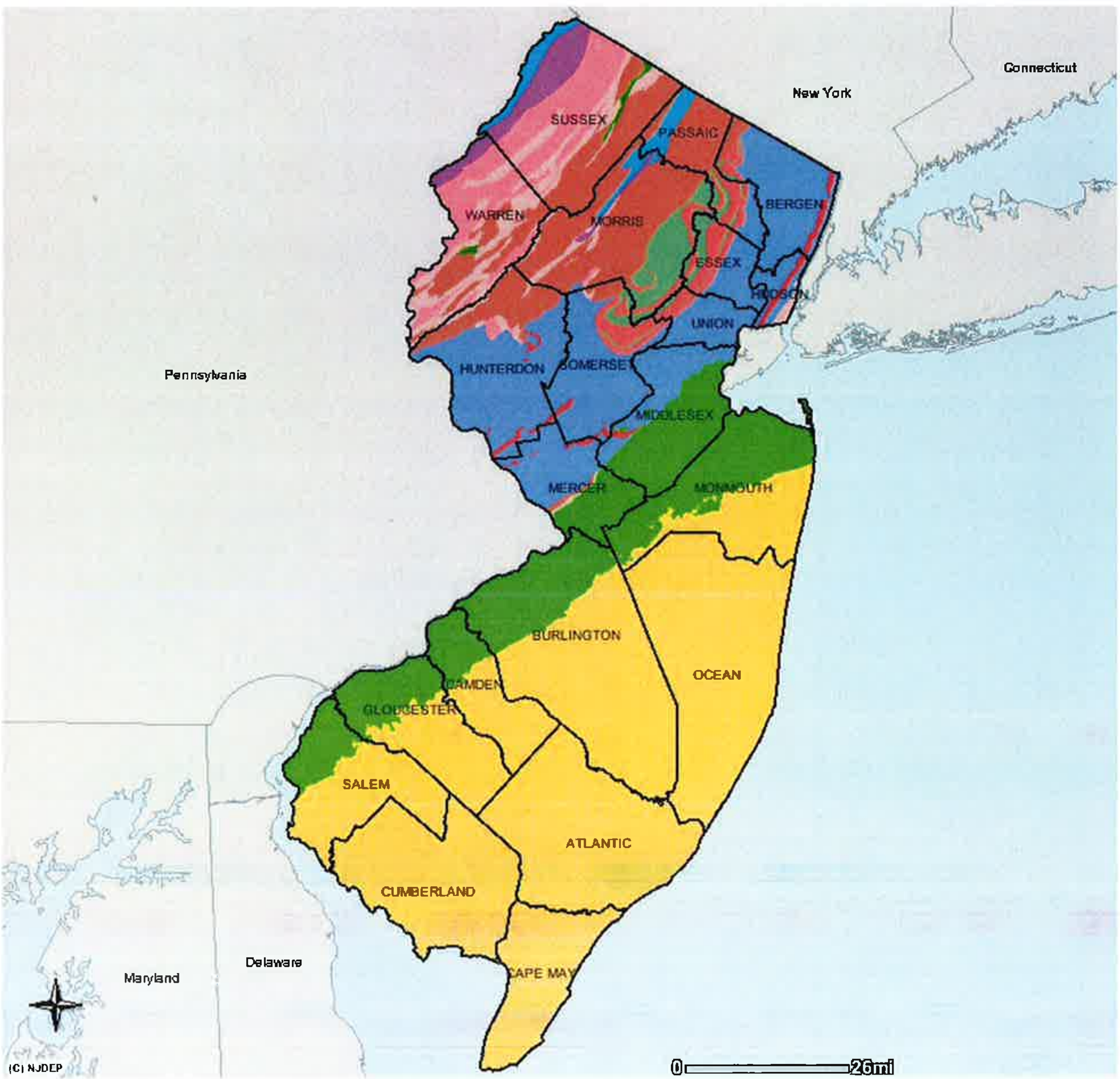
Geology of New Jersey and Eastern Pennsylvania Grand Tour

June 23, 2012



Brief Outline of the Itinerary: A Geology Field Trip into West Central New Jersey and East Central Pennsylvania.

In general the field trip for the most part will traverse a route paralleling the Delaware River and will proceed from Sewell, Washington Township, New Jersey in the south to Hellertown, Pennsylvania in the north. In doing so the itinerary will course through several different physiographic provinces including the outer and inner Coastal Plain, the Piedmont Upland, the Piedmont Lowlands and the Lehigh Valley. You will be able to collect a representative suite of rocks and perhaps fossils. The purpose of the trip is for you to learn about geologic processes and geologic history noting field observations. The locations chosen are classic ones to geologists and the ride is a particularly scenic one; so relax and enjoy. The initial meeting place for this trip is in the parking lot for Washington Township High School at the corner of Hurffville Cross Keys Road and Gantown Road across from the T & D Bank and Rite Aid. We will be leaving promptly at 7:30 a.m.

Meeting Place: Washington Township High School

39° 44.388 N

75° 04.487 W

Stop #1: Inversand Marl Pits, Sewell, NJ (Mantua Twp. - (not Washington Twp.) located behind Lowe's Shopping Center and Rt553, Woodbury-Glassboro Rd. Here you will see an excellent exposure of greensand marl (glauconite) in the Inner Coastal Plain of NJ. This site has the distinction of being the very last mining operation of its kind in the world. The sedimentary material is processed at the plant and utilized as a soil conditioner (fertilizer); it also has been used in water treatment to remove iron and manganese. The deposits are marine, mid to outer continental shelf and are represented by the Upper Cretaceous (Maastrichtian) Navesink Formation (Fm) and the Hornerstown Fm. of Uppermost Cretaceous and Tertiary (Paleocene) astride the K/T Boundary. Both formations are richly fossiliferous. Most commonly found are pelecypods, steinkerns, shark's teeth and "pyritized" (marcasite) remains of sponges, bryozoans, worm tubes, brachiopods, etc. Paleontologists have also excavated the remains of dinosaurs such as Hadrosaurus and Dryptosaurus as well as those of crocodiles, turtles, mosasaurs and even birds. Now and then one can find vivianite nodules and selenite (gypsum) clusters. This site is most certainly a classic one, important enough to be visited by Edward Drinker Cope in the nineteenth century and by members of the New Jersey State Museum with their ongoing excavations.

Stop #1 GPS Coordinates:

39° 45.648N

075° 07.514W

Stop #2: Irish Hill, Runnemede, NJ on Irish Hill Road off Clement Bridge Road (Rt. 41). The hill on which you are standing is approximately 120 feet above sea level but descends sharply to the flat-lying plain below. You are at the summit of an asymmetrical hill called a cuesta which gently slopes southeastwardly to the Atlantic Ocean at 5 to 10 feet per mile. The major sedimentary units exposed in the Irish Hill area include the highly dissected dark sandy clays of the Marshalltown Fm. At the very bottom of the hill following upward to the fine micaceous quartz sand of the Wenonah Fm., the coarser Mt. Laurel Fm. Glauconitic quartz sand, and finally under your feet the Navesink Fm.Glauconitic Sand. All are Upper Cretaceous marine sediments and unfossiliferous at this locality. On a clear day you can see the Philadelphia skyline.

