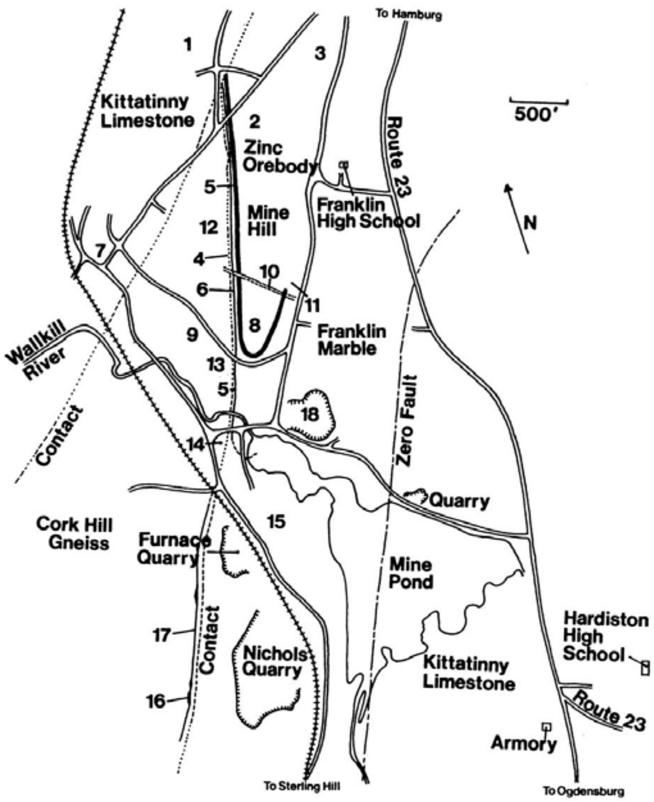
DUKE GEOLOGICAL LABORATORY

Web: www.dukelabs.com
E-Mail: CharlesM@dukelabs.com

TRIPS ON THE ROCKS

Guide 11: Franklin Furnace, New Jersey

Trip 12: 17 June 1990; Trip 37: 29 October 1995



1 Palmer Shaft
2 Hamburg Mine Area
3 Parker Shaft & Dump
4 Double Rock
5 Magnetite Bed In Marble
6 Weights & Measures Pit
7 Samuel Fowler House
8 Buckwheat Pit
9 Buckwheat Dump Area
10 Camptonite Dike
11 Taylor Mine Area
12 Trotter Mine & Dump Area
13 Franklin Mineral Museum
14 Site Of Old Iron Furnace
15 Site Of Franklin Iron Co. Furnace (1874)
16 Gooseberry Mine
17 Magnetite Bed In Gneiss
18 Pistol Range Quarry

Figure 1 – Index map showing the important mines, shafts, and sites of historic interest in Franklin Furnace, New Jersey. (From Frondel, 1972.)

Field Trip Notes by:

Charles Merguerian and John E. Sanders

© 2010

CONTENTS

DUKE GEOLOGICAL LABORATORY

TRIPS ON THE ROCKS

Guide 11: Franklin Furnace, New Jersey

Trip 12: 17 June 1990
Trip 37: 29 October 1995

INTRODUCTION

On Trip 37 we visit northwestern New Jersey's unique mineral deposits of the Franklin-Sterling area, Sussex County (Figure 1, on cover). In the words of Robert W. Jones (1982, p. 194): "The next time you are stuck in turnpike traffic or have had it with the moribund world, head for the rolling hills of northwest New Jersey and revel in the history and beauty of America's unique zinc mines and minerals." Jones neglects to add how you get unstuck from the traffic to go to northwestern New Jersey. We offer no miracle cures for this necessary unsticking. But assuming you have become unstuck, our suggestion for the best way for heading to the rolling hills of northwest New Jersey is to join the On-The-Rocks trippers.

But, back to Jones (1982, p. 190): "Franklin and Ogdensburg (Sterling Hill mine) are neighboring towns nestled in the rolling hills of northwest New Jersey. Each is situated next to a zinc-iron-manganese ore deposit the likes of which exist nowhere else in the world. The deposit has yielded nearly 300 different minerals, a number vastly greater than from any other known source in the world. More amazing, nearly 60 of these minerals exhibit luminescence, in the form of almost instantaneous fluorescence or as more laid-back but persistent phosphorescence."

Four minerals constitute the primary ore group: (1) franklinite (a spinel-type oxide mineral of zinc, divalent- and trivalent manganese and -iron, identified in 1820); (2) willemite (a zinc silicate, first reported in 1824); (3) zincite (a zinc-manganese oxide, first discovered in 1810); and (4) calcite, much of which contains manganese. Franklinite and zincite, abundant in the Franklin area, are known only in trace amounts elsewhere. Manganiferous calcite, one of the so-called gangue minerals, fluoresces bright red. By contrast, willemite, a valuable ore mineral, fluoresces bright green. Thus, sorting of the mined material was aided by using ultraviolet light. We shall visit the Franklin Mineral Museum, where the display of fluorescent minerals is dramatic beyond description.

Today's trip will enable participants not only to revel in the minerals but also to study some of the general geologic features of the bedrock and the glacial deposits. Our guidebook summarizes some of the current research results on these topics. Two recent compilations have proved very useful: (1) E. B. Evenson's 1985 guidebook for the 48th meeting of the Friends of the Pleistocene, entitled "Woodfordian deglaciation of the Great Valley, New Jersey"; and (2) C. B. Sclar's symposium on the character (sic) and origin of the Franklin-Sterling Hill orebodies, held on 19 May 1990 at Lehigh University, sponsored by the Department of Geological Sciences, Lehigh, and the Franklin-Ogdensburg Mineralogical Society, whose proceedings volume was also edited by Sclar (1990). JES attended the Sclar symposium and there met Bob

Metsger, formerly chief geologist for the New Jersey Zinc Company. Metsger took a keen interest in this On-The-Rocks trip and may join us for a second time this October.

We are fortunate to be able to visit some new exposures of the bedrock that include the Proterozoic gneisses, the Sauk carbonates (Cambro-Ordovician; protoliths of the Inwood Marble of New York City and vicinity), and the remarkable Proterozoic Franklin Marble. Past geologic interest in these rocks has been stimulated by interpretations that proved to be controversial. We mention only a few of these controversies: (1) the age of the Franklin marble; (2) the origin of the mineral deposits; and (3) the relationships of the Proterozoic rocks.

The debates over the Franklin Marble involved its age. The critical questions were: Is it merely an extreme altered facies of the Cambro-Ordovician carbonates, thus of Paleozoic age? Or is it an older formation, thus of Proterozoic age? The first idea was suggested by early workers on the New Jersey Geological Survey (summarized by F. L. Nason, 1891; also J. F. Kemp, 1893a). The case for Proterozoic ("Pre-Cambrian" of the older usage) age was first made by L. G. Westgate (1894) and settled for once and all by Wolff and Brooks (1898).

Various ideas have been prompted by studies of the other Proterozoic rocks. These rocks contain magnetite deposits as well as the unique zinc-iron-manganese ores of Franklin and Sterling Hill. A few of the authors of papers on the magnetite deposits include Baker and Buddington (1970); Bayley (1910, 1941); Buddington (1957, 1966); Collins (1969); Hager, Collins, and Clemency, 1963; Hotz (1953); Sims (1953, 1956); and Sims and Leonard (1952). The zinc deposits associated with the Franklin Marble have been studied by many generations of geologists, mineralogists, and geochemists. A comprehensive regional survey was carried out by the combined staffs of the United States Geological Survey and Geological Survey of New Jersey and published as part of the United States Geological Survey folio series by Spencer, Kümmel, Wolff, Salisbury, and Palache (1908). We discuss briefly the question of origin of the zinc deposits in a following section. Suffice it to note here that the burning issue of their origin centered over whether the chief mineral growth had resulted from the emplacement of one- or more granitic plutons and associated pegmatites (the popular early view of how all metallic ore deposits formed) or from a two-stage development starting with some conditions associated with the history of deposition of the calcite precursor of the marble and including metamorphism under great depths of burial and temperatures in the range of 750 to 800° C. The current thinking on this question, as indicated by the 1990 symposium, favors the high-temperature metamorphism of distinctive minerals of depositional origin [but agreement on the specific depositional-mineral precursor(s) of the ore minerals has not been reached].

The general relationships among the Proterozoic rocks have been studied from several points of view. One viewpoint has been particular rock types (for example, Fenner, 1914; Hinds, 1921; Drake, Aleinikoff and Volkert, 1991a, b; Drake and Volkert, 1991; Puffer, 1980; B. L. Smith, 1957, 1969). Much effort by some of these investigators comes under the heading of "lithology" or detailed descriptions of individual specimens. In some cases, no corresponding effort has been devoted to aggregating individual rock types into mappable formations. By contrast, formation recognition and mapping (for example, by Offield, 1967; and Drake, 1969, 1990) has shown that the geologic history has been complex. The concept that the Proterozoic rocks of the Reading Prong are part of a vast low-angle thrust sheet, or allochthon, proposed in 1964 by Isachsen (Figure 2), has been supported by geophysical research.

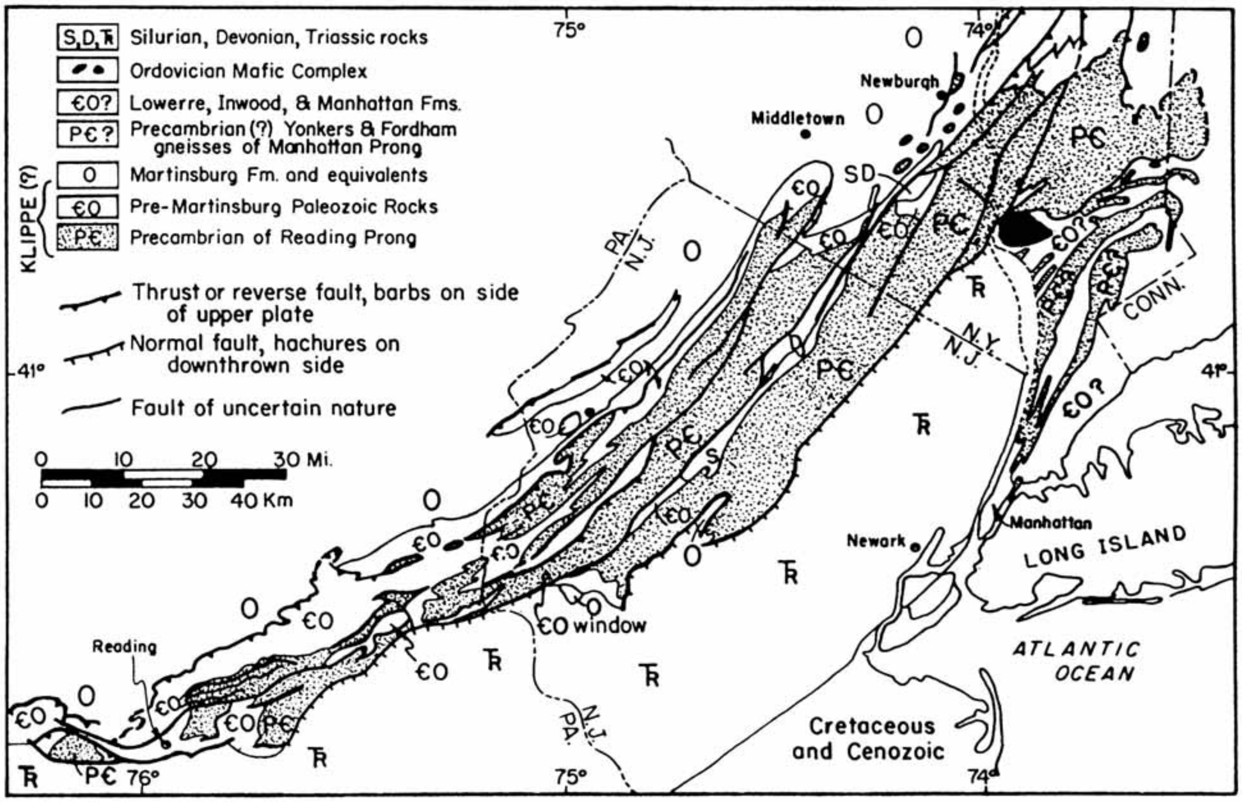


Figure 2. Sketch map showing extent of Reading Prong klippe [stippled areas]. (Yngvar W. Isachsen, 1964, fig. 5, p. 821.)

The Pleistocene deposits have been studied in detail by recent investigators. The main focus of their attention has been on reconstructing the history of the retreating ice front that was in contact with the waters of one- or more proglacial lakes held in by high tracts of bedrock and/or dams composed of glacially deposited moraines. Sussex County, New Jersey, serves as headwaters for three drainage networks (Figure 3): (1) The Paulins Kill, which flows southwestward to join the Delaware River at Portland; (2) the Pequest River, which flows from the Newton area southwestward to the Delaware River at Belvidere; and (3) the Wallkill, which drains northeastward from its source in Mohawk Lake, southwest of Ogdensburg, to join the Hudson River at Kingston, New York (Merguerian and Sanders, 1990b [Trip 11] Catskills I; Merguerian and Sanders, 1994e [Trip 32] Catskills II).

Although both of the famous zinc mines have been exhausted. The last ore was lifted from the Franklin mine at 1530 (3:30 PM) on 28 September 1954 (Kozykowski, 1982, p. 189) and at Sterling Hill in early 1987 (Frondel, 1990, p. 3; but Robbins, 1990, p. 2 stated 1988), much effort has been devoted by the local residents to keeping the two towns from becoming "ghost towns" of the kind found in Nevada, for example. Notable efforts have been made by the Kiawanis Club of Franklin and Steve Sanford to establish the Franklin Mineral Museum; by the

Franklin-Ogdensburg Mineralogical Society in promoting various mineral-related activities such as the annual Franklin-Sterling Hill Mineral Show; and by Richard and Elna Houck, who have organized the Sterling Hill Mining Company which has purchased the Sterling Hill property and is operating the Sterling Hill Mine and Museum as a tourist attraction. Many documents related to the long history of the mining operations are housed in the Sussex County Historical Society's building in Newton. JES and CM have been busy clipping back tumble weeds.

The remainder of this guidebook is organized under the following first-order headings: GEOLOGIC BACKGROUND (including sections on the physiographic setting; geologic structure, a primer; bedrock units encountered on trip route; geology of Franklin Furnace, New Jersey; and glacial history and drainage); OBJECTIVES; ROAD LOG AND DESCRIPTIONS OF LOCALITIES ("STOPS"); ACKNOWLEDGEMENTS; AND REFERENCES. Tables and illustrations are included after the References.

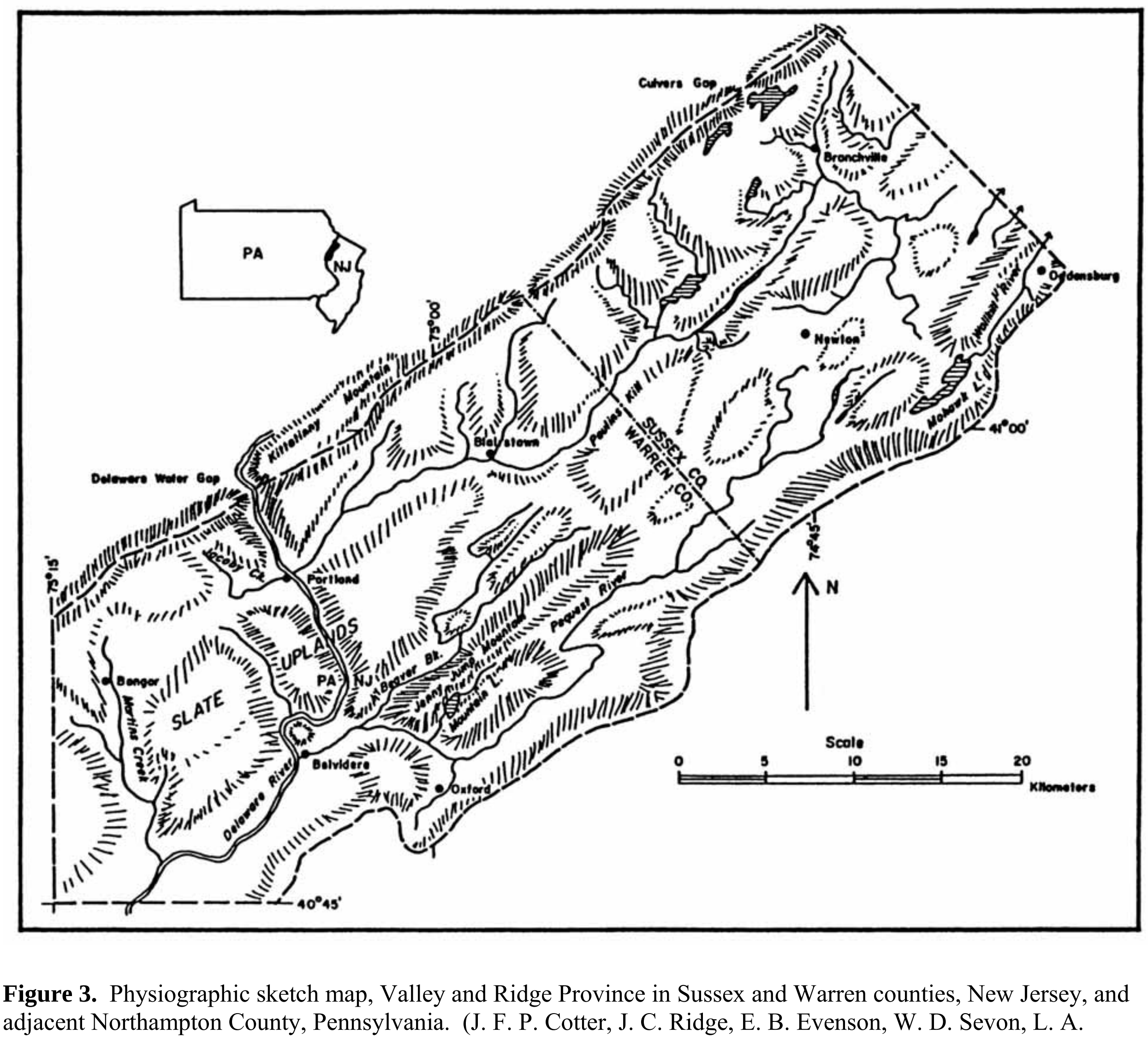


Figure 3. Physiographic sketch map, Valley and Ridge Province in Sussex and Warren counties, New Jersey, and adjacent Northampton County, Pennsylvania. (J. F. P. Cotter, J. C. Ridge, E. B. Evenson, W. D. Sevon, L. A. Sirkin, and R. Stuckenrath, 1985, fig. 2, p. 7.)

GEOLOGIC BACKGROUND

Under this heading, we discuss the physiographic setting, some fine points of geologic structure and stratigraphy (a primer), bedrock units, the glacial deposits, the drainage history, and local geologic summaries of our field-trip route. Refer to Tables 1 and 2 for details not fully explained in text.

PHYSIOGRAPHIC SETTING

The area of northwestern New Jersey that we shall study today is part of the Appalachians, near the boundary between the Central Appalachians and the Northern Appalachians (two of the transverse subdivisions). From NW to SE, the longitudinal subdivisions of the Appalachians are: Appalachian Plateau; Valley and Ridge Province, of which a prominent feature is the Appalachian Great Valley; Appalachian Highlands; Newark Lowland; and the New England Upland-Manhattan Prong-Piedmont (Figure 4). We discuss these subdivisions in the order we shall cross them en route to Franklin, thus we begin on the SE with the Manhattan Prong of the New England Upland.

Manhattan Prong of New England Upland

The crystalline bedrock of New York City is part of a physiographic province known as the Manhattan Prong (Figure 5) that widens northward into the New England Upland physiographic province of the Appalachian mountain belt. The Manhattan Prong is underlain by several sequences of metamorphosed rocks, one Proterozoic in age, and several of Early Paleozoic ages. Although these rocks have been subjected to several episodes of deformation, their effect on the landscape is controlled by lithologic resistivity to erosion and a late episode of tight folds whose axes trend NNE-SSW and plunge dominantly southward. Erosion of these folds has produced a landscape of elongate ridges and -valleys. The ridges are underlain by gneisses or schists and the valleys, by a thick carbonate unit, the Inwood Marble or faults.

Newark Lowland

The Newark Lowland refers to the territory underlain by the Newark basin-filling strata. These strata, originally horizontal, now dip more-or-less uniformly WNW about 12°. (See cutaway slice across middle of Figure 6 and Figure 7.) The Newark strata are thick, possibly 8 km or so in north-central New Jersey (Olsen 1980b). They consist mostly of nonmarine sedimentary rocks and 4 associated sheets of mafic igneous rock. Paleontologic data indicate that the sedimentary strata are of Late Triassic and Early Jurassic ages. The Triassic-Jurassic boundary is placed at the base of the ancient lava flow underlying the First Watchung Mountain (=Orange Mountain Formation of Olsen, 1980a, b). The sedimentary rocks generally underlie lowlands that have been thickly blanketed by Pleistocene glacial sediments, whereas the igneous rocks form curvilinear ridges. From the SE toward the NW these ridges are the Palisades, First Watchung (=Orange) Mountain, Second Watchung (=Preakness) Mountain, and Third Watchung (=Hook) Mountain. The ridges, too, have been glaciated; along their crests evidence of glacial erosion and deposition of erratics is abundant.

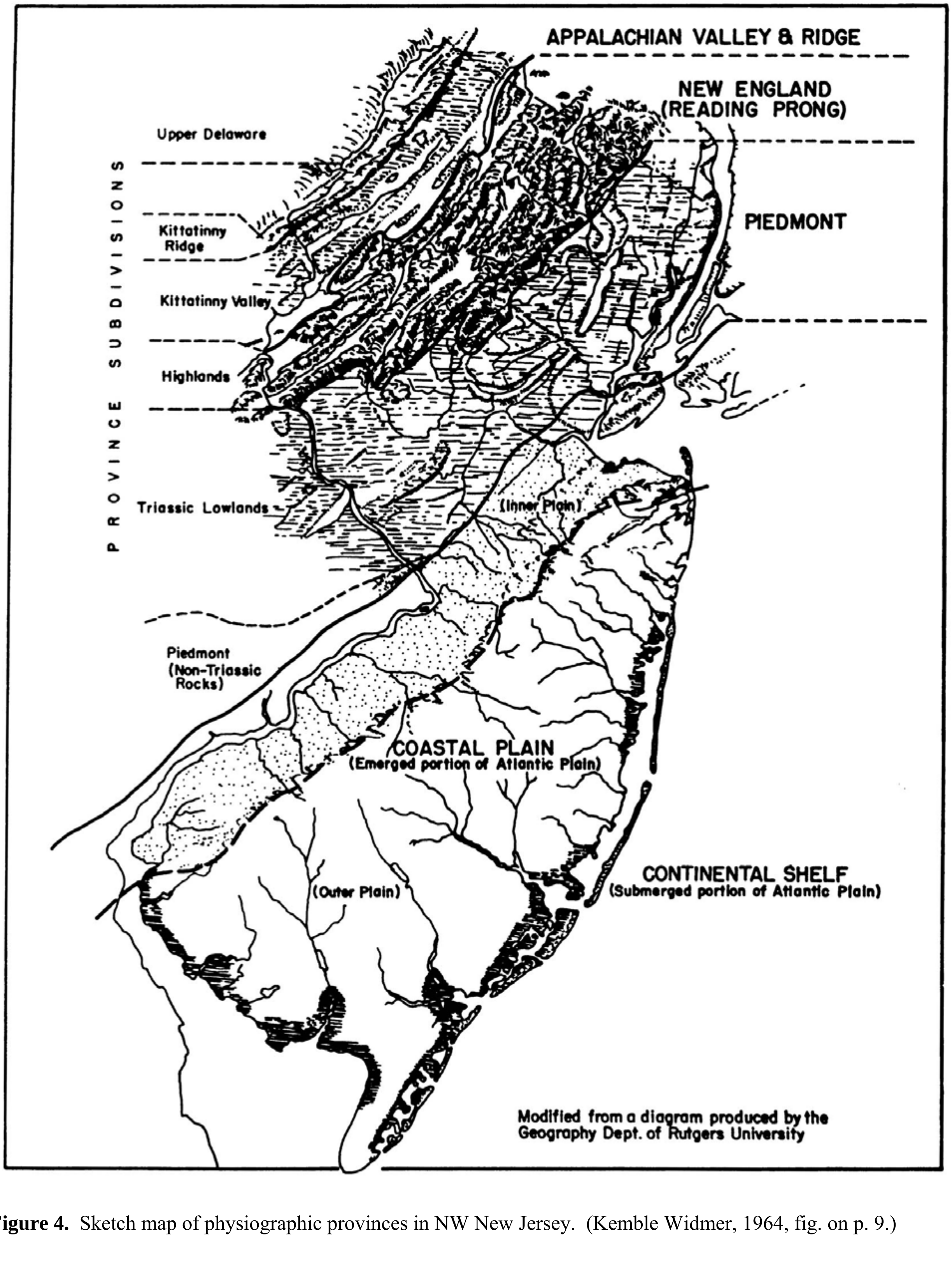


Figure 4. Sketch map of physiographic provinces in NW New Jersey. (Kemble Widmer, 1964, fig. on p. 9.)

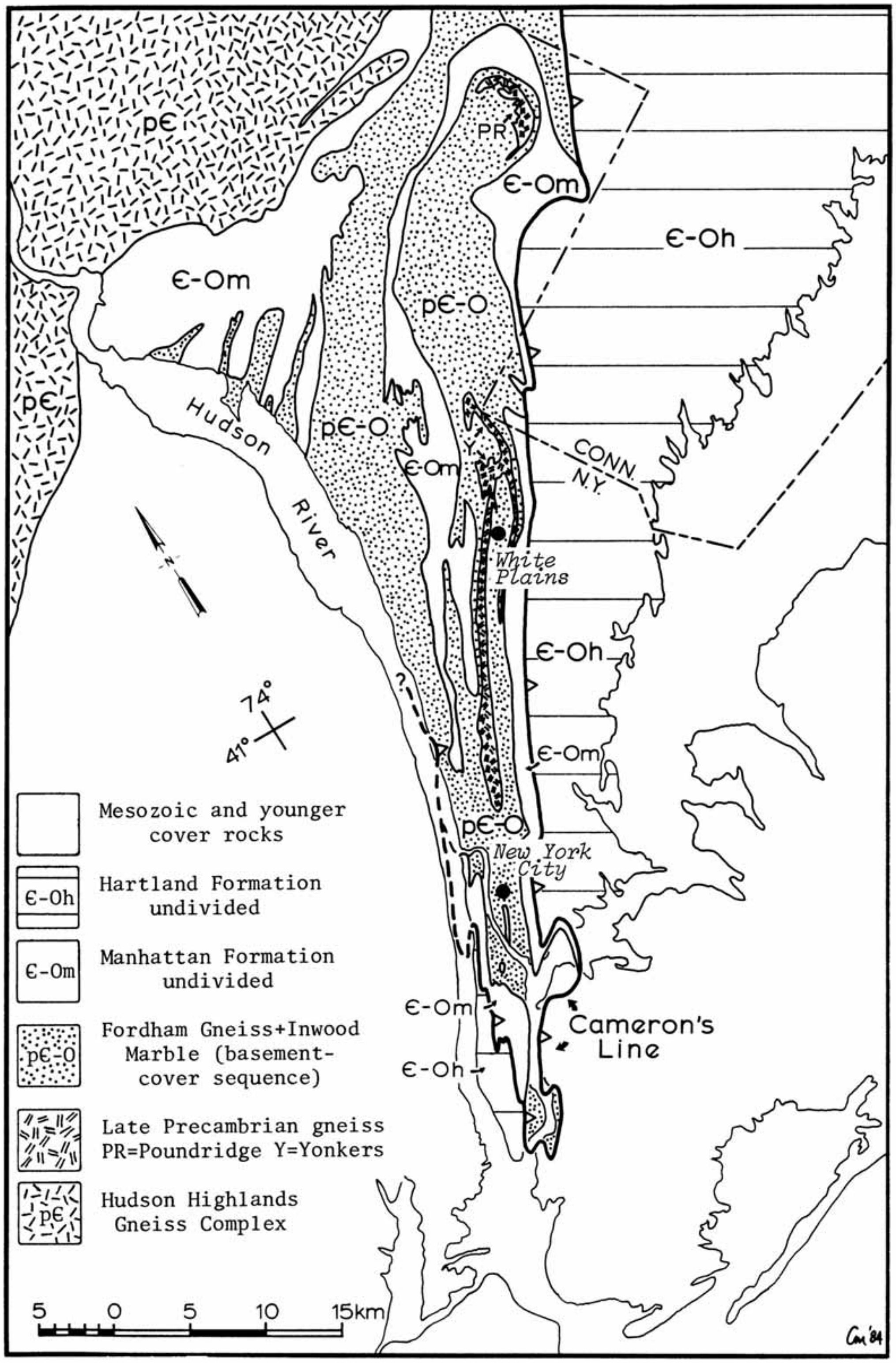


Figure 5. Simplified geologic map of the Manhattan Prong showing the distribution of metamorphic rocks (Layers I and II) ranging from Proterozoic Y through Early Paleozoic in age. Most faults and intrusive rocks have been omitted. (Douglas G. Mose and Charles Merguerian, 1985, fig. 1, p. 21.)

