of life in relation to global and regional geologic events and the fossil record of the Northeast. (Time scale is not to scale.)*

The ***history of life*** in the Northeast has been pieced together from fossil records in many different areas. As is evident in the Northeast, a complete record of rocks from every period is not preserved. Not all sediments end up as rocks, and likewise, not all rocks that have formed are still preserved. Many have been weathered and eroded away completely. It is the same with the fossil record. Not all organisms are preserved as fossils and rocks that have contained fossils have not necessarily been preserved (or may be well below the surface, out of sight from ***paleontologists***). The majority of the fossil record in the Northeast is comprised of marine invertebrate organisms such as brachiopods, bivalves and gastropods. There are relatively few fossil remains from dinosaurs and other land-dwelling vertebrate organisms. However, this does not mean that dinosaurs and other vertebrates did not live in the Northeast! They probably did but were simply not preserved. The fossil record is only a small window to the past, reflecting the type and diversity of organisms that once lived and the environments they inhabited. The primary opportunity for sedimentary deposition over a large part of the Northeast has been an inland ocean that existed for many millions of years. Thus it should not be surprising that marine organisms dominate the fossil record of much of the Northeast.

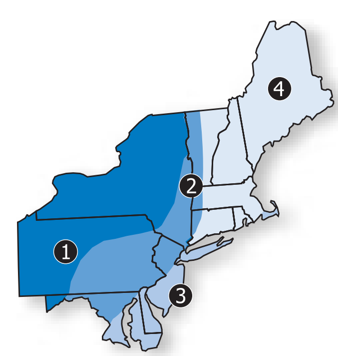
## Determining the environment

*The kind of animals and plants living in a particular place depend on the local environment. The fossil record preserves not only a fossil organism, but also elements of the local environment in which the organism lived. By looking at the geological and biological information recorded in a rock that preserves a fossil, you can often determine the type of environment that a fossil organism lived in:*

- **Grain size and composition** *of the rock tells you the type of surface the animals and plants lived on (unless they have been transported).*
- **Sedimentary structures** *such as ripples and cross-beds indicate the organism lived in moving water. Mud cracks and wave ripples are characteristic of shoreline environments.*
- **Broken shells** *or* **concentrated layers of shells** *may indicate pounding waves or storms.*
- **Clarity of the water** *in the environment can be determined by the type of rock. Fine grained shales are made of tiny clay particles that easily remain suspended in water. Thus a fossil found in a shale might have lived in muddy water. Filter feeding organisms such as corals and sea lilies are not usually found in muddy water because the suspended clays clog their filters!*
- **Amount of oxygen in the water** *can be determined indirectly from the rock. If there is not enough oxygen in the water, organic material in sediments will not decompose and the rock formed will be dark gray to black in color.*

*Not only is the* **history of life** *recorded in rocks of the Northeast, life has had a direct influence on the type of rocks formed in the Northeast. For example, limestones are formed from an accumulation of skeletons of sea life, which in turn affect soil composition, agriculture and topography. Pennsylvanian-age forests and swampy, wetland vegetation are responsible for the coal and dark-colored, fine grained rocks formed in the Inland Basin and Appalachian/Piedmont regions.*

**Paleontology** *is the study of fossils. The field of paleontology grew quickly in the 19th and early 20th centuries because fossils could be applied to determine the relative age of a rock and something about the environment in which a sedimentary rock was created. This information was (and is) helpful in tracking down energy resources such as petroleum and coal.*

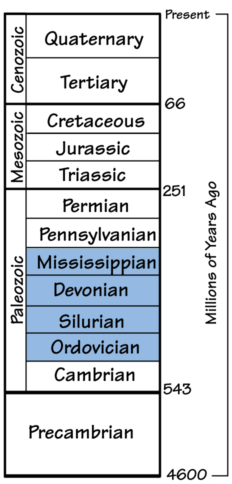


# Fossils of the Inland Basin

## *Region 1*

The Inland Basin region primarily contains the story of the evolution of marine and coastal plant life superimposed on the story of mountain-building events, associated sediments deposited in the inland ocean, and changes in relative sea level. The earliest fossils in the Inland Basin region are ***stromatolites***, formed from cyanobacteria in the warm shallow Iapetus Ocean. Stromatolites are preserved in late Cambrian rocks, found to the southwest and southeast of the Adirondacks. Abundant marine fossils are found in Ordovician through Mississippian rocks formed in the inland ocean that existed through most of the Paleozoic. Pennsylvanian-age rocks preserve an excellent record of plant material.

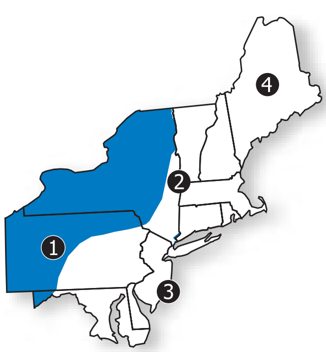
*see Fossils, p.91 for more on* **stromatolites**




### *Ordovician to Mississippian*

Ordovician, Silurian and Devonian marine fossils of the Inland Basin, especially in New York, are world-famous for their quantity and quality. Ordovician-to-Devonian fossil assemblages are nearly always dominated numerically by brachiopods, and may also contain trilobites, sea lilies, corals, clams and other mollusks, and many other less common organisms. What is perhaps the most striking is the differences in fossil assemblages from different types of paleoenvironments. The type of environment determined the types of organisms that lived there, and thus the fossils that are preserved in the rock.

**Clear, shallow marine environments**, generally preserved as limestones, often have abundant ***corals*** *(Figure 4.3)*, ***bryozoans*** *(Figure 4.2)* and ***sea lilies*** *(Figure 4.4)*. Corals, bryozoans and sea lilies are all filter feeders, collecting fine particles from the water. These environments form in places and at times when there is little sediment settling in the water. Western New York and Pennsylvania, far from the Taconic and Acadian highlands where sediment was being eroded into the inland ocean, preserve rocks recording this environment. Also, throughout the Inland Basin, and relatively undeformed sections of the Appalachian/Piedmont, rocks formed in-between mountain-building events record clear, shallow marine conditions because there was no highland to erode sediment into the basin.



### BRYOZOANS

*Many animals that are not easy to study, and in some cases even recognize without the aid of a microscope, have a long and exemplary fossil record. One such group is the bryozoans, colonial marine animals that have evolved a wide variety of skeletal shapes and textures. One of the more common Paleozoic varieties looks like fine mesh cloth with numerous tiny holes in which the individual animals in the colony lived. Small tentacles on the animals captured food particles from the water.*

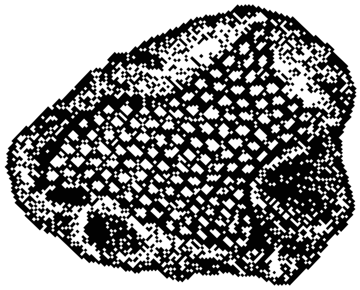


*Figure 4.2: Bryozoan, mid-Devonian fenestellid (4 cm wide).*

*Though functioning somewhat like a coral, and often found in similar environments, bryozoans are more closely related to brachiopods.*

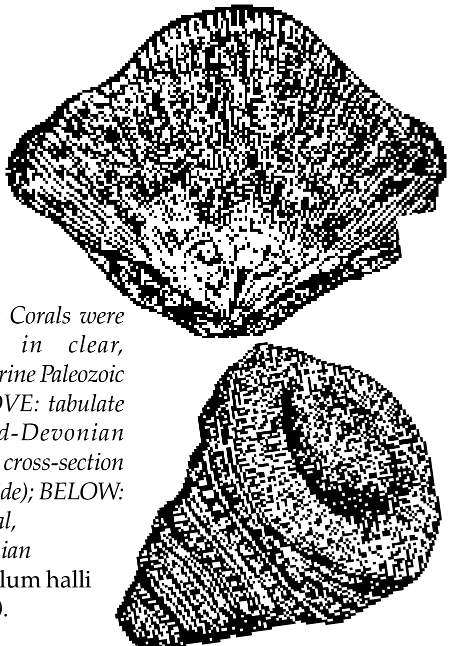


*Figure 4.3: Corals were abundant in clear, shallow marine Paleozoic seas. ABOVE: tabulate coral, mid-Devonian* Favosites, *cross-section (11.5 cm wide); BELOW: rugose coral, mid-Devonian* Heliophyllum halli *(7 cm long).*

### CORALS

*Corals have been important and common elements of clear, shallow marine waters since the Ordovician. Ordovician, Silurian and Devonian rocks of the Inland Basin region have numerous examples of reefs or other shallow environments in which colonial 'tabulate' corals are common. Even more abundant in these rocks is the solitary 'rugose' or horn coral. Both tabulate and rugose corals became extinct at the end of the Permian. Soon after, a new type of coral had appeared which are present today: the* **scleractinians**. *Though scleractinians look somewhat similar to rugose and tabulate corals, each group possesses distinctive features in the shape of the skeletal cup holding the individual animals.*

*Corals have been an important creator of limestone and also, as reef-builders, an important part of building homes for a diverse number of different organisms.*

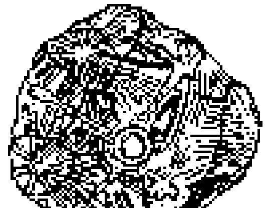
*see Fossils, p.93 for more on* **scleractinian corals**

### SEA LILIES
### BLASTOIDS & CYSTOIDS

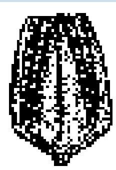
*Several groups of stemmed echinoderms appeared in the early Paleozoic, including crinoids, blastoids and cystoids. All have in common 5-fold symmetry and a head (calyx) held off the sea floor by a stem, where it collected organic particles from the water. The stems, which are the most often preserved part, are made of a series of stacked discs that look like Cheerios. Upon the death of the organism, the stems often fall apart and the individual disks are seen separated in the rock. Feathery arms radiated from the head of crinoids, looking something like a lily flower on a stem. Thus, crinoids are commonly called 'sea lilies', though they are not actually plants.*

*The head and arms of crinoids are rarely found preserved, while the heads of blastoids and cystoids, on the other hand, are commonly found whole. Though blastoids and cystoids went extinct at the end of the Paleozoic, crinoids still exist today.*

*crinoid stems, mid-Devonian (largest is 4 cm long)*



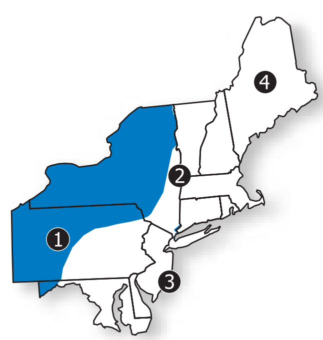
*crinoid cup, mid-Devonian* Dolatocrinus *(4 cm diameter)*



*blastoid theca, mid-Devonian* Devonoblastus *(2 cm wide)*

*cystoid theca, Silurian* Caryocrinites ornatus *(5 cm diameter)*

*Figure 4.4: Stalked echinoderms, common in clear, shallow marine environments.*



*Rocks that preserve muddy, well-oxygenated environments are especially common in the middle of the Inland Basin, away from the shoreline, such as the late Ordovician and the middle Devonian rocks in central to western New York and western Pennsylvania.*

*see Fossils, p.94 and 95, to learn about* **cephalopods and clams**

**Brachiopods** *have a special structure formed by tissue with thousands of tiny hair-like tentacles stretched along a coiled piece of internal shell material. These tentacles catch and move small particles towards their mouth. This body plan is very different from that of bivalves, which have a larger fleshy body and collect particles with their gills.*

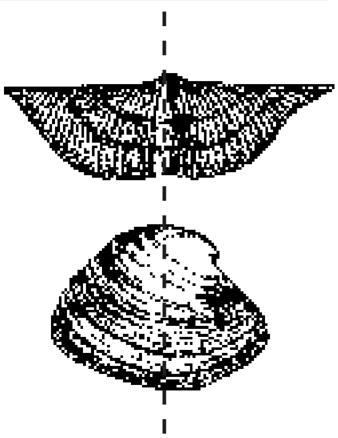
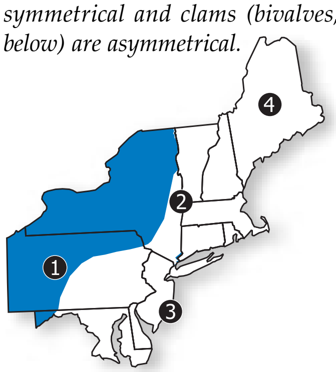


*Figure 4.6: Brachiopods (top) are symmetrical and clams (bivalves, below) are asymmetrical.*




**<u>Muddy, well-oxygenated environments,</u>** generally preserved as gray shales, often have abundant **brachiopods**, **trilobites** *(Figure 4.8)*, ***cephalopods*** and small ***clams*** *(Figure 4.7)*. Small or flattened brachiopods that are not likely to sink into the mud, such as *Mucrospirifer*, are common in this environment.

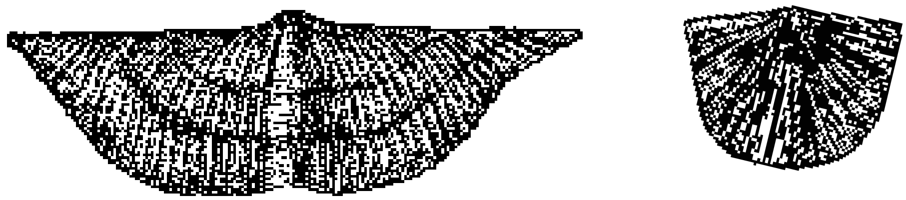


*Figure 4.5: LEFT: brachiopod, Mid Devonian* Mucrospirifer *(5 cm wide).*
*RIGHT: brachiopod, Ordovician* Rafinesquina (2.5 cm wide).

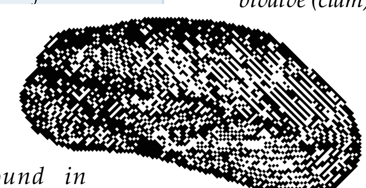
### *BRACHIOPODS*

*Brachiopods look somewhat similar to clams you might find at the beach today. However, from the soft parts of modern brachiopods, we know that they are completely unrelated to the animals that make 'shells' that are common today (bivalves); brachiopods are rare today and are unlikely to wash up on shore. Brachiopods are the most common fossil in Paleozoic sedimentary rocks and are therefore very common in the Inland Basin region where these rocks are preserved.*

### Brachiopod or bivalve?

*Brachiopods and bivalves both have a pair of hinged shells ('valves') to protect themselves while feeding. To tell the difference between a brachiopod and a bivalve, look for symmetry on the surface of the shells. Brachiopods are symmetrical across the shell, like your face. Bivalves are asymmetrical (Figure 4.6). The exception would be a deformed brachiopod, which might be found in the relatively more compressed rocks of the Appalachian/Piedmont. The size of the valves also helps to identify to which organism the shell belongs. Bivalve valves are of equal size and mirror image shapes. Brachiopods bottom valves, however, are slightly bigger and often have a different shape.*

*bivalve (clam)*



*ammonoid (cephalopod)*

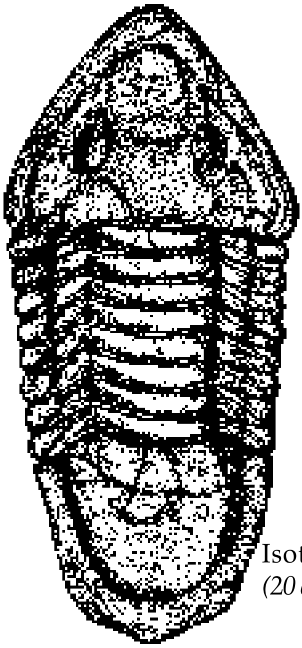
*Figure 4.7: Mollusks found in muddy,well-oxygenated environments: (clockwise) bivalve, mid Devonian* Modiomorpha *(5.5 cm); gastropod, mid Devonian,* Platyceras *(4 cm); nautiloid cephalopod, early-mid Devonian (20.5 cm long); ammonoid, mid Devonian,* Tornoceras *(5.5 cm).*

*gastropod (snail)*

*nautiloid (cephalopod)*

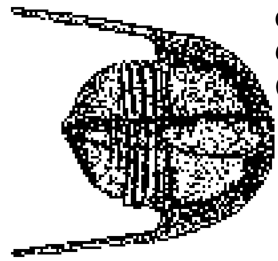
### *TRILOBITES*

*These marine organisms were bottom dwellers, present in a variety of environments and in Paleozoic rocks in the Inland Basin, Appalachian/Piedmont, and a few locations in the Exotic Terrane. Trilobites had a well-defined head, often with large eyes that had multiple lenses usually visible with the naked eye. A primitive arthropod distantly related to horseshoe crabs, trilobites have been extinct since the end of the Paleozoic.*



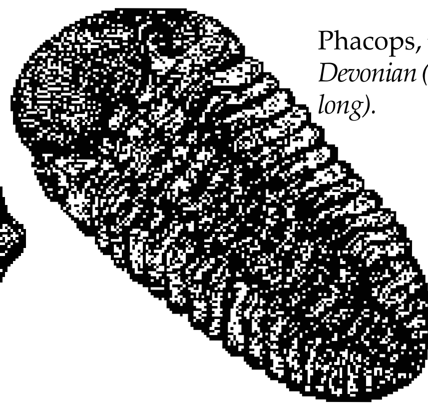
Isotelus, *Ordovician (20 cm long).*

*Figure 4.8: Trilobites were abundant in muddy, well-oxygenated environments in the early to mid Paleozoic.*



Cryptolithus, *Ordovician (1.5 cm).*

*Like crabs and lobsters,* **trilobites** *molted their exoskeleton when they grew. Most fossils of trilobites are actually molts, often broken as they were shed off the trilobite. Thus, it is common to find only parts of trilobites, such as the head, mid-section or tail.*



Phacops, *mid-Devonian (7 cm long).*

Dalmanites, *Silurian (6 cm long).*

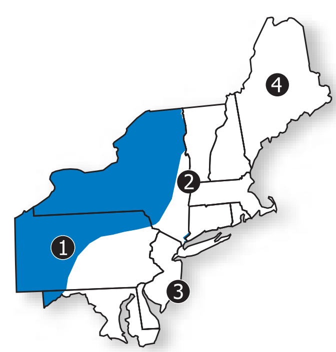
**<u>Muddy, oxygen-poor marine environments</u>** are preserved as black shales, which often are completely lacking fossils, though plankton such as ***graptolites*** may be found *(Figure 4.9)*. This environment forms in stagnant basins and areas where there is abundant organic material settling to the bottom; sometimes it is apparently associated with basin deepening due to down-warping crust during stages of rapid mountain building.

*Inland Basin rocks preserving* ***muddy, oxygen-poor environments*** *include especially some late Ordovician and mid Devonian rocks, formed at the beginning of the Taconic and Acadian mountain-building events.*

### *GRAPTOLITES*

*Graptolites are a group of extinct, puzzling planktonic organisms found in dark shales. No clear soft parts have been found, though they appear to be related to a minor group of modern colonial invertebrate organisms known as pterobranchs. They are relatively common fossils in the Ordovician rocks of the Inland Basin.*

*Figure 4.9: graptolites, Ordovician* Didymograptus *(2 cm long).*

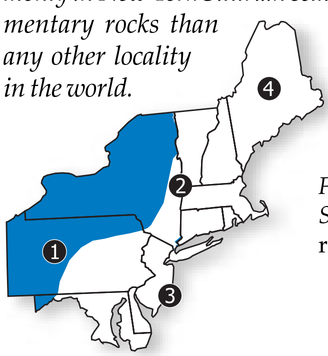


*High energy,* **silty or sandy environments** *were common near the eastern shoreline of the inland sea, and are preserved in places such as the mid-Devonian rocks of the Catskills. As the inland basin gradually filled over time, the shoreline moved westward. Thus, fossil-rich siltstones and sandstones are also found in the late Devonian rocks of southern New York and the late Devonian and Mississippian rocks of northern Pennsylvania.*

*see Rocks, p.35, for more on rocks preserving* **hypersaline** *environments.*

**Evaporites** *are sedimentary rocks created by the precipitation of minerals directly from seawater, including gypsum, carbonate and halite.*

*Rocks preserving hypersaline marine environments are found in the Silurian dolostones of central and western New York, associated with large salt deposits precipitated in the inland ocean. Eurypterids are preserved more commonly in New York Silurian sedimentary rocks than any other locality in the world.*




**Silty to sandy marine environments,** preserved as siltstone and sandstones, may contain abundant rugose corals, large thick-shelled brachiopods, sea lilies, and bryozoans and lesser amounts of many other organisms such as ***sponges*** *(Figure 4.10)*. These organisms were robust filter feeders.

*SPONGES*

*Technically known as poriferans, sponges come in a variety of shapes and body forms, and have been around at least since the Cambrian. Entire sponges are rarely preserved, but their tiny skeletal pieces, called 'spicules,' are common in sedimentary rocks. Glass sponges (with skeletons made of silica) are a particular group of sponges that existed from the Cambrian to the present. Though now largely found in deep water environments, they were sometimes part of shallow marine environments in the Paleozoic. The best-known glass sponge fossils are from New York Devonian sedimentary rocks of the Inland Basin.*

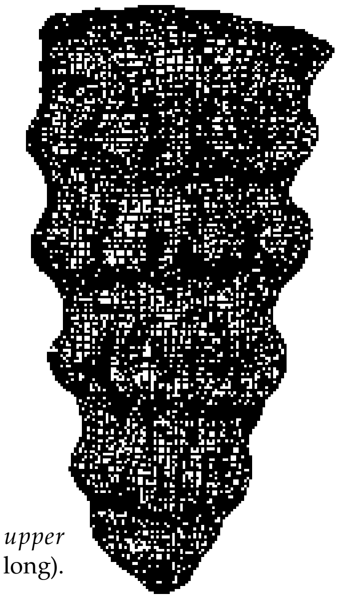


*Figure 4.10: Glass sponge, upper Devonian* Hydnoceras (16 cm long).

**Hypersaline marine environments** are preserved as ***evaporite*** deposits. Because ***hypersaline*** environments have higher than normal levels of salt, most organisms cannot survive. Unusually tolerant organisms generally inhabit these environments. ***Eurypterids***, or sea scorpions, were able to withstand the salty water and are well-preserved fossils in rocks of this environment *(Figure 4.11)*.

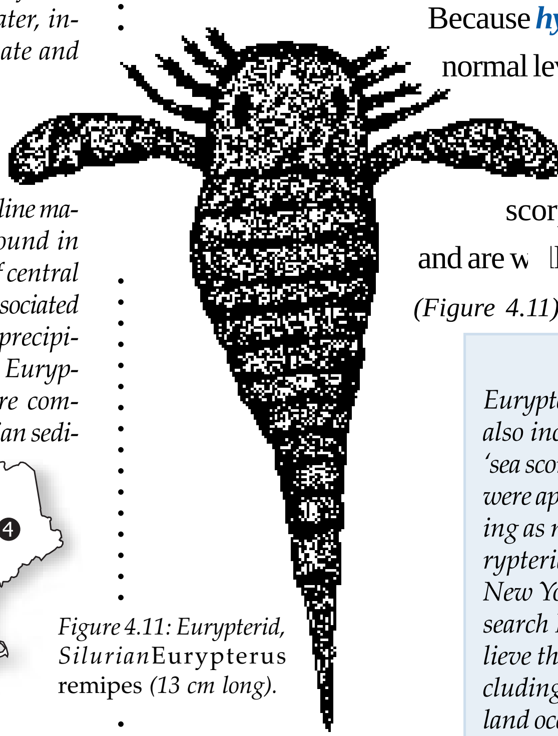


*Figure 4.11: Eurypterid, Silurian* Eurypterus remipes *(13 cm long).*

*EURYPTERIDS*

*Eurypterids are an extinct group of arthropods, the group that also includes horseshoe crabs. Though known by the name 'sea scorpions', they were not actually scorpions. Eurypterids were apparently one of the great predators of their time, reaching as much as 3 meters in length. The largest complete eurypterid in the world, about 1.3 meters long, was found in New York State and is on display at the Paleontological Research Institution in Ithaca, New York. Paleontologists believe that eurypterids lived in near shore environments, including salty, shallow sea environments like the Silurian inland ocean.*

**Intertidal and river environments** are often preserved as coarse grained sandstones and conglomerates. Rocks preserving these environments commonly contain plant fossils. When land plants first evolved in the Silurian, they were non-vascular, relatively small plants with only very tiny, hair-like roots, if any. Gradually plants began to evolve and diversify. ***Vascular*** plants became more common, leading to taller plants and larger, more extensive root systems. By the Devonian, woody matter from vascular plants is commonly found in the fossil record of the Northeast. The Gilboa forest, in mid-Devonian shales of Scoharie Creek Forest in central New York, contains fossilized tree stumps and is the oldest preserved ***forest***. More commonly, though, Devonian plant material is restricted to thin carbonized sticks.

*Early* **forests** *were composed of quite different types of plants than today's forests. For example, progymnosperms are a group of plants with spores rather than true seeds; those with two different forms of spores probably were the ancestors to gymnosperms. An important progymnosperm was* Archaeopteris, *a leafy tree of the late Devonian.*

*Rocks preserving* **intertidal, land,** *or* **river environments** *tend to be found close to the mountain range that existed on the eastern side of the inland ocean or associated with the deltas that formed as sediments eroded off the highlands.*

**Vascular** *plants have stiffer tissues that help support them and transport nutrients and water to all parts of the plant. This allows vascular plants to grow taller and further from water.*

***PROBLEMATICA***

*There exists a formal Latin name even for enigmatic fossil groups: problematica. Most Problematica are late Precambrian or Paleozoic organisms, all of which have become extinct and so provide no modern organism that would enable us to clarify their anatomy and genetics. Two commonly seen Problematica fossils in the Inland Basin sedimentary rocks are hyolithids (Figure 4.12), conical tubes with a shell covering; and tentaculitids (Figure 4.13), small, cone-shaped, ribbed shells. Both have been considered mollusks in the past, though hyolithids are believed by some to be a distinct phylum.*

*Figure 4.12: Hyolithid, mid-Ordovician (2 cm).*

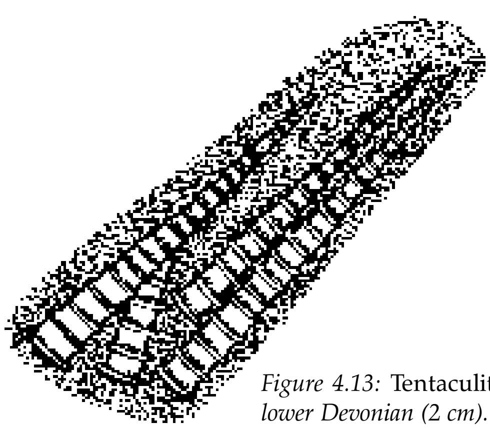
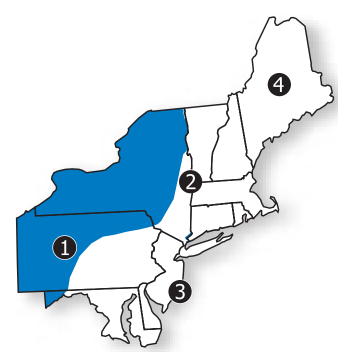
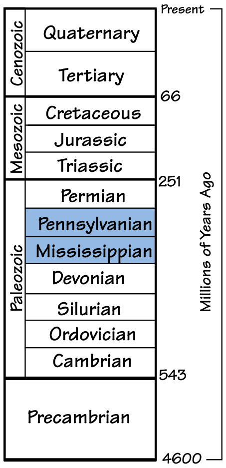


*Figure 4.13:* Tentaculites *lower Devonian (2 cm).*



## Mississippian and Pennsylvanian




*Plants can be tricky to reconstruct because their parts (wood, leaves, seeds) tend to break apart and are found separately. Usually each plant part gets its own Latin name. Careful analysis may enable putting a species back together, but there have been many cases in which several plant parts assumed to belong to very different groups of plants turned out to be the same species.*

Pennsylvania preserves one of the best-known Pennsylvanian-age plant communities in the world *(Figures 4.14-4.17)*. Large amounts of sediment were being rapidly eroded from the Acadian Mountains to the east, quickly burying plant material in coastal floodplain environments and creating oxygen-poor conditions that prevented the decomposition of organic matter. Plant and other non-marine fossils from the Mississippian and the early Permian are also present in Pennsylvania, but are far less extensive. Common Mississippian and Pennsylvanian plants include horsetails, ferns, seed ferns, and scale trees. These plants formed extensive forests in swampy areas along the edge of the inland ocean that led to the formation of coal deposits found in Pennsylvania and Maryland. Plants are not the only fossils recorded in the Pennsylvanian and Mississippian rocks of the Inland Basin, as the inland ocean still existed in much of the basin at this time. The plant fossils represent typical ferns, seed ferns, and horsetails, while the marine fossils represent typical Inland Basin brachiopods, cephalopods, clams, corals, and snails.

*Pennsylvanian-age horsetails reached over 30 meters high. Their stems are known as* Calamites *and their leaves are called* Annularia. *The modern horsetail equivalents are known as sphenopsids (Figure 4.14).*

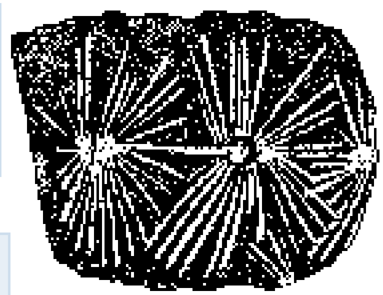


*Figure 4.14:* Annularia *leaf, Pennsylvanian (specimen 9.5 cm wide).*

*Scale trees (lycopsids) grew up to 45 meters high in Mississippian and Pennsylvanian forests. The roots of a scale tree are called* Stigmaria. *The entire tree is known as* Lepidodendron. *The modern scale tree equivalents are known as lubmosses or ground pines (Figure 4.15).*

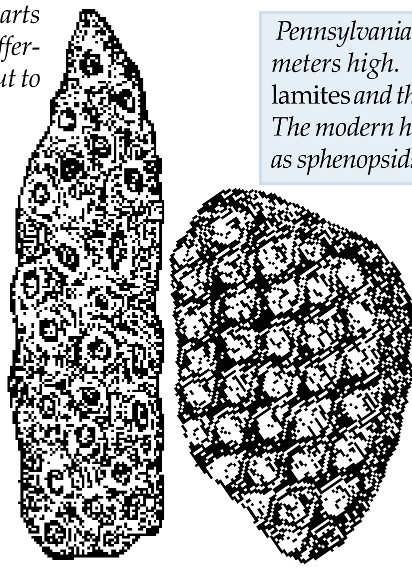
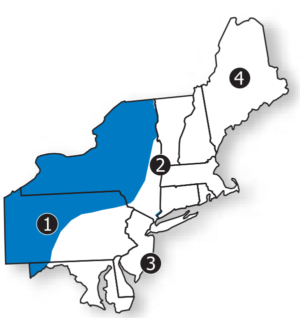


*Figure 4.15: LEFT ABOVE: Plant root,* Stigmaria, *Pennsylvanian (14 cm long); RIGHT: Lycopod* Lepidodendron, *bark with leaf scars, Pennsylvanian (10.5 cm wide).*

*see Non-Mineral Resources, p.156, for more on the formation of* **coal.**




*Seed ferns (pteridosperms) lived from the Mississippian to the Jurassic. The leaves (*Neuropteris*) resemble ferns, but have seeds instead of spores (Figures 4.16 and 4.17).*

*Figure 4.16: Seed fern plant,* Neuropteris, *Pennsylvanian (5.5 cm long).*

*Figure 4.17: Seed fern plant,* Alethopteris, *Pennsylvanian (8 cm long).*

# Fossils of the Appalachian/Piedmont

## *Region 2*

The Paleozoic fossils in the Appalachian/Piedmont region are generally the same as those of the Inland Basin because the rocks were originally sediments deposited along the same inland ocean. The rocks of the Appalachian/Piedmont, however, are in general more ***deformed*** structurally because they were closer to or part of the Taconic, Acadian and Alleghanian mountain-building events. Because of the deformation, the fossils in this region are less well preserved. The Triassic and Jurassic age Rift Basin fossils, however, are only found in the Appalachian/Piedmont and the Exotic Terrane region.

*see Fossils, p.84, for fossils of the Inland Basin.*

**When fossils are deformed:**

- *the carbonate in the shell material may recrystallize, often obliterating the original shape of the shell;*
- *they are often deformed in shape, which can be used by structural geologists to determine the amount and direction of stress;*
- *the sediments surrounding the fossil are sometimes altered so that it is more difficult to discern the type of environment in which the organism lived.*

### *Cambrian*

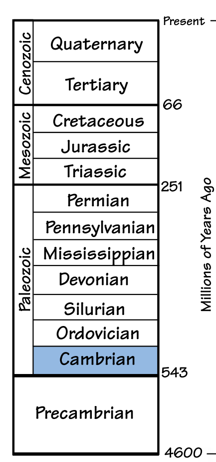
Cambrian rocks in the Appalachian/Piedmont record the erosion of sediment from the Grenville Mountains into the Iapetus Ocean. Early Cambrian fossils near Lancaster, Pennsylvania are among the earliest fossils found in Paleozoic rocks and in the entire Northeast *(See **LAGERSTATTEN** below.)* Western Vermont and northern New Jersey also have early Cambrian shale containing the trilobite *Olenellus*. Late Cambrian ***stromatolites*** are found in Washington County, Maryland and Bucks County, Pennsylvania *(Figure 4.18).*

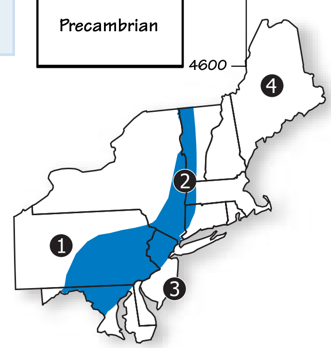
*Figure 4.18: Stromatolite, Cambrian (14.5 cm long).*

***STROMATOLITES***

*Stromatolites are layers of millimeter thick laminations that were once bacterial mats (full of photosynthetic cyanobacteria) at the surface of very shallow water. Cyanobacteria emit a sticky substance that binds settling clay grains and creates a chemical environment leading to the precipitation of calcium carbonate. The calcium carbonate then hardens the underlying layers of bacterial mats, while the living bacteria move upward so that they are not buried. There are still stromatolites today, but they form thick layers only in 'stressful environments', such as very salty water, that exclude animal grazers.*

*see Geologic History, p. 7, for more on the Cambrian.*




***LAGERSTATTE***

*A locality of Cambrian fossils near Lancaster, Pennsylvania, is an example of a lagerstatten. Lagerstatten are deposits containing animals or plants that are preserved unusually well, sometimes even including the soft organic tissues. Lagerstatten are important for the information they provide about soft-bodied organisms that we otherwise would know nothing about. Lagerstatten form in chemical environments that slow decay of organic tissues or enhance preservation through mineralization. Also, quick burial of the organism leaves no opportunity for disturbance of the fossils.*

## Ordovician to Devonian

see *Fossils*, p.85 for more on fossils that lived in **shallow marine environments**

There are some fossil-rich Ordovician and Silurian (and a few Devonian) sites in the Appalachian/Piedmont region, in spite of the deformation of the rocks from the various Paleozoic mountain-building events. For example, eastern Pennsylvania and western Vermont both preserve assemblages of brachiopods, trilobites, corals, bryozoans, clams, and other organisms typical of shallow marine environments.

## Triassic to Jurassic

see *Fossils*, p.97, for more on **rift basin fossils.**

The Appalachian/Piedmont has extensive outcrops of Mesozoic rocks, preserved in the rift basins that formed during the Age of Reptiles, when Pangea was breaking apart *(Figure 4.19)*. The sedimentary rocks preserved in the rift basins record the presence of dinosaurs in the Northeast. In particular, the extensive **dinosaur trackways** found in these rocks have become among the most publicly known fossils in the Northeast. Many of the small three-toed dinosaur footprints are known as *Grallator*, and were probably made by the late Triassic dinosaur known from the southwestern United States as ***Coelophysis***.

*Trace fossils receive Latin names independent of the species name of the organism that created them, largely because the species is not known with certainty. Apparent* **Coelophysis** *tracks in Nyack, New York, near New York City, are the only dinosaur fossils known from New York State.*

Some areas contain not only footprints, but also abundant freshwater fish, mollusks, and plant fossils such as cycads, ferns, conifers, and ginkos. A locality in Princeton, New Jersey, for example, contained hundreds of coelocanth (known in the fossil record as 'lobe-finned' fish) and small bony fish. In general, however, the Northeast rift valley deposits have relatively few vertebrate bone fossils compared to footprints.

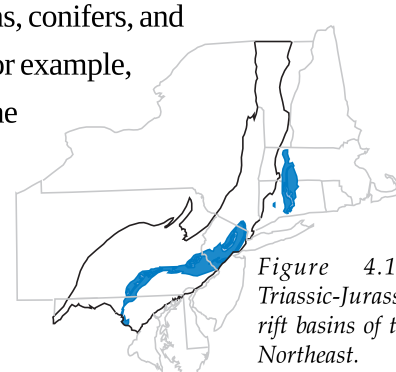
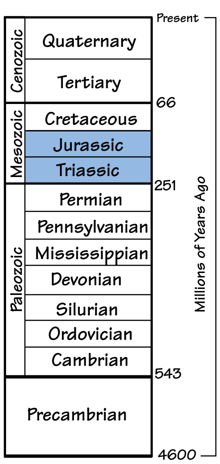
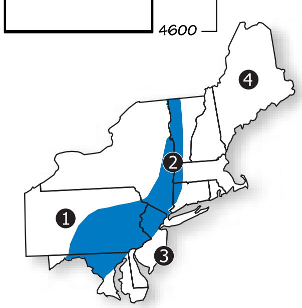


*Figure 4.19: Triassic-Jurassic rift basins of the Northeast.*




### The Age of Reptiles

*The Mesozoic Era is commonly known as the Age of Reptiles, a time dominated both on land and in the sea by large reptiles.* ***'Dinosaur'*** *technically refers to the group of land reptiles with a common ancestor and thus certain anatomical similarities, including long ankle-bones and erect limbs. At the same time as the dinosaurs, other reptile groups also became important: the pterosaurs, flying reptiles with wingspans up to 15 meters, and plesiosaurs, mosasaurs and ichthyosaurs, marine reptiles that were probably similar in size and habitat to toothed whales, dolphins and large sharks of today. Mammals, evolving from a group known as the 'mammal-like reptiles' that were a dominant land animal in the Permian and Triassic. Mammals appeared at roughly the same time as the dinosaurs in the mid-Triassic. Mammals, however, occupied only rodent-like niches until the dinosaurs went extinct. All the large reptile groups disappeared at or before the mass extinction at the end of the Cretaceous.*

# Fossils of the Coastal Plain
## *Region 3*

*see* Rocks*, p.46, for more on Coastal Plain sediments.*

*see* Fossils*, p.85, for more on* **corals.**

The Coastal Plain is underlain by a wedge of flat-lying Cretaceous and Cenozoic unconsolidated sediments. These sediments preserve striking evidence of how much sea life has changed from the Paleozoic to the Cenozoic. Fossils from the Coastal Plain are very different from the Paleozoic marine fossils found in the Inland Basin and Appalachian/Piedmont regions. The Coastal Plain sediments are especially rich in mollusks (**bivalves** and **gastropods**, and, in Cretaceous sediments, cephalopods). ***Shark teeth***, scleractinian corals *(Figure 4.20)*, barnacles, and sand dollars are also found in the Coastal Plain but are rare or absent in Paleozoic rocks. Brachiopods, so common in Paleozoic sedimentary rocks, are all but absent in the Coastal Plain.

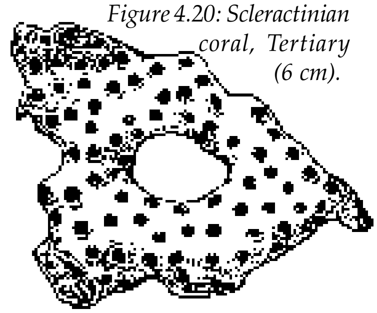


*Figure 4.20: Scleractinian coral, Tertiary (6 cm).*

### *Cretaceous*

Good outcrops of marine and non-marine Cretaceous fossils are found in New Jersey and famous outcrops along the Chesapeake and Delaware canals in Delaware. Outcrops with clams are common, especially including oysters such as *Gryphaea (Figure 4.21)*, in some cases creating small oyster 'reefs.' Snails, ammonoids, belemnites *(Figure 4.23)*, and claws of the shrimp *Calianassa* are common.

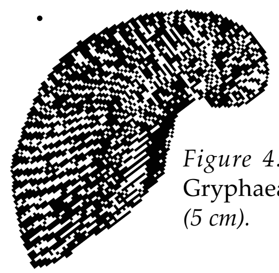
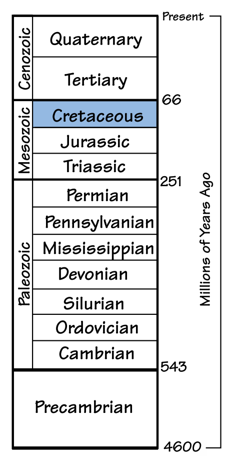


*Figure 4.21: Oyster,* Gryphaea*, Cretaceous (5 cm).*

Rare remains of dinosaurs and other terrestrial vertebrate organisms have also been found in the Cretaceous sediments of the Coastal Plain. Parts of marine reptiles, such as mosasaurs, giant crocodiles, plesiosaurs, bony fishes, turtles, lizards, snakes, and even a wing and neck bone from a pterosaur have been found in sediments in the Chesapeake and Delaware canals. Perhaps the most celebrated discovery was that of a duck-billed dinosaur known as *Hadrosaurus* in Haddonfield, New Jersey *(Figure 4.22)*. Discovered by John Hopkins in 1835, the bones did not receive much attention until pieces were sent to Joseph Leidy in Philadelphia, who determined that they were from a dinosaur that stood on its hind legs. This was America's first dinosaur skeleton find.



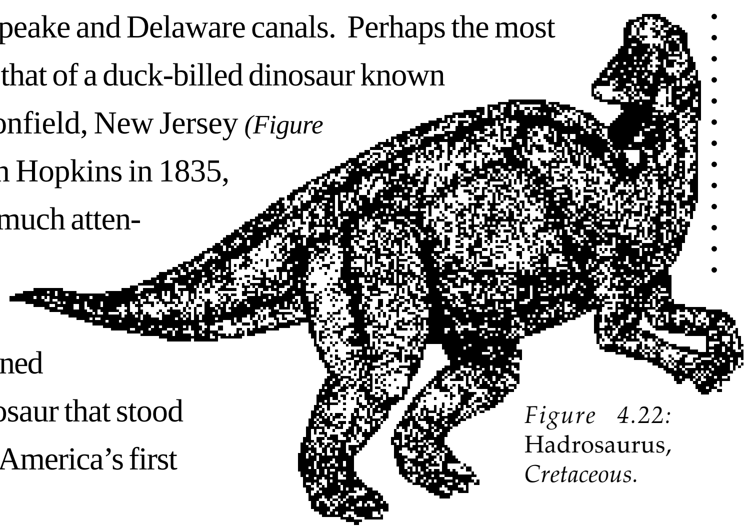
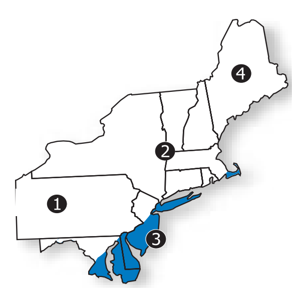



*Figure 4.22: Hadrosaurus, Cretaceous.*



# Fossils

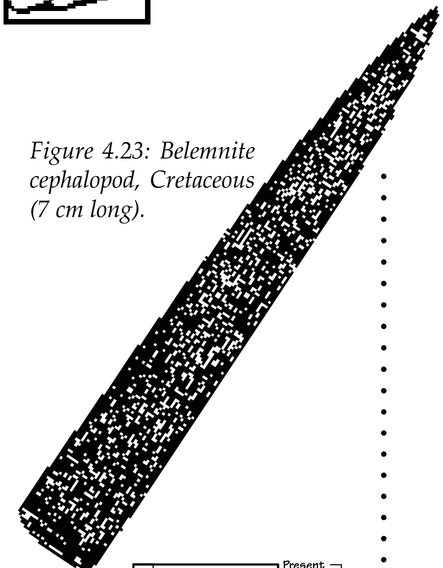
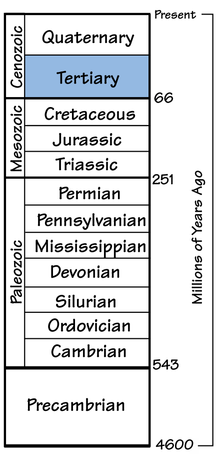


Figure 4.23: Belemnite cephalopod, Cretaceous (7 cm long).