Stop #2 GPS Coordinates:

39° 51.449 N

075° 04.104 W

Stop # 3: New Jersey State Museum, Trenton, NJ off West State Street (I-295 to exit 60 to Rt. 29 to Calhoun Street to West State Street) into Museum parking lot. Trenton, the capital city of New Jersey is situated on the Trenton Prong of the Piedmont Upland Providence along the Fall Line.. The Trenton Prong trends southwest into Pennsylvania and further south. It is composed mostly of Mesoproterozoic and Lower Paleozoic metamorphic lithologies including the Wissahickon Gneisses and Schists of Ordovician age which outcrop along the Schuykill Expressway in the Philadelphia area. Along Rt. 29 in Cadwallader Park, Trenton is an exposure of the Stockton Arkose of Triassic age which lies unconformably (nonconformity) over the Mesoproterozoic metamorphic crystalline rocks. The NJ State Museum established in 1895 carries collections of natural history dating from the 1840's. The current building with its planetarium dates from 1964. You will be able to see exhibits of local NJ fossil forms, Indian artifacts, minerals, rocks, etc. Don't miss seeing a simulated model of the famous "Haddonfield Giant" Hadrosaurus foulkii, an ornithopod from the Cretaceous Woodbury Fm. Also look for "Matilda," an Ice Age Mastodon from the Pleistocene of Sussex County, NJ. Also look for the fluorescent display, most of the minerals of which (including calcite and willemite) are from Sterling Hill (Ogdensburg and Franklin, NJ, the "Fluorescent Mineral Capital of the World." Enjoy a run of the museum for about an hour. Incidentally the museum has a fine art collection, too. One last item, on exhibit is the toothy skull of Mosasaurus maximus excavated from Sewell's Inversand Marl Pits, visited earlier this morning.

Stop #3 GPS Coordinates:

40° 13.244 N

74° 46.406 W

Stop #4: Abandoned Red Shale Quarry, Titusville, NJ off Rt. 29, north of Washington Crossing State Park. (Follow the designated trail through the woods). The lithology at this locality is a friable bright red shale of Upper Triassic age (ca. 210 Ma). This unit as well as others seen on this trip formed from lithified mud and sands. The Passaic Fm. (Old Brunswick) Shale as this unit is called is the youngest and dominant rock of the western portion of the Piedmont in NJ, the "redbeds" include the Towaco, Feltville and Boonton Fms. All of Lower Jurassic age and associated with the Watchung lava flow ridges (Orange Mt., Preakness Mt.and Hook Mt.). Common in this shale as will also be noted in the Frenchtown area are "fossilized" ripple marks, mudcracks and raindrop impressions. Occasionally you may even be lucky enough to find plant fossil remains and even dinosaur tracks. Good luck! These sediments were laid down in ancient rivers which meandered back and forth on the valley floor prior to and perhaps during the creation of the rift valley system. At the beginning of the Mesozoic Era (age of Dinosaurs), New Jersey was at the center of the giant Supercontinent of Pangaea which was beginning to rupture to produce the incipient Atlantic Ocean. Tensional forces are still operating today to create an ever-widening of the Atlantic Ocean Basin. The rift valley system, which once was the major physiographic feature of New Jersey during the early Mesozoic in Death Valley, California and in the Jordan Valley between Yisrael and Jordan.

Stop #4 GPS Coordinates:

40° 18.500 N

74° 52.801 W

Stop #5: Belle Mountain Quarry (Mercer County Correctional Facility – Workhouse Quarry) along Rt. 29 just north of the quarry at Baldpate Mountain. Incidentally, Baldpate Mountain is an Early Jurassic diabase sill intruding the Passaic Fm. Contemporaneous with the sill is Belle Mt., a dike exhibiting cross-cutting (discordance) with the Passaic Passaic Fm., and is also cut by the northern limb of the Hopewell Fault. The rock is therefore highly fractured and many of the fragments and quarry wall itself exhibit polished slickensides and serpentinization. The lithology is a melanocratic ferromagnesian-rich igneous rock called diabase, similar to a basalt in mineral composition but coarser in texture. This is due to the fact that a dike is hypabyssal rather than surficial as in a lava flow. Magmas contained within the Earth cool more slowly than do lavas at the surface. Again, to the east lie the basalts of the Watchung Ridges which are the result of Early Jurassic lava flows. An extension of the Belle Mt. dike can be seen across the Delaware River in Pennsylvania and is known as Bowman Hill which will be visited on our last stop. Belle Mt and Bowman Hill may be "feeders" to Sourland Mt. (Lambertville Sill) and Solebury Mt. Sill (in PA), respectively.

Stop #5 GPS Coordinates:

40° 19.806 N

74° 55.489 W

<u>**Stop # 6:**</u> **Small roadside exposure in Sourland Mt.(Goat Hill)** along Rt. 29 north and Weeden Street, Lambertville, NJ. **DO NOT TAKE SAMPLES FROM THE WALL FACE; THIS IS A WARNING!** There is a danger of undermining the "ground" on which these homes are built. This is an exposure of the Lambertville Sill, a concordant hypabyssal igneous intrusive body. Magmas originally intruded parallel to the bedding of the Passaic Fm. During the Early Jurassic Period. Tens of millions of years of differential weathering and erosion have removed the enclosing bedrock and exposed this and the other intrusive along the Delaware River as well as the Watchungs and Palisades Sill along the Hudson River. Again, the typical lithology exposed here is a diabase but very fine-grained, almost a basalt. Some rocks exhibit columnar jointing. This sill extends across the Delaware River as Solebury Mt. in Pennsylvania. North of Lambertville along Rt. 29 the traverse proceeds over the Lockatong Fm. Cut by the Dilt's Corner Fault. Rising behind the school is the Mt. Gilboa Sill quarried further on for its diabase. The sill is cut by the Flemmington Fault.

Stop #6 GPS Coordinates:

40° 21.528 N

74° 56.558 W

Stop #7: Abandoned Quarry in the Stockton Fm. Along Rt. 29 north of the town of Stockton and the Wickecheoke Creek.

This is a fine outcrop but now (2012) largely overgrown but still worthwhile. The Stockton Fm. Is the oldest member of the Newark Supergroup of Middle Triassic age, ca. 220 Ma. It lies unconformably on the underlying Precambrian and Lower Paleozoic rocks of the Piedmont Upland from which the quartz sands (and feldspar) were derived. Here for the most part, the rock exhibited is a gray to yellowish gray arkose with abundant sodic and potassic feldspar (2:1) and the so-called "Brownstone", a fine-grained micaceous sandstone. The latter was once quarried as a building stone for many 19th century buildings (including) churches in New York, Philadelphia and elsewhere. Also common is a fine-grained micaceous mudstone shale which is extensively burrowed by a crayfish-like crustacean called **Scoyenia.** Continue north on Rt. 29 (River Road), the Stockton Fm crosses back into the Lockatong Fm. at Raven Rock.

Stop #7 GPS Coordinates:

40° 24 N

74° 59 W

Stop #7A: Stockton Formation locality along the Delaware River at the Prallsville Mill off Rt. 29 at the north end of the town of Stockton. (Mailing address: 33 Risler Street, Stockton, NJ).A short walk from the parking area to the water's edge of the Delaware river reveals a flat-lying area heterogeneously strewn with water-worn rocks many of which exhibit good sphericity and roundness. You will find many examples of pebble and cobble-sized particles, some even approaching boulder size. There are many examples of the local lithology including the light-colored arkose (arkosic sandstone), the tough "brownstone", and the red mudstone showing evidence of bioturbidation (e.g. Scoyenia). Interestingly you will also see large particles of limestone and chert which postglacially were washed down from further north, especially from the NJ Highlands Physiographic

Province. Glacial striae can be found on some of the black cherts. A nice diversion from the geology are the art shows on site. In all it is a scenic overlook.

Stop # 7A GPS Coordinates:
40° 24.498 N
74° 59.163 W

<u>Stop #8:</u> **Roadside Exposure of the Byram Intrusive into the Lockatong Argillite Formation** at Byram, NJ near the site of the destroyed bridge in Point Pleasant, Pennsylvania. The Lockatong Fm. Argillite is a tough well-jointed gray to black (red 2.5 miles further north) slightly metamorphosed shale representing a Triassic lacustrine environment. Pyrite nodules as well as fossil plants and fish (Palaeoniscoid and Crossopterygian) may be found in the argillite. At the place where the Byram diabase intrusive, a sill of Lower Jurassic age invades the argillite, the rock is further altered into very tough gray metamorphic rock called hornfels rich in biotite and albite. To the south section of the outcrop the hornfels contains nepheline, cancrinite, pyroxene and amphibole. In the contact metamorphic zone (aureole), the hornfels is well-exposed where a small stream flows over the rocks creating a miniature waterfalls. The swirling waters even produce potholes. Much of the diabase is spheroidally weathered as will be seen later at Ringing Rocks. In places the diabase is fine-grained; it mimics a basalt.