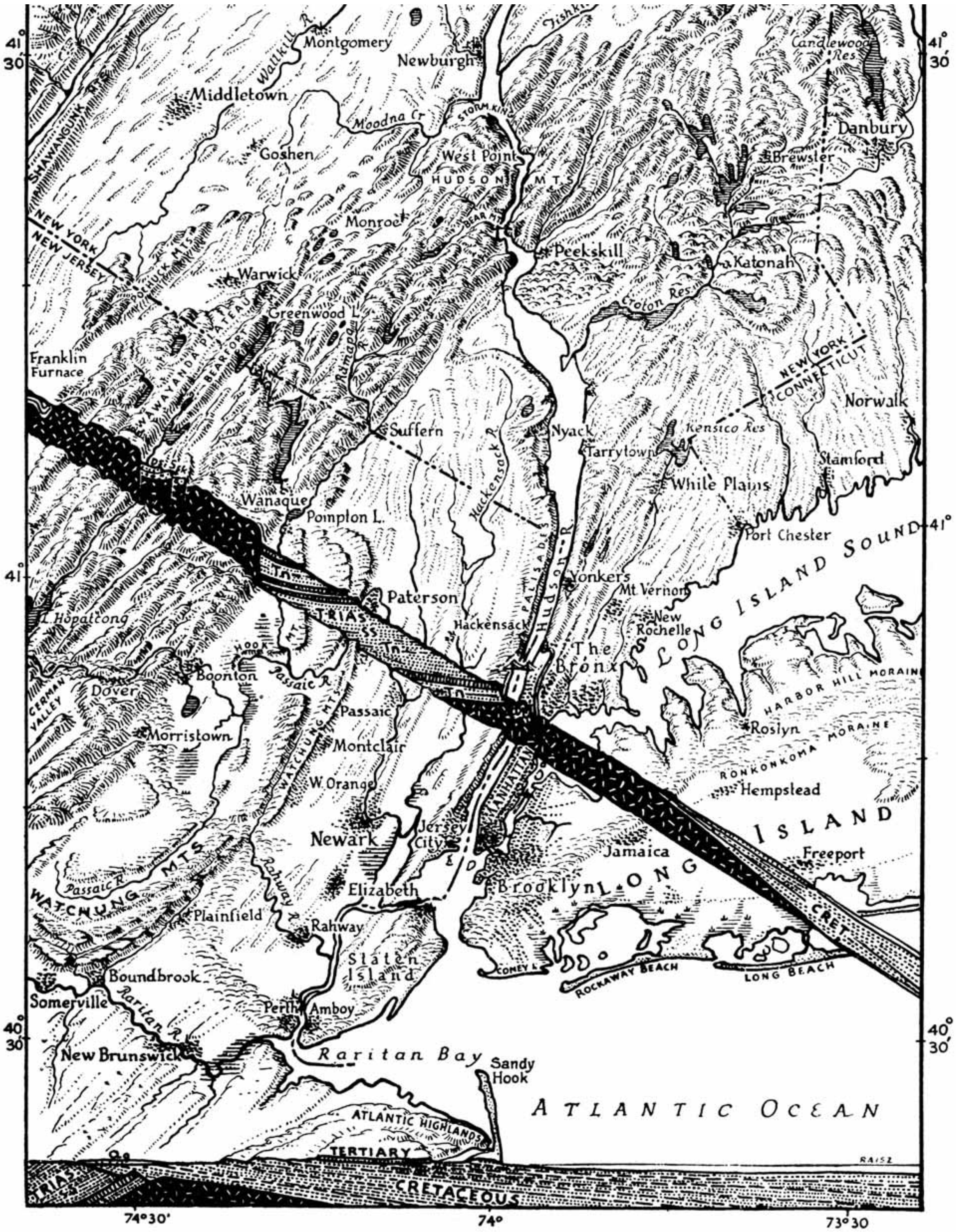


Figure 6. Oblique bird's-eye-view physiographic diagram of the Appalachians, Newark Basin, and Atlantic Coastal Plain [NY, NJ, PA], with vertical slice oriented NW-SE to show geologic structure. (E. Raisz).

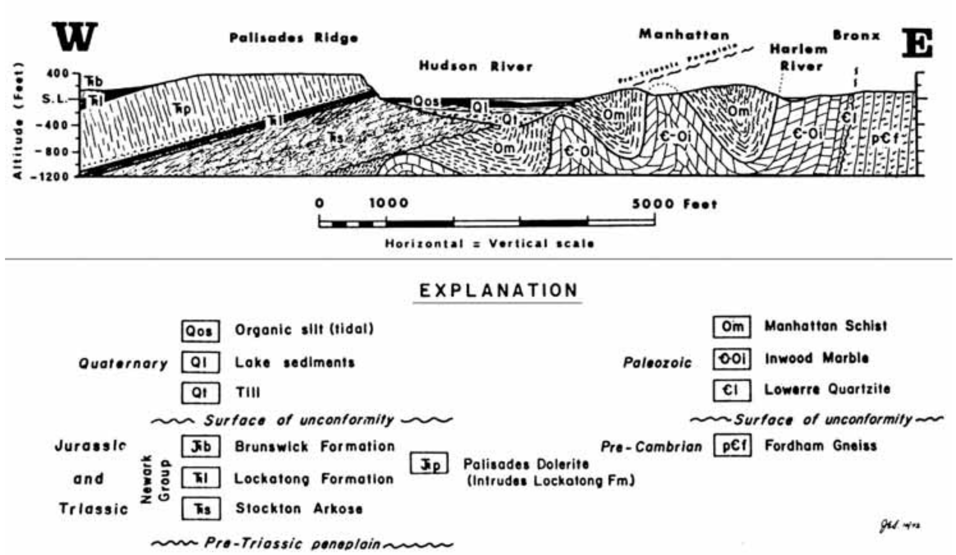


Figure 7. Profile-section across Hudson River at George Washington Bridge. Profile drawn from contours shown on U. S. Geological Survey Central Park 7.5-minute topographic quadrangle map. (J. E. Sanders, 1974a, fig. 3, p. 11.)

The formal stratigraphic name for the Newark strata is Newark Supergroup. Included are various sedimentary formations, of which the basal unit is the Stockton Arkose. Above it is the Lockatong Formation, the unit into which the Palisades intrusive sheet has been intruded. The Newark sedimentary strata were deposited in a fault-bounded basin (Stop 8) truncated on the northwest by the Ramapo fault (See Figure 6.) to which the sea never gained access. In this basin, the filling strata were deposited in various nonmarine environments, including subaerial fans, streams, and shallow- and deep lakes. Lake levels varied according to changes in climate (Olsen, 1980).

After the Newark strata had been deeply buried, they were elevated and tilted, probably during a period of mid-Jurassic tectonic activities. They were then eroded and truncated to form a surface upon which the Upper Cretaceous and younger coastal-plain strata were deposited.

The most-obvious characteristic of the strata composing the Newark Lowland is their reddish-brown color. Most of the sedimentary bedrock and virtually all of the Pleistocene glacial sediments found toward the S and SE display this distinctive color. Ground elevations in the true lowland part of this province range from sea level in the Hackensack Meadowlands to 150 feet up to 200 feet in the lowland enclosed between the Third Watchung Mountain and the wall-like SE margin of the Ramapo Highland block to the NW. The relief of the ridges underlain by igneous rocks locally amounts to 800 feet but generally falls in the range of 500 to 600 feet.

Appalachian Highlands

The Appalachian Highlands province in northwestern New Jersey consists of several elongate blocks that trend NE-SW and are separated by elongate lowland/ridge areas. (See

Figure 6.) The highlands are underlain by resistant Proterozoic rocks, mostly various gneisses, but locally include other rocks such as granites, coarse marbles, and amphibolites. The intervening lowland/ridge areas are underlain by Paleozoic sedimentary strata. On the cutaway slice across Figure 6, the Proterozoic rocks are shown as consisting of elevated horst-type blocks composed of pre-Paleozoic basement, and the lowland/ridge areas as downdropped graben blocks underlain by folded Paleozoic strata. (For definitions of horst and graben, see following section entitled Geologic Structure--A Primer.) Collectively, these highland blocks are classified as part of the Reading Prong of the New England upland (as contrasted with the Manhattan Prong, previously mentioned).

Ever since Isachsen (1964) assembled the evidence in favor of the interpretation that the Proterozoic rocks of the Reading Prong have been massively displaced over the Paleozoic rocks along one or more low-angle thrusts (See Figure 2 and also the section in the text entitled Geologic Structure--A Primer.), the subject of the regional relationships of the rocks in northwestern New Jersey has been unsettled.

Appalachian Valley and Ridge Province

The Appalachian Valley and Ridge Province designates a subdivision within the Appalachian chain underlain by Paleozoic sedimentary rocks that are parts of large folds (anticlines and synclines). Deep erosion of these folded strata has created a pronounced linearity to the landscape consisting chiefly of elongate valleys and -ridges. Resistant formations, usually of sandstone, underlie the ridges. Weaker formations, usually shales or carbonate rocks, tend to underlie the valleys (Figure 8). Folds are not the only major geologic structural features found in this province; low-angle thrusts and high-angle faults are also present.

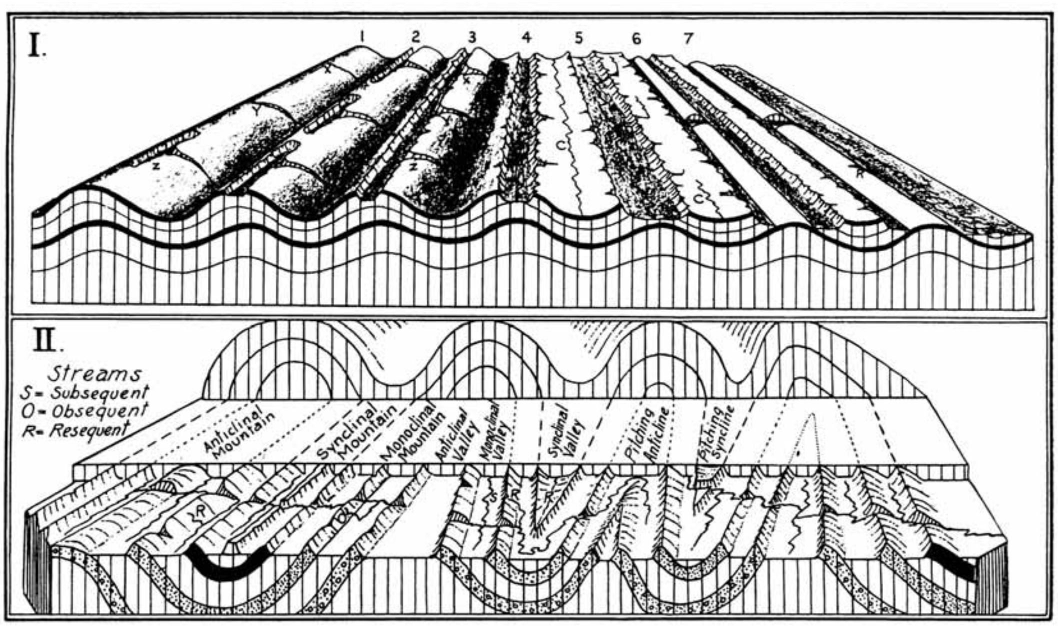


Figure 8. Schematic block diagram through eroded anticlines and -synclines showing how resistant layers form linear ridges and weak layers, linear valleys. The relationships shown here are common in the Appalachian Valley and Ridge Province of central Pennsylvania. (A. K. Lobeck, 1939, fig. on p. 588.)

Strangely enough, the best place in northwestern New Jersey to see typical Appalachian Valley-and-Ridge-type landscape is in the Schunnemunk-Bellvale-Green Pond belt within the Highlands. In this belt are two thick resistant, ridge-making formations: the Lower Silurian Green Pond Conglomerate and the Devonian Schunnemunk Conglomerate, which are separated by thick shale/siltstone units that form valleys. These strata have been folded on a large scale; deep erosion of these folds has created a typical ridge-and-valley landscape. (See Figure 8 and Trip 36 guidebook.)

Where the Cambro-Ordovician rocks of the Sauk and Tippecanoe Sequences are thick, the stratigraphic column lacks any prominent ridge-making units. Accordingly, the outcrop of these rocks has been eroded into a wide lowland known as the Great Valley of the Appalachians. The local representative of the Great Valley subprovince in northwestern New Jersey is Kittatinny Valley.

The Kittatinny Valley is bounded along its NW side by a nearly continuous ridge, Kittatinny Mountain, which is composed of the thick, resistant Lower Silurian sandstone known by the New York name of Shawangunk Formation. Kittatinny Mountain is part of a prominent ridge that extends from the Shawangunks SW of Kingston, New York, to Harrisburg, Pennsylvania. The major break in this mighty ridge is the Delaware Water Gap, occupied by the Delaware River. High Point State Park (See Trip 36 guidebook) is situated at a place where several folds cross the ridge.

Appalachian Plateau

The Appalachian Plateau province refers to a region of rough countryside that is underlain by essentially flat-lying strata that are of Devonian age in the Catskills of New York State and of Mississippian age in the Poconos in northeastern Pennsylvania. Two essential features must be fulfilled to qualify a region as meeting the geologic definition of a plateau: (1) it is an area displaying high relief; and (2) the strata underlying the high-relief area are still horizontal; they have not been closely folded. In this respect, the strata underlying the Appalachian Plateau contrast with the much-deformed strata in the adjoining Appalachian Mountain belt. Because of the contrast between folded- and faulted strata of the Appalachian Valley and Ridge Province and the flat-lying strata of the Appalachian Plateau, geologists have tended to presume that a major tectonic boundary exists between these two provinces. The term "Appalachian Structural Front" has been used to designate this boundary, long thought to separate the deformed strata from nondeformed strata. As we shall see, however, evidence has now been discovered that at least one major horizontal thrust fault underlies the Appalachian Plateau and that along this thrust, the flat-lying strata have been shifted westward. Accordingly, any appropriate "structural front" between deformed strata and nondeformed strata, should be located wherever the thrust fault beneath the Appalachian Plateau comes to the surface, and not at the geomorphic boundary between the Appalachian Valley and Ridge Province and the Appalachian Plateau.

GEOLOGIC STRUCTURE - A PRIMER

Geologists use terminology to confuse the layman and to enable them to amass a huge library of terms that are undeniably useless in most social situations. Luckily, our On-The-Rocks trips are an exception. We will not try to bury you in a mountain (how about a deeply eroded mountain range?) of terms to help you understand the major types of structures and geologic features that you will read- and hear about today. But, if you are to understand what we are talking about, you need to know some important definitions. What we hope to do in this section is make the reader aware of the kind of information that enables a geologist to infer that deformation has taken place, to define some of the major geologic structural features formed as a result of tectonic activity, and to evaluate the evidence upon which geologists establish the time when deformation took place. We begin with sedimentary strata and work our way upward through geologic structures to lithosphere plates. The term geologic structure refers to any feature made as a result of deformation related to tectonic activity. Nowadays, we ascribe most tectonic activity to the motion of the Earth's lithosphere plates.

Along the way, we examine some mechanical aspects of rock deformation. Up next are descriptions of folds, faults, effects on sedimentary strata of deformation, structures in sedimentary- vs. metamorphic rocks, and tectonostratigraphic units. We conclude this section with a summary of methods for geologic dating of episodes of deformation.

Strata

The most-important single feature used by geologists to infer that a body of rocks has been deformed is the primary attribute known as stratification. During normal deposition, or settling from a fluid in a rainfall of particles, a thick body of more-or-less featureless sediment may be deposited. The presence of original sedimentary layers, technically known as strata, implies that conditions of deposition changed. As a result, most geologists appreciate the fundamental point that layers in sedimentary rocks imply CHANGE in big letters. The change may have been in the parent area of the sediment, in the sizes of particles supplied, or in the style of deposition.

Thick layers are known as beds and thin layers as laminae. (The word laminae is the plural of lamina. The attribute word applicable to sediments displaying laminae is lamination. Please avoid the temptation to perpetuate the widespread usage indulged in by geologists who don't seem to know their attributes from a hole in the ground, namely the use of lamination in the plural form when they are discussing laminae.)

The particle sizes within a stratum may be uniformly distributed across the bed or may display grading in which larger particles are present at the base of a particular layer and the sizes diminish or "grade" upward into finer particles (Figure 9). A graded bed is the result of a kind of a "lump-sum distribution" from a current carrying a wide range of particles and depositing them within a short time span, largest first and progressively smaller ones later. A common kind of current that deposits layers showing size grading is a gravity-induced turbidity current that flows down a subaqueous slope and crosses a flat part of the basin floor.

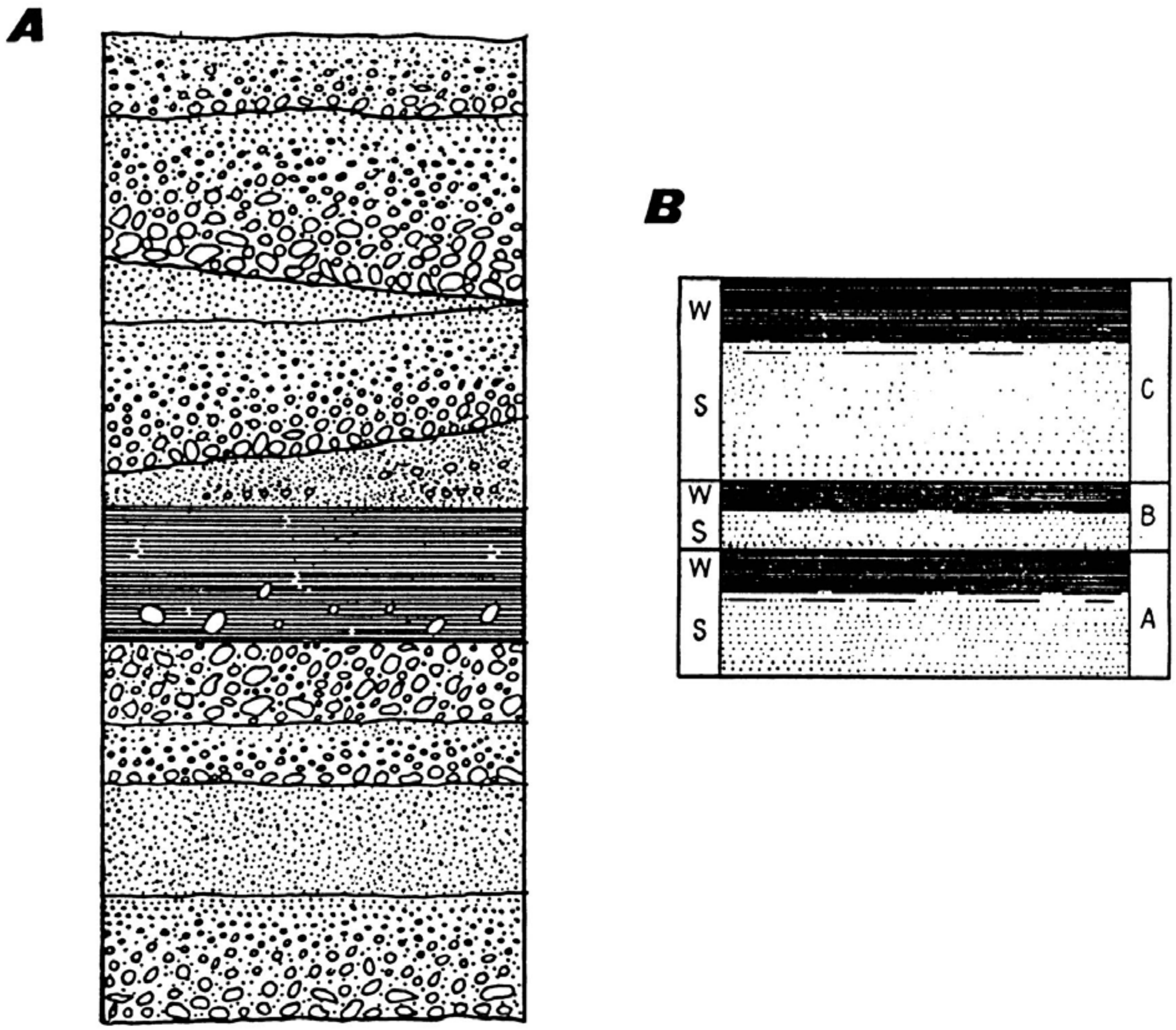


Figure 9. Contrasting kinds of sediments showing internal upward-fining grading.
A. Conglomeratic layers, some graded, some uniform, interbedded with shale containing scattered pebbles. Nonmarine Wamsutta Formation, (Pennsylvanian), E side of Great Pond, Braintree, MA. (R. R. Shrock, 1948, fig. 43, p. 84)
B. Schematic view of varved silt and -clay deposited in a proglacial lake showing light-colored, coarser graded silty layers deposited during the short summer season when lake is free of ice (marked with S) alternating with dark-colored clay layers deposited during the much-longer winter season when the lake surface is frozen over (marked with W). (R. R. Shrock, 1948, fig. 44, p. 85.)

Fundamental principles about strata were recognized in the 1660s by Nicolaus Steno. He proposed four "rules" for understanding strata of which we include only the following two:

Steno Rule No. 1: Most strata are deposited with an original orientation that is horizontal. (We explain some important exceptions to this rule farther along.) Therefore, strata that are not horizontal usually lost their horizontality as a result of tectonic activity.

Steno Rule No 2: The oldest stratum is at the bottom and successively younger strata occupy higher positions. Two important corollaries of this rule are that each stratum was spread out, one at a time, at the Earth's surface. The materials forming the stratum, therefore, buried a former surface of the Earth. In turn, the top of the stratum was itself such a surface. The top, or face, of a stratum was initially in the up position. (Therefore, if strata are vertical, the tops of the strata indicate the former up direction.) As is discussed in a following section, certain features on the bottoms, within, or on the tops of strata, enable the former top direction to be determined unambiguously. Such features are known as geopetal criteria (Shrock, 1948).

Strata are such fundamental reference surfaces that we emphasize the importance of being able to recognize strata. Where all the particles are about the same size, bedding may not be so easy to identify. This is especially true with uniformly fine sediments (silt size, for example) or with uniformly coarse sediments (boulder gravel). In some cases, such recognition is self evident: materials of contrasting composition or -particle size (Figure 10) form distinct layers that are set off from adjacent layers by prominent surfaces along which the rock separates easily. These are termed bedding-surface partings. In many exposures, the most-prominent partings visible are the bedding-surface (or "bedding-plane") partings. In other exposures, however, tectonic activity has imposed a secondary (structural) parting that may be more prominent than the bedding-surface partings. (Such secondary partings are discussed farther along.)

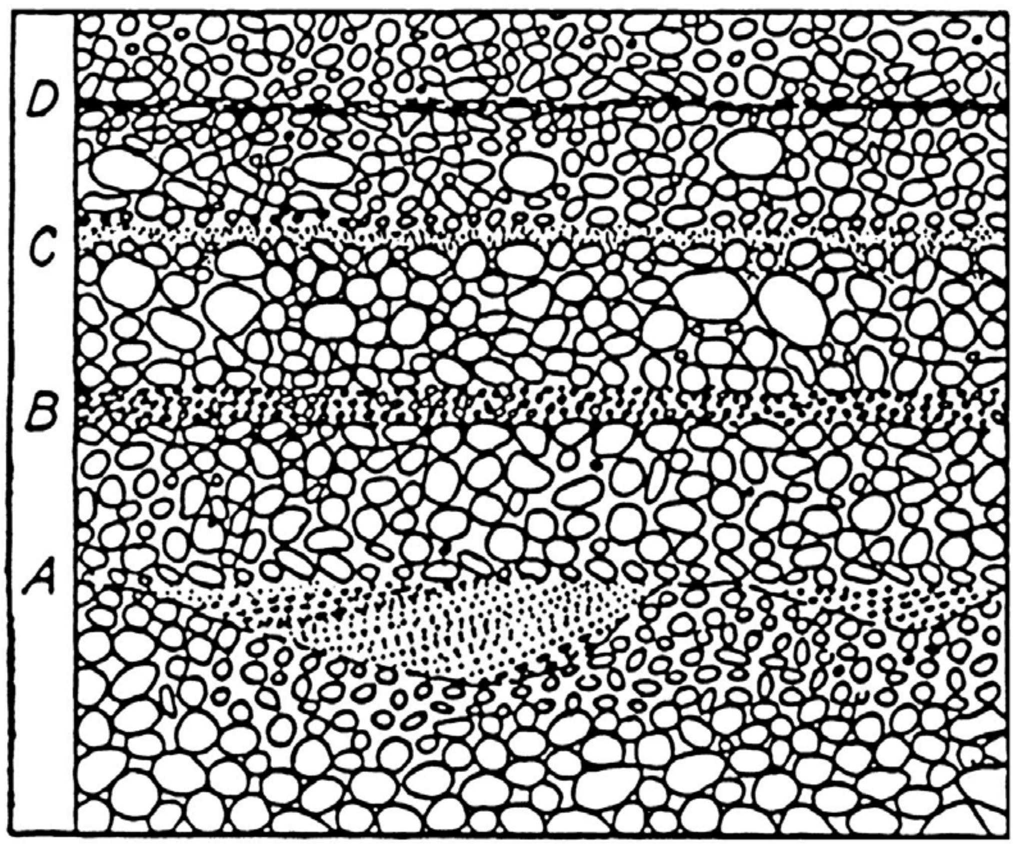


Figure 10. Sketch of gravel (or conglomerate) showing how bedding is revealed by finer sediment in planar layers (such as B, C, and D) or in lenses (as in A). (R. R. Shrock, 1948, fig. 3, p. 12.)

Always make careful note of the feature or features that you have used to support your identification of the bedding. Some such features include changes of color, changes of particle sizes (Figure 11), aligned shells of invertebrates, differences in degree of cementation, or whatever.

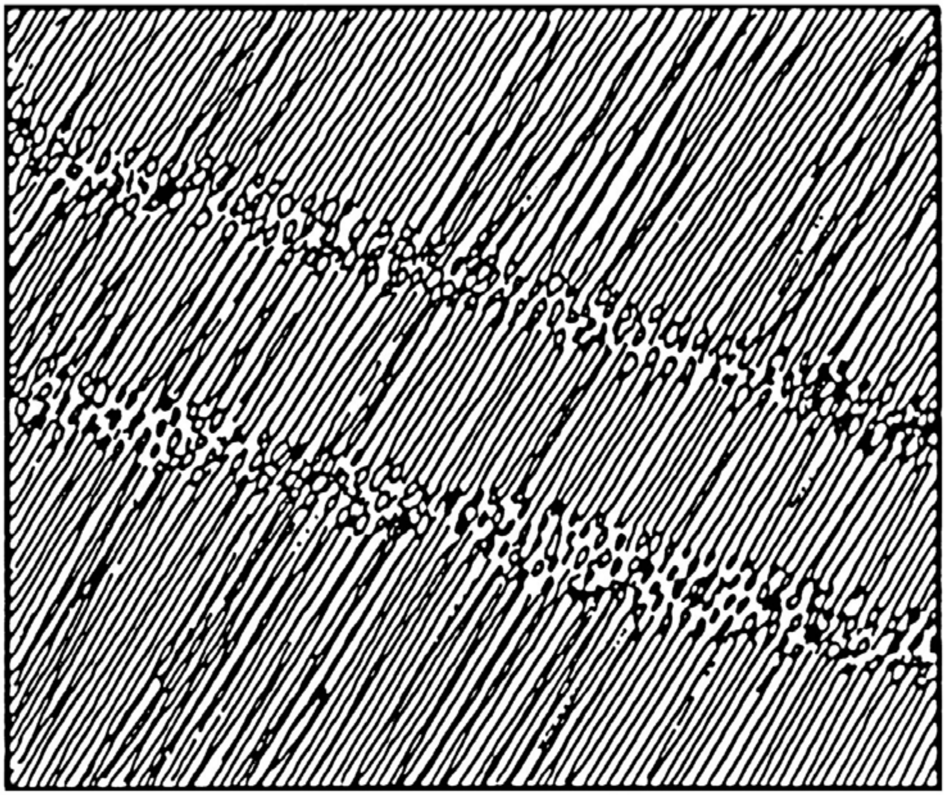


Figure 11. Sketch of slate (dark color) with prominent parting (slaty cleavage) dipping steeply to the left; two layers composed of silt-size sediment (stipple) show that bedding dips gently to the right. (R. R. Shrock, 1948, fig. 7, p. 15.)