### CEPHALOPODS

*Cephalopods are swimming predators with tentacles and a beak-shaped mouth that move using a jet of water. The group includes belemnites, nautiloids, ammonoids, squid and octopi. A mass extinction between the Cretaceous and Tertiary eliminated many varieties of cephalopods. The shells of cephalopods range from long straight cones to spirals, but some have internal shells or no significant shell at all, like the octopus. Early to mid-Paleozoic rocks of the Inland Basin preserve cephalopods, mostly nautiloids, but they are generally neither abundant nor well preserved. The* Nautilus *is the only living member of this group. Belemnites, bullet-shaped fossils related to squids, were common in the Cretaceous seas. Though belemnites are commonly found in Cretaceous sediments of the Coastal Plain, they did not survive past the Cretaceous. Ammonoids, with somewhat more complex chambering than nautiloids, first appear in Devonian-age rocks. They were especially successful in the Mesozoic, and went extinct at the end of the Cretaceous with the dinosaurs.*

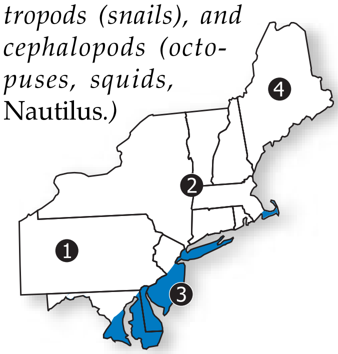



## Tertiary

The best-known fossil-rich sections of the Tertiary Coastal Plain deposits in the Northeast are at Calvert Cliffs in Maryland. ***Barnacles*** *(Figures 4.24)*, crab claws, sand dollars and ***bryozoans*** are present in relatively small amounts, in addition to the mollusks that characterize deposits in the Coastal Plain region *(Figures 4.25 and 4.26)*. Among the vertebrates found at Calvert Cliffs have been inner ear bones, teeth, and vertebrae of many species of whales and porpoises, shark teeth *(Figures 4.27)*, ribs, jaws, crocodile teeth, turtle remains, stingray spines and teeth, and skeletal elements of bony fish. There is only one species of ***brachiopod*** at Calvert Cliffs, an organism that had dominated the Paleozoic sea.

*see* Fossils, *p.85, for more on* **bryozoans** *and* **brachiopods**

*Mollusks are characterized by a muscular foot, calcareous shell, and rough, tongue-like organ called a radula. The group includes creatures as widely varied as bivalves (clams), gastropods (snails), and cephalopods (octopuses, squids,* Nautilus.*)*




### BARNACLES

*Barnacles are filter-feeding crustaceans, something like shrimps living upside down in a box. They are surrounded by calcareous plates and live attached to shells, such as the large* Chesapecten *shells found in Tertiary sediments of the Coastal Plain. It is sometimes possible to find them whole, often still attached to other shells.*

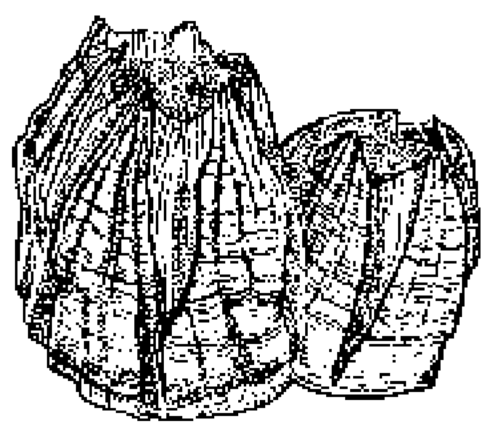
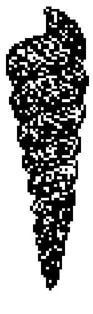


*Figure 4.24: Barnacles,* Balanus, *Tertiary (5 cm wide).*



### *GASTROPODS*

*Gastropods are known popularly as 'snails'. Unlike bivalves, gastropods have only one shell. The soft parts of gastropods are anatomically similar to bivalves, but the foot is made to crawl along the surface and the shell is usually coiled. Gastropods are only sometimes found in early and mid-Paleozoic sedimentary rocks of the Inland Basin, but are extremely common in the Cenozoic rocks of the Coastal Plain, and in Late Pleistocene glacial lake deposits and marine deposits in the Northeast.*

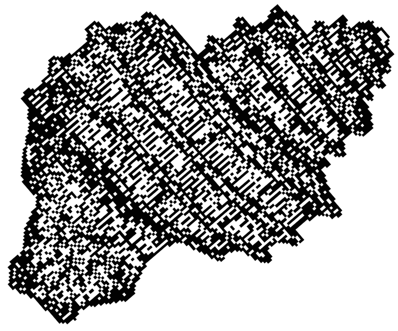
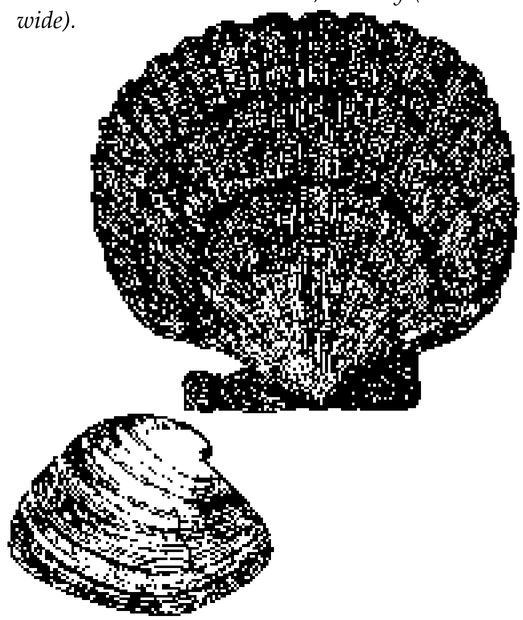


*Figure 4.25: Gastropods. ABOVE:* Ecphora, *Tertiary (6 cm long); FAR LEFT:* Turritella, *Tertiary (3.5 cm long).*

### *BIVALVES*

*Bivalves are often called clams, but they also include scallops, mussels, cockles and oysters. Bivalves have a protective pair of hinged valves and feed off particles in the water by collecting them with their gills. Bivalves are known as 'filter feeders'. During the Paleozoic, bivalves lived mostly on the surface of the ocean floor. In the Mesozoic, bivalves became extremely diverse and some evolved the ability to burrow into ocean floor sediments. Bivalves are the dominant fossils in the Cretaceous and Cenozoic Coastal Plain sediments. They are also common in late Pleistocene marine sediments, for example along the St. Lawrence Seaway and and submerged the coast of Maine and in smaller numbers in Paleozoic rocks of the Inland Basin and freshwater deposits of the Triassic rift basins.*

*Figure 4.26: Bivalves of the Coastal Plain. BELOW:* Chesapecten, *Tertiary (9.5 cm wide); BOTTOM LEFT:* Mercenaria, *Tertiary (7 cm wide).*



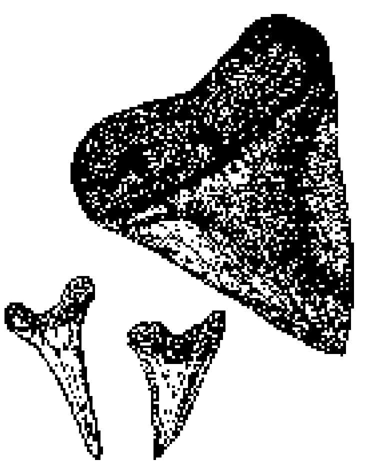


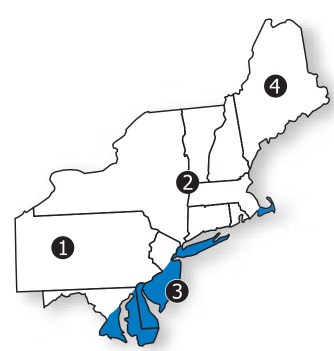
*Figure 4.27: Shark teeth from Tertiary sediments at Calvert Cliffs. TOP:* Carcharodocles *(7 cm long); BOTTOM: Tiger and sand shark teeth (~3cm long).*

### *SHARK TEETH*

*Shark teeth are one of the more common and prized fossils to come from Coastal Plain deposits. A good knowledge of how shark teeth vary both among sharks and in position within the mouth can often aid in identification. Among the shark teeth found in Tertiary Coastal Plain sediments in Maryland are teeth of the requiem, tiger, mako, angel and great white sharks. The fossil great white shark, or* Carcharocles megalodon, *is most famous for its enormous size, having teeth over 15 cm long. Since shark skeletons are cartilaginous, except for teeth and vertebrae, there has been considerable debate over the actual body size of* Carcharocles. *Even conservative estimates, though, suggest a body size well over 17 meters long, nearly twice the size of the living great white sharks.*

*Perfectly round holes of only a few millimeters in size can often be found in Cenozoic shells. Though the holes can be so regular in shape and position that they seem human-made, they are actually predatory bore holes. The most common bores are made by moon snails, which use both acid and their rough, tongue-like organ (radula) to drill their holes. The snails then extend their radula into the hole and suck out the soft tissues of their prey.*

*Preservation of fossils in Coastal Plain sediments is also very different from that in Paleozoic rocks. The sediments range from well consolidated and cemented Cretaceous layers to unconsolidated sands in the Tertiary. Shells are often very well preserved, and except for the absence of color, look much like modern shells. In some cases, especially for fossils in the late Tertiary, the species are the same as modern species. In fact, along cliff faces near the ocean, modern and ancient shells are often found together. Coastal Plain assemblages of fossils, however, tend to be different than modern shells in the same latitude, because many Cenozoic deposits contain species that lived in relatively warm water.*



# Fossils of the Exotic Terrane

## *Region 4*

Rocks of the Exotic Terrane region in general do not have preserved fossil communities because either they are metamorphosed sedimentary rocks or they are igneous rocks without fossil communities. Interesting exceptions occur in Paleozoic rocks, which include both fossils from the Ordovician onward, fossils from the accreted terranes, and fossils of organisms that lived in the Iapetus Ocean. Fossils after accretion of the terranes to the Northeast contain organisms that actually lived in the region and were not transported on the terrane.

### *Paleozoic*

Fossils as old as the Cambrian are known from the eastern Massachusetts ***Boston Basin*** and are preserved in rocks of the exotic terrane Avalonia. These rocks are believed to have originally been part of northern Africa, sutured to the side of North America during the Acadian mountain-building event. The fossil assemblages are like those in northern Africa but different from equivalent-aged fossils in North America. These fossil assemblages were among the earliest evidence for continental plate movement and exotic terranes.

Graptolites have been found in Ordovician rocks in Maine, possibly existing within the Iapetus Ocean. Silurian and Devonian fossils (which also existed in the Paleozoic inland ocean) are found in limestones from Maine and New Hampshire, including ***corals, crinoids, brachiopods, trilobites, bryozoans, bivalves,*** and ***tentaculids***. Devonian fossils in New Hampshire, though badly preserved in schist, include brachiopods. The Devonian plant fossil, *Pertica quadrifaria*, *(Figure: 4.28)* is preserved in parts of northern Maine, an area of the Exotic Terrane that experienced only weak metamorphism.

Pennsylvanian basins found in

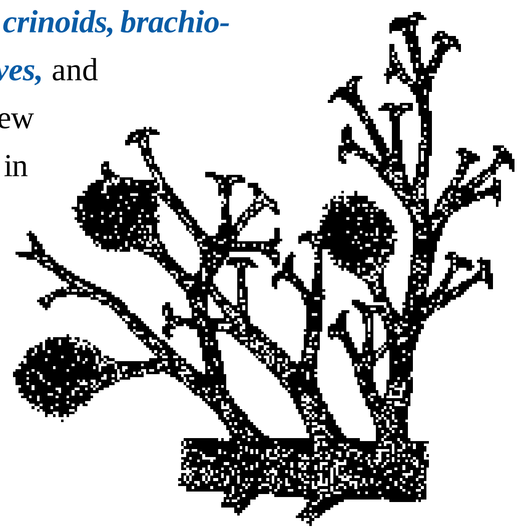
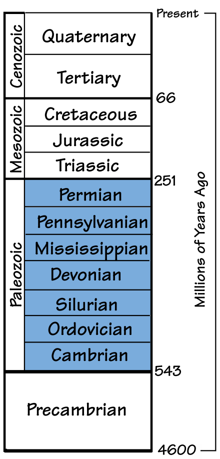


*Figure 4.28: Maine state fossil:* Pertica quadrifaria, *Devonian.*

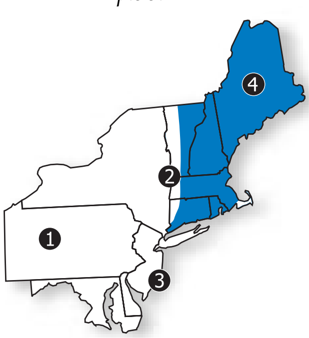



*see Geologic History, p.12, for more on the New England basins.*

*see Rocks, p.49 for more on the* Boston Basin

*Some species of trilobites* (Paradoxides) *found in the Boston Basin rocks of Braintree, Massachusetts are significantly larger than Inland Basin trilobites of the same age, averaging 30 cm long.*

*see Fossils, p.5, for more on* **these organisms;** *for* Bivalves, *see p.96.*



Rhode Island and Massachusetts contain a rich record of plant fossils, and rarer amphibian tracks, insects, and arachnids. These fossils are similar to those preserved in ***Pennsylvanian-age rocks*** in the Inland Basin, though in less extensive deposits.

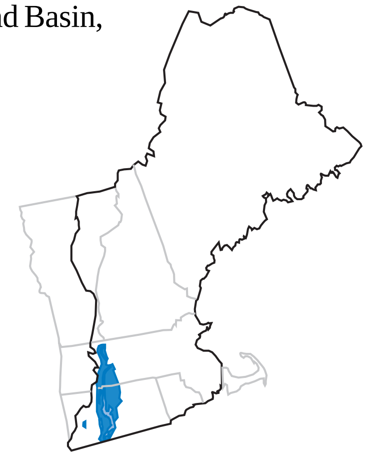


*Figure 4.29: Triassic-Jurassic rift basin in the Exotic Terrane.*

## *Triassic to Jurassic*

The western Massachusetts Connecticut River Valley, part of a Triassic rift basin *(Figure 4.29)*, is the site of Pliny Moody's 1800 description of *three-toed* dinosaur footprints, which he thought were made by a raven from Noah's Ark *(Figure 4.30)*. This was also the area of Edward Hitchcock's early to mid-1800's interpretation of hundreds of dinosaur tracks as bird footprints. At one locality in ***Connecticut***, the footprints are so numerous that a museum has been built over them. In some localities there have also been discoveries of dinosaur bones, fish *(Figure 4.31)* , crocodiles, and other vertebrates. One well-known discovery by a teenage fossil collector was of an unusual gliding reptile. However, as in the Newark and Gettysburg rift basins in the Appalachian/Piedmont, vertebrate bone fossils are rare compared to the numerous footprints.

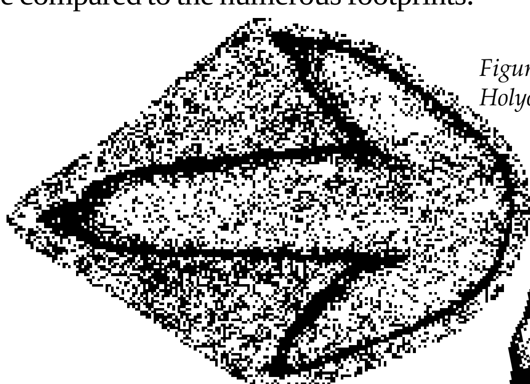


*Figure 4.30: Three-toed dinosaur track from Holyoke, Massachusetts (13 cm long).*

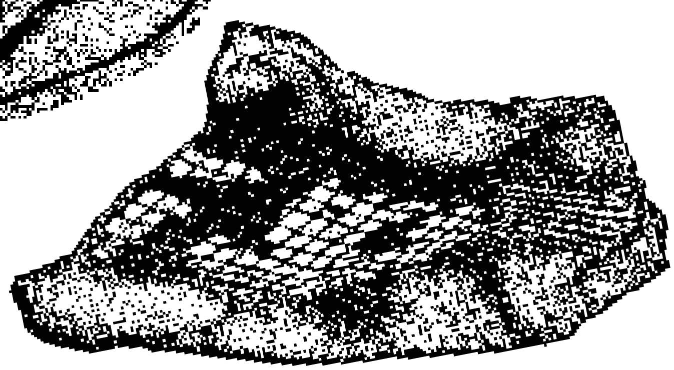


*Figure 4.31: Fish, Semionotus, Early Jurassic, Massachusetts (5.5 cm long).*

*see Fossils, p.92 for more on fossils found in* **Pennsylvanian-age rocks.**

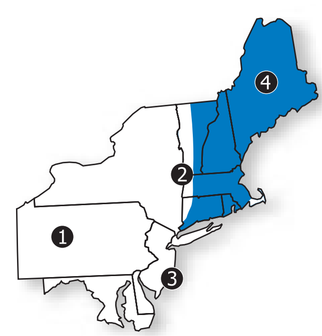
*see Fossils, p.92, for more on* **rift basin fossils.**

*Many three-toed footprints named* Grallator *are thought to have been made by the dinosaur* Coelophysis.

*Dinosaur State Park in Rocky Hill,* **Connecticut** *was established where the rift basin dinosaur trackways are particularly numerous.*

### Where did the dinosaurs go?

*Based on considerable geochemical and mineralogical evidence, many scientists have concluded that the Cretaceous-Tertiary boundary extinction was caused by a meteorite impact leading to the demise of the dinosaurs. In this scenario, a worldwide layer of dust was created by the impact, blocking out sunlight long enough to destroy the food chain and causing other ecological problems. The large reptiles disappeared, as well as significant numbers of ma-*



# Ice Age Fossils

## *in Pleistocene deposits of the Northeast*

*see Glaciers, p.57*

Pleistocene deposits are like frosting over the rest of the geological layer cake. They follow mostly from Pleistocene climate and topography, so are in general less tightly controlled by bedrock than some other phenomena. Most terrestrial fossil remains are found either in ponds dating from the receding of previous glaciers or isolated teeth or bone fragments in glacial till. Some important faunas, however, are preserved in Pleistocene caves.

*One Maryland cave contained Pleistocene remains of vertebrates from a spectrum of climates:*

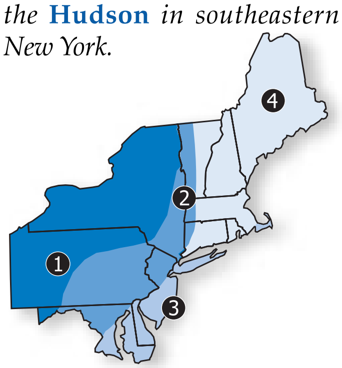
*Pleistocene mammals representing **northern climates** included wolverine, lemming, long-tailed shrew, mink, red sqirrel, muskrat, porcupine, jumping mouse, pika, hare, and elk.*

*Pleistocene animals representing **southern climates** included bats, peccaries, tapirs, crocodiles.*

*Pleistocene animals representing an **intermediate climate** included: horses, coyotes, badgers, several species of bears, otters, pumas, beavers, smaller rodents, mastodons, and deers.*

*see Glaciers, p.61, for more on ice-margin deposits.*

*Over 100 mastodons have been recovered from Orange County, NY, which sits on the west side of the **Hudson** in southeastern New York.*




### *Terrestrial and Lake Fossils*

Caves are an example in which the underlying geology, generally limestone, influences the Pleistocene record. Cave faunas are not terribly common in the Northeast, but are very important in some other areas of the country where caves are numerous. Important examples in the Northeast include a cave in Montgomery County, southeast PA, which produced a large number of glacial age mammals, described by Edward Drinker Cope (more famous for his dinosaur descriptions), inluding a species saber tooth cat, a small species of black bear, and the sloth *Megalonyx*. Another Pleistocene cave formed from Devonian limestone in Allegheny County, Maryland, included a wide range of mammals representing both ***northern*** and ***southern climates***, as well as those of more ***intermediate climates***, suggesting a biogeographic transitional zone in which the climate had fluctuated.

Important and extensive freshwater and terrestrial remains occur in the innumerable pond sediments (not in the least lithified into rocks) left behind after retreat of the last glaciers. These ponds are well known from areas that were covered with ice and glacial sediment, especially kettles that formed along moraines and other ***ice-margin deposits.*** The ponds with large vertebrate remains are not randomly distributed, but can be clustered around well-known drainage systems, such as along the ***Hudson*** River Valley. Since such pond sediments are not surface outcrops, and since there is no foolproof technology for searching for bones under the sediment, most skeletons turn up during construction or pond alteration rather than through systematic searches for remains. Large vertebrate remains include mastodons, mammoths, giant beavers, peccaries, tapirs, foxes, bears, seals, deer, caribou, bison, and horses.

Nearly all glacial-age ponds contain a rich fossil record beyond vertebrates. In a typical pond, the first sediment to fill up the pond is fine-grained clays, followed later by organic-rich clays due to sedimentation of plant fragments as plant communities started to colonize the area after the glaciers had retreated. These clays often have plentiful late Pleistocene small freshwater mollusks, small pieces of fossil wood, and pollen, increasing as the plant community increased. The topmost sediment is often very late Pleistocene or Holocene peat, essentially pure plant matter made of innumerable tiny sticks and larger branches, leaves, cones, and other plant material. Since pollen shapes are indicative of the kinds of plants they come from, the pollen record can give a rather detailed account of how vegetation moved into the area as climate changed.

***MASTODONS & MAMMOTHS***

*Among the most common Pleistocene vertebrate fossils in the Northeast are those of mastodons and mammoths. People frequently confuse these two kinds of ancient elephants (or, more technically, proboscideans). Both were common in the Northeast in the Pleistocene, but they had different ecological preferences and are usually found separately; mastodons (Figure 4.32) are by far the more common of the two in most areas of the Northeast. Mammoths are from the same line of proboscideans that gave rise to African and Asian elephants; mastodons are from a separate line of proboscideans that branched off from the modern elephant line in the Miocene. In body proportions mastodons have a shorter, stockier build and longer body; mammoths are taller and thinner, with a rather high "domed" skull. In skeletal details, the quickest way to tell the difference is with the teeth: mastodons have teeth with conical ridges, a bit like the bottom of an egg carton; mammoths, in contrast, have teeth with numerous parallel rows of ridges. The teeth are indicative of the ecological differences: Mastodons preferred to bite off twigs of brush and trees, for example from spruce trees, while mammoths preferred tough siliceous grasses, thus mastodon teeth are more suitable for cutting, while mammoth teeth are more suitable for grinding (Figure 4.33).*

*Figure 4.33: A mastodon tooth, suited for cutting twigs of spruce trees.*

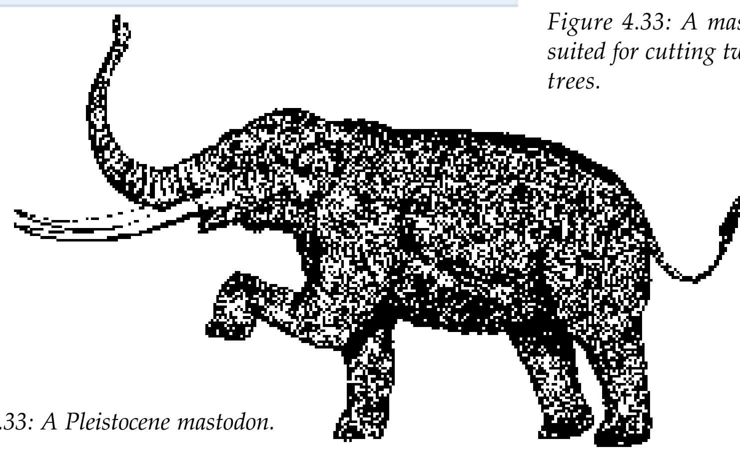
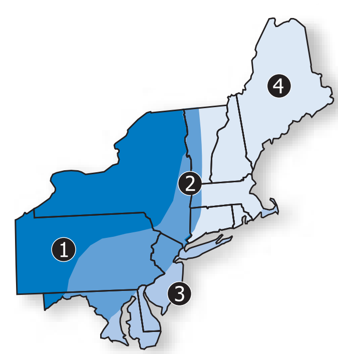


*Figure 4.33: A Pleistocene mastodon.*

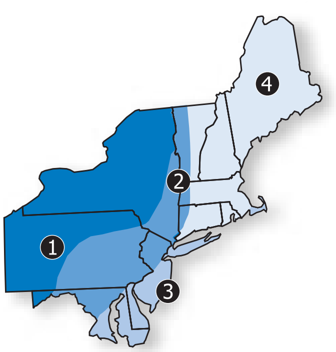
*One of the most complete and best preserved* **mastodons** *recovered to date in the Northeast was excavated by the Paleontological Research Institution in late summer, 2000. It was found when a family in a suburban neighborhood, in Hyde Park near Poughkeepsie, NY, was deepening their backyard (glacial-age) pond. Other mastodons have been found near Rochester, Buffalo, and Albany, New York, and Amherst and Cambridge, Massachusetts (just to name a few.)*



*see Glaciers, p.65, for more on rebounding crust.*

*The Charlotte beluga whale can be seen in the University of Vermont's Perkins Museum of Geology. Today about 500 beluga whales live in the Gulf of the St. Lawrence.*

*Other common fossils in the* **Champlain Sea** *include marine clams that today can be found living in cool Atlantic and Arctic Ocean waters. Other invertebrates include barnacles, gastropods, and sponges. A number of species of marine fish have been found as fossils, such as the Atlantic cod, which on the whole are most similar to fish in the southern coast of Labrador today. Several species of seals that breed on sea ice have been found, such as the harp seal, bearded seal, and ringed seal.*




## *Marine Fossils*

One can visit places in the Northeast where sea level rise outpaced the rebounding continental crust after meltback of the glaciers, flooding lowlands such as areas of Massachusetts and along the St. Lawrence Seaway. The Champlain Sea refers to an ocean bay that filled most of the Ottawa-St. Lawrence-Lake Champlain basin about 11,000 to 8,000 years ago. The fossils from these sediments are so recent that most or all are represented by living populations today, but mostly in more northerly, cooler locations. Lowland areas of the coastline in southern Maine are covered with glacial marine clay dating to about 11,000 years ago that also contain marine bivalves and other marine invertebrates.

The most celebrated fossil from the ***Champlain Sea*** deposits has been the '***Charlotte whale***,' a specimen of the modern beluga whale, found in Chittendon County, Vermont in 1849 by workers digging a railroad. Though initially shocked to find whale remains so far inland, it eventually became apparent that the whale had come down the St. Lawrence Seaway at a time that this area had been flooded with sea water. The Champlain Sea extended into New York, where a fossil beluga whale was also discovered in 1987. Other whale remains found have included the harbor porpoise, humpback whale, finback whale, and bowhead whale.

### How old does it have to be?

*Fossils are any evidence of ancient life, whether shell, its imprint, or the trace made by a moving animal. Dictionary definitions often suggest that fossils are such remains greater than 10,000 years old. Popular conception holds that some process, such as permineralization (infilling of cavities and replacement by minerals), must occur for an object to be considered a fossil. The latter is not true — Pleistocene shells and bone materials are frequently nearly indistinguishable from modern material, except in some cases through color changes, such as by leaching of color or staining from tannins and iron in the sediment. The former (10,000 years) may be true by definition, but is only a practical guideline. Those studying successions of plant or animal remains since the last glaciation, from 20,000 years ago to the present, would not recognize any sudden change in the material at 10,000 years, and would typically refer to all material buried in sediments as fossil material. A compromise is to call younger material "subfossils," especially if they are in sediment that is still prone to movement by currents and burrowing organisms (as in surface sediment in shallow aquatic environments).*

# State Fossils
## *of the Northeast*

The state fossils tell the geologic history of the Northeast in their own way *(Figure 4.34)*. New York and Pennsylvania are dominated by Paleozoic sedimentary rocks from the inland ocean and their state fossils, a eurypterid and trilobite, reflect this history. Because of its preservation in only the salty shallow sea deposits of the Silurian, the eurypterid in particular is testimony to the rise and fall of sea level in the inland ocean during this time. Northern Maine, which was only weakly metamorphosed during the mountain-building events of the Paleozoic, preserves the Devonian fossil plant, *Pertica quadrifaria*. This rare fossil was first discovered in Maine and reflects the vascularization and diversification of plants during this period in geologic history. New Jersey, Connecticut and Massachusetts all have dinosaur footprints as their state fossil. Not surprisingly, the rift basins of the Northeast that preserve Mesozoic sedimentary rock in which one might be able to find dinosaur fossils or traces, cut through each of these states. Cretaceous belemnites, the state fossil of Delaware, are preserved in abundance in Delaware Cretaceous sediments, indicative of the change in sea life since the Paleozoic. Gastropods from the Tertiary, found at the famous fossil-collecting location, Calvert Cliffs, Maryland, are the state fossil of Maryland. The beluga whale from late Pleistocene deposits of the Champlain seaway is the state fossil of Vermont. Buried in sediment when the ice sheet retreated and Lake Champlain was flooded by ocean water, the whale is a spectacular reminder of the relatively recent ice age history of the Northeast.

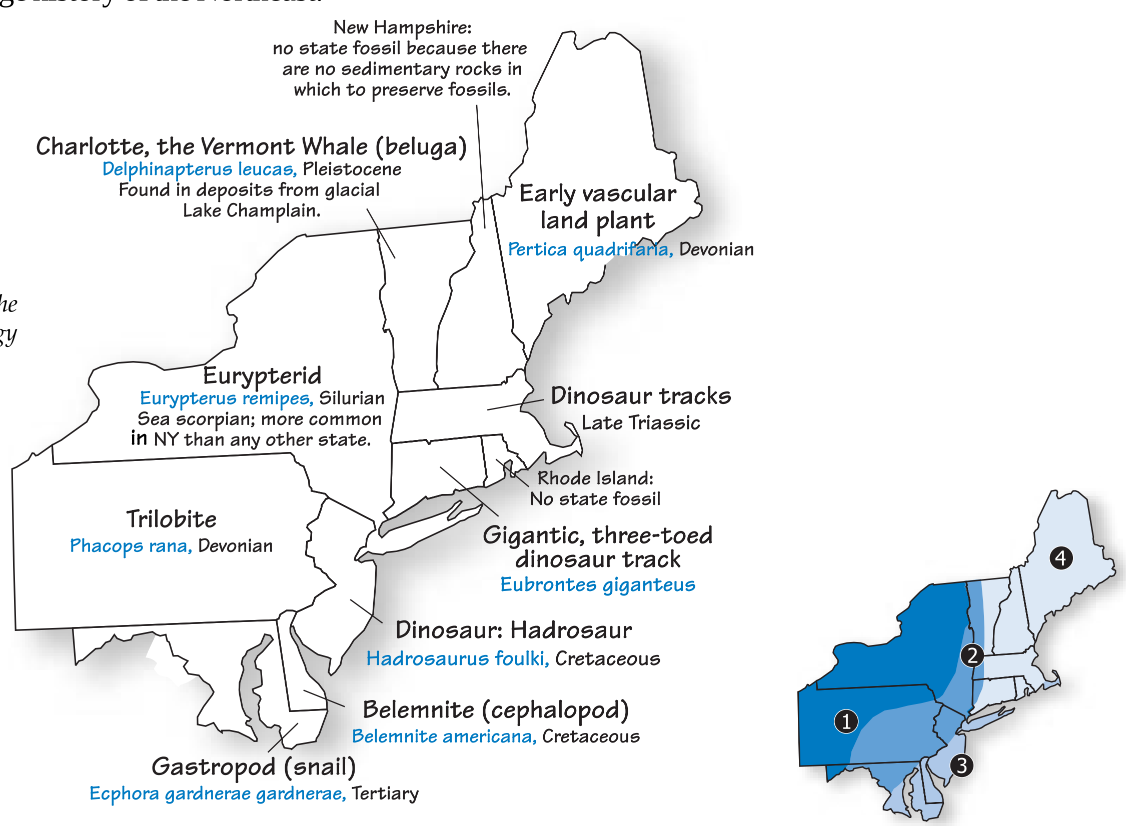



*Figure 4.34: State fossils of the Northeast reflect the geology of the region.*

# Activities

1. A bizarre new competition among avocational paleontologists involves racing to collect representative fossils of a set taxonomic groups. You can start anywhere in the northeast, you can collect the fossils in rocks of any age, and you mustn't exceed the speed limit. This means to win you have to be efficient about your route and know where to go. You must find the following:

| | | | |
|---|---|---|---|
| 100 bivalves | 100 trilobites | 5 crinoids | 5 stromatolites |
| 100 gastropods | 100 brachiopods | 5 blastoids | 5 barnacles |
| 100 cephalopods | 100 bryozoans | 5 cystoids | 5 shark teeth |

*A local natural history museum sponsors you with a driver and travel funding. Make a plan to enter the race. Give the route you would take that would make it likely you could find enough of each of these organisms quickly. Given highway speed limits, collecting 10 hours/day, how much time do you think it would take to collect these fossils? Explain your assumptions and calculations. What factors would influence this time?*

2. Nova, the Public Broadcasting System science documentary specialists, hear that you won the race. They like the action of the race, but had been planning to create a movie on the history of life. Thus they wish to sponsor another race, this time collecting the organisms sequentially through geologic time rather than solely by kind of animal.

*Explain how you would change your route to collect fossils from oldest to youngest. In this race, one must find just <u>one</u> specimen of each of 3 kinds of fossils from the list in part (1) for each geological period in order from the Cambrian to the Quaternary. How fast could you do it? How do these fossils fit into the following geologic events?*

(1) the Grenville passive margin
(2) the Taconic converge,
    (2a) interval (Silurian-Early Devonian) between Taconic and Acadian
(3) the Acadian convergence,
    (3a) interval (Mississippian-Early Permian) between Acadian and Alleghenian
(4) the Alleghenian convergence,
    (4a) interval (Early-mid Triassic) between Alleghanian and rifting
(5) the rifting apart of Pangea, and
    (5a) interval (mid-Jurassic-late Jurassic) between rifting and creation of Coastal Plain
(6) the Coastal Plain passive margin and shaping by erosion of many of current land-forms
(7) Pleistocene glaciation and Holocene post-glacial

3. Given your new celebrity status, the local fossil club calls you to give a talk on the history of life from the local area, based on fossils. You patiently explain that this isn't possible with fossils, because no one place has anywhere near a complete record. However, you can guess what happened, since missing rock sometimes indicates the presence of land environments, and these land organisms may have been recorded elsewhere. You promise to give them a presentation about this.

*Write a script for a nontechnical talk, giving your estimation of the history of life (the land and sea) in your neighborhood. Point out what we know from local fossils and what we know from elsewhere. Choose illustrations for your talk.*

# For More Information...

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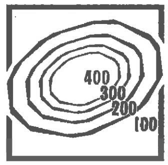
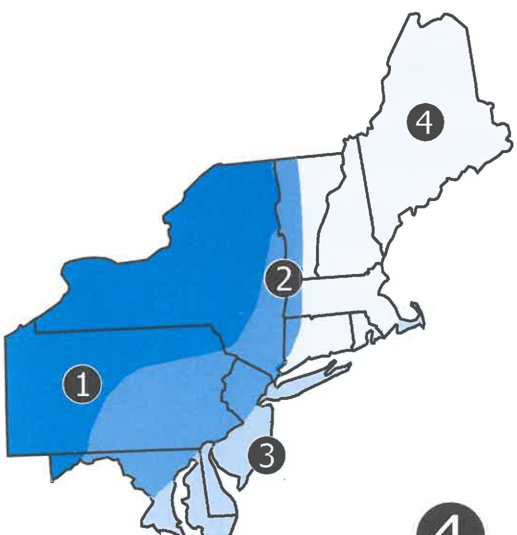
**Special thanks to Rob Ross for providing the content for this chapter, and to Paul Krohn for the fossil illustrations.*

# Topography of the Northeastern US:
## *the BIG picture*




### ❶ Inland Basin

*The Allegheny Plateau dominates the Inland Basin topographically. The Plateau is deeply dissected by many streams, eroding through the bedrock to create relief throughout the area. The rugged peaks of the Adirondacks, composed of uplifted Precambrian rock, tower above the surrounding Lowlands of Lakes Ontario and Erie, and the St. Lawrence and Mohawk Rivers.*




### ❷ Appalachian/Piedmont

*Traditionally, the Appalachian/Piedmont region is divided into the Valley and Ridge Province, characterized by distinctive long, narrow ridges and valleys; the Precambrian ridges, which make up the rugged Precambrian rock core of the Appalachians and includes the Blue Ridge province of Pennsylvania and Maryland; the Triassic Rift Basins, formed as Pangea ripped apart; and the Piedmont, an area of rolling hills at the foot of the Appalachians. Within these divisions lie other distinctive topographic features, such as the Great Valley that extends nearly the entire length of the region, and the Taconic Mountains, pushed to their present position from the east when a volcanic island arc collided with the continent in the early Paleozoic.*

### ❸ Coastal Plain

*Topographically, the Coastal Plain is a relatively flat region. Underlain by a wedge of unconsolidated sediments deposited over the last 100 million years (which is recent in geologic time), the Coastal Plain is easily eroded and remains fairly level, with a slope of less than one degree.*

### ❹ Exotic Terrane

*The Exotic Terrane region is known as the New England Uplands because of the dominance of north-northeast trending mountainous and hilly terrain in the region. Resistant metamorphic Silurian and Devonian rocks dominate the region, cross cut by intrusions and volcanic rocks from the Taconic and Acadian mountain-building events. There are a few notable exceptions to the general highland nature of the region, including the Boston and Narragansett Basins, the Connecticut Valley Rift Basin and the New England Coastal Lowlands.*

# Topography of the Northeastern US: *a brief review*

Does your region have rolling hills? Mountainous areas? Flat land where you never have to bike up a hill? Topography is the change in elevation over an area. The topography of the Northeast is intimately tied to weathering and erosional forces, and the type and structure of the underlying bedrock.

***Weathering*** includes both mechanical and chemical processes that break down a rock. Wind and water in all forms, including streams, the ocean, and ice, are all media by which physical weathering and ***erosion*** occur. Streams are constantly trying to erode their way down through bedrock to sea level, creating valleys in the process. With sufficient time, streams can cut deeply and develop wide flat floodplains on the valley floor.

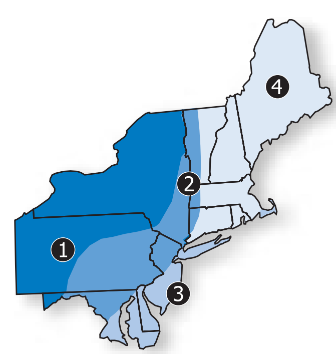
*__Weathering__ is the break down of rocks; __erosion__ is the transport of weathered materials.*

The pounding action of ocean waves on the coastline contributes to the erosion of coastal rocks and sediments. Ice plays a major role in the weathering and erosion of the Northeast landscape because of the frequent episodes of ***freezing*** and ***thawing*** in temperate latitudes. On a small scale, as water trapped in fractures within the rock freezes and thaws, the fractures widen further and further. This alone can induce significant break down of large rock bodies. On a larger scale, ice in the form of glaciers in mountain valleys and continental ice sheets can reshape the surface of a continent.

*see Glaciers, p.60 for more on* **freeze-thaw** *fracturing.*

Working in conjunction with mechanical weathering, chemical weathering also helps to break down rocks. Some minerals of igneous and metamorphic rocks that are formed at high temperatures and pressures, far below the surface of the Earth, become unstable when they are exposed at the surface where the temperature and pressure are considerably lower, especially in contact with water. Unstable minerals are altered to more stable minerals, which in the process results in the breakup of rock. Weak acids, such as carbonic acid found in rainwater, promote the disintegration of certain types of rocks. Limestone and marble may be rapidly broken down chemically as carbonic acid reacts with the carbonate mineral composition of these rocks, forming cavities and caverns in the rock. Other sedimentary rocks held together by carbonate cement are also particularly sensitive.

Rock type at the surface has an important influence on the topography

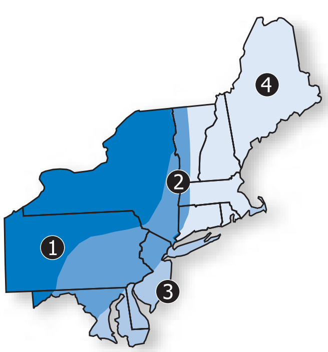


of a region. Certain rocks are able to resist weathering and erosion more easily than others; resistant rocks that overlie weaker layers act as caps and form ridges. The inland ocean basins of the Ordovician Taconic and the Devonian Acadian mountain-building events collected and preserved sediments that became sedimentary rocks. Sedimentary rocks weather and erode differently than crystalline, generally harder igneous and metamorphic rocks that are more common in the Exotic Terrane and Appalachian/Piedmont region. Silica-rich igneous rocks have a crystalline nature and mineral composition that resists weathering far better than the cemented grains of a sedimentary rock. The metamorphic equivalents of sedimentary and igneous rocks are often more resistant due to ***recrystallization***. However, there are exceptions, such as schist, which is much weaker than its pre-metamorphism limestone or sandstone state. The unconsolidated sediments of the Coastal Plain region, which are not even yet considered rocks, are the least resistant to erosion. The Coastal Plain sediments have little cement, compaction, or interlocking crystals to stand up to the effects of wind, oxygen, and water.

**Recrystallization** *refers to the change in mineral crystals that make up rocks. When rocks are metamorphosed, recrystallization often occurs as the pressure allows crystals to grow larger into a tighter, interlocking arrangement.*

The underlying structure of the rock layers also plays an important role in the topography at the surface. Sedimentary rocks are originally deposited in flat-lying layers on top of each other. Movement of the plates creates stress and tension within the crust, especially at plate boundaries, which often deform the flat layers by folding, faulting, intruding or overturning. These terms are collectively used to describe rock structure and can be used to interpret what forces have affected rocks in the past. The folding of horizontal rock beds followed by erosion and uplift expose layers of rock to the surface. Faulting likewise exposes layers at the surface to erosion, due to movement and tilting of blocks of crust along the fault plane. Tilted rocks expose underlying layers. Resistant layers stick out and remain as ridges, while surrounding layers of less resistant rock erode away.