Stop #8 GPS Coordinates:
40° 25.420 N
75° 03.592 W

<u>Stop #9</u> **Lunch break at small city park near the junction of Rt. 29 and Rt. 12 in Frenchtown, NJ.** Here you again can see the Passaic Fm. red Mudstone Shale along the Nishisakawick Creek. In the creek bed the Passaic Fm. exhibits

sedimentary structures such as "fossilized" mudcracks, ripple marks and raindrop impressions. Alternate lunch at the "Lovin Oven" in town.

The itinerary courses north along Rt. 29 toward Milford, NJ. In Milford make a left toward the bridge and a right onto Church Road and another right onto Spring Garden Road (Hunterdon Co. 627). The road can be **very hazardous** because it is extremely narrow, and it is at the foot of a massive cliff with 300 foot drop to the Delaware River. Go slowly and be watchful of oncoming vehicles. As you proceed, the cliff face exhibits tilted red beds (dipping) at 10 to 15 degrees NW) of alternating layers of coarse and fine particles, shales, sandstones and conglomerates reflecting changes in the energy flow of ancient streams at the end of the Triassic.

Stop #9 GPS Coordinates:

40 ° 31.645 N

75° 03.522 W

Mile Marker 27.5

Stop #10: Pebble Bluffs, an exposure of the Hammer Creek conglomerates of the Lower Passaic Fm along Spring Garden Road, Milford, NJ. The outcrops here are quite spectacular and the lithology represents a giant alluvial fan deposit or fanglomerate. The source area was not more than 25 miles from here and the sediments were derived from the erosion of the Precambrian and Lower Paleozoic rocks of what is now called the NJ Highlands Physiographic: Province (Old Appalachia). The red to purplish conglomerates exhibit clasts mainly of quartzite, limestone, or dolostone and vary in size from a few inches to over a foot. Along the road numerous faults are noticeable mostly normal faults. At our actual stop is a prominent reverse fault. A few miles to the north lies the Border Fault separating the Newark Basin Piedmont Lowland from the NJ Highlands Physiographic Province. Return to the center of Milford and cross over the bridge into Pennsylvania (Upper Black Eddy). Proceed north for a short distance on Rt. 32 and make the first left onto Bridgeton Hill Road and continue up Coffman Hill. **Be**

Careful! At the foot of the hill, the road makes a sharp right angle bend and is a steep ride to the top. Put your vehicle in low gear. Reaching the surface, proceed right to Ringing Rocks Road and the entrance to the park (on your right).

Stop # 10 GPS Coordinates:
40° 34.605 N
75° 08.260 W

Stop #11: Ringing Rocks, a Bucks County Park, Upper Black Eddy, Pennsylvania. Free admission. This unusual circular hill causes the Delaware River to make a sharp bend noticeable on any road map. Coffman Hill is described as a diabase sill, the magmas of which invaded the Passaic Formation in the north and east and the Lockatong Formation in the south and west during the Early Jurassic Period. As at Byram contact metamorphism altered the sediments to a hornfels. Remember that a sill is a hypabyssal concordant igneous intrusive body, a high level "structure" intruding parallel to the bedding despite its circular emplacement. Down the trail the exposed surface exhibits a spectacular boulder field of diabase (a felsenmeer, literally a "sea of rocks" auf Deutsch) many of which are spheroidally weathered. Some of these rocks do actually "ring" when struck with a blunt metallic object (hammer); many of them do not, a mystery? There is a probable explanation. Also, what is the cause of this boulder field?

Down the trail still further is a beautiful little waterfall cascading over a sharp escarpment comprised of well-jointed and terraced hornfels. During a dry season there will be barely a trickle. Enjoy the refreshing sight and feel. **Do not drink the water!** (Same goes for the Byram Intrusive!)

Retrace your "stops" back to Rt. 32 and proceed north on Rt. 32 and Rt. 611, and continue west on Rt. 212 and north on Rt. 412 in Hellertown, Pennsylvania. Traversing north and west you are crossing over the Border Fault into the Lehigh Valley underlain by Precambrian and Lower Paleozoic rocks.

Stop #11 GPS Coordinates:
40° 33.833 N
75° 07.718 W

Stop #12: Lost River Caverns, Hellertown, Pennsylvania. The lithology at this outcrop is a dolomitic limestone from the Leithsville Formation of Cambrian age. This cave is a typical solution cave created by the action of acidified groundwater on carbonate rocks. The host rock has abundant magnesium (Mg) making the rock more difficult to dissolve. Thus caves such as this tend to be smaller than "pure" limestone caves composed of typically calcium carbonate ($CaCO_3$).

$$2H_2CO_3 \rightleftharpoons 2H^+ + 2(HCO_3)^-$$

$$2H^+ + 2(HCO_3)^- + CaCO_3 \rightleftharpoons$$

$$HOH + CO_2 + Ca^{+2} + 2(HCO_3)^-$$

Basically, carbonic acid acts on carbonates to produce calcium bicarbonate which is soluble and is carried away producing a hollow called a cave. Also when carbonic acid attacks carbonates from above, the calcium bicarbonate trickles down into the hollow and with evaporation of the watery component, calcium carbonate is precipitated in the form of speleothems, cave formations. At Lost River Caverns (Lost Cave) you will see the typical cave formations such as stalactites, stalagmites, columns, flow stone, eggs and bacon, etc. Note the mineral spring. Yes, you can drink the water, it is really delicious. Note the geological exhibits, and visit the cave shop. Admission is $11.00 for adults; $7.50 for children, 3-12. On-line there is a coupon, $1.00 for adults and $0.50 for children. Incidentally, the five room tour will provide much more specific information.

Backtrack out of Hellertown and proceed on Rt. 412 and then south on Rt. 611. Then proceed south on Rt. 413 to the town of Buckingham, then north and east on Rt. 202 through Lahaska and New Hope, Pennsylvania. Make a right and proceed south on Rt. 32 to the entrance of Bowman Hill, the northern section of

Washington Crossing State Park, Pennsylvania. The gate to the entrance closes at sun-down.

Stop #12 GPS Coordinates:
40° 34.940 N
75° 19.845 W

<u>**Stop #13:**</u> **Washington Crossing State Park, Bowman's Hill (Tower) Section,** south of New Hope, Pennsylvania, along Rt. 32. Bowman's Hill is a diabase dike, a discordant, hypabyssal igneous intrusive body, the magmas of which invaded the Passaic Formation during the Early Jurassic age. Again, the magmas cut across the bedding , and the dike probably is a feeder to the Solebury Mountain Sill, an extension of the Lambertville Sill on the NJ side. This hill was an excellent observation site for the Continental Army for determining the positions and maneuvers of the British during the Revolutionary War. Personally, I think you will be too tired and exhausted to make it up Bowman Hill on foot and then the climb to the lookout tower. If you can make it, the rewards are great. You will be able to see much of our itinerary from above including the striking hills created by the diabase sills and dikes and their trap rock quarries. The view of the Delaware River and its alluvial plain is quite spectacular, a high point of the trip, to be sure!

Stop #13 GPS Coordinates:

<u>**Addendum to Stop#13:**</u> **Bowman's Hill and Tower, Washington Crossing State Park, Pennsylvania.** Because of budget cuts, Bowman's Tower is not open until sun-down as it was previously. It is now open from April to November 10:00 am to 4:00 pm. Tuesday to Saturday and 12:00 noon to 4:00 pm on Sundays. Thus, we will visit the Tower after **Stop #6** (Exposure in Sourland Mt.-Lambertville Sill). After

visitation to Stop #6, vehicles will proceed north to the light and left (west) onto Bridge Street (Rt. 179) in Lambertville and continue across the bridge to New Hope, Pennsylvania. Then we will proceed south on Rt. 32 and in the park make a right onto Lurgan Street and another right onto Bowman's Hill Tower Road to the tower area. After visitation, we will proceed north back to New Hope and cross the bridge back into Lambertville. Then we will resume the original itinerary traveling north on Rt. 29 to **Stops # 7 and 7A.**

Finis

Side trip to New Hope if you like.

