APPENDIX F
GEOLOGY

INTRODUCTION

This chapter introduces the use of geology for the exploration and evaluation of naturally occurring construction materials for use as concrete aggregate, rip-rap, quarry stone, fill, and filter materials in the Mid-Atlantic Region. The Mid-Atlantic Region includes Pennsylvania (PA), New Jersey (NJ), West Virginia (WV), Maryland (MD), Delaware (DE), and Virginia (VA)

GEOLOGICAL PRINCIPLES

GEOLOGIC TIME

Geologists are used to thinking of millions of years in the same way normal people think in terms of days. Geologic time encompasses the interval from the formation of the Earth and Solar System (approximately 4.5 billion years ago) to now. It is measured by using radioactive isotopes (that decay at constant rates) and by fossils. The consolidated rocks in the Mid-Atlantic Region range in age from 1 billion to 200 million years old, and unconsolidated sediment ranges in age from 70 million years old to the present.

The geologic time scale is divided into the Precambrian Era (4.9 billion to 590 million years ago), Paleozoic Era (590 to 250 million years ago), Mesozoic Era (250 to 67 million years ago), and Cenozoic Era (67 million years ago to the present). The Mid-Atlantic Region has rocks or unconsolidated sediment representing portions of all the Eras (see Figure F-1). The Eras are subdivided into Periods. Periods are generally named after the place where their rocks were first described. Thus, the Devonian Period is named after Devonshire in the UK, the Permian Period is named after the Perm region in Russia, the Jurassic Period is named after the Jura Mountains in Europe, and the Pennsylvanian Period is named after Pennsylvania.

The rock record is not continuous in any one place. The geologic story is put together from bits and pieces of rocks preserved across the globe. The gaps in the local rock record occur because of nondeposition or erosion. The rocks in the Mid-Atlantic Region record a fairly large portion of the Paleozoic Era (Figure F-2), but the earth's story is incomplete even in this stack of rocks. The rocks have been mapped, described, and analyzed by geologists, paleontologists, and geochemists from the state geological surveys, the state transportation departments, universities, the United States Geological Survey, and industry.

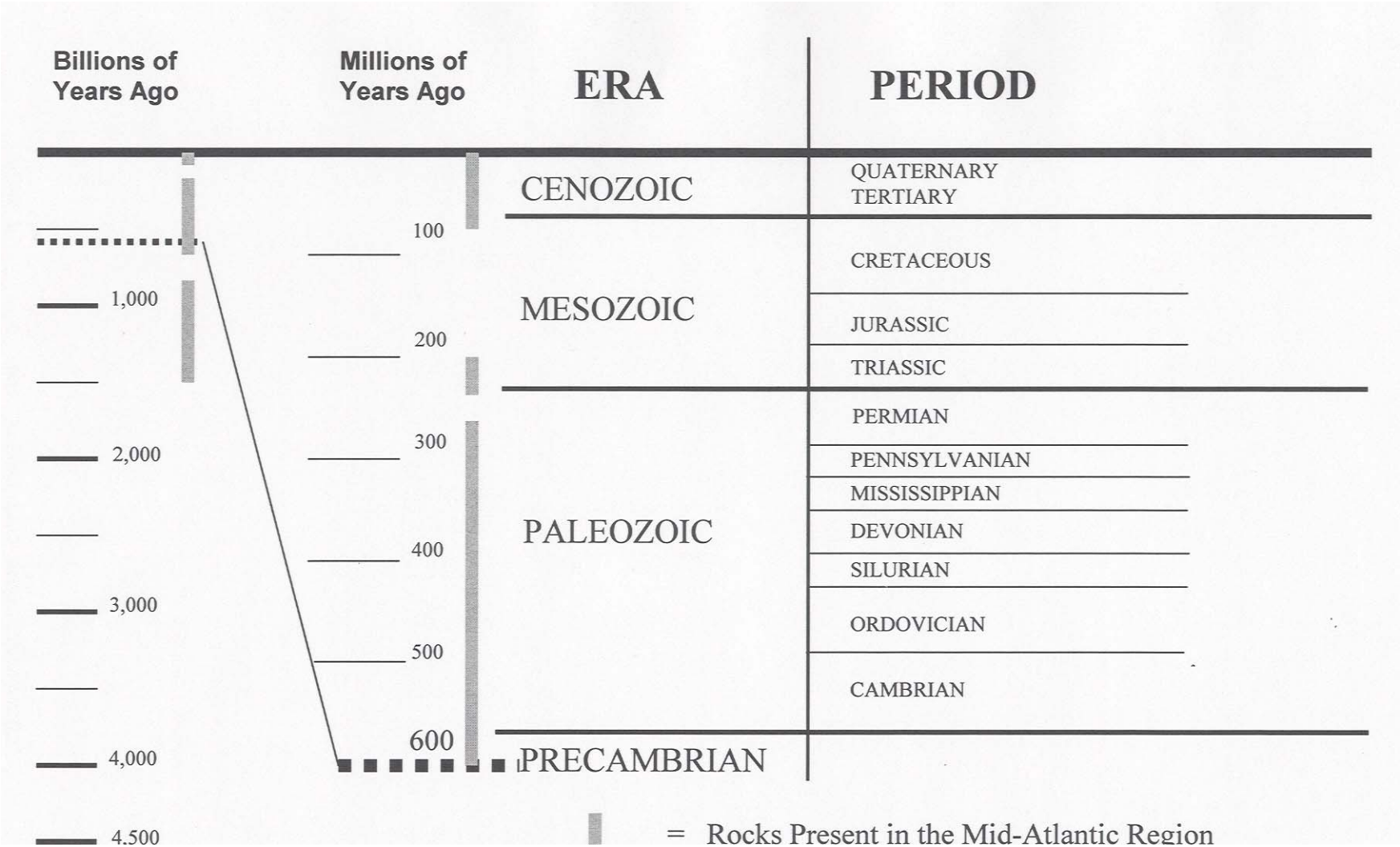


FIGURE F-1: GEOLOGIC TIME

LAW OF SUPERPOSITION

One of the primary tools of the geologist is the Law of Superposition, which simply states that rocks or sediment on the bottom of a pile are older than rocks or sediment at the top of the pile (assuming that the pile has not been intruded, tipped, folded, or faulted).

PALEOENVIRONMENTS

Paleoenvironments are environmental conditions (climate, latitude, topographic relief, depth of marine or fresh water, absence of water, and/or vegetation) that existed during a specified portion of geologic time in a particular place. For instance, the latitude of the continents have changed, sea level rose and fell, and mountain ranges rose and were eroded away many times during geologic time.

The latitude, configuration, and size of the continents and oceans have changed over geologic time because of *Plate Tectonics*. Plate Tectonics is the mechanism that has driven the migration of the continents across the Earth's surface. Plate Tectonics is the theory that the Earth's surface consists of a group of solid lithologic (rocky) plates that slide on more ductile or molten material at depth. These plates underlie the oceans and continents. Their motion gives Earth the most dynamic planetary surface in the Solar System.

The plates are created at spreading centers, usually marked by mid-ocean ridges, where molten magma comes to the surface along a narrow, long fracture zone, and are consumed at deep trenches overlying subduction zones, where the plates plunge into the depths of the Earth. Plates that are composed of 'continental rocks' (mostly granite) are less dense than plates comprised of 'oceanic rocks' (mostly basalt). At the subduction zones, the continental plates float on the hot ductile and molten rocks that lie below, while the oceanic plates sink or are dragged into the deeper rocks. Thus, oceanic plates tend to be consumed at subduction zones, and continental plates survive and accumulate new material along their edges. The new material is scrapped off the colliding plate. High mountains and plateau are forced up where two continental plates collide. The Indian and Asian plates are colliding today, and the Himalayas are being pushed up along their suture zone. The Great Lakes of Africa and the Red Sea and Dead Sea in the Middle East lie along new spreading centers. Collisions and splits of continents have controlled the rising and sinking of the land, size and shape of the continents, and the extent of the oceans.

The Mid-Atlantic Region is on the North American Plate. It was on the eastern edge of the plate for much of the Early Paleozoic Era. The North American Plate presently extends from the center of the Atlantic Ocean to the San Andreas Fault in California. The North American Plate only extended east to the cities of Newark, NJ- Philadelphia- Baltimore-Richmond during the early Paleozoic. Islands, small continents, and the African and European plates were welded to the North American Plate at various times during the Middle and Late Paleozoic. The welding occurred when the continental plates collided. Each collision resulted in compression or squeezing at the suture, and the pushing up of lofty mountain ranges. Portions of the adjacent continents were left behind on the North American Plate when the continents subsequently split apart during the Triassic Period. Thus, the region contains pieces of islands, micro-continents, Africa, and Europe because of earlier collisions and fissioning.

The changing latitude of the continents has controlled climatic changes. During the Early Paleozoic, the Mid-Atlantic Region was near the Equator and the mountain ranges plowed up by the plate collisions were eroded by tropical rains and rivers.