The glacial ice sheet of the most recent ice age covered part of the region, leaving its mark on the topography of the Northeast. Glaciers carved away at the land's surface as they advanced generally southward, creating many classic glacial U-shaped valleys and characteristic glacial depositional features such as drumlins and moraines. Mountains were sculpted, leaving high peaks and bowl-like cirques. As the ice sheet melted, other characteristic glacial features were left



behind to mark its former presence, including glacial lakes and eskers.

Just as we were able to make sense of the type of rocks in an area by knowing the geologic history of the region, we are able to make sense of the topography of the Northeast based on the rocks and structures resulting from past geologic events.

*see Glaciers, p.60, for more on the scouring and deposits of glaciers.*

# Topography of the Inland Basin
## *Region 1*

The Inland Basin has three main topographic divisions: the ***Allegheny*** Plateau, the Adirondacks and the Lowlands *(Figure 5.1)*. The existence of the basin itself is due to the downward buckling of the crust at the onset of the Taconic and Acadian mountain-building events. What makes the Inland Basin distinct from the other regions of the Northeast are the structure and nature of the sedimentary rocks that fill the basin. Unlike the Appalachian/Piedmont region or the complexly deformed Exotic Terrane region, the surface rocks of the Inland Basin have been gently tilted and folded, and were far enough removed from the mountain-building events to have escaped being metamorphosed. The exception to this pattern is the ***Adirondack region***, where uplift independent of the Paleozoic mountain-building events raised bedrock metamorphosed during the late Precambrian to the surface as erosion removed the overlying Inland Basin sedimentary layers.

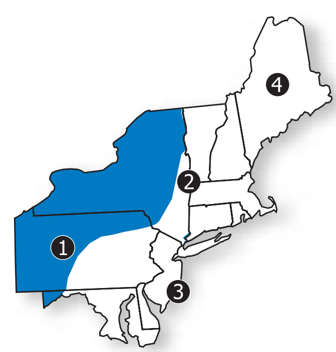
***'Allegheny'** refers to the plateau or front; 'Alleghanian' refers to the mountain-building event.*


*Figure 5.1: Generalized topographic divisions of the Inland Basin.*

*see Rocks, p.32 for more on the rocks of the* **Adirondack region**.

### *Allegheny Plateau*

The Allegheny Plateau dominates much of the Inland Basin region, extending from the southern tier of New York through Pennsylvania and Maryland to Alabama *(Figure 5.1)*. The layers of rock within the plateau have been only gently folded and tilted slightly to the south during the final mountain-building event during the Permian. A drive through the Allegheny Plateau region reveals a landscape contrary to the common concept of a plateau as an



elevated flat-topped region. The Allegheny Plateau was probably flat, but since its uplift 400 million years ago it has been deeply dissected by streams, making the area quite hilly and in some places even mountainous in appearance. The Plateau is bounded on the eastern side by the Allegheny Front, a scarp separating it from the Appalachian Mountains.

*The Shawangunks, or 'Gunks' as they are locally known, are famed for being the best rock climbing spot in the Eastern United States.*

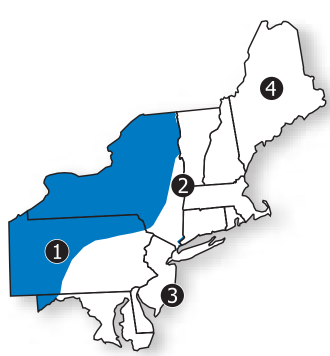
The scarp includes the white cliffs of the ***Shawangunk*** Ridge that extend southwest from the Hudson River into New Jersey and Pennsylvania, where it is known as Kittatinny Mountain. The Catskill ***Mountains*** form the eastern boundary of the Allegheny Front in New York. They are often called one-sided mountains because there is a steep scarp on the eastern side, but the west side has a gentle slope that grades more gradually into the surrounding provinces. The layers of rocks forming the Catskills are the Devonian sedimentary beds of the Catskill Delta, created during the Acadian mountain-building event as sediment eroded from the Acadian highlands. The mountains are thus unusual, as the rocks are flat lying and the relief over the area comes from deep erosion of the flat-lying layers. The elevation in the Catskills is much higher than other parts of the Allegheny Plateau because of the thicker sequences of sediments deposited on the eastern side of the Catskill Delta (closer to the Acadian highlands) and erosional differences by glaciers during the last ice age.

*The Catskills are not considered by some to be technically* **'mountains'** *because of the underlying layers of rock lack deformation.*

*The highest point in the Catskills is over 914 m above sea level.*

The Paleozoic sedimentary rock layers of the basin, tilted just a few degrees to the south, form many of the east-west ridges that stretch across New York. These gentle ridges are called cuestas, formed from the more resistant layers of tilted rocks, while the softer surrounding rocks have eroded away *(Figure 5.2)*. The tilting most likely occurred during the Permian ***Alleghanian*** mountain-building event, the final crunch on the east coast of North America.

*see Geologic History, p. 14, for more on the* **Alleghanian** *event.*



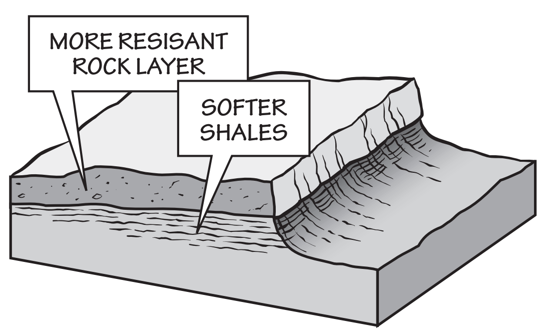




*Figure 5.2: A cuesta ridge is formed from a resistant layer of gently tilted rock.* Figure by J. Houghton.

### The different looks of different mountains

*A mountain may be formed from any rock type and a variety of underlying structures. The type of mountain that we see today all depends on the amount of erosion, the resistance of the rock, the structure of the rock layers and the events occurring in geologic history that formed the mountains. There is a wide variety of mountains throughout the Northeast that formed in diverse geologic situations relating to the geologic history of the region (Figure 5.3).*

| Mountains | Location | Origin |
|---|---|---|
| The Catskills | New York | erosion of flat-lying rock layers |
| Kittatinny Mountain/ (Shawangunks) | PA, NJ, NY | hogback/cuesta formed from resistant conglomerate |
| Green Mountains | Vermont | resistant Precambrian gneiss |
| White Mountains | New Hampshire | igneous intrusions |
| Mt. Katahdin | Maine | exposed volcano magma chamber |
| Taconics | NY, VT, MA, CT | slices of resistant metamorphosed Cambrian rocks, stacked on top of each other and moved west |
| Bolton Range | Connecticut | resistant Ordovician volcanic rocks originating fromTaconic volcanic islands |
| Adirondacks | New York | Precambrian resistant rock, uplifted during the Tertiary |

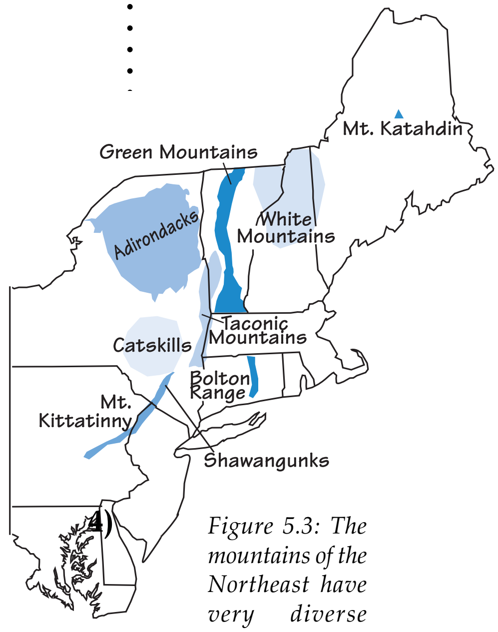



*Figure 5.3: The mountains of the Northeast have very diverse origins.*

## *Adirondacks*

The Adirondacks loom high over the surrounding lowlands *(Figure 5.4)*. Uplifted during the late Mesozoic and Tertiary, much of this mass of crystalline metamorphic Precambrian rock is extremely ***resistant*** to erosion. The surrounding lowland rocks are considerably less resistant and are made of much younger sedimentary rocks. Both the relatively recent uplift of the area and the resistant metamorphic rocks contributed to the height of the Adirondacks. Additional scouring by glaciers during the ice age helped to carve the Adirondack peaks.

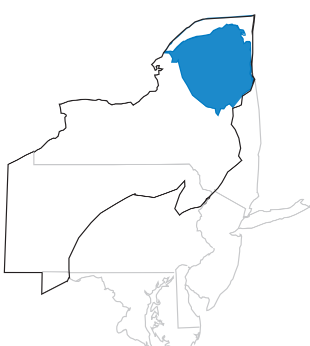


*Figure 5.4: The Adirondack region of the Inland Basin.*

*Not all Precambrian metamorphic rock is extremely* **resistant** *or uniformly resistant to erosion. Precambrian schists, for example, are not as resistant as harder sedimentary rock found in other parts of the Inland Basin.*

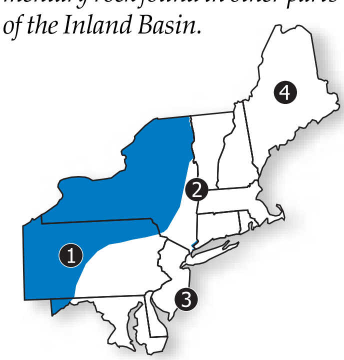
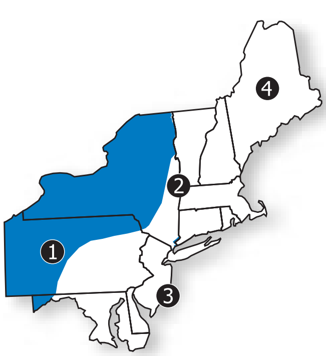



*Figure 5.5: The Lowlands of the Inland Basin.*


*see Glaciers, p.67, for glacial features of the* **lowland** *areas.*


## *Lowlands*

The Lowlands of the Inland Basin surround the Adirondack region on all sides, including the Erie, Ontario, St. Lawrence and Mohawk Valley lowlands *(Figure 5.5)*. Many of the topographic features of the Lowlands region were formed during the most recent Ice Age. The Lowlands preserve remnants of large glacial lakes scoured by glaciers and filled with glacial meltwater as the continental ice sheet advanced and retreated over the Northeast. The region of Lake Ontario was formerly occupied by a series of glacial lakes, including Glacial Lake Iroquois. The Tug Hill Plateau, which is actually a part of the Allegheny Plateau has been isolated through erosion by meltwater escaping through the present Mohawk Valley from former Lake Iroquois. As the glacial lakes shrunk, or altogether disappeared, characteristic glacial lake deposits were left behind: sand, silt and clay, and other evidence of ancient shorelines. Many striking glacial features are evident within the ***Lowlands***, including thousands of drumlins in the Ontario Lowlands.



# Topography of the Appalachian/Piedmont
## *Region 2*

The dominance of northeast-southwest trending ridges and valleys throughout the Appalachian/Piedmont region is characteristic of the Northeast, reflecting the compression of the crust during the mountain-building events of the past. Nowhere is this distinctive topography seen better than in the Valley and Ridge region of Pennsylvania and Maryland *(Figure 5.6)*. The Great Valley runs lengthwise through the whole region, defining the eastern edge of the Valley and Ridge province. The ridges of the Blue Ridge, Reading Prong, Hudson Highlands, Berkshires and Green Mountains, made of resistant Precambrian gneiss, form the spine of the ***Appalachian Mountains***. The Taconic Mountains, made of stacked slices of Cambrian and Ordovician-age rock, stretch across the north-south border between New York and Vermont, Massachusetts and Connecticut. They were pushed westward to their present position during the Taconic mountain-building period.

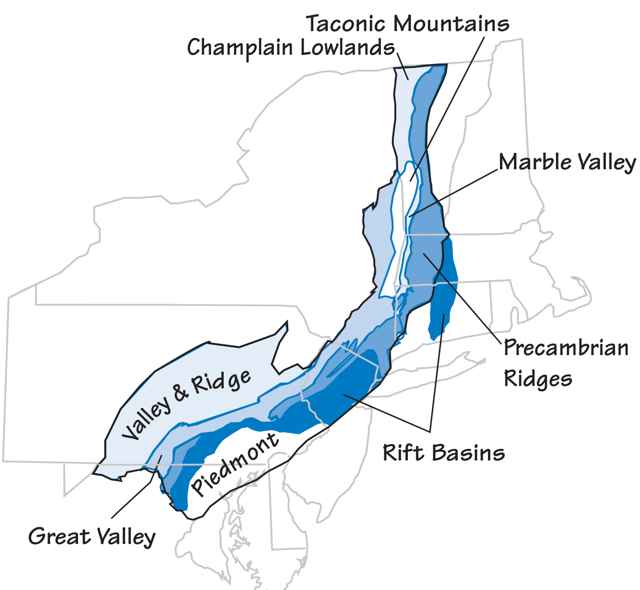


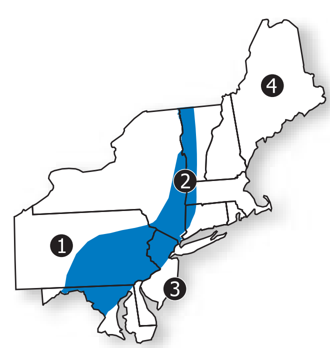

*Figure 5.6: Generalized topographic regions in the Appalachian/Piedmont.*

### *Valley and Ridge*

The Valley and Ridge region is bounded by the Great Valley to the east and the Allegheny Plateau of the Inland Basin to the west *(Figure 5.7)*. Tight, narrow folds in the layers of rock from the final Alleghanian mountain-building event, created the long thin ridges and valleys throughout the province, with relief between 300 and 1000 meters or more *(Figure 5.8)*. These folds are much tighter than the broad bends of the adjacent Allegheny Plateau of the Inland Basin region. Sandstone and quartzite make up the ridges of the Valley and Ridge region; more easily eroded shale, limestone and dolostone floor the valleys. The valleys are

*The Appalachian Mountains include many (but not all) ranges within the Appalachian/Piedmont region. The term 'Appalachian Mountains' denotes the chain of mountains that stretch from north to south parallel to the east coast that were compressed during the last two mountain-building events. The Appalachian Mountains proper include the mountains of New England, and the Precambrian ridges (with the exception of the Green Mountains of Vermont, considered an extension of the Appalachian Mountains.)*

*Figure 5.7: Valley and Ridge region of the Inland Basin.*



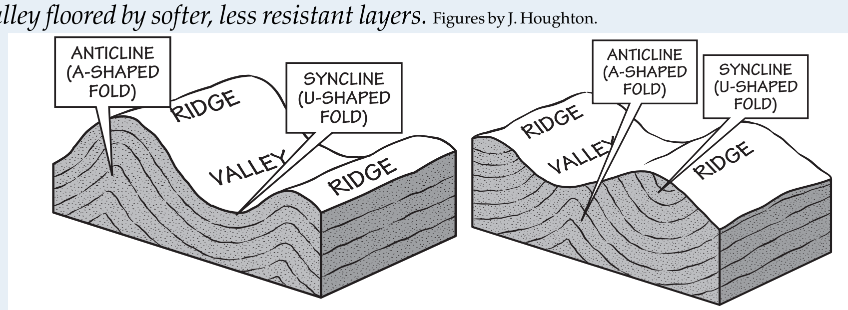
*One of the great debates concerning the Valley and Ridge region is the reason for the even heights of ridge tops in the area over long distances. Are the ridges all capped by equally resistant beds? Or was the region eroded flat and subsequently uplifted, to be eroded to its present topography by dissecting streams?*

commonly formed from rock layers that have been folded upward and eroded in the center; ridges in the region often form from rock layers that have been folded downward, with resistant centers. This is known as ***topographic inversion***, because one would expect ridges to form from upfolds and valleys to form from downfolds.

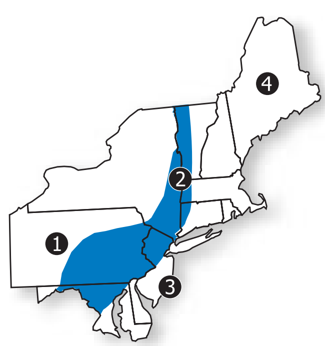
*Figure 5.8: Topographic map of the Valley and Ridge region of the Appalachian/Piedmont.*
Topographic map provided by Topozone.com: http://www.topozone.com.

## Topographic inversions

*Common sense would have us believe that more often than not, synclines (U-shape folds) form valleys and anticlines (A-shape folds) form ridges. However, we often see 'topographic inversions', especially in the Appalachian/Piedmont region. Topographic lows (valleys) form from the structural high (top of an anticline), where the term 'structure' refers to the form of the rock layers. At the top of the anticline, a layer may erode away because of cracks at the top of the fold caused by bending of the rock. Fracturing at the top of the fold allows increased water penetration, and topographic highs are subjected to more severe weather. Thus, the less resistant layers below the eroded top quickly erode away to form a valley. The limbs of the resistant layer, however, are generally still intact. This leaves two ridges of resistant rock on either side of a valley floored by softer, less resistant layers.* Figures by J. Houghton.

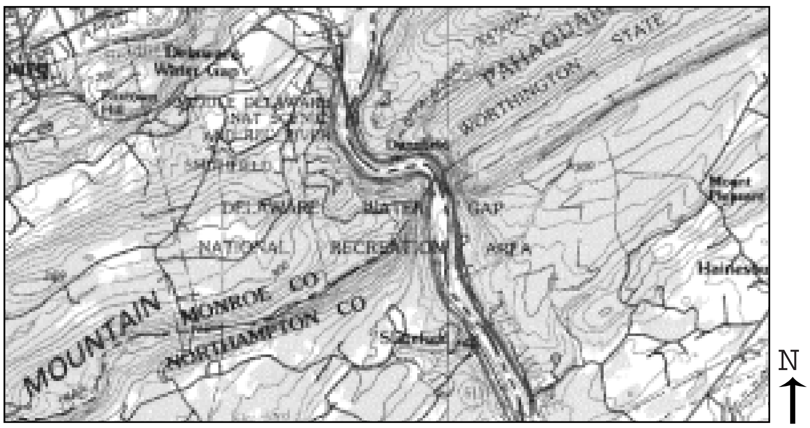



*Normal erosion of a fold.* *Topographic inversion.*



## Water gaps

*Generally, streams move along the path of least resistance, carving valleys into the softest, least resistant rock units following weak layers along structure. The majority of streams and rivers have cut valleys between pre-existing ridges. There are exceptions, however, in which streams are constrained to cut through resistant ridges. One of the most spectacular examples is the Delaware Water Gap. Water gaps are an unusual topographic feature found in the Appalachian/Piedmont, where the elongate ridges are made of resistant rock and are otherwise generally continuous. The rivers bisect the ridges in places where the structure of the rock is weak (at faults, folds or changes in rock type), often cutting across at an angle perpendicular to the ridge. Although the formation of water gaps is not well understood, it is thought that runoff on opposite sides of a ridge cuts ravines that drain to their respective sides. As the ravines develop, becoming larger streams, the headwaters on either side erode further up the ridge. Eventually a notch is formed when the two headwaters meet and become one stream, flowing through the ridge.*




*Topographic map of the Delaware Water Gap, Pennsylvania.* Topographic map provided by Topozone.com: http://www.topozone.com.

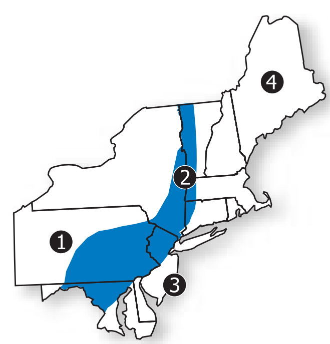
## *The Great Valley*

The Great Valley is adjacent to the Valley and Ridge region extending from New York as far south as Georgia *(Figure 5.9)*. Floored by Cambrian and Ordovician limestone and dolostone, the wide valley forms a topographic low because of the less-resistant nature of the rock. The local names of the Great Valley vary throughout the Northeast. In Maryland the Great Valley is the Hagerstown Valley; in Pennsylvania it is the Cumberland, Lebanon and Lehigh Valley respectively from south to north. The Great Valley cuts across northern New Jersey and up into New York as the Hudson Lowlands. Finally, in Vermont, the Valley is known as the Champlain Lowlands. The Hudson and Champlain Lowlands exist because of the weak Cambrian and

*Figure 5.9: The Great Valley of the Appalachian/Piedmont.*

### Interstate 81

*Just like the rivers which seek to erode through the least resistant layers of rock, early road-builders chose the path of least resistance. Interstate 81 is a classic example of a roadway built in a valley floored by less resistant rocks, following a prominent geologic feature of the east coast: the Great Valley. Rather than build multiple interstates across the rugged and resistant Appalachian Mountains, we have one long highway that runs the length of the Great Valley.*



Ordovician rocks that line the Valley, which were easily eroded by glaciers during the most recent ice age.

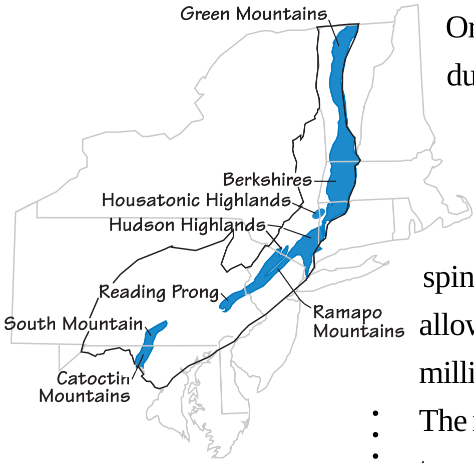



*Figure 5.10: Precambrian ridges of the Appalachian/Piedmont.*

*Mt. Mansfield, the tallest of the* Green Mountains*, is 1339 meters above sea level.*

### *Precambrian Ridges*

Extending up and down the Appalachian/Piedmont region is a rigid spine of Precambrian rock *(Figure 5.10)*. The crystalline, metamorphic rock has allowed the spine to resist erosion to some extent over the last several hundred million years, while the overlying younger sedimentary rocks have eroded away. The resistant nature of the Precambrian rock is responsible for the mountainous topography of the ***Green Mountains***, the Berkshires, Hudson and Housatonic Highlands, Reading Prong, Ramapo Mountains, South Mountain and the Catoctin Mountains.

At the southern end of the Precambrian Ridges region, Pennsylvania's South Mountain marks the northern extent of the Blue Ridge physiographic province. The Blue Ridge refers to the Precambrian rock making up the spine of the southern Appalachian Mountains from Pennsylvania to Georgia. The rocks of the Blue Ridge are bent into a large upward fold. The upward fold has many smaller folds superimposed upon it. The wrinkles cause the rolling topography of much of the mountainous Precambrian Ridge region. In Maryland, the Catoctin Mountains are part of the Blue Ridge region as well.

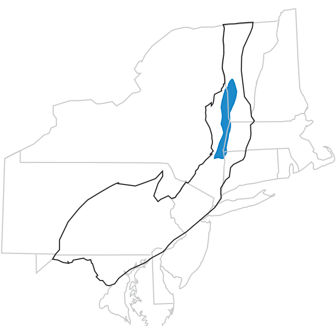
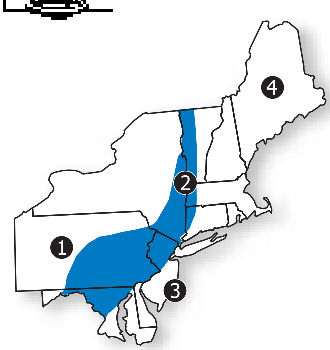


*Figure 5.11: The Taconic Mountains of the Appalachian/Piedmont.*

*see Geologic History, p. 7 for more on* **Taconic events.**




### *Taconic Mountains*

The ***Taconic*** mountain-building event during the Ordovician created the modern Taconic Mountains of the Appalachian/Piedmont region, located between New York, Vermont, Massachusetts and Connecticut *(Figure 5.11)*. The Taconic volcanic islands, formed over the subduction zone of the North America and Baltica plates, were on a collision course with North America. As the volcanic islands drew nearer to the continent, they pushed ahead of them like a bulldozer the Cambrian and Ordovician sedimentary rocks of the seafloor. The crust continued to compress until the volcanic islands were sutured to the side of North America. The compression stacked slices of the seafloor on top of one another, like a collapsed telescope, and pushed the slices a good distance to the west. The Cambrian sedimentary rock resisted erosion, protecting the less-resistant underlying layers of rock. Today's Taconic Mountains are a section of the stacked slices that have been isolated by erosion.

## *Piedmont*

The Piedmont region abuts the Triassic Rift Basins of Pennsylvania and extends south through Maryland to the Coastal Plain boundary *(Figure 5.12)*.

The topography of the Piedmont is primarily rolling hills, composed mostly of metamorphic rock that is uniform in its resistance to erosion. Therefore no ridges stand out in particular from differential weathering. There are a few notable exceptions, however, due to the presence of highly resistant rocks such as the quartzite of Sugarloaf Mountain. Near Baltimore, there are a series of '***domes***' that have Precambrian gneiss in the middle, surrounded by rings of quartzite and marble. The Piedmont rocks have been squeezed so tightly and are so complexly deformed, that the folds have been overturned and folded, and later eroded to expose the resistant Precambrian gneiss that stand out in relief as domes.

*Figure 5.12: The Piedmont region of the Appalachian/Piedmont.*

*These **domes** are not technically domes, but rather, overturned folds.*

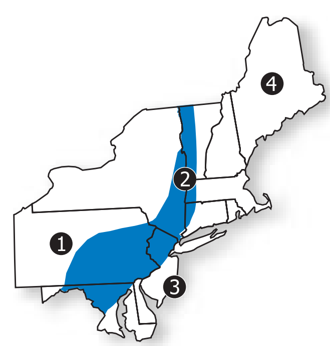
## *Rift Basins*

Two connected ***rift basins***, the Gettysburg and Newark Basins, form lowlands in the Appalachian/Piedmont region *(Figure 5.13)*. The basins begin at the southeastern tip of New York and continue through New Jersey, Pennsylvania, and Maryland. The basins exist because of the rifting of Pangea during the Triassic and Jurassic. As the continents tore apart, cracks in the crust acted as fault planes on which blocks of crust slipped downward to form basins. The basins were filled with layers of less-resistant sedimentary rock as well layers of cooling lava on the surface, which formed basalt. Occasionally, the magma did not make it to the surface. Instead, it squeezed its way between the rock layers and cooled to form diabase. Over time, the basins were tilted and eroded, exposing the alternating layers of sedimentary and igneous rock. The layers of basalt and diabase are far more resistant to erosion than the sedimentary rock, so they stick out in relief as ridges while the surrounding sedimentary rock is eroded away.

The Palisades, along the west side of the Hudson River in New York and New Jersey, are resistant exposures of diabase. The Wachtung Mountains of New Jersey are tilted remnants of three basaltic lava flows. The basin remains a topographic low today, bounded on the west by the up-faulted Precambrian Ramapo Mountains.

*Figure 5.13: The Triassic Rift Basins of the Appalachian/Piedmont.*

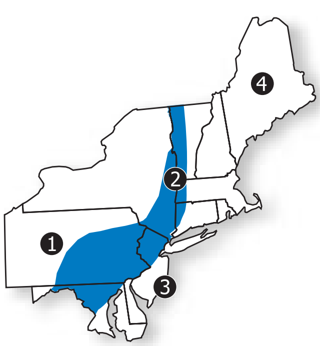
*see Geologic History, p. 16 for more on the* **rift basins.**



## *The Marble Valley*

A narrow valley bounded by steep walls runs from southern Vermont through western Massachusetts and Connecticut *(Figure 5.14)*. The valley is floored with Cambrian and Ordovician limestone that has been metamorphosed to marble. Due to the less-resistant nature of marble, a valley was scoured out by weathering and erosion, separating the Green Mountains from the Taconic Mountains.

*Figure 5.14: The Marble Valley of the Appalachian/Piedmont.*



# Topography of the Coastal Plain
## *Region 3*

Generally, the land surface of the Coastal Plain rises only about 30 meters above sea level and dips less than one degree. The primary reason for the flat nature of the Coastal Plain is the unconsolidated sediments that are the 'bedrock' of the region. The sediments in the Coastal Plain have not been significantly compacted or cemented and have certainly not become rock. There is little resistance to erosion because of the nature of the sediments, and therefore ridges do not form in the Coastal Plain. There is some moderate difference in relief between the western Coastal Plain and the eastern Coastal Plain due to the ages of the deposits. Cretaceous and Tertiary deposits dominating the western Coastal Plain show more relief than the younger Quaternary deposits that are close to the shoreline and constantly pounded by wave action and flooding.

Long Island, Cape Cod and the smaller islands off the New England Coast, though formed from glacial deposits, have the same flat nature as the topography of the rest of the Coastal Plain. The glacial deposits are unconsolidated sediments that erode as easily as the sediments of the Coastal Plain further south.

The wedge of sediments that forms the bulk of the Coastal Plain eroded from the topographically higher Appalachian/Piedmont region to the west. The hard bedrock of the Appalachian/Piedmont region lies beneath the Coastal Plain, but is deeply buried by the wedge of sediments. The boundary between the exposed Appalachian/Piedmont rocks and the wedge of Coastal Plain sediments is called the ***Fall Zone***. At numerous places along this boundary line are cascades and small waterfalls, such as the Great Falls of the Potomac. Rivers have eroded very slowly through the Appalachian/Piedmont bedrock and then very quickly through the soft Coastal Plain sediments to create a sharp drop in stream elevation at the Fall Zone *(Figure 5.15).*

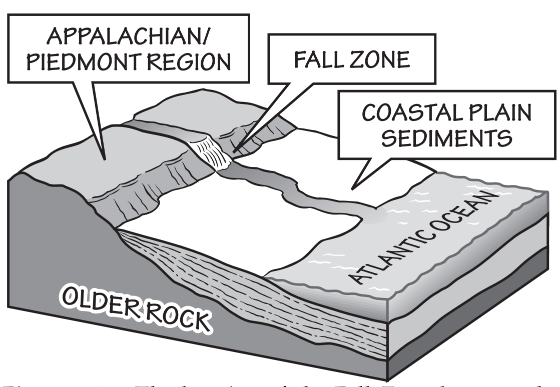
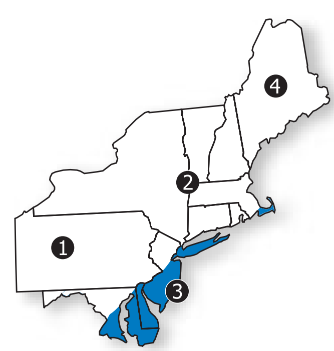



*Figure 5.15: The location of the Fall Zone between the Appalachian/Piedmont and Coastal Plain regions.* Figure by J. Houghton.

### Cities along the Fall Zone

*Follow the boundary between the Coastal Plain and the Appalachian Piedmont regions and count the number of cities that you find there: Washington, D.C., Baltimore, Wilmington, Philadelphia and Trenton. When settlers first came to America, they found that they were unable to navigate their ships past the Fall Zone, where the relief of the land was considerably greater than the flat Coastal Plain. Thus, many of the large cities of the East Coast, sprung up along the Fall Zone where shipping was still viable and cheap water power for mills was available.*



# Topography of the Exotic Terrane
## *Region 4*

### *New England Uplands*

Much of the Exotic Terrane region is simply classified as the New England Uplands. The region is characterized by rolling hills and valleys, and mountainous terrain. The Uplands include the mountainous terrain of the mountains of Maine, the White Mountains, the Bolton Range and the Mohegan Range *(Figure 5.16)*. The mountains of the Exotic Terrane region were formed over the last billion years from a variety of rock types: Ordovician-age ***igneous intrusions*** related to the Taconic mountain-building event; Ordovician volcanic rocks from the Taconic volcanic islands; Devonian-age intrusions related to the Acadian mountain-building event; Jurassic-age intrusions; and metamorphosed Silurian and Devonian sedimentary rock that originated as seafloor sediments in the Iapetus Ocean.

*see Rocks, p.50 for more on Ordovician* **igneous intrusions.**

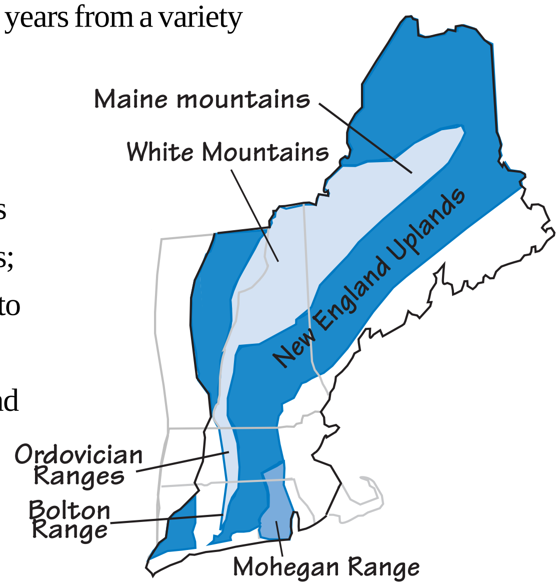
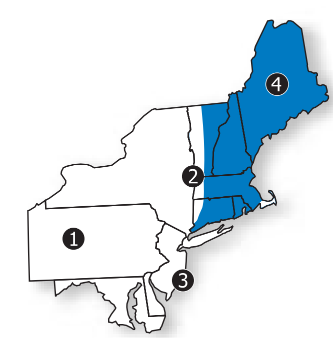



*Figure 5.16: New England Uplands mountains found in the Exotic Terrane region.*

The mountains of Maine stretch in a belt from the high peaks of the southwest to central Maine. The mountains are generally higher in the southwestern part of the state. Mt. Katahdin in central Maine is an exception; made of an unusually resistant granite from an Acadian mountain-building igneous intrusion, it is the highest peak in Maine at 1605 meters above sea level. During the Acadian mountain-building event, intense metamorphism of the rocks in southeastern Maine and the highly resistant volcanic rocks of the area created the Maine mountains. Further north in Maine, the rocks were subjected to less metamorphism. There are fewer ridges in this region because the rocks are less resistant to weathering and erosion.



The White Mountains of New Hampshire include the Presidential Range, the Franconia Mountains, and the hills of northern New Hampshire and northeastern Vermont. Igneous intrusions from the Taconic and Acadian mountain-building event, as well as volcanics from a possible hot spot during the Jurassic, form many of the peaks of the White Mountains. Some of the highest peaks of the range, however, are formed from Devonian schist, including ***Mt. Washington***, at nearly 1900 meters above sea level.

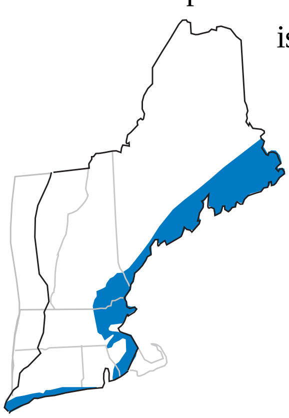
*see Rocks, p.53, for more on the* ***hot spot..***

**Mt. Washington** *is the highest peak in the Northeast.*

Ordovician igneous intrusions and volcanic rocks from the Taconic mountain-building event form a narrow range of resistant mountains. The Ordovician ranges begin in Connecticut as the Bolton Range, and extend north to New Hampshire and Maine, where the Ordovician-age rocks intermingle with rocks of other ages to form the Maine and New Hampshire mountains.

The Mohegan Range, a series of north-northeast ridges in Connecticut and Rhode Island, was carved from one of the Exotic Terranes of the Exotic Terrane region. The microcontinent Avalonia, which was sutured to North America during the Devonian, had Precambrian bedrock exposed in certain places at the surface. This resistant, Precambrian rock became the Mohegan Range through weathering and erosion of surrounding less-resistant rocks.

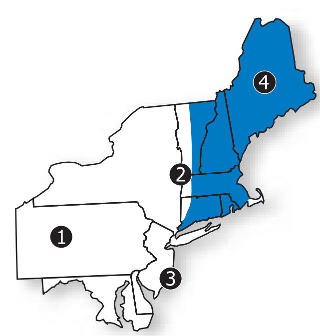
Unusual features of the Uplands topography include knobs of resistant rock that stick out high above the relief of the local landscape. These are known as monadnocks, the most famous example of which is Mt. Monadnock in New Hampshire. Throughout New Hampshire and northern Vermont, isolated mountains of resistant rock stick up above the local landscape, left standing after erosion of less-resistant surrounding rock.



*Figrue 5.17: The New England Coastal Lowlands of the Exotic Terrane region.*

## *New England Coastal Lowlands*

The Coastal Lowlands of the New England Exotic Terrane region are a discontinuous swath of land along the coastline from Maine to Connecticut that has a lower elevation than the rest of the Exotic Terrane region *(Figure 5.17)*. The lower elevations of the Coastal Lowlands area are not due to softer, less-resistant rock types or the structure of the rocks. The glaciers of the last ice age depressed the



crust of the Northeast somewhat. When the continental ice sheet began to retreat back north and melt, the crust rebounded from the removal of the heavy weight of the glaciers. However, the crust could not rebound before the melting glaciers raised sea level high enough to flood much of the coastal portion of New England. Submergence and erosion by wave action are the cause of lower elevations in the Coastal Zone area of New England.

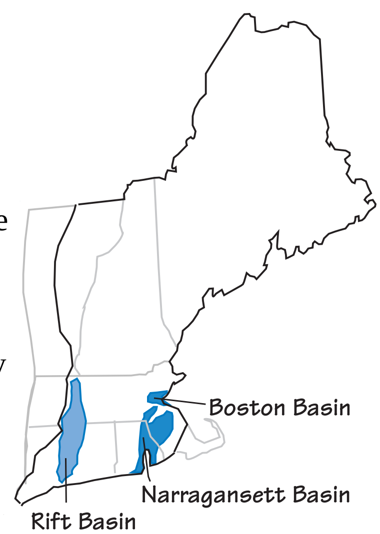
The New England coast is famous for its rocky shoreline. The ***rocky headlands*** are made of resistant granites, igneous intrusions that occurred through the Taconic, Acadian and Devonian mountain-building events. The resistant nature of these rocks, and the inadequate supply of sediment delivered to the coast by local rivers, prevent the formation of wide beaches and a flat coastal plain. Other sections of the New England coast have less-resistant rocks. Erosion of the bedrock creates a greater supply of sediment in local rivers to form wider beaches in these areas. Glacial sediment, dumped as the ice sheet retreated at the end of the most recent ice age also provides the sand, silt and clay making up the beaches in many parts of the Northeast.

*The wide beaches of New Jersey, Delaware and Maryland do not have* **rocky headlands** *like many New England coasts. New Jersey, Delaware and Maryland are all in the Coastal Plain region, underlain by a wedge of loose, unconsolidated sediments that are easily eroded flat by wind and wave-action, allowing wide beaches to develop.*

## *New England Basins*

The Connecticut Valley ***Rift Basin***, formed from the rifting of Pangea during the Triassic and Jurassic, creates a distinctive lowland area in the New England Exotic Terrane region that is very similar to the Newark and Gettysburg Basins of the Valley and Ridge.

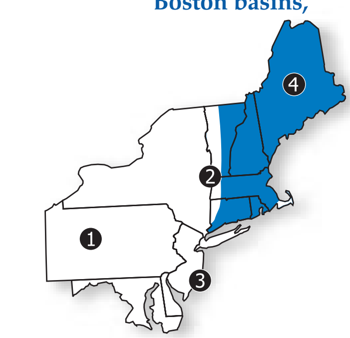
As the basin tilted, layers of sedimentary and igneous rocks were exposed. The soft sedimentary rocks are easily eroded, forming the basin floor, while the igneous basalts and diabase stand out as ridges. The Pennsylvanian-age ***Narragansett Basin*** in Rhode Island, the Precambrian ***Boston Basin*** in Massachusetts and several other Pennsylvanian-age small basins in Massachusetts and Rhode Island also form lowland areas of the Exotic Terrane Region *(Figure 5.18)*.




*Figrue 5.18: The New England Basins of the Exotic Terrane region.*

*see* ***Geologic History****, p. 16, for more on* **rift basins.**

*see* ***Rocks****, p.49 and 52 for more on the* **Naragansett** *and* **Boston basins,**



# Activities

1. A college professor of history has become fascinated that ancient geologic events created our landscape and that landscapes have influenced human history, linking in interesting ways the history of our planet with the history of people. You are hired part-time by to create for him a map of the Northeast, with topographic features colored according to the geologic event(s) that had the most influence on the topography. In many cases two events were influential, since the type of rock and structure in the rock combine (after erosion) to create landforms.

*Use the following events to create your map:*

(1) the Grenville passive margin
(2) the Taconic converge,
 (2a) interval (Silurian-Early Devonian) between Taconic and Acadian
(3) the Acadian convergence,
 (3a) interval (Mississippian-Early Permian) between Acadian and Alleghenian
(4) the Alleghenian convergence,
 (4a) interval (Early-mid Triassic) between Alleghanian and rifting
(5) the rifting apart of Pangea, and
 (5a) interval (mid-Jurassic-late Jurassic) between rifting and creation of Coastal Plain
(6) the Coastal Plain passive margin and shaping by erosion of many of current land-forms
(7) Pleistocene glaciation and Holocene post-glacial

*Create a map for the professor, using your creativity and judgment to make the map easy to read; you will have to generalize some detail.*

2. Your local Visitors Association hears about your project and recognizes that it may be interesting for them to describe the history of the your area in terms of landforms and geologic events, in their dealings with tourists to your community. You suggest that you may not be able to interpret every landform, but the Visitors Association representatives say that having a few interesting examples is more important than completeness

*Describe your local topography in terms of geologic history, underlying rock type, and erosion.*

3. Seeing that the Visitors Association is creating business from your knowledge, you sense an entrepreneurial opportunity: you could sell, to communities throughout the Northeast, interesting geological information about landforms to businesses advertising about their geographic areas and tour guides wanting information about the local scenery.

*To take a stab at starting your own business, you choose several widely separated locations to link topography to geological history. Create a description like (2) for several locations. Create also a pricing sheet that indicates cost for your work.*

# For More Information...

## *Book*

Bloom, A.C., 1998, *Geomorphology: A systematic analysis of late Cenozoic landforms*, 3rd ed., Prentice Hall: Upper Saddle River, New Jersey.

## *Map*

*Landform Map of the Northeastern Region*, modified from R. E. Harrison, 1969, *Shaded Relief Map* and E. Raisz, 1957, *Physiographic Diagrams*.