Trip run by: Louis B. Detofsky and Mark Leipert

Suggested Useful Items

For the Field Trip

- **Clothing:** Light-colored long pants, long sleeve shirt, hat, light jacket (for the cave), sturdy shoes of hiking boots, small poncho. Light colored clothing is particularly good for spotting ticks or other "critters". Don't forget hard hats.
- **Small First Aid Kit,** medications, bug spray (25% DEET like "Deep Woods Off"), sun block (SPF 45), sunglasses.
- **Lunch, snacks, and plenty of water.**
- **Tools:** Rock Hammer (Brick-layers hammer), chisel, hand lens (10X), newspaper or paper towels for wrapping and protecting specimens, cameras, binoculars, cell phones, GPS devices, NJ road map and itinerary (field guide).
- Backpacks, lots of plastic bags (zip-lock) of various sizes, marking pens (preferably waterproof), small field notebook, tape, labels to place inside the plastic bags or on the outside with tape.
    - Labels should include:
        - Collector's name
        - Date of sample collected
        - Rock/Mineral/Fossil name
        - Formation name
        - Age: e.g. Geologic "name" periods, epochs, etc.
        - Locality keyed to the itinerary (Stops #1 -13).

Be careful and be safe so that you can enjoy and learn about the environment. Listen carefully to the field leaders so that you can avoid accidents. However, be prepared to sustain a couple of bumps and bruises. To make this trip positively memorable for yourself take lots of pictures.

Drawings, Maps and Tables

A Geology Field Trip into West Central New Jersey and East Central Pennsylvania

ALLENTOWN
Bethlehem
Easton
Phillipsburg
READING
PHILADELPHIA
Camden
TRENTON
WILMINGTON
Levittown
Doylestown
Norristown
Pottstown
Lansdale
Flemington
Stockton
Lambertville
New Hope
Washington Crossing
Yardley
Morrisville
Bordentown
Burlington
Frenchtown
Milford
Upper Black Eddy
Riegelsville
Start
Finish
BUCKS
BERKS
LEHIGH
NORTHAMPTON
MONTGOMERY
CHESTER
CARBON
MONROE
SCHUYLKILL
HUNTERDON
MERCER
SOMERSET
WARREN
SUSSEX
MORRIS
BURLINGTON
CAMDEN
GLOUCESTER
SALEM
ATLANTIC

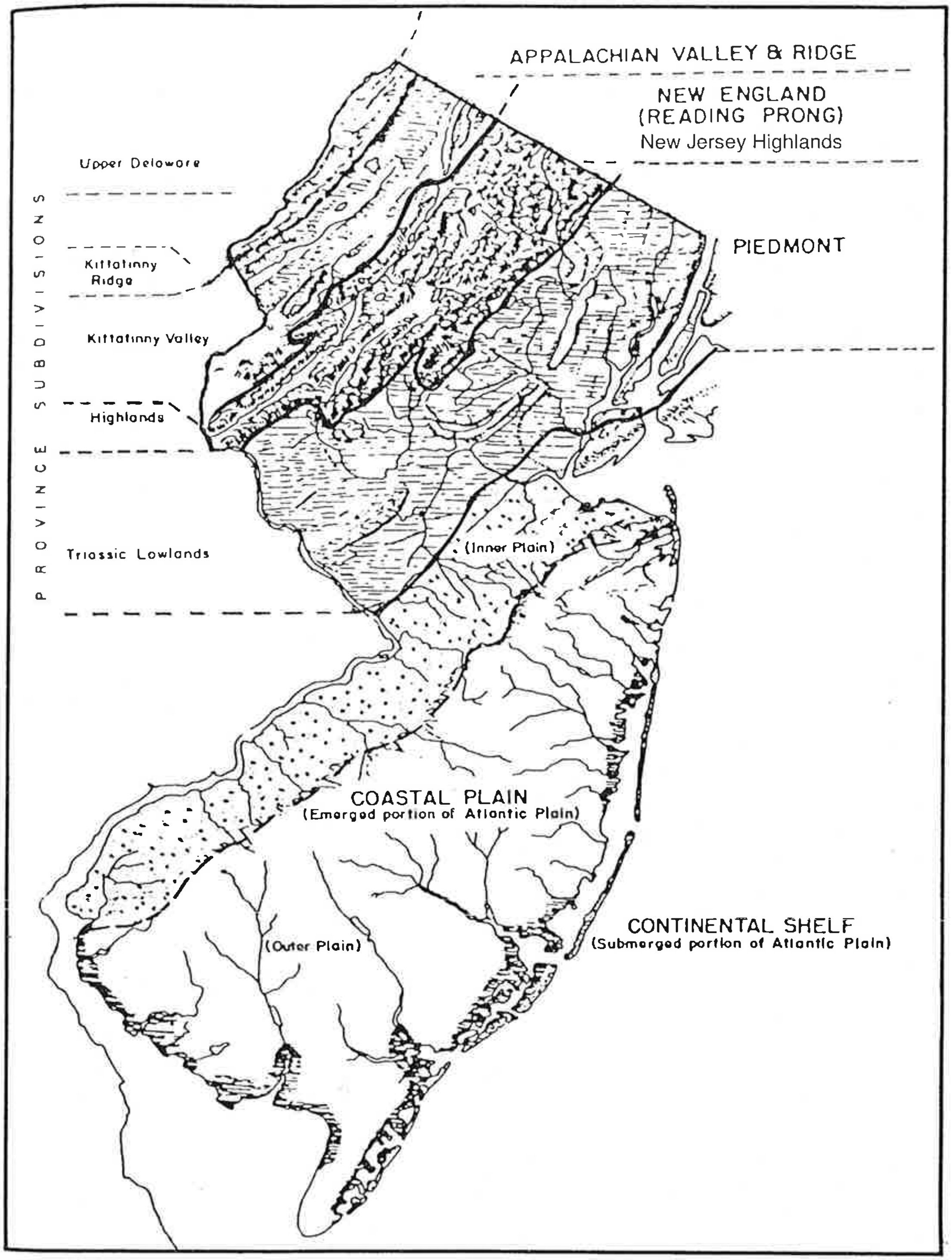
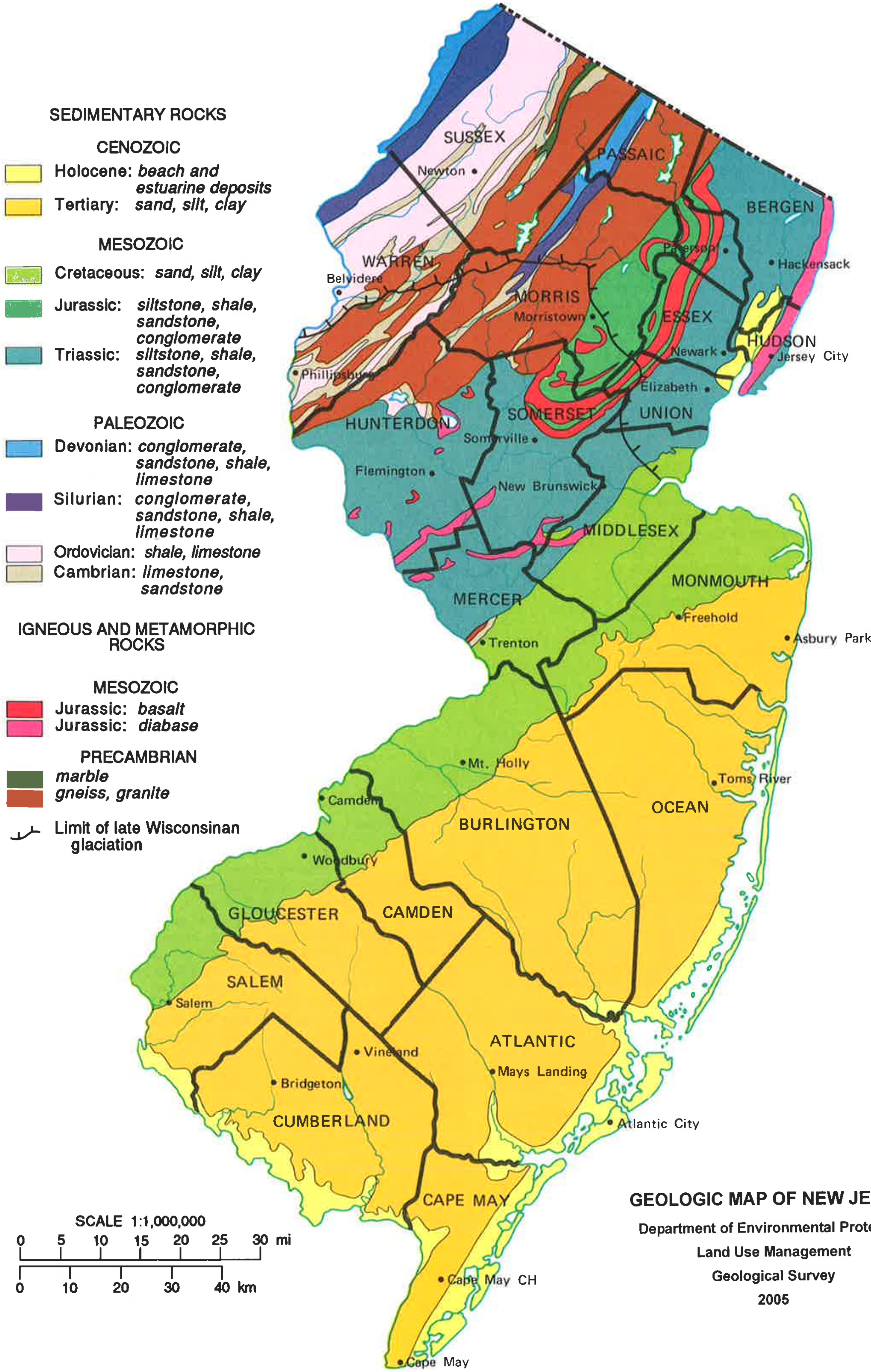