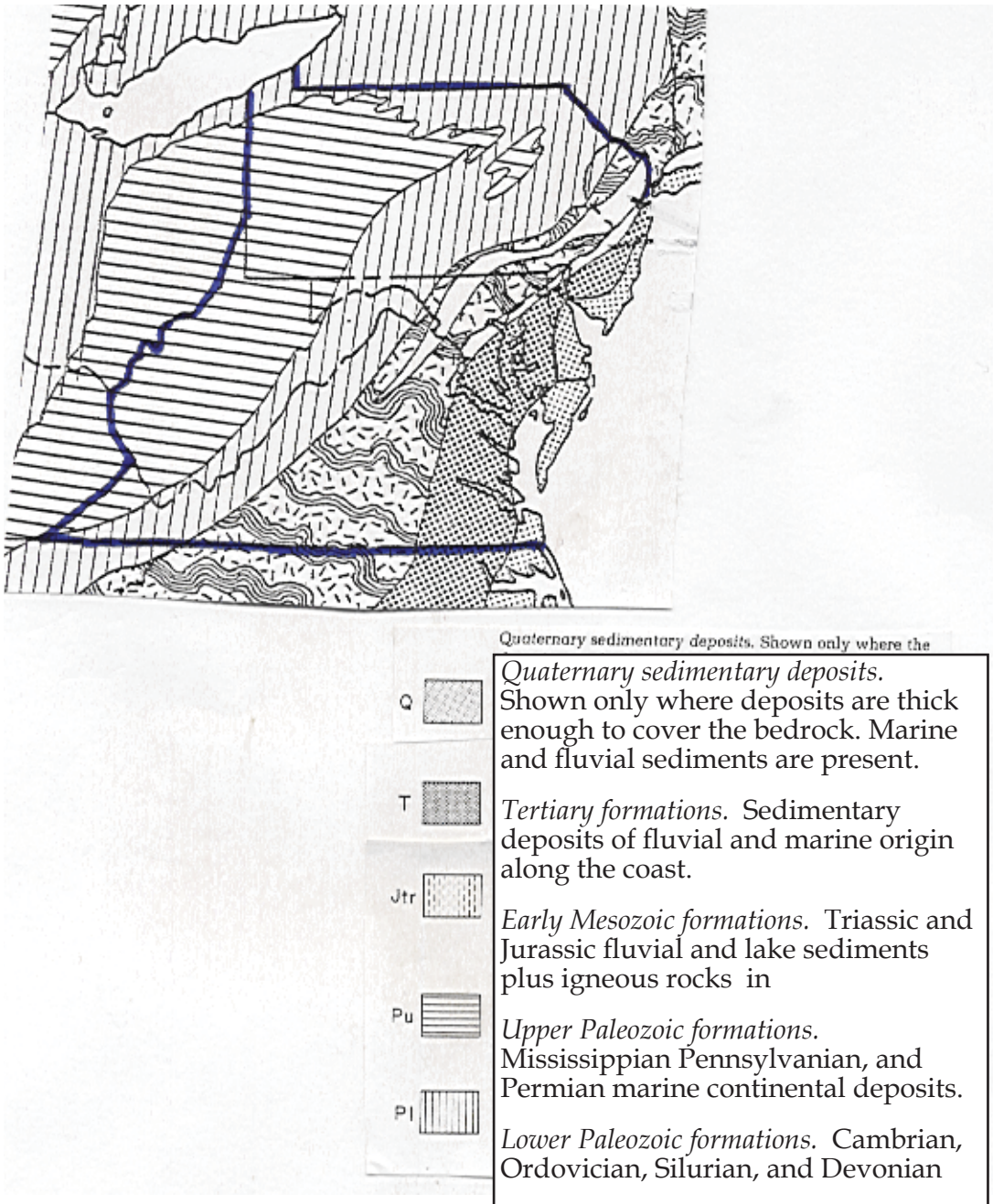
ROCKS AND MINERALS

The rocks of the region can be divided into three basic types: igneous, sedimentary, and metamorphic. The distribution of the basic rock types in the region is depicted on Figure F-2. The rocks are composed of one or more *minerals*- naturally occurring elements or compounds formed by inorganic chemical reactions. Minerals have relatively consistent chemical compositions and physical properties.

There are over 4,000 described minerals, but only nine rock-forming minerals or mineral groups are common:

Quartz
Feldspar Group
Clay Group
Mica Group
Pyroxene Group
Amphibole Group
Carbonates (calcite and dolomite)
Iron Oxides (limonite, hematite, and magnetite)
Pyrite

Igneous rocks are derived from molten rock or lava. They are composed of minerals such as feldspars, pyroxenes, amphiboles, mica, quartz, and/or metal oxides. Igneous rocks that solidify slowly at depth are coarsely crystalline, while igneous rocks that crystallize rapidly at shallow depths or at the Earth's surface are finely crystalline. *Granite*, *granodiorite*, and *gabbo* are typical coarsely crystalline rocks. *Basalt* and *diabase* are generally finely crystalline rocks.



Quaternary sedimentary deposits. Shown only where deposits are thick enough to cover the bedrock. Marine and fluvial sediments are present.

Tertiary formations. Sedimentary deposits of fluvial and marine origin along the coast.

Early Mesozoic formations. Triassic and Jurassic fluvial and lake sediments plus igneous rocks in

Upper Paleozoic formations. Mississippian Pennsylvanian, and Permian marine continental deposits.

Lower Paleozoic formations. Cambrian, Ordovician, Silurian, and Devonian

Metamorphic rocks. Mostly Precambrian with considerable infolded Paleozoic metamorphic

Modified from Hunt, 1974

FIGURE F-2: BEDROCK GEOLOGY OF THE MID-ATLANTIC REGION

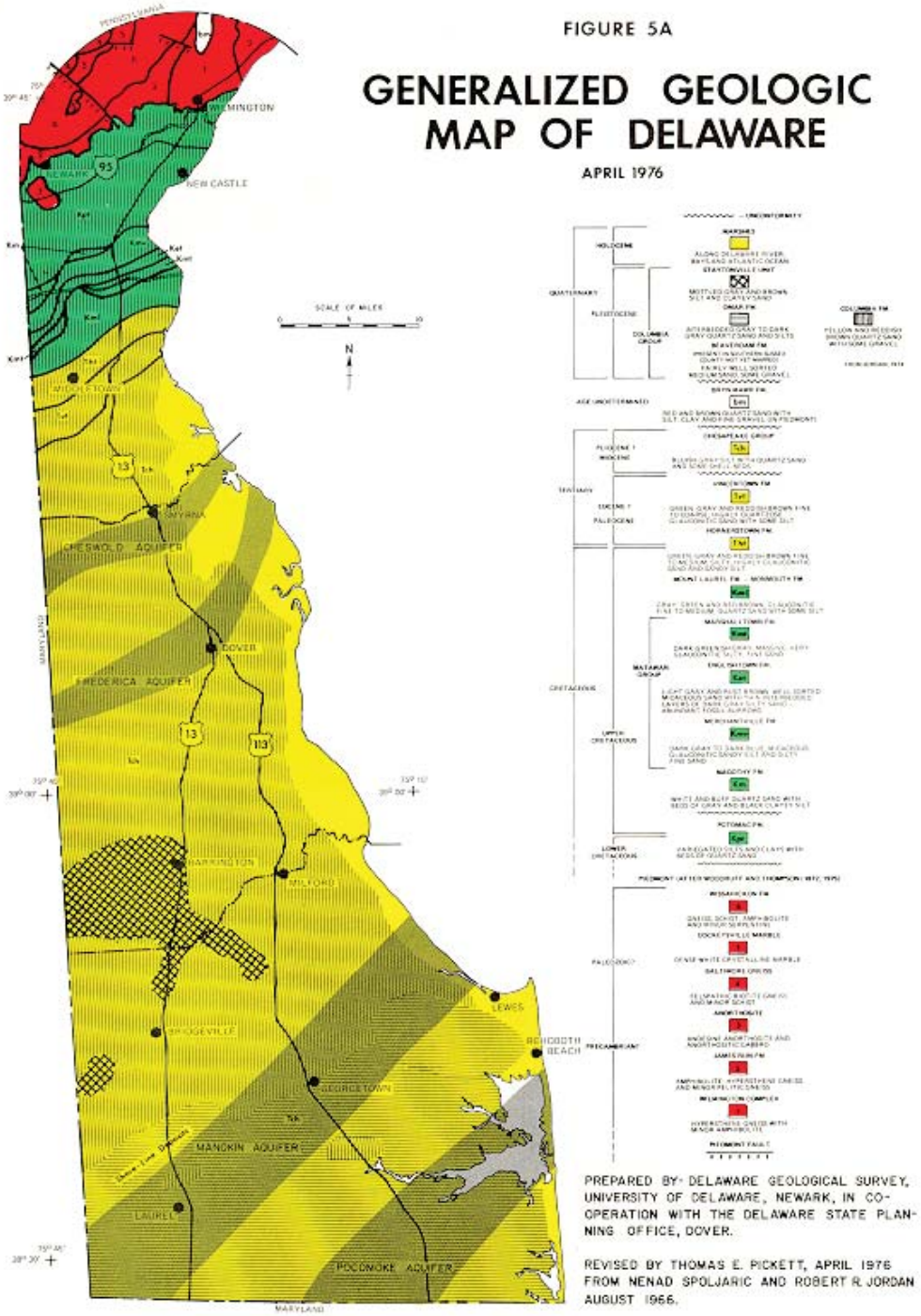


FIGURE 5A
GENERALIZED GEOLOGIC MAP OF DELAWARE
APRIL 1976
NEW CASTLE
MIDDLETOWN
SMYRNA
CHESWOLD AQUIFER
DOVER
FREDERICA AQUIFER
HARRINGTON
MILFORD
LEWES
REHOBOTH BEACH
BRIDGEVILLE
GEORGETOWN
MANOKIN AQUIFER
LAUREL
POCOMOKE AQUIFER
MARYLAND
SCALE OF MILES
N
PREPARED BY: DELAWARE GEOLOGICAL SURVEY, UNIVERSITY OF DELAWARE, NEWARK, IN CO-OPERATION WITH THE DELAWARE STATE PLANNING OFFICE, DOVER.
REVISED BY THOMAS E. PICKETT, APRIL 1976 FROM NENAD SPOLJARIC AND ROBERT R. JORDAN AUGUST 1966.