## *Internet*

A Tapestry of Time and Terrain: Geology and Topography maps combined
http://jazz.wr.usgs.gov/tapestry/physio.html

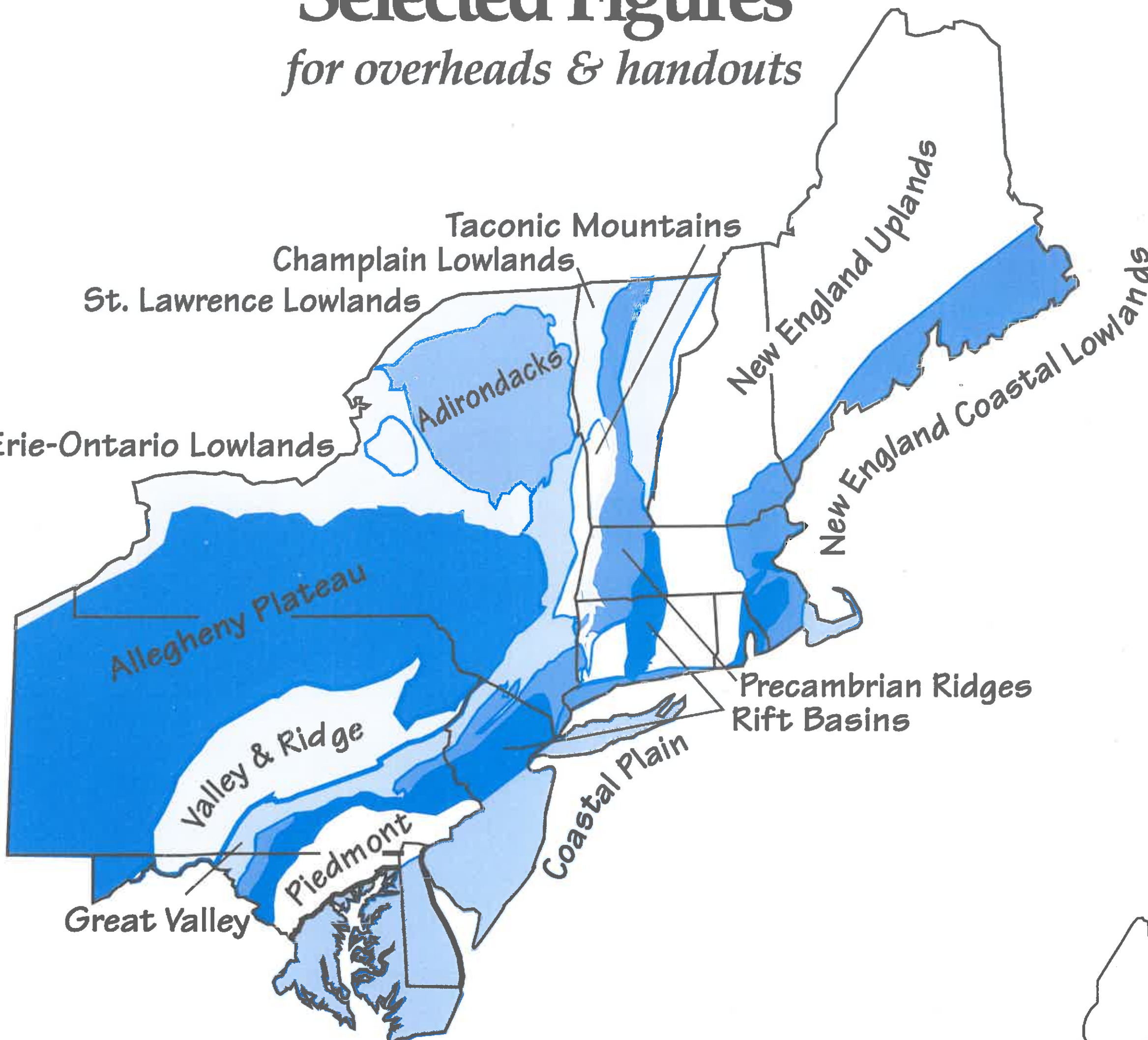
Color Landform Atlas of the US: shaded relief maps of each state
http://fermi.jhuapl.edu/states/states.html

Geomorphology from Space; A Global Overview of Regional Landforms
http://daac.gsfc.nasa.gov/DAAC_DOCS/geomorphology/GEO_HOME_PAGE.html

Topozone
http://www.topozone.com/

# Selected Figures

*for overheads & handouts*



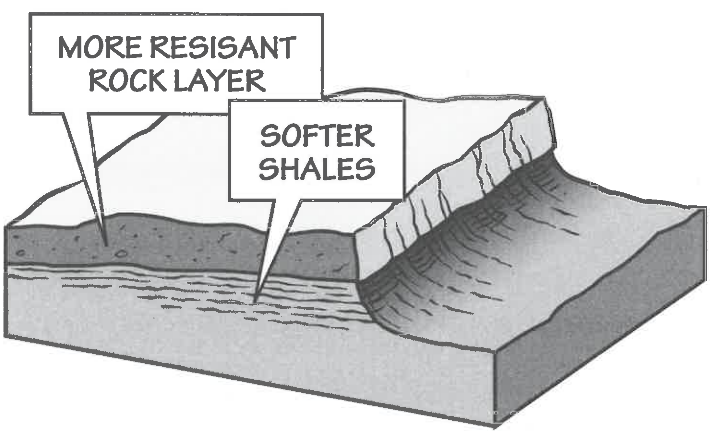




*Figure 5.2: A cuesta ridge is formed from a resistant layer of gently tilted rock.* Figure by J. Houghton.

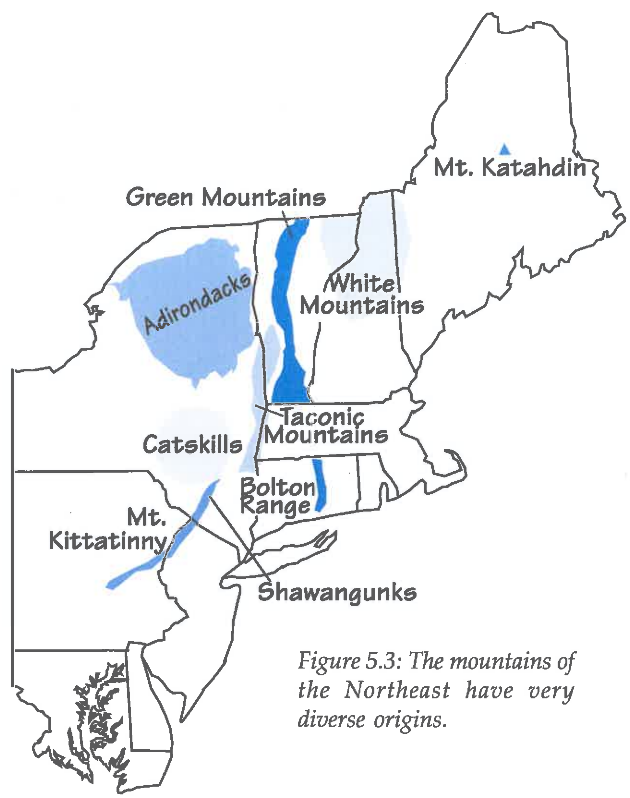
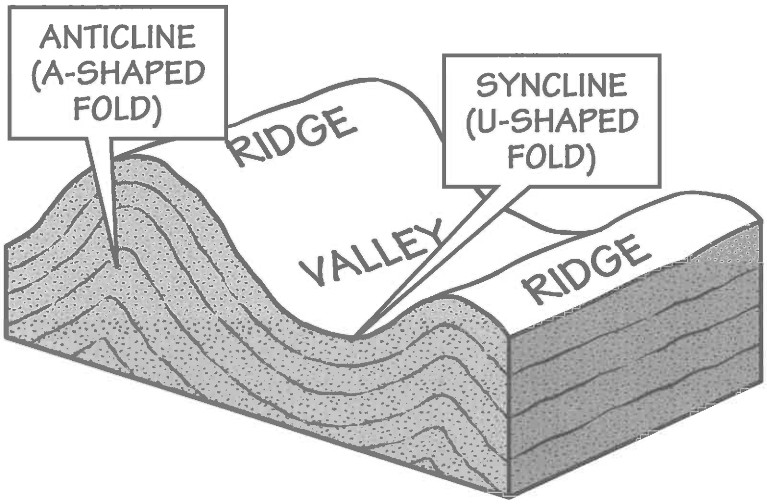
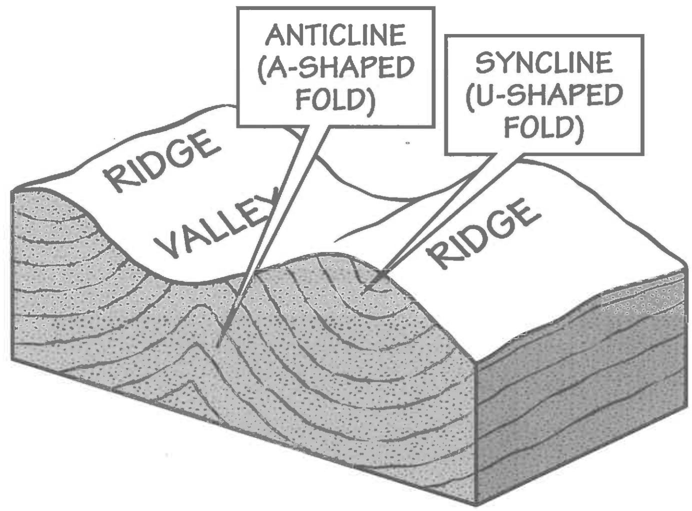



*Figure 5.3: The mountains of the Northeast have very diverse origins.*




*Normal erosion of a fold.*




*Topographic inversion.*

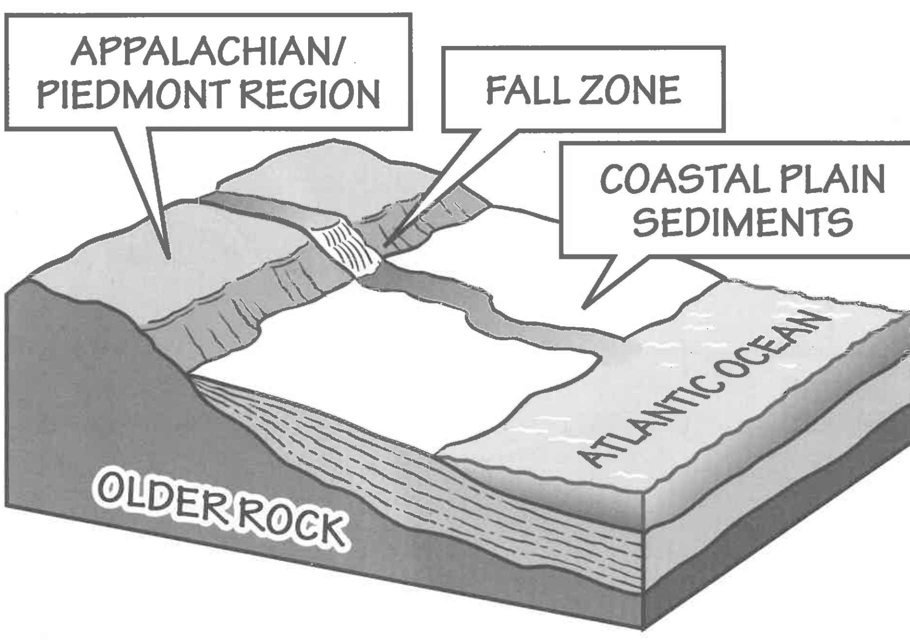
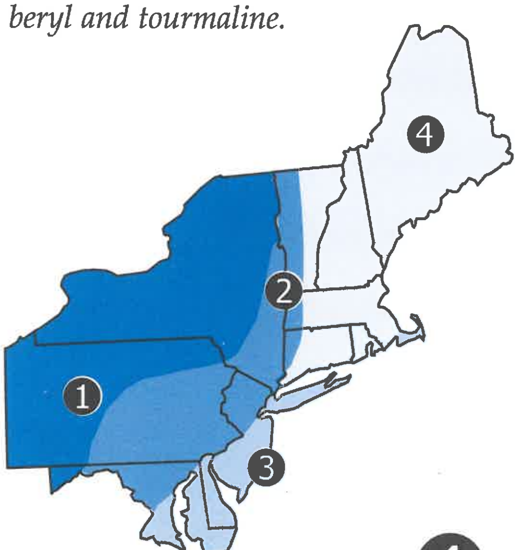



*Figure 5.15: The location of the Fall Zone between the Appalachian/ Piedmont and Coastal Plain regions.* Figure by J. Houghton.

# Mineral Resources of the Northeastern US: *the BIG picture*

## 1 Inland Baisn

*The Inland Basin has two areas of mineral resources that produce very different mineral assemblages: the Precambrian Grenville rocks of the Adirondacks, and the Paleozoic sedimentary rocks that make up the bulk of the region. The Adirondacks produce most of the metallic minerals as well as important non-metallic minerals such as garnet and wollastonite. The sedimentary rocks to the southwest contain an abundance of non-metallic minerals, including salt, gypsum, beryl and tourmaline.*




## 2 Appalachian/Piedmont

*The metallic and non-metallic mineral resources of the Appalachian/Piedmont originate from the Precambrian Grenville rocks, the Ordovician-age Ultramafic Belt, and the Rift Basin rocks formed in the Triassic and Jurassic. Metallic mineral resources include zinc, aluminum, copper and magnesium. Non-metallic minerals include talc, mica, kaolin and asbestos. There is also a wide variety of gemstones found in the region.*

## 3 Coastal Plain

*Unlike the other regions of the Northeast, there are no igneous and metamorphic rocks in the Coastal Plain. The relatively young sediments of the Coastal Plain do not have the proper conditions to produce the variety of minerals found elsewhere. Gypsum and magnesium compounds are the only mineral resources currently being produced.*

## 4 Exotic Terrane

*The addition of the exotic terranes to North America in the Paleozoic deformed the crust, providing excellent conditions for the formation of a broad spectrum of metamorphic minerals and granite pegmatites. Metallic minerals in the Exotic Terrane include pyrite, gold, lead, silver and copper. Non-metallics include rare minerals derived from the pegmatites as well as metamorphic minerals that reflect the varying degrees of metamorphism across the region. The pegmatites are also the source of many of the region's fine-quality gemstones.*

# Mineral Resources of the Northeastern US:
## *a brief review*

A mineral is a naturally occurring solid with a definite chemical composition and crystalline structure that is formed through inorganic processes. Minerals are literally the foundations of our everyday world. Not only do minerals make up the rocks we see around us in the Northeast, they are used in nearly every aspect of our lives. The wide variety of minerals found in the rocks of the Northeast, are used in industry, construction, machinery, technology, food, makeup, jewelry, and even the paper on which these words are printed.

*Minerals provide the building blocks for rocks. For example, granite, an igneous rock, is typically made up of crystals of the minerals feldspar, quartz, mica and amphibole. Sandstone may be made of cemented grains of feldspar, quartz and mica. The minerals and the connections among the crystals define the color and resistance to weathering of a rock.*

Luster refers to the appearance of the mineral surface in reflected light. Metallic minerals have a luster like an aluminum pan or a dull metal like a rusty nail. Metallic minerals are vital to the machinery and technology of modern civilization. Geologists seek out ores that contain significantly more metal than is normal in the crust. Many metallic minerals occur in extremely small amounts in the crust. It is almost always necessary to process ore minerals in order to get the useful element. A mineral is called an ore when one or more of its elements can be profitably removed. For example, ***chalcopyrite***, which contains copper, iron and sulfur, is referred to as an ore when the copper can be profitably extracted from the iron and sulfur.

**Elements:**
***the building blocks of minerals***

*Elements are the building blocks of minerals. The mineral quartz, for example, is made of the elements silicon and oxygen. Most minerals present in nature are not composed of a single element, though there are exceptions such as gold (Au). Eight elements make up (by weight) 99% of the Earth's crust, with oxygen being by far the most abundant (46.4%). The remaining elements in the Earth's crust occur in very small amounts, some in concentrations of only a fraction of one percent (Figure 6.1). Since silicon (Si) and oxygen (O) are by far the most abundant elements in the crust by mass, it makes sense that quartz (SiO2, silicon dioxide or silica) is one of the most common minerals in the Earth's crust and is found all over the Northeast.*

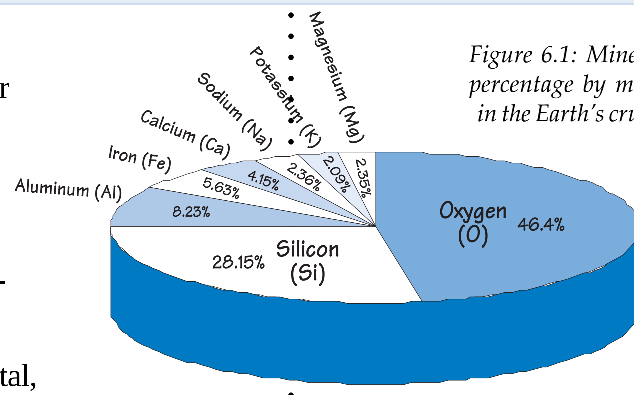
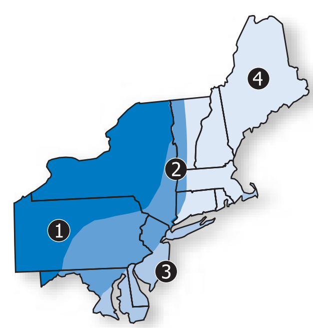



*Figure 6.1: Mineral percentage by mass in the Earth's crust.*

**chalcopyrite**: *$CuFeS_2$*

Non-metallic minerals do not have the flash of a metal, though they may have the brilliance of a diamond or the silky appearance of gypsum. Generally much lighter in color than metallic minerals, non-metallic minerals can transmit light, at least through pieces or edges.

What distinguishes a regular mineral from a gem? Beauty, durability and rarity of the mineral qualify it as a gemstone. Beauty refers to the luster, color, transparency and brilliance of the mineral, though to some degree it is dependent on the skillfulness of the cut. Most gems, including tourmaline, topaz and corundum, are durable because they are hard (scratch-resistant). On the Mohs Scale



### Mohs Scale of Hardness

*In 1824, the Austrian mineralogist, F. Mohs, selected ten minerals to which all other minerals could be compared to determine relative hardness. The scale became known as Mohs scale of hardness, and is very useful as a means for identifying minerals or quickly determining hardness. A piece of glass has a hardness of approximately 5 on the scale; your fingernail is just over 2; and a pocketknife blade is just over 5.*

| | |
|---|---|
| 1 | Talc |
| 2 | Gypsum |
| 3 | Calcite |
| 4 | Fluorite |
| 5 | Apatite |
| 6 | Feldspar |
| 7 | Quartz |
| 8 | Topaz |
| 9 | Corundum |
| 10 | Diamond |

of Hardness, the majority of gemstones are greater than 7.

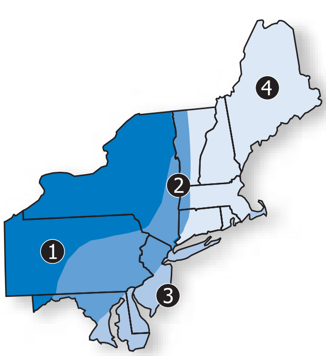
Hardness is important because it helps us understand why some rocks are more or less resistant to weathering and erosion. Quartz (7 on Mohs scale) is a relatively hard mineral, but ***calcite*** (3 on Mohs scale) is significantly softer. Therefore, it should be no surprise that a quartz sandstone is significantly more resistant to erosion and weathering than a limestone, the primary constituent of which is the mineral calcite. Quartz is a very common mineral in the Earth's crust and very resistant due to its hardness and relative insolubility. Thus, quartz grains are the dominant mineral in nearly all sands.

**calcite**: *$CaCO_3$*

A gem's value is also dependent on the rarity of the mineral. With limited supply (commercially or in nature), the value of a gem increases significantly, such as with rubies or diamonds. Quartz may have a brilliant luster and be quite durable, but it is hardly rare. Therefore, quartz has significantly less value as a gemstone, though some microcrystalline and colored varieties of quartz are of moderate value.

Geologists looking for particular minerals do not make haphazard guesses as to the location of ore bodies. The occurrence of minerals in the Earth's crust is due to the geologic processes that formed certain rock types in a given area. An understanding of the environments in which minerals form, the minerals that make up different rocks, and the geologic history of an area, helps the geologist to ascertain with a higher probability where minerals of interest are concentrated. Metallic minerals are often associated with igneous and metamorphic rocks, which typically occur in either very ancient rocks (Precambrian) or in areas of severe deformation of the crust (such as where continents have collided) *(Figure 6.2, 6.3)*.

Non-metallic minerals are found associated with sedimentary, igneous and metamorphic rocks of all ages, and in both deformed and undeformed crust *(Figure 6.2, 6.4)*. The apparent concentration of non-metallic minerals along the east coast



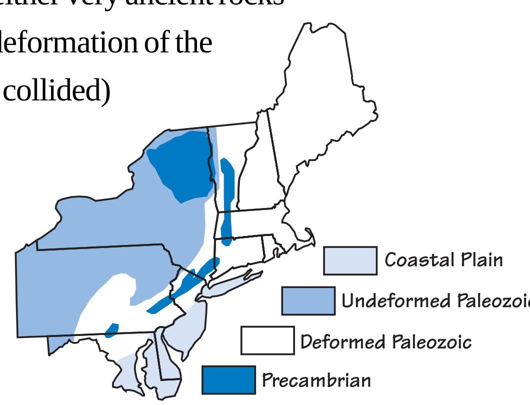




*Figure 6.2: Generalized geology of the Northeast.*
Figure adapted from USGS 1998 Mineral Resource Evaluation of the Northeastern U.S.

of the United States reflects the high demand for non-metallic minerals in a densely populated region that has led to intense mining of the immediate area.

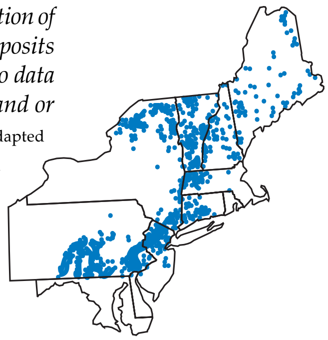


*Figure 6.3: Distribution of metallic mineral deposits of the Northeast. No data available for Maryland or Delaware.* Figures adapted from USGS 1998 Mineral Resource Evaluation of the Northeastern U.S.

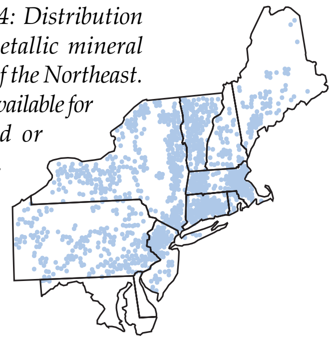


*Figure 6.4: Distribution of non-metallic mineral deposits of the Northeast. No data available for Maryland or Delaware.*

Mineral deposits may be formed in one of several ways: evaporation of water; crystallization of magma or lava; or the dissolution and later precipitation of minerals by hot water moving through cracks and openings in the rock well below the surface. A mineral is not necessarily restricted, however, to one method of concentration or environment of formation. For example, gypsum may form as a precipitate from evaporating water, but is also associated with volcanic regions where limestone and sulfur gases from the volcano have interacted.

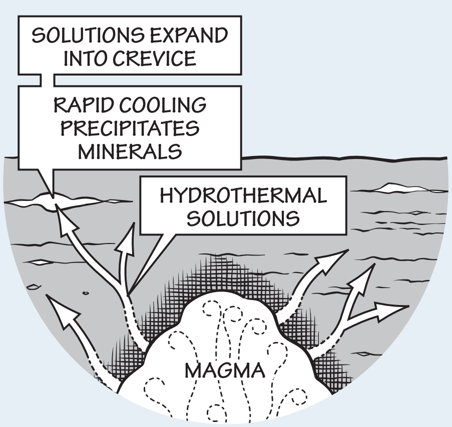
## Common rock-forming minerals

*There are over 3,500 different minerals identified in the world, and a wide variety occur in the Northeast. However, the number of common rock-forming minerals is much smaller. The most common minerals that form igneous, metamorphic and sedimentary rocks (and the ones that you will most commonly see) include quartz, feldspar, micas, pyroxenes and amphiboles. Though quartz occurs in several colors, it is most commonly white, gray or clear. Feldspar may be a variety of colors, including pink, white, and black or gray. Mica, a thinly sheeted, flaky mineral, is most commonly either light in color (muscovite) or black (biotite). Pyroxene and amphibole are dark green to black, generally needle-like crystals.*

*In the discussions of each region to follow, the focus is on: currently mined and other significant minerals; where the minerals are most common (though they may occur in other places as well); and how the minerals formed in each particular area relate to the surrounding rocks and geologic history.*

## What are hydrothermal solutions?

*Hot water moving through rocks, also known as hydrothermal solutions, is always enriched in salts (such as sodium chloride NaCl, potassium chloride KCl, and calcium chloride $CaCl_2$) and thus is called a 'brine'. The brine is as salty or even saltier than seawater. Salty water, surprisingly, may contain minute amounts of dissolved minerals such as gold, lead, copper and zinc. The presence of salt in the water suppresses the precipitation of the metallic minerals from the brine because the chlorides in the salt preferentially bond with metals. Additionally, because the brine is hot, minerals are more easily dissolved, just as hot tea dissolves sugar more easily than cold tea. These hot water brines, or hydrothermal solutions, can have varying origins. As magma cools, hydrothermal solutions form because water is often released into the surrounding rock. The water is hot because the nearby magma is still hot (though cooling). Rainwater becomes a hydrothermal solution by picking up salt as it filters through rocks. And seawater (already enriched in salt) is often a hydrothermal solution in the vicinity of volcanic activity on the ocean floor where tectonic plates are pulling apart. Rapid cooling of the hydrothermal solution over short distances allows concentrations of minerals to be deposited. Water moving quickly through fractures and openings in the rock, experiencing changes in pressure or composition, and dilution with groundwater can rapidly cool a hydrothermal solution.* Figure by J. Houghton.



# Mineral Resources of the Inland Basin

## *Region 1*

The Inland Basin is rich in a variety of minerals, though only a few are mined commercially *(Figure 6.6)*. The sedimentary rocks, making up the thick sequences of the Queenston and Catskill Deltas, formed from sediments eroded off of the Taconic and Acadian Mountains into the inland ocean during the Ordovician and Devonian. The Adirondacks, strikingly different from the surrounding sedimentary rock, are made of billion-year-old Grenville rocks.

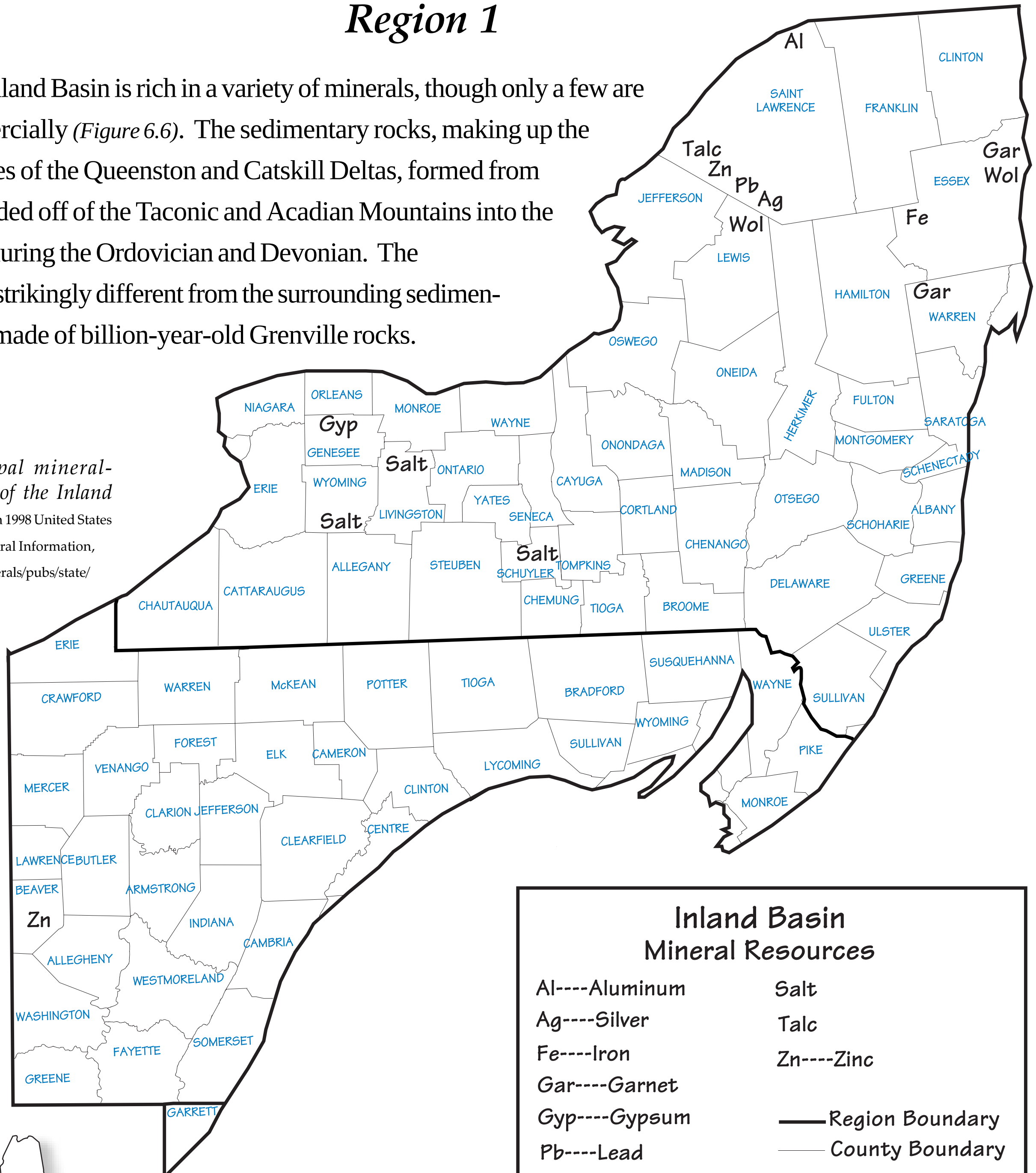
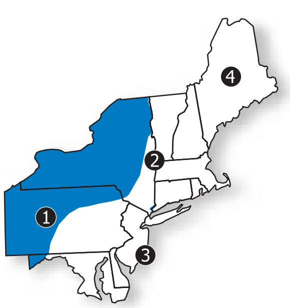



*Figure 6.6: Principal mineral-producing localities of the Inland Basin.* Figure adapted from 1998 United States Geological Survey State Mineral Information, http://minerals.usgs.gov/minerals/pubs/state/




Between the sedimentary rocks of the basin and the igneous and metamorphic rocks of the Adirondacks, there is a wide diversity in the principal mineral resources found in the region, including metallic minerals such as iron, zinc and illmenite, and non-metallic minerals such as gypsum and salt.

## Metallic Minerals

### *in Grenville Rocks:*

see *Geologic History*, p. 3, for more on **Grenville Rocks.**

see *Rocks*, p.32, for more on **Grenville rocks.**

The Precambrian ***Grenville rocks*** of the Adirondacks, formed as the Grenville marine sediments were compressed and tacked on to North America, are seen poking through the younger sedimentary rock cover in the Adirondack region of New York *(Figure 6.7)*. The Grenville rocks include metamorphosed sedimentary rocks such as marble, gneiss, and quartzite, as well as anorthosite, an igneous rock crystallized from asthenosphere magma. With a mineral assemblage unique in the Inland Basin, the Adirondacks produce most of the metallic minerals in the region. The principal metallic mineral resources of the Adirondacks include iron, zinc, lead, silver, aluminum and titanium.

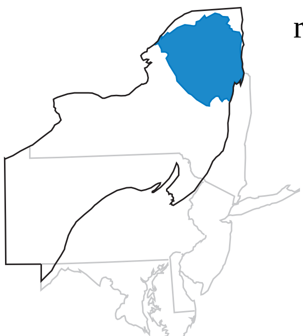


*Figure 6.7: Precambrian Grenville rocks of the Adirondacks.*

**magnetite**: *$Fe_3O_4$*
**hematite**: *$Fe_2O_3$*
**siderite**: *$FeCO_3$*

Iron in the Adirondacks is mined from the ore ***magnetite***. Though geologists disagree on the origin of the iron, it may possibly have formed as deposits of iron in sedimentary rock that were later metamorphosed, or from concentration and later precipitation of magnetite crystals by ***hydrothermal solutions***. Though iron may also be mined from other minerals, including ***hematite*** and ***siderite***, and was at one time or another mined from every state in the Northeast, the only profitable site currently being mined for iron is in the Adirondack Precambrian gneiss.

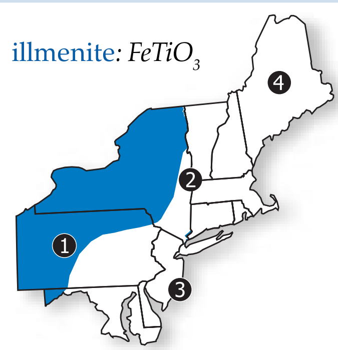
see *Minerals*, p. 131 for more on **hydrothermal solutions.**

**sphalerite**: *ZnS*
**galena**: *PbS*
**silver**: *Ag*

***Zinc, lead,*** and ***silver*** are often found in association with each other. Sphalerite is the most important ore mineral of zinc; galena is nearly the only regional source for obtaining lead; and silver is found in small amounts with galena. Both sphalerite and galena are found in commercial quantities in the Adirondacks. The minerals were initially concentrated by hydrothermal solutions and recrystalized through metamorphism when the Grenville sediments were compressed a billion years ago.

**Zinc** *is typically used in metal alloys and galvanized steel. Lead is necessary for batteries, communication systems, and building construction. Silver is used in photographic film emulsions, utensils and other tableware, and electronic equipment.*

illmenite: *$FeTiO_3$*




Until recently, ***illmenite*** was mined in the northeastern section of the Adirondacks where anorthosite rocks are found. Illmenite is an ore of titanium and was produced for use as a white pigment in paint. Titanium is also an important metal because of its lightweight nature, strength, and resistance to corrosion. As the Grenville rocks were compressed and metamorphosed, magma from the asthenosphere welled up through overlying rocks. The magma crystallized to form the igneous rock, anorthosite. Crystallization, however, did not happen all at one time. In a process known as crystal settling, the dense, heavy minerals crystallized first and sank to the bottom. Illmenite, being a heavier mineral, became concentrated at the bottom of the crystallizing magma to form the large deposits of the ore that we see today.

**kyanite, sillimanite** *and* **andalusite** *all have the same chemical composition:* $Al_2SiO_5$

Aluminum is also mined in the northernmost part of the Inland Basin. Aluminum is a common component of high-grade metamorphic minerals such as ***kyanite, sillimanite*** and ***andalusite***.

*The ready availability of* **iron** *at the surface made iron one of the earliest mined mineral resources in the US. Iron by itself is extremely rare, usually only occurring in meteorites. Iron is more often found in combination with other elements to form ores of iron, such as hematite, magnetite, siderite and pyrite (FeS), among others.*

### *in Other Rocks*

*The mineral name* **hematite** *has its origins in the Greek word* haimatos, *meaning blood. The vivid red pigment that iron lends to the mineral is valuable as a commercial pigment. Iron from hematite is also used in the manufacture of steel.*

***Iron*** is also found in Pennsylvania and other parts of New York besides the Adirondacks. In particular, layers of limestone in the Clinton Group of rocks, located in the Silurian deposits at the edge of the Appalachian Plateau, contain deposits of ***hematite*** and siderite. These iron-rich layers stretch as far south as Alabama and are important indicators of sea level rise and fall. Hematite forms in shallow ocean water and siderite forms in relatively deeper water.

## *Non-Metallic Minerals*

The Inland Basin also has a diverse assemblage of non-metallic minerals, from the wollastonite, garnet, tourmaline, and beryl of the Adirondacks to the salt and gypsum of the sedimentary rocks further south.

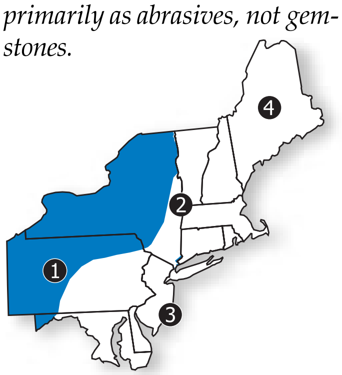
**wollastonite**: $CaSO_3$

**Wollastonite** *is primarily mined for use in ceramic tiles, porcelain, and paints. It is also used as a replacement for asbestos in brake linings.*

### *in Grenville Rocks*

The mineral ***wollastonite*** is currently mined in the Adirondacks in Lewis and Essex County, New York. Wollastonite formed in the Adirondacks when the Grenville limestone was metamorphosed and intruded by magma. Ninety-nine percent of the wollastonite produced in the US comes from New York.

**Gore Mountain** *garnets are used primarily as abrasives, not gemstones.*




The Adirondacks have also been a leading producer of ***garnets***. Spectacular crystals, as large as 1 m across (though typically 2-2.5 cm across) have been found at the famous ***Gore Mountain*** garnet mine. Though the Gore

Mountain mine is now closed, the mine at nearby Ruby Mountain continues to be a leading producer of industrial garnet for use as an abrasive. When the Grenville sediments were compressed and metamorphosed over a billion years ago, the heat and pressure melted the deeply buried rocks to magma. As the magma pushed up through the overlying Grenville marble, gneiss and quartzite, it gradually crystallized to form anorthosite and other igneous rocks. When these igneous rocks were also metamorphosed, the heat and pressure recrystalized some of the rock to form the famous garnets.

**garnet:** *$A_3B_2(SiO_4)_3$ in which A and B may be substituted by different elements to produce a given variety of garnet.*

## *in Evaporite Rocks*

The Inland Basin was part of an inland ocean for hundreds of millions of years as the continents pulled apart and pushed together. A shallow restricted sea is the ideal environment for the evaporation of water and deposition of evaporite minerals. ***Halite*** (salt) and ***gypsum*** are examples of ***evaporite*** minerals. The Silurian, in particular, was a time of especially shallow seas with poor circulation in the region. It makes sense, therefore, that salt and gypsum are both found in Silurian sedimentary rocks exposed across central New York *(Figure 6.8)*. The salt is at the surface, as natural salt springs, around Syracuse, New York. The gentle tilt of the Silurian rocks to the south means that salt is also found and mined underground south of the exposed salt beds, buried beneath Devonian rocks.

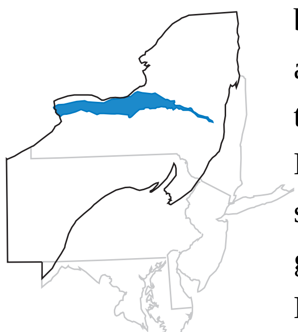


*Figure 6.8: Silurian rocks of the Inland Basin.*

**salt**: *NaCl*

**gypsum:** *$CaSO_4 \cdot H_2O$*

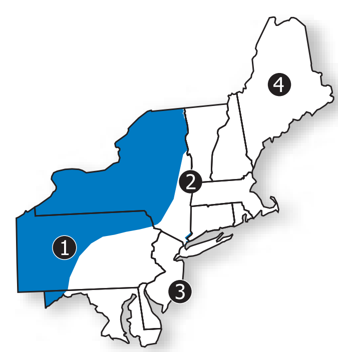
*see Rocks, p.35, for more on the formation of on* ***evaporite*** *minerals.*

***Salt*** has played a key role in the economy of upstate New York, and was the reason for the founding of cities like Syracuse, NY. The Retsof Mine near Geneseo, NY was the largest underground salt mine in the world before its collapse in 1993.

***Salt*** *is used throughout the Northeast for de-icing roads in winter and is also an important part of the chemical industry. Gypsum is mined for use in plaster and wallboard.*

## *Gemstones*

In addition to the abundance of metals and non-metallic minerals produced for industrial use in the Adirondacks, the Grenville rocks also contain the minerals tourmaline and beryl, prized as gemstones. Further south in Herkimer County, New York, in a patch of Cambrian rocks southwest of the Adirondacks, gem collectors seek out 'Herkimer diamonds.' Herkimer diamonds are not in

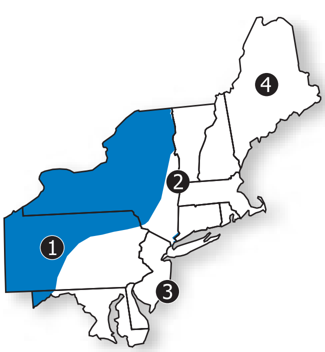


**quartz**: *$SiO_2$*

fact diamonds at all. Rather, they are very well formed, clear crystals of quartz found in the Little Falls dolostone. Dolostone is made in part of calcite, a mineral that is highly susceptible to reacting chemically with acids. The weakly acidic nature of rainwater and groundwater commonly dissolve away parts of dolostone, leaving open cavities in the rock. As groundwater, rich in silica, moved through the Little Falls dolostone, ***quartz*** crystallized in the cavities to form Herkimer diamonds.

### The many faces of quartz

*Quartz may be one of the most common minerals in the crust, but it does not always appear in the same form. There are a wide variety of different types of quartz, including coarsely crystalline and microcrystalline quartz. Several common minerals, including chert, agate and jasper, are actually varieties of quartz. Onyx, agate and petrified wood are fibrous, microcrystalline varieties of quartz known as chalcedony. Though agate is naturally banded with layers of different colors and porosity, commercial varieties of agate are often artificially colored. Flint, chert and jasper are granular microcrystalline varieties of quartz, with the bright red color of jasper due to the inclusion of small amounts of iron within the mineral structure. The most common, coarsely crystalline varieties include massive quartz veins, the distinct, well formed crystals of 'rock crystal', and an array of colored quartz, including amethyst (purple), rose quartz (pink), smoky quartz (gray), citrine (orange) and milky quartz (white).*



# Mineral Resources of the Appalachian/Piedmont

## *Region 2*

Though most of the mineral mining in the Appalachian/Piedmont stopped before the early 1900's, there are still several principal mining localities in the region producing zinc, aluminum, titanium, talc and mica *(Figure 6.9)*. Other important mineral resources of the Appalachian/Piedmont (though not currently mined) include: the kaolin of the Precambrian Grenville rocks; the Ultramafic Belt chrome and asbestos, formed from metamorphosed serpentinite when the Taconic volcanic islands collided with North America; and copper and magnetite deposits of the Triassic Rift Basin.

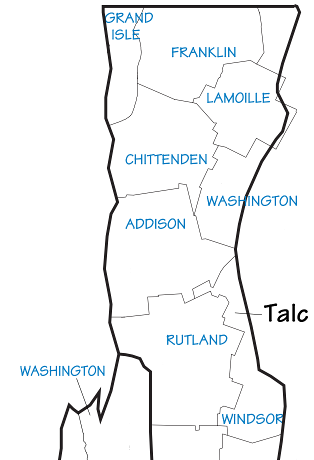
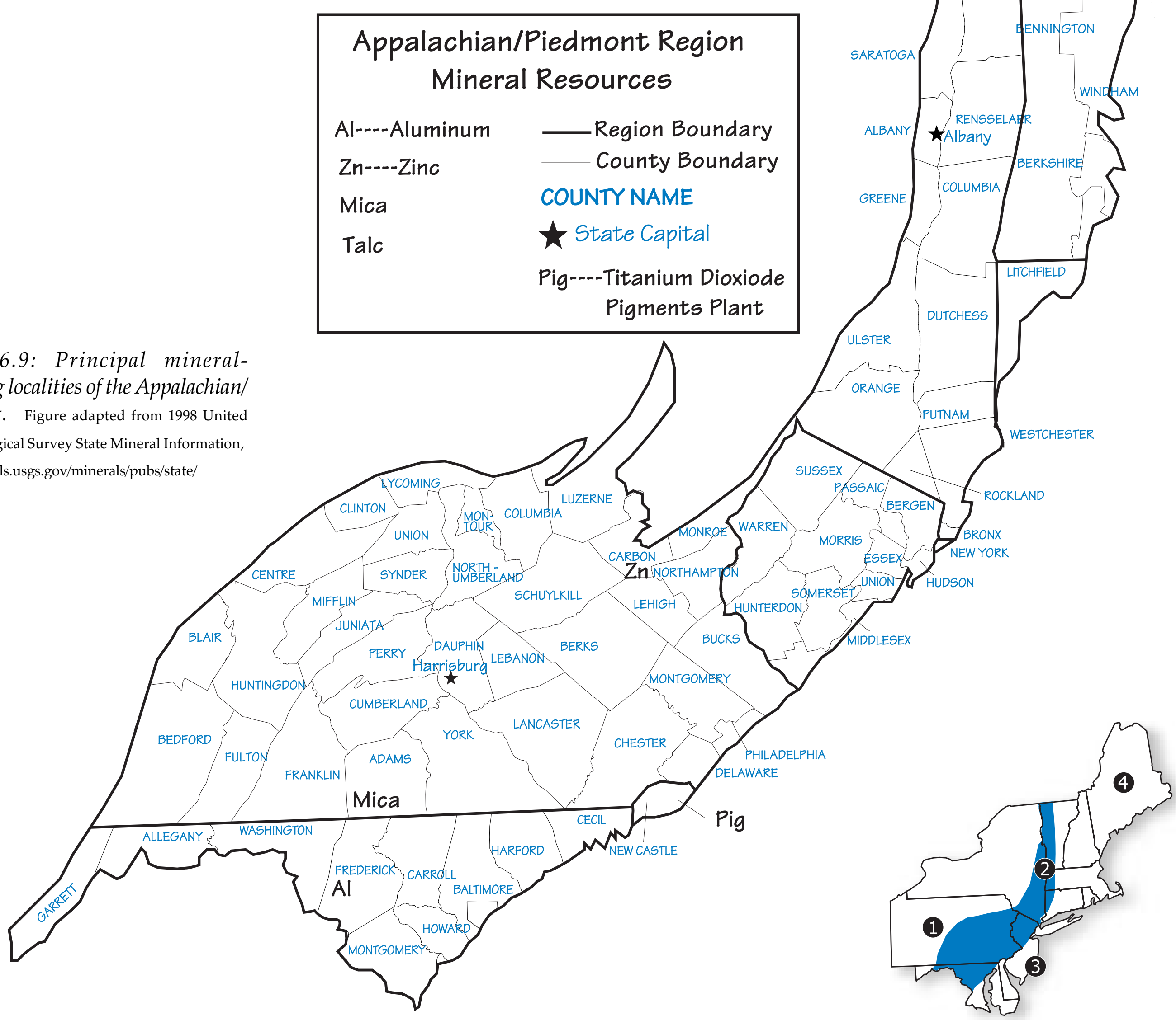




*Figure 6.9: Principal mineral-producing localities of the Appalachian/Piedmont.* Figure adapted from 1998 United States Geological Survey State Mineral Information, http://minerals.usgs.gov/minerals/pubs/state/

see Rocks, p.39, for more on the Grenville rocks.