Figure 7-1. Map of the geomorphic provinces of New Jersey.



GEOLOGIC MAP OF NEW JERSEY

Department of Environmental Protection
Land Use Management
Geological Survey
2005

THE GEOLOGY OF NEW JERSEY

For an area of its size, New Jersey has a uniquely diverse and interesting geology. The state can be divided into four regions, known as physiographic provinces, which have distinctive rocks and landforms.

The **Valley and Ridge** Province is underlain by faulted and folded sedimentary layers of sandstone, shale, and limestone that range in age from Cambrian to Devonian (570 to 345 million years old). These rocks originated as sand, mud, and lime sediment deposited in former seas and floodplains. During Ordovician time (approximately 450 million years ago) and again during Pennsylvanian and Permian time (approximately 300 million years ago) the rocks were deformed by compression into folds and thrust along faults. As a result of the deformation, the originally flat sedimentary layers were tilted and now outcrop as linear belts.

Alternation of belts of erosion-resistant sandstone and easily-eroded shale and limestone creates the long, parallel northeast-southwest trending ridges and valleys characteristic of this province. Resistant sandstone and siltstone layers underlie Kittatinny Mountain and Walpack Ridge; shale and limestone underlie the valley of Flat Brook, the Delaware Valley upstream from the Delaware Water Gap, and the broad valley between Kittatinny Mountain and the Highlands to the east.

The limestone is quarried for construction material and cement aggregate. Some of the limestone units yield large quantities of ground water. The shales and sandstones and some limestone units are generally less productive aquifers.

On the eastern edge of the Valley and Ridge Province, along a line from Franklin through Andover to the Delaware River just north of Phillipsburg, an irregular escarpment averaging 500 feet in height marks the boundary of the **Highlands** Province. The Highlands are underlain predominantly by granite, gneiss, and small amounts of marble of Precambrian age. These rocks, the oldest in New Jersey, were formed between 1.3 billion and 750 million years ago by melting and recrystallization of sedimentary rocks that were deeply buried, subjected to high pressure and temperature, and intensely deformed. The Precambrian rocks are interrupted by several elongate northeast-southwest trending belts of folded Paleozoic sedimentary rocks equivalent to the rocks of the Valley and Ridge Province.

The granites and gneisses are resistant to erosion and create a hilly upland dissected by the deep, steep-sided valleys of major streams. The belts of sedimentary rock form long, parallel ridges and valleys (for example, Bearfort Mountain, Long Valley, and the Musconetcong Valley) that extend through the province.

The Highlands contain magnetite iron ore deposits that formerly supplied an industry of national importance. A mineralogically unique zinc ore in the Franklin Marble in Sussex County was worked until 1987. The ore, which fluoresces bright red and green, is in museums throughout the world. In places the rocks of the Highlands are quarried for crushed stone. The Precambrian rocks are generally unproductive aquifers except where they are fractured or weathered. The more productive aquifers of the region are the glacial deposits and some of the Paleozoic sedimentary rocks.

Rocks of the **Piedmont** Province are separated from the rocks of the Highlands Province by a series of major faults, including the Ramapo Fault. The more resistant gneisses and granites on the upthrown northwest side of the faults make a prominent escarpment, 200 to 800 feet in height, extending from Mahwah through Boonton and Morristown to Gladstone, and from there westward in an irregular line to the Delaware River near Milford.

South and east of this escarpment, interbedded sandstone, shale, conglomerate, basalt, and diabase of the Piedmont Province underlie a broad lowland interrupted by long, generally northeast-southwest trending ridges and uplands. The rocks of the Piedmont are of Late Triassic and Early Jurassic age (230 to 190 million years old). They rest on a large, elongate crustal block that dropped downward in the initial stages of the opening of the Atlantic Ocean -- one of a series of such blocks in eastern North America. These down-dropped blocks formed valleys known as rift basins. Sediment eroded from adjacent uplands was deposited along rivers and in lakes within the basins. These sediments became compacted and cemented to form conglomerate, sandstone, siltstone, and shale. They commonly have a distinctive reddish-brown color.

In the course of rifting, the rock layers of the Piedmont became tilted northwestward, gently folded, and cut by several major faults. Volcanic activity was also associated with the rifting, as indicated by the basalt and diabase interlayered with the sandstone and shale. Diabase is a rock formed by the cooling of magma at some depth in the crust; basalt is formed by cooling of an identical magma that has been extruded onto the surface as lava. Both basalt and diabase are more resistant to erosion than the enclosing sandstone and shale, and therefore they form ridges and uplands. The Palisades, Rocky Hill, Sourland Mountain, and Cushetunk Mountain are underlain by diabase layers. The Watchung Mountains, Long Hill, and Hook Mountain are underlain by basalt layers. Valleys and lowlands between these ridges are underlain by shale and sandstone.

The basalt and diabase are extensively quarried for crushed stone. In the past, "brownstone" was widely quarried from sandstone units. Also, minor quantities of copper were extracted from sandstone and shale associated with the diabase and basalt. The basalt and diabase generally are poor aquifers but the sedimentary rocks are, in places, capable of yielding large quantities of water.