Figure F-3

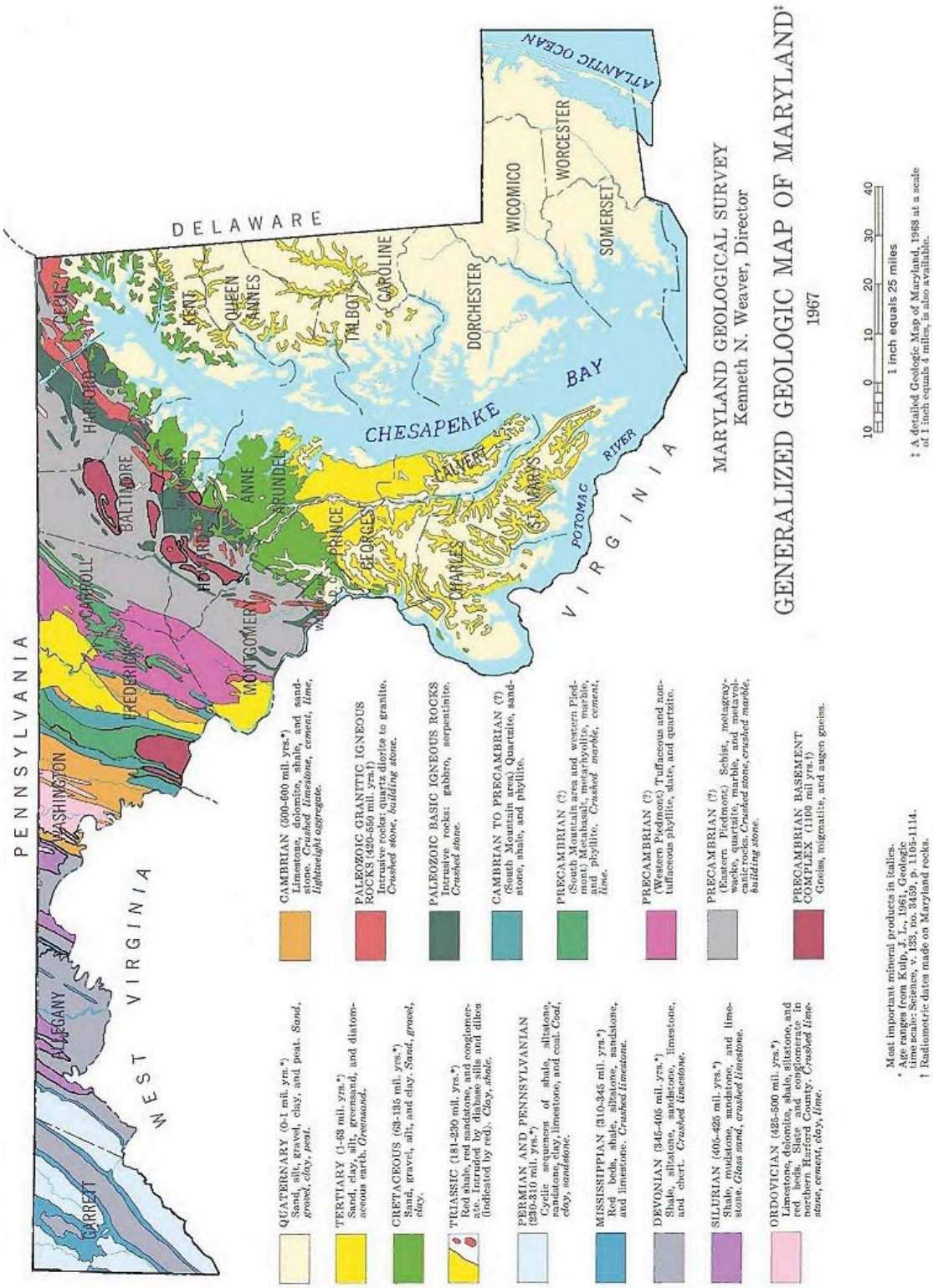

GENERALIZED GEOLOGIC MAP OF MARYLAND‡
1967
MARYLAND GEOLOGICAL SURVEY
Kenneth N. Weaver, Director
1 inch equals 25 miles
‡ A detailed Geologic Map of Maryland, 1968 at a scale of 1 inch equals 4 miles, is also available.
PENNSYLVANIA
DELAWARE
WEST VIRGINIA
VIRGINIA
ATLANTIC OCEAN
CHESAPEAKE BAY
POTOMAC RIVER
GARRETT
ALLEGANY
WASHINGTON
FREDERICK
CARROLL
BALTIMORE
HARFORD
CECIL
KENT
QUEEN ANNES
TALBOT
CAROLINE
DORCHESTER
WICOMICO
WORCESTER
SOMERSET
ANNE ARUNDEL
PRINCE GEORGES
MONTGOMERY
CALVERT
CHARLES
ST. MARYS
QUATERNARY (0-1 mil. yrs.*) Sand, silt, gravel, clay, and peat. Sand, gravel, clay, peat.
TERTIARY (1-63 mil. yrs.*) Sand, clay, silt, greensand, and diatomaceous earth. Greensand.
CRETACEOUS (63-135 mil. yrs.*) Sand, gravel, silt, and clay. Sand, gravel, clay.
TRIASSIC (181-230 mil. yrs.*) Red shale, red sandstone, and conglomerate. Intruded by diabase sills and dikes (indicated by red). Clay, shale.
PERMIAN AND PENNSYLVANIAN (230-310 mil. yrs.*) Cyclic sequences of shale, siltstone, sandstone, clay, limestone, and coal. Coal, clay, sandstone.
MISSISSIPPIAN (310-345 mil. yrs.*) Red beds, shale, siltstone, sandstone, and limestone. Crushed limestone.
DEVONIAN (345-405 mil. yrs.*) Shale, siltstone, sandstone, limestone, and chert. Crushed limestone.
SILURIAN (405-425 mil. yrs.*) Shale, mudstone, sandstone, and limestone. Glass sand, crushed limestone.
ORDOVICIAN (425-500 mil. yrs.*) Limestone, dolomite, shale siltstone, and red beds. Slate and conglomerate in northern Harford County. Crushed limestone, cement, clay, lime.
CAMBRIAN (500-600 mil. yrs.*) Limestone, dolomite, shale, and sandstone. Crushed limestone, cement, lime, lightweight aggregate.
PALEOZOIC GRANITIC IGNEOUS ROCKS (420-550 mil. yrs.†) Intrusive rocks: quartz diorite to granite. Crushed stone, building stone.
PALEOZOIC BASIC IGNEOUS ROCKS Intrusive rocks: gabbro, serpentinite. Crushed stone.
CAMBRIAN TO PRECAMBRIAN (?) (South Mountain area) Quartzite, sandstone, shale, and phyllite.
PRECAMBRIAN (?) (South Mountain area and western Piedmont) Metabasalt, metarhyolite, marble, and phyllite. Crushed marble, cement, lime.
PRECAMBRIAN (?) (Western Piedmont) Tuffaceous and nontuffaceous phyllite, slate, and quartzite.
PRECAMBRIAN (?) (Eastern Piedmont) Schist, metagraywacke, quartzite, marble, and metavolcanic rocks. Crushed stone, crushed marble, building stone.
PRECAMBRIAN BASEMENT COMPLEX (1100 mil yrs.†) Gneiss, migmatite, and augen gneiss.
Most important mineral products in italics.
* Age ranges from Kulp, J. L., 1961, Geologic time scale: Science, v. 133, no. 3459, p. 1105-1114.
† Radiometric dates made on Maryland rocks.

Figure F-4

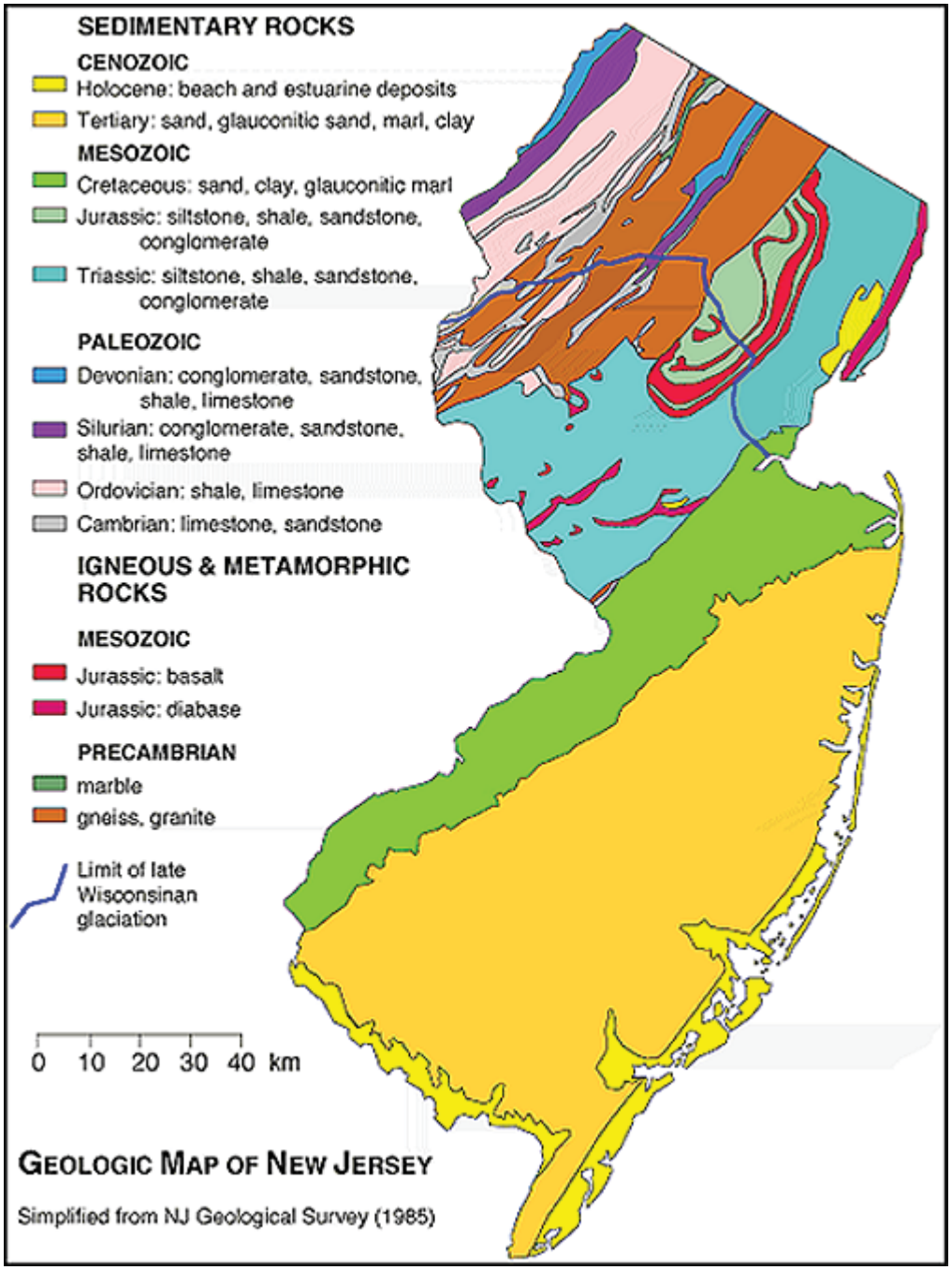
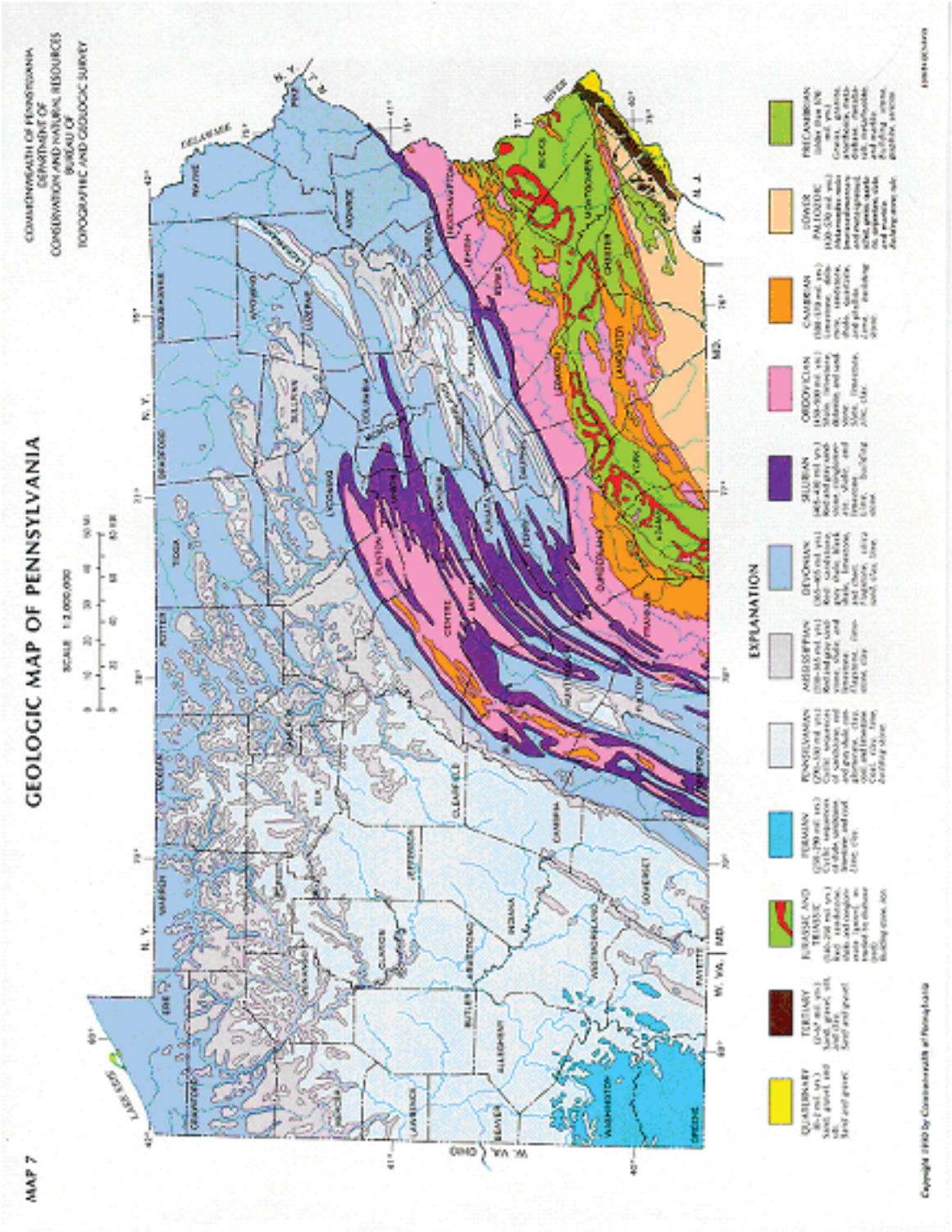