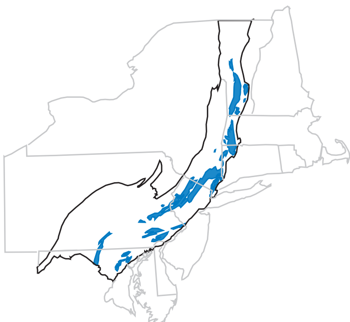


Figure 6.10: Precambrian Grenville rocks of the Appalachian/Piedmont region.

**sphalerite**: *ZnS*

***Zinc** is used in galvanized steel.*

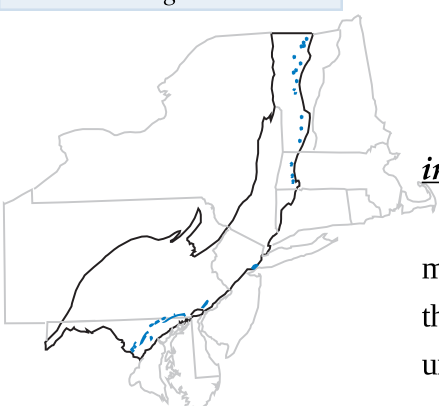
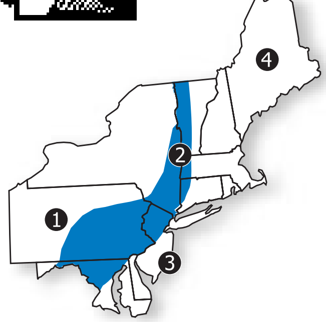


Figure 6.11: Ultramafic Belt rocks in the Appalachian/Piedmont.

see Rocks, p.42, for more on the Ultramafic Belt.




## *Metallic Minerals*

### *in Grenville Rocks*

The Precambrian ***Grenville rocks*** of the Appalachian/Piedmont region, located along the spine of the Appalachians, peek through the sedimentary rock cover such as in the Adirondacks of the Inland Basin region *(Figure 6.10)*. Associated with the Grenville rocks in Pennsylvania and Maryland are significant deposits of ***zinc*** ore, in its most common form, ***sphalerite***. At ***Franklin Furnace*** and ***Sterling Hill***, New Jersey, zinc ore in the Grenville rocks is also found, though the ore minerals are unusual.

**The Franklin-Sterling Hill mining district**

*The Franklin-Sterling Hill mining district of northern New Jersey has yielded more than 340 different kinds of minerals, more than any other known place in the world. Franklin is known as the fluorescent mineral capital of the world because 80 of the 340 minerals fluoresce, or give off light, under ultra-violet light. The two large deposits of zinc, iron and manganese contain the ore minerals franklinite (Zn, Fe, Mn)(Fe, Mn)$_2$O$_4$), unique to the area, willemite ($Zn_2SiO_4$), and zincite (ZnO). The ore deposits at Franklin are found in Precambrian Grenville marble.*

### *in Serpentine Rocks*

The ***Ultramafic Belt*** that extends the length of the Appalachian/Piedmont region from Vermont to Maryland contains a variety of minerals unique to the serpentinite rock found in the belt *(Figure 6.11)*. The serpentinite rock itself is unusual, produced from the alteration of peridotites by metamorphism. The peridotite, derived from magma from the upper mantle of the Earth, was originally part of the oceanic crust. However, as the North American tectonic plate and the Taconic volcanic islands gradually drew closer together, the intervening oceanic crust was being pushed beneath the North American plate. Some of the oceanic crust was scraped off and welded onto the side of North America as the rest of the oceanic crust was shoved down into the mantle. The peridotite of the oceanic crust was metamorphosed to form serpentinite, a rock rich in minerals not often found as part of the continental crust. A metallic mineral of note in the serpentinite rocks is chromite. The only ore of chromium, chromite was at one time mined in the Ultramafic Belt serpentinite rocks of Pennsylvania and Maryland. A dense, heavy mineral, chromite is one of the first minerals to crystallize and settle to the bottom of a cooling magma. It was thus concentrated in the serpentinite rocks in quantities sufficient to be profitably mined.

**Chromium** *is used as a component of certain pigments; as a component of steel, providing resistance and hardness; and in the production of chrome and stainless steel.*

### *in Rift Basin Rocks*

The Newark and Gettysburg Triassic rift basins of the Appalachian/Piedmont region stretch through southeastern New York, New Jersey, Pennsylvania and Maryland. Formed during the rifting of Pangea away from North America, the rift basins contain alternating layers of igneous and sedimentary rocks *(Figure 6.12)*. The resistant, ridge-forming igneous rocks, produced from lava flows (basalt) or igneous intrusions (diabase), contain mineral resources of economic importance to the region.

*Figure 6.12: Triassic rift basins in the Appalachian/Piedmont.*

*see Rocks, p.5*

In particular, ***magnetite*** is an important mineral resource in the Pennsylvania and New Jersey diabase rocks, concentrated and subsequently precipitated by hot flowing water through the rocks. Magnetite is one of the common ores of iron. ***Copper*** deposits are also associated with the basalt lavas of the rift basins.

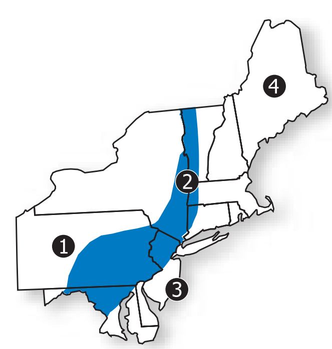
**magnetite**: $Fe_3O_4$

**Copper** *is used extensively as wiring in the electrical industry as well as in alloys such as brass and bronze. Brass is a combination of copper and zinc; bronze combines copper, tin and small amounts of zinc.*

### *in Other Rocks*

Other important metallic minerals in the Appalachian/Piedmont region include nickel, molybdenum, titanium, manganese, cobalt, and graphite. In northern Delaware, titanium is an important mineral resource associated with the igneous rocks of the area, mined commercially for use as a paint pigment. In the Piedmont, gold is found in small quantities associated with quartz veins and fault zones in the metamorphic rocks of the region. ***Sillimanite***, Delaware's state mineral, is found in the Appalachian/Piedmont region of northern Delaware as large crystals produced from aluminum-rich rocks that were deeply buried and subjected to intense metamorphism. Though the mineral is not limited to Delaware, the unusually large crystals of sillimanite found there are rare elsewhere.

**sillimanite**: $Al_2SiO_5$



### *Non-Metallic Minerals*

The Grenville and Serpentine rocks of the Ultramafic Belt, and the Rift Basins of the Appalachian/Piedmont, host a plethora of non-metallic mineral resources in addition to the metallic minerals discussed above.

**kaolinite**: $Al_2Si_2O_5(OH)_4$

*Brandon, Vermont is famous for its large deposit of the white clay* **kaolinite** *used in paint, kaopectate, linoleum, porcelain and fillers.*

#### *in Grenville Rocks*

There is an abundance of non-metallic mineral resources in the billion-year-old Grenville rocks, including mica, feldspar and quartz. Mica, a common mineral in igneous, metamorphic and sedimentary rocks, is mined in southern Pennsylvania in Adams County from the Precambrian Grenville rocks that form South Mountain. ***Kaolinite***, a white clay formed from the weathering of feldspar, is mined in Vermont.

**asbestos**: $Mg_3Si_2O_5(OH)_4$
**talc**: $Mg_3Si_4O_{10}(OH)_2$

**Asbestos** *is a very slow conductor of heat, and thus was commonly used as a fireproofing material and electrical insulation. Concerns over the health effects on the lungs of this fibrous mineral have led to its removal from most common uses.*

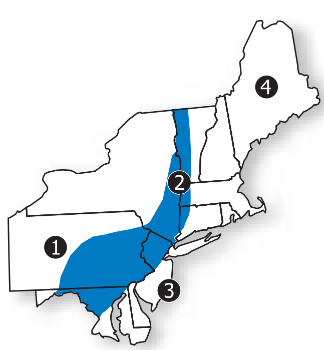
*Used in talcum powder, paint, ceramics, rubber and paper,* **talc** *is an economically valuable non-metallic mineral.*

#### *in Serpentinite Rocks*

The Ultramafic Belt of serpentinite contains at least two important associated non-metallic minerals, which commonly form through the metamorphism of the magnesium-rich rocks: ***asbestos*** and ***talc***. At one time, Vermont produced the most asbestos in the United States, though it is no longer mined there. Talc continues to be mined in Vermont today. An extremely soft mineral, talc can be scratched easily with your fingernail and has a soapy, greasy feel typical of very soft minerals.

**prehnite**: $Ca_2Al(AlSi_3O_{10})(OH)_2$

**Prehnite** *is used as a gem mineral.*




#### *in Rift Basin Rocks*

The Triassic Rift Basin of the Appalachian/Piedmont also has its share of non-metallic minerals. Basalt, formed as lava broke out of the crust and flowed across the surface of the basin, cooled quickly, trapping gas bubbles within the rock that left small cavities. Later, as water flowed through the rock, minerals were precipitated in the cavities, forming crystals such as the green mineral ***prehnite***. Paterson and Bergen Hill, New Jersey are known for this mineral.

#### *Gemstones*

In addition to the non-metallic minerals discussed above, the Appalachian/Piedmont region produces several types of gemstones. The very common mineral ***feldspar*** has several relatively rare varieties found in Pennsylvania that are sold as the gemstones sunstone and moonstone. Amethyst, smoky quartz, agate, garnet and ***beryl*** are also found in the region. Beryl is common in granites and pegmatites and comes in a variety of colors.

**beryl**: *$Be_3Al_2(Si_6O_{18})$*

*Though not found in the Northeast, the precious stone emerald is the green variety of beryl.*

**Feldspars**

*Feldspar is an extremely common, rock-forming mineral found throughout the Northeast in igneous, metamorphic and sedimentary rocks. There are two groups of feldspar: alkali feldspar (which ranges from potassium (K)-rich $KAlSi_3O_8$ to sodium (Na)-rich $NaAlSi_2O_8$) and plagioclase feldspar (which ranges from sodium (Na)-rich $NaAlSi_3O_8$ to calcium (Ca)-rich $CaAl_2Si_2O_8$). Potassium feldspars of the alkali group are commonly seen as pink crystals in igneous and metamorphic rocks, or pink grains in sedimentary rocks. Plagioclase feldspars are even more abundant than the alkali feldspars, ranging in color from light to dark. Sunstone and moonstone, gem varieties of plagioclase feldspar, are found throughout the Appalachian/Piedmont region, particularly in Pennsylvania.*

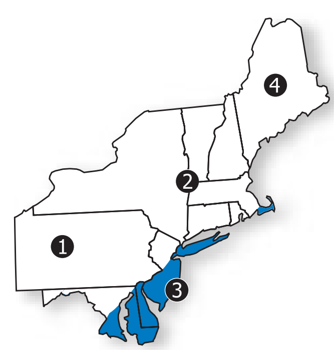
*Feldspars are commercially used in ceramics and scouring powders.*

# Mineral Resources of the Coastal Plain

## *Region 3*

The Coastal Plain region of the Northeast has very few mineral producing localities. Gypsum and magnesium compounds are the extent of the current mineral production, and kaolin was produced in the past in Maryland. The Coastal Plain, made entirely of a wedge of loose sediments (not cemented or compacted sufficiently to have become sedimentary rock), does not have the abundance of valuable minerals and ores found in igneous and metamorphic rocks, nor the proper conditions to create such minerals. Unlike the other regions, minerals are concentrated in the Coastal Plain only through density separation by streams and wave action along the shoreline.

*see Rocks, p.46, for more on the* **Coastal Plain sediments.**



# Mineral Resources of the Exotic Terrane

## *Region 4*

The formation of the igneous and metamorphic rocks that dominate the Exotic Terrane region provided the perfect conditions for spectacular concentrations of metallic and non-metallic minerals. The first chartered mining company in the US started in the Exotic Terrane region in 1709 at the Simsbury Copper Mine, Connecticut (now East Gransby, CT). Other very early mines were located in the Blue Hills along coastal Maine.

### *Metallic Minerals*

With the collision of the Taconic volcanic islands in the Ordovician, Baltica and Avalonia in the Devonian, and the final collision with Africa during the Permian, the various slices of the Exotic Terrane region have undergone significant periods of compression, deformation, metamorphism and intrusion by magmas. These dynamic geologic conditions gave rise to the formation of many metallic minerals (often associated with igneous and metamorphic rocks). Granite pegmatites, common in this area, often include uranium, gold, antimony, graphite, and iron. ***Gold***, lead, silver and copper are associated with the metamorphic rocks in the region and commonly found in association with one another.

Exceptionally fine quality crystals of ***pyrite***, 'fools gold,' are found in Chester, Vermont. A very common and widespread mineral, pyrite forms in igneous, metamorphic and sedimentary environments as well as through the chemical alteration of other minerals. Other metallic minerals and ores found in the Exotic Terrane region include molybdenum, cobalt, nickel, tin, and tungsten.

The largest manganese deposit on the North American continent is found in Maine in Silurian rocks of Aroostook County. The mildly metamorphosed Silurian rocks were once sediments at the bottom of the Iapetus Ocean. Concentrations of manganese commonly form on ocean bottoms today.

### *Non-Metallic Minerals*

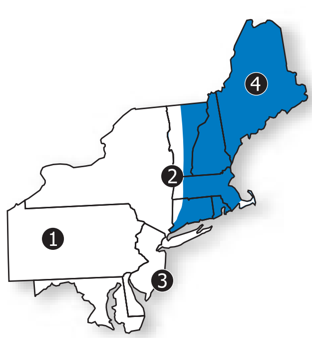
The primary non-metallic minerals of the region are metamorphic and pegmatite minerals, which are so common in the Exotic Terrane area because of the foundation of igneous and metamorphic rock.

**Gold**

*Gold (Au) has been found throughout the Exotic Terrane region as well as the Appalachian/Piedmont. However, having an average abundance in the crust of only 0.004 parts per million, gold can be profitably mined only where hydrothermal solutions have concentrated it. Gold is not found in high concentrations in the Northeast. Most often occurring in its native state (not combined with other elements), gold has been found in stream sediments in very small amounts.*

**pyrite**: *$FeS$*

**Manganese** *(Mn) is used in the production of steel.*



## *in Metamorphic Rocks*

The process of metamorphism ranges from low grade (with only mild increases in pressure and temperature) to high grade (with severe increases in pressure and temperature). Mildly deformed rocks may be subjected to very low grades of metamorphism and outwardly exhibit little change in appearance. Severely deformed rocks, on the other hand, have usually been subjected to very high grades of metamorphism and appear distinctly different. The higher the degree of metamorphism, the greater the change is to the original rock. The changes include, to varying degrees, the alignment of minerals within the rock, recrystallization of minerals, and, in many cases, the crystallization of new minerals.

Geologists have determined that specific minerals will form at specific temperature and pressure conditions when a given type of rock is metamorphosed. Low-grade metamorphism of clay-rich rocks such as shale, produce the mineral chlorite. Higher-grade increased metamorphism produces the minerals kyanite and sillimanite. The minerals associated with certain grades of metamorphism are known as index minerals, indicative of the combination of the temperature and pressure conditions a rock has undergone *(Figure 6.13)*.

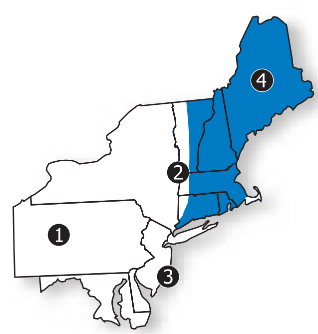
| METAMORPHIC GRADE | Clay-rich rocks | Limestone | Mafic igneous rocks |
|---|---|---|---|
| low | chlorite | chlorite | chlorite |
| ↓ | biotite | garnet | garnet |
| | staurolite | hornblende | hornblende |
| high | kyanite | augite | |
| | sillimanite | | |

resulting metamorphic minerals

*Figure 6.13: Minerals formed through varying degrees of metamorphism in different types of rocks.*

Thus, by examining the minerals found in the Exotic Terrane region, it is clear that the rocks have been metamorphosed to varying degrees. Chlorite is found in northern Maine, indicating that the rocks were only mildly deformed because they were not the center of the collision between continents and have fewer igneous intrusions. Eastern New Hampshire and southern Maine, however, clearly show evidence of high-grade metamorphism by the presence of minerals such as sillimanite and kyanite.

Considering the plate tectonic history of the Exotic Terrane region, the



*The Taconic, Acadian and Alleghanian mountain-building events repeatedly compressed and deformed the rocks of the Northeast.*

*The grade of metamorphism generally decreases to the west, with variation due in part to contact metamorphism by intrusions of magma.*

*see Minerals, p. 134 for more on* **garnet.**

presence of ***high-grade*** metamorphism in the rocks is no surprise. The rocks with high-grade metamorphic minerals indicate the area of greatest stress during the episodes of mountain building throughout the Paleozoic, as well as areas that have been intruded by magma.

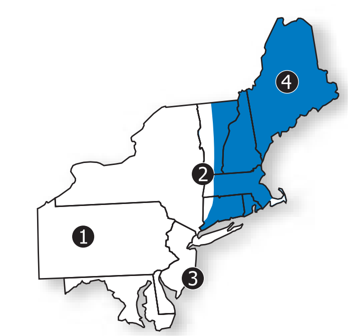
***Garnet***, a metamorphic mineral indicative of moderate metamorphism, is found throughout the Exotic Terrane region. Connecticut has spectacular garnets in the metamorphic rock, mica schist. Garnet is used as a gemstone and an abrasive in sandpaper and polishing. The substitution of different elements into the crystal structure produces several common types of garnets, all of which have the same basic chemical composition: uvarovite, pyrope, andradite, almandite, grossularite and spesartite. Almandite is particularly common in Connecticut.

## *Gemstones and Other Non-Metallic Minerals*

The plate tectonic history of the Exotic Terrane region provided the right conditions to produce slow-cooling magmas far below the surface. Volatiles escaping from those deep magma chambers, enriched in water and rare elements, led to the creation of outstanding pegmatites: lithium pegmatites in Massachusetts; phosphate pegmatites in New Hampshire; and the famous gem-quality tourmalines and beryl of Maine. The first Maine tourmaline, and the start of gemstone production in the United States, was mined at Mt. Mica, where crystals have been found as large as 39.4 cm long, 17.8 cm wide and weighing 14.3 kg. Many minerals in a pegmatite are common and not gem quality, such as quartz, mica, and feldspar. However, gemstones frequently are found in association with ***pegmatites***. Other gemstones found in the Exotic Terrane region include garnet, zircon, topaz, corundum, feldspar, and quartz varieties including jasper, rock crystal, amethyst, and smoky, rose and clear quartz.

*see Rocks, p.52 for more on* **pegmatites.**

**Pegmatites** *often contain rarer minerals such as lithium, beryllium, uranium, lepidolite, spodumene, apatite, and fluorite, in addition to the more common quartz, feldspar, and mica.*



# Activities

1. A family friend from Luxembourg, rich from generations of family-owned mining businesses, has an enormous collection of exotic mineral ores from countries worldwide. She takes an interest in the fact that you are studying northeast U.S. geology and says she'd like to give you a summer job tracking down mineral resources for her collections from the Northeast U.S. She asks what it would take financially for her to be able to hire you for the job. Coming from a line of business people, she wants your estimates written out and itemized.

*Assuming you can collect your own examples of mineral resources, plot out a travel course to take you to as many sites as you could visit during one summer and list the minerals you could collect. Find the shortest possible route to find as many minerals as possible. Also explain, for her educational benefit, the age and geologic context in which each formed using the following events:*

(1) the Grenville passive margin
(2) the Taconic converge,
    (2a) interval (Silurian-Early Devonian) between Taconic and Acadian
(3) the Acadian convergence,
    (3a) interval (Mississippian-Early Permian) between Acadian and Alleghenian
(4) the Alleghenian convergence,
(4a) interval (Early-mid Triassic) between Alleghanian and rifting
(5) the rifting apart of Pangea, and
    (5a) interval (mid-Jurassic-late Jurassic) between rifting and creation of Coastal Plain
(6) the Coastal Plain passive margin and shaping by erosion of many of current land-forms
(7) Pleistocene glaciation and Holocene post-glacial

2. Your friend grows interested in the number of mineral resources in the Northeast, and wonders if there are any potentially financially lucrative mining operations in your local area. Although you make it known that your community must consider environmental implications of future mining, you do agree to look for some background information on the Web and in the library.

*Based on figures from the NE Guide or elsewhere, figure out (a) what has been mined in your area and (b) explain in a letter to your friend how these minerals relate to your local geological history.*

3. Through her connections, a European geographer grows interested in the amount of experience you have accumulated tracking down mineral resources. He wonders if the northeast might be self-sufficient in mineral resources, which would have implications for understanding the economy and human history of the Northeast. He says he will hire you for the next summer to help him in his research.

*Using an almanac or other resources and your creativity, estimate as best you can which minerals are abundant enough to supply the Northeast and which are not. Predict if this has changed over the last 200 years. Describe how the varied geology contributed to the variety of minerals, and similarly explain the absence of any prominent minerals from the area.*

# For More Information...

## Books

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Jensen, D.E., 1978, *Minerals of New York State*, Ward Press: Rochester, New York.

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Thompson, W. B., D. L. Joyner, R. G. Woodman, and V. T. King, 1998, *A Collector's Guide to Maine Mineral Localities*, 3rd ed., Maine Geological Survey: Augusta, Maine.

## Internet

Atlas of Igneous and Metamorphic Rocks, Minerals & Textures
http://www.geolab.unc.edu/Petunia/IgMetAtlas/mainmenu.html

Franklin Minerals
http://simplethinking.com/franklinminerals/

International Colored Gemstone Association
http://gemstone.org/index.html

The Mineral Gallery
http://mineral.galleries.com/

Mineral Industry Surveys
http://www.liccini.com/Mining/Overview.htm

Mineral Information Institute
http://www.mii.org

Mineral Resources for Teachers
http://www.womeninmining.org/

National Mining Association
www.nma.org

Smithsonian Gem and Mineral Page
http://www2.galaxy.com/images/gems/gems-icons.html

Sterling Hill Mining Museum
http://sterlinghill.org

State Gems and Minerals
www.jewelrymall.com/stategems.html

State Mineral Statistics and Information
http://minerals.usgs.gov/minerals/pubs/state/

## Other Resources

***used in compiling this chapter***

Klein, C. and C.S. Hurlbut, Jr., 1993, *Manual of Mineralogy*, John Wiley and Sons, Inc.: New York, New York.

Skinner, Brian J., 1989, *Mineral Resources of North America*, vol. A, The Geological Society of America: Denver, CO.

Skinner, Brian J. and Stephen C. Porter, 1987, *Physical Geology*, John Wiley and Sons: New York, New York.

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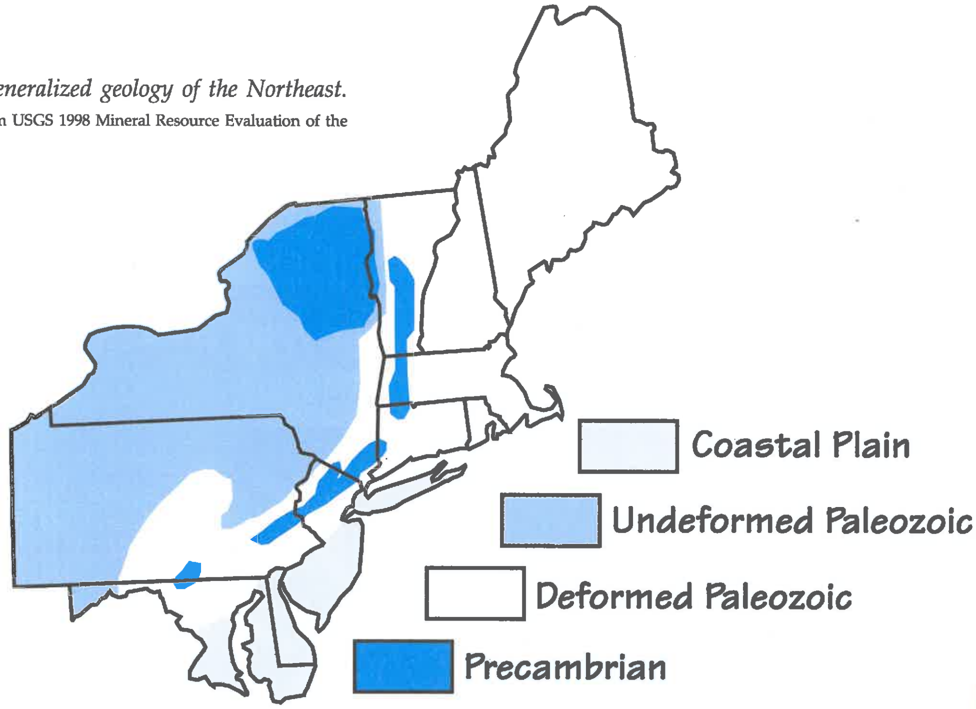
Denver, CO 80202
(303) 297-3226

# Selected Figures

## *for overheads & handouts*

*Figure 6.2: Generalized geology of the Northeast.* Figure adapted from USGS 1998 Mineral Resource Evaluation of the Northeastern U.S.



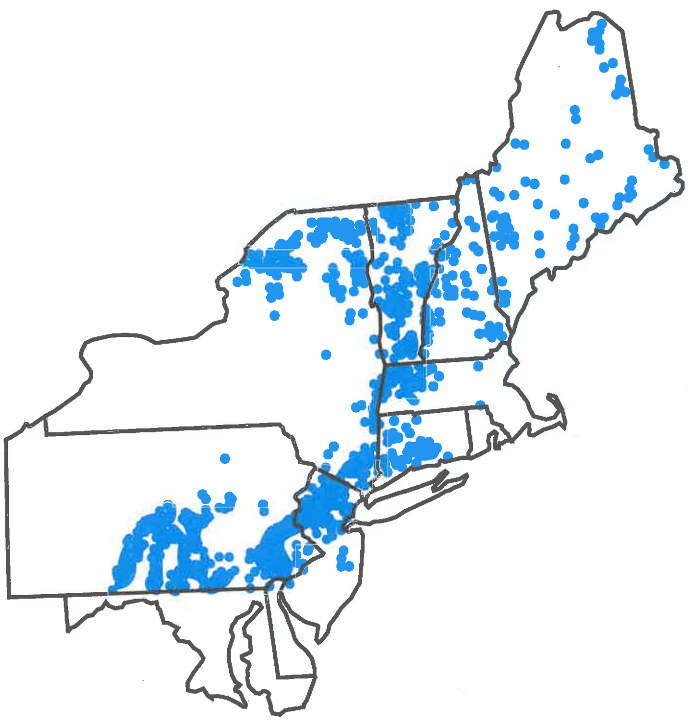



*Figure 6.3: Distribution of metallic mineral deposits of the Northeast. No data available for Maryland or Delaware.* Figures adapted from USGS 1998 Mineral Resource Evaluation of the Northeastern U.S.

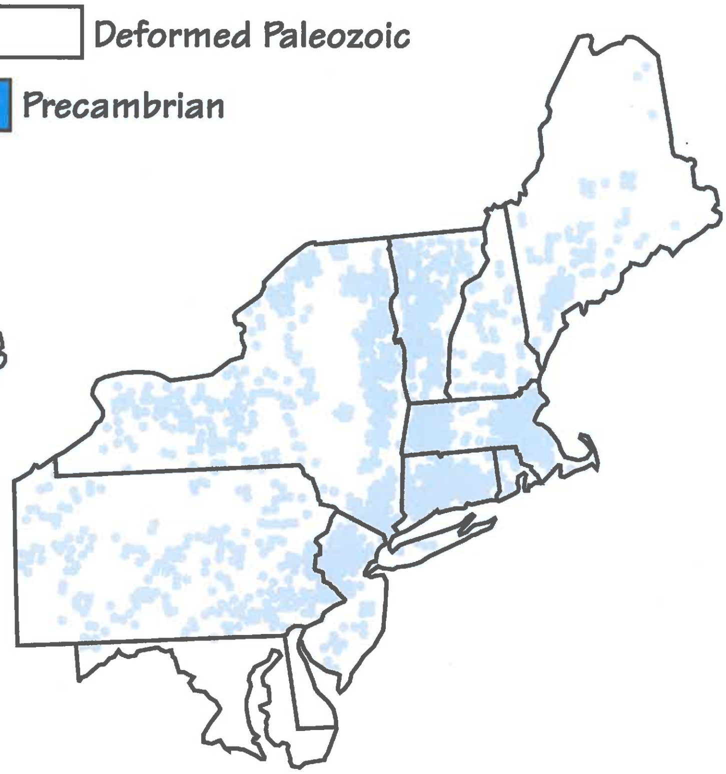
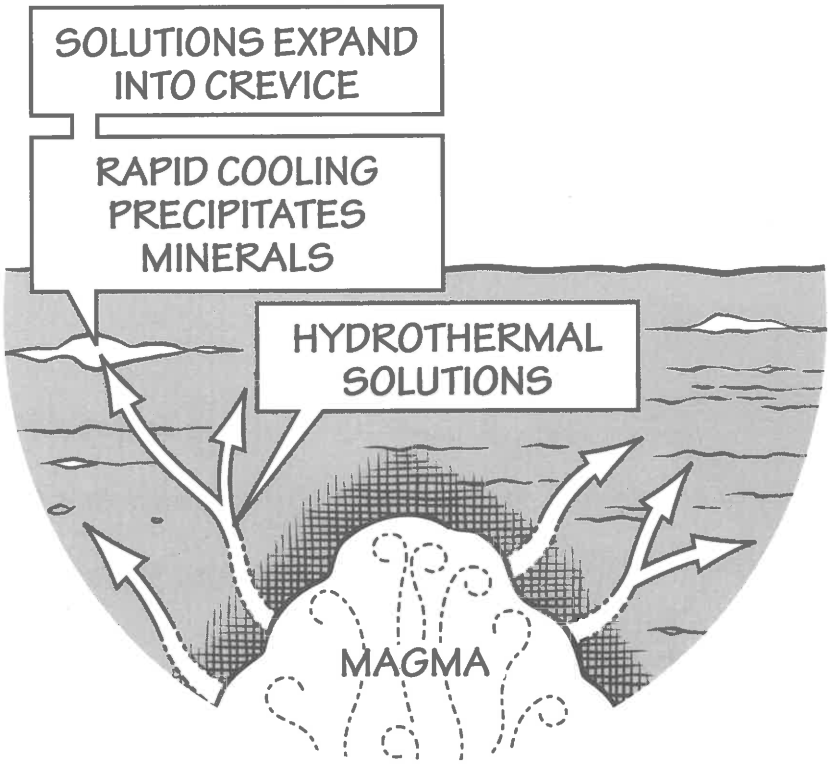
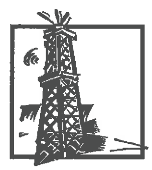


*Figure 6.4: Distribution of non-metallic mineral deposits of the Northeast. No data available for Maryland or Delaware.*




*The process of mineral crystallization from hydrothermal solutions.*

# Non-Mineral Resources of the Northeastern US: *the BIG picture*

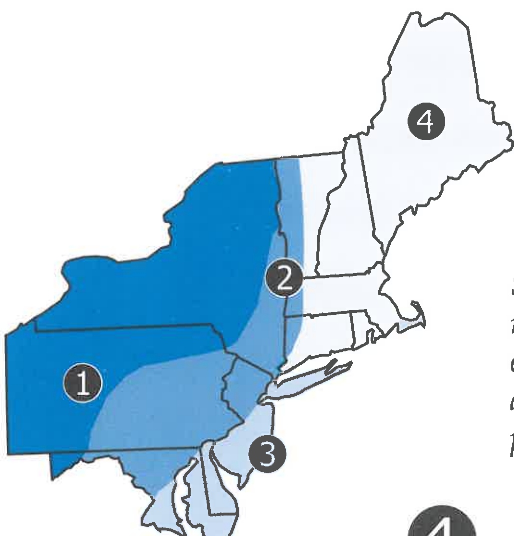


## 1 Inland Basin

*The sedimentary rocks of the Inland Basin provide dimension stone, industrial sand, cement, concrete, clay and carbonate rock, economically important regional resources. The metamorphic rocks of the Adirondacks are quarried for use as dimension stone. The region also has sizeable fossil fuel resources, including bituminous coal, oil and gas.*

## 2 Appalachian/Piedmont

*The Appalachian/Piedmont has a variety of non-mineral resources because of the variety of rock types within the region. Sedimentary rocks produce clay, lime, crushed stone, industrial sand and brownstone. Metamorphic rock resources include marble, slate and serpentine. The Triassic rift basins in the region produce the igneous rock diabase for use as a dimension stone. Anthracite, the hardest form of coal, is also found in the folded rocks of the region.*




## 3 Coastal Plain

*Sand and gravel, greensand, and soil are the most important non-mineral resources of the Coastal Plain. Because a wedge of unconsolidated sediments underlies the Coastal Plain, there are no igneous, metamorphic or sedimentary rock resources produced in the region.*

## 4 Exotic Terrane

*The primary non-mineral resources of the Exotic Terrane are very similar to the Appalachian/Piedmont region because of similar rock types. Brownstone, clay, shale, cement and crushed rock are important sedimentary rock resources. Granite, from numerous igneous intrusions during the Taconic and Acadian mountain-building events, and quartzite, a metamorphic rock, are quarried throughout the region.*

**Glacial:** *All four regions of the Northeast have glacial deposits that provide important non-mineral resources, including clay, peat, soil, sand and gravel.*

# Non-Mineral Resources of the Northeastern US:

Non-mineral resources include: the sedimentary, igneous and metamorphic rock that we quarry for buildings, monuments, construction and decoration; deposits from the glaciers that covered much of the Northeast over the last two million years, such as clay, peat, sand and gravel; and the soil, which provides the nutrients and minerals for crops, forests and grasslands. Non-mineral resources also encompass the fossil fuels: coal, oil and gas. Just as minerals are vital to the economy and functioning of modern civilization, so too are the non-mineral resources found in the Northeast. According to the Mineral Information Institute, every American born will need in a lifetime, on average, 3.75 million pounds (1.7 million kilograms) of natural resources, including minerals *(Figure 7.1)*. The maps in this chapter depict the principal non-mineral resources currently being mined in each region of the Northeast.

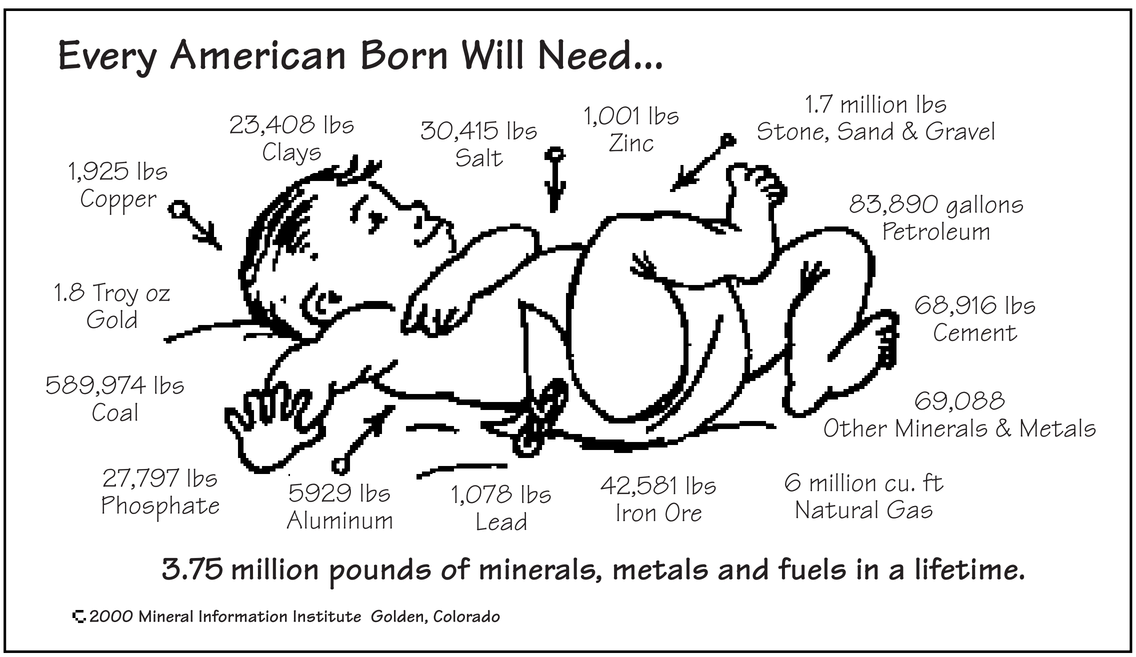
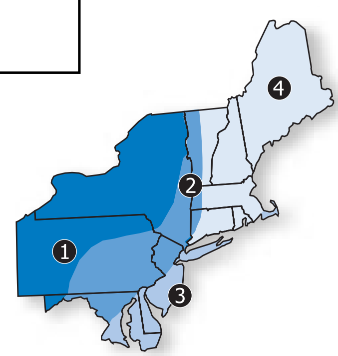


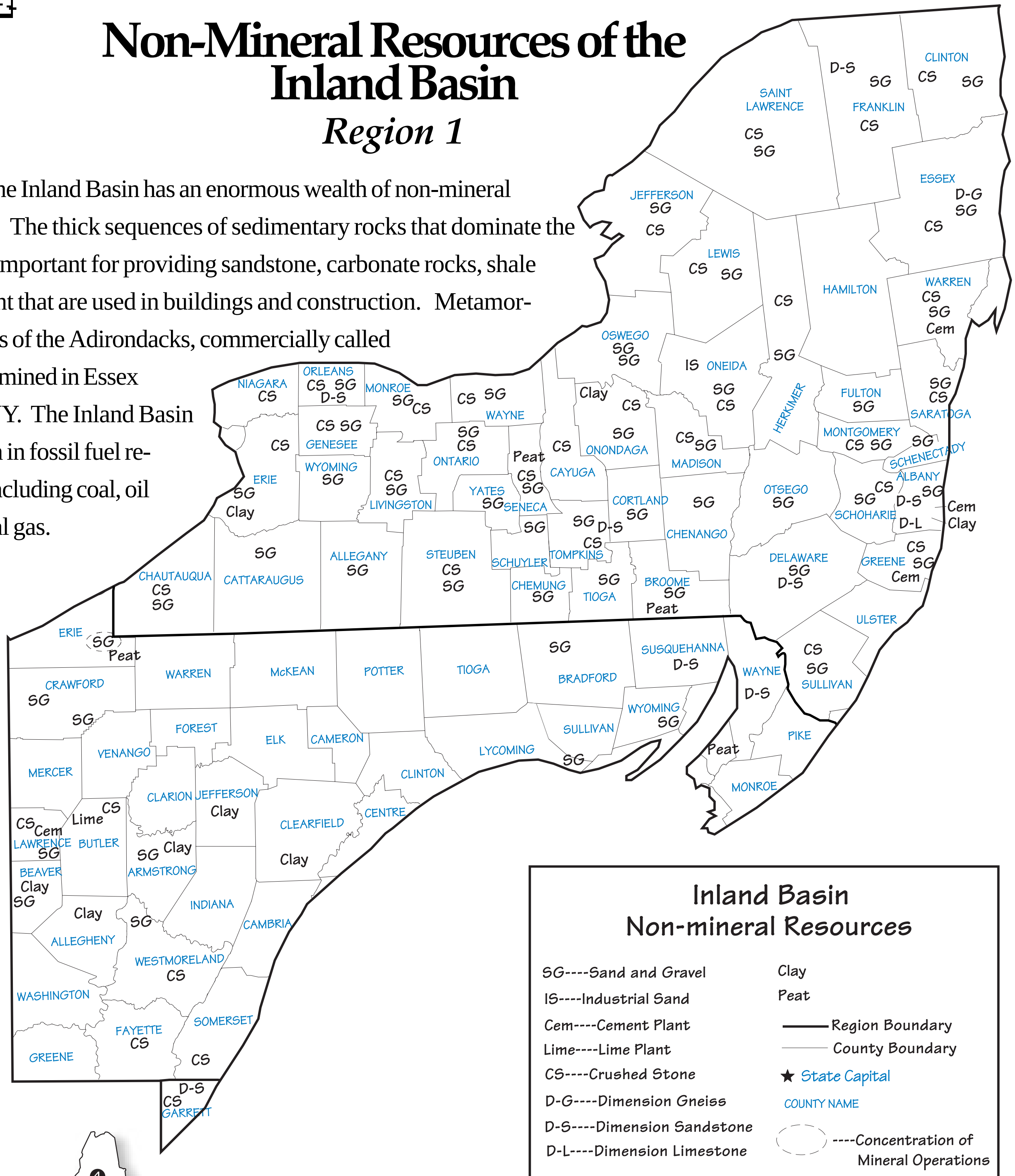

*Figure 7.1: Mineral Information Institute mineral and non-mineral resources statistics.*



# Non-Mineral Resources of the Inland Basin

## *Region 1*

The Inland Basin has an enormous wealth of non-mineral resources. The thick sequences of sedimentary rocks that dominate the basin are important for providing sandstone, carbonate rocks, shale and cement that are used in buildings and construction. Metamorphic gneiss of the Adirondacks, commercially called granite, is mined in Essex County, NY. The Inland Basin is also rich in fossil fuel resources, including coal, oil and natural gas.