Southeast of a line roughly between Carteret and Trenton, unconsolidated sediments of the **Coastal Plain** Province overlap rocks of the Piedmont Province. These sediments, which range in age from Cretaceous to Miocene (135 to 5.3 million years old), dip toward the coast and extend beneath the Atlantic Ocean to the edge of the Continental Shelf. The Coastal Plain sediments thicken southeastward from a featheredge along the northwestern margin of the province to approximately 4,500 feet near Atlantic City to a maximum of more than 40,000 feet in the area of the Baltimore Canyon Trough, 50 miles offshore from Atlantic City. The sediments consist of layers of sand, silt and clay deposited alternately in deltaic and marine environments as sea level fluctuated during Cretaceous and Tertiary time. These layers of sediment outcrop in irregular bands that trend northeast-southwest. Wide areas of the Coastal Plain are covered by a thin veneer of Late Tertiary and Quaternary sand and gravel deposited by rivers.

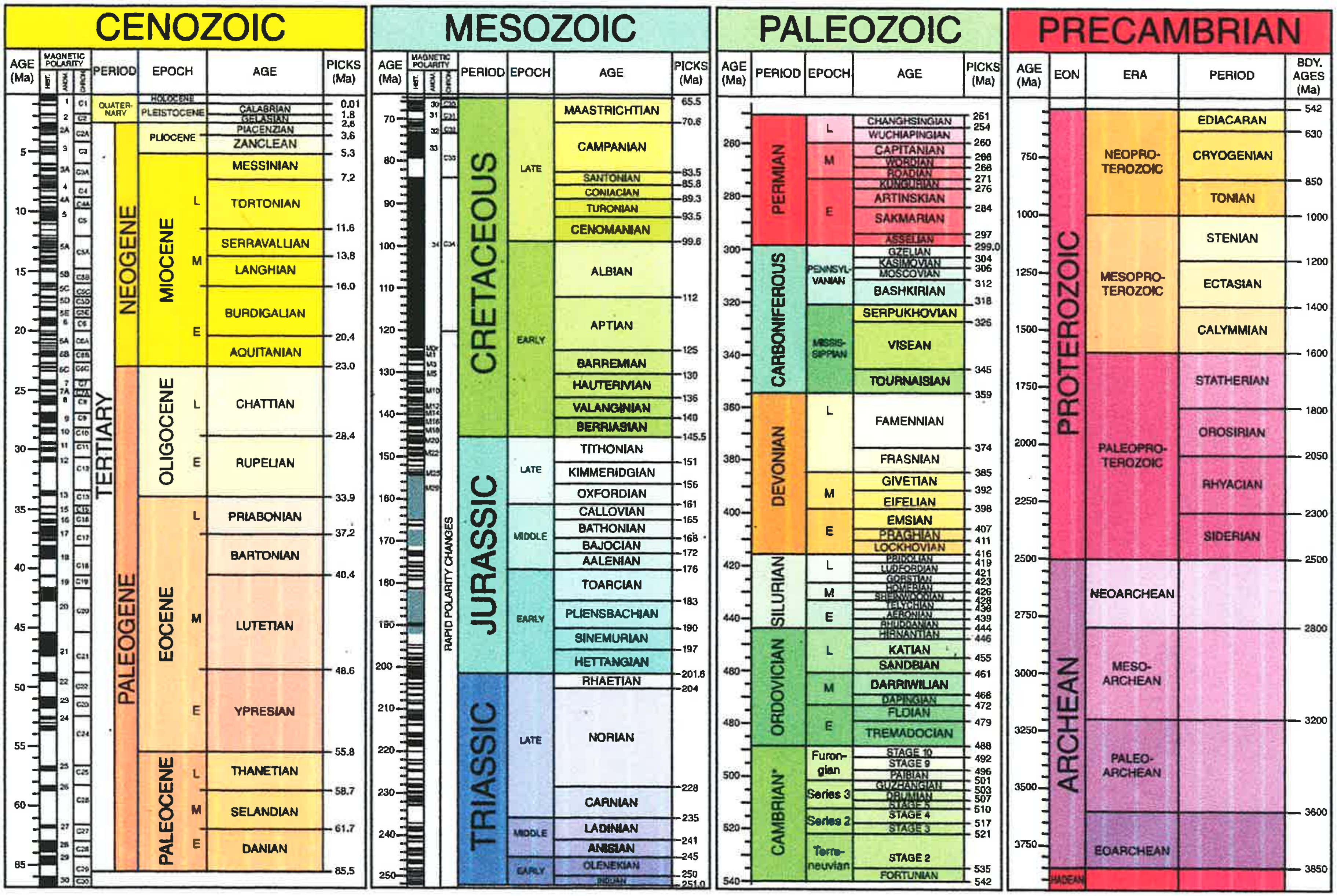
The topography of the Coastal Plain generally is flat to very gently undulating. However, erosion-resistant gravel or iron-cemented sediment underlie upland areas and isolated hills, such as the Atlantic Highlands, Telegraph Hill, Mount Holly, and Arneys Mount.

Coastal Plain sediments have been mined in the past for bog iron, glass sand, foundry sand, ceramic and brick clay, the mineral glauconite for use in fertilizer, and titanium from the mineral ilmenite in sand deposits. Today the Coastal Plain sediments continue to supply glass sand and are extensively mined for sand and gravel construction material. The sand formations are productive aquifers and important ground water reservoirs.

Within each of these physiographic provinces there have been major changes during the past two million years. In this time New Jersey has undergone three glaciations. The last glacier (the late Wiconsinan advance) began to melt back from its maximum extent approximately 20,000 years ago. North of the limit of the last glaciation much of the surface is covered by glacial deposits. Upland areas in this region are thinly draped with till, an unsorted mixture of sand, clay and boulders deposited directly from the glacier. Valleys and lowlands are filled with up to 350 feet of sand and gravel deposited from glacial meltwater and silt and clay that settled in glacial lakes. The sand and gravel deposits are important sources of construction material, and productive aquifers are found where sand and gravel occur in buried or filled valleys. South of the limit of Wisconsinan glaciation, there are discontinuous patches of till from older glaciations. These deposits occur on uplands and are found as far south as the Somerville area.

During each glaciation, sea level dropped as water from the oceans was transferred to ice sheets. Rivers extended and deepened their valleys to conform to the lower sea levels. When the ice sheets melted, sea level rose, flooding the deepened valleys and establishing new shorelines. The present configuration of the coast is the result of the rapid post-glacial rise in sea level, which slowed approximately 6,000 years ago. Many of the estuaries along the coast are the drowned lower reaches of former river valleys. To the east of the mainland, barrier islands were formed, and continue to be shaped, by erosion and deposition of beach sand by waves and currents. Mud and sand transported by rivers and from offshore is gradually filling the bays and estuaries between the mainland and the barrier islands, creating extensive wetlands.

2009 GEOLOGIC TIME SCALE



*International ages have not been fully established. These are current names as reported by the International Commission on Stratigraphy.

Walker, J.D., and Geissman, J.W., compilers, 2009, Geologic Time Scale: Geological Society of America, doi: 10.1130/2009.CTS004R2C.

Sources for nomenclature and ages are primarily from Gradstein, F., Ogg, J., Smith, A., et al., 2004, A Geologic Time Scale 2004: Cambridge University Press, 589 p. Modifications to the Triassic after: Furin, S., Preto, N., Rigo, M., Roghi, G., Gianolla, P., Crowley, J.L., and Bowring, S.A., 2006, High-precision U-Pb zircon age from the Triassic of Italy: Implications for the Triassic time scale and the Carnian origin of calcareous nannoplankton and dinosaurs: Geology, v. 34, p. 1009–1012, doi: 10.1130/G22967A.1; and Kent, D.V., and Olsen, P.E., 2008, Early Jurassic magnetostratigraphy and paleolatitudes from the Hartford continental rift basin (eastern North America): Testing for polarity bias and abrupt polar wander in association with the central Atlantic magmatic province: Journal of Geophysical Research, v. 113, B06105, doi: 10.1029/2007JB005407.

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Table 1. Chronostratigraphic and lithostratigraphic units of the New Jersey Coastal Plain.