SEDIMENTARY ROCKS
CENOZOIC
Holocene: beach and estuarine deposits
Tertiary: sand, glauconitic sand, marl, clay
MESOZOIC
Cretaceous: sand, clay, glauconitic marl
Jurassic: siltstone, shale, sandstone, conglomerate
Triassic: siltstone, shale, sandstone, conglomerate
PALEOZOIC
Devonian: conglomerate, sandstone, shale, limestone
Silurian: conglomerate, sandstone, shale, limestone
Ordovician: shale, limestone
Cambrian: limestone, sandstone
IGNEOUS & METAMORPHIC ROCKS
MESOZOIC
Jurassic: basalt
Jurassic: diabase
PRECAMBRIAN
marble
gneiss, granite
Limit of late Wisconsinan glaciation
0 10 20 30 40 km
GEOLOGIC MAP OF NEW JERSEY
Simplified from NJ Geological Survey (1985)

Figure F-5


GEOLOGIC MAP OF PENNSYLVANIA
MAP 7
COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF
CONSERVATION AND NATURAL RESOURCES
BUREAU OF
TOPOGRAPHIC AND GEOLOGIC SURVEY
SCALE 1:2,000,000
EXPLANATION
QUATERNARY
TERTIARY
JURASSIC AND TRIASSIC
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
LOWER PALEOZOIC
PRECAMBRIAN
LAKE ERIE
DELAWARE
N. Y.
W. VA.
MD.
OHIO
ERIE
WARREN
POTTER
TIOGA
BRADFORD
SUSQUEHANNA
WAYNE
CRAWFORD
MERCER
VENANGO
CLARION
JEFFERSON
CLEARFIELD
CAMBRIA
SOMERSET
FAYETTE
GREENE
LAWRENCE
BEAVER
BUTLER
ALLEGHENY
WASHINGTON
INDIANA
WESTMORELAND
CLINTON
CENTRE
MIFFLIN
JUNIATA
PERRY
CUMBERLAND
FRANKLIN
FULTON
BEDFORD
BLAIR
HUNTINGDON
ADAMS
YORK
LANCASTER
LEBANON
DAUPHIN
SCHUYLKILL
LUZERNE
COLUMBIA
MONTOUR
NORTHUMBERLAND
SNYDER
UNION
LYCOMING
CLINTON
CAMBRIA
BERKS
LEHIGH
CHESTER
MONTGOMERY
BUCKS
MONROE
CARBON
LEHIGH
NORTHAMPTON
PIKE
WAYNE
SUSQUEHANNA
BRADFORD
TIOGA
POTTER
WARREN
ERI

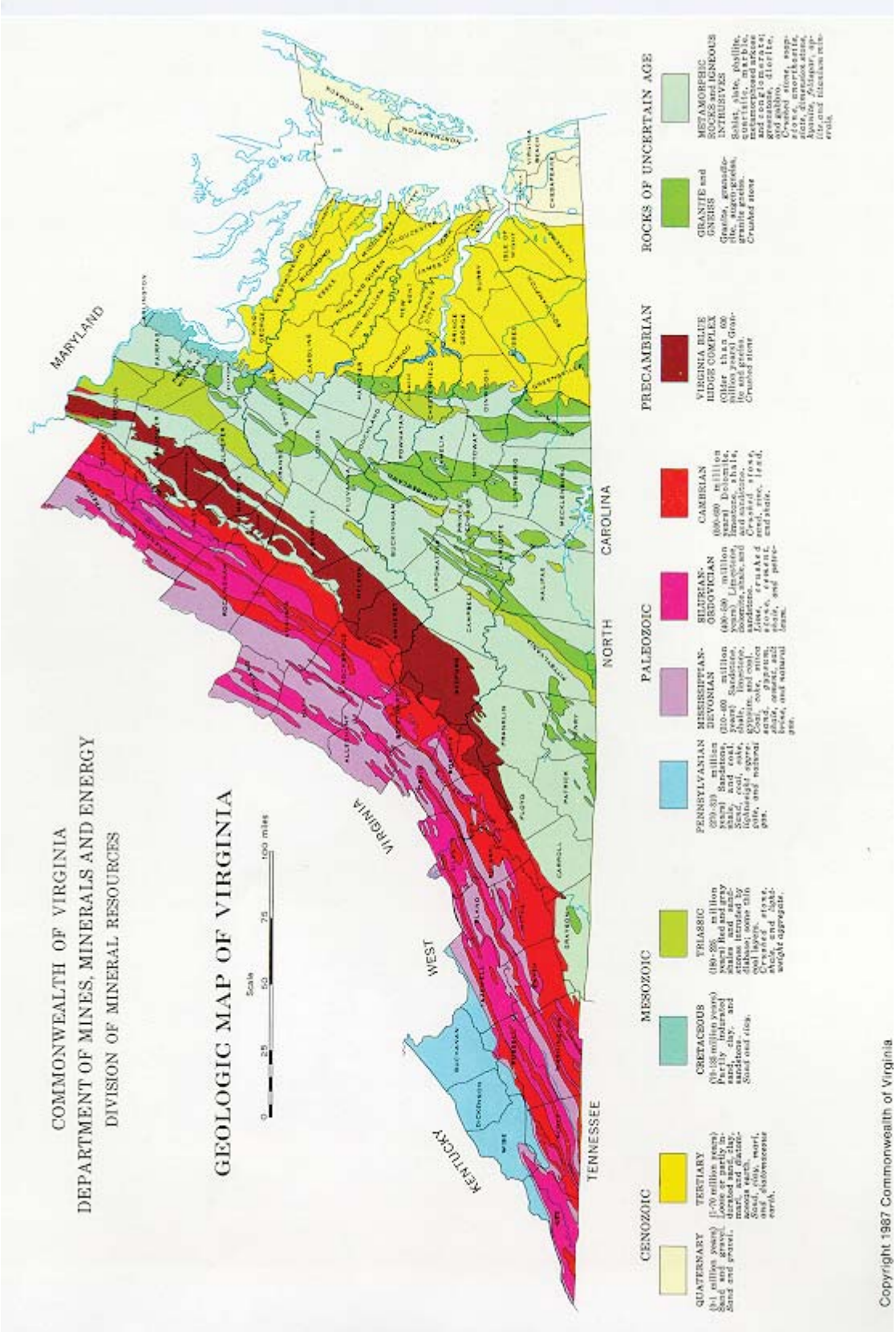

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS AND ENERGY
DIVISION OF MINERAL RESOURCES
GEOLOGIC MAP OF VIRGINIA
Scale
0
25
50
75
100 miles
MARYLAND
VIRGINIA
WEST
KENTUCKY
TENNESSEE
NORTH
CAROLINA
CENOZOIC
QUATERNARY
(0-1 million years) Sand and gravel.
TERTIARY
(1-70 million years) Loose or partly indurated sand, clay, marl, and diatomaceous earth. Soil, clay, marl, and diatomaceous earth.
MESOZOIC
CRETACEOUS
(70-136 million years) Partly indurated sand, clay, and sandstone. Sand and clay.
TRIASSIC
(180-225 million years) Red and gray shales and sandstones intruded by diabase; some thin coal layers. Crushed stone, shale and basalt; weight aggregate.
PALEOZOIC
PENNSYLVANIAN
(270-310 million years) Sandstone, shale, and coal; clay, coal, coke, limestone, iron ore, gas, and natural gas.
MISSISSIPPIAN-DEVONIAN
(310-400 million years) Sandstone, shale, limestone, gypsum, salt, iron ore, coal, and natural gas.
SILURIAN-ORDOVICIAN
(400-500 million years) Limestone, dolomite, shale, and sandstone. Crushed stone, shale, and natural gas.
CAMBRIAN
(500-600 million years) Dolomite, limestone, shale, and sandstone. Crushed stone, zinc, lead, and shale.
PRECAMBRIAN
VIRGINIA BLUE RIDGE COMPLEX
(Older than 600 million years) Granite and gneiss. Crushed stone
ROCKS OF UNCERTAIN AGE
GRANITE and GNEISS
Granite, granodiorite, augengneiss, granite gneiss. Crushed stone
METAMORPHIC ROCKS and IGNEOUS INTRUSIVES
Schist, slate, phyllite, quartzite, marble, metaconglomerate and conglomerate; amphibolite, diorite, and gabbro. Crushed stone, soapstone, chrysotile, talc, emeryite, and Amanite, Feldspar, apatite and Blackburn minerals.
Copyright 1987 Commonwealth of Virginia