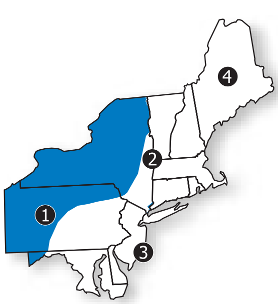



*Figure 7.2: Principal non-mineral resource-producing localities of the Inland Basin.* Figure adapted from 1998 United States Geological Survey State Mineral Information, http://minerals.usgs.gov/minerals/pubs/state/

## *Sedimentary Rock*

The sandstone, siltstone and shale of the Inland Basin were formed by the Queenston and Catskill ***Deltas*** in the Ordovician and Devonian, and were composed of sediments eroding into the inland ocean from the successive Taconic and Acadian Mountains. As relative sea level rose and fell, different sediments were deposited in a given area. The shale represents deeper, quieter water; siltstone and sandstone represent shallower water and a more energetic environment. During periods when less sediment was being carried into the inland ocean, limestone and dolostone (carbonate rocks) formed.

*see Geologic History, p.7 and 12, for more on* **deltas.**

Sandstone is quarried throughout the Inland Basin region as a ***dimension stone***. The most famous dimension sandstone of the region is bluestone, found in northeastern Pennsylvania and the Catskills of New York. These well-laminated sandstones with distinct horizontal bedding are called 'bluestone' because the mineral feldspar lends a bluish-tint to the rock, though a variety of colored sandstones are now commercially sold as bluestone. The bluestone industry dates back to the 1800's, and quickly grew until bluestone became commonly used throughout the Northeast as flagstones, sidewalks, curbs, building stones and patios. The industry has gradually declined since its peak in the late 1800's, and now cement has taken the lead economically.

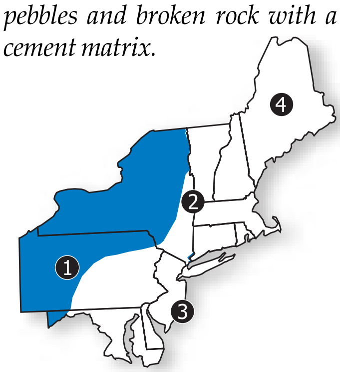
**Dimension stone** *is the commercial term applied to quarried blocks of rock cut to specific dimensions and used for buildings, monuments, facing and curbing.*

Industrial sand, though once taken from surficial deposits left by the glaciers, is now produced from crushed sandstone or quartzite. Industrial sand, primarily composed of quartz (silica), is distinguished from glacial sand and gravel deposits, which are less uniform in composition. Industrial sand is important for sandblasting, filter sand, making bricks for furnaces and ovens, mixing with clay to make metal castings, and manufacturing glass. Limestone and dolostone, used in agriculture, the chemical industry, and construction, are also important components of ***cement*** and ***concrete***. In some areas, limestone is also quarried as a dimension stone for buildings and facings.

*There are two varieties of* **cement:** *natural and Portland cement. Both types incorporate limestone. Natural cement uses limestone with a particular amount of clay that hardens into a cement. Portland cement is made through a heated combination of limestone with other rocks and minerals.*

**Concrete** *consists of gravel, pebbles and broken rock with a cement matrix.*

Used in the steel and glass industries and for pottery and bricks, clay has also long been an important natural resource of the Inland Basin region. The extremely fine-grained, smooth nature of pure clay, which makes it ideal for these purposes, is a result of its environment of deposition. Clay-sized particles do not settle unless the water is a very low energy environment. Thus, the main sources of clay are glacial lake bottoms and the marine shales of the westward reaches of the Paleozoic inland ocean.



**Granite** *is an igneous rock and gneiss is a metamorphic rock, though they are often lumped together under the name 'granite' for commercial uses.*

*see Geologic History, p. 4, 6 and 10*

*Coal, oil and gas are all are made of the remains of plants and animals, hence the term* ***'fossil fuels.'***

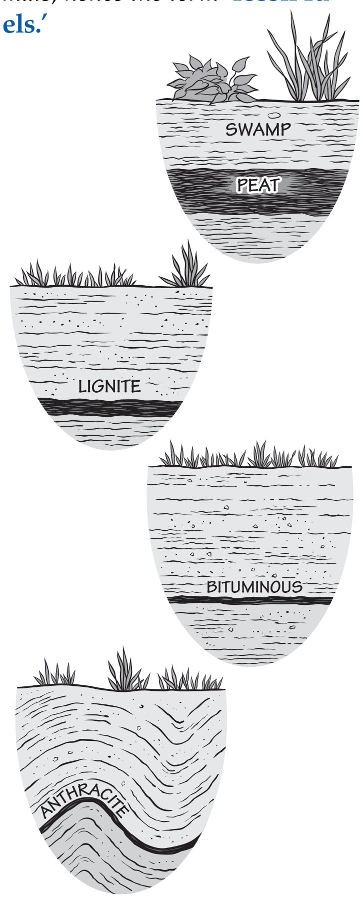
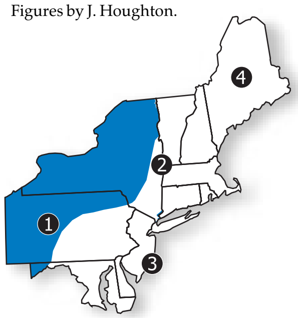



*Figure 7.3: The formation of coal.*

Figures by J. Houghton.




## *Metamorphic Rocks*

Though sold commercially as '***granite,***' Precambrian Grenville gneiss of the Adirondacks is quarried in Essex County, New York for use as dimension stone. The gneiss formed from the metamorphism of Grenville sedimentary rocks, deposited in the Iapetus Ocean.

## *Fossil Fuels*

Fossil fuels include coal, oil and natural gas; the Inland Basin produces all three. These fossil fuels are clearly important to our economy and standard of living, providing the fuel we need for heating, cooling, cooking, driving and operating in everyday life.

The abundance of plant material in swamps, bogs and marshy areas makes these environments ideal for the formation of coal. As sediment is flushed into the swamp by water, plant material is buried. Bacterial decay of large quantities of plant material uses up available oxygen, causing aerobic decay rates to drop. In non-swampy conditions, running water replenishes oxygen to the bacterial community, and plant material rots away. As organic material gets buried more and more deeply, pressure on it builds from overlying sediments, squeezing and compressing the peat. Coal becomes successively more enriched in carbon as water and other components are squeezed out: peat becomes lignite, bituminous and eventually anthracite coal, which contains up to 95% carbon. Found in deformed rocks, anthracite is the cleanest burning of the four types of coal, because it has the highest amount of pure carbon. By the time a peat bed has been turned into a layer of anthracite, the layer is one-tenth its original thickness *(Figure 7.3)*.

In the Inland Basin, only Pennsylvania and Maryland have layers of coal. However, the Inland Basin coal is the northernmost extent of a long expanse of coal that stretches down the Allegheny Plateau the length of the Appalachians. The existence of coal in the region is a result of the inland ocean formed from the Acadian mountain-building event in the Devonian period. The inland sea became increasingly shallow as sediment from the Acadian Mountains filled in the ocean basin and worldwide sea level gradually dropped. Widespread coastal wetlands, river floodplains, and swampy areas were perfect for the accumulation of dead plant material, which was later compressed enough to become bituminous

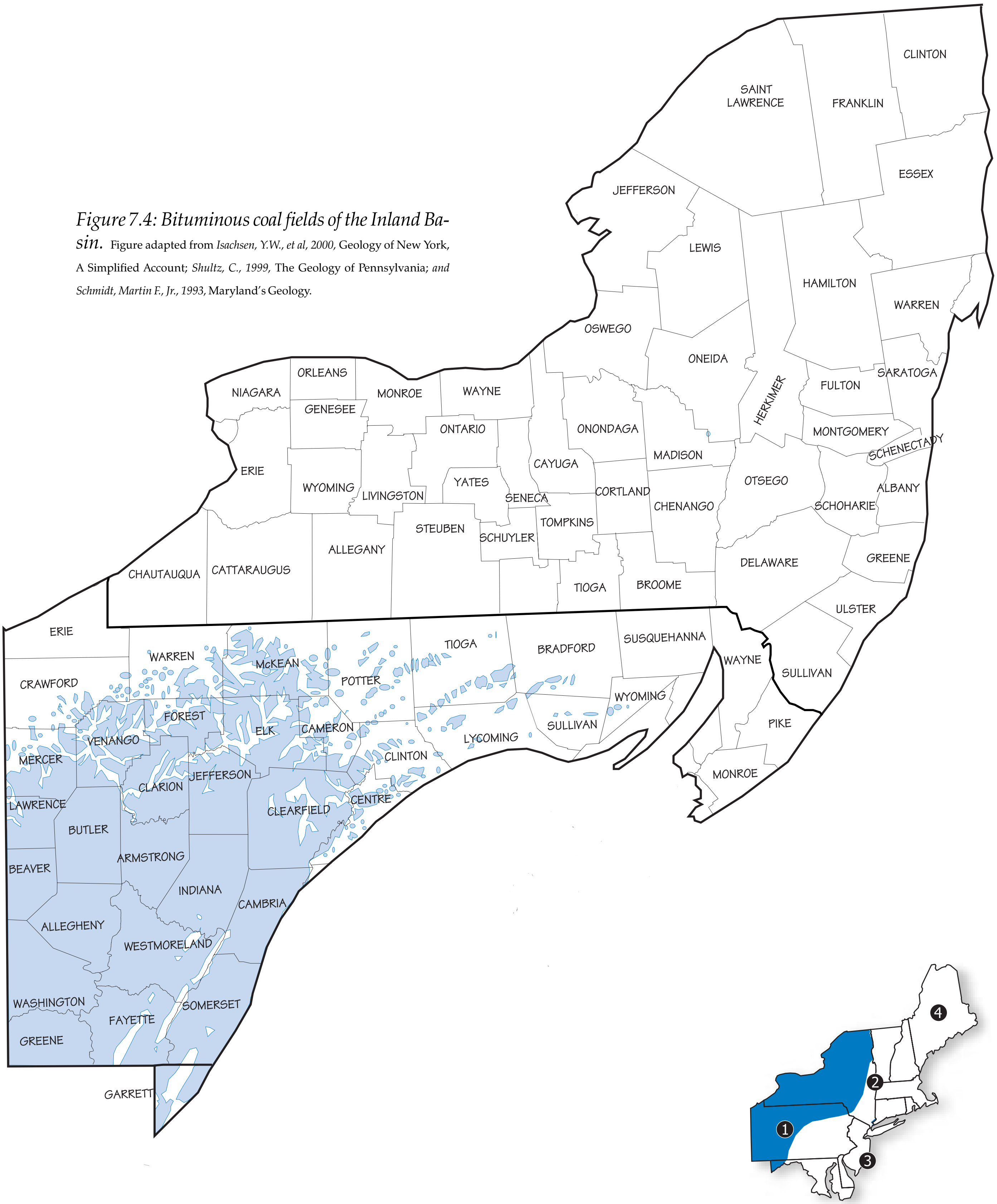



*Figure 7.4: Bituminous coal fields of the Inland Basin.* Figure adapted from *Isachsen, Y.W., et al, 2000,* Geology of New York, A Simplified Account; *Shultz, C., 1999,* The Geology of Pennsylvania; *and Schmidt, Martin F., Jr., 1993,* Maryland's Geology.

see *Fossils*, *p.5*

coal. Plants had only just arrived on the scene during the Silurian period. Diversification and evolution of plants was rapid, leading to a proliferation of swamp loving land plants during the Pennsylvanian, when the coals from the Inland Basin formed. During the Pennsylvanian, a tropical climate prevailed because the Northeast was at the equator. Globally, Pennsylvanian-age rocks produce more than 80% of the world's coal.

*Coal is not usually found as a single bed. More often one sees repeated cycles of coal layers and sedimentary rock layers. These cycles are called 'cyclothems,' and are evident in the coal-rich area of the Inland Basin region.*

Coal cyclically alternates with other sedimentary rocks during the Pennsylvanian. This cyclicity in sedimentation reflects cyclicity in sea level, repeatedly creating and submerging coastal environments appropriate for coal formation. Because the Inland Basin was not severely deformed and compressed, the coals of Maryland and Pennsylvania are bituminous, unlike the ***anthracite*** coal found further east in the intensely folded Appalachian/Piedmont region *(Figure 7.4)*. Strip-mining is the primary means employed in the extraction of coal in the Inland Basin coal beds. The overlying layers of rock are stripped away and flat-lying coal layers are mined directly at the surface or outcropping.

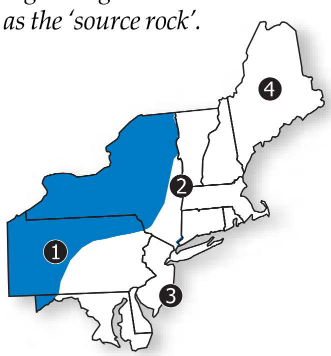
*see Non-Mineral Resources, p.162, for more on* **anthracite.**

*Coal is used for more than just heating and generating electricity. It is also used in plastics, synthetic rubber, fertilizer, cosmetics, medicine, paint and dyes. Additionally, bituminous coal is important in the steel and glass industry coking process in which bituminous coal is heated to very high temperatures in a low-oxygen environment. The result is a residue of fused carbon and ash used in blast furnaces.*

Coal, oil and gas are all made of organic matter. The differences in the kinds of organic matter determine which type of fossil fuel is formed. Coal tends to be formed from land plants, accumulating in swampy areas. Oil, on the other hand, is made primarily of phytoplankton, bacteria and plant material from the ocean. Coal remains solid because of the nature of the land plant material, whereas the marine organic material transforms under high heat into oil and natural gas. Natural gas, primarily made of methane, forms either alone or in association with coal and oil, when high temperatures transform solid organic material to a gas.

Unlike coal, which forms and stays in one place, oil and gas form in one place and then migrate to another. Organic material from marine plants and animals becomes buried under increasing amounts of sediments that squeeze and heat up the organic material over time. The sediments containing the organic material eventually become ***sedimentary rock***, commonly shale. The oil and gas generally do not stay in the rock that originally contained them because they tend to migrate upwards through cracks and permeable rocks to the surface where there is less pressure. If the oil and gas reach the surface, they evaporate into the atmosphere or are broken down chemically. However, if they are somehow trapped below the surface, the oil and gas pool within the rock. An impermeable

*The* **sedimentary rock** *containing the organic material is known as the 'source rock'.*



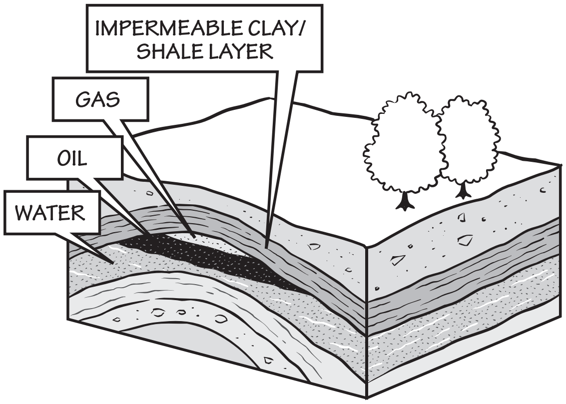



Figure 7.5: Folds act as traps for oil and gas. Figure by J. Houghton.

layer, such as shale, is what halts the oil and gas ***migration*** to the surface. To pool the fossil fuels, in addition to an impermeable layer, a trapping mechanism is necessary. Folds or faults in rock layers are common trapping mechanisms *(Figure 7.5)*.

*The rock to which the oil and gas* ***migrate*** *is called the reservoir rock.*

## Permeable vs. impermeable rocks

*Rocks that are permeable allow fluids and gas (such as water, oil and natural gas) to move through the rock. Fractures within the rock and spaces between the grains of a rock are pathways for fluids and gas. Sandstone, limestone and fractured rocks generally are permeable rocks. Shale, on the other hand, is usually impermeable because the small, flat clay particles that make up the rock are tightly packed into a dense rock with very little space between particles. Poorly sorted sedimentary rocks may also be impermeable because the smaller grains fill in the spaces between the bigger grains, restricting the movement of fluids and gas (Figure 7.6).*

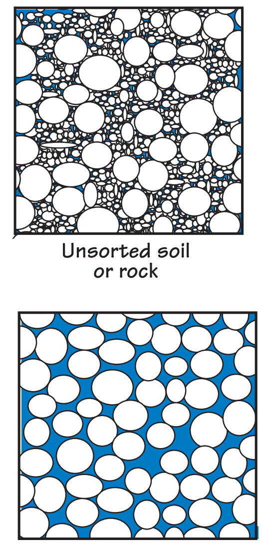
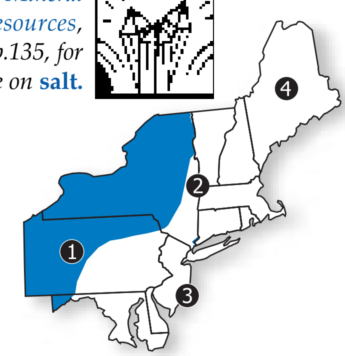



*Figure 7.6: Sorted and unsorted soil or rock affects porosity and permeability.*

The Inland Basin has the combination of features necessary for the formation and trapping of oil and gas. The source of the oil and gas in the Inland Basin is the accumulation of dead plants, animals, phytoplankton and bacteria that were deposited on the floor of the inland ocean and buried by sediments. As the organic material was increasingly more deeply buried, it was squeezed and heated to become oil and gas and subsequently migrated upwards. The Devonian Oriskany Sandstone, a well-sorted sandstone that has excellent permeability and that is overlain by an impermeable layer, has provided a reservoir rock in which oil and gas pooled. The gentle folds of the region, formed during the Paleozoic mountain-building events, are excellent traps for oil and gas. The layers of ***salt*** found beneath Devonian rocks were instrumental in the folding of the overlying rock layers. Layers of salt beneath the surface are easily deformed by the weight of overlying rocks. Just as oil and gas try to migrate upward, so do layers of salt. As salt pushes upward, it warps and folds the overlying rocks. The folds provide traps for the migrating oil and gas.

*The* ***salt*** *in the Inland Basin region was deposited during the Silurian when shallow water and poor circulation caused the evaporation of water and precipitation of layers of salt.*

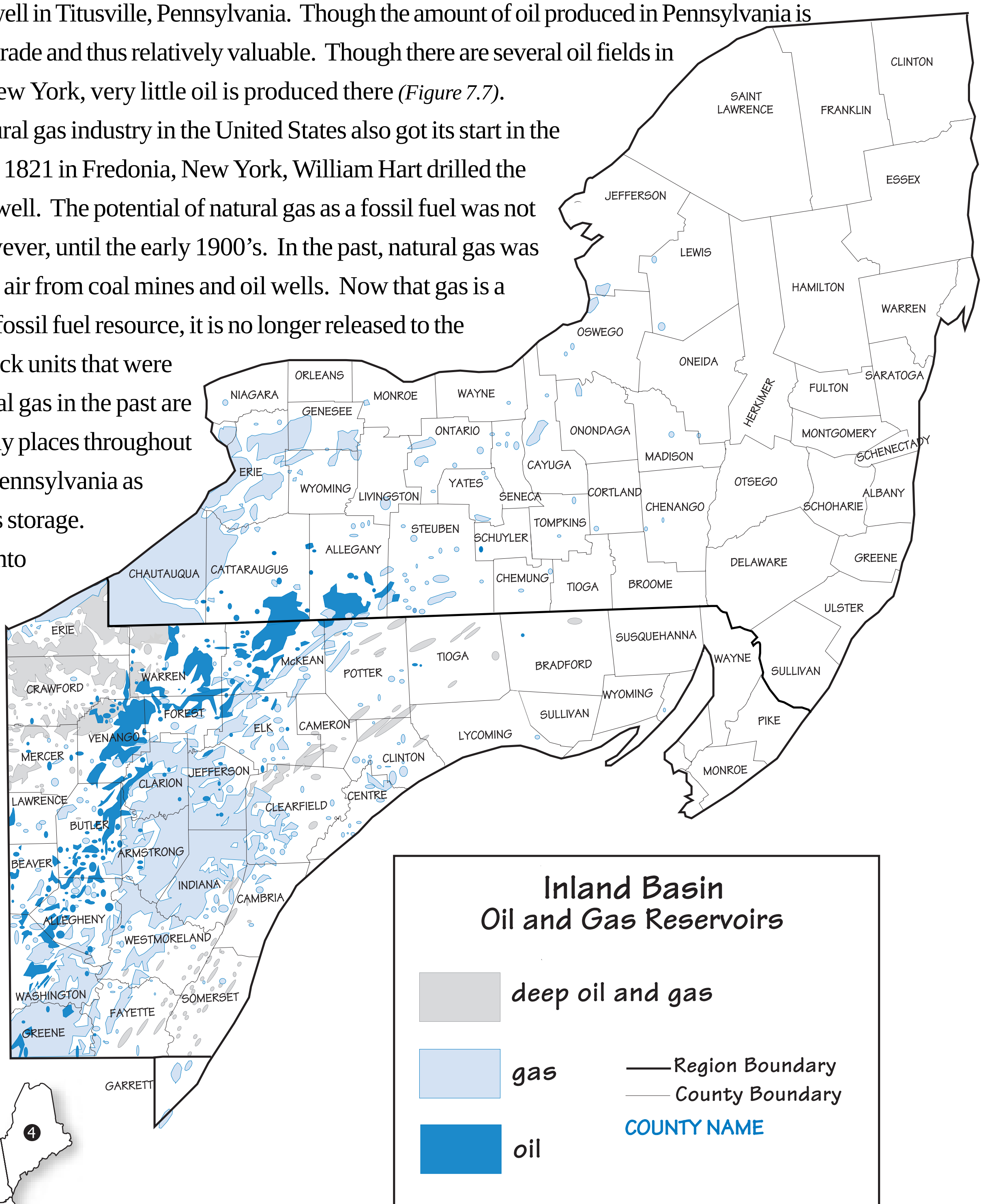
*see Mineral Resources, p.135, for more on* ***salt.***



# Non-Mineral Resources

The oil industry got its start in the Inland Basin. In 1859, Colonel Edwin Drake drilled the world's first commercial oil well in Titusville, Pennsylvania. Though the amount of oil produced in Pennsylvania is small, it is high grade and thus relatively valuable. Though there are several oil fields in southwestern New York, very little oil is produced there *(Figure 7.7)*.

The natural gas industry in the United States also got its start in the Inland Basin. In 1821 in Fredonia, New York, William Hart drilled the first natural gas well. The potential of natural gas as a fossil fuel was not recognized, however, until the early 1900's. In the past, natural gas was released into the air from coal mines and oil wells. Now that gas is a frequently used fossil fuel resource, it is no longer released to the atmosphere. Rock units that were sources of natural gas in the past are now used in many places throughout New York and Pennsylvania as underground gas storage. Gas is pumped into the rock in summer, and removed in winter for use as heating fuel.



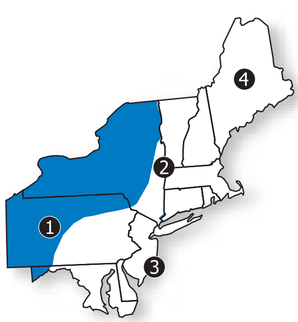
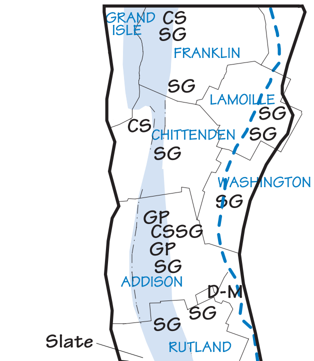




*Figure 7.7: Oil and gas fields of the Inland Basin.* Figure adapted from *Isachsen, Y.W., et al, 2000,* Geology of New York, A Simplified Account; *Shultz, C., 1999,* The Geology of Pennsylvania; *and Schmidt, Martin F., Jr., 1993,* Maryland's Geology.

# Non-Mineral Resources of the Appalachian/Piedmont

## *Region 2*

The Appalachian/Piedmont region has a diverse assortment of non-mineral resources because of the diverse rocks in the region *(Figure 7.8)*. The sedimentary rock non-mineral resources include the brownstone of the Triassic Rift Basins, as well as clay, lime, crushed stone and industrial sand. Diabase is an igneous rock resource. Metamorphic rocks, such as marble, the serpentinite of the Ultramafic Belt, and slate, are important to the regional economy. Additionally, the Appalachian Piedmont has the fossil fuel anthracite, a form of coal.



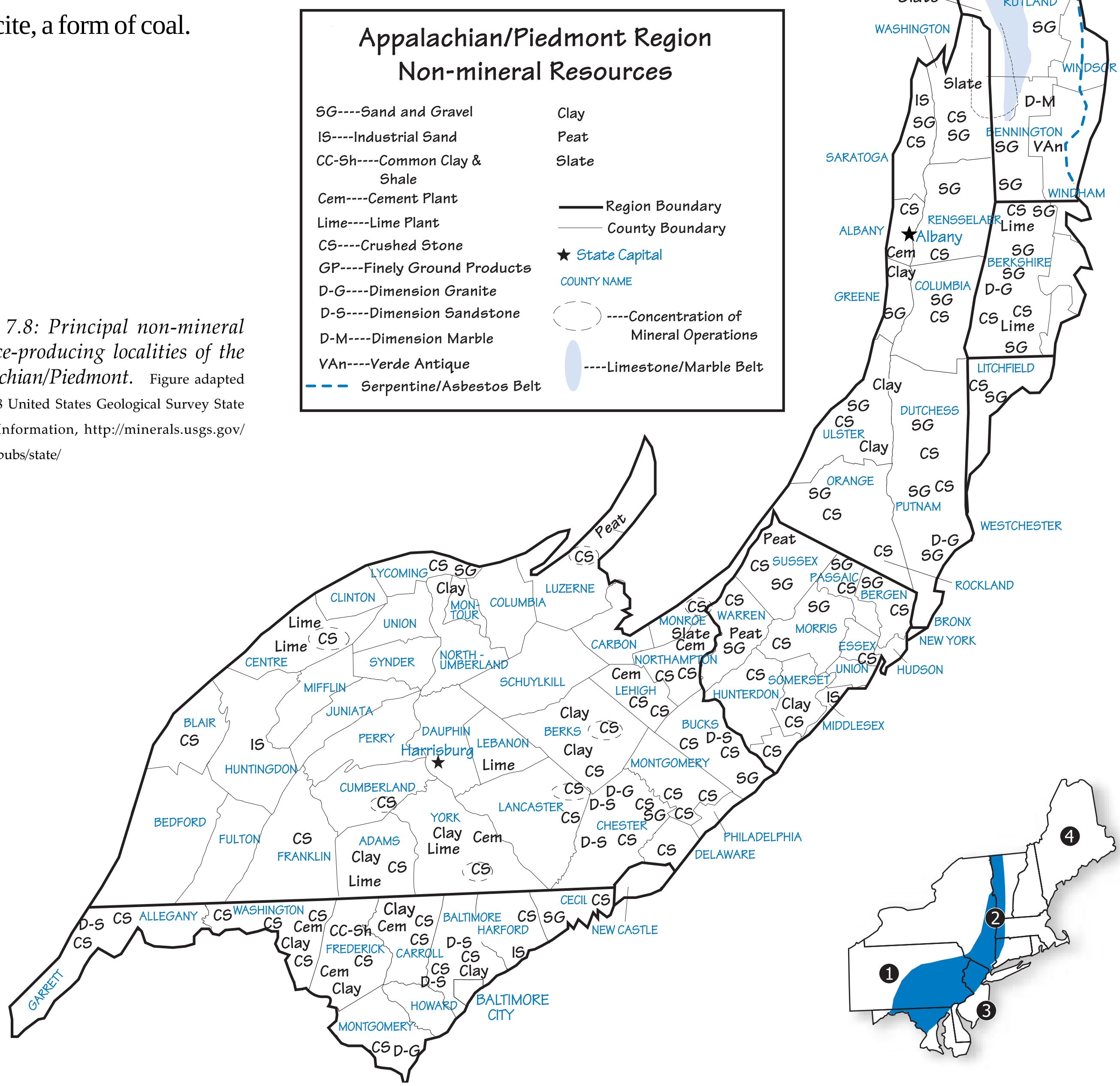




*Figure 7.8: Principal non-mineral resource-producing localities of the Appalachian/Piedmont.* Figure adapted from 1998 United States Geological Survey State Mineral Information, http://minerals.usgs.gov/minerals/pubs/state/

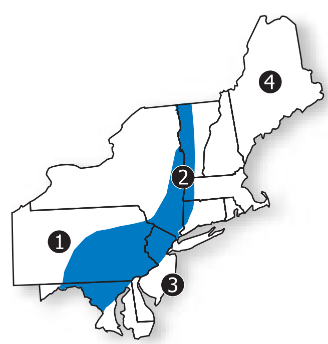
# Non-Mineral Resources

*see Geologic History, p.16, for more on* **rift basins.**

*see Rocks, p.45, for more on* **the color of rocks.**

**Limestone and dolostone** *are both carbonate rocks formed from calcium carbonate and calcium magnesium carbonate respectively.* **Marble** *is metamorphosed carbonate rock.*

*Chester and Lancaster Counties in Pennsylvania have some of the best farmland in the country because of the lime-rich soils resulting from the underlying limestone.*




## *Sedimentary Rocks*

The most distinctive sedimentary rock of the Appalachian/Piedmont region is brownstone, a red to brown sandstone found in the Triassic rift basins of southeastern New York, New Jersey, Pennsylvania and Maryland. As the united continents of Pangea began to break apart during the Triassic and Jurassic, the crust rifted and cracked. Blocks of crust slid downward to produce the rift basins that gradually filled in with sediment. Because of the position of North America with respect to the equator, the Northeast climate was warm and dry. The arid climate and the oxidation of iron in the sediments produced red to brown sedimentary rocks locally known as 'brownstone.' The fine polish of brownstone made it a popular building and decorative stone that has been used throughout the Northeast, especially in New York City.

Clay, lime, and crushed stone of various rock types are also used in production of cement. Lime, originating from ***limestone, dolostone*** or ***marble***, has a variety of uses in construction, the chemical industry and manufacturing of concrete and cement. Lime is very important to agriculture, where it is regularly applied to make the soils 'sweeter' or less acidic. Additionally, industrial sand is mined from crushed sandstone and quartzite, as in the Inland Basin Region.

## *Igneous Rocks*

The igneous rock non-mineral resources in the Appalachian/Piedmont region are limited to diabase, formed from magma close to the surface pushing its way through the sediments of the Triassic rift basins. Locally known as 'traprock', diabase has the same composition as basalt. Diabase, however, cooled somewhat more slowly beneath the surface, allowing time for formation of visible crystals. Diabase is commercially called 'black granite,' and thus is listed in Figure 7.8 as dimension-granite in Pennsylvania. It is used as a building stone and facing.

## *Metamorphic Rocks*

There is a wide array of metamorphic rocks in the Appalachian/Piedmont region that are important as non-mineral resources, including marble, serpentinite, slate, and emery. The Marble Valley, stretching from Vermont into western Massachusetts and Connecticut, is the focus of marble quarrying today in the Northeast. Proctor, Vermont, home of the now defunct Vermont Marble

Company, was the center of Vermont marble production. Quarrying of marble has significantly declined in the last few decades, as synthetic materials have begun to replace it for many purposes.

The formation of the Marble Valley dates back to the ***Taconic*** mountain-building event. As limestone was deposited along the continental shelf in the Iapetus Ocean during the Cambrian, the Taconic volcanic islands and Baltica were approaching from the east. As the approaching volcanic islands compressed the limestone, it was metamorphosed to become marble. The earliest 'marbles' quarried were at Isle LaMotte in the Champlain Islands of Vermont because it was easy to transport the marble down Lake Champlain. The islands were a natural place for the development of the marble industry in the Northeast. Technically, though, the Lake Champlain Islanders were quarrying limestone, as the rock had not been metamorphosed enough to be considered a ***true marble***. It is quarried today under the name 'Champlain Black,' which signifies the black color of the Chazy Limestone.

The slate belt of Vermont and New York is immediately west of the Marble Valley. Slate, which is mildly metamorphosed shale, is used for roofing, flagstones, floor tiles, blackboards and pool tables. In a process similar to the formation of marble in the Marble Valley, the slate formed from Cambrian and Ordovician sediment (in this case, shale) deposited on the seafloor was metamorphosed to slate during the subsequent mountain-building events. More extreme metamorphism than seen in slate resulted in the 'emery rock' found in New York in the Manhattan Schist. Emery, an intensely metamorphosed rock made of magnetite, corundum, sillimanite, sapphirine and cordierite, is used as an abrasive for grinding and polishing. Emery is no longer mined in the Appalachian/Piedmont, because synthetic abrasives, less expensive to produce, have replaced it. At one time, though, emery was an important natural resource of the region.

*Figure 7.9: Ultramafic Belt in the Appalachian/Piedmont.*

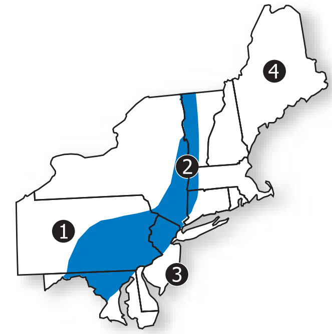
*Danby, Vermont is now the center of Vermont marble production.*

*Beautiful, crystalline marble takes a fabulous polish, and is thus commonly used as a decorative stone for buildings, monuments, interior facings and countertops. Crushed marble is useful as a filler, food additive and paper coating.*

*see Geologic History, p.7, for more on* **Taconic events.**

## Marble?

*Not everything commercially called a marble is a* **'true' *marble,*** *which lacks fossils and is recrystallized from limestone. The limestone in northwestern Vermont was only very weakly metamorphosed, if at all. Actual marble is found between Manchester and Middlebury Vermont, and parts of western Massachusetts and Connecticut. Green serpentinite rock from the Ultramafic Belt is also quarried and sold as a marble under the name Verde Antique. Serpentinite is hardly a marble. It was formed from the metamorphism of slices of oceanic crust and upper mantle that were scraped off of the oceanic plate being subducted beneath the North American continent during the Ordovician. The Ultramafic Belt, stretching the length of the Appalachian Mountains along the Taconic volcanic island suture zone, also has concentrations of the soft rock soapstone, made primarily from the mineral talc (Figure 7.9).*



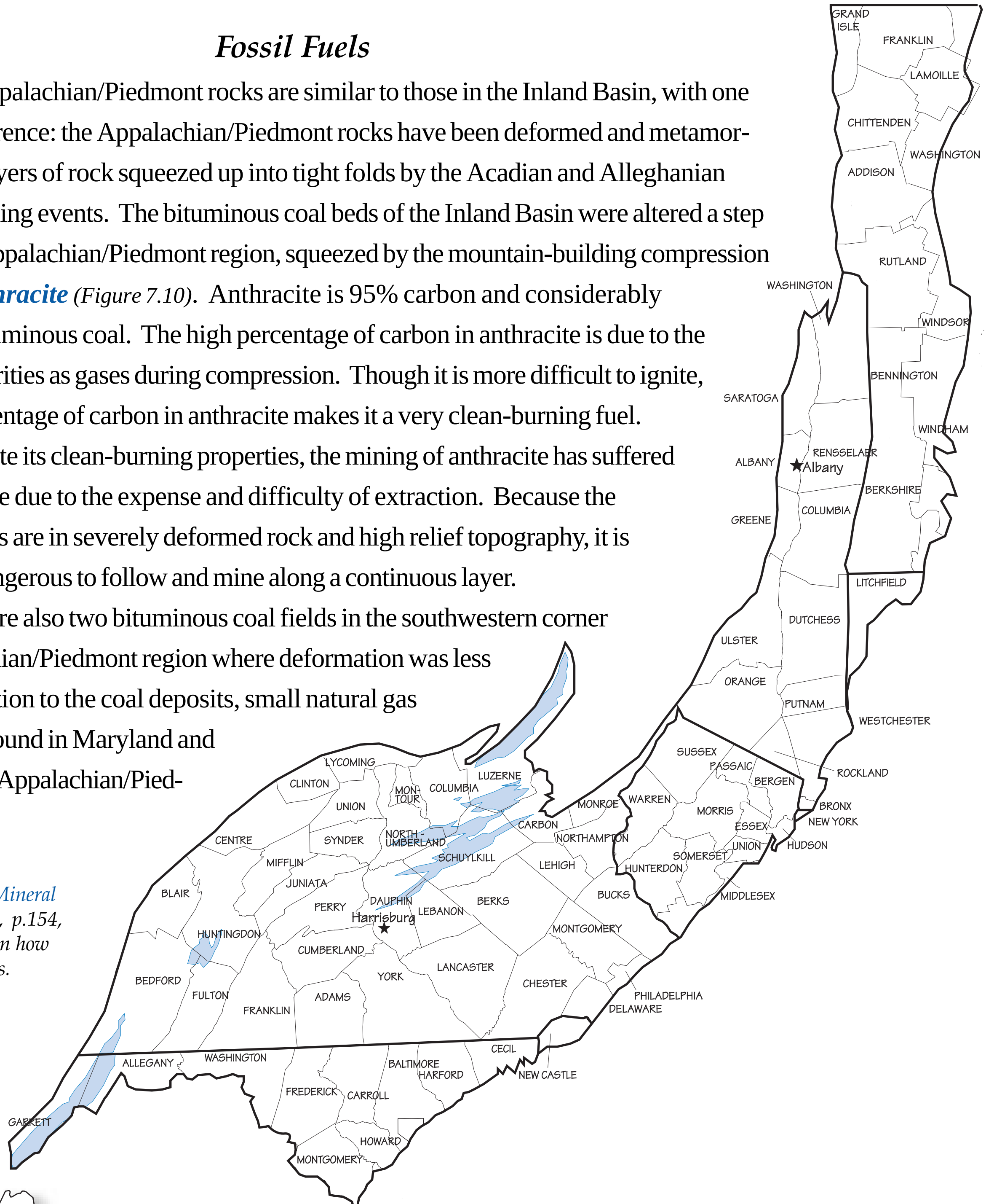
# Non-Mineral Resources

## *Fossil Fuels*

The Appalachian/Piedmont rocks are similar to those in the Inland Basin, with one important difference: the Appalachian/Piedmont rocks have been deformed and metamorphosed, with layers of rock squeezed up into tight folds by the Acadian and Alleghanian mountain-building events. The bituminous coal beds of the Inland Basin were altered a step further in the Appalachian/Piedmont region, squeezed by the mountain-building compression to become ***anthracite*** *(Figure 7.10)*. Anthracite is 95% carbon and considerably harder than bituminous coal. The high percentage of carbon in anthracite is due to the release of impurities as gases during compression. Though it is more difficult to ignite, the higher percentage of carbon in anthracite makes it a very clean-burning fuel. However, despite its clean-burning properties, the mining of anthracite has suffered a serious decline due to the expense and difficulty of extraction. Because the anthracite layers are in severely deformed rock and high relief topography, it is difficult and dangerous to follow and mine along a continuous layer.

There are also two bituminous coal fields in the southwestern corner of the Appalachian/Piedmont region where deformation was less severe. In addition to the coal deposits, small natural gas reservoirs are found in Maryland and Pennsylvania's Appalachian/Piedmont region.

*see Non-Mineral Resources, p.154, for more on how* ***coal*** *forms.*



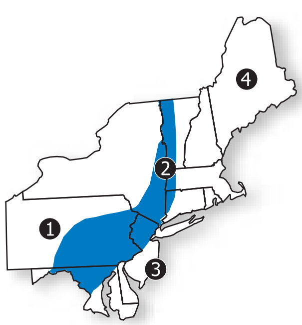
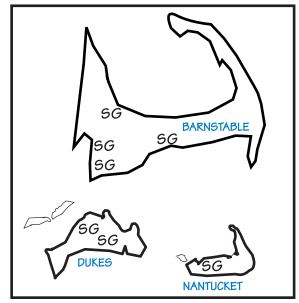




*Figure 7.10: Anthracite coal fields of the Appalachian/Piedmont.* Figure adapted from *Isachsen, Y.W., et al, 2000,* Geology of New York, A Simplified Account; *Shultz, C., 1999,* The Geology of Pennsylvania; *and Schmidt, Martin F., Jr., 1993,* Maryland's Geology.

# Non-Mineral Resources of the Coastal Plain

*Region 3*

The primary non-mineral resources of the Coastal Plain are the layers of sand and gravel eroded from the Appalachian Mountains to the west *(Figure 7.11)*. Greensand and diatomaceous earth were also at one time important resources. Since the region does not have solid rock and is composed entirely of layers of loose ***sediments***, the Coastal Plain does not have the same kinds of resources that are abundant in the other regions.




*see Rocks, p.46, for more on the Coastal Plain* ***sediments.***

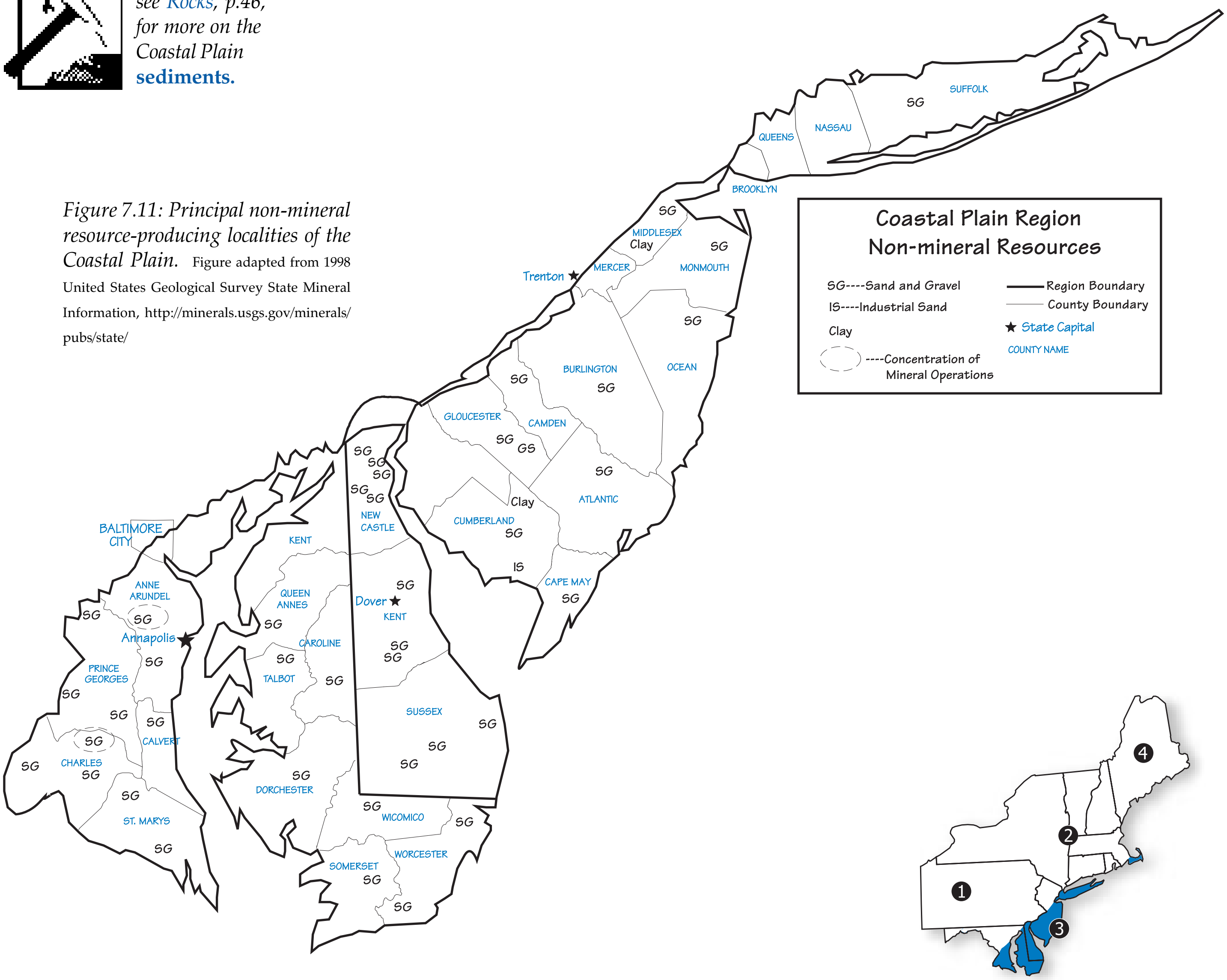



*Figure 7.11: Principal non-mineral resource-producing localities of the Coastal Plain.* Figure adapted from 1998 United States Geological Survey State Mineral Information, http://minerals.usgs.gov/minerals/pubs/state/

### *Sediments*

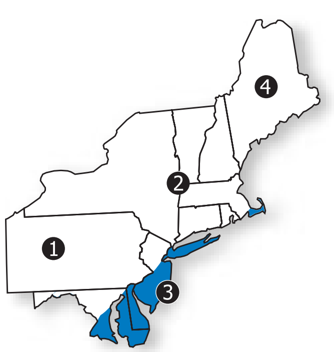
Sand and gravel, eroded from the Appalachian Mountains to the west, are easily accessible, extremely abundant and useful natural resources in the Coastal Plain region. Due to the nature of the Coastal Plain, which is loose sediment and not rock, sand and gravel deposits are plentiful and easily mined. Sand and gravel are primarily used in construction, concrete and road fill. Industrial sand, mined in Cumberland County, Maryland, has a slightly different nature than ordinary sand and gravel. Important for its predominantly quartz content, industrial sand is used in sandblasting, filtering and in the manufacture of glass.