Chronostratigraphic Units			Lithostratigraphic Units	
System (Periods)	Series (Epochs)	Stage	Group	Formation
Tertiary	Eocene	Ypresian		Manasquan Shark River
T	Paleocene	Thanetian Danian	Rancocas	Vincentown Hornerstown
K Cretaceous	Upper	Maastrichtian	Monmouth	Tinton \ New Red Bank \ Egypt Navesink Mount Laurel
		Campanian	Matawan	Wenonah Marshalltown Englishtown Woodbury Merchantville
		Santonian-Cenomanian		Magothy Raritan

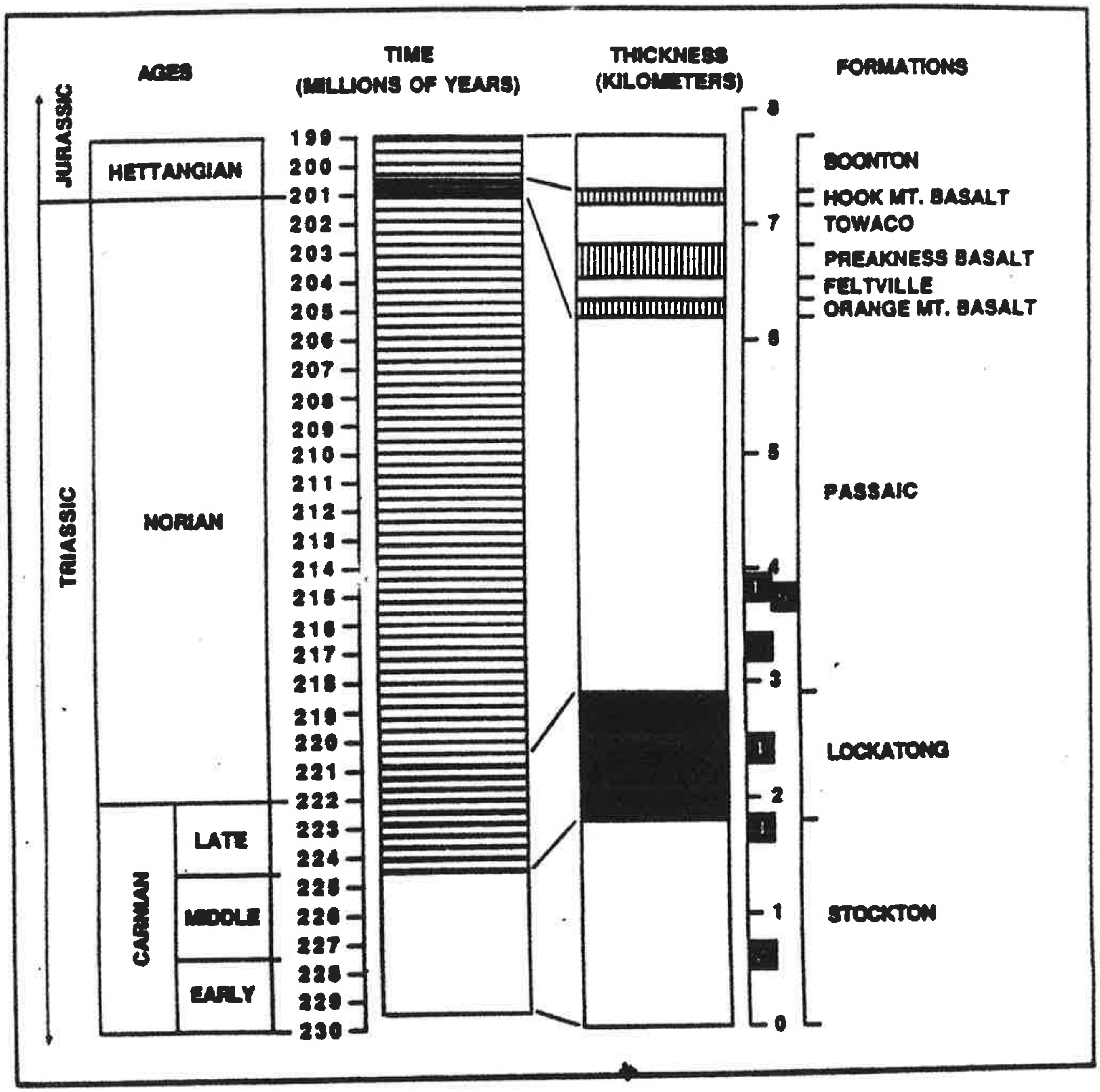

Figure 4. Stratigraphy of the Newark Basin in time based on calibration by Van Houten cycles (left) and thickness (right) showing stratigraphic position of the field stops.

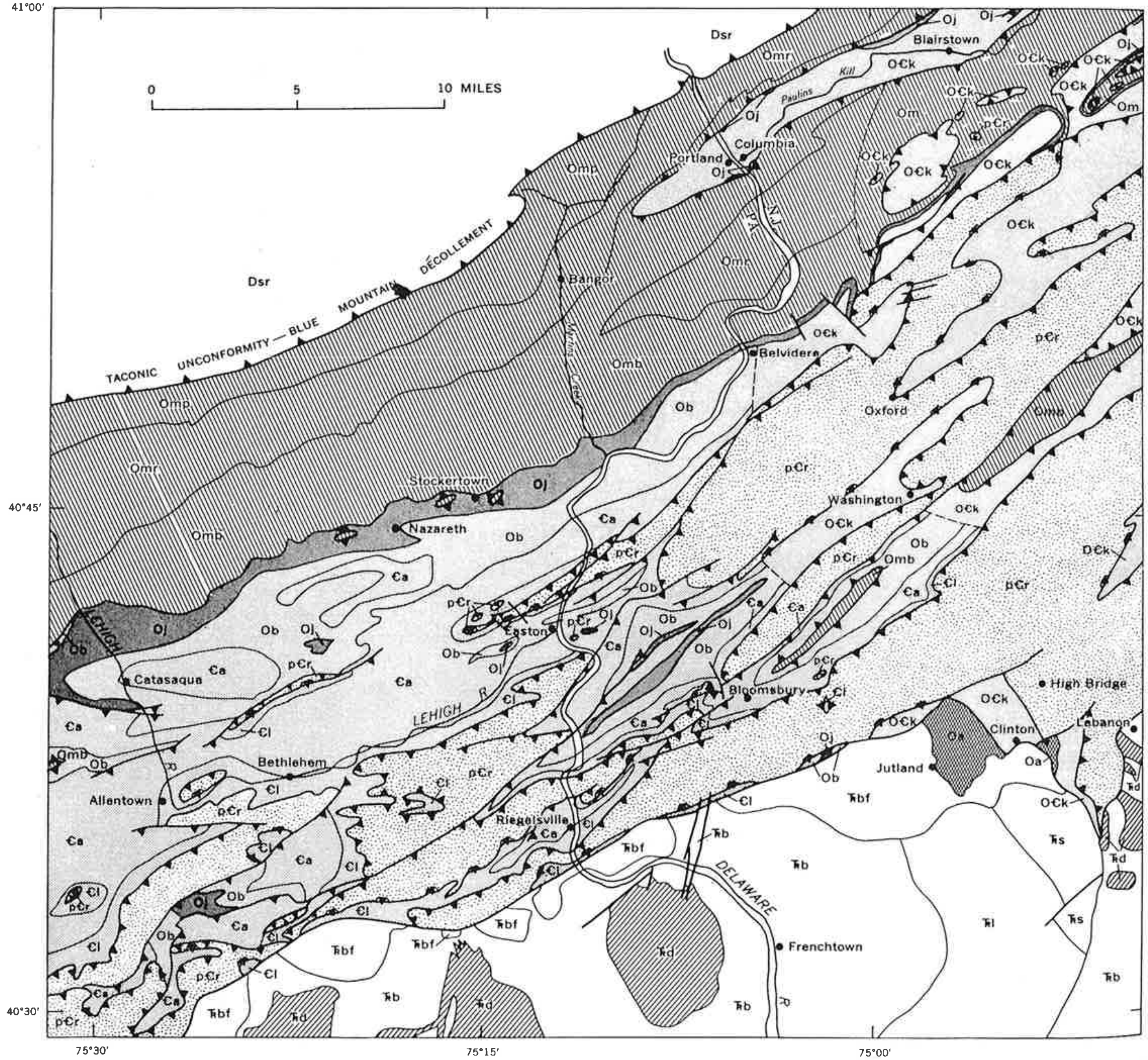

Figure 2. Generalized geologic map of the Delaware Valley and adjacent areas, New Jersey–Pennsylvania. Modified from Bayley and others (1914), Drake (1967a, b), Drake and others (1961, 1967, 1969), and Gray and others (1960).