Figure F-7

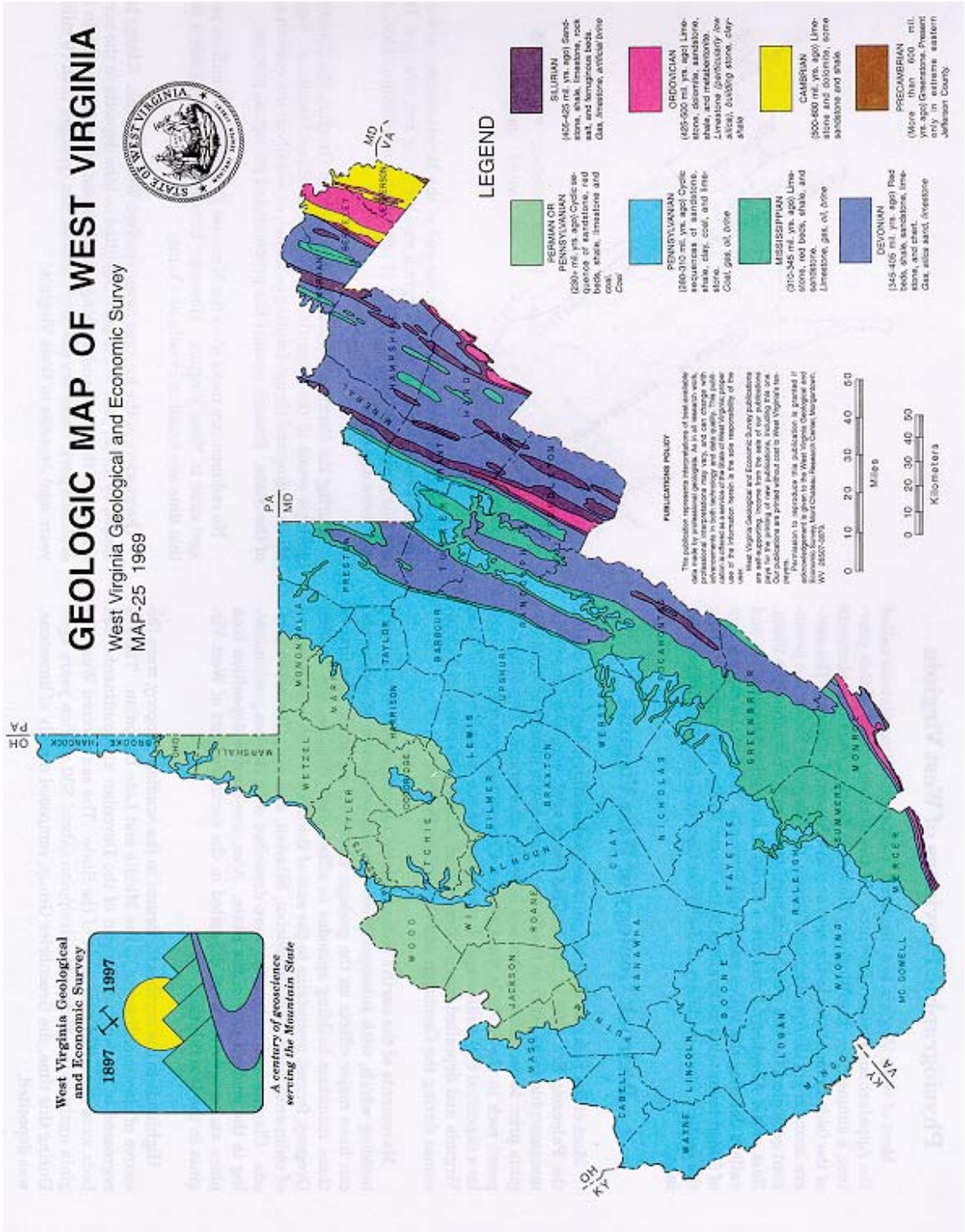

GEOLOGIC MAP OF WEST VIRGINIA
West Virginia Geological and Economic Survey
MAP-25 1969
LEGEND
PERMIAN OR PENNSYLVANIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
PRECAMBRIAN
PUBLICATIONS POLICY
Miles
Kilometers
West Virginia Geological and Economic Survey
1897 1997
A century of geoscience serving the Mountain State

Figure F-8

Sedimentary rocks are either derived from older rocks (clastic sedimentary rocks) or from biochemical or chemical precipitates in aqueous solutions (chemical sedimentary rocks). Clastic rocks include *conglomerate*, *sandstone*, *siltstone*, and *shale*, based on decreasing grain size. They were derived from gravel, sand, silt, and clay, respectively. The clastic sedimentary rocks are cemented with various materials, such as quartz or silica, clay, carbonate, or iron oxides. Clay-cemented sandstones or siltstones are *graywackes*. Carbonate-cemented sandstones are *calcareous*. Quartz-cemented sandstones are *quartzose* sandstone or *quartzite*.

The chemically precipitated rocks include *gypsum* and *salt*, the silicate *chert*, and the carbonates *limestone* and *dolomite*. Gypsum and salt are highly soluble and soft, and rarely are exposed at the Earth's surface. They are not used in road construction (although gypsum is used in wallboard). The carbonates are the primary chemically derived rocks used in aggregates because they are harder and less soluble. Chert is generally a minor constituent in rocks, although it can cause deleterious chemical reactions in concrete if it is too plentiful.

Metamorphic rocks are pre-existing igneous or sedimentary rocks that have been chemically or texturally altered by heat and pressure. Metamorphic rocks are composed of many of the same minerals that occur in igneous rocks. Metamorphic sedimentary rocks include *quartzite*, which was originally conglomerate or sandstone; *gneiss*, which was originally clay-rich sandstones and siltstones; *argillite*, *phyllite*, *schist*, or *slate*, which were derived from siltstone and shale; and *marble*, derived from limestone or dolomite. Gneiss can also be derived from diabase, granite, and granodiorite. *Serpentine* is a serpentine, chlorite, and mica-rich rock that was derived from oceanic sediment that has been squeezed and injected by water-rich magmas in the suture between colliding continents or between colliding oceanic and continental plates. Serpentine rich areas form *greenstone* belts. Greenstone Belts are common in central VA and eastern MD and PA.

WEATHERING AND SOILS

Soil is defined by engineers as unconsolidated accumulations of solid particles produced by the chemical or physical weathering of bedrock. The organic matter content of soil can vary from nil to 100%. Weathering can involve simple mechanical breakdown of the bedrock into smaller particles or can cause complete chemical alteration of the original mineral assemblage. Engineering soils are further divided into fine-grained soil and coarse- grained soil. Fine-grained soil passes through the 200 sieve (0.0029 inch, 75 micrometer). Fine-grained soil is classified as silt or clay, depending on the grain size, plasticity, and compressibility of the material. Generally, the smaller the grain size, the higher the plasticity and compressibility. Coarse-grained soil is retained on the 200 sieve, and is noncohesive and nonplastic. It is classified into sand, gravel, cobble, and boulders, based on increasing grain size. Organic matter tends to behave somewhat like clay, it increases the compressibility and plasticity of the soil. Organic soils are not suitable for highway construction or most other engineering purposes.

Igneous, sedimentary, and metamorphic rocks are weathered at the Earth's surface and converted into unconsolidated soils. Weathering includes physical and chemical processes. Physical weathering includes disaggregation by crystals (ice or salts); stress release; heat stress; abrasion and fracturing by glacial ice, water, or air; and swelling of clays or iron oxides due to absorption of water. Physical weathering reduces the size and increases the surface area of particles, making them more susceptible to movement and chemical weathering.

Chemical weathering processes include oxidation, solution and leaching, hydration, cation exchange, carbonation, and chelation. Carbonation is caused by the reaction of carbonic acid (derived from carbon dioxide gas in the atmosphere reacting with water vapor) with carbonates and feldspar. Chemical and physical weathering are accelerated by the presence of water, by fracturing (faults or joints), and by higher temperatures.

The common rock forming minerals break down into the following soil forming minerals:

Table F.1 Common Rock and Soil Forming Minerals

Rock Forming Mineral	Soil Forming Mineral
Quartz	Quartz
Feldspar Group	Clay Minerals and Quartz
Mica Group	Clay Minerals, Quartz, and Iron Oxides
Pyroxene Group	Clay Minerals, Quartz, and Iron Oxides
Amphibole Group	Clay Minerals, Quartz, and Iron Oxides
Carbonates	None (dissolved)
Iron Oxides	Iron Oxides and Hydroxides
Pyrite	Iron Oxides and Hydroxides

Mass movements, water, ice, and air, transport the soils created by physical and chemical weathering.

The common soils in the Mid-Atlantic Region are:

Residual soil: derived from bedrock that has weathered and remained in place. Residual soils occur in most of the region, particularly to the south of the limit of the glacial soils.

Alluvial soil: derived from soil particles that have been transported and redeposited by running water. Alluvial soils are found along most of the streams and rivers of the region.

Colluvial soil: derived from materials transported downslope by gravity and water (mass movement). The colluvial soils are deposited along the base of steep slopes. They are found throughout the mountainous regions of the region.

Glacial soils: were transported and redeposited by glacial ice. They range from non-stratified, unsorted glacial till to well-washed and sorted kame, esker, and outwash sand and gravel. Glacial soils are common in PA and NJ.

Aeolian soils: are formed by material transported and redeposited by the wind. Aeolian soils tend to be sand (dune) and silt (loess) sized. Aeolian soils are locally abundant along the Lake Erie and Atlantic coasts and along the valleys of large rivers or shorelines of extinct glacial lakes.

Organic soils: are soils rich in organic matter.

SEDIMENTARY FACIES

Sedimentary facies is the total appearance of a sedimentary rock or deposit. It includes grain size, sorting (or grading), degree of compaction, color, bedding, and shape of the overall deposit. The environment of deposition controls the facies. High energy environments, such as river channels or wave washed beaches, winnow away fine grained particles, leaving coarse sand, gravel, and/or boulders behind that become conglomerate or sandstone when they *lithify* (turn to stone). Sand is deposited in moderately energetic environments, such as deltas and coastal plains. Relatively quiet or low energy environments, such as portions of floodplains, deep oceans, or lake basins, receive fine-grained materials, such as clay or silt that become siltstone or shale. The sedimentary facies control the engineering characteristics of rocks. Beach sandstones have large mineable volumes and consistent sorting. River sandstones have smaller volumes and more variable sorting, but are generally more durable.

The paleoenvironments of the Mid-Atlantic Region have changed through time, sometimes the change was abrupt and at other times it was gradual. During the Paleozoic Era, sea level rose and fell many times in response to Plate Tectonic events and to the melting and formation of glaciers. As the sea rose onto the North American Plate, waves eroded the older land surface, and sheets of winnowed gravel and sand were deposited. Mud (silt and clay) then was deposited as the sea deepened. At the same time, mountains rose in the eastern part of the region as the African or European plates collided with North America, and rivers delivered large quantities of sediment to the sea, forming broad coastal plains and deltas as the sea filled up. The episodic rise and fall of the sea, and rising and disintegration of the mountains resulted in the migration or shifting of shorelines and deltas, and in repeating sequences of coarse- to fine-grained sedimentary rock. The changing sea level resulted in sequences of shale and siltstone alternating or interfingering with sandstone and conglomerate.

The rocks are metamorphosed when they are subjected to heating by deep burial, by intrusions of molten rock, and by intense pressure during plate collisions. Argillites and slates were shales and siltstones that were metamorphosed by diabase intrusions during

the Paleozoic and Mesozoic Eras.

PHYSIOGRAPHIC PROVINCES

A *Physiographic Province* is a natural region having characteristics peculiar to itself- a distinctive geologic structural framework giving rise to distinctive landforms and, for the most part, distinctive climate, soil, water, and other resources (modified from Hunt, 1974, pg. 3). Knowledge of a locality's Physiographic Province allows one to make predictions of the landscapes, topography, geologic resources, soils, and drainage in the locality's vicinity.

One of the most important geomorphological concepts is "*hard rocks erode slower than soft rocks*." Generally, hard rocks, such as granite, gneiss, quartzite, or sandstone, form ridges, while soft rocks, such as shale or limestone, form valleys. Limestones are especially susceptible to chemical erosion because they are soluble in weak acid. Carbon dioxide in the air forms a natural acid rain (carbonic acid) that easily dissolves the limestone.

The Physiographic Provinces of the region are the Atlantic Coastal Plain, Piedmont, Blue Ridge, New England Uplands, Ridge and Valley, Appalachian Plateau, and Central Lowlands (Figure F-9). The provinces form southwest to northeast trending bands across the region.