Sedimentary Structures

During deposition in a variety of environments, primary- and secondary sedimentary structures can develop above-, below-, and within strata.

During high-energy transport of sand-size or coarser particles (defined as cohesionless sediment), a moving current reacts with the sediment it is transporting and over which it is flowing to create repeating patterns of linear- or curvilinear relief features having long axes that may be transverse to- or parallel with the direction of the current. These are collectively designated as bed forms (Figure 12). In many cases, the tops of sandstone beds display such bed forms, which are named ripples if their relief and crestal-separation distances are measured in centimeters or up to a few tens of centimeters or dunes, if their dimensions measure in meters, tens of meters, or even kilometers. Many bed forms are asymmetric; they slope gently into the current on their upcurrent sides and steeply downcurrent on their downcurrent sides. The shearing-drag effect of the current on the cohesionless-sediment substrate causes these bed forms to migrate downcurrent. They migrate bodily as sediment is eroded from their upcurrent sides and added to their downcurrent sides. The result is a distinctive kind of internal cross strata in which the layers are concave up, tangential at their bases, and truncated at their tops. If the crests of the bed forms are linear, then downcurrent migration creates planar cross strata. (See Figure 12, A.) If the crests of the bed forms are sinuous and concave downcurrent, then downcurrent migration creates trough-type cross strata. (See Figure 12, B.)

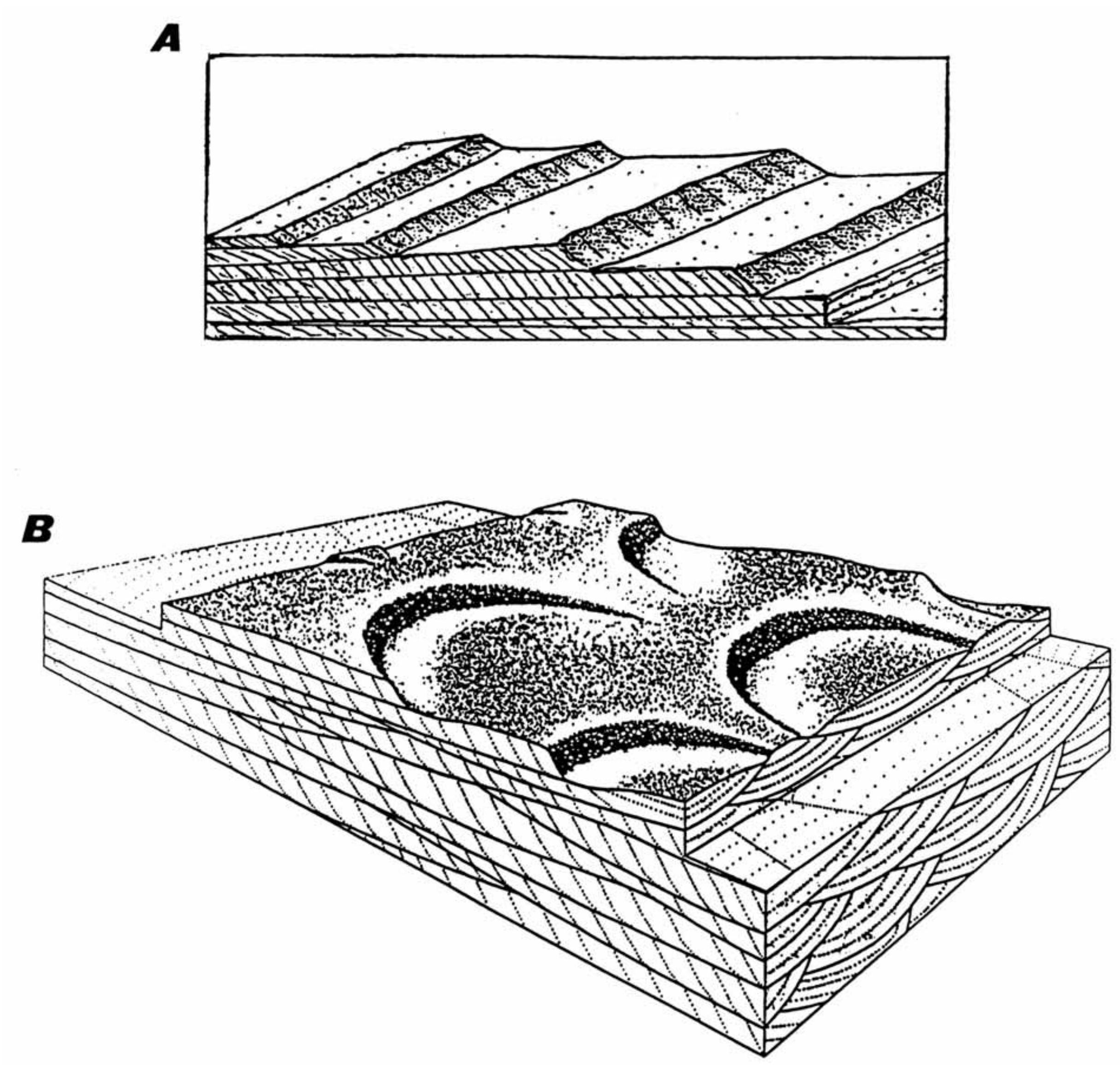


Figure 12. Sketches of contrasting shapes of bed forms created by a current flowing from left to right and cross strata resulting from their downcurrent migration.
A. Linear bed forms create planar cross strata. (G. M. Friedman, J. E. Sanders, and D. C. Kopaska-Merkel, 1992, fig. 5-19, A, p. 166.)
B. When cuspate (lunate) megaripples migrate downcurrent trough-type cross strata form. In sections that are parallel to the current, trough cross strata and planar cross strata look about alike. The difference between them is immediately apparent in sections normal to the current. (H. E. Reineck and I. B. Singh, 1980, fig. 52, p. 43.)

Not all cross strata result from downcurrent migration of rhythmic bed forms composed of cohesionless sediment (as in Figure 13, A and D). In some places, local depressions in the bottom are filled in by sand transported from one side and deposited in inclined cross strata (Figure 13, B). In other places, cross strata are deposited at the fronts of sediment embankments where a water current encounters a deeper place. The embankment lengthens in the downcurrent direction as sediment is deposited in inclined layers (cross strata) along the growing front of the embankment (Figure 13, C and E).

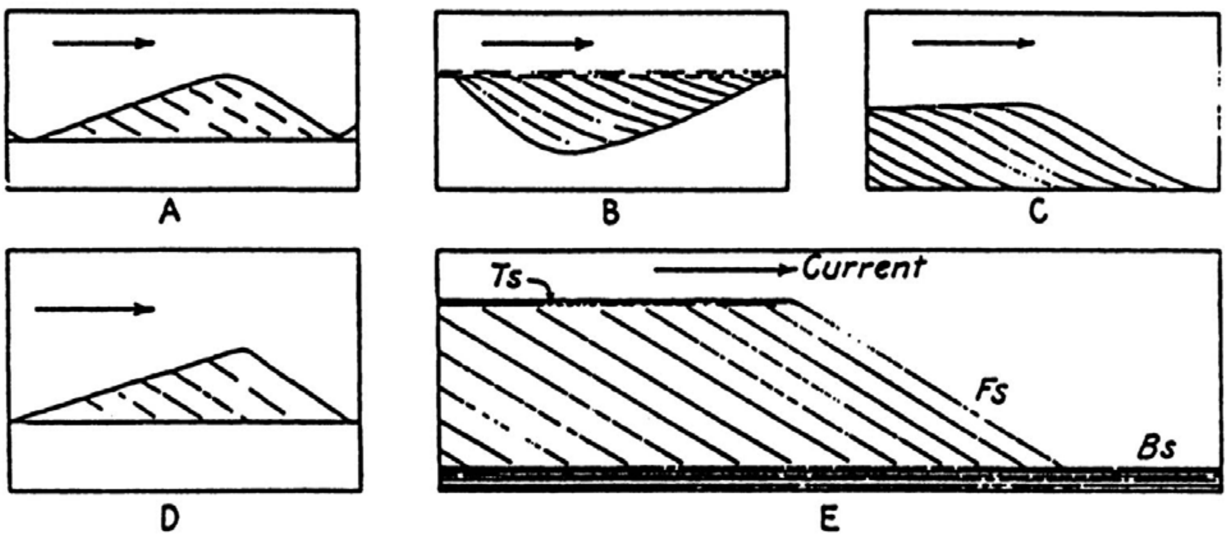


Figure 13. Sketches showing various settings in which cross strata dipping to the right can be deposited by a current flowing from left to right.
A and D, Longitudinal profiles through individual bed forms that have migrated to the right (downcurrent) by at least one wavelength, thus preserving as internal cross strata many former downcurrent faces.
B, Longitudinal profiles through cross strata that have filled in an asymmetric depression.
C and E, Longitudinal profiles through cross strata deposited by downcurrent growth of an embankment (such as a delta lobe), built where the flow enters slightly deeper water. (R. R. Shrock, 1948, fig. 207, p. 245.)

Once a current has established a pattern of asymmetric ripples, various kinds of ripple cross laminae are deposited depending on the abundance of sediment. At one extreme, the ripples may migrate and no new sediment is added (Figure 14, A). At the other extreme are ripples that persist as more sand-size- and other sediment is added from the suspended load of the current. Addition of sediment to a field of active ripples creates a kind of rolling-type stratification known as climbing-ripple strata (Figure 14, B).

In some settings, the bed-form pattern is not one of regularly spaced linear ridges, but of irregular convex-up hummocks. Deposition in a field of hummocks yields hummocky strata (Figure 15).

Where current direction oscillates, as it does every few seconds beneath shoaling waves or every few hours in some parts of the intertidal zone, the result may be symmetrical ripples that display pointed crests and broadly rounded, concave-up troughs (Figure 16).

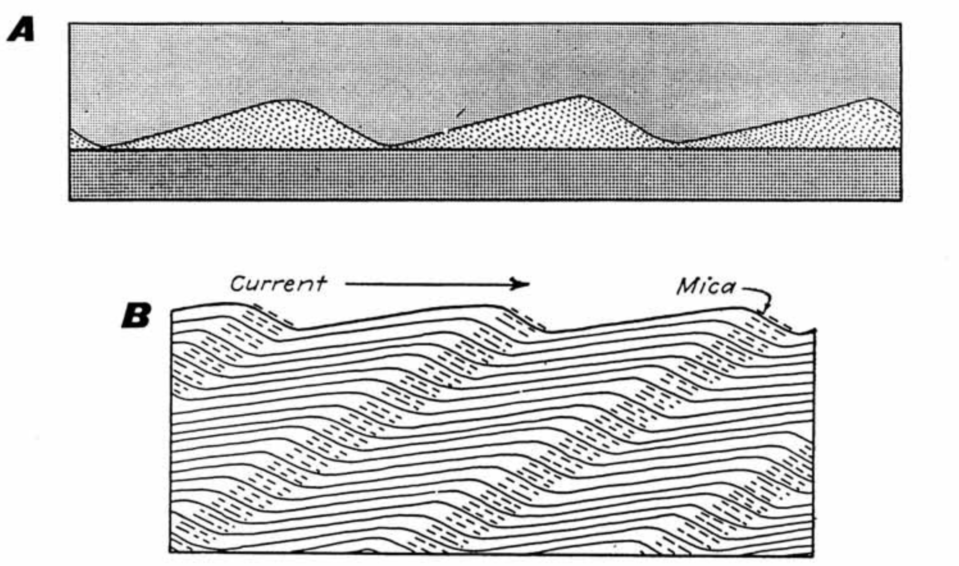


Figure 14. Sketches of ripple cross laminae formed under varying conditions of sediment supply.
A. Cross laminae formed by migration of ripples from left to right when no new sediment is added from the current. (R. R. Shrock, 1948, fig. 57, p. 103.)
B. Climbing-ripple laminae formed when sediment falls out from suspension while the current is still moving fast enough to form ripples. Concentration of mica on the downcurrent faces of ripples creates a large-scale "false bedding" dipping upcurrent (to the left). (R. R. Shrock, 1948, fig. 60, p. 105, based on J. B. Woodworth, 1901b.)

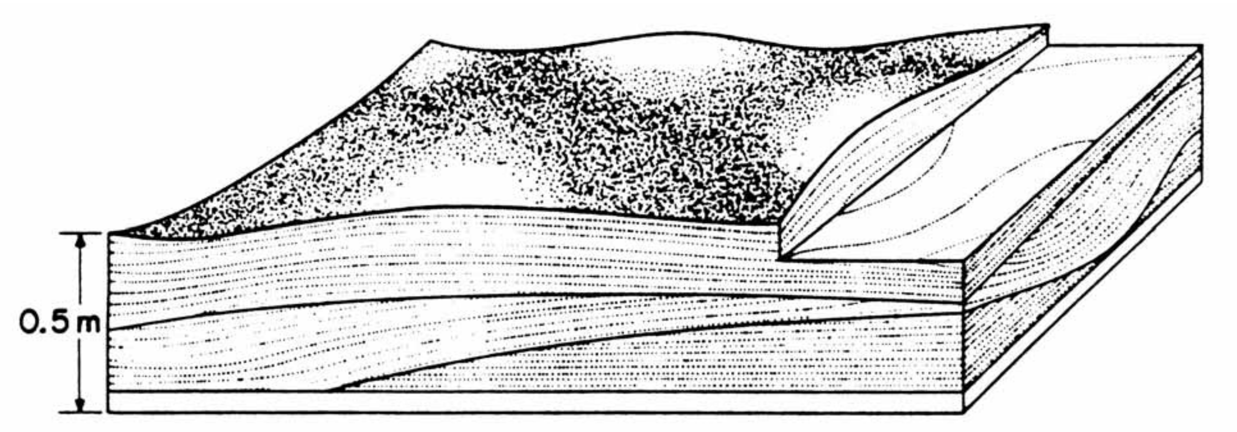


Figure 15. Sketch of hummocky strata. (R. H. Dott, Jr. and Joanne Bourgeois, 1982, fig. 1, p. 663.)

A current carrying sand in suspension that crosses a substrate composed of cohesive fine sediment (as contrasted with the coarser, cohesionless sediment discussed previously) may interact with the bottom to form scour marks or tool marks. These features, sculpted in the cohesive "mud," are usually preserved in the geologic record as counterparts on the base of the overlying sandstone bed. All features found on the bases (i. e., the "soles") of such sandstone beds are collectively designated as sole marks. Patterns of sole marks vary, but many are elongated parallel to the direction of the current (Figure 17).

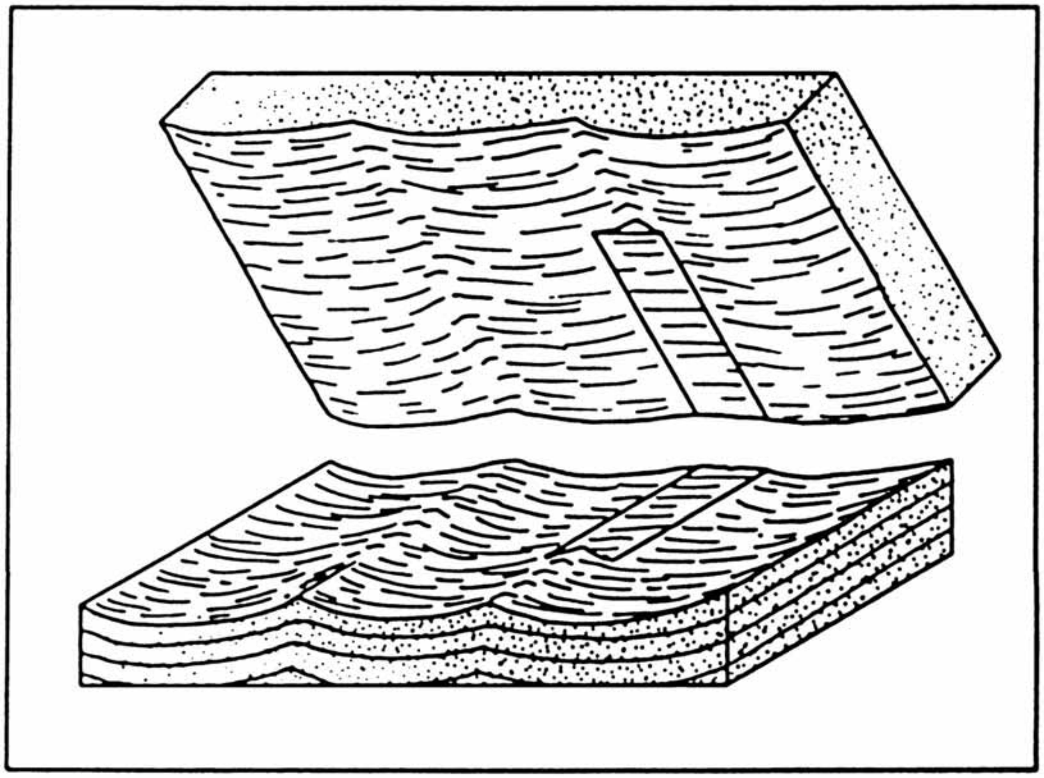


Figure 16. Sketch of symmetrical ripples.

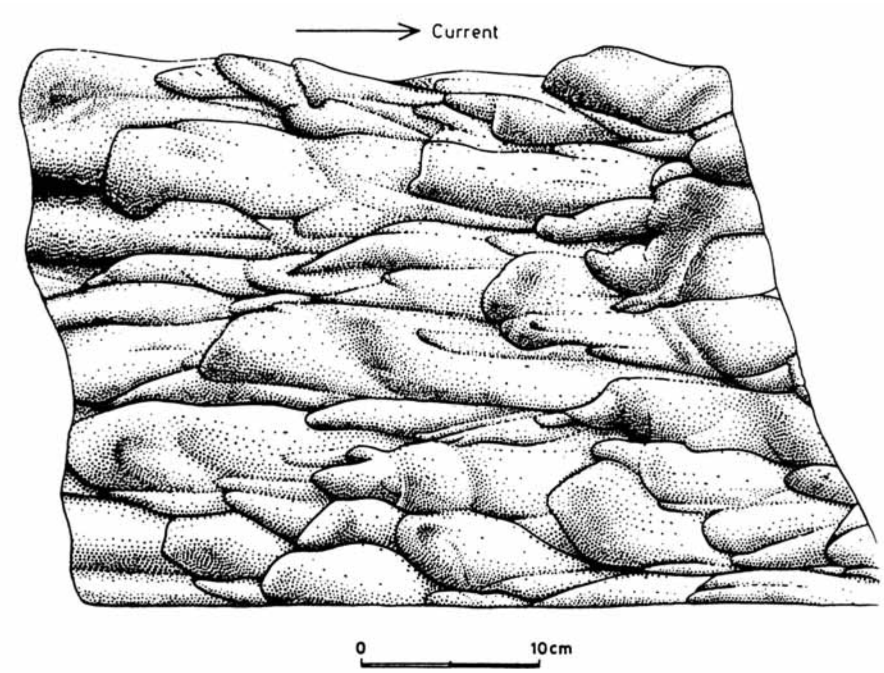


Figure 17. Sketch of counterparts of flutes, sole marks on base of Miocene sandstone bed, Apennines, Italy. (P. E. Potter and F. J. Pettijohn, 1977, fig. 5-2, p. 160, from E. ten Haaf, 1959, fig. 12.)

Cross strata, hummocky strata, and asymmetric current ripple marks deposited by moving currents yield valuable clues for unraveling the paleocurrent directions in which the ancient currents flowed. Many such features are also useful for indicating the original facing direction.

Secondary sedimentary features are developed on already deposited strata and include mud (or desiccation) cracks, rain-drop impressions, and animal footprints. Figure 18 is a composite diagram illustrating common sedimentary structures.

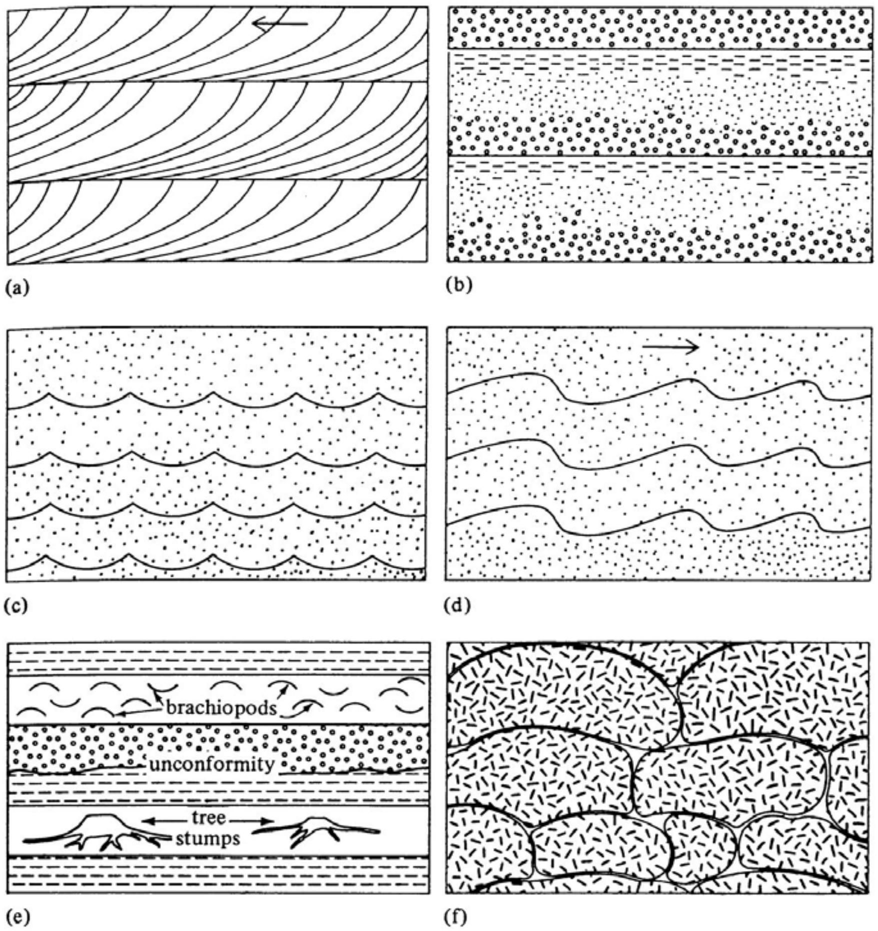


Figure 18. Diagrammatic sketches of of primary sedimentary structures (a through e) and cross sections of pillows (f) used in determining topping (younging) directions in layered rocks.

Together, these primary- and secondary sedimentary structures help the soft-rock structural geologist unravel the oft-asked field questions--namely.... Which way is up? and Which way to the package store? The direction of younging of the strata seems obvious in horizontal- or gently tilted strata using Steno's principle of superposition. But steeply tilted-, vertical-, or overturned beds can be confidently unravelled and interpreted structurally only after the true topping (stratigraphic younging) direction has been determined. As we may be able to demonstrate on this field trip, simple observations allow the card-carrying geologist to know "Which way is up" at all times.

It's now time to turn to some geometric aspects of the features formed as a result of post-depositional deformation of rocks in the Earth. We start with a brief lead-in discussion concerning the mechanical aspects of deformation and the strength of materials.

Mechanical Aspects of Deformation

We begin with some concepts and definitions based on the engineering discipline known as strength of materials. Given today's sophisticated laboratory apparatus, it is possible to subject rocks to temperatures- and pressures comparable to those found deep inside the Earth.

Imagine taking a cylinder of rock out of the Earth and torturing it in a tri-axial compression machine to see what happens. Some geologists get a big charge out of this and tell us (the field geologists) that they really understand how rocks behave under stress. [CM feels that they need to perform these experiments over a longer time frame than a few generations of siblings will allow and thus relies more on observation of field relationships than rock-squeezing data to gain a feel for the complex nature of how rocks are deformed in nature.]

Despite the limitations of the experimental work, measurements in the laboratory on specimens being deformed provide some fundamental definitions. One key definition is the elastic limit, which is the point at which a test specimen no longer returns to its initial shape after the load has been released. Below the elastic limit, the change of shape and/or volume (which is known as strain) is proportional to the stress inside the specimen. Above the elastic limit, the specimen acquires some permanent strain. In other words, the specimen has "failed" internally. Irrecoverable strain manifests itself in the distortion of crystal lattices, grain-boundary adjustments between minerals composing the rock, and minute motions along cleavage- or twin planes.

When differential force is applied slowly (or, according to CM, over long periods of time), rocks fail by flowing. This condition is defined as behaving in a ductile fashion (toothpaste being squeezed out of a tube is an example of ductile behavior). Folds are the result of such behavior. If the force is applied under low confining pressure or is applied rapidly (high strain rates), rocks do not flow, but fracture. This kind of failure is referred to as rocks behaving in a brittle fashion (as in peanut brittle). The result is faults and/or joints. Once a brittle failure (fracture) has begun, it will propagate and may produce offset thus forming a fault surface. Joint surfaces commonly exhibit distinctive "feathers" which show the direction of joint propagation.

In some cases, during deformation, rocks not only undergo simple strain, but also recrystallize. New metamorphic minerals form and newly formed metamorphic minerals acquire a parallel arrangement. More on metamorphic textures later. From the laboratory studies of rock deformation, a few simple relationships are generally agreed upon regarding brittle- and ductile faulting and these are discussed below.

When subjected to differential forces, under high confining pressures and elevated temperatures, rocks (like humans) begin to behave foolishly, squirming in many directions and upsetting the original orientation of primary- or secondary planar- and linear features within them. Geologists try to sort out the effects of deformation by working out the order in which these surfaces or linear features formed using a relative nomenclature based on five letters of the alphabet: D, F, S, L, and M. Episodes of deformation are abbreviated by (Dn), of folding by (Fn), of the origin of surfaces (such as bedding or foliation) by (Sn), of the formation of linear features (such as mineral streaking or intersection lineations produced by intersections of S1 and S0) by Ln, and of metamorphism by (Mn), where n is a whole number starting with 1 (or in some cases, with zero). Bedding, for example, is typically designated as S_0 (or surface number zero) as it is commonly overprinted by S_1 (the first foliation). To use this relative nomenclature to describe the structural history of an area, for example, one might write: "During the second deformation (D_2), F_2 folds formed with the development of an L_2 mineral lineation. An axial-planar S_2 schistosity developed and crosscut both an early foliation (S_1) and bedding (S_0). These features were produced under progressive M_1 metamorphic conditions."

Folds

If layers are folded into convex-upward forms we call them anticlines. Convex-downward fold forms are called synclines. In Figure 19, note the geometric relationship of anticlines and synclines. Axial planes (or axial surfaces) physically divide folds in half. Note that in Figure 19, the fold has been deformed about a vertical axial surface and is cylindrical about a linear fold axis that lies within the axial surface. The locus of points connected through the domain of maximum curvature of the bedding (or any other folded surface of the fold) is known as the hinge line (which is parallel to the fold axis). This is geometry folks; we have to keep it simple so geologists can understand it.

In eroded anticlines, strata forming the limbs of the fold dip away from the central hinge area or core (axis) of the structure. In synclines, the layers forming the limbs dip toward the hinge area. Given these arrangements, we expect that in the arches of eroded anticlines, older stratigraphic layers will peek through whereas in the eroded troughs of synclines, younger strata will be preserved.

In metamorphic terranes, field geologists are not always sure of the correct age relationships of the metamorphosed strata. Therefore, it is helpful to make use of the general terms antiform and synform which describe the folds by whether they are convex upward (antiform) or concave upward (synform) but do not imply anything about the relative ages of the strata within them.

Realize that in the upright folds shown in Figure 19, axial surfaces are vertical and fold axes, horizontal. This is a very rare case. Generally the axial surfaces are not vertical and the fold axes are not horizontal.

The scale of folds varies through an enormous range from tiny features that can be present in a hand specimen to great structures measuring many kilometers across and hundreds of kilometers long. A large anticline having a broad wave length and displaying smaller folds along its limbs is known as an anticlinorium. A companion large-scale synclinal feature is a synclinorium.