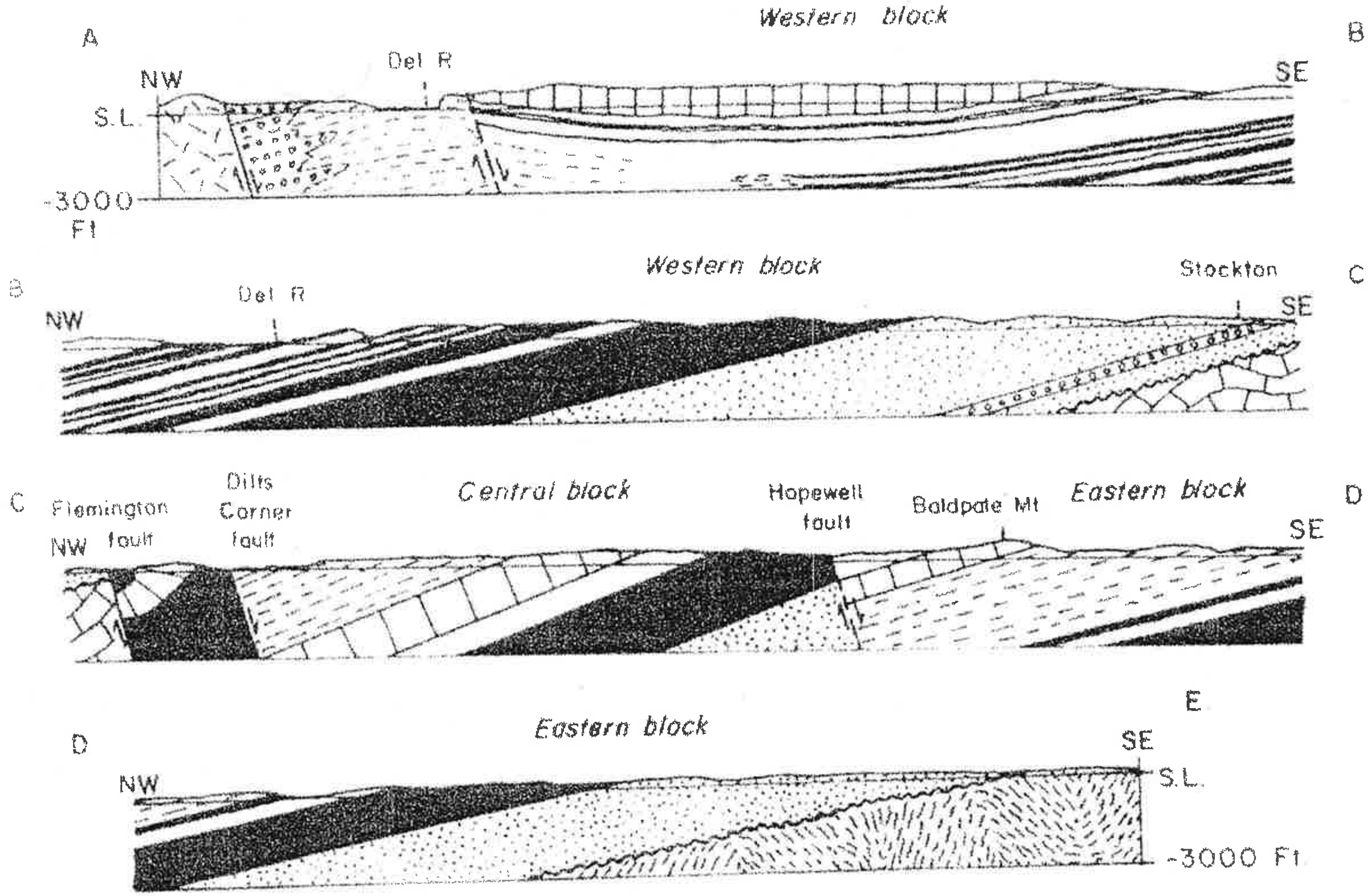

Figure 8. NW-SE profile section across central Newark Basin in Delaware valley showing three major fault blocks. Lockatong Argillite shown in black, intrusives with brick pattern, and pre-Newark unconformity with wavy solid line. (Drawn by J. E. Sanders from Johnson and McLaughlin 1957 figure 1, p. 8.)

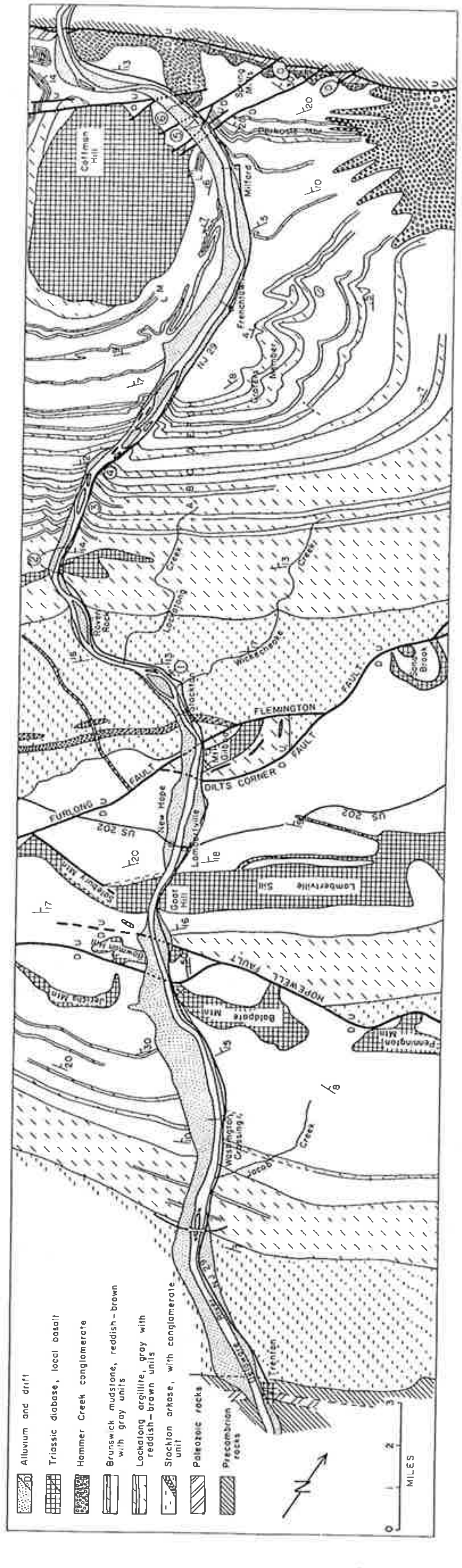

Figure 14. Geologic map of Triassic rocks along Delaware River, west-central New Jersey and adjacent Pennsylvania. Mainly after Johnson and McLaughlin 1957, pl. 1; and Drake, McLaughlin and Davis, 1961. Shows location of field trip stops.

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B. **DIPLODOCUS GIGANTICUS - 1 Only (either sex) and not less than 5000 lbs. live weight.**

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The holder of this license agrees to remove all such game, legally bagged by him under the proper restriction, properly preserved and in sanitary condition within 5 days of time of reptile's death, and further agrees to have said game inspected by the Utah Game Warden before removal.

Signed *Al O'Saurus*

ISSUED BY AL O'SAURUS
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