The *Atlantic Coastal Plain Province* forms a belt of unconsolidated, eastward dipping, Late Mesozoic and Cenozoic marine and continental sediments in eastern NJ, PA, DE, MD, and VA. It is bordered by the Atlantic Ocean on the east, and by the Piedmont Province on the west. The boundary between the Coastal Plain and Piedmont is marked by rapids flowing across lithified rocks, and is called the *Fall Line*. The topography of the Coastal Plain is low, with small hills underlain by the unconsolidated sediments. Rivers on the Coastal Plain are relatively wide and meandering. Tidal waters flood their lower reaches, frequently as far west as the Fall Line. The Coastal Plain has grown eastward through time by incremental additions of river-borne and coastal sediment. The present coastline is quite dynamic, and is presently subject to radical alteration by storms and slow sea level rise.

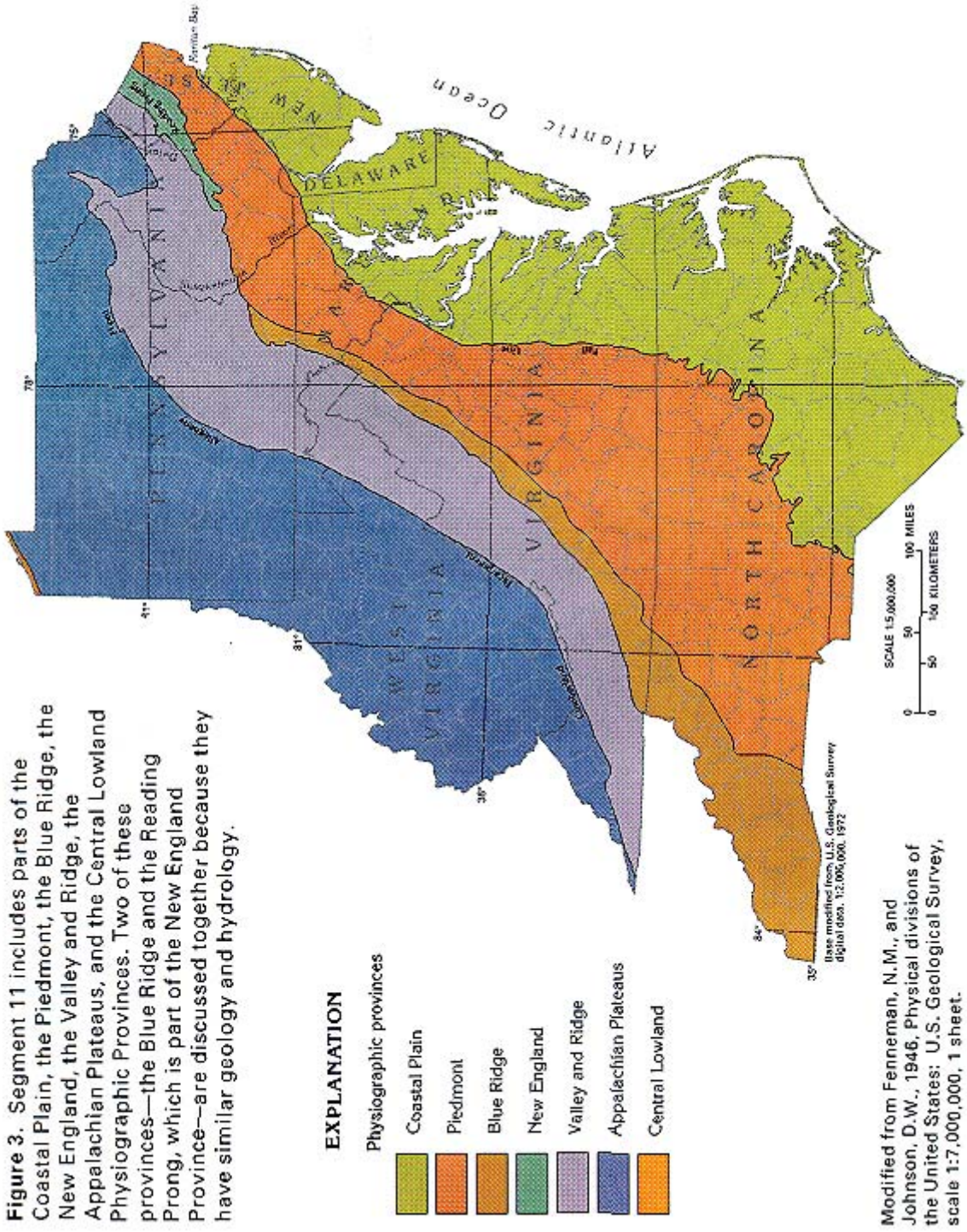


Figure 3. Segment 11 includes parts of the Coastal Plain, the Piedmont, the Blue Ridge, the New England, the Valley and Ridge, the Appalachian Plateaus, and the Central Lowland Physiographic Provinces. Two of these provinces—the Blue Ridge and the Reading Prong, which is part of the New England Province—are discussed together because they have similar geology and hydrology.
EXPLANATION
Physiographic provinces
Coastal Plain
Piedmont
Blue Ridge
New England
Valley and Ridge
Appalachian Plateaus
Central Lowland
Modified from Fenneman, N.M., and Johnson, D.W., 1946, Physical divisions of the United States: U.S. Geological Survey, scale 1:7,000,000, 1 sheet.
Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972
SCALE 1:5,000,000
0 50 100 MILES
0 50 100 KILOMETERS
Atlantic Ocean
DELAWARE
NEW JERSEY
PENNSYLVANIA
WEST VIRGINIA
VIRGINIA
NORTH CAROLINA
MARYLAND
Raritan Bay
Delaware Bay
Susquehanna
Potomac
Rappahannock
Rappahannock
Chesapeake Bay
Roanoke
Tar
Neuse
Cape Fear
Pee Dee
Santee
Cape Hatteras
Cape Lookout
Cape Fear
Cape Hatteras
Cape Lookout
Pamlico Sound
Albemarle Sound
Currituck Sound
Chesapeake Bay
Delaware Bay
Raritan Bay
Susquehanna
Potomac
Rappahannock
Roanoke
Tar
Neuse
Cape Fear
Pee Dee
Santee