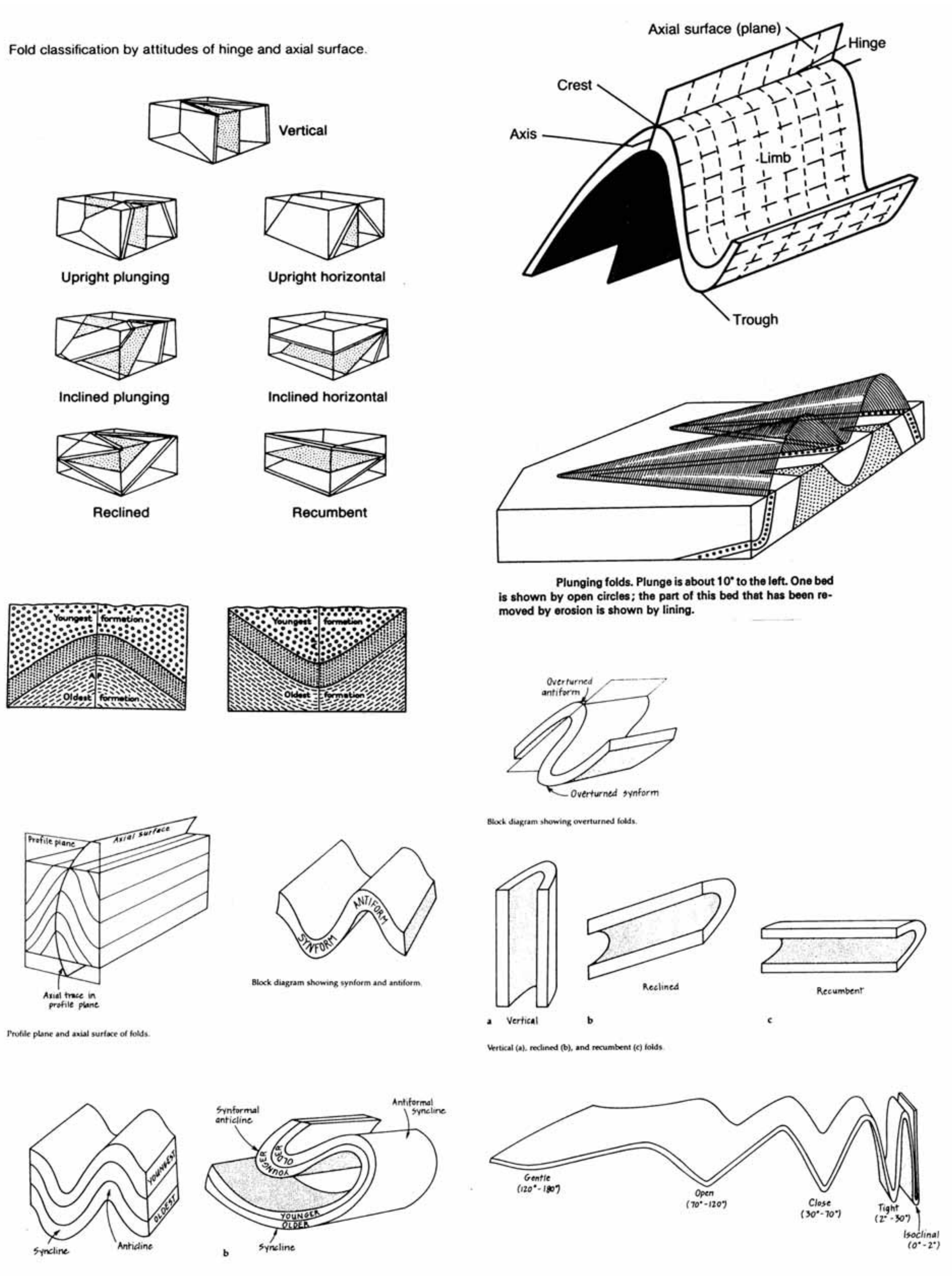


Figure 19. Composite diagram from introductory texts showing various fold styles and nopersonsclature (non-sexist, 90s, politically correct terminology) as discussed in the text.

After the pioneering work of William Smith in 1812, who first mapped a large-scale plunging structure (we would call this a synclinorium today) in the southern England lowland areas, the Appalachians were the first mountains in which major geologic structures known as folds (anticlines and synclines) were demonstrated (by the Rogers brothers, H. D., and W. B., in the middle of the nineteenth century from their studies in Pennsylvania). To be sure, small folds had been recognized where seen in coastal exposures in numerous localities in western Europe. But, it was a giant step (and anything but an intuitively obvious leap) from seeing small folds in cross section to the reconstruction of very large-scale folds based on working out the stratigraphic relationships of Paleozoic strata, thousands of meters thick, underlying strike ridges that extend for tens, even hundreds of kilometers.

Folds could care less about the orientation of their axes or axial surfaces and you can certainly imagine that axial surfaces can be tilted, to form inclined or overturned folds. Or the axial surfaces may be sub-horizontal, in which case the term recumbent folds is used. In both overturned folds and recumbent folds, the fold axes may remain subhorizontal. (See Figure 19.) It is also possible for an axial surface to be vertical but for the orientation of the fold axis to range from horizontal to some angle other than 0° (thus to acquire a plunge and to produce a plunging fold). Possible configurations include plunging anticlines (or -antiforms) or plunging synclines (or -synforms). Vertical folds (plunging 90°) are also known; in them, the terms anticline and syncline are not meaningful. In reclined folds, quite common in ductile shear zones, the fold axes plunge directly down the dip of the axial surface.

In complexly deformed mountain ranges, most terranes show the superposed effects of more than one set of folds and faults. As a result of multiple episodes of deformation, the ultimate configuration of folds can be quite complex (i. e., plunging folds with inclined axial surfaces and overturned limbs).

We need to mention one additional point about the alphabet soup of structural geology. Seen in cross section, folds fall into one of three groups, the S's, the M's, and the Z's. Looking down plunge in the hinge area of a northward-plunging anticlinal fold, for example, dextral shearing generates asymmetric Z folds on the western limb and sinistral shearing forms S folds on the eastern limb. Usually only one variety of small, asymmetric folds will be found on a given limb of a larger fold. Therefore, if one notices a change in the pattern from S folds to Z folds (or vice versa), one should be on the lookout for a fold axis. The hinge area is dominated by M folds (no sense of asymmetry).

One final note on folding -- it is generally agreed, in geologically simple areas, that axial surfaces form perpendicular to the last forces that ultimately produced the fold. Therefore, the orientation of the folds give some hint as to the direction of application of the active forces (often a regional indicator of relative plate convergence). In complex regions, the final regional orientation of the structures is a composite result of many protracted pulses of deformation, each with its unique geometric attributes. In these instances, simple analysis is often not possible. Rather, a range of possible explanations for a given structural event is commonly presented.

Faults

A fault is defined as a fracture along which the opposite sides have been displaced. The surface of displacement is known as the fault plane (or fault surface). The enormous forces released during earthquakes produce elongate gouges within the fault surface (called slickensides) that may possess asymmetric linear ridges that enable one to determine the relative motion between the moving sides (Figure 20, inset). The block situated below the fault plane is called the footwall block and the block situated above the fault plane, the hanging-wall block.

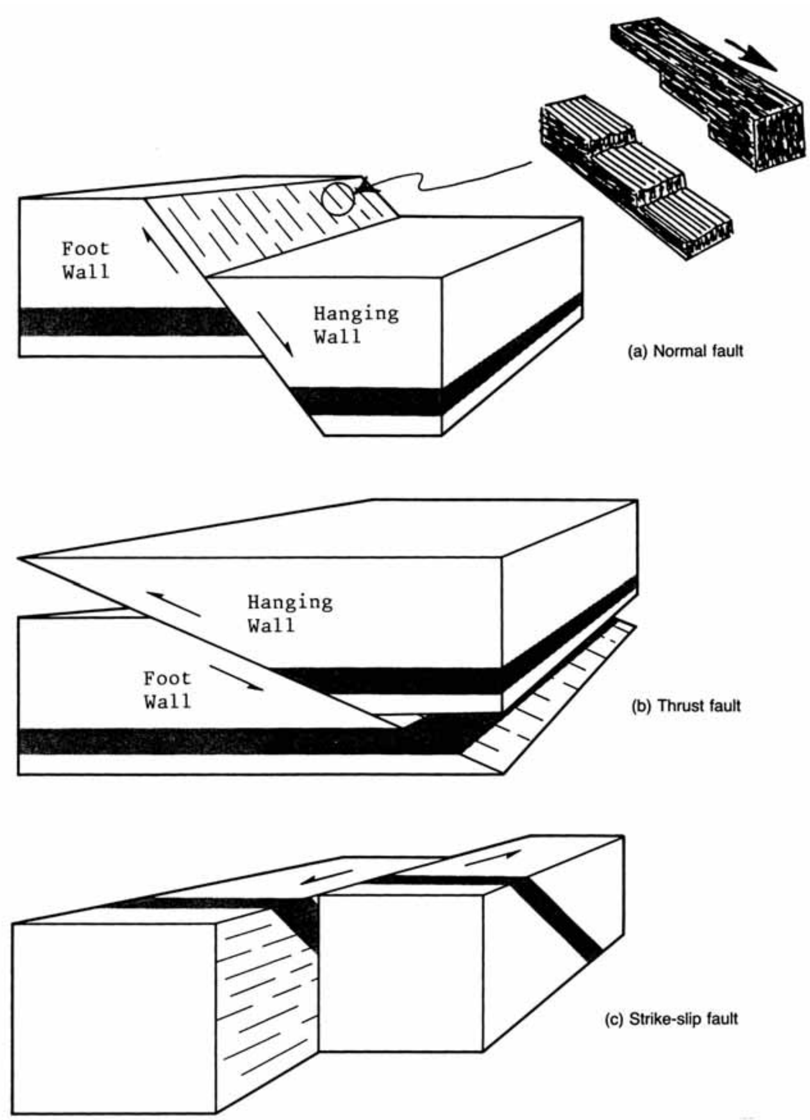


Figure 20. The three main types of faults shown in schematic blocks. Along a normal fault (a) the hanging-wall block has moved relatively downward. On a thrust fault (or reverse fault) (b) the hanging-wall block has moved relatively upward. Along a strike-slip fault (c), the vertical reference layer (black) has been offset by horizontal movement (left-lateral offset shown here). Inset (d) shows segments of two blocks along a slickensided surface show how the jagged "risers" of the stairsteps (formed as pull-apart tension fractures) can be used to infer sense of relative motion. [(a), (b), (c), Composite diagram from introductory texts; (d), J. E. Sanders, 1981, fig. 16.11 (b), p. 397.]

Normal- and Reverse Faults

Imagine extending (stretching) or compressing a block-like portion of the Earth's crust. Extensional force may causes the crust to rupture along a fracture that is not vertical. In this case, the block above the dipping fracture, known as the hanging-wall block, will slide down the fracture surface producing a normal fault. [See Figure 20 (a).] Compressive forces drive the hanging-wall block up the fracture surface to make a reverse fault. A reverse fault with a low angle (<30°) is called a thrust fault. [See Figure 20 (b).] In all of these cases, the slickensides on the fault will be oriented more or less down the dip of the fault plane and the relationship between the tiny "risers" that are perpendicular to the striae make it possible to determine the relative sense of motion along the fault. Experimental- and field evidence indicate that the asymmetry of slickensides is not always an ironclad indicator of relative fault motion. As such, displaced geological marker beds or veins are necessary to verify relative offset. Fault motion up- or down the dip (as in normal faults, reverse faults, or thrusts faults) is named dip-slip motion.

Low-angle Thrusts

A low-angle thrust is a special kind of reverse fault that initially contained one or more segments that are parallel to the originally horizontal strata. Such low-angle faults have also been referred to as overthrusts, but this term implies a sense of motion that may not be correct. In order to beg the question of whether motion was one of overthrusting or underthrusting, P. B. King (1960) advocated use of the term low-angle thrust.

The large-scale repetition of strata on low-angle thrusts was first shown in the Scottish Highlands. Soon thereafter, spectacular examples were found in the Alps and, indeed, in nearly all mountain chains. Studies in the Appalachians made possible new understanding between thrusts and folds. Examples were found illustrating all gradations from small breaks across the axes of overturned folds (Figure 21) to what are known as imbricate thrusts in which the deformed strata and the overthrusts dip southeastward at about the same angles; during deformation, the right-way-up strata of the northwest (normal) limbs of two synclines have been brought together and the southeastern (overturned) limbs and the central parts of the intervening anticlines have vanished (Figure 22).

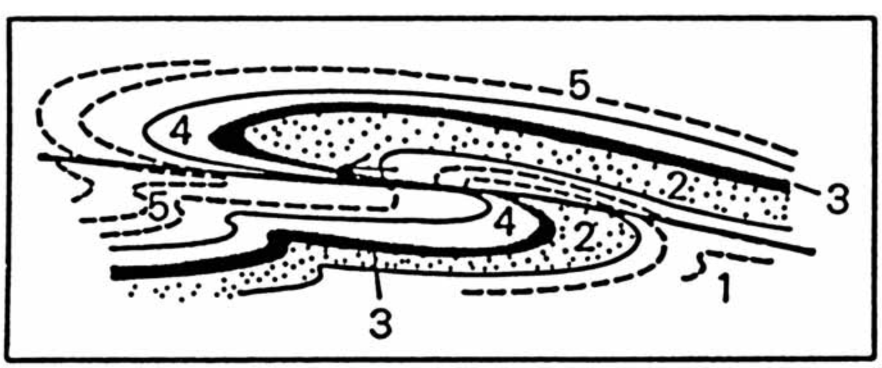
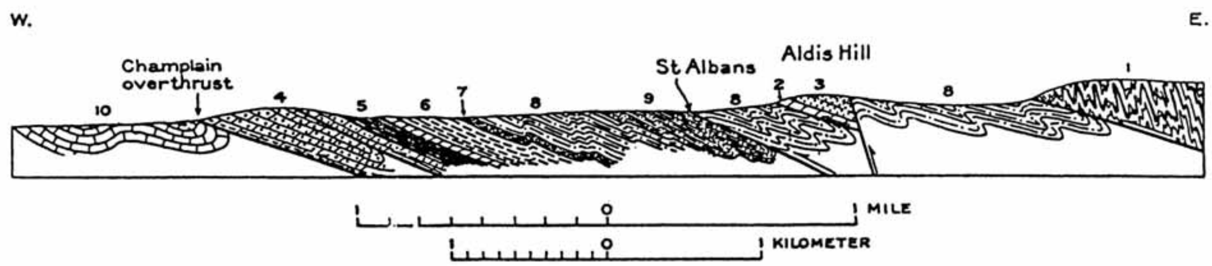


Figure 21. Overturned fold broken by a low-angle thrust fault, schematic profile section. Units are numbered in order of decreasing age, from 1 (oldest) to 5 (youngest). (J. E. Sanders, 1981, fig. 16.14, p. 398.)



Section from west to east near St. Albans, Vermont, showing the principal thrusts at that latitude and the three sequences of Paleozoic formations separated by the thrusts. 1, Undifferentiated pre-Cambrian and lower Paleozoic; 2, dolomite and schist, probably late pre-Cambrian; 3, Lower Cambrian quartzite (eastern sequence); 4–9, central sequence; 4, Lower Cambrian dolomite; 5, Lower Cambrian slate and dolomite; 6, Middle Cambrian slate; 7, conglomerate, base of Upper Cambrian (thickness exaggerated); 8, Upper Cambrian slate; 9, Lower Ordovician slate; 10, Ordovician of the western sequence. The coarse conglomerate at the base of the Ordovician in the central sequence (No. 9) is not exposed in the vicinity of this section

Figure 22. Imbricate thrusts that are essentially parallel to the strata that have been duplicated; example from Paleozoic strata in northwestern Vermont. (C. R. Longwell, 1933, fig. 14, p. 63.)

Bedding-plane thrusts are more-localized features but are geometrically the same as thrust faults in that they involve layer-parallel shortening of strata and produce low-angle imbrication of strata. They can easily be "missed" in the field but result in overthickening of strata and can produce anomalous stratigraphic thickness in sedimentary units. The field geologist can identify them by careful bed-by-bed examination of known sequences based on duplication of key- or marker beds and by identification of highly veined rocks adjacent to- or zones of gouge or slickensides along the surfaces of dislocation.

Studies in the Appalachians led John L. Rich (1934) to propose the concept of "bedding thrusts." By this term, he referred to overthrusts along which two contrasting segments can be recognized: (1) segments that are parallel to the bedding; and (2) segments that cut across bedding at steep angles (Figure 23). (These segments that cut bedding at steep angles have subsequently been named ramps.) What was totally different about Rich's analysis is the relationship between thrusts and folds. Because of the geometric arrangement of the ramps and the beds, any forward displacement causes the strata of the upper block to be folded. As the strata are pushed against the ramp, they become parallel to it, forming one limb of a ramp-related anticline. Where the strata that have been displaced past the ramp return to the next bedding-parallel segment of the thrust surface, they dip downward toward this surface, thus forming the second limb of the ramp-related anticline. Where later deformation has not obscured the relationships, Rich's mechanism creates flat-topped anticlines whose widths are direct functions of the amount of displacement on the thrust and intervening flat-bottom synclines whose widths are determined by the spacing between adjacent ramps.

For about 35 years, the only person who seems to have understood the fundamental new point that John L. Rich was trying to make was John Rodgers. In numerous important papers, Rodgers (1949, 1950, 1953, 1963, 1964, 1970) established what he referred to as the "thin-skinned" mechanism of Appalachian deformation. A synonym of the "thin-skinned" style of Appalachian deformation was the term "no-basement" style. That is, the deformation of the strata took place independently of the basement. Therefore, in between the deformed strata and the non-involved basement was a surface of detachment, or décollement. Where the basement was involved, the term "thick-skinned" style was applied. These two styles were thought to be mutually exclusive.

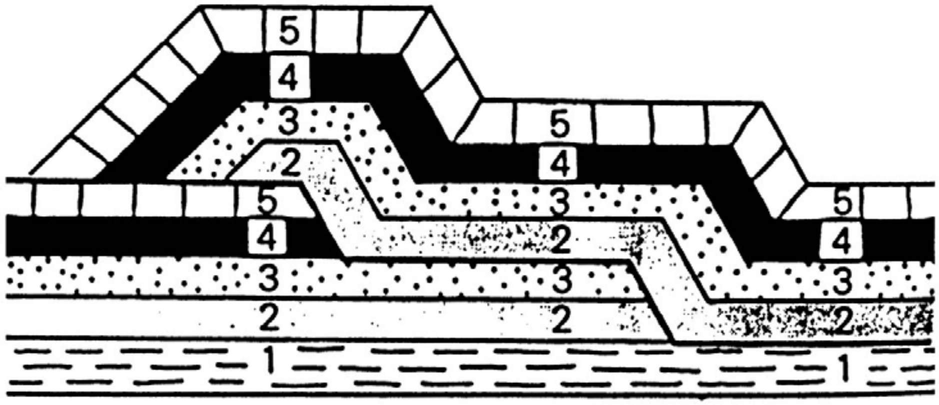


Figure 23. Folds formed by movement on a bedding-plane thrust according to the mechanism proposed by J. L. Rich; schematic profile section with units numbered in order of decreasing age from 1 (oldest) to 5 (youngest). (J. E. Sanders, 1981, fig. 16.1e, p. 390.)

Major new understanding of the importance of John L. Rich's insights have resulted from the discovery of large reserves of petroleum in the Rocky Mountains. For many years, searchers for petroleum avoided drilling in places where the strata had been overthrust. They believed that deformation on a scale that creates overthrusts would destroy any petroleum present in the strata. Therefore, overthrust belts ranked high on the list of places to avoid. Much to everybody's surprise, major discoveries were made by drilling through overthrusts to petroleum traps formed in the strata on the lower block (Gries, 1983). After several giant gas fields had been discovered, "overthrust belts" were stricken from the "no-no" list and quietly moved to the head of the list of places to be explored. As a result, seismic profiles were shot across mountain chains and deep holes were drilled through complex geologic structures. The result has been the acquisition of great quantities of new subsurface information from places that probably would have remained "terra incognita" forever had it not been for petroleum exploration.

All of which brings us back to the Appalachians. The next major point about Appalachian overthrusts is the displacement of basement rocks over the strata. In other words, the basement becomes "involved." (What's that story about ham and eggs? The hen is "involved" but the pig is "committed.") In this respect, northwestern New Jersey and adjacent southeastern New York provides some critical evidence that most Appalachian geologists have overlooked. In the discussions about "thin-skinned" vs. "thick-skinned" deformation, this part of the Appalachians seems to have been studiously avoided The evidence pointing to basement involvement in the northern Appalachian overthrusts was presented by Isachsen (1964). Isachsen argued that on a regional scale, the Proterozoic basement rocks had been thrust over the Paleozoic sedimentary strata. (See Figure 2.) He inferred that this displacement had taken place during the Late Ordovician Taconian orogeny. (We discuss the subject of age of deformation in a following section.)

A critical locality demonstrating the displacement of Proterozoic rocks over Paleozoic strata is the Musconetcong tunnel built by the Lehigh Railroad more than 100 years ago (Figure 24). Isachsen (1964, p. 822) cited Kümmel (1940) as his source of the information about this tunnel. As we pointed out in our On-The-Rocks Guidebook for Trip 12 to Franklin Furnace (17 June 1990), however, the correct citation is not Kümmel (1940) but rather Lewis and Kümmel (1915; fig. 3, p. 58).

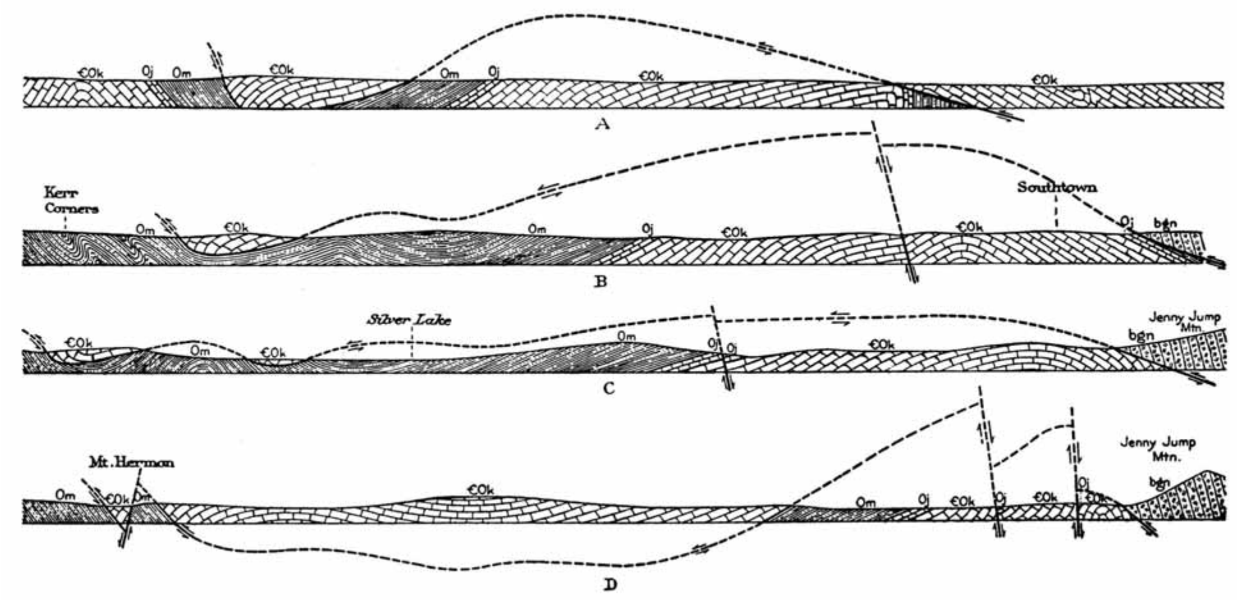


Figure 24. Geologic sections illustrating the vast thrust sheets of Cambro-Ordovician strata in the Kittatinny Valley and klippe composed of Proterozoic rocks at Jenny Jump Mountain. (J. V. Lewis and H. B. Kümmel, 1915, fig. 3, p. 58.)

In 1980, JES began to wonder about the geologic circumstances under which the gas had been trapped at the Middletown gas well in Orange County, New York. Not far SE of this well are several klippe in which Proterozoic rocks had been thrust over the Paleozoic strata (usually, but not exclusively, the Ordovician shales (Figure 25). Despite these clear examples of basement involvement with the Paleozoic strata, the authors who were writing about the "basement" vs. the "no-basement" style of Appalachian deformation seemed to be avoiding any discussion of the relationships in northwestern New Jersey and southeastern New York. JES (Sanders, Friedman, and Sternbach, 1981) concluded that the emphasis on the John L. Rich mechanism as a basis for the distinctness of "thin-skinned" deformation was omitting an important point, namely, that the Rich-style mechanism need not be confined to the strata. Deep seismic profiles were showing what appeared to be strata beneath outcropping basement (Ando and others, 1983; Ando and other others, 1984; Brown and others, 1983; Cook and others, 1979; Cook, Brown, and Oliver, 1980; Cook and Oliver, 1981). Therefore, JES suggested that the Rich-style low-angle thrusts were a general phenomenon, and that the depths of their horizontal segments could be the basis for classifying mountain belts into three longitudinal zones: (A) a distal zone in which strata were thrust over strata (the happy home of the "thin-skinned" style); (B) a median zone in which basement was thrust over strata (the habitat of the so-called "thick-skinned" style where basement was clearly "involved"); and (C) a proximal zone in which basement was thrust over basement (Figure 26).

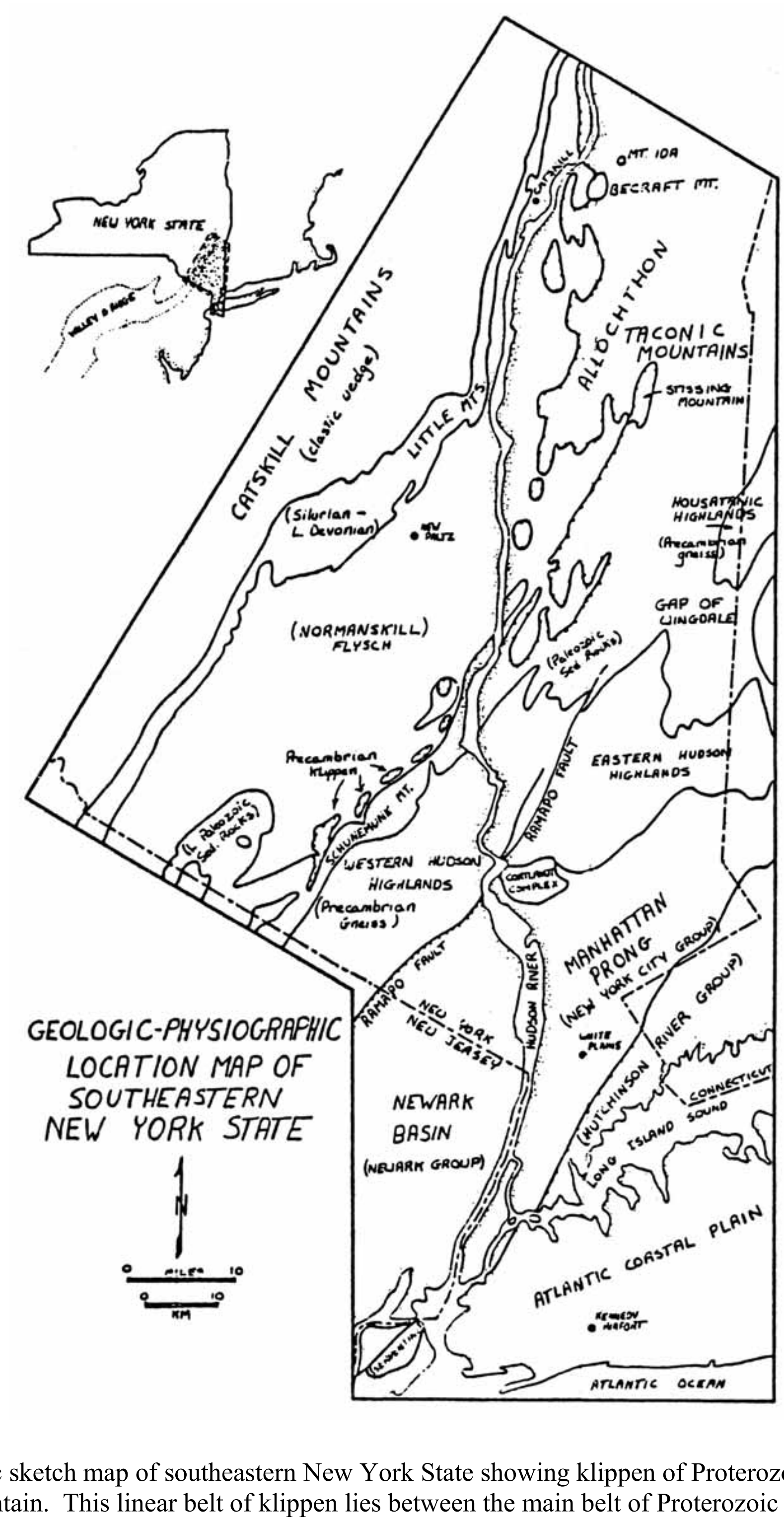


Figure 25. Tectonic sketch map of southeastern New York State showing klippen of Proterozoic rocks lying NW of Schunnemunk Mountain. This linear belt of klippen lies between the main belt of Proterozoic rocks of the Hudson Highlands and the NE-plunging anticline south of Middletown, NY. (R. Stephen Marshak and Peter Geiser, 1980, courtesy Terry Engelder.)