Greensand, containing the relatively common Coastal Plain mineral glauconite, is still used today as a soil conditioner and water softener. It also has potential for use in landfills and as a filter for heavy metals from industrial wastes. ***Diatomaceous earth*** from the Maryland Calvert Formation was at one time an important natural resource for Maryland (and the only place in the United States where it was mined). Made of the hard shells of microscopic marine organisms, known as diatoms, diatomaceous earth is used in filtering and as an abrasive.

**Diatomaceous earth** *is used today in swimming pool filter systems.*

### *Soil*

The soil of the Coastal Plain developed on the already loose, unconsolidated layers of sediment that make up the region. As there is no hard, cemented rock, soil forms much more easily and quickly in the Coastal Plain than in other regions of the Northeast. In most areas of the Coastal Plain, the soil for agriculture is an excellent mix between sand and clay, with the sand providing good drainage. Areas that are too clay rich have poor drainage due to the impermeable nature of clay. Depressions in the landscape or areas of slightly lower topography in the Coastal Plain often remain too wet and are not good areas for cultivation of crops.



# Non-Mineral Resources of the Exotic Terrane

## *Region 4*

The Exotic Terrane region has a variety of non-mineral resources, many similar to those of the Appalachian/Piedmont region because of the rock types these regions share. Coal is even found in the Exotic Terrane region in the Narragansett and Boston basins, though it is not currently mined *(Figure 7.12)*.

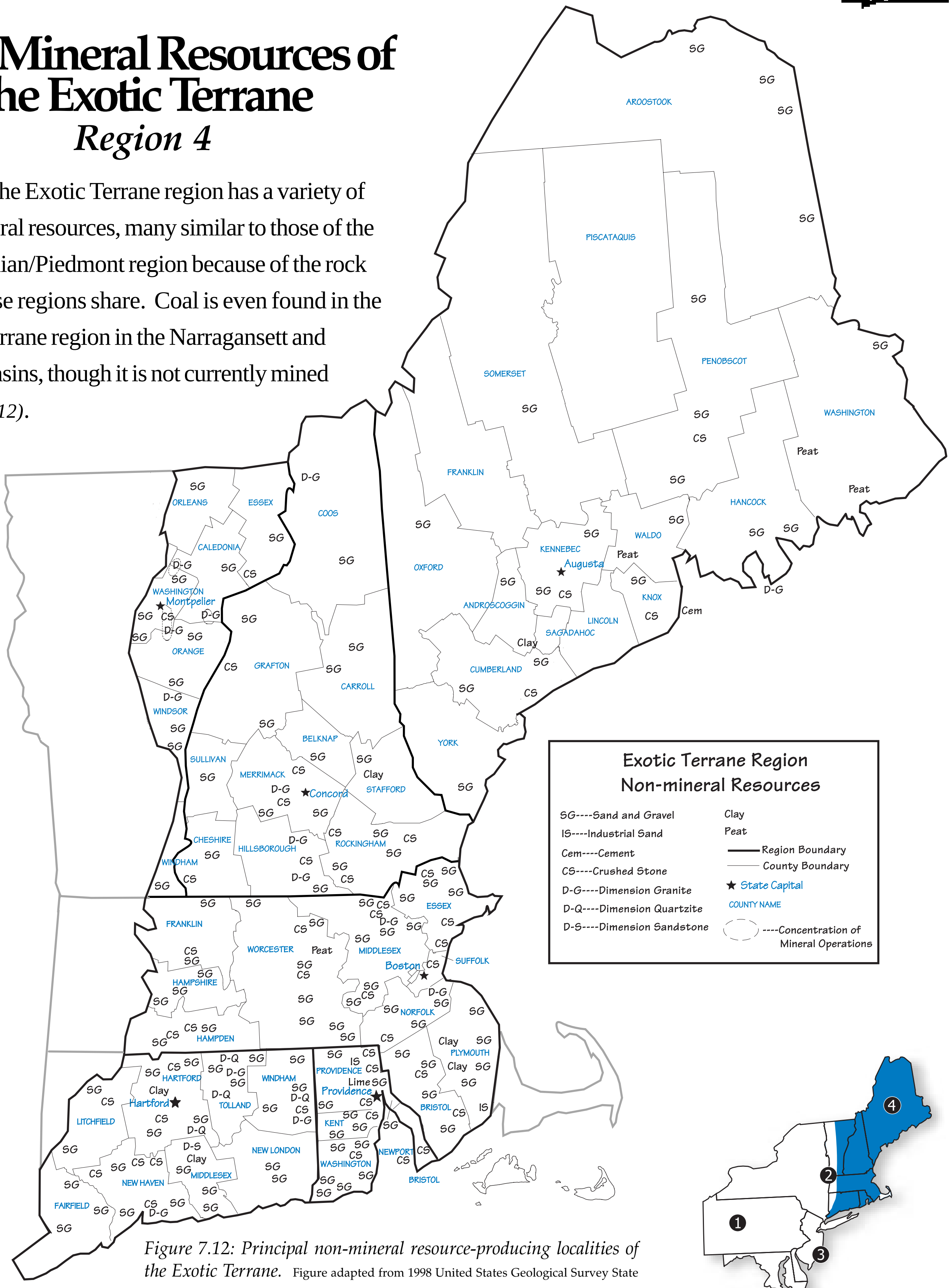



*Figure 7.12: Principal non-mineral resource-producing localities of the Exotic Terrane.* Figure adapted from 1998 United States Geological Survey State Mineral Information, http://minerals.usgs.gov/minerals/pubs/state/

# Non-Mineral Resources

see *Non-Mineral Resources*, p.160, for more on **rift basin** resources.

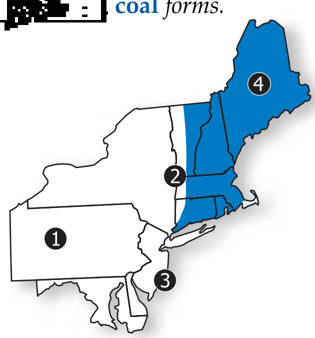
see *Geologic History*, p. 7 and 12.

see *Rocks*, p.51, for more on the **Barre Granite.**

*Barre, Vermont is the home of the famous Rock of Ages Quarry, which quarries the* **Barre Granite.**

**Quartzite** *is quarried for use as a building and decorative stone.*

see *Non-Mineral Resources*, p.156, for more on how **coal** forms.




## *Sedimentary Rock*

The sedimentary rock non-mineral resources of the Exotic Terrane are similar to those of the Appalachian/Piedmont and Inland Basin regions. Brownstone is quarried from the ***rift basin*** in the Connecticut River Valley; clay and shale are mined from glacial deposits and marine shales of the Silurian and Devonian; and cement and crushed rock are produced from a variety of rock types to be used in the construction industry.

## *Igneous Rock*

Granites, formed from intrusions of magma during the Taconic and Acadian mountain-building events, appear all over the Exotic Terrane region. It is quarried throughout the region for use in buildings and monuments, though the demand is not as great as it was in the past. Granite is more expensive to quarry than the much softer marbles found in Vermont, and the issue of transportation raises costs even higher. Though New Hampshire is known as the Granite State for its abundance of granite of varying ages, Barre, Vermont is known as the granite center of the world. The famous ***Barre Granite***, formed from an intrusion of magma into overlying rock during the Acadian mountain-building event, is a uniform light gray that takes an excellent polish and is widely used for monuments.

## *Metamorphic Rock*

Quartzite is being actively quarried from Silurian and Devonian metamorphic rock in Connecticut. Quartz is derived from sandstone deposited in the Iapetus Ocean. The sandstone became compressed, metamorphosed and attached to the continent when Baltica collided with North America. When sandstone is metamorphosed, it recrystallizes to become ***quartzite***.

## *Fossil Fuels*

***Coal*** is found in the Narragansett Basin of Rhode Island and Massachusetts. The coal was formed during the Pennsylvanian when the collision of North America and Baltica compressed the Avalonia microcontinent caught in the middle. The collision buckled the crust to form small basins that gradually filled in with sediment. Accumulations of dead plant material in the swampy basins provided the proper conditions for minor amounts of bituminous coal to form, though there are not large enough amounts to make mining profitable.

# Glacial Deposit Resources
## *of the Northeast*

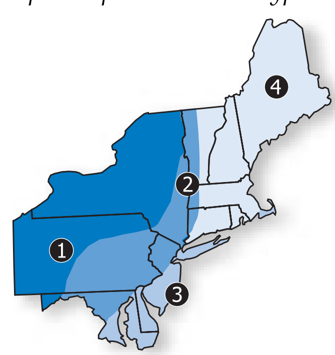
All four regions of the Northeast share a common source of non-mineral resources: the deposits left by glaciers of the most recent ice age. For the last 1.8 million years, a continental ice sheet originating in northern Canada has advanced and retreated over North America. Around 20,000 years ago, a warming climate put the glaciers in retreat, bringing the Northeast to its current interglacial period. Deposits associated with the massive, moving and melting ice remain today as valuable non-mineral resources in the Northeast. The glaciers covered the northern parts of all four regions of the Northeast as far south as northern Pennsylvania, New Jersey and Long Island.

*see Glaciers, p.64.*

The main non-mineral resources resulting from the last glacial advance are clay, peat, soil, sand and gravel. As the glaciers moved over the surface of the Northeast, they scraped and gouged the landscape. The numerous lakes dotting the Northeast resulted from the vigorous scouring activity of the glaciers. Much of the clay mined today in the Northeast comes from the bottom of these glacier-formed lakes. Used in bricks and pottery, the glacial clays are an important natural resource of the Northeast. Clay is also commonly used in place of heavier stone and gravel to make a lightweight concrete. As the glacial lakes filled and later drained to become bogs and swamps, organic material accumulated at the bottom. Bogs and swamps are ideal environments for the accumulation of dead plants. Kept wet and buried by more dead plant material, the stagnant water of a bog provides little if any oxygen for bacteria to completely decompose the plant material as it would on the forest floor or in a flowing stream. The resulting peat, a precursor to coal, is mined and used as mulch and as a soil conditioner.

The glaciers also left deposits on the surface on which the Northeast ***soils*** have developed. In combination with the underlying bedrock, the glacial deposits contribute good and bad characteristics to the soil (from the perspective of cultivation). Till, the unsorted mix of sand, silt, clay and gravel that was deposited by melting glaciers, developed into impermeable soils that cannot properly drain water. The unsorted material has no spaces between particles, leaving nowhere for water to drain. Likewise, clay deposits from glacial lakes are also impermeable, being uniformly composed of very small, flat clay particles. Glacial outwash

**Soil** *is an important natural resource because the cultivation of crops is dependent on soil type.*



deposits of sand and gravel, on the other hand, are generally well sorted and thus well-drained.

The soils developed in the Northeast are a direct result of the underlying rock type and transported glacial sediment. Glacial clay, till, sand and gravel blanket much of the region and affect the permeability of soil. Also, the reason why New Englanders find so many rocks in their farms and gardens is because the glacial till became incorporated into the soil. The till has since become incorporated into the famous stone walls of New England.

Perhaps the most important resource left to the Northeast by the glaciers is sand and gravel. Dominating the natural resource economies of many of the Northeast states, sand and gravel is an extremely abundant, easily mined natural resource of the area. Naturally broken rock the size of sand and gravel was dumped all over the Northeast landscape by the glaciers. As the glaciers advanced over the landscape, their vigorous scraping action incorporated boulders, gravel, sand, silt and clay from the underlying bedrock and already loose sediment into the moving ice. Each time the glaciers stopped moving forward or backward, melting ice deposited drift and till in front of and to the sides of the glacier, creating mounds (called moraines) of sand and gravel. Significant ***deposits*** of sand and gravel were produced by deltas formed by glacial streams and in valleys filled by retreating glaciers. Sand also accumulated in snake-like tunnels beneath the ice, in which sand was deposited by flowing subglacial streams; these sinuous deposits of sand are called eskers. Glacial sand and gravel are easily mined because the glacial deposits are all at the surface and there is little if any processing involved. Sand and gravel composed of chunks of limestone, dolostone, sandstone, metamorphic and igneous rocks are mostly used for construction purposes. Shale and siltstone, being softer rocks, are generally too weak for construction, and are more often used together with lime in making concrete.

*see Glaciers, p.61, for more on glacial* **deposits.**

# Activities

1. A local architect hires you for a summer internship. Knowing that you know your regional geology, she has you make a list of where to obtain a variety of stone building materials. Among the materials she wants you to find are:

* tan or gray (marine) sandstone
* red sandstone
* granite
* slate
* gneiss
* limestone

*The architect has you rent a truck to pick up a little bit of each kind of building stone. For her official records, she has you write up a travel report, in which you must answer the following questions:*
*What route would you follow?*
*Where would you go?, and*
*What is the geologic context under which these rocks formed?*

The following is a list of the contexts:
(1) the Grenville passive margin
(2) the Taconic converge,
(2a) interval (Silurian-Early Devonian) between Taconic and Acadian
(3) the Acadian convergence,
(3a) interval (Mississippian-Early Permian) between Acadian and Alleghenian
(4) the Alleghenian convergence,
(4a) interval (Early-mid Triassic) between Alleghanian and rifting
(5) the rifting apart of Pangea, and
(5a) interval (mid-Jurassic-late Jurassic) between rifting and creation of Coastal Plain
(6) the Coastal Plain passive margin and shaping by erosion of many of current land-forms
(7) Pleistocene glaciation and Holocene post-glacial

2. Since it is difficult to imagine how a certain kind of building stone will look in a building until the building is built, the architect suggests you create a walking tour of your town buildings showing people various kinds of building stones. She asks you to create such a tour, with a written report that she can follow.

*Go to an area of your town with stone buildings. Make a list of buildings and stone materials. Try to find out the history of the buildings and stones, and place the building stones in the context of geological history.*

3. A local politician with no background in geology suggests that your community depends too much on fossil fuel from abroad, and that in fact all fossil fuel resources should come from the Northeast region. The architect, being an active voice against public misinformation, decides to give you a different job for awhile — to write an article summarizing the presence of fossil fuels in the northeast U.S. and their origin.

*Write an editorial that explains (1) why fossil fuels are largely restricted to the Inland Basin area of the Northeast, (2) why coal is so abundant in Pennsylvania, but not elsewhere in the Northeast, and (3) why we have reason to believe that there is not substantially more natural gas and oil in the Northeast than we have already discovered.*

# For More Information...

## Internet

National Gas Information and Educational Resources
www.naturalgas.org/

National Mining Association
www.nma.org

Oil and Gas
http://www.dcnr.state.pa.us/topogeo/Oil_Gas_Coal.htm

State Mineral Statistics and Information
http://minerals.usgs.gov/minerals/pubs/state/

Vermont Marble
http://www.vermont-marble.com/home.htm

## Organizations

American Coal Foundation
1130 17th St. NW, #220
Washington, DC 20036
(202) 466-8630

Mineral Information Institute
475 17th St. #510
Denver, CO 80202
(303) 297-3226

## Other Resources

***used in compiling this chapter***

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Isachsen, Y.W., E. Landings, J.M. Lauber, L.V. Rickard, and W.B. Rogers, eds., 2000, *Geology of New York, A Simplified Account*, New York State Geological Survey, New York State Museum Cultural Education Center: Albany, New York.

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# Environmental Issues of the Northeastern US

*One invites trouble if construction is sited in the bottom of a narrow valley, on a floodplain, on a steep slope underlain by ancient landslide debris, on non-engineered fill, above solution cavities in carbonate rocks, above an underground mine, on a rapidly eroding wave-cut cliff or radioactive rocks. These points may be obvious to geologists, but flying into the face of natural laws and processes by stepping into potentially hazardous situations without much forethought seems to be a common human propensity.*

-Charles H. Schulz, 1999
*The Geology of Pennsylvania*

# Environmental Issues
## *of the Northeastern US*

Geology affects where we live, how we live, and how we use the land. In the Northeast, earthquakes, landslides, land subsidence, and radon are important issues tied to the type of rocks found at the surface and underlying the region. They are 'issues' only because they disrupt human lives and constructs. Whether directly caused by human activity (such as landslides and land subsidence in some cases) or simply a natural process (such as earthquakes or the production of radon gas), the significance is magnified because of the presence of people. Ideally, growing knowledge of environmental issues and an understanding of their foundation in geology, will help us to make wiser and more informed decisions on land use and planning. In this chapter we will discuss the Northeast region as a whole.

### *Earthquakes*

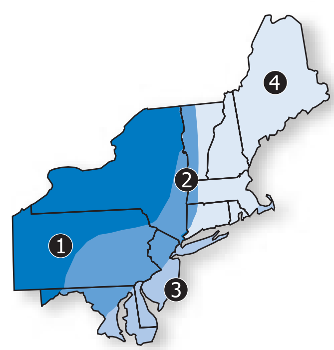
Ninety-eight percent of earthquakes occur at tectonic plate boundaries. As the plates collide, pull apart, or move past each other, their grinding and shifting build up stress. When these stresses are released suddenly at the plate boundary or at faults near the boundary, the crust shifts and ***seismic waves*** are released, causing an earthquake. In the US, most earthquakes occur west of the Rocky Mountains, where there is currently an active plate boundary between the North American and Pacific Plates. During the break up of Pangea and the preceding mountain-building events, there was an ***active plate boundary*** at the margin of the east coast of North America. The eastern margin of the continent no longer is at an active plate boundary. Now the active plate boundary lies thousands of kilometers to the east at the Mid-Atlantic Ridge, where the North American and Eurasian plates are pulling apart and new crust is forming.

Though large quakes are not a common event in the Northeast, earthquakes *do occur*, most likely caused by old faults formed when the eastern margin of North America was an active plate boundary. Stress upon the old faults may force them to shift suddenly, causing an earthquake. Geologists have not had much luck, though, relating earthquake events in the Northeast to known faults. Unlike the west coast, where there is a clear relationship between earth-

Seismic waves *are the shock waves or vibrations radiating in all directions from the center of an earthquake.*

*see Geologic History, p. 16*

*An* active plate boundary *exists where two plates of the Earth's crust are colliding, pulling apart, or moving past each other.*



### Largest earthquakes in each state

data from the United States Geological Survey

| *State* | *Date* | *Magnitude* | *Intensity* |
|---|---|---|---|
| *Connecticut* | *1791* | - | *VII* |
| *Delaware* | *1871* | - | *VII* |
| *Maine* | *1904* | *5.1* | *VII* |
| *Maryland* | *1990* | *2.5* | *V* |
| *Massachusetts* | *1755* | - | *VIII* |
| *New Hampshire* | *1940* | *5.5* | *VII* |
| *New Jersey* | *1783* | *5.3* | *VI* |
| *New York* | *1944* | *5.8* | *VIII* |
| *Pennsylvania* | *1998* | *5.2* | *VI* |
| *Rhode Island* | *1976* | *3.5* | *VI* |
| *Vermont* | *1962* | *4.2* | *V* |

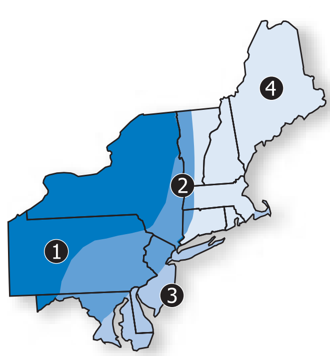
quakes, faults and the active plate boundary, there is no clear relationship in the Northeast between earthquakes and known faults.

Most earthquakes in the Northeast are minor, rarely causing any damage. Minor earthquakes occur in every state throughout the Northeast, though relatively few have been located in the Inland Basin region, where the crust experienced little deformation relative to the rest of the Northeast *(Figure 8.2)*. Occasionally, large earthquakes actually do occur in the region. One of the largest was on November 18, 1755 off Cape Anne, Massachusetts. The vibrations from the quake were felt over 450,000 square kilometers.

Due to the vague relationship between earthquakes and faults in the Northeast, it is difficult to assess the risk of earthquakes in the region. Using historical records of the Northeast dating back to the 1500's, geologists predict

### Measuring Quakes

*Earthquakes are measured using the descriptive Mercalli Intensity Scale and the more quantitative Richter Scale. The Mercalli Intensity Scale (Figure 8.1) measures the intensity of an earthquake by describing the effects of the earthquake on people, man-made structures and natural features. The Richter Scale is a measurement of the amount of energy released at the center of an earthquake. Because the scale is logarithmic, an earthquake with a magnitude of 5 is 10 times greater than a magnitude 4 earthquake. Likewise, an earthquake with a magnitude of 6 is 100 times greater than a magnitude 4 earthquake. Very few earthquakes in the Northeast have a magnitude greater than 5 on the Richter Scale; most have a magnitude less than 2.*




**Modified Mercalli Scale**
(1931 Abridged Version)

| Corresponding Richter Scale Intensity | | |
|---|---|---|
| <3.0 | I. | Not felt except by a very few under especially favorable circumstances. |
| <3.0 | II. | Felt only by a few persons at rest, especially on the upper floors of buildings. Delicately suspended objects may swing. |
| 3.0 | III. | Felt quite noticeably indoors, especially on the upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration is like a passing truck. Duration is estimated. |
| 3.7 | IV. | During the day felt indoors by many, outdoors by few. At night some are awakened. Dishes, windows, and doors are disturbed. Walls make a creaking sound. Sensation is like a heavy truck striking a building. Standing motor cars are rocked noticeably. |
| 4.3 | V. | Felt by nearly everyone; many are awakened. Some dishes, windows, etc. are broken; a few instances of cracked plaster occur. Unstable objects are overturned. Disturbance of trees, poles, and other tall objects is sometimes noticed. Pendulum clocks may stop. |
| 5.0 | VI. | Felt by all; many are frightened and run outdoors. Some heavy furniture is moved; a few instances of fallen plaster or damaged chimneys occur. Damage is slight. |
| 5.6 | VII. | Everybody runs outdoors. Damage is negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures. Some chimneys are broken. Noticed by persons driving motor cars. |
| 6.3 | VIII. | Damage is slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls are thrown out of frame structures. Chimmneys, factory stacks, columns, walls, and monuments fall; heavy furniture is overturned. Sand and mud are ejected from the ground in small amounts. Changes occur in well water. Persons driving motor cars are disturbed. |
| 7.0 | IX. | Damage is considerable in specially designed structures; well-designed frame structures are thrown out of plumb; damage is great in substantial buildings with partial collapse. Buildings are shifted off their foundations. Ground is cracked conspicuously. Underground pipes are broken. |
| 7.7 | X. | Some well-built wooden structures are destroyed; most masonry and frame structures are destroyed along with their foundations. Ground is badly cracked. Rails are bent. Considerable landslides occur on river banks and steep slopes. Sand and mud are shifted. Water is splashed (slopped) over banks. |
| 8.4 | XI. | Few, if any, masonry structures remain standing. Bridges are destroyed. Broad fissures occur in the ground. Underground pipelines are completely out of service. Earth slumps and land slips occur in soft ground. Rails are bent greatly. |
| 9.0 | XII. | Damage is total. Waves are seen on the ground surface. Lines of sight and level are distorted. Objects are thrown upward into the air. |

*Figure 8.1: The Modified Mercalli Intensity Scale.*

that future earthquakes are most likely to occur in the same general areas as past earthquakes. Despite such attempts to assess the level of risk in the region, it is still not possible to predict the place and time of individual earthquakes on either the west coast or the east coast *(Figure 8.3)*.

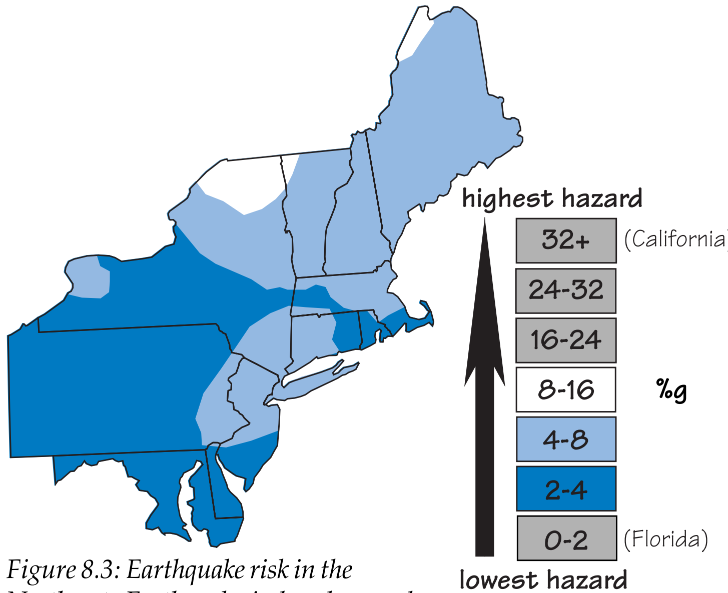



*Figure 8.3: Earthquake risk in the Northeast. Earthquake-induced ground movement is expressed as a percentage of the force of gravity (%g). The map illustrates the amount of ground shaking that is predicted in a given period of time.* After the National Seismic Hazard Maps, United States Geological Survey.

The Northeast has a lower risk of earthquakes than California or other states west of the Rocky Mountains. However, the more densely populated east coast makes the infrequent large quake possibly more damaging than similar earthquakes in the West. Many buildings in the Northeast were not built with earthquakes in mind and could potentially be damaged by stronger tremors. Additionally, seismic waves travel further in the eastern US. The active plate boundary on the west coast makes near-surface rocks west of the Rocky Mountains warmer than rocks east of the Rocky Mountains. Heat absorbs seismic waves and they are unable to travel as far. Cooler rocks, like those of the Northeast, are less of an impediment to seismic waves, allowing them to travel further and potentially cause more damage.

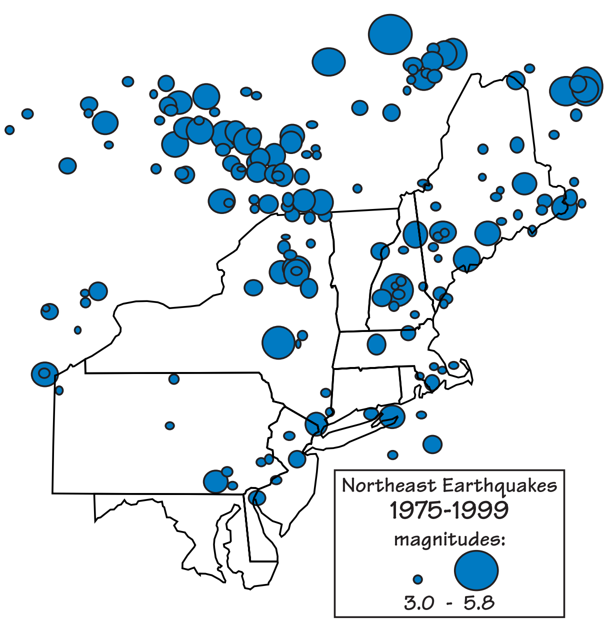
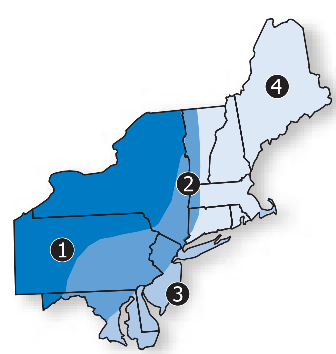



*Figure 8.2: Earthquakes with a magnitude greater than 3.0 in the Northeastern US from 1975 to 1999.* *Image courtesy of Alan Kafka, Weston Observatory, **http://www2.bc.edu/~kafka/Why_Quakes/why_quakes.html.***



## Land Subsidence

Land subsidence *is the sinking, or depression of the land surface.*

**Land subsidence** is an issue in the Northeast, though more often in the Appalachian/Piedmont and Inland Basin regions. Mines and carbonate rocks are the primary causes of land subsidence. The large amount of underground excavation during mining, especially the coals of western Pennsylvania and Maryland, has left large areas beneath the surface empty or filled with loose sediment. The empty spaces and sediment fills are sometimes unable to wholly support the weight of overlying rocks. As a result, the overlying rocks and soil sag or sink downward to create a depression in the land surface. In extreme cases, the overlying rocks collapse completely or the subsidence causes a landslide.

Carbonate rocks *include limestone, dolostone and marble.*

*see Rocks, p.41*

Areas of the Northeast underlain by **carbonate rocks**, in particular the Valley and Ridge region of the Appalachian/Piedmont, are susceptible to land subsidence. Rainwater, which is naturally slightly acidic and becomes more acidic after passing through acidic soils, is capable of breaking down carbonate rocks. Within a carbonate rock layer might be caverns, widened fractures, and spaces that make the layer an unstable support for overlying rocks. Similar to mine collapses, the overlying rock in a carbonate area has a high potential for collapsing and creating sinkholes *(Figure 8.4)*.

Land subsidence can cause major problems, particularly in urban areas where sewer systems, water lines, and gas pipes can be damaged due to the sagging ground surface. In places where the surface collapses, buildings and roads can be badly damaged. Sinkholes also provide a fast drainage from the surface to groundwater, increasing the chances of polluting groundwater supplies.

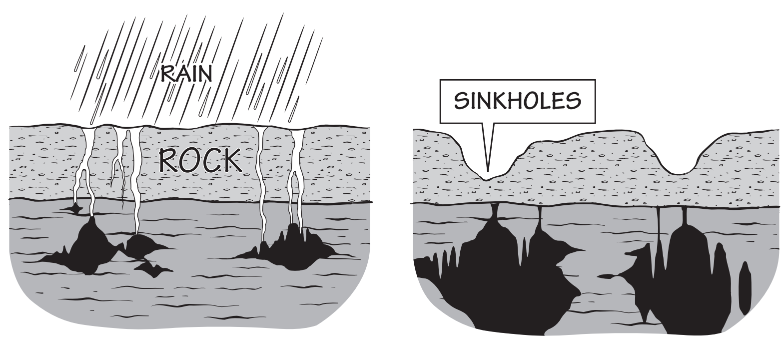
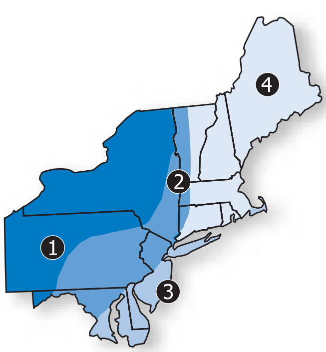



*Figure 8.4: Naturally acidic rainwater creates cavities within carbonate rock, making the overlying rock unstable (left). As the cavities enlarge, the overlying rocks collapse to form a sinkhole (right).* Figures by J. Houghton.



## *Landslides*

Intense rainfall, rapid snowmelt and steep hillsides are prime conditions for a ***landslide*.** Landslides range from watery mud to thick mud carrying rock, boulders and trees, to toppling rocks off steep slopes. Moving as fast as 60 kilometers/hour, landslides can potentially cause millions of dollars of damage to buildings and roads as well as human fatalities. In the Northeast, landslides are common in the Appalachian Mountains, New England, and the ***Appalachian Plateau*** due to steep slopes, a fairly rugged landscape and clay-rich soils. Though the Appalachian Plateau is called a ***plateau***, it is deeply dissected by river valleys that have formed steep slopes along which landslides are common.

Clay and clay-rich soils that become saturated with water have drastically reduced friction, allowing other rock layers or sediment to slide rapidly upon it. In the glaciated areas of the Appalachian Plateau, including northern Pennsylvania and most of New York, clays were deposited at the bottom of glacial lakes occupying glacially carved valleys. Though many of the lakes no longer exist, the clay deposits still remain and are a source of landslides in the region.

Other causes of landslides, especially in the Appalachian Plateau region, are the result of the activities of humans. Underground mining, common in the bituminous ***coal*** fields of western Pennsylvania and Maryland, reduces the stability of overlying rock and often results in landslides. When older mines are filled, the settling rocks and sediments can cause landslides. Poorly engineered fills on slopes can also trigger landslides.

Recognition of landslide-prone areas is important for land use planning and zoning decisions. Damage from landslides can be prevented by not building in areas that commonly experience landslides or show evidence of past land-slides.

## *Radon*

Radon is a chemical element: an odorless, colorless, radioactive gas that commonly forms from the breakdown of the element uranium. Radon first came to wide public attention as an environmental issue in the mid 1980's when high concentrations of the gas were found in houses overlying the Precambrian rocks of the Reading ***Prong*** in southeastern Pennsylvania. Though scientists continue to debate the health risks of radon, it is clear that smokers exposed to high levels of radon gas have an increased risk of lung cancer.

*The term landslide includes rock falls, avalanches, debris flows, mudflows and the slumping of rock layers or sediment.*

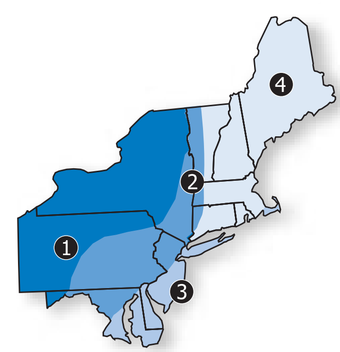
*The topographic term, Appalachian Plateau, includes part of New York, Pennsylvania and Maryland, and corresponds with the Inland Basin region.*

*see Topography, p.109, for more on the* **Appalachian Plateau.**

*see Glaciers, p.70, for more about glacial deposits.*

*see Non-Mineral Resources, p. 154, for more on* **coal.**

*see Rocks, p.40, for more about Precambrian* **prongs.**



*The number following the name of an element (U-238) refers to the mass number of the element. Though any two atoms of the same element will have the same number of protons and electrons, the number of neutrons may vary. Variations in the number of neutrons will change the mass of an atom. Atoms of the same element with different numbers of neutrons are called* **isotopes**. *Thus uranium-238 and uranium-235 are both isotopes of uranium.*

Uranium-238, the uranium isotope from which radon originates, is a radioactive substance. When a radioactive substance decays, the nucleus breaks down by the loss of protons, electrons or neutrons, forming another element. The decay process continues until a stable (non-radioactive) ***isotope*** is reached. The decay of uranium-238 produces a series of unstable elements, including radon-222 *(Figure 8.5)*.

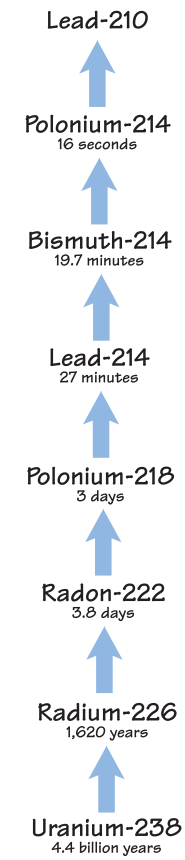



*Figure 8.5: The radioactive decay of Uranium-238.*

Radon-222 is also radioactive, decaying to eventually produce a stable form of lead. Though it takes 4.4 billion years for half of a given amount of uranium-238 to decay, it takes radon-222 only a few days.

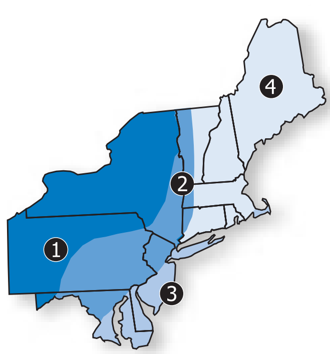
Both uranium and radium are solids and incapable of moving through rocks and soil. Radon, however, is a gas. Where soils and rocks are ***porous*** and ***permeable***, radon can migrate upwards towards the surface. We are naturally exposed to low levels of radon in the air and water around us with no ill effects; radon, however, can become concentrated at high levels indoors. Poorly sealed house foundations with inadequate air flow allow the radon gas to enter homes, becoming concentrated and possibly inhaled. Radon may also be naturally dissolved in well water and released indoors when the tap is turned on.

**Half-life**

*Radioactive elements have a* half-life. *After 4.4 billion years, half of the uranium-238 in a given rock has decayed to radium-226. The radium continues the decay process, producing radon-222, polonium-218, lead-214 (an unstable isotope of lead), bismuth-214 and finally a stable isotope of lead (Lead-210). Radon-222 has a much shorter half-life than uranium-238. It only takes 3.8 days for radon to decay. For some radioactive elements, such as polonium-218 and bismuth-214, the decay process is a matter of minutes.*

Porosity *is the amount of pore space within a rock;* permeability *is the connectedness of the pore spaces, allowing water or gas to move through a rock or soil.*

Most susceptible to high radon levels, are those areas with uranium-rich rocks. Though most rocks have a small amount of uranium, certain types of rocks have higher concentrations of the radioactive element, such as light-colored volcanic rocks, granites, dark shales, sedimentary rocks with phosphates and some metamorphic rocks. Rocks that have pathways such as fractures, faults and connected pore spaces between grains allow radon gas to move upwards to



the surface. Likewise, thin, permeable and porous soils with cracks aid in the upward migration of radon. Additionally, because moisture inhibits the movement of the gas, radon moves more quickly in dry, well-drained soils. The igneous and metamorphic rocks of the Appalachian Mountains and Adirondacks are uranium-rich and sliced by numerous faults, resulting in an area with the potential for high levels of indoor radon. The mineral glauconite, found in parts of the Coastal Plain sediments, is also uranium-rich. For the most part, however, the Coastal Plain has one of the lowest levels of radon risk in the country *(Figure 8.6)*.

*Local radon risk depends upon the type of bedrock underlying a home (uranium-rich bedrock may cause elevated radon levels); the porosity and permeability of the bedrock (which provides pathways for movement of the radon gas); the porosity and permeability of soils; and the air flow rate and foundation construction that could potentially concentrate radon indoors.*

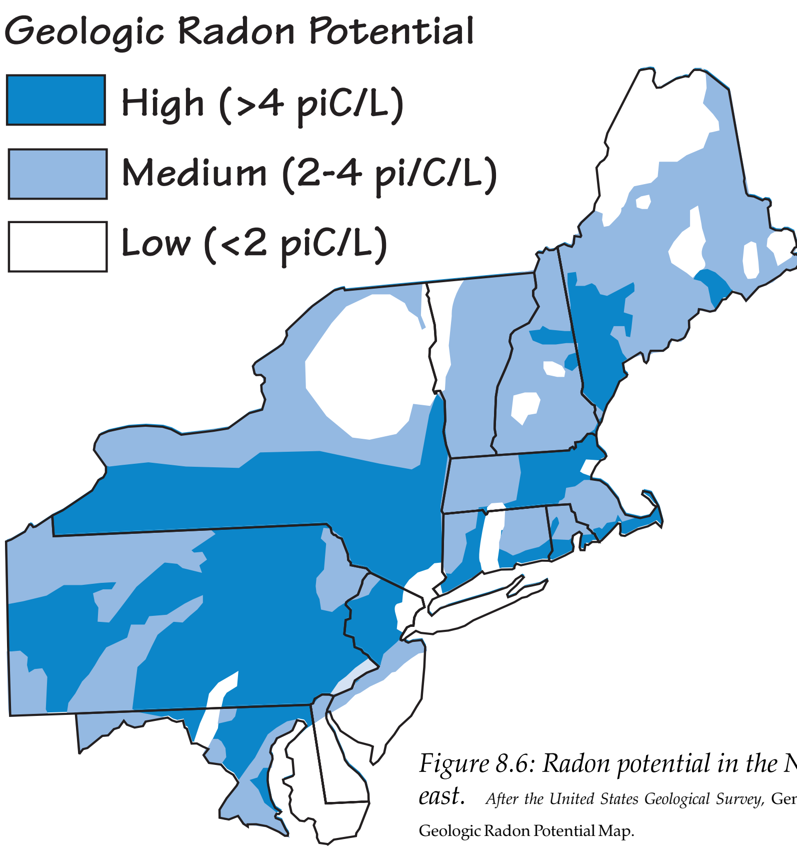
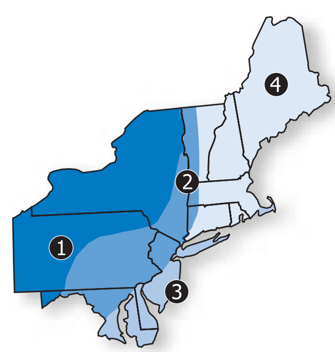



*Figure 8.6: Radon potential in the Northeast. After the United States Geological Survey,* Generalized Geologic Radon Potential Map.



# Activities

1. You get a job with an insurance company that offers a wide variety of coverage, from health to homes. Like other insurance companies, they keep careful track of risks, so they are interested to know that you know something about environmental geology.

*Create "relative risk" maps for the Northeast United States for each of the following:*

* earthquakes,
* land subsidence,
* landslides, and
* radon.

Do this by taking into account the main factors controlling each of these risks:

* earthquakes: plate boundaries and older faults
* land subsidence: areas with coal and limestone
* landslides: intense rainfall, rapid rainfall, steep slopes
* radon: iron-magnesium-poor volcanic rocks, granites, dark shales, some metamorphic rocks

*Use your own scaling and mapping system to describe the amount of risk.*

2. Your insurance company has many local clients.

*Looking at geologic and topographic maps, do this same exercise (1) for your local neighborhood.*

3. A publisher of a book on the best and worst places to live in the Northeast hears about your maps. She'd like a way to summarize the information for her purposes and hires you as a consultant to provide one generalized map of best and worst places with respect to geological hazards. To do this you will have to take into account the *relative* risk of the different kinds of hazards and combine them into one scale of risk.

*Using your maps from (1), find in the Northeast a system to combine the different risks, so that you have one number (say from 0 to 10) describing risk. Explain your reasoning and the caveats involved in using just one number to express risk.*

*Draw another map, now using your 'combined' risk scale.*
*Make a list of the top 5 and worst 5 places in the Northeast for natural geological hazards.*

# For More Information...

## Earthquakes

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## Earthquake Internet Sites

Earthquakes in Eastern North America
http://www.nysm.nysed.gov/geodame.html

Earthquakes in Vermont
http://www.anr.state.vt.us/geology/erthqks.htm#risks

National Earthquake Information Center
USGS Earthquake Hazards Program
http://wwwneic.cr.usgs.gov/current_seismicity.shtml

New England Seismic Network/MIT
http://www-erl.mit.edu/NESN/homepage.html

Weston Observatory
www.bc.edu/bc_org/avp/cas/wesobs/

Why does the earth quake in New England?
http://www2.bc.edu/~kafka/Why_Quakes/why_quakes.html

## Radon

1992, *A Citizen's Guide to Radon: The guide to protecting yourself and your family from radon*, 2nd edition, EPA 402-k92-001.