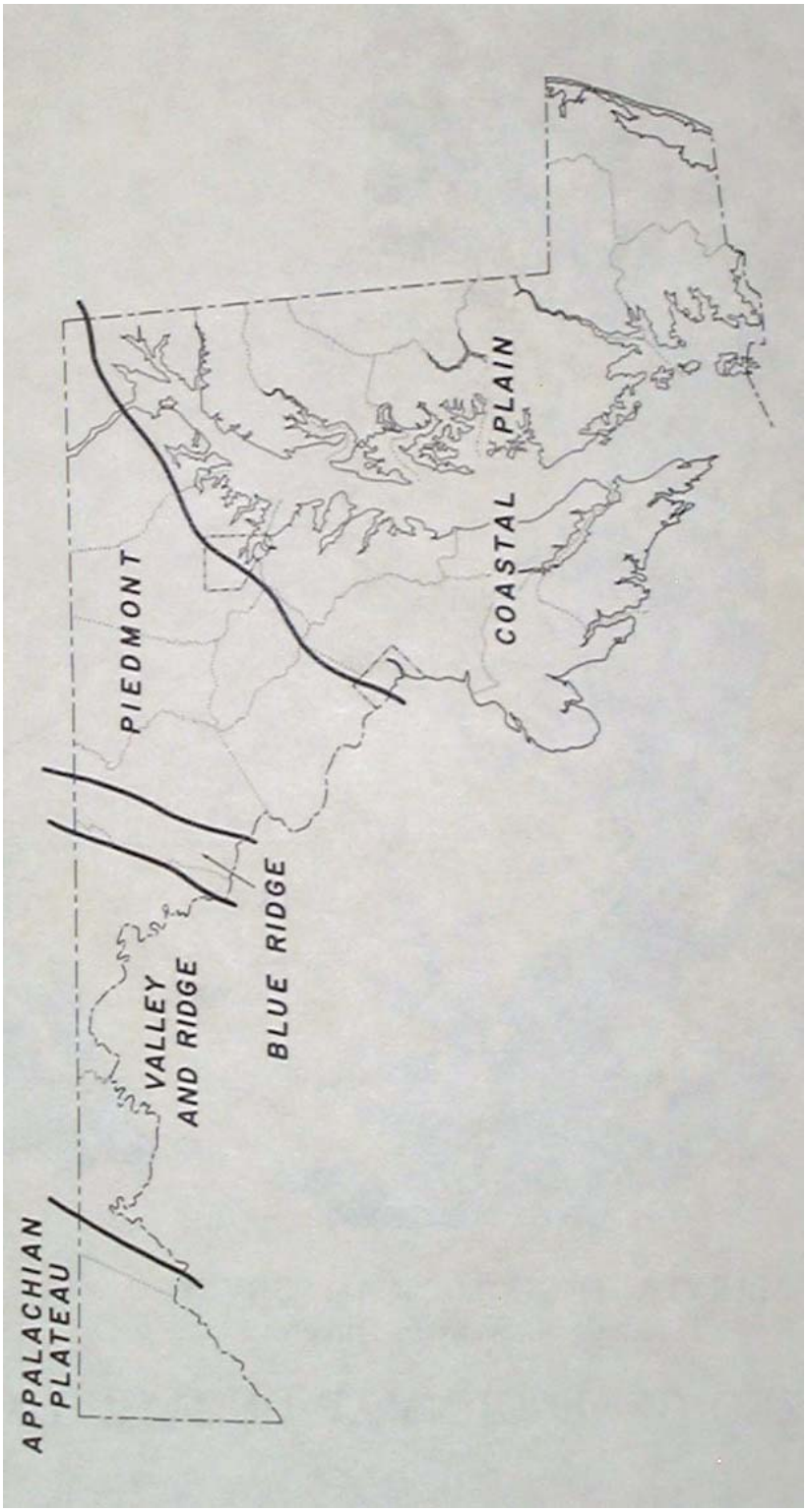


Figure F-10 Physiographic Map of Maryland

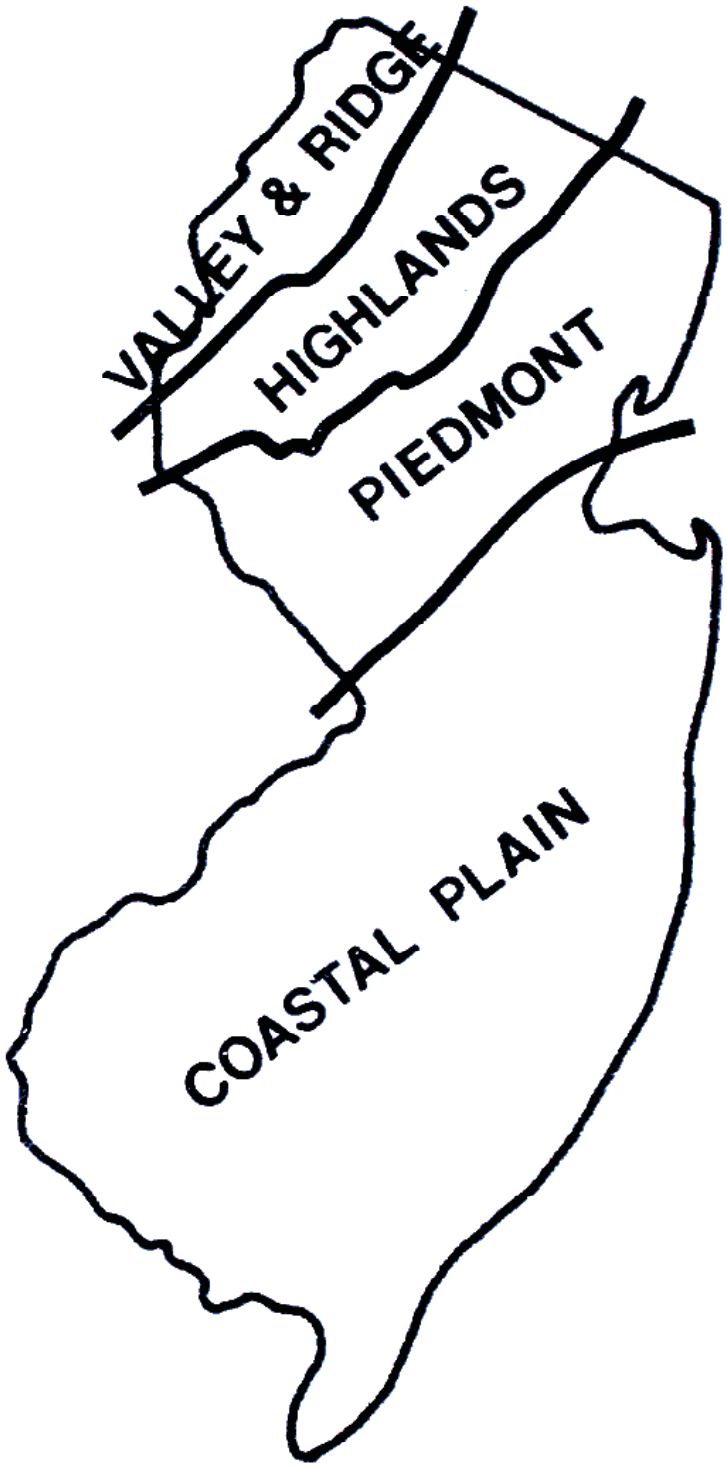


Figure F-11 Physiographic Map of New Jersey

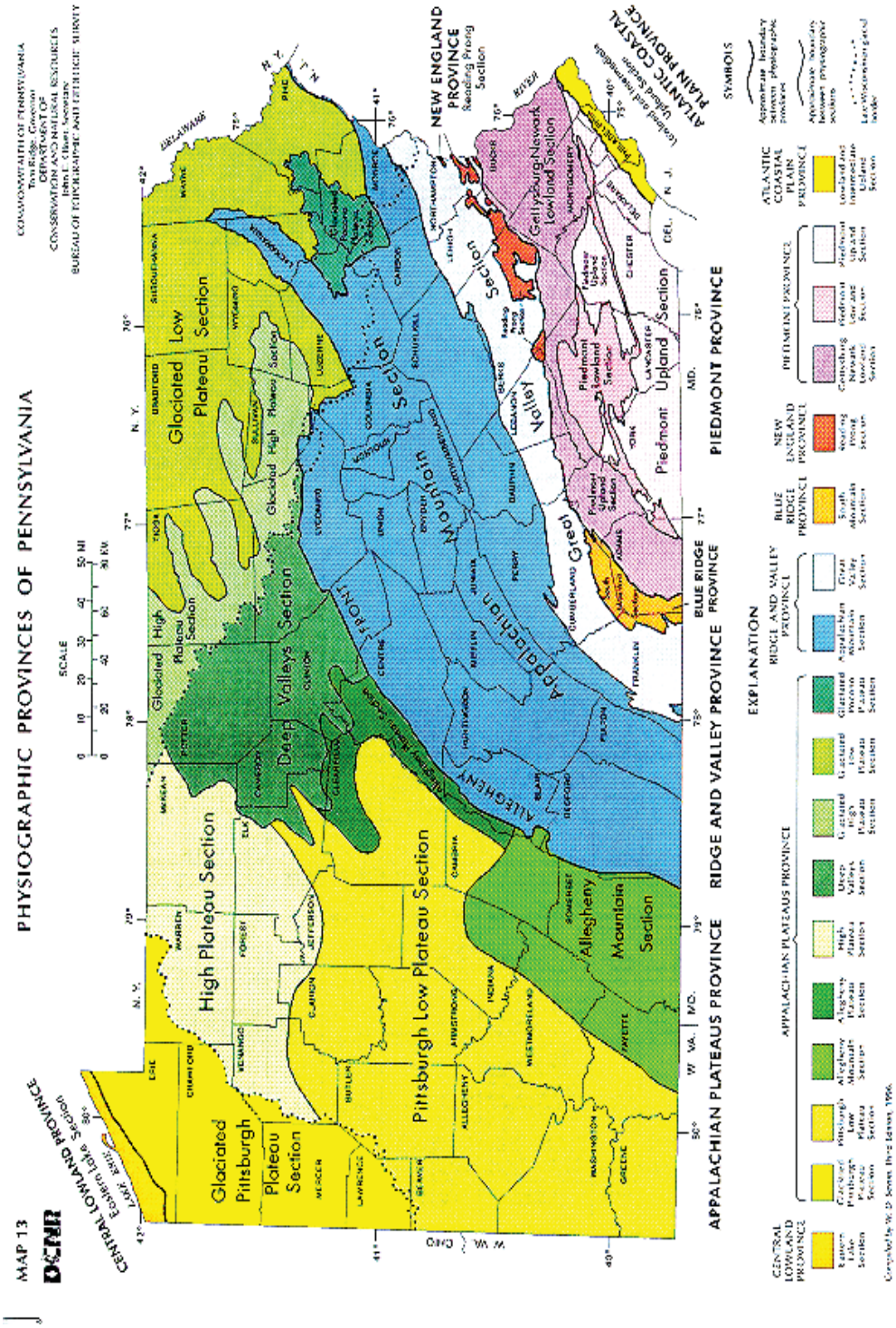


Figure F-12 Physiographic Map of Pennsylvania

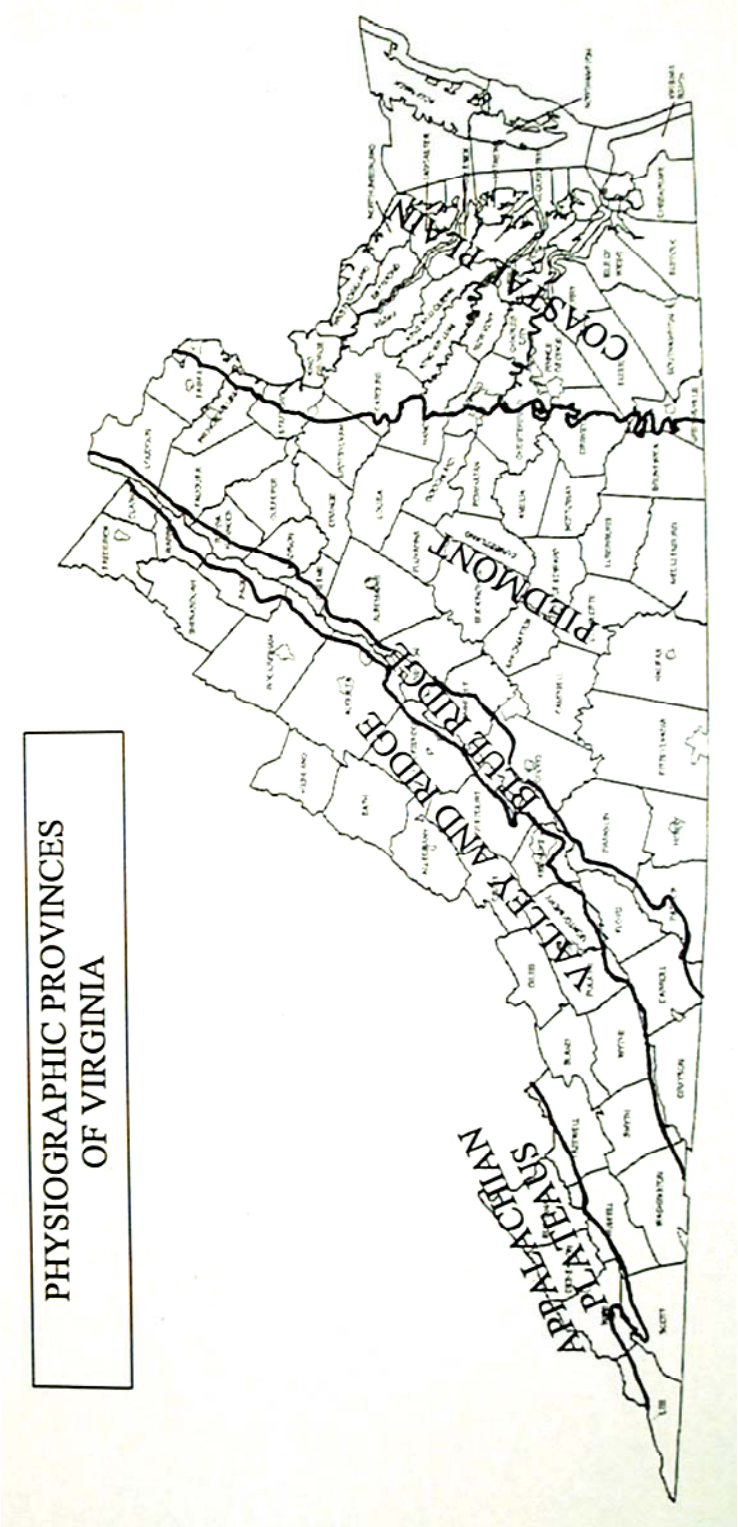


Figure F-13 Physiographic Map of Virginia

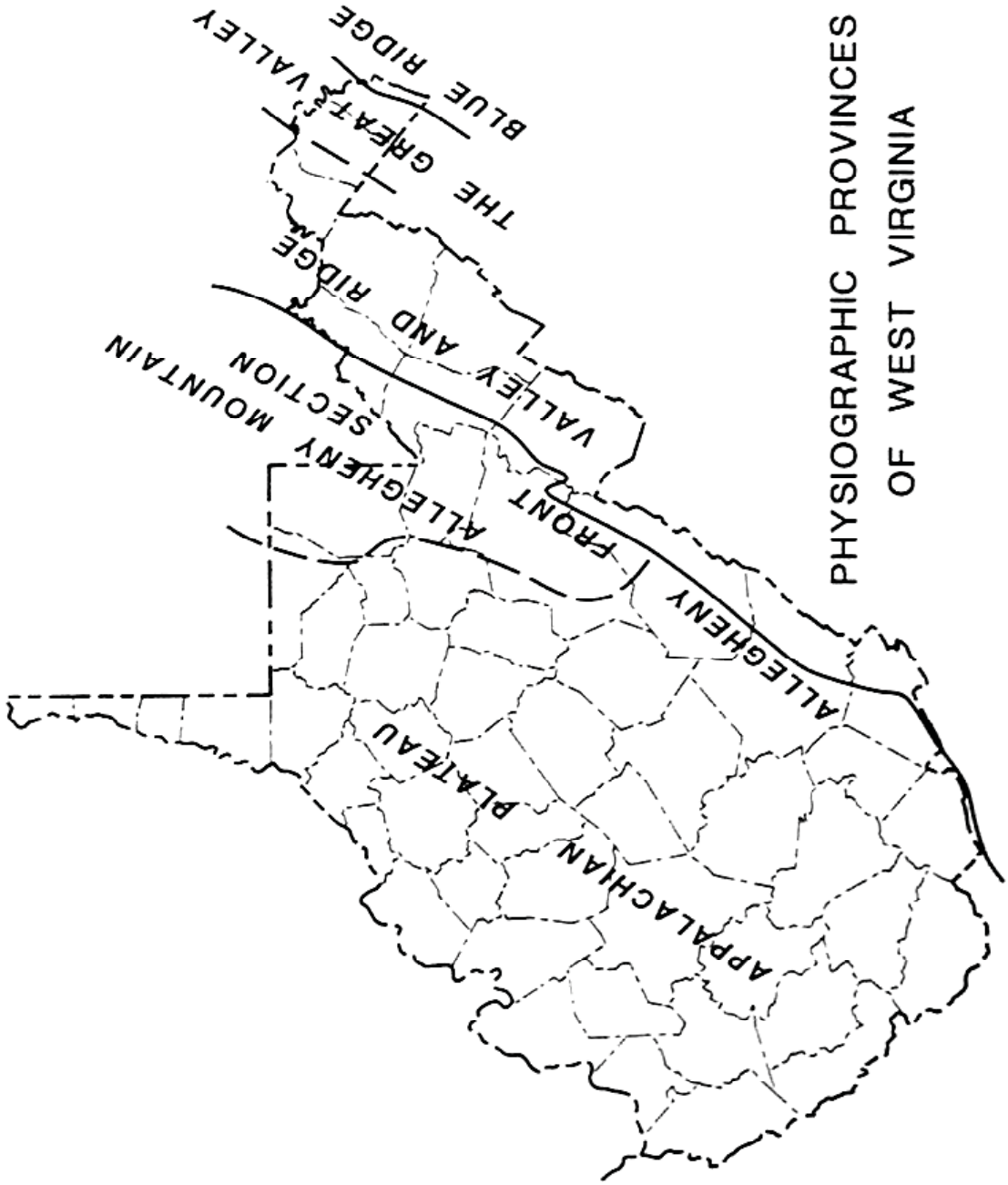


Figure F-14 Physiographic Map of West Virginia

Engineering soils in the Coastal Plain include residual soils, aeolian soils, alluvial soils, and beach and tidal soils. Glacial soils occur in northernmost PA and NJ.

The *Piedmont Province* underlies portions of NJ, PA, DE, MD, and VA (Figures F-9 and F-10). It bordered on the east by the Fall Line and on the west by the rugged topography of the Blue Ridge Province. The Piedmont Province is characterized by gently rolling topography that is developed on folded Precambrian and Early Paleozoic igneous and metamorphic rock and interior basins of relatively undeformed Early Mesozoic sedimentary and igneous rock (Triassic Lowlands).

A complex of metamorphic rocks, such as schist and gneiss or igneous rocks and gneiss underlies the Piedmont. Schist floored valleys tend to lie several hundred feet below adjacent gneiss cored hills. The hills trend northeast to southwest. Precambrian and Lower Cambrian quartzites, Cambrian and Ordovician carbonates, and Ordovician shales underlie much of the Piedmont. The shales and carbonates underlie valleys and the quartzites underlie low, northeast-southwest ridges.

The *Triassic Lowlands* are underlain by Triassic conglomerates, sandstones, and shales, with intrusions of Jurassic diabase. The tilted sandstones, lava flows, and diabase form low, parallel ridges and the interlayered shales form valleys. The conglomerates form high ridges that tower above the adjacent landscape.

The soils of the Piedmont Province are mainly residual, except for alluvial soils along the streams and rivers and extensive glacial soils in northern NJ, northwestern PA, and northeastern PA.

The *Blue Ridge* and *New England Uplands provinces* are both rugged areas underlain by metamorphosed Precambrian and Early Paleozoic igneous and sedimentary rock (Figures F-2 and F-10). The Blue Ridge Province underlies portions of VA, MD, and southern PA, the New England Uplands Province underlies northeastern PA and NJ.

The soils of the Blue Ridge are predominantly colluvium, with thin ribbons of alluvium along rivers. The soils of the New England Uplands are colluvium, limited alluvium, and thin glacial soils. The colluvium has accumulated at the base of the Blue Ridge and southern New England Uplands. They are unstable and susceptible to sudden mass movements caused by earthquakes, precipitation events, and construction. The lower slopes of the northern New England Uplands are mantled by thick glacial soils; many of these soils contain sources of gravel.

The *Ridge and Valley Province* underlies portions of eastern WV, VA, MD, PA, and NJ (Figure F-10). The Ridge and Valley Province includes the Great Valley of VA, MD, and PA. It is underlain by highly folded and faulted Early to Middle Paleozoic sedimentary rock (Figure F-2).

The Great Valley is developed over Ordovician shale, slate, and Cambrian and Ordovician carbonates. The shale and slate stand higher in elevation than the carbonates. Minor variations in lithology control the locations of low ridges in this province. Sandy beds form linear ridges in the shales, and cherty or silicified zones form ridges in the carbonates. The carbonate area contains many sinkholes, springs, caves, and disappearing streams because of solution by acidic rain water.

The province contains long, narrow, even-crested mountains underlain by tightly folded and faulted Silurian and Ordovician quartzites and sandstones in the south, and Mississipian and Pennsylvanian conglomerates and sandstones in the north. Cambrian and Ordovician carbonates, Silurian siltstones and limestones, and Devonian siltstones underlie the narrow, elongate valleys. Resistant beds, such as interbedded sandstones or cherty zones, form lower ridges in the valleys. The high cuesta of the Allegheny Front forms the western border of the province.

The northern portion of the Ridge and Valley has been glaciated, and is blanketed by glacial soils, especially lacustrine clay and silt and glacial till. The Great Valley contains abundant alluvium, and the ridges are mantled with residual soils. Colluvium occurs along the bases of slopes.