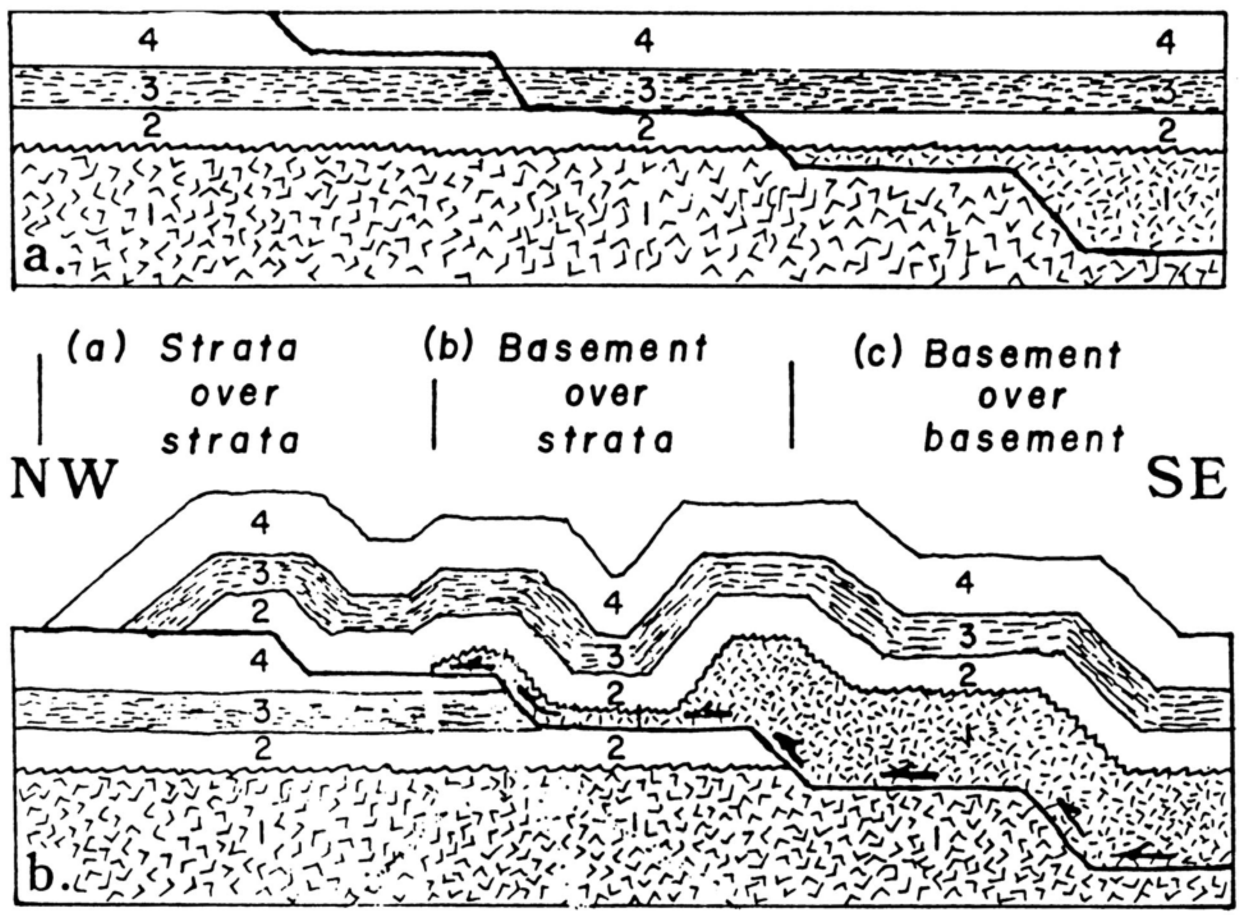


Figure 26. "Bedding thrusts" as described by J. L. Rich (1934), but extended downward so as to includes sheets of basement rock, schematic profile-section with no erosion. Where basement rocks move over other basement rocks, the cause of the separation is probably thermal, as argued by Armstrong and Dick (1974).

a. Reference sketch before movement on multi-level thrust (thick line).

b. Result of motion forward and up the footwall ramps has created anticlines above each ramp. Three thrust zones: (a), (b), and (c), are based on the relationships of the overthrust strata to other strata, of overthrust basement to strata, and of overthrust basement to other basement. (J. E. Sanders, G. M. Friedman, and C. A. Sternbach, 1981, Fig. 15, p. 218.)

Using this approach, JES (Sanders, 1983) reinterpreted the geologic structure at the Middletown well. He inferred that the large anticline south of Middletown in which the basement is exposed is a ramp-related anticline above a tectonic ramp that extended upward from some level within the Proterozoic rocks to a higher level in the Ordovician shales (Figure 27). A corollary of this interpretation is that the NW dips of the Silurian strata of Shawangunk Mountain/Kittatinny Mountain and the Devonian strata underlying the adjacent strike valley to the NW should not flatten with depth under the Catskill-Pocono Plateau, as generally presumed, but rather should be as shown in Figure 28. That is, the NW dips should continue downward to a horizontal segment of a bedding-type thrust beneath which the strata should be horizontal (Figure 28). Since 1983, JES has seen the seismic profile that was shot along N.Y. Route 17. Much to his delight, this profile shows that the dip of the Silurian strata continues downward more or less unchanged from its surface value to a level where these strata are truncated. At greater depth the reflector traces are horizontal. JES takes this to be dramatic confirmation that bedding thrusts on a regional scale are present beneath the Catskill-Pocono Plateau. It establishes on a regional scale the local relationships of NW-dipping bedding thrusts that JES found in the Devonian strata exposed NW of Catskill, New York (Sanders, 1969).

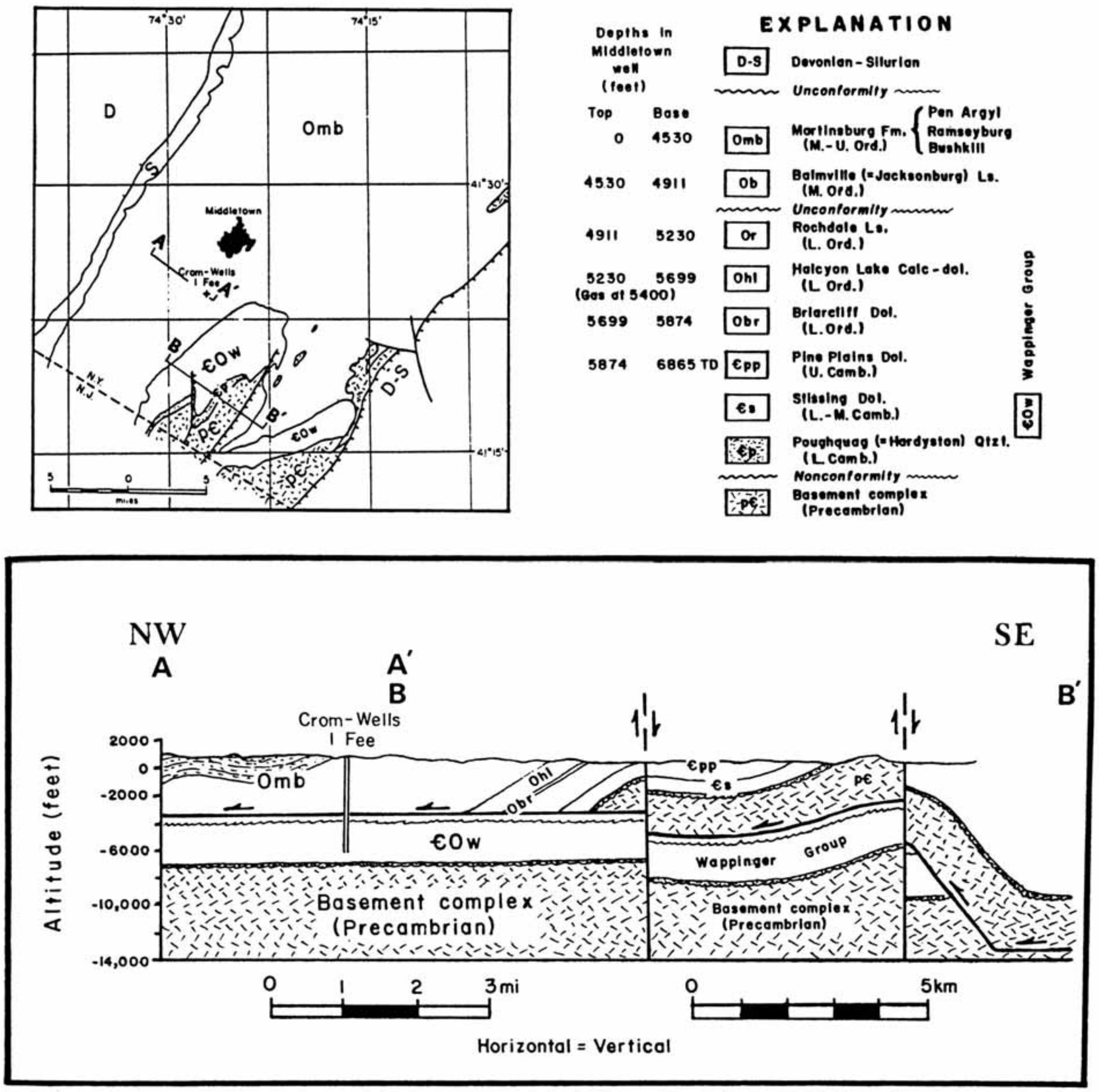


Figure 27. Geologic setting of Middletown gas well (Crom-Wells 1 Fee), Orange County, NY.

a. Simplified geologic map showing locations of lines of sections AA' and BB'. (J. E. Sanders, 1983, fig. 3, p. 173, after New York State Geologic Map, 1970, Lower Hudson Sheet.)

b. EXPLANATION of geologic map and sections including depths of formation boundaries in Midletown well (depths from Warthin and Pack, 1956 ms., in Offield, 1967). (J. E. Sanders, 1983, fig. 4, p. 174.)

c. JES interpretation of structure along lines AA' and BB.' Contacts of formations at surface from Offield (1967), but with subsurface relationships changed to show one possible arrangement according to overthrust interpretation. (J. E. Sanders, 1983, fig. 8, p. 176.).

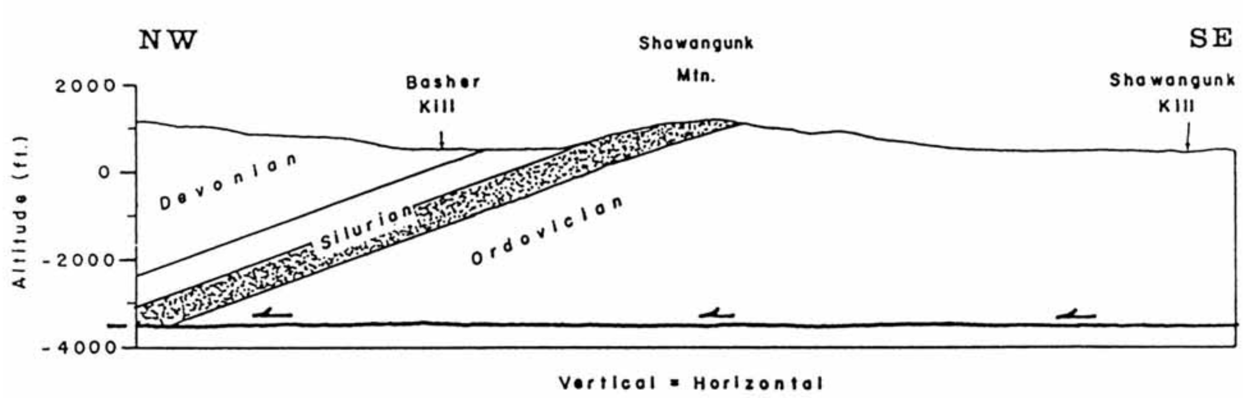


Figure 28. Profile section across the Shawangunk Ridge based on seismic data showing northwest-dipping strata abruptly truncated against a horizontal surface.

Over the years, field geologists have noted special geologic features associated with thrust faults. Because they propagate at low angles with respect to bedding, thrusts commonly duplicate strata. In addition, thrust faults can displace strata for great distances and wind up transporting rock deposited in one environment above rocks deposited in markedly disparate environments. In such cases, we call the displaced strata of the upper plate above a thrust fault an allochthon or describe an entire displaced sequence of strata as an allochthonous terrane (see Tectonostratigraphic Units below). In other words, allochthonous rocks were not originally deposited where they are now found. By contrast, regions consisting of rock sequences that were originally deposited where they are now found constitute an autochthon or autochthonous terrane.

Interesting geometric patterns result from the erosion of overthrust sheets of strata that have been folded after they were overthrust. Where a "hole" has been eroded through the upper plate (allochthon), it is possible to peer downward through the allochthon and see the autochthon exposed in a window (synonyms: inlier, or, in the German tongue, fenster) surrounded by the trace of the thrust fault that was responsible for the dislocation (Figure 29). By contrast, if most of the upper plate has been eroded, only a remnant outlier or klippe may remain. (See Figure 29.) Both klippen and windows (or fensters) produce similar map-scale outcrop patterns. The difference is that the thrust surface typically dips toward the center of a klippe (a remnant of the allochthon) and away from the center of a window (which shows a part of the underlying autochthon).

During episodes of mountain building associated with continuous subduction and/or collisions near continental margins, thrusting is typically directed from the ocean toward the continent. Accordingly, one of the large-scale effects of such periods of great overthrusting is to impose an anomalous load on the lithosphere which causes it to subside and form a foreland basin. These basins receive tremendous quantities of sediment which fill the basin with debris derived from erosion of uplifted areas within the active collision zone. In the late stages of convergence, forces transmitted from the collision zone into the developing foreland basin create a diachronous secondary stage of folding and continent-directed overthrusting of the strata filling the foreland basin. Thus, a thrust may override debris eroded from it (Sanders, 1995).

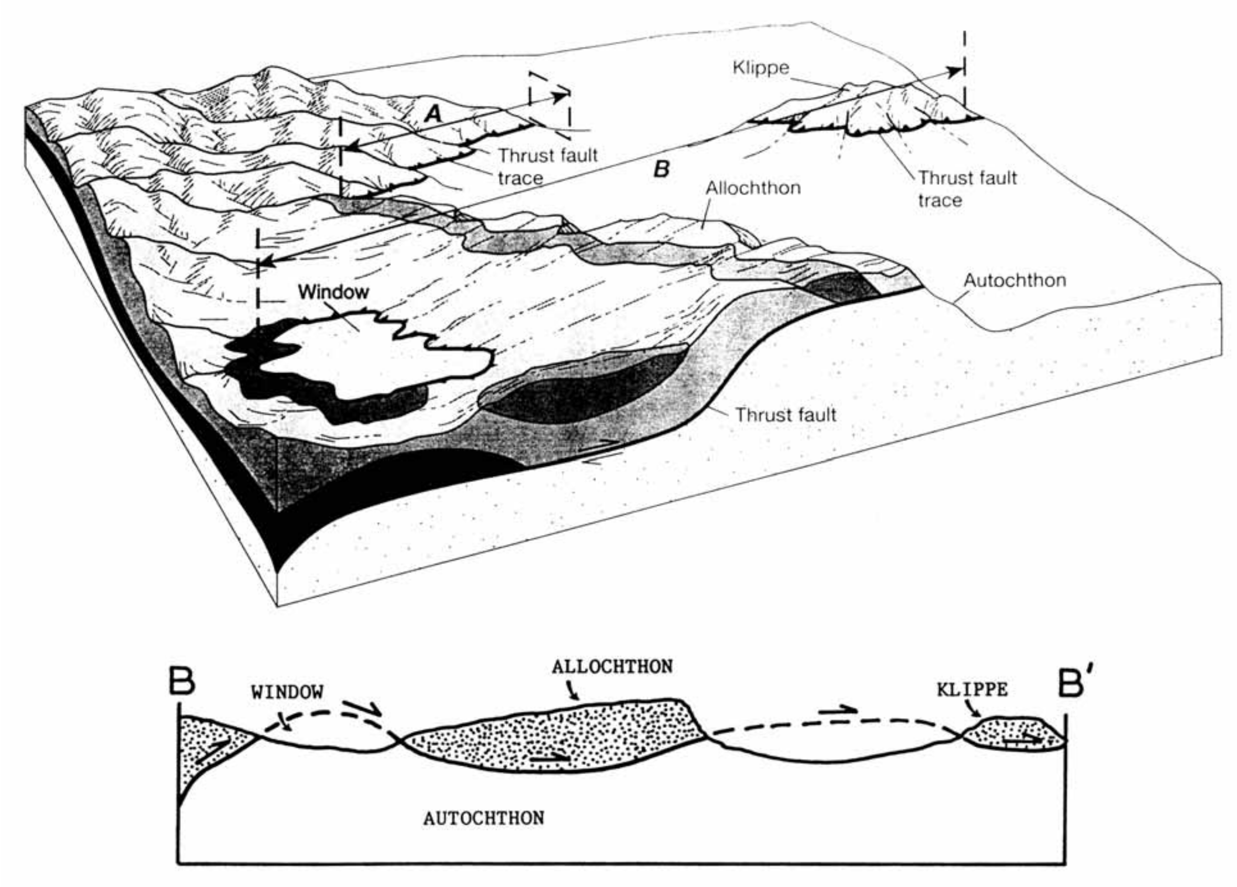


Figure 29. Block diagrams illustrating the relationships among major components of low-angle thrust sheets, including allochthons, autochthons, klippen, and windows. (R. J. Twiss and E. M. Moores, 1992, Fig. 6.4, p. 99; section B-B' drawn by CM.)

Strike-slip Faults

Rather than simply extending or compressing a rock, imagine that the block of rock is sheared along its sides (i. e., that is, one attempts to rotate the block about a vertical axis but does not allow the block to rotate). This situation is referred to as a shearing couple and could generate a strike-slip fault. [See Figure 20 (c).] On a strike-slip-fault plane, slickensides are oriented subhorizontally and again may provide information as to which direction the blocks adjoining the fault surface moved.

Two basic kinds of shearing couples and/or strike-slip motion are possible: left lateral and right lateral. These are defined as follows. Imagine yourself standing on one of the fault blocks and looking across the fault plane to the other block. If the block across the fault from you appears to have moved to the left, the fault is left lateral [illustrated in Figure 20 (c)]. If the block across the fault appears to have moved to the right, the motion is right lateral. Convince yourself that no matter which block you can choose to observe the fault from, you will get the same result! Naturally, complex faults show movements that can show components of dip-slip-and strike-slip motion, rotation about axes perpendicular to the fault plane, or reactivation in a number of contrasting directions or variety. This, however, is no fault of ours.

Distinctive Fault Rocks

Tensional-, compressional, or strike-slip faulting results in brittle deformational response at crustal levels above 10 to 15 km. Such faulting is episodic and accompanied by seismicicity and the development of highly crushed and granulated rocks called fault breccias and cataclasites (including fault gouge, fault breccia, and others). Figure 30 lists brittle- and ductile fault terminology as adapted from Sibson (1977) and Hull et al. (1986). Begining at roughly 10 to 15 km and continuing downward, rocks under stress behave aseismically and relieve strain by recrystallization during ductile flow. These unique metamorphic conditions prompt the development of highly strained (ribboned) quartz, feldspar porphyroclasts (augen), and frayed micas, among other changes, and results in highly laminated rocks called mylonites. (See Figure 30.)

The identification of such ductile fault rocks in complexly deformed terranes can be accomplished only by detailed mapping of metamorphic lithologies and establishing their geometric relationship to suspected mylonite zones. Unfortunately, continued deformation under load often causes early formed mylonites to recrystallize and thus to produce annealed mylonitic textures (Merguerian, 1988), which can easily be "missed" in the field without careful microscopic analysis. Cameron's Line, a recrystallized ductile shear zone showing post-tectonic brittle reactivation, is an original ductile fault zone (mylonite) having a complex geologic history.

Effects on Sedimentary Strata of Deformation

The most-obvious effect of deformation on sedimentary strata is change of attitude: originally horizontal strata are no longer horizontal. Apart from such changes, other indicators of deformation include displacement of strata, disruption of strata, and rock cleavage (Figure 31).

Where two sets of cleavage have been superimposed upon each other (or more than two sets of cleavage on one another), the rocks tend to break into wedge-like, triangular shapes or into long, slender faceted "pencils." This property of shape is further promoted if the deformed rocks contain a planar parting parallel to bedding.

In regions where several episodes of deformation intense enough to form rock cleavage have been superimposed, it may be very difficult to unravel the relative ages of cleavage. If deformation has beem along subparallel trends, tlhis problem may become acute. Normally, cleavage direction parallels the axial surface of folds. That is, the layer-type minerals whose parallelism causes the cleavage are oriented parallel to the plane of maximum compression. (See Figure 31.)

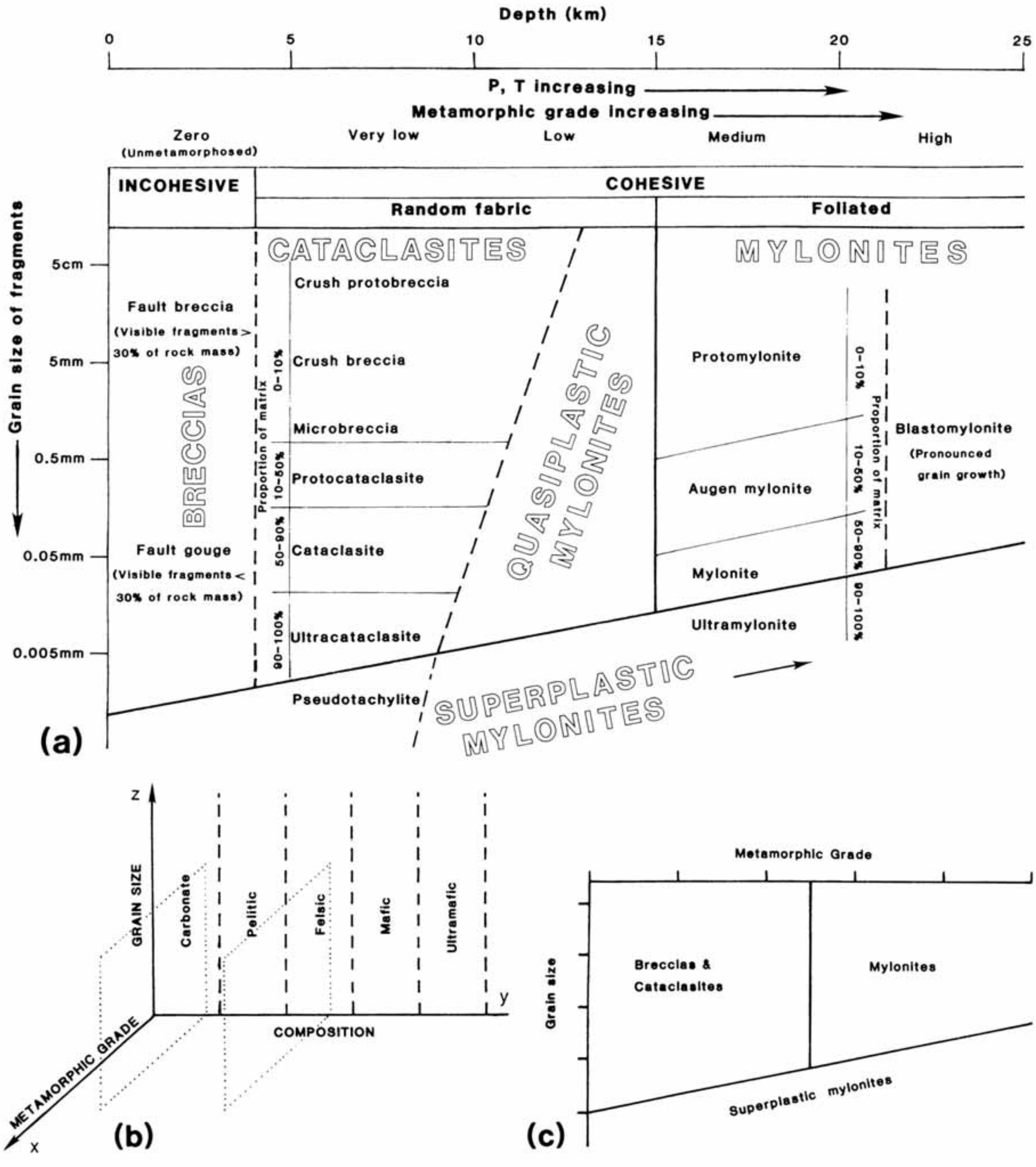


Figure 30. Fault-rock terminology. (a) Classification of fault rocks that have been derived from quartzo-feldspathic lithologies (e. g. granite). (Adapted from R. Sibson, 1977.) (b) The particle size - metamorphic grade - lithologic composition grid used for classifying fault rocks. (After J. Hull, R. Koto, and R. Bizub, 1986.) (c) Fault-rock diagram for marl showing expanded mylonite (sic) and superplastic mylonite fields as compared to those shown on the diagram for granite in (a) (Gautam Mitra and R. Stephen Marshak, 1988, fig. 11-23, p. 227.)

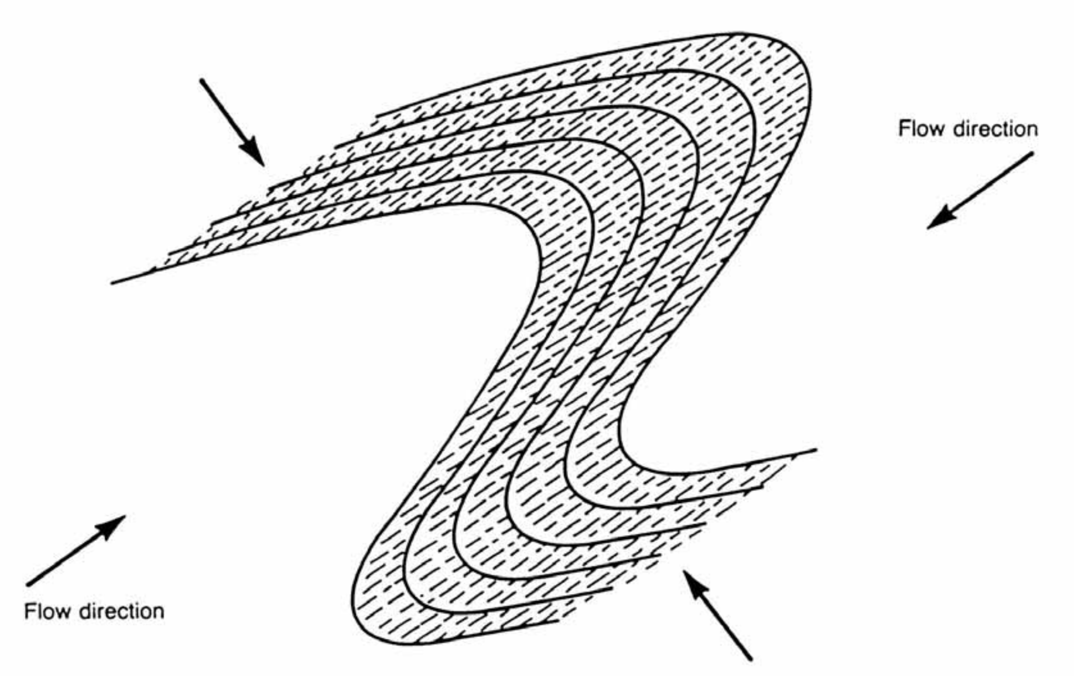


Figure 31. Sketch of slaty cleavage oriented parallel to axial surface of folds. (R. D. Hatcher, Jr., 1990, fig. 15-22, p. 335.)

Structures in Sedimentary- vs. Metamorphic Rocks

For hard-rock geologists working in metamorphic terranes, simple sedimentary observations will not allow the card-carrying geologist to know "Which way is up" at all. Rather, because of intense transposition and flow during ductile deformation, stratification, fossils for age dating, tops and current-direction indicators are largely useless except to identify their hosts as sedimentary protoliths. Thus, according to CM, "at the outcrop scale, metamorphism can best be viewed as the great homogenizer." Commonly during metamorphism, the increase in temperature and -pressure and presence of chemically active fluids severely alter the mineral compositions and textures of pre-existing rocks. As a result, in many instances, typical soft-rock stratigraphic- and sedimentologic analysis of metamorphic rocks is not possible.