Otton, James K., Linda C.S. Gundersen, and R. Randall Schumann, 1995, *The Geology of Radon*, US Department of the Interior/US Geological Survey: Reston, Virginia.

EPA Radon
http://www.epa.gov/iaq/radon/

Environmental Health Center/ National Safety Council on Radon
www.nsc.org/ehc/radon.htm

Radon in Earth, Air, and Water
http://sedwww.cr.usgs.gov:8080/radon/radonhome.html

## Landslides

USGS National Landslide Information Center
Federal Center
Box 25046
MS 966
Denver, CO 80225-0046

Landslides
http://landslides.usgs.gov/index.shtml

USGS Landslide Map of the United States
http://geopubs.wr.usgs.gov/map-mf/mf2329/

## Land Subsidence

Kochanov, William E., 1999, *Sinkholes in Pennsylvania*, Educational Series 11, Pennsylvania Geological Survey: Harrisburg, Pennsylvania.

# Selected Figures

## *for overheads & handouts*

*Figure 8.2: Earthquake risk in the Northeast. Earthquake-induced ground movement is expressed as a percentage of the force of gravity (%g). The map illustrates the amount of ground shaking that is predicted in a given period of time.* After

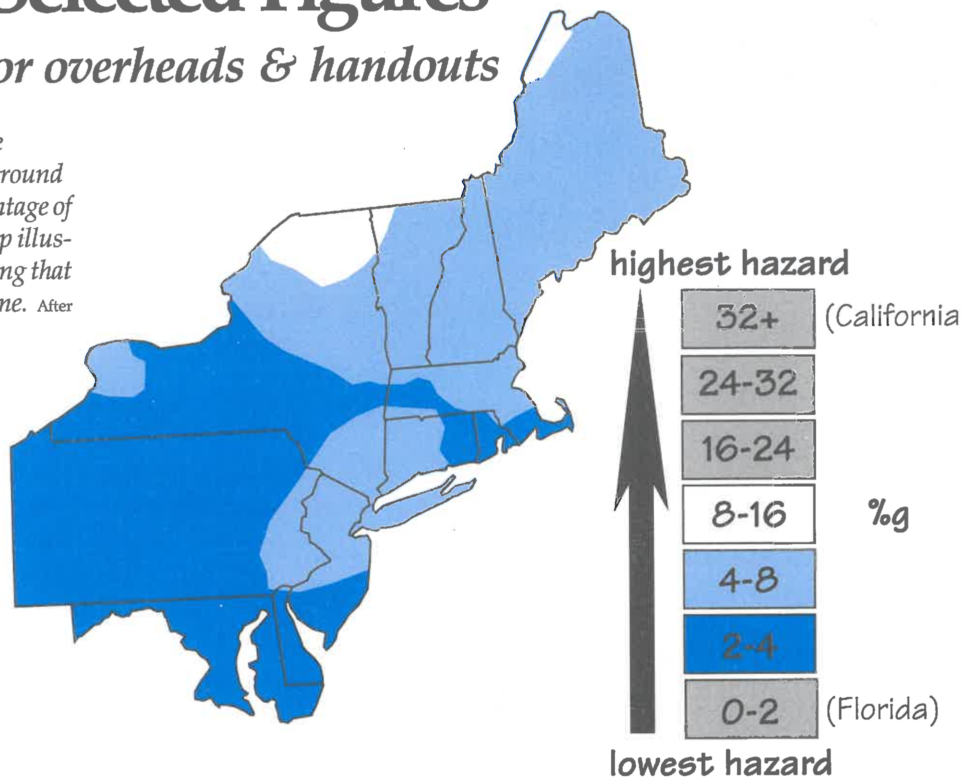
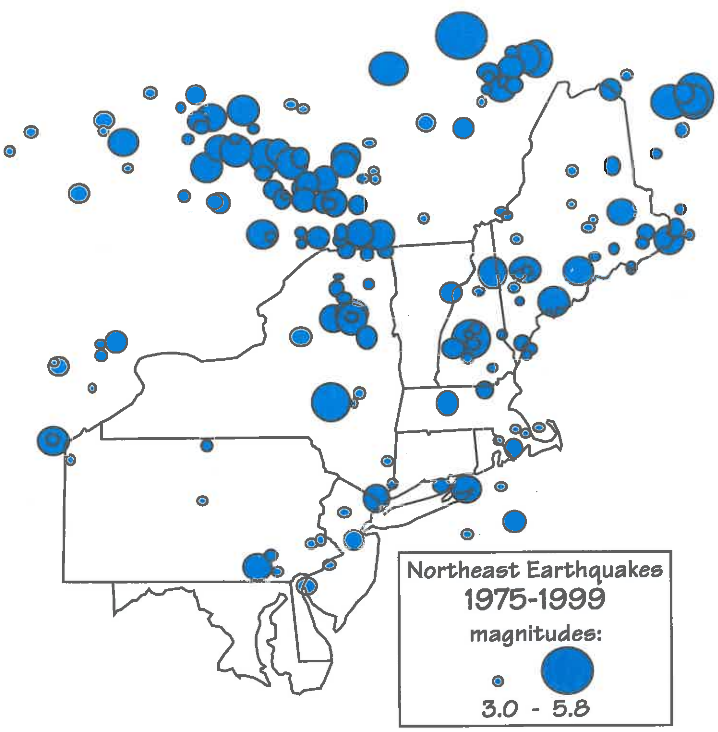



*Figure 8.3: Earthquakes with a magnitude greater than 3.0 in the Northeastern US from 1975 to 1999.* Image courtesy of Alan Kafka, Weston Observatory, http://www2.bc.edu/~kafka/Why_Quakes/why_quakes.html.



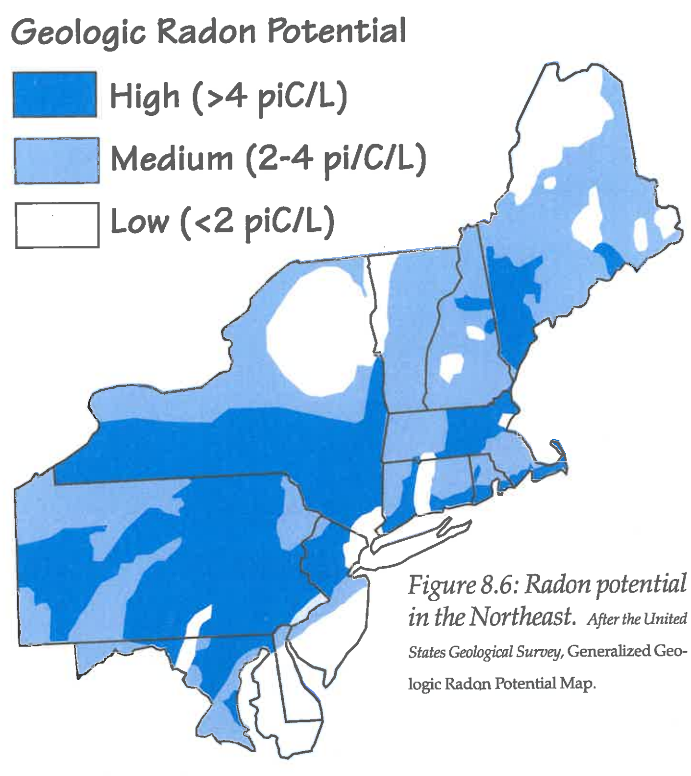




*Figure 8.6: Radon potential in the Northeast.* After the United States Geological Survey, Generalized Geologic Radon Potential Map.

# Earth System Science:
# *The Big Ideas*

*Like all scientific disciplines, the Earth sciences continually evolve over time. New discoveries fuel new ideas, providing an ever-increasing understanding of the planet. But of the overwhelming number of observations, theories, and principles that form the foundation of Earth system science, what is essential for every American to understand? All too often, curricula are too ambitious and, as a result, may fail to cover topics in any substantial depth. An alternative approach is to build one's curriculum upon a foundation of focused, interconnected* ***big ideas****. A well-designed set of big ideas can provide an all-encompassing conceptual framework for any discipline, including Earth system science. Developed alongside scientists and Earth science teachers, presented here is a set of big ideas that illuminates fundamental concepts of the Earth sciences:*

❶ **The Earth is a System of Systems**

❷ **The Flow of Energy Drives the Cycling of Matter**

❸ **Life influences and is influenced by the environment.**

❹ **Physical and chemical principles are unchanging and drive both gradual and rapid changes in the Earth system.**

❺ **To Understand (Deep) Time and the Scale of Space, Models and Maps are Necessary**

*These ideas are designed to cover the breadth of any Earth science curriculum, but they also require dissection to build deep understanding. Each idea is essentially bottomless; that is, while a meaningful understanding of these ideas is readily attainable, the details contained within are endless. Each of the ideas can be understood, but the depth of understanding can vary greatly.*

*Introduction of these ideas also invites discussion of the* ***nature of science****. As curricula are designed and implemented, the traditional topics of Earth system science should be complemented with ideas on how we come to know what we know about the natural world.*

# Big Idea I:

## *The Earth is a System of Systems*

The Earth is composed of many systems, which cycle and interact in both space and time. It is also part of a multitude of systems, nested in larger systems like the solar system and the universe. Systems are composed of an untold number of interacting parts that follow simple rules, but they can and do evolve. For example:

- Outlining the geologic history of any region demonstrates the concept of the Earth as a system of systems. ***Plate tectonics*** drives the formation of mountains. Subsequent weathering and erosion of the uplifted mountains leads to the formation of deltas in the adjacent shallow seas. And with uplifted continents, shorelines change and the distribution of marine communities are altered.

- The planet's systems are intimately connected: the forces of one system affect other systems nested within it. Systems that drive plate tectonics are obviously linked to the formation of mountains, as plates collide, but they are ultimately linked to and influence much smaller systems. The intense heat and pressure resulting from collisions can lead to the metamorphism of existing strata, or it can melt existing rocks to later form igneous rocks.

- As ***glaciers*** extended down from the north, they cut into river valleys in the central portion of New York. This glacial system shaped the landscape, carving the rivers into lakes and, after the glaciers' retreat, leading to the formation of deeply cut gorges. Had the glaciers never advanced so far south, the erosional forces that led to the formation of the gorges would have never been initiated.

> *Each of the remaining big ideas operates across multiple systems within the larger Earth system.*

**Plate tectonics** *is a theory based on the observation that the rigid layers of the Earth are composed of multiple plates that move and interact with one another and their boundaries.*

*For more information on the glacial features of New York, see the* **Glaciers** *chapter in PRI's Teacher-Friendly Guide to the Geology of the Northeastern U.S.*

# Big Idea II:

## *The Flow of Energy Drives the Cycling of Matter*

The Earth is an open system. Energy flows and cycles through the system; matter cycles within it. This cycling is largely driven by the interaction of the differential distribution of solar radiation and internal heat: the constant flow of solar radiation powers much of Earth's ocean and atmospheric processes on the surface of the system, while the flow of heat from radioactivity within the Earth drives plate tectonics. For example:

*see Rocks, p. 29, for a diagram of the **rock cycle**.*

- One of the fundamental processes known to Earth system scientists is the ***rock cycle***. The rock cycle illustrates steps involved in the formation of one type of rock from another. It is a system that has operated since the Earth's origin, and it continues today. The energy that drives weathering and erosion, melting, or an increase in heat or pressure drives the continuation of the rock cycle.

*For more information on the **Grenville Mountains** see the Geologic History chapter in PRI's Teacher-Friendly Guide to the Geology of the Northeastern U.S.*

- The landscape of the Northeast that we see today has been shaped by the geologic forces of the past. Evidence littered throughout the terrain tells a story that began some one billion years ago with the formation of the ***Grenville Mountains***, which resulted from the collision of proto-North America and another continent. The movement of Earth's plates is driven by plate tectonics, illustrating one example of how the flow of energy drives the cycling of matter–the flow of heat from radioactivity within the Earth drives plate tectonics.

- During the most recent ice age, glaciers advanced and retreated many times during the past two million years. One of the great questions in the Earth sciences revolves around the causes of these glacial cycles, with the general consensus pointing toward cyclic variations in the planet's tilt, movement about its axis, and its orbital shape around the sun. These variations lead to changes in the amount of solar radiation that reaches the Earth, which in turn affect global climate.

***Convection** is the rising of less dense material and the sinking of more dense material. Variations in density are commonly caused by temperature or compositional variations.*

- The rock cycle, plate tectonics, and the water cycle are all ***convection*** driven. Without convection, Earth would be extraordinarily different.

# Big Idea III:

## *Life—including human life—influences and is influenced by the environment.*

Across its four billion year history, the course of life's evolution has been intimately tied to the Earth's physical environment. Global cooling led to the relatively recent spread of grasslands, which then triggered an evolutionary shift in many herbivorous mammals from browsing to grazing. Conversely, the evolution of life alters the physical environment. Photosynthetic bacteria released free oxygen into the early oceans and atmosphere, making Earth habitable for later types of organisms. Humans, with an interesting population and expanding technology, have altered the landscape, altered the distribution of flora and fauna, and are changing atmospheric chemistry in ways that alter the climate. Earth system processes also affect where and how humans live. For example:

- During the Precambrian, the evolution of photosynthetic organisms led to significant change in the planet's atmosphere. Prior to this event, there was little free oxygen in the atmosphere, but with photosynthesis producing oxygen as a waste product, the very existence of these organisms flooded the seas and atmosphere with free oxygen, changing the planet forever. But life's evolution represents just one of the processes working upon the Earth system.
- With human populations increasing the world over, the emission of greenhouse gases has also increased dramatically. These gases alter the chemical composition of the atmosphere and directly influence the planet's climate. It is generally agreed that the rapid and immense pouring of carbon dioxide into the atmosphere will lead to global warming, which will have incredible impacts throughout the world.
- Around three million years ago, a land bridge formed between North and South America. For the first time in more than 150 million years, the two continents were linked, and the mammals inhabiting both lands migrated across the bridge. Horses, mastodons, cats, and dogs moved south, while opossums, porcupines, ground sloths, and armadillos moved north (to name a few). Today, half the mammal species in South America are descended from North American migrants.

*For more infomartion on humans' effect on the environment, visit PRI's Global Change Project online at:* **www.priweb.org/globalchange.html**

## Big Idea IV :

### *Physical and chemical principles are unchanging and drive both gradual and rapid changes in the Earth system.*

Earth processes operating today, everything from local erosion to plate tectonics, are the same as those operating since they arose in Earth history, and these processes are obedient to the laws of chemistry and physics. While the processes that constantly change the planet are essentially fixed, their rates are not. Tipping points are reached that can result in rapid changes cascading through Earth systems. For example:

- Extending from southern Maine up through New Hampshire, the White Mountain Series initially formed deep within the crust as plumes of magma rose from the mantle. As the plate moved over a hot spot, magma pushed upward through the crust to form the string of igneous bodies. It is thought that the Hawaiian Islands may have formed (and are still forming!) in a similar manner.

- Today, the ice sheets of Greenland and Antarctica make up some 95% of all the current glacial ice on Earth. The study of these modern glaciers and their influences on the environment, such as the formation of U-shaped valleys, is key to interpreting glacial deposits of the past, which are thought to have formed under the same processes as those operating today.

# Big Idea V :

## *To Understand (Deep) Time and the Scale of Space, Models and Maps are Necessary*

The use of models is fundamental to all of the Earth sciences. Maps and models: 1) aid in the understanding of aspects of the Earth system that are too big or small for direct observation, or where observation is not possible; and 2) help make complex systems comprehensible through strategic simplification. When compared to the size and age of the universe, humanity is a speck in space and a blip in time; models assist in the comprehension of time and space at both sub-microscopic and immense scales. For example:

- Much of scientists' understanding of the inner workings of our planet is derived from mathematical modeling. It is not possible to measure directly the movement below Earth's surface, but modeling of ***convection*** currents brings us closer to the true nature of these immense geologic phenomena.

- The observation of natural phenomena today, such as deposition along a stream, is critical for interpreting the geologic record. But for processes that operate on much larger, slower scales, modeling within the lab is required. Understanding the formation of mountain ranges, such as the Acadian and Appalachians, are better understood by examining the effects of stress and strain in the laboratory.

- What is the effect of a two-kilometer thick glacier on the terrain? In addition to changes related to deposition, the shear weight of such an object depresses the continental mass. Understanding this compression—and the rebound that occurs upon the glaciers' retreat—is improved through modeling in the laboratory.

**Convection** *is the rising of less dense material and the sinking of more dense material. Variations in density are commonly caused by temperature or compositional variations.*

**Glaciers** *are build-up of snow, firn, and ice—partially or wholly on land—which move down-hill under their own weight.*

### *In conclusion...*

***Taken individually, these*** **big ideas** ***represent important aspects of Earth system science, but together they are more significant. Keeping these ideas in mind—and considering how these ideas arose through scientific methods and investigation—as one proceeds throughout his or her curriculum can provide a conceptual framework upon which to build an enduring understanding of the discipline.***

# Earth Science Fieldwork:
## *"Why Does This Place Look the Way it Does?"*


*Geology was built upon observations of the natural world. These observations are the clues that scientists use to reconstruct the history of the Earth. Shelly fossils along the Himilayas tell of ancient sea floors that have been uplifted into mountains. Ripple marks since turned to stone tell of ancient shorelines. And scratches along the bedrock in Central Park tell of massive glaciers that—some 20,000 years ago—created a skyline much different than the steel and glass of New York today. That massive glaciers once advanced as far south as New York is not a conclusion derived from mathematical modeling in a lab, but is instead evidenced by those scratches and a host of observed glacial deposits that litter not only New York, but much of the Northeast and Midwest.*

***The story of a place is written in its landscape, rocks and fossils. Fieldwork investigations help scientists—and students and teachers—tell that story.***

*Introducing students to the practice of geologic fieldwork can be a tremendous experience. Exploring local geology through inquiry-based approaches emphasizes critical thinking. And by conducting such investigations, students have taken a tremendous leap: they are not merely learning about science; they are doing science! But getting students into the field can be difficult. An alternative is for the educator to visit the field on their own time, returning to the classroom with a series of images and specimens that permit a* ***Virtual Field Experience*** *(VFE). Virtual fieldwork offers the experience of exploring an area without leaving the classroom, and it allows multiple "visits" to a site. VFEs can also enhance and extend the experience when actual fieldwork is possible. The Earth is a system, after all, and any one site—virtual or real—can display a host of natural phenomena, from simple erosion and deposition to the principles of superposition and faunal succession to the formation of ripple marks or mud cracks. Ideally, virtual fieldwork in the classroom captures the active experience of a geologist examining an area for the first time: It provides opportunities to actively explore, discover, ask questions, and make observations to answer those questions, ultimately allowing students to develop educated responses to the question,* Why does this place look the way it does?

# Fieldwork 101:
## *Gathering Information & Creating Your Own VFE*

What follows are recommendations. These recommendations are intended to help prepare you for fieldwork, but they are just guidelines, not steadfast rules. Bringing the field to the classroom at any scale is better than not bringing the field to the classroom at all. The careful attention to detail described here will prove extremely helpful, but avoid being discouraged if your first trip to the field isn't as productive as you had initially imagined. Scientists of all disciplines continually refine their methods and procedures, leading to more productive and "better" results over time. With time and more fieldwork, confidence will grow. Get into the field, be safe, and do your best to capture the experience in a way that allows you to best reproduce it for your students!

### *Before Visiting the Site*

#### *Understand the Geologic History of the Region*

In order to make sense of a local site, it's best to first understand the geologic history of the region before your visit. Did inland seas once flood the area? Have mountain-building events shaped the landscape and its rocks? The ***Teacher-Friendly Guides*** are an excellent source for discovering the history of a region, as well as that history's effect on the rocks, fossils, and other features of the area.

*Visit **www.teacherfriendlyguide.org** to download the regional guides.*

#### *Questions to Keep in Mind*

When visiting or examining any area, the ultimate question to answer is: Why does this place look the way it does? But to help answer such an overarching thought, it's important to have certain other questions in mind. These questions will guide exploration, and they will help ensure that important information is recorded during your visit:

- What kind(s) of rock(s) are found in the area? How do you know?
- In what environment did these rocks probably form?
- What is the arrangement of the rocks?
- Are fossils preserved in the rocks? If so what can they tell you about past environments?

- What has happened to this area to make it look the way it does today? (That is, what has happened to the area since the rocks formed?) Why do you think so? (What is the evidence for your claim?)

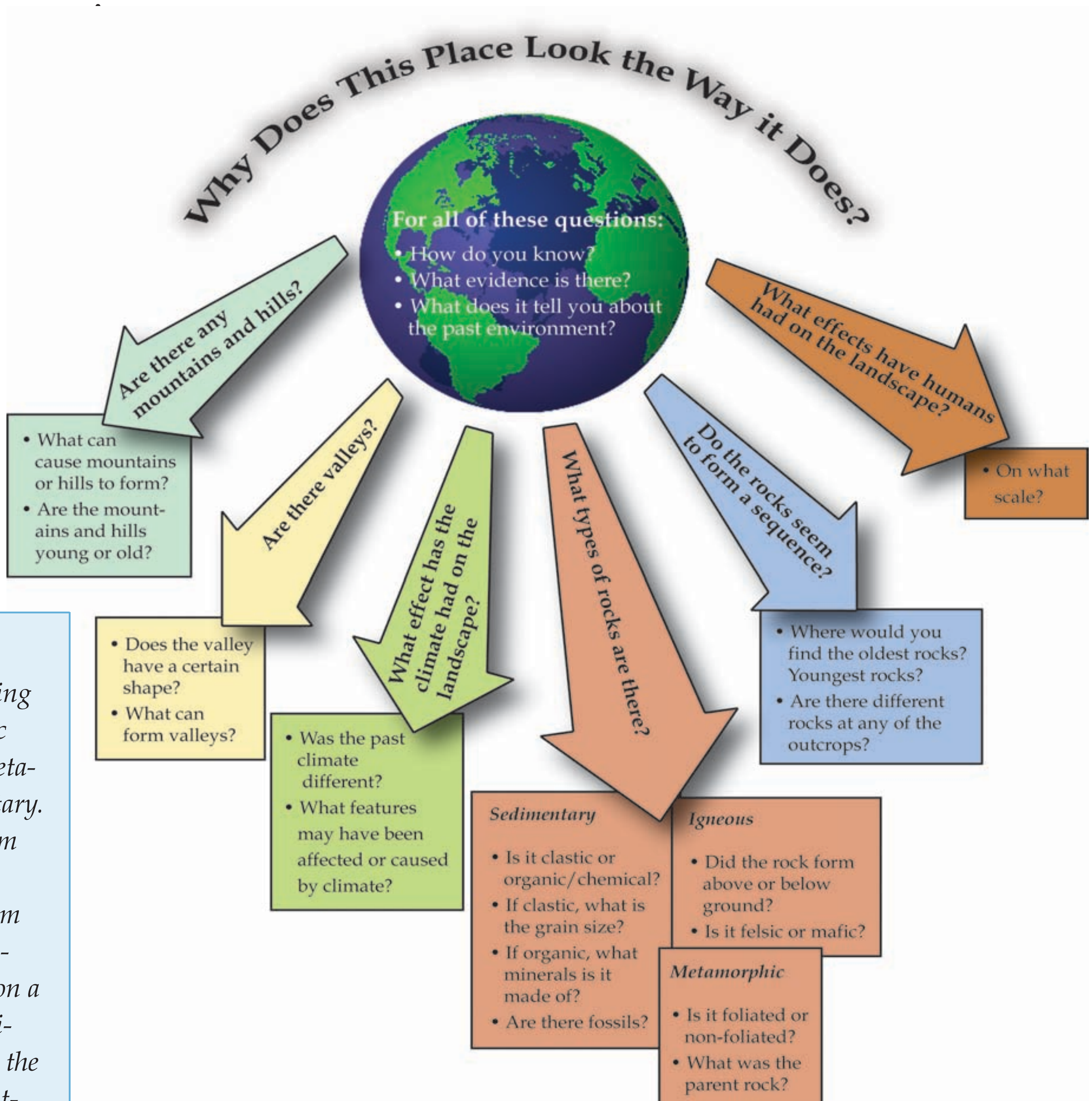



*Figure 10.1:*
*This flow chart shows various paths of inquiry that stem from the question:* Why does this place look the way it does?

**Three types of rock**

*Minerals are the building blocks of the three basic rock types: igneous, metamorphic, and sedimentary. Igneous rocks form from cooling molten rock. Metamorphic rocks form by increasing the temperature and pressures on a pre-existing rock. Sedimentary rocks form by the compaction and cementation of sediment particles resulting from the breakup of pre-existing igneous, metamorphic and sedimentary rocks.*

## *At the Site*

### *Safety in the Field*

At any field site, safety is the first priority. No photograph, measurement, or fossil is worth the risk of personal injury or death. To ensure safe and productive field work, keep the following thoughts in mind:

- Wearing the proper clothing is very important. Long pants are recommended, as are sturdy boots, which will help prevent twisted ankles as you scurry over uneven or loose surfaces.
- While walking through a valley or next to any outcrop, always be on the lookout for rock falls. Remember, slopes with no vegetation tend to produce more falls.
- If more than one individual is climbing an outcrop, do not climb single file. Rocks dislodged from one climber can quickly tumble down the outcrop and hit the next climber.
- When using your rock hammer, protective eye wear should always be worn. If your hammer possesses a sharp pick opposite the flat surface, always use the flat surface when striking. And if you are working with others, notify all in the vicinity before striking any surface with your hammer.
- Never use one hammer to strike another. Metal chips can be broken off and thrown at high speeds.
- Finally, always carry a small, standard first-aid kit.

### *Documentation & Specimen Collection*

*Photographs:* Once at a field site—for both professional and amateur scientists alike—it is easy to immediately begin taking photographs without recording notes to accompany them. But the lack of proper documentation is perhaps the most common mistake in the field, especially with digital photography, where it is possible to take tens to hundreds of photographs at a site. Also, before you begin photographing it is advisable to first explore the entire location and develop a plan for how you will communicate the site to your students back in the classroom. This plan will guide your photography, and the recorded notes will ensure that every image makes sense long after you've visited the site. Proper documentation includes:

- Note the location and orientation of the photographs you take.

#### *Materials to Take*

**Documenting the Site:**

- *Camera (esp. digital cameras for easy download and presentations)*
- *Notebook, ideally* Rite in the Rain *brand*
- *Map of the area, ideally a topographic map*

Recording this information on a map is very helpful.

- In each photograph, it is important to have a sense of scale. For smaller structures (like ripple marks or fossils) or close-ups of an outcrop or rock, it is important to show scale by using a common object, such as a penny, rock hammer, an unsharpened pencil, or (ideally) a clearly-marked ruler. For larger structures, a really great scale is a person, so feel free to step into the picture! The importance of a scale can not be overstated, as the proper identification of geologic features in photographs often depends on knowing the feature's size.

*Drawings:* Although photographs are key, simple sketches or drawings are also useful for documenting a field site. In fact, subtle changes in rock layers, for example, may not show in photographs, so to capture such features, drawing may be required. Drawing also forces you (or your students) to observe closely. It will be usefull to use either a *Rite in the Rain* notebook (available at www.riteintherain.com) or a large, clear plastic bag to hold your notebook in case of rain. When drawing, keep in mind that you should document the same type of information that is documented in photographs (location, orientation, scale).

*Collecting specimens:* Rocks and fossils often provide significant clues for interpreting past environments. Layers of basalt indicate past volcanism, for example, whereas shales bearing trilobite and other fossils indicate deposition in a shallow sea. Collecting specimens from a site provides a wonderful opportunity to take a piece of the field into the classroom, allowing you to engage students in hands-on learning. Collecting specimens also permits further study away from the field site. Both time and field conditions limit the study of samples at a site; collecting allows extended study of samples. You can and are encouraged to identify rock, mineral, and fossil types in the field, but studying them indoors with additional tools and references can confirm—or force you to revise—your identification.

*Important: Before any rocks or fossils are removed from a site, be sure to confirm that collecting is permitted on the grounds!*

***Materials to Take***

**Collecting Specimens:**

- *Rock hammer, chisel-head is preferred*
- *Goggles or other eye protection*
- *Resealable bags or small specimen boxes, ideally clear durable bags, like freezer bags with white areas for writing*
- *Small boxes or plastic totes for carrying bagged specimens*
- *Permanent marker for labeling bags and/or boxes*
- *Specimen labels (a few examples are available at the end of this chapter)*

**Miscellaneous Items:**

- *Hand lens, about 10x*
- *Tape measure and/or measuring stick*
- *Scale to include in photographs*
- *Pocket knife*
- *Compass to allow proper orientation within the site. If available, a brunton compass is useful for measuring the angle, or dip, of bedding*
- *First-aid kit*
- *A GPS unit is beneficial, but not truly necessary*

So, what do you need to know about collecting specimens?

- You first need to confirm that collecting specimens at the site you are visiting is legal. Typically, collecting is not allowed in parks, so be sure to check.
- Just as you made decisions about photography based on how you will communicate the site to students, collect specimens that will help tell the story of the site back in the classroom. If rock types change from area to area, either vertically or horizontally, then specimens of each type are ideal.
- Before collecting a specimen, take a photograph of it ***in situ***, both close-up as well as from a distance. Don't forget to include an object for scale in the photograph!
- Document the location from which the specimen is collected, preferably on a map of the area. Labeling the specimen with a number that corresponds to the same on your map is an effective technique.
- Specimens should be broken directly from the outcrop so the exact source is known. Eroded rocks scattered about on the floor of the site may have originated from multiple locations.
- The weathered surface of rocks often carries a different appearance than a "fresh" break. Ideally, collected specimens possess one weathered surface but are otherwise not weathered. Rocks broken directly from outcrops will ensure fresh surfaces.
- As specimens are collected, place each in a separate resealable bag, noting on the bag with permanent marker each specimen's location as indicated on your map.

*An* **in situ** *object is one that is situated in its original position.*

## *Back in the Classroom: Virtual Field Experiences (VFEs)*

Perhaps the most critical step after your trip to a field site is to, once back in your lab or classroom, examine all of your photographs, illustrations, specimens, and notes associated with each. Sometimes even the most diligent geologist forgets to record notes that, in hind sight, are critical. It is therefore recommended that one makes sure that his or her notes are legible and complete. Recopy your notes. Such an activity will not only ensure legibility for the future, but it will help indicate any gaps in your note taking. If gaps exist, then it is easiest to fill them when your memory of the site is fresh.

Once your materials from the site visit are in order, it is time to develop an activity that will allow your students to experience the site much like you did—but in the classroom. One recommended activity is the *Virtual Field Experience* (VFE). Scientists in the field do not have a single possible way to operate, nor do they have a guide explaining what they see at every turn. In the field, one might pick up a rock and take a closer look, or pull out a magnifying glass and look at a cliff face. Exploration drives inquiry in the field; inquiry and exploration are the goal of VFEs.

The concept of VFEs can take on multiple forms. For example, kits containing maps, printed photographs, and specimens (with notes on the map indicating where the specimens were collected or photographs taken) can be produced. Or, your digital photographs can be embedded within a PowerPoint presentation, website, or Google Earth tour with notes indicated where the specimens were collected. But keep in mind that these electronic presentations may take on a very linear, directed feel. In that respect, be careful that your VFE does not turn into a Virtual Field *Trip*. Virtual Field Trips have become increasingly common at many levels of education. But these experiences are typically guided tours rather than opportunities for inquiry. An online search will yield many examples of these tours, as will a search of the Digital Library of Earth System Education (DLESE). Such resources clearly have value, but they are passive experiences for students. VFEs, in contrast, stress the importance of inquiry; learning for understanding involves students figuring things out.

In considering VFEs as a recurring practice, initial experiences are perhaps more guided than the later experiences; allow a gradual transfer of responsibility from teacher to student. But VFEs ideally offer the same opportunities for exploration as those provided at an actual field site, with occasional moments of discovery that lead to new questions about the site. By asking such questions and then seeking answers, students are doing science. And it is perfectly reasonable to virtually visit a site several times for further data collection, or to study different concepts at the same site. Scientists, of course, do this exactly.

***Be sure to visit www.virtualfieldwork.org on a regular basis to find a constantly updated selection of VFEs created by scientists and educators around the country.***

## A VFE Vignette

To get you thinking about how to deliver a VFE, the following vignette illustrates how a VFE might look in an Earth science classroom. The story reflects a classroom familiar with fieldwork experiences. It is not meant to serve as a standard model for VFEs, but simply one possible outcome. In this example:

> Ms. G had taken a hike in the woods and found a rock feature that didn't match its surroundings. Through a VFE that she created, she engaged her students in the puzzle of figuring out why the place looked the way it did. She had shot several photographs at the site, and she brought back a few rocks.
>
> She'd done this a few times over the course of the year, in effect taking her students on virtual fieldtrips. Over time, she'd built up a number of such activities that took her students where she'd been through the power of her description and a framework that she was forever developing.
>
> There were certain things she'd learned to do on each one of these trips (whether with the kids or when she went on her own to create a virtual field trip for her kids). She took a GPS unit and recorded the coordinates of points of interest. She took her digital camera, and sometimes her video camera. She could then incorporate images of the place into both student handouts and into computer slideshows. If it was in a place where she had permission to collect, she'd bring her rock hammer (if she thought she'd need it).
>
> This time, she took a slightly different approach with her use of pictures. She created a quick and simple webpage of the pictures. This was very simple to do with the photo management software that came with her computer. She used the web space provided by the school district. She added a label on the top of the page and gave a few of the photo titles, but she didn't sort through them. She didn't have time for such sorting, for one, but she thought it would be interesting to have the kids figure out which pictures were better for showing whatever it was they wanted to show. Earlier in the year, she'd done more of the sorting through of things like this, but was consciously trying to gradually shift more and more of the responsibilities of learning and teaching to her students.
>
> The class begins by Ms. G talking about the hike she'd taken over the week-end. She was hiking in the woods on a hilltop not too far away, but far enough away and remote enough that it wasn't likely her students had been there.
>
> She told the class that she was walking along the trail through the woods, and

*This vignette highlights some elements of Teaching Standards A, B, C, D, and E; 9-12 Content Standards A, D, and F; the Unifying Concepts and Processes; and Program Standards A, B, and D.*

then she came around a bend in the trail and found an area that was partly surrounded by vertical rock walls about 10 meters high. She showed several pictures by clicking through the webpage mentioned above. The students got into their regular working groups of three or four. Each group was given two rock samples and a handout that included pictures of the area. Ms. G told the class to take about ten minutes to analyze the information they had about this place and then be prepared to talk about it: "If you think you know something about the area, remember to be prepared to describe how you know what you know."

The handout included a set of questions, but these questions were, for the most part, not new to the students. The question page was titled "Why does this place look like this?" and all the questions that followed were intended to connect back to this main question. The questions that followed the lead question were:

1. What kind(s) of rock(s) are found in the area? How do you know? What environment did these rocks probably form in?
2. Describe the arrangement and variety of rocks shown in the photographs.
3. Tell a story of how these rocks may have formed referring back to the photographs and what you have determined about the rock sample(s).
4. What has happened to this area to make it look the way it does today? (That is, what has happened to the area since the rocks formed?) Why do you think so (what is the evidence for your claim)?
5. If you could go to the site, what else would you want to do to answer the above questions?

Ms. G wanted to teach through inquiry methods. She wondered if this somewhat formulaic approach would be considered inquiry. In all these virtual fieldtrips, she had a good idea of what students would discover. In this case, she expected them to figure out that it was an abandoned quarry, where the limestone came from, that built the old buildings at a nearby university.

In the last year she added what she hoped would be an additional motivation for learning. She'd added a new essential question to her list: "What does learning this empower you to do?" This allowed her to more explicitly teach metacognition (thinking about thinking) and it allowed her to draw out of her students answers to the question, "Why do we have to learn this stuff?" If they answered it themselves, they were being metacognitive and they were getting answers to this important question.

While she wondered about whether or not what she was doing could truly be classified as inquiry, she had confidence that it was more effective than what she used to do—stand at the overhead and deliver notes.

She believed it was more effective for many reasons, but perhaps most importantly she saw a more clear connection among the different things she taught and it seemed her students did, too. Instead of identifying rocks and minerals for the sake of identifying rocks and minerals and learning something more broadly about taxonomies and dichotomous keys, students now had a purpose for identifying those things. If they figured out what it was, then they also had a good idea of how it formed. If they had a good idea of how it formed, they could use that to understand something about the history of a place. They could use this understanding as part of a story, an unraveling mystery that they were active in unraveling themselves. In this case that story also connected to the human history of the area. This quarry provided the stone that built some of the oldest buildings in the county and at least the first one of those buildings was built by students working together with their professors. This use of story provided a sense of wholeness that had been missing in her teaching.

*What the area looked like*: The area that was partially surrounded by those vertical rock walls had a flat floor that was largely moist but didn't have any spots where the water was more than several centimeters deep. Bare, flat rock was exposed in several places on the floor of this place. She had paced some of it out to get a rough idea of the dimensions of the place and had taken several photographs.

Her photographs showed the lay of the land for the larger area surrounding the spot. All the hills were about the same height--it looked to the students that she was in the same region as where they lived, and a few recognized that her first pictures included a nearby university's campus. Once this word was out, students knew that it was in the same landscape region. "That means it's all sedimentary rock," said Joe.

This was confirmed by the presence of fossils in some of the samples. As the students studied the rock samples, and the pictures of the cliff faces, you could hear them working through rock ID tables.

"Is it a sandstone?" "No, it's too smooth," came a quick reply. "Look at how flat the sides are. Are they crystal faces?" "That's one ugly crystal if they are. Remember, the other piece looks a lot like this one, but it's got fossils in it. Oh look! There's a fossil on this one too!" "Is it limestone?" "Should we do the acid test?" They tested it with dilute hydrochloric acid and it fizzed. Limestone it was.

One group wanted to know the coordinates immediately, and Ms. G knew but she wouldn't surrender that information without the students first having explained how the area in the pictures came to look the way it did. They didn't have much to say initially so she made them wait. She knew they wanted to go to the computer and to the USGS map viewer. Once they plugged in the coordinates, they'd see the quarry symbol on the map. (The coordinates were: 75˚ 31' 56" West, 42˚ 48' 50" North; Stated in decimal degrees, -75.532; 42.814.)

Another group was more focused on the pictures. Katelyn said, "In 823, you can see rock layers, so it definitely looks like sedimentary rock." Ms. G was standing nearby and was glad they were sorting through the pictures as she'd hoped. "It looks kind of like a gorge, but it looks like there's only one side to it." "There's not really anything that looks like a stream bed, but that might just be missing from the pictures. That's one thing to look for if we were able to go up there." "Or if we knew where it was on a topo map." "Ms. G!" They got her attention. "Can we look on a topo map? We want to know if there's a stream there that might have carved out a gorge." Ms. G responded, "That's a good idea to investigate. I want you to think a bit more before I give you the coordinates though. I will tell you that it wasn't a gorge. It's fairly close to the hill top you see here." She was pointing to a spot on one of the pictures taken from across the valley. "Do you think a gorge would be on a hilltop?"

The group who had wanted the coordinates right off was moving somewhat slower than the other groups. Ms. G wandered over to check in and maybe push them along a bit. She asked, "What can you tell me?" There were shrugs. "What kind of rock is it?" "Sedimentary" is mumbled. "That's right. How do you know?" Another mumble, "Fossils." At least she was getting some kind of answers and they were in very much the right direction, but she was frustrated that she had somehow asked these questions that allowed a one-word way out. "Where did it go?" Ms. G asked. "What do you mean?" came back. "Well, when this rock formed, do you think it was formed all stacked up like this with an almost straight edge sticking out into the air or water or whatever it formed in?" Justin said, "Who cares?" Ooh. They were a frustrating group, but Ms. G kept her cool. "I thought maybe you did when you asked for the coordinates. Come up with an answer that you can support using the information you have and I'll give you the coordinates to look up on the map viewer." She moved on, hoping they'd try to figure it out.

After letting the frustrating group hash it out a bit longer, Ms. G turned her last question for them to the whole class, "Where did the rocks go?" She got the same response as earlier, but from a different student. "What do you mean?" Justin chimed in, more favorably this time, "There doesn't seem to be much of a stream to have washed it away, but it wouldn't form just straight up like that, or at least not having that flat, bare rock right at the base of the cliff. I think it's an old quarry." From Katelyn's group came an affirmation--"That's why she wouldn't let us look on the topo maps. It'd be marked and give it away. Can we bring it up on the map viewer now?"

Ms. G had Audrey, from Katelyn's group, bring the map viewer up on one of the computers and plugged in the coordinates. "I knew it. There's the quarry symbol!" Ms. G asked what else she could tell from the map. "It's on the Colgate campus, and there's a dirt road leading into it. I'll bet it's where they got the stone for the campus buildings." Ms. G responded in the affirmative. "Ok, we've figured out why it didn't match the surrounding forest. Now I want you to work through the questions on your sheet and I've got another set of questions that are more specific to the quarry." She handed out a sheet with these questions:

1. Why do you think the quarry was dug in this particular location?
2. Colgate's added a lot of buildings in the last several years, and many of them are stone. But this quarry has obviously been unused for many years. Why do you think they stopped using it?
3. Imagine that Colgate has asked you to find a new quarry site for a new science building they plan to construct. Use the geologic and topographic maps to select another quarry site that would likely contain similar stone. Together with your partners, write a proposal for siting the quarry in a particulary location. In your proposal, you should address not only the nature of the stone the quarry can produce but also at least three other factors that you determine to be important for siting the quarry. Plan to present this to the rest of the class next week. You may use either a poster or a PowerPoint presentation.

*A map viewer is available at* ***http://nmviewerogc.cr.usgs.gov/view.htm***

*References*:

National Research Council. (1996). *National science education standards*. Washington, D.C.: National Academy Press.

United States Geological Survey (2005 access date). *The National Map Viewer*. Washington, D.C.: USGS http://nmviewogc.cr.usgs.gov/viewer.htm.

# For More Information...

## *Books*

Compton, Robert R., 1962, *Manual of Field Geology,* John Wiley & Sons, Inc.: New York, New York.

Maley, Terry S., 2005, *Field Geology Illustrated, Second Edition*, Mineral Land Publications: Boise, Idaho.

Walker, J. Douglas, and Harvey A. Cohen, 2007, *The Geoscience Handbook: AGI Data Sheets, 4th Edition*, American Geological Institute.

## *Online*

Visti the official home of VFEs at www.virtualfieldwork.org to learn more and explore the online database of educator-created VFEs!

Tips on teaching in the field, including notes on safety, liabilty and other issues http://www.nagt.org/nagt/field/index.html

*Rite in the Rain* notebooks are available online at http://www.riteintherain.com

Topographic maps are available at http://topomaps.usgs.gov/ or by clicking *Terrain* at http://maps.google.com

Field equipment items are available at http://geology-outfitters.com

# Selected Figures

## *for overheads & handouts*

### *Specimen Labels for Collecting in the Field*

**Specimen Label**

*Collection Location:*

*Rock or Fossil Type:*

*Geologic Period or Age of Rock:*

*Collector:*

*Collection Date:*

**Specimen Label**

*Collection Location:*

*Rock or Fossil Type:*

*Geologic Period or Age of Rock:*

*Collector:*

*Collection Date:*

**Specimen Label**

*Collection Location:*

*Rock or Fossil Type:*

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