The *Appalachian Plateau Province* underlies portions of WV, VA, MD, and PA (Figure F-10). The Appalachian Plateau Province includes the Cumberland Plateau in VA. It is underlain by relatively flat-lying Middle through Late Paleozoic sedimentary rocks (Figure F-2). Most of the coal deposits of the region occur in this province, and strip mines are common. The province is deeply dissected by rivers and streams, and contains deep valleys with moderate to steep sideslopes and flat-bottomed valleys. The intervening uplands are gently rolling.

The northernmost portion of this province has been glaciated. A 25 to 100-foot mantle of glacial deposits cover the bedrock. The rivers in the glaciated section have been diverted to the southwest. Residual soils coat the uplands, colluvium mantles lower portions of the valley sides, and alluvium is found along the rivers.

The *Central Lowland Province* occupies a small portion of PA along the Lake Erie shoreline (Figure F-10). It is developed on nearly flat-lying Devonian rocks, which are covered by 25 to 100 feet of glacial deposits (Figure F-2). Beach and aeolian soils are developed along the Lake Erie shoreline

CONTROLS ON AGGREGATE QUALITY

DURABILITY, EROSION RESISTANCE, AND SKID RESISTANCE

The Mohs Hardness Scale is a measure of the relative hardness of minerals (and rocks) based on the ability of selected common minerals and objects to scratch each other. The hardness scale ranges from 1 to 10, with 10 the hardest, and is as follows:

Table F.2 Moh's Scale of Hardness	
Hardness	Mineral
1	Talc
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Feldspar
7	Quartz
8	Topaz
9	Corundum
10	Diamond

Your fingernail has a hardness of 2+ (it will scratch talc, serpentine, or gypsum, and be scratched by calcite), a copper penny of 3, a steel knife blade has a hardness of 5, glass of 5 ½, and a steel file of 6 ½. Thus, you can amuse yourself by scratching a window with a quartz crystal or a diamond ring. Your Significant Other might not be amused, however, if you try this experiment at home or in the car.

The Mohs Hardness Scale can be used to make general predictions on the relative resistance to erosion and the durability of common rocks in the region.

The minerals comprising igneous rocks tend to have a narrow range of hardness, from 6 for feldspars, pyroxenes, and amphiboles to 7 for quartz. Secondary minerals, such as the micas, are significantly softer (hardness of 2 to 3). The igneous rocks tend to be erosion resistant, particularly if they have low iron and magnesium contents. The iron and magnesium rich minerals are somewhat less resistant to chemical erosion than quartz or iron-poor minerals. The igneous rocks usually hold up hills and mountains. They make durable aggregates in roads, but have low skid resistance because their minerals wear evenly due to the similar hardness. They contain variable amounts of micas. The mica group is composed of platy minerals that easily split apart, and can weaken igneous (and metamorphic) rocks if they are too plentiful.

Skid resistance tends to parallel hardness. There is not a simple relationship between hardness, erosion resistance, and skid resistance, however. The higher skid resistance corresponds to rocks that are composed of minerals of dissimilar hardness. The harder materials erode slower than the softer, and stick above the general road surface, forming irregularities that the tires can grip. Variable crystal size can impart skid resistance, as smaller crystals tend to erode faster than larger crystals

Sedimentary rocks range widely in relative hardness, resistance to erosion, and skid resistance. Most of the sand-size particles in sandstones are quartz, with lesser amounts of feldspars and rock fragments. Conglomerates and sandstones tend to be erosion-resistant, and hold up plateau and ridges. Rocks that are susceptible to chemical weathering, such as dolomite and limestone, and soft rocks, such as shale, underlie valleys. Unconsolidated material, such as gravel and sand, erode easily. Rocks with dissimilar matrix and grains, such as Calcareous Sandstone (calcite matrix and quartz grains, hardness of 3 and 7) or Graywacke Sandstone and Graywacke Siltstone (clay matrix and quartz or feldspar grains, hardness of 4 and 6 1/2), have high skid resistance.

Metamorphic rocks also vary widely in resistance to erosion, skid resistance, and hardness. Fine-grained rocks are usually rich in micas and chlorite (hardness from 2 to 3), while coarser rocks contain quartz and feldspars (hardness from 6 to 7). Gneiss and hornfels have similar composition, but the crystals in gneiss are distinctly banded or layered, while the quartz and feldspar crystals in hornfels are randomly oriented. Both rock types are resistant to erosion and hold up ridges. The micas and chlorite in schist and serpentine are easily eroded, resulting in valleys developing over these rocks. Marble is both soft (hardness of 3 to 4) and easily chemical weathered, so it usually underlies valleys.

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