Keep in mind that folding under metamorphic conditions commonly produces a penetrative mineral fabric with neocrystallized minerals (typically micas and amphiboles) aligned parallel to the axial surfaces of folds. Such penetrative metamorphic fabrics are called foliation, if primary, and schistosity, if secondary. Minerals can also become aligned in a linear fashion producing a metamorphic lineation. Such features can be useful in interpreting a unique direction of tectonic transport or flow direction. Because folds in metamorphic rocks are commonly tight- to isoclinal (high amplitude-to-wavelength aspect ratio) with limbs generally parallel to axial surfaces, a penetrative foliation produced during regional dynamothermal metamorphism will generally be parallel to the re-oriented remnants of stratification (except of course in the hinge areas of folds). Thus, in highly deformed terranes, a composite foliation + remnant compositional layering is commonly observed in the field. Departures from this common norm are important to identify as they tend to mark regional fold-hinge areas.

Tectonostratigraphic Units

In metamorphic terranes, tectonostratigraphic units can best be described as large-scale tracts of land underlain by bedrock with similar age range, protolith paleoenvironment, and structure. Such terranes are generally bounded by ductile-fault zones (mylonites), surfaces of unconformity, or brittle faults. Unravelling the collisional plate-tectonic history of mountain belts is greatly facilitated by identifying former cratonic (ancient crustal), continental-margin, continental-slope-, and rise, deep-oceanic, and volcanic-island tectonostratigraphic units. The major distinction in unravelling complexly deformed mountain belts is to identify former shallow-water shelf deposits (originally deposited on continental crust) and to separate them from deep-water oceanic deposits (originally deposited on oceanic crust). The collective adjectives miogeosynclinal (for the shallow-water shelf deposits) and eugeosynclinal (for the deep-water oceanic deposits) have been applied to the products of these contrasting depositional realms.

Geologic Dating of Episodes of Deformation

Geologists use many methods to establish the geologic date of deformation. These include analysis of surfaces of unconformity, obtaining the dates on formations containing pebbles- or inclusions of deformed rock, relationships to associated plutons, and radiometric ages on minerals that grew as a result of deformation.

Surfaces of Unconformity

Surfaces of unconformity mark temporal gaps in the geologic record and commonly result from periods of uplift and erosion. Such uplift and erosion is commonly caused during the terminal phase of regional mountain-building episodes. As correctly interpreted by James Hutton at the now-famous surface of unconformity exposed in the cliff face of the River Jed (Figure 32), such surfaces represent mysterious intervals of geologic time where the local evidence contains no clues as to what went on! By looking elsewhere, the effects of a surface of unconformity of regional extent can be recognized and piecemeal explanations of evidence for filling in the missing interval may be found.

Surfaces of unconformity resulting from erosion can be classified into three categories: (a) surfaces of angular unconformity, (b) surfaces of nonconformity, and (c) surfaces of disconformity (Figure 33). Along surfaces of angular unconformity (such as that James Hutton saw exposed in the banks of the River Jed), dipping strata below the surface have been truncated and thus angular discordance is present between the strata below- and above the surface of erosion. A surface of nonconformity separates sedimentary strata above from eroded igneous- or metamorphic rocks below. Surfaces of disconformity are the most-subtle variety; the separate subparallel sedimentary strata. They are commonly identified by paleontologic means, by the presence of channels cut into the underlying strata, or by clasts of the underlying strata in their basal part. The strata above a surface of unconformity may or may not include clasts of the underlying strata in the form of a coarse-textured, often bouldery basal facies.

Following the proposal made in 1963 by L. L. Sloss, surfaces of unconformity of regional extent within a craton are used as boundaries to define stratigraphic Sequences.

Dating Formations that Contain Pebbles- or Inclusions of Deformed Rock

In certain situations, it is possible to find pebbles- or inclusions of deformed rock in another formation that can be dated. The date of the formation containing the pebble or inclusion places an upper limit on the date of deformation indicated by the pebble. For example, pieces of Martinsburg slate have been found as inclusions in the Late Ordovician igneous rocks in northwestern New Jersey. This proves that the age of the slate is pre-Late Ordovician. In other cases, pebbles of mylonite might be found in a datable conglomerate and the age of the conglomerate thus marks an upper limit on the age of the mylonite.

Relationships to Associated Plutons

Commonly orogenic episodes are accompanied by plutonic activity. Where a pluton cuts a fault, for example, the pluton clearly is younger. The date on the pluton thus sets an upper limit on the age of the fault. Plutons can be dated directly by a radiometric age on minerals, a whole-rock age, or indirectly by crosscutting relationships with formations of the country rock or by finding pebbles of the pluton in younger formations.

Radiometric Ages on Minerals that Grew as a Result of Deformation

Dating deformation by radiometric ages on minerals that grew as a result of deformation is analogous to obtaining radiometric ages on minerals from a deformation-associated pluton, but need not always involve a pluton. In some cases, micas or other minerals recrystallized as a result of deformation and the radiometric date yields the date of recrystallization. Other kinds of minerals may grow in veins whose emplacement accompanied an episode of deformation.

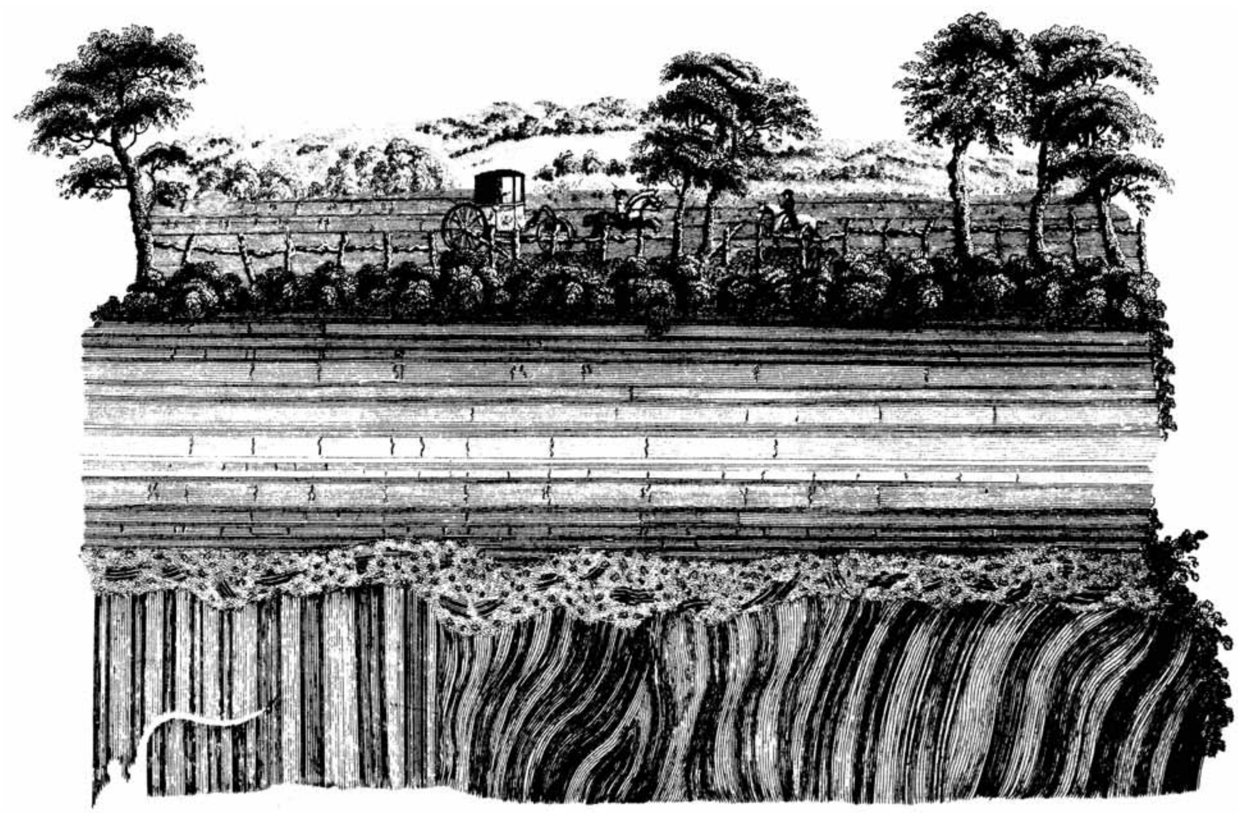


Figure 32. Unconformity with basal conglomerate along the River Jed, south of Edinburgh, Scotland. [James Hutton, "Theory (sic) of the Earth", 1795.]

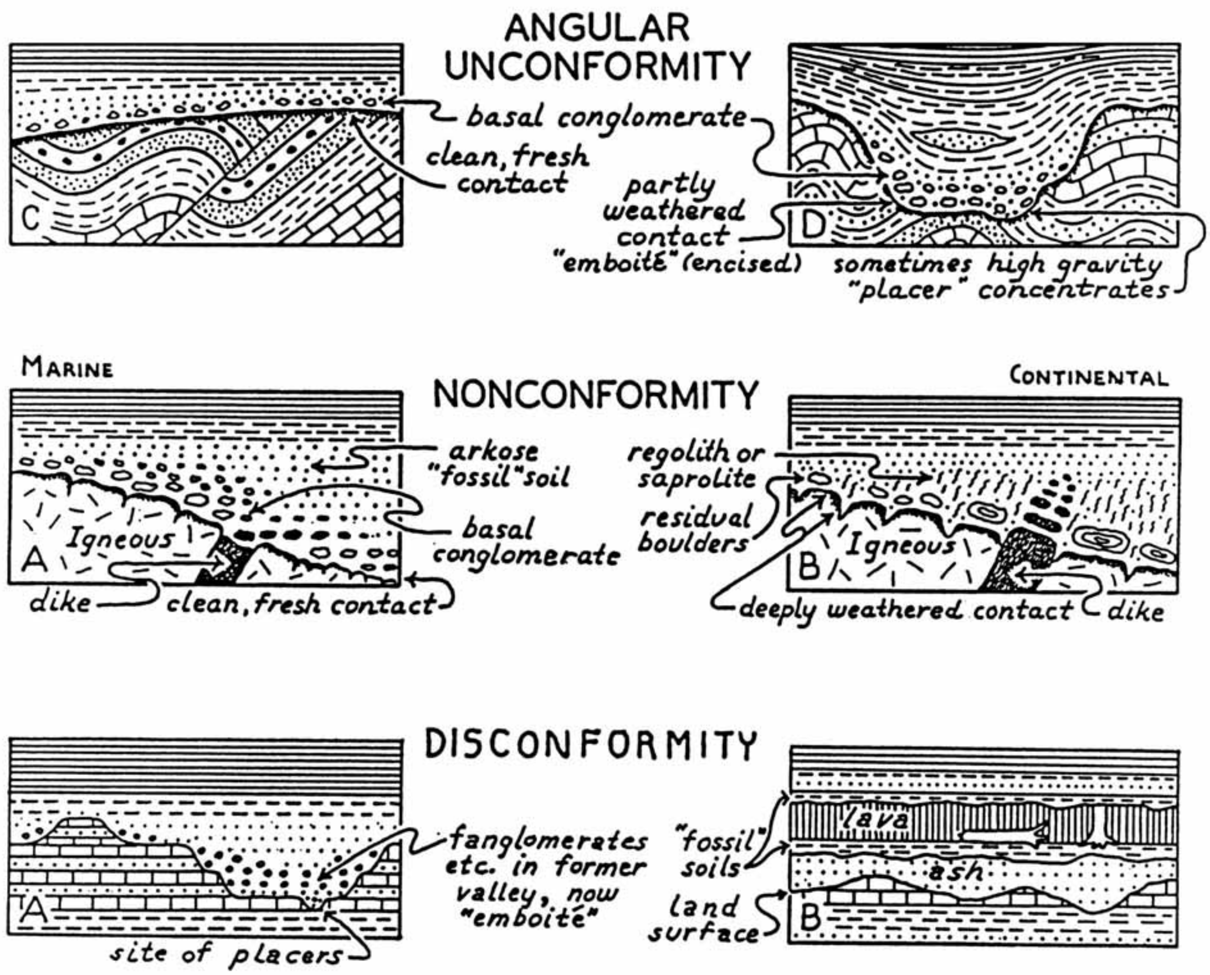


Figure 33. Varieties of geologic relationships along surfaces of unconformity, which mark gaps in the geologic record. (Drawings by Rhodes W. Fairbridge.)

BEDROCK UNITS ENCOUNTERED ON TRIP ROUTE

Layer I: "Basement Complex" (Proterozoic Z, Y and X)

The basement complex of northwestern New Jersey is part of a major tectonostratigraphic unit known as the Reading Prong massif (Figure 2). Paralleling the main trend of the core zone of the Appalachians, the Reading Prong trends northeasterly from Reading, Pennsylvania through New Jersey into New York as the Hudson Highlands. We have examined parts of this belt on many of our On-The-Rocks trips in the past (Bear Mountain Gneisses, Fordham Gneiss, Hudson Highlands Gneiss, etc.). Paleozoic sedimentary rocks occur in fault-bounded basins and interrupt the across-strike continuity of the Proterozoic rocks. Most interpretations of these occurrences would put the Paleozoic in fault-bounded grabens (down-faulted basins with normal faults at the boundaries). Modern views (and our views, as presented in Merguerian and Sanders, 1989f; 1995 Trips 9 and 36 to the Shawangunks and Bellvale Mountains) offer the suggestion that some of the Paleozoic strata are parts of upfaulted horsts in contact with downdropped remnants of one- or more formerly continuous low-angle thrust sheets.

The Proterozoic rocks of the Reading Prong and the Hudson Highlands, long considered to indicate greatly elevated parts of the "basement complex" underlying all the Paleozoic strata (and thus continuing indefinitely downward through the felsic-crust part of the continental lithosphere), are now thought to be parts of a vast allochthon or overthrust belt. According to the allochthon interpretation, as first proposed by Isachsen in 1964, the Proterozoic rocks do not extend indefinitely downward into the "ewige Tiefe," but rather end abruptly downward against a low-angle overthrust, beneath which are Paleozoic strata (and, of course, beneath them, the expected "basement complex"). The extent and date(s) of the overthrusting of Proterozic rocks over Paleozoic rocks (See Figure 2.) are topics now engaging the efforts of some of the current generation of Appalachian structural geologists.

The first proof of such overthrusting came to light about 100 years ago when the Lehigh Railroad excavated a tunnel through Musconetcong Mountain, New Jersey. Isachsen (1964, p. 822) cites Kümmel (1940) as his source for what the tunnel revealed, but Kümmel (1940) does not mention the tunnel. Instead, the correct citation should be Lewis and Kümmel (1915), not included among Isachsen's list of references, but listed in our reference section, of course (Figure 24).

Isachsen (1964) thought that the age of overthrusting had been Taconian (late Ordovician), but the current preference of A. A. Drake and associates, of the United States Geological Survey, based on extensive detailed mapping in eastern Pennsylvania and NW New Jersey, is Late Paleozoic ("Alleghanian," a term we prefer to cease using in favor of the prior term "Appalachian"). Thus, we keep open the idea that significant continentward overthrusting of basement occurred during the Late Ordovician Taconic orogeny, as demonstrated in southern New England along the fronts of the Berkshire and Green Mountains massifs, but suggest that another episode of cratonward basement and cover displacement may have happened late in the Paleozoic Era.

The Proterozoic rocks of the Reading Prong in the vicinity of Franklin, New Jersey consist of a wide variety of granitoid igneous rocks, metaigneous-, and metasedimentary rocks as described by Spencer and others (1908), Hague and others (1956), and more recently by Puffer (1980); Drake (1984, 1990); Drake, Hall, and A. E. Nelson (1988): and Drake, Aleinikoff, and Volkert, 1991a, b). Figure 34 displays a generalized section for the Proterozoic rocks. The oldest part of this sequence crops out in Pennsylvania as the Hexenkopf Complex (Drake, 1984) an ancient (Proterozoic X), highly metamorphosed oceanic suite consisting of mafic- and ultramafic rocks and chert. These rocks are overlain by the Losee Metamorphic Suite of New Jersey which is, in turn, overlain by Proterozoic Y metamorphosed quartzofeldspathic and calcareous rocks, known as the "Grenvillian" terrane farther north in the Adirondack Mountains of New York State. The Proterozoic Y rocks have been intruded by numerous syntectonic and post-tectonic granitoid- and syenitic intrusives (Figure 35).

Figure 34. Generalized columnar section of the metasedimentary and metavolcanic rocks of the Franklin-Sterling Hill area (Hague and others, 1956, fig. 18, p. 468.)

Locally, the Chestnut Hill Formation of Drake (1984), lies unconformably above the Proterozoic Y gneisses and granitoids, and consists of less-metamorphosed Proterozoic Z arkose, ferruginous quartzite, quartzite conglomerate, possible metarhyolite, and metasaprolite (Drake, 1990). The Proterozoic basement complex is unconformably overlain by deformed sedimentary rocks of the Kittitinny Supergroup.

The Proterozoic rocks surrounding the Franklin-Ogdensburg area consist of the Losee Metamorphic Suite whose type locality is the Beaver Lake Antiform near Losee Pond (now Beaver Lake on edge of map shown in Figure 36. The Losee, which also crops out to the west of Sterling Hill in the Pimple Hills, is interpreted as a metamorphosed volcano-plutonic pile consisting originally of dacite, splitic basalt, tonalite, and trondhjemite. Associated with the Losee are orthopyroxene-bearing granitoids known as charnockites. These unusual rocks were first identified and named from the tombstone of Job Charnock, the British founder of Calcutta, who died in 1693. Charnockites are felsic rocks consisting of 10 to 60% quartz; the proportion of alkali feldspar to total feldspar ranges from 35 to 90%. Charnockites form under conditions of high temperature and -pressure and may be either igneous- and/or metamorphic rocks.

Similar sequences of Proterozoic Y rocks are present in the Green Mountains of Vermont and in the Adirondacks of New York State. Most of the Proterozoic rocks we will examine today are part of the "Grenvillian" metasedimentary sequence developed unconformably above the Losee sequence. (See Figure 34.) The most- distinctive Proterozoic unit we will examine today is the Franklin Marble, host for the Franklin and Sterling Hill ore bodies. Below we discuss the geology and deformational history of the Proterozoic rocks in the Franklin-Ogdensburg area. The Proterozoic basement complex formed a unique cratonal substrate atop which Paleozoic sediments accumulated by Cambrian times as discussed below.

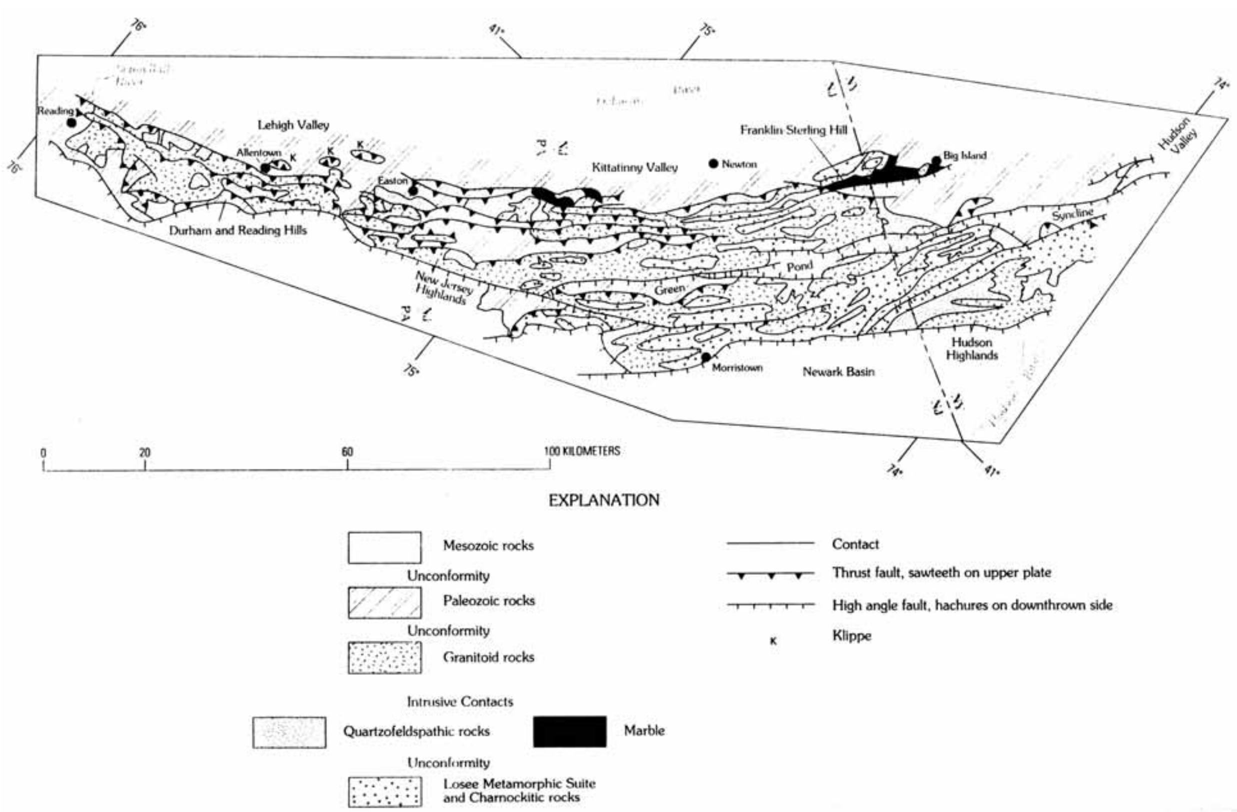


Figure 35. Generalized geologic map of the Durham and Reading Hills, New Jersey Highlands, and part of the Hudson Highlands (A. A. Drake, Jr., 1990, fig. 2, p. 27.)

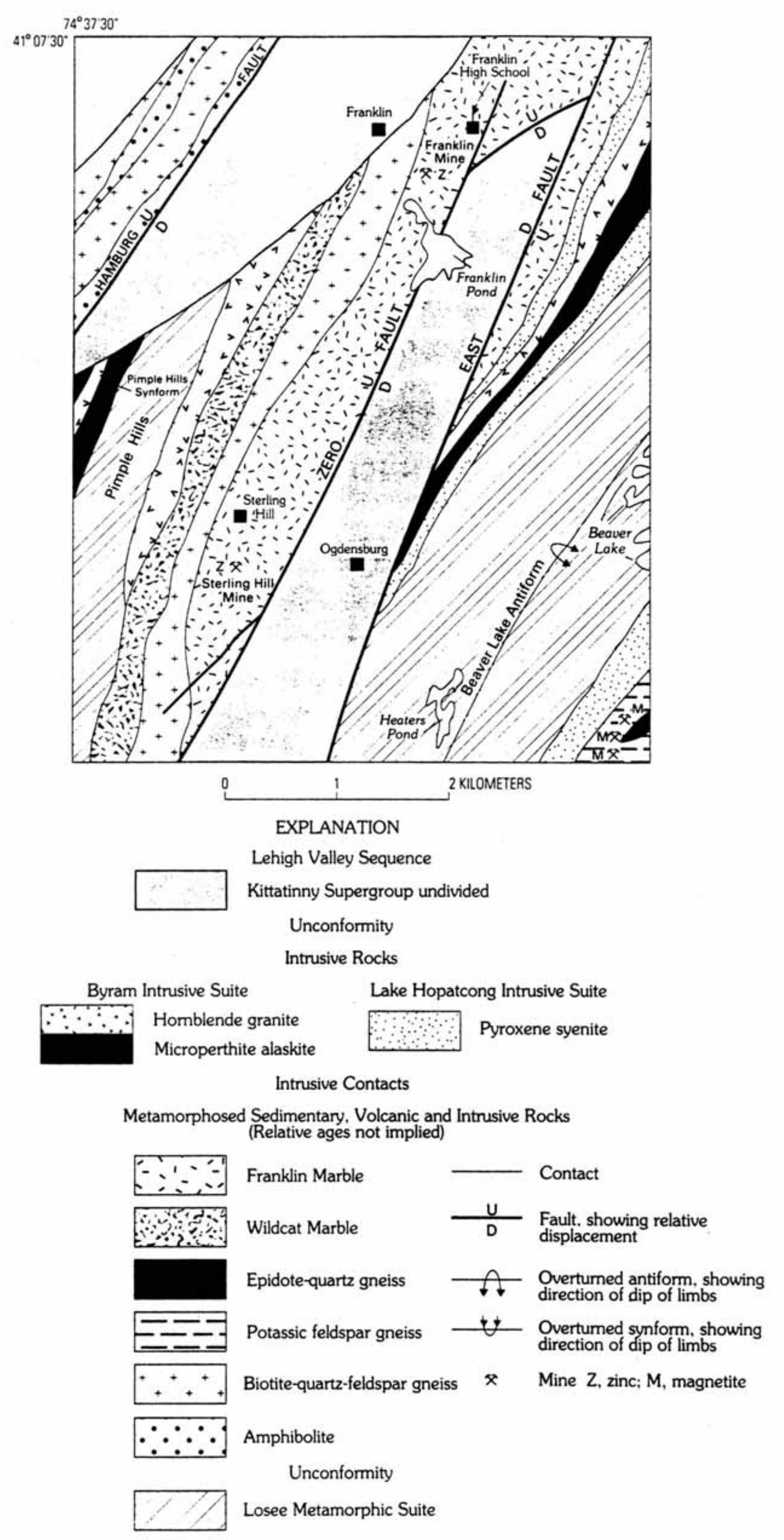


Figure 36. Generalized geologic map of the Franklin-Sterling Hill district. (A. A. Drake, Jr., 1990, fig. 3, p. 28.)

Layers IIA and IIB: Cambro-Ordovician Strata

Early in the Paleozoic Era, this part of the Appalachian region became the trailing edge of a continental plate, a passive continental margin. This tectonic setting persisted until the Taconian orogeny late in the Ordovician Period (Tables 1, 2). Interestingly, the current plate-tectonic passive-continental-margin setting of eastern North America [deformed Paleozoic and older basement covered by essentially nondeformed Mesozoic and younger sediments that were (and continue to be) deposited as the margin subsides toward an ocean basin to the east] more or less duplicates that of Early Paleozoic time (Figure 37).

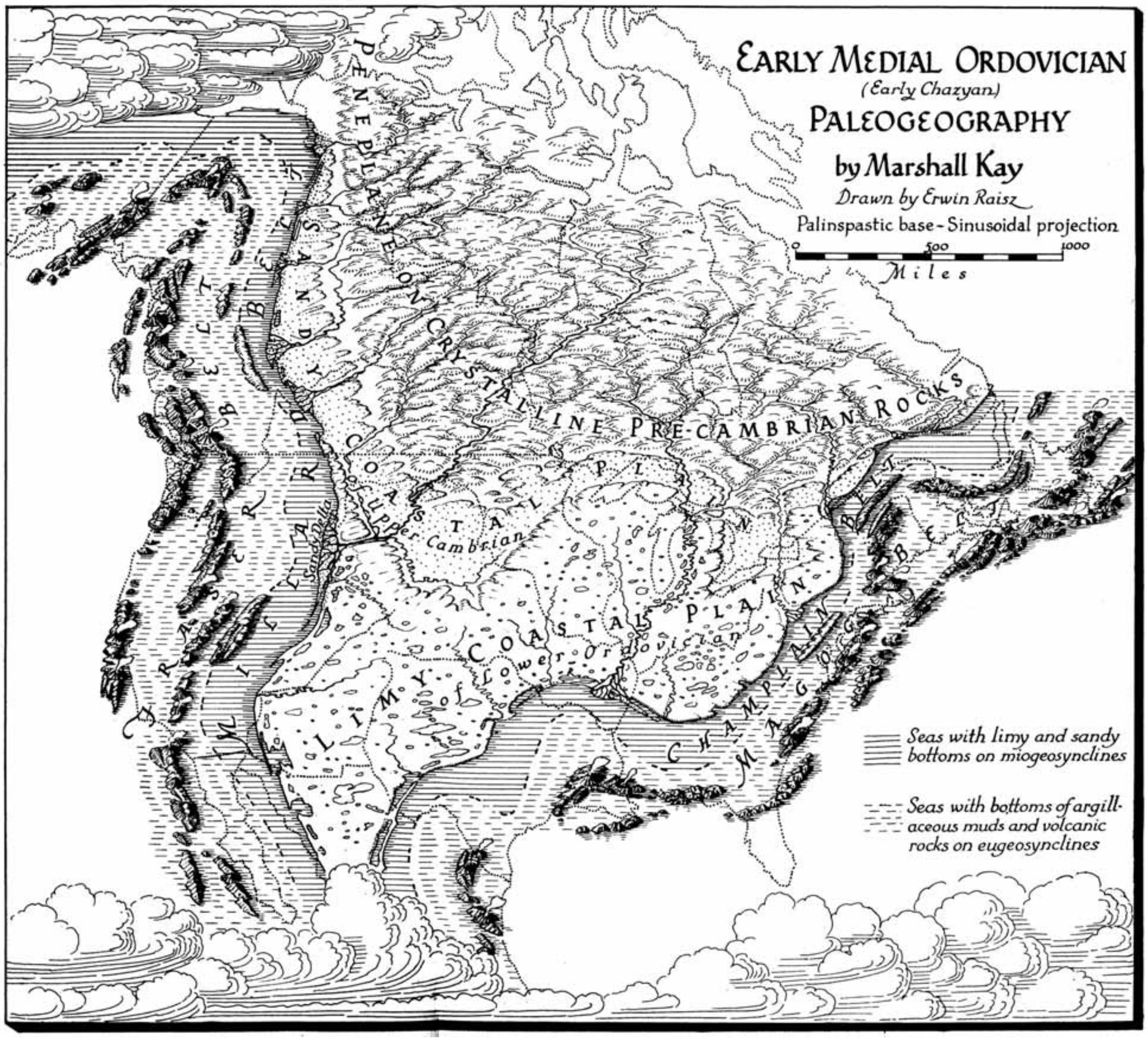


Figure 37. Paleogeographic reconstruction of North America as it is inferred to have existed during the Cambrian Period. Not shown are paleolatitudes and position of the Early Paleozoic Equator, which extended across what is now North America passing through Oklahoma, Kansas, and the Dakotas such that what is now east in the Early Paleozoic was south. (G. M. Kay, 1951, plate 1, facing p. 1.)

The Cambrian and Ordovician bedrock units (Layer II) underlying the Manhattan Prong and adjacent parts of central New Jersey consist of sedimentary rocks that formed near the Earth's surface. They began their geologic lives approximately 550 million years ago as thick accumulations of both shallow- and deep-water sediments adjacent to the Early Paleozoic shores of proto-North America. (See Figure 37).

Layer II can be divided into two sub-layers, IIA and IIB. The older of these, IIA, represents the ancient passive-margin sequence of the proto-Atlantic (Iapetus) ocean. In turn, these rocks can be subdivided into two facies that differ in their original geographic positions with respect to the shoreline and shelf. A nearshore-shelf facies [Layer IIA(W)] was deposited in shallow water and is now represented by the Cambrian Hardyston Quartzite in New Jersey (Stop 5), the Lowerre Quartzite and Cambro-Ordovician Inwood Marble in New York City, the Cambro-Ordovician Kittitinny "Blue" Limestone in New Jersey (Stops 1 and 4), and the coeval Cheshire Quartzite and Stockbridge Marble sequence in western Connecticut and Massachusetts. These strata were deposited first as sandy and then as limey sediments in an environment closely similar to that of the present-day Bahama Banks. The chief difference is that the salinity of the Paleozoic seas exceeded that of normal seawater (inferred from the features of the dolostones).

Farther offshore, fine-grained terrigenous time-stratigraphic equivalents of the shallow-water strata (shelf sequence) were evidently deposited under deep water on oceanic crust [Layer IIA(E)]. This sequence, not a focus of today's trip, is also of Cambrian to Ordovician age and is known as the Taconic sequence in upstate New York, as units Ꞓ-Om and Ꞓ-Oh of the Manhattan Schist(s) in New York City and vicinity (Figures 38, 39) according to CM (OTR Trips 3 and 16: Manhattan and the Bronx, Merguerian and Sanders, 1991b; OTR Trips 21 and 26: Cameron's Line and the Bronx Parks, Merguerian and Sanders, 1991c, 1993a; OTR Trip 28: Southern Central Park, Merguerian and Sanders, 1993c).

Layer IIB consists of younger, mostly terrigenous, strata that were deposited unconformably above the products of the western shallow-water platform [Layer IIA(W)]. In eastern New York State, the metamorphosed equivalents of these terrigenous rocks are mapped as the Walloomsac Schist and Manhattan Formation.

We have mentioned the rocks of Layer II in the Manhattan Prong, where they have been subjected to Taconic overthrusting and high-grade metamorphism. In the belts northwest of the Reading Prong-Hudson Highlands, these rocks have been folded and faulted, but never subjected to the temperatures that metamorphose rocks. Moreover, throughout most of the Appalachian Great Valley, no Taconic klippen are present. The same general two-fold subdivision of predominantly carbonates below and predominantly terrigenous rocks above can be recognized. In New Jersey, the names for these formations are, from base upward: Hardyston (Lower Cambrian clastics, equivalent to the Poughquag Quartzite and Lowerre Quartzite), Kittatinny Supergroup (the Cambro-Ordovician carbonates equivalent to the Wappinger of New York and also to the Inwood-Stockbridge marbles), regional unconformity, Jacksonburg Limestone (equivalent to the New York Balmville Limestone), and the Martinsburg Formation (equivalent to the Hudson River "Shales," a correlation suggested by faunal-, physical-, and chemical evidence.

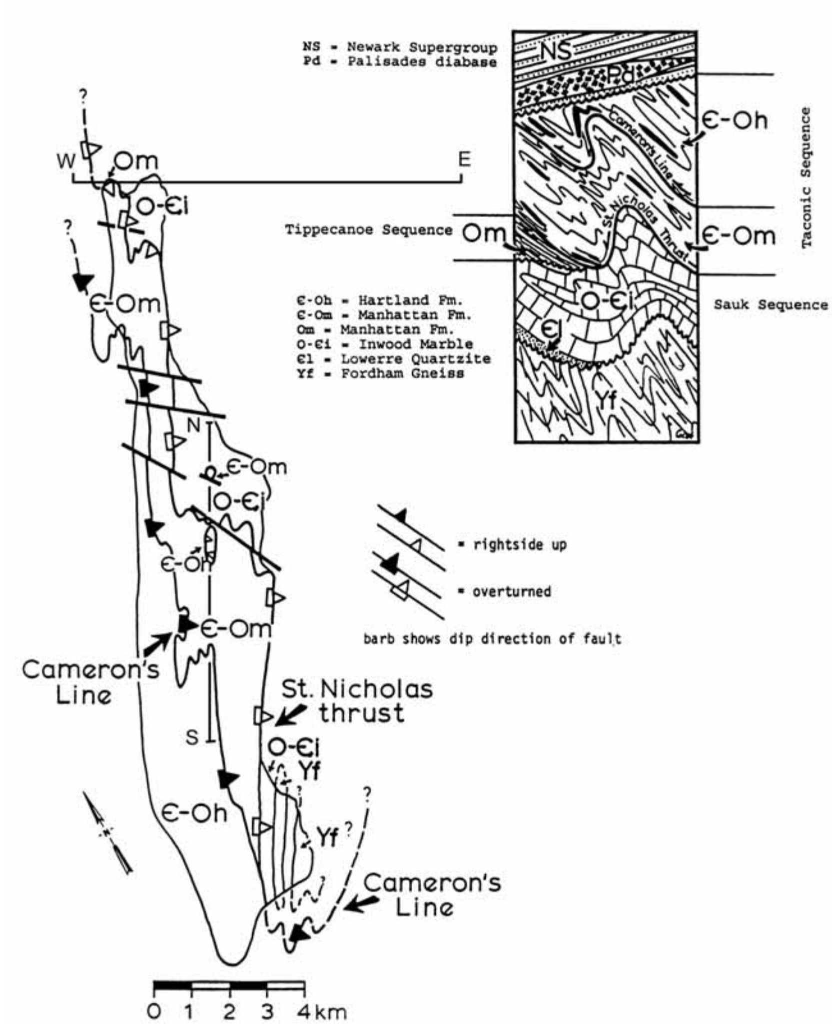


Figure 38. Geologic map of Manhattan Island showing a new interpretation of the stratigraphy- and structure of the Manhattan Schist. (Drawn and mapped by Charles Merguerian.)

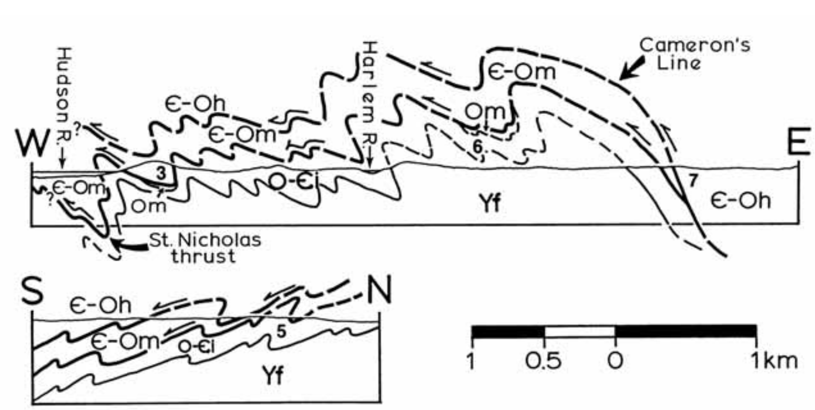


Figure 39. Folded overthrusts, Manhattan Island. Symbols defined on Figure 38. (Charles Merguerian, unpublished data.)

In the region of our field trip, these rocks were folded and eroded several times. Initially, the Cambro-Ordovician dolomitic carbonates were elevated and gently folded. The overlying limestone filled local sinkholes and rests on various units. During the Taconic orogeny, the folding was more intense and, the erosion cut more formations than during the Medial Ordovician. Accordingly, the basal unit of Layer III (Lower Silurian Green Pond or Shawangunk Conglomerate) rests on any of these units, even on the Proterozoic "basement" (Finks and Raffoni, 1989).

On our trip we will visit (Stop 1), a new roadcut (near Sparta, New Jersey, where part of the Cambro-Ordovician carbonate succession displays numerous features made by a peritidal environment. Present are dolomitic rocks that formed from what were originally calcium-carbonate muds and -sands. Chert is locally abundant. Finally, as a result of deep burial, some layers have been subjected to pressure solution, as is evidenced by the numerous stylolites on several scales.

Layer III: Silurian and Devonian Strata

The rocks of Layer III are not at center stage on this trip. We will briefly examine rocks of the Green Pond Conglomerate at Stop 7 (time permitting). In northwestern New Jersey the Green Pond consists of purple-red conglomerate interbedded with and grading upward into purple-red sandstone. The conglomerate has a quartz cement with pebbles, up to 8 cm, consisting of white quartz, chert, red sandstone, and shale. The stratigraphic succession that has been established in the eastern belt (Layer IIIE, Table 2) begins with the Lower Silurian Green Pond Conglomerate and ends with the Middle Devonian Schunemunk Conglomerate. We will only examine the lowest part of this succession.

A renewed interest in the structural geology of the eastern belt of Layer III has developed on the part of investigators studying the features made as the rocks were deformed (i. e., strained). The latest wrinkle is that "flower structures" (Figure 40) are present along the SE side of the Reservoir fault zone, which forms the border of the western belt of the Green Pond outlier in NW New Jersey and which has been inferred to display significant right-lateral strike-slip movement. Latest movement on the Reservoir Fault has been inferred to be of Late Paleozoic age, although the constraints listed range from post-Medial Devonian to Triassic (Malizzi and Gates, 1989). JES finds this evidence for right-lateral strike-slip movement of more than casual interest in view of the JES "minority-of-one" interpretation of the strike-slip offsets on the Hopewell and Flemington faults that cut the Newark and associated strata in the Delaware River Valley and adjacent areas (Sanders, 1962b; Merguerian and Sanders 1993c OTR Trip 27, Del Valley, Figure 41). Not much straining of geologic credulity is required to connect the Flemington fault (with its JES-inferred 19 km of right-lateral strike-slip displacement accompanying a dip-slip shift of approximately 3 km) and the Reservoir fault. If this intuitive leap by JES proves to be correct, then the age of the deformation on the Reservoir fault becomes Medial Jurassic and the combined Hopewell-Reservoir fault assumes a big-league status not heretofore imagined.

The most-prominent unit of Layer IIIW is the ridge-making Shawangunk Formation (conglomerate and sandstone), of Early Silurian age. Along the northwest side of the

Appalachian Great Valley, this formation forms a wall-like ridge in which the strata dip to the NW. The younger strata share this direction of dip, but upward, the dip becomes less and less. Beneath the Catskill and Pocono plateaus, the strata are essentially horizontal. This NW dip grading northwest into horizontal strata has been taken to mean that the strike ridge marks the NW limit of deformation in the Appalachian chain. Granted the possibility of large-scale over-thrusts of Late Paleozoic age, then this NW dip may result from a ramp-related anticline and be the NW limb of such a structure (Sanders, 1983; See Figure 28.)

Another noteworthy aspect of the Silurian strata is their thinning toward the northeast (Merguerian and Sanders, 1990a, 1994b; Figure 42). Shawangunk Mountain disappears northeastward because of the overlapping out of the basal Shawangunk Conglomerate-Sandstone. This disappearance was the result of a comparatively high area on the Silurian sea floor. It implies that a transverse basement high crosses the Appalachian region, possibly centered on Albany, New York. North of Rosendale, New York, where the Shawangunk Formation is absent, the "big" mountains of the central Appalachians give way to the "Little Mountains east of the Catskills." Between Rosendale and Albany, the thickness of the Silurian strata is only a few meters. The Devonian strata underlying the Catskill Plateau are virtually in contact with the Ordovician beds.

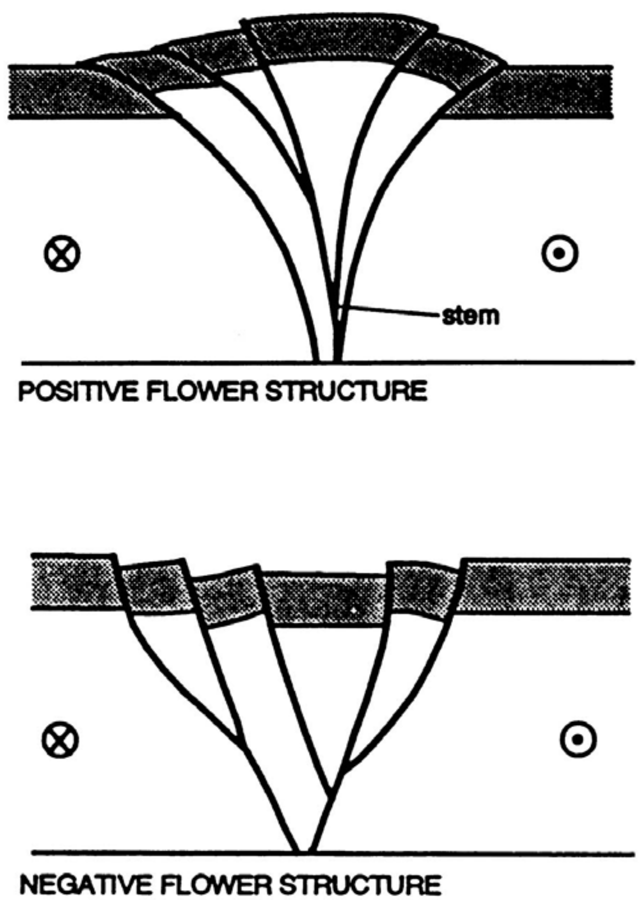


Figure 40. Sketches of "flower structures," upward-diverging faults associated with a strike-slip fault. (N. H. Woodcock and C. Schubert, 1994, fig. 12.13, p. 259.)

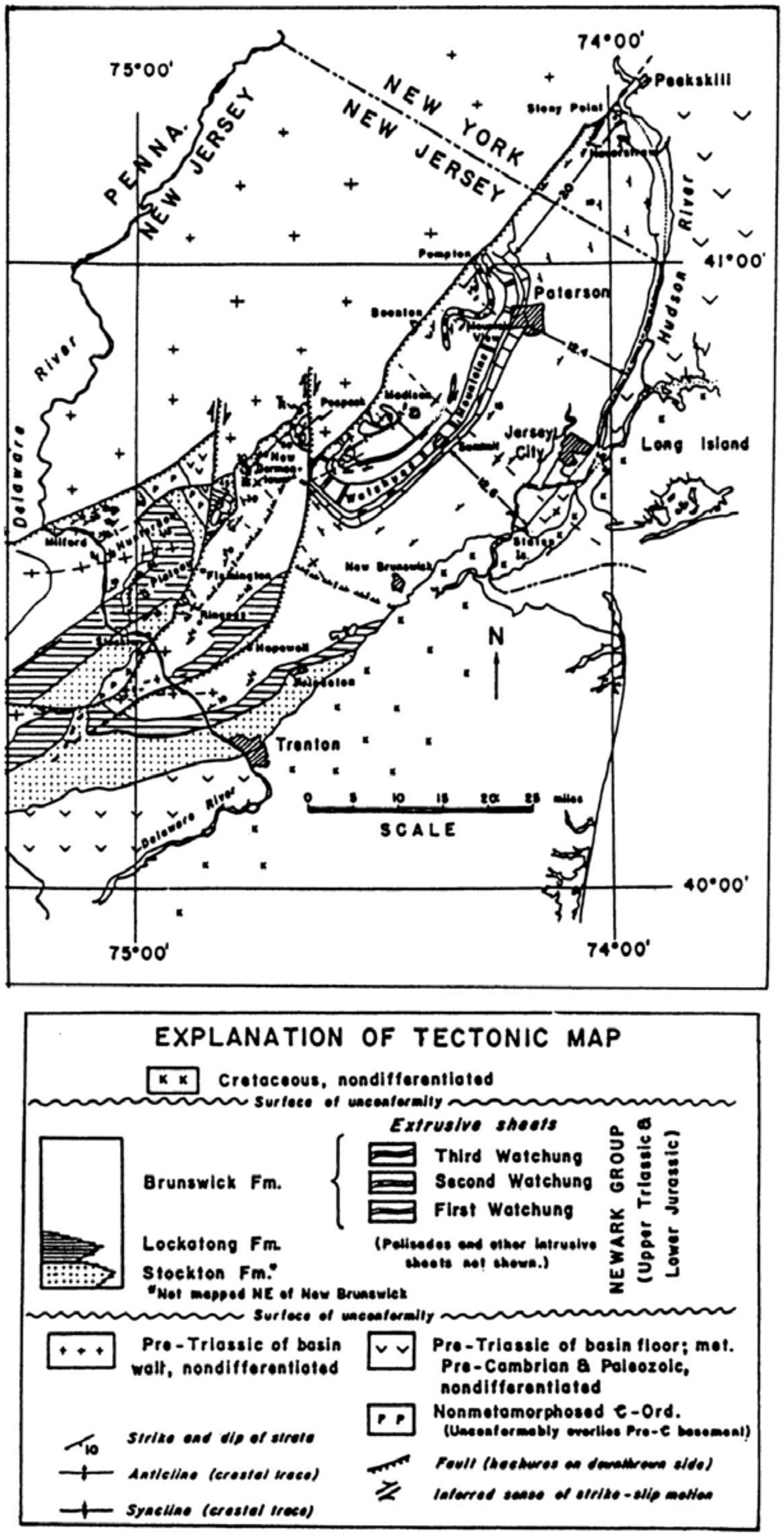
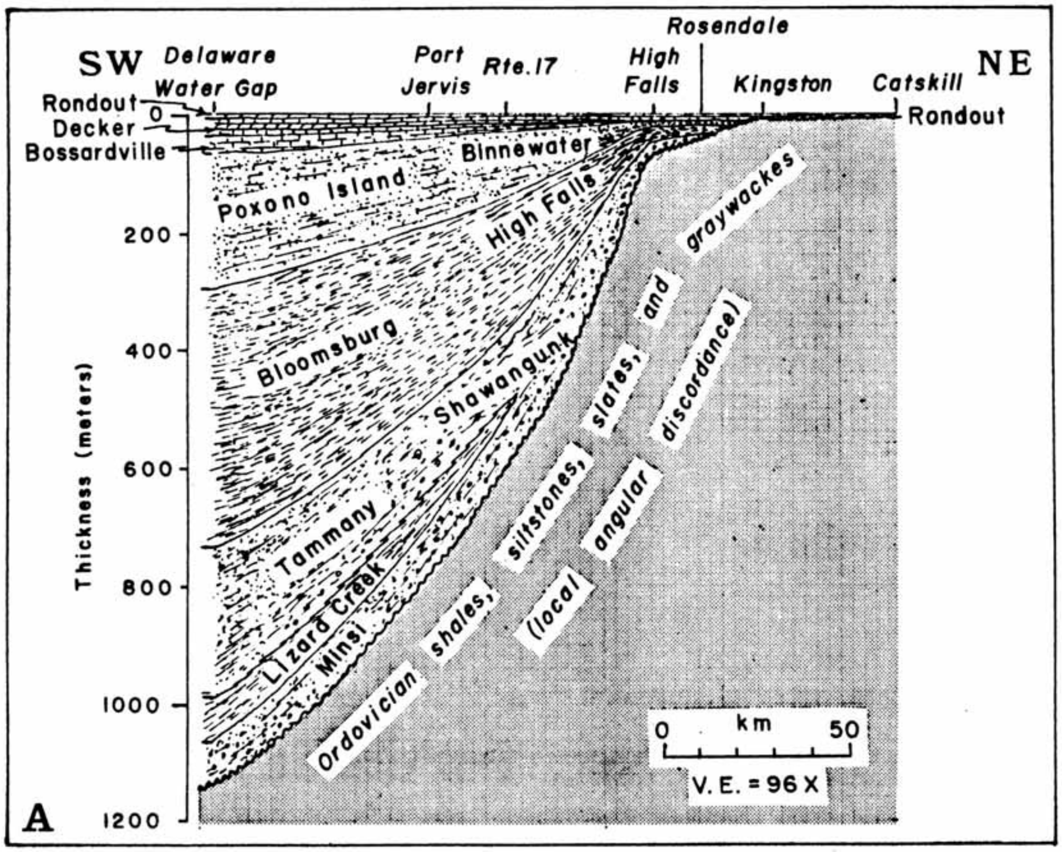


Figure 41. Tectonic map of Newark basin in New Jersey, with Hopewell and Flemington faults shown as displaying significant right-lateral strike-slip offsets, according to JES. If these faults are correctly shown here, then they probably extend to the north, and perhaps curve around to become parallel to the NE-SW trend of the Appalachian structures. On the EXPLANATION, the pre-Olsen stratigraphic usage is shown.



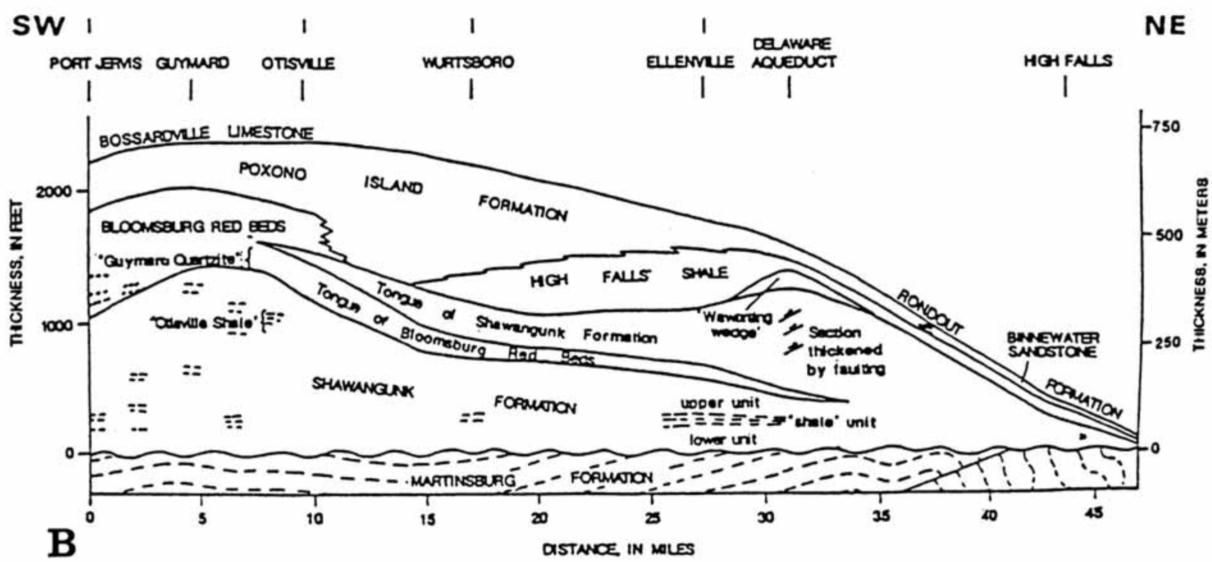


Figure 42. Two contrasting presentations of the northeastward, along-strike thinning of the Silurian strata, Kittatinny-Shawangunk Mountain belt.

A. Capping carbonates shown as horizontal. (J. E. Sanders, in G. M. Friedman, J. E. Sanders, I. P. Martini, and others, 1982, fig. 7. p. .)

B. Relationships shown with base horizontal. (A. R. Prave, M. L. Alcala, and J. B. Epstien, 1989, fig. 2, p. 123.)

Finally, a few words about the paleogeography and environments of deposition. Paleogeographic reconstructions indicate that the Silurian Equator passed through New York State. Moreover, the conditions in the equatorial sea fluctuated within a wide range. At times, great floods of sediment from the E were transported by streams across fans to deltas and this sediment pushed the shoreline westward. At other times, the sea submerged the alluvial tracts. A notable feature of the terrigenous sediment, especially during the Early and Medial parts of the Silurian Period, was an enormous abundance of quartz, ranging in size from pebbles to silt. Although deep burial doubtless contributed to the dissolution of easily dissolved minerals, such as feldspar, it is still remarkable that so much sand-size and coarser quartz was spread throughout such a vast area and to the thickness of many tens of meters. The sheet of Silurian sand extends unbroken from New York to Tennessee and has been found in the subsurface as far west as eastern Ohio (Figure 43).

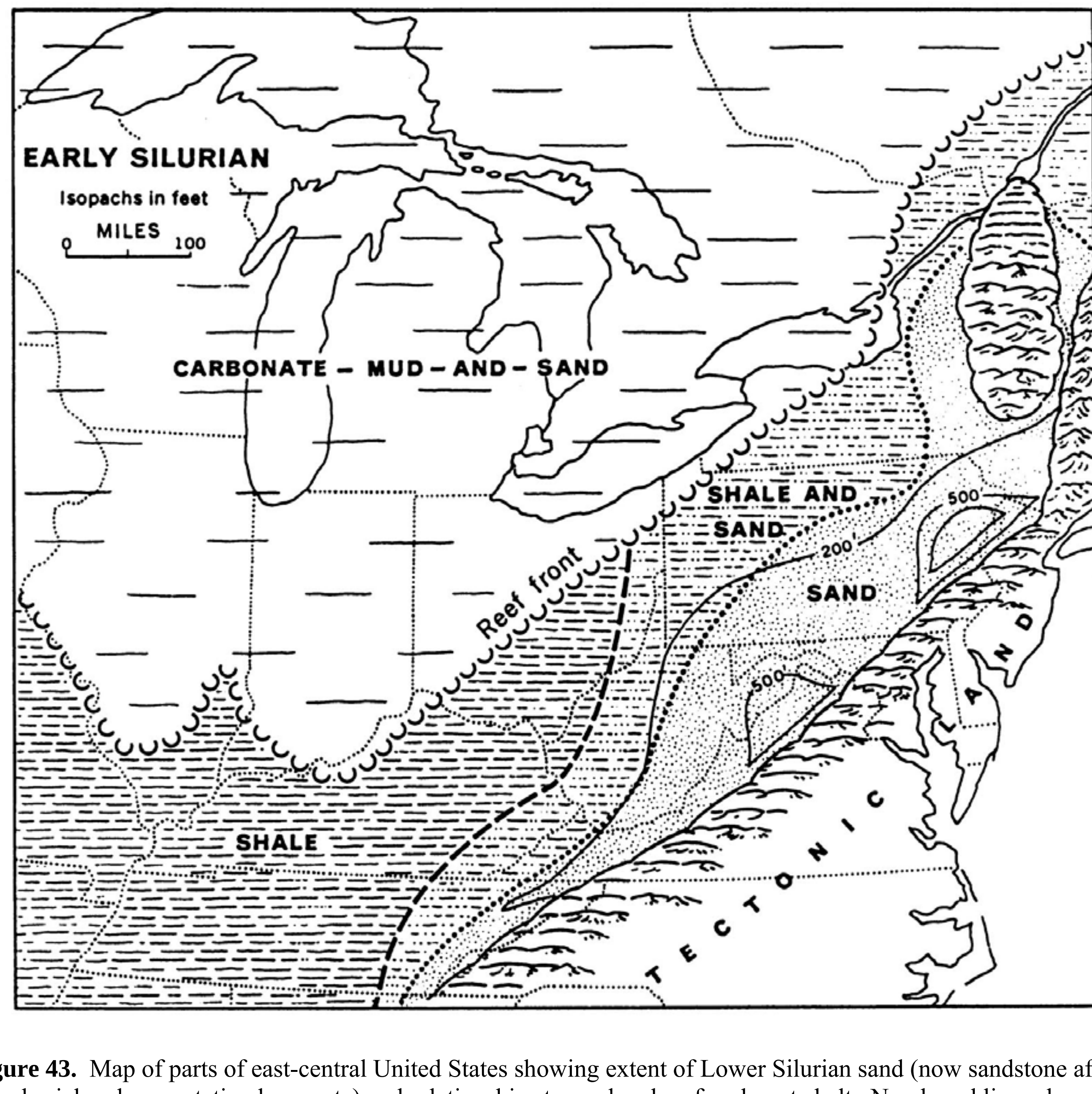


Figure 43. Map of parts of east-central United States showing extent of Lower Silurian sand (now sandstone after deep burial and cementation by quartz) and relationships to mud and reef-carbonate belt. Numbered lines show thicknesses in feet. (G. M. Kay and E. H. Colbert, 1965, fig. 10-12, p. 192.)

GEOLOGY OF FRANKLIN FURNACE, NEW JERSEY

Ask any mineral collector where the most-phenomenal assemblage of minerals can be found in a small area and the response will undoubtedly be: "Franklin Furnace, New Jersey" (unless the mineral collector is a wisecrack and names the Smithsonian where George Roebling deposited his vast collection to start them off!). Surely, with roughly 300 reported species, more minerals have been recorded from the Franklin area than any place in the world with at least 20 minerals unique to the deposit. If hosting roughly 20% of all known minerals in one place were not enough, Franklin also boasts the world's most-spectacular fluorescent minerals with more than 60 varieties known and described, largely by amateur mineral collectors like yourselves. Tables 3 and 4 list by name and fluorescent coloring these unique mineral species and, for reference, the most useful and comprehensive work on the subject is by Gleason (1972).

Short-wave (2537 nanometers) radiation yields the best results from the Franklin-Sterling Hill suite although long-wave (3660 nanometers) radiation produces an effect on some species. The dominant minerals that show spectacular color are the manganoan calcite (white, cream, yellow, orange, red, green, and pink fluorescence), smithsonite (yellow), and willemite (green, yellow-orange, and yellow fluorescence) although many, many more fluoresce (Tables 3 and 4).

Fluorescence, and its allied physical property phosphorescence, result from the presence of loosely held electrons in the outer electron shells of elements such as, but not limited to, manganese. In the presence of an energy source, a UV lamp producing short- or long-wave radiation, electrons become over excited and leap, upon absorption of energy, to higher electron energy levels. After a number of electrons make the jump an equilibrium is established between jumpers and those that choose to return back to their former (lower-energy) electron sites. This "jump back" results in the production of visible light with the color corresponding to the rate and degree of jumping.

Phosphorescence is the ability of some minerals to give off visible light even after the energy source has been removed. Thus, if a delay in "electron jump shut-off" by procrastinating electrons occurs, the mineral will continue to glow in the dark. You will marvel at these phenomena at the Franklin Mineral Museum display.

Let us now draw our attention to the history of the Franklin Furnace Mining District and a discussion on the geology and genesis of the ores, the latter a controversial, unsettled subject. The following draws heavily, if not bordering on plagiarism, from the following sources which can be looked up and hunted down from the reference list: Spencer and others (1908), Palache (1935), Frondel (1972), Metsger (1990), Drake (1990), Leavens and Nelen (1990), and Johnson and others (1990).

The east limb of the orebody at Sterling Hill cropped out boldly on a hillside west of the Wallkill Valley (present site of Sterling Hill Mine headframe) and the Franklin orebody originally cropped out on Mine Hill. (See Figure 1.) Thus, discovery of these ores was not difficult by modern standards. The oldest reported workings of the district, from tree-ring studies, indicate that ore was mined prior to 1739, probably by Dutch settlers who operated a copper mine near the Delaware Water Gap, Pennsylvania, in the interval from 1640 to 1657.

Pinger (1950) suggested that the Dutch mined hemimorphite (zinc-rich saprolite) from the top of the orebody at Sterling Hill for use in the production of brass. The Reading-Hudson Highland Prong is well known for its iron deposits and the earliest mining in the region (near Sparta) was directed toward that end (Figure 44). The first iron smelter (or furnace) was built before 1787 in Sparta by Robert Ogden, after whom Ogdensburg is named. An iron forge was built in Franklin, named incidentally after William Franklin, son of Benjamin Franklin, in about 1765 and a smelting furnace was added in 1770. The forge and furnace were located west of the dam on Mine Pond but was covered in the 1930's (See Figure 1.) to build a small park. These early miners worked the magnetite vein (Pikes Peak and Longshore Mines) that cropped out to the west of the Franklin orebody. Thus, the name Franklin Furnace was founded on the presence of iron ore in the region. A large, modern blast furnace was built in the area in 1874 and continued operation until 1906.

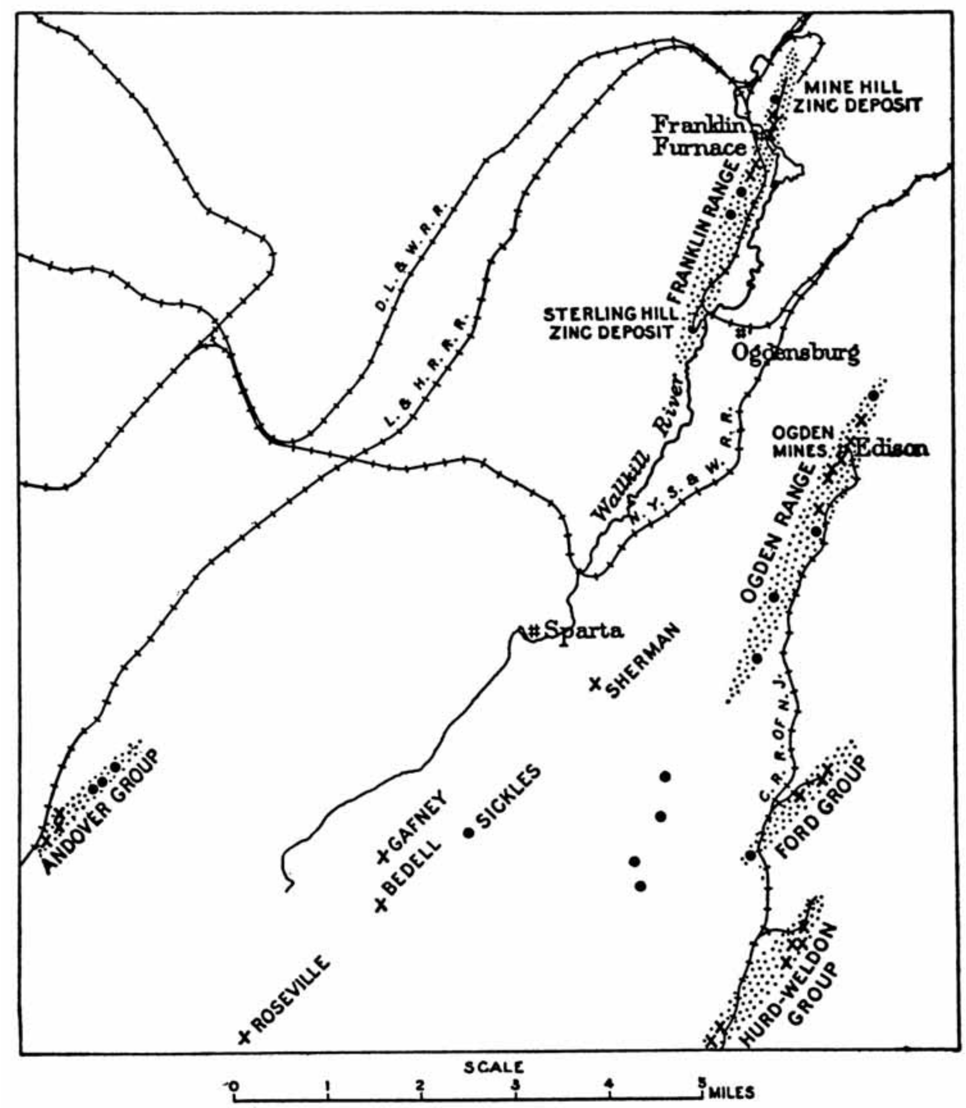


Figure 44. Sketch map showing the distribution of ore ranges south of Franklin Furnace. (A. C. Spencer, H. B. Kümmel, J. E. Wolff, R. D. Salisbury, and C. Palache, 1908, fig. xx, p. yy.)

Sterling Hill was named after Lord Stirling, originally known as William Alexander (1726-1783), an American patriot born in New York City. He adopted the title Lord in 1756 having laid claim to the Earldom of Stirling, in Scotland, to which his father was heir. He was an officer in Washington's army, and found himself in possession of extensive estates in New York and New Jersey and was active in developing iron mines in Sussex County. He owned the Sterling Hill mine from 1761 to 1776, and made numerous attempts at developing and smelting the ores. Early mining efforts at the Franklin and Sterling Hill mines were hampered by the difficulty in smelting the Mn, Zn, Fe ores as the combination produced a refractory ore that was difficult to purify.

The Franklin-Sterling Hill orebodies are situated in the Franklin Marble belt which is located on the northwest edge of the Reading Prong roughly 50 miles from New York City. (See Figure 36.) The Franklin Marble, as discussed earlier, is part of a diverse sequence of metamorphic- and igneous rocks of Proterozoic Y age that were subjected to intense regional metamorphism of sillimanite grade and intruded by a host of synkinematic and post-tectonic intrusive rocks. The Proterozoic (or "white") marble is faulted against the Cambro-Ordovician (or "blue") marble of the Kittatinny Supergroup along the Zero Fault and the Rutherford Cross Fault (Stop 4) on the west side of the Wallkill valley (Figure 45). Palache's (1935) map and geologic sections of the Franklin orebody (redrafted from Spencer) are reproduced in Figure 46. Note the northeast trend of the geologic units and their fault-bounded relationships. The overall shape of the ore-bearing zone is shown in a stereogram in Figure 47. The Proterozoic rocks consist of interlayered mafic and felsic gneiss and the Franklin Limestone (marble). The Paleozoic units are the Kittitinny Supergroup and underlying Hardyston Quartzite. All of these metamorphic rocks are cut by numerous intrusives ranging in composition from felsic pegmatites to mafic- and alkalic dikes.

The structure of the Franklin orebody is one of a synformal fold that plunges northeast at an angle of roughly 25° (Figure 48). The trough of the plunging synform crops out at Mine Hill (See sections C-C', D-D', and E-E' in Figure 46 for down-plunge projections of synformal structure). The overall synformal shape has, in the view of Metsger, resulted from negative diapirism. That is, downward sinking of the dense, metalliferous ores into a lower-density marble during plastic deformation that resulted in flow in the Franklin Marble. One question that remains to be answered is whether the Franklin Marble acted as a ductile solid or whether it actually became a fluid and moved as a liquid carbonate "magma".

The structure of the Sterling Hill orebody is much-more complex than the body at Franklin and occurs as a delicately folded synform that plunges steeply toward the northeast. Figure 49 is a detailed geologic map of the regional geologic relationships of the Franklin Sterling Hill area and shows that both orebodies lie west of the Zero Fault and are developed in the Franklin Marble. A detailed geologic map (Figure 50) and geologic section (Figure 51) show the intricate details of the ore zone of the Sterling Hill orebody and the subsurface distribution of units and their relationship to the Zero Fault. The mineral composition of the orebodies is in accord with the high degree of regional metamorphism of the area (sillimanite grade). The degree of ore remobilization during Paleozoic orogenesis and the nature of ore genesis are questions that still prevail today. In the following section, we briefly discuss these problems.

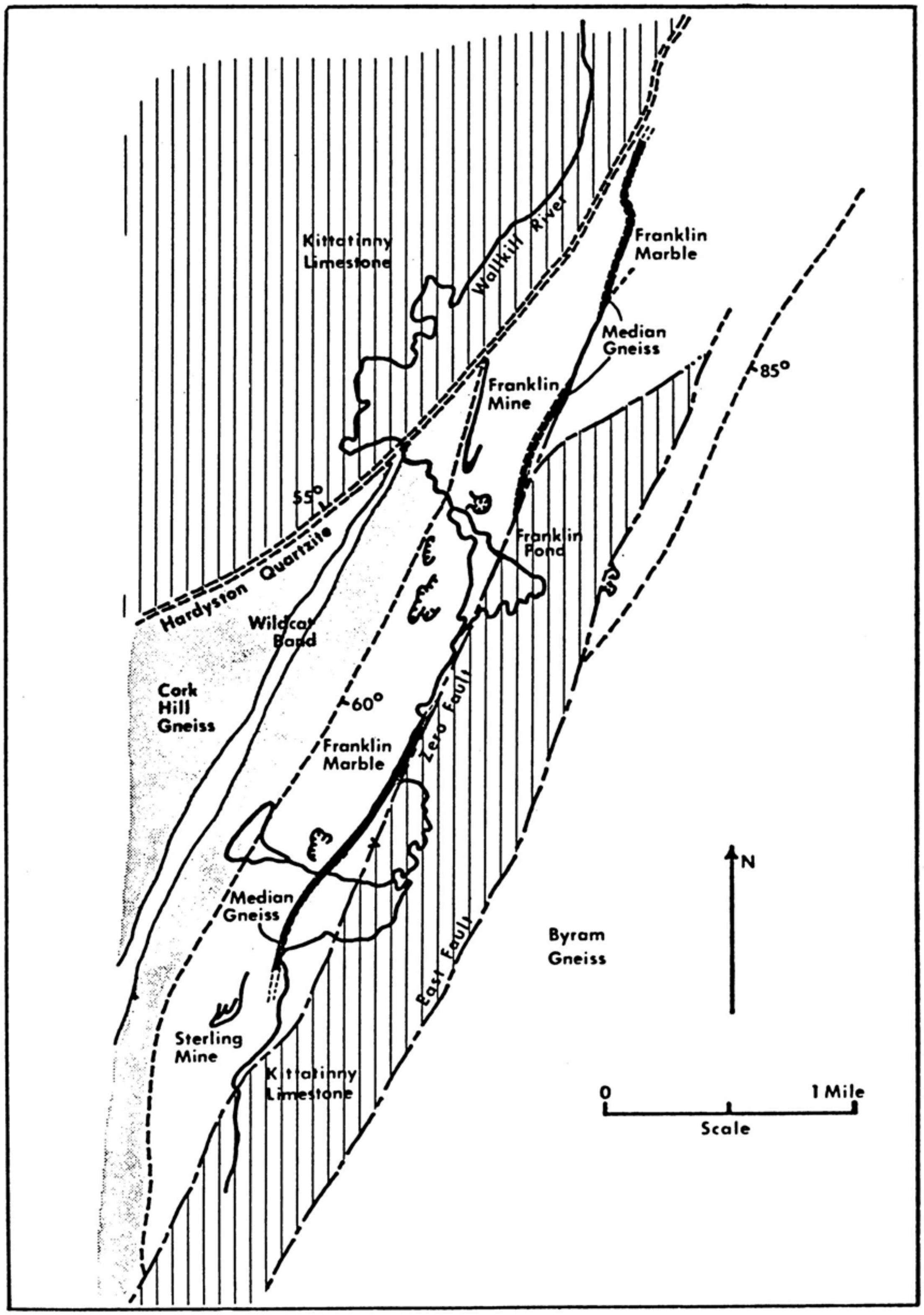


Figure 45. Sketch map of the Franklin-Sterling Hill area based on map of A. Pinger (1950). (C. Frondel and J. L. Baum, 1974, fig. 1, p. 159.)

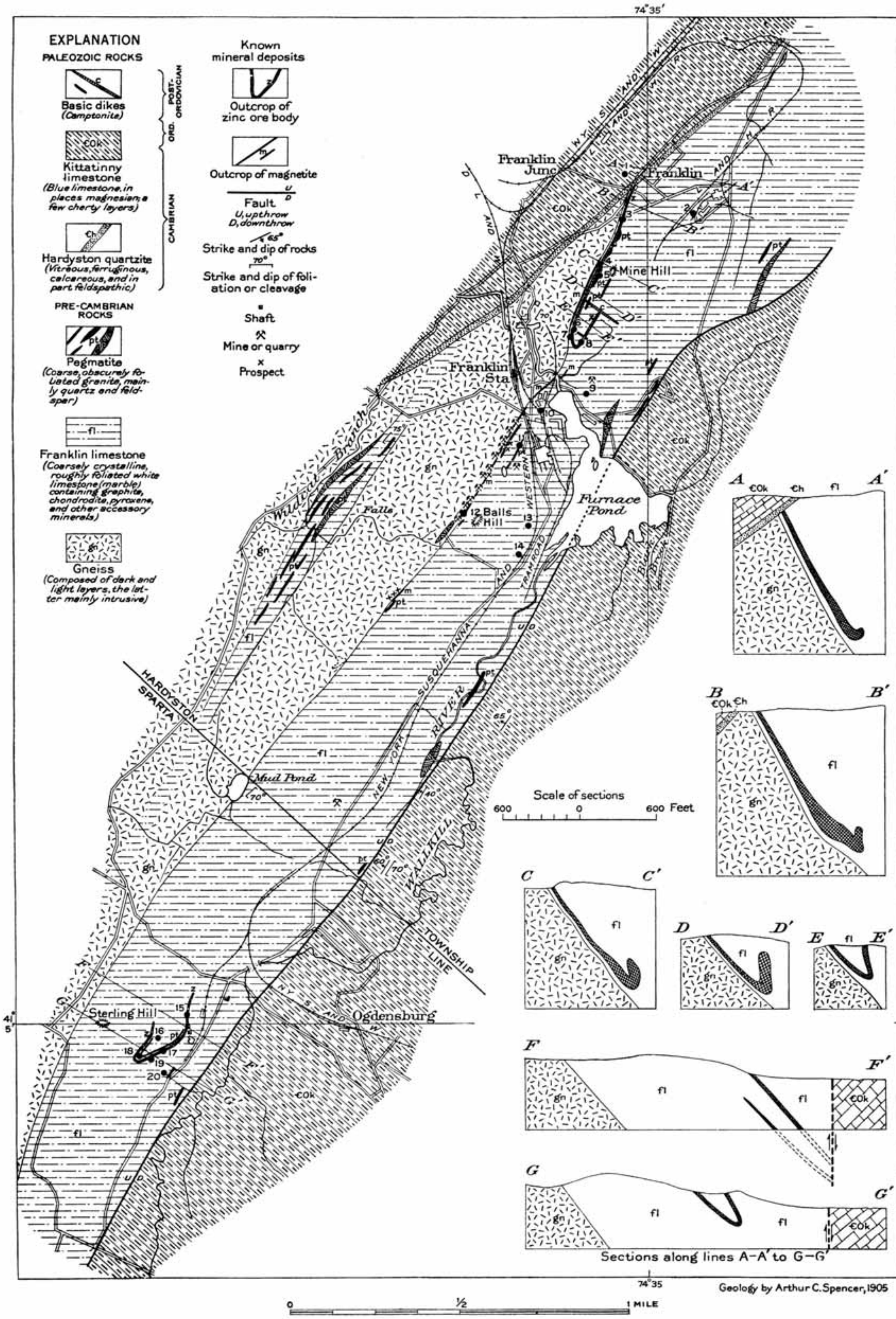


Figure 46. Geologic map of the Franklin Mining District showing sites of principal mineral localities. (C. Palache, 1935, plate 1, p. 18.)

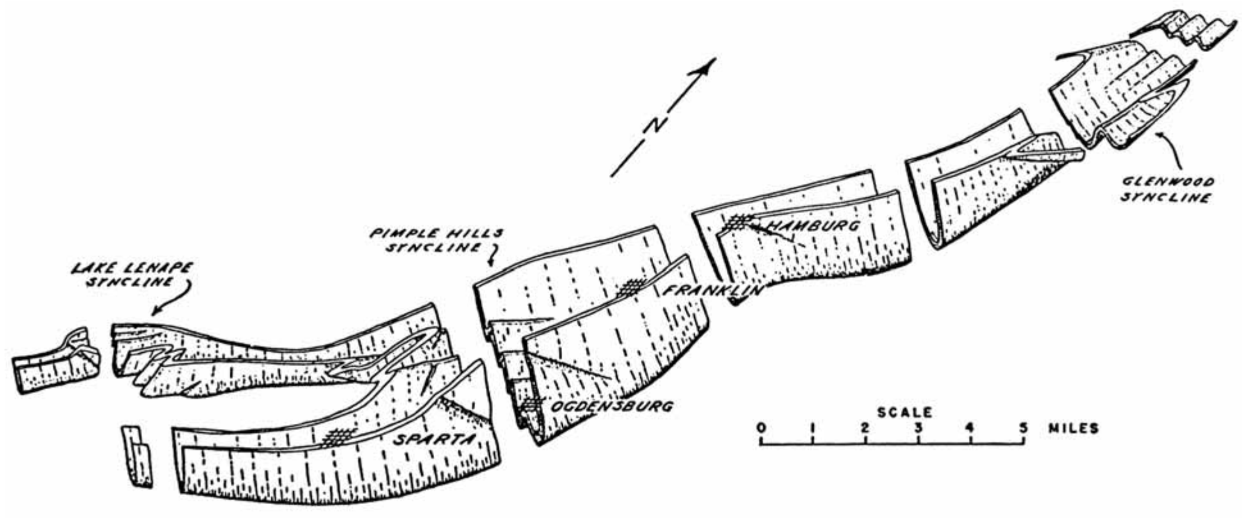


Figure 47. Stereogram illustrating pre-faulting structural interpretation of the Wildcat marble horizon. (J. M. Hague, J. L. Baum, L. A. Hermann, and R. J. Pickering, 1956, fig. 17, p. 466.)

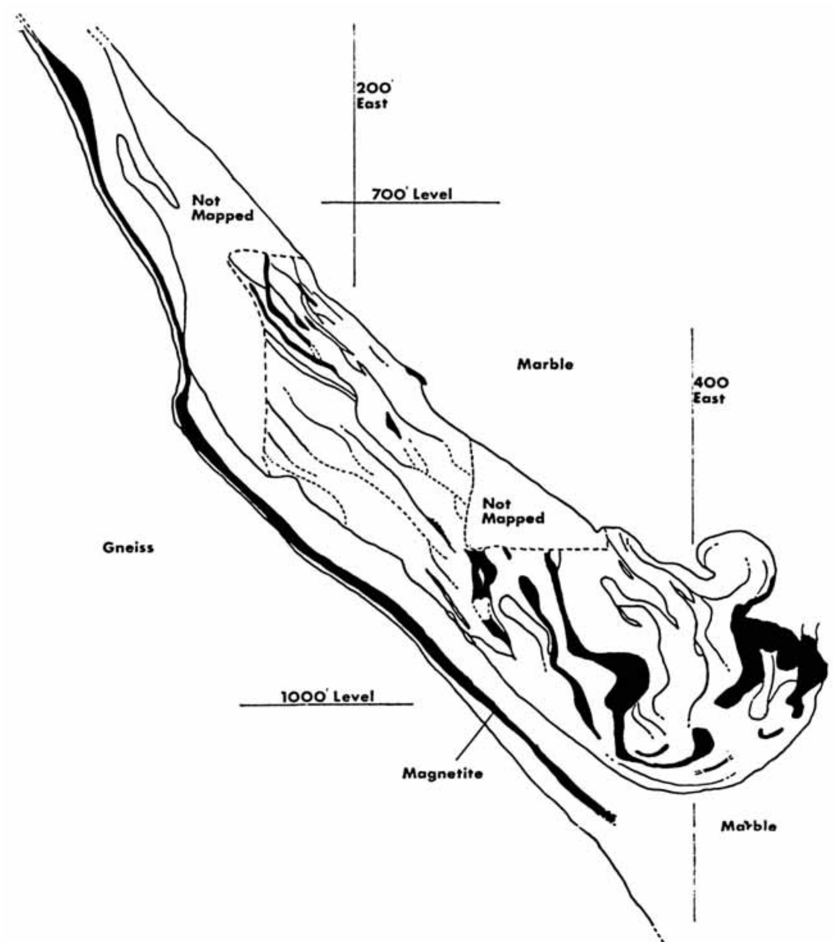


Figure 48. Vertical cross section of the Franklin ore body. Calcsilicate rocks are shown in black and only the boundaries of the ore are indicated. (C. Frondel and J. L. Baum, 1974, fig. 3, p. 162.)

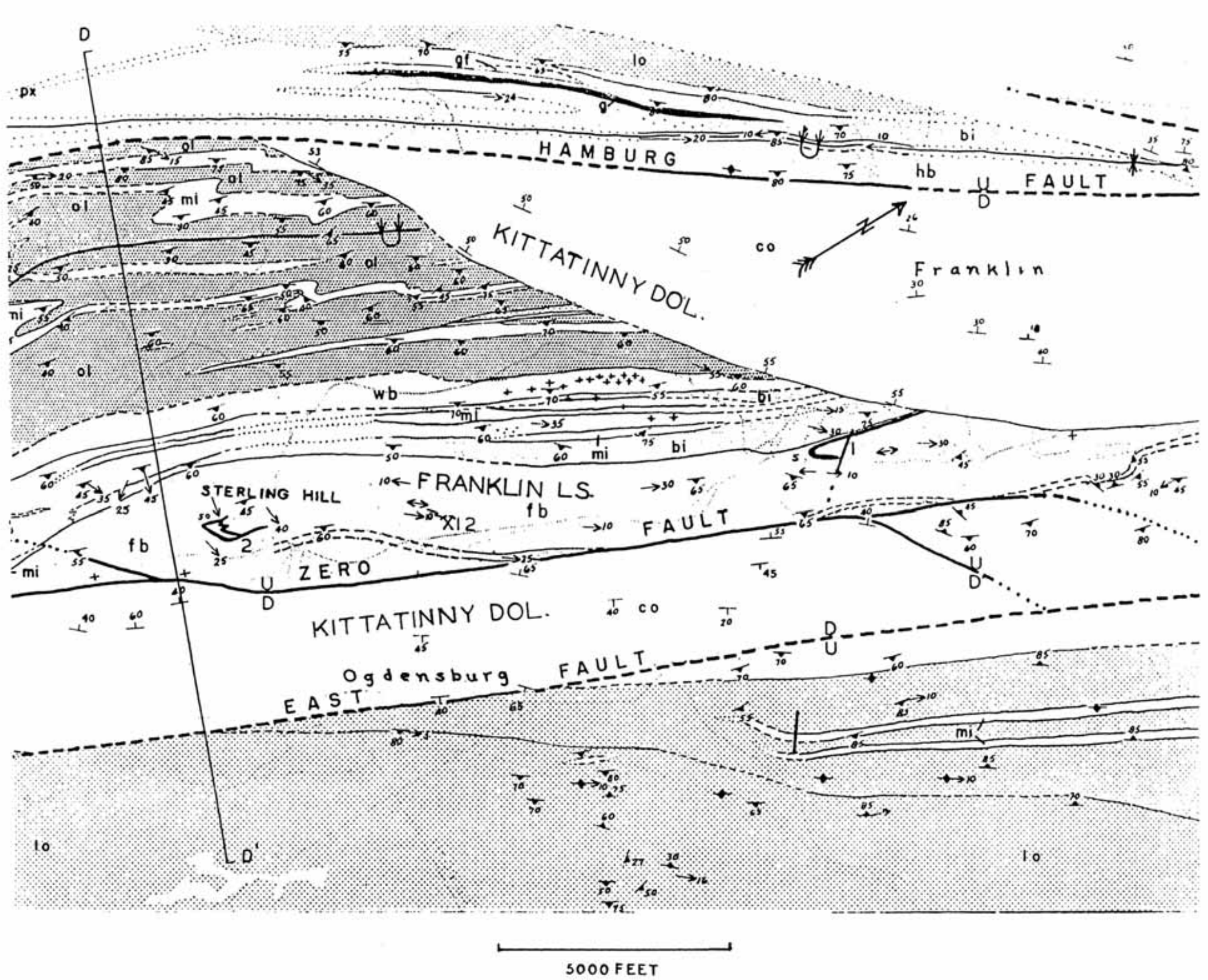


Figure 49. Detailed geologic map showing the distribution of major rock units in the Franklin-Sterling Hill area. [Adapted from J. M. Hague, J. L. Baum, L. A. Hermann, and R. J. Pickering, (1956) by R. W. Metsger, 1990, fig. 2, p. 44.]

As described above under the heading of Layer I - The Proterozoic X, Y, and Z, we discuss the regional framework of the Proterozoic units exposed in the vicinity of northwestern New Jersey. In the vicinity of Franklin and Sterling Hill, these rocks consist of quartz-feldspar-epidote gneiss, amphibolite, and massive carbonate rocks. Separated by an interval of biotite-quartz-plagioclase gneiss, the massive carbonate layers of the Franklin area, form two outcrop belts to the west of the Zero Fault. (See Figure 7.) They have been formally named, from west to east, the Wildcat and Franklin Marbles by Drake and others (1991). Drake (1990) suggests that the Franklin Marble, host for the Franklin and Sterling Hill ore bodies, is a locally massive, but discontinuous unit that may have originated not on a passive margin but as a local carbonate buildup on the flanks of an ancient rift zone. Drake cites the Everonia Limestone of the Virginia Piedmont as a type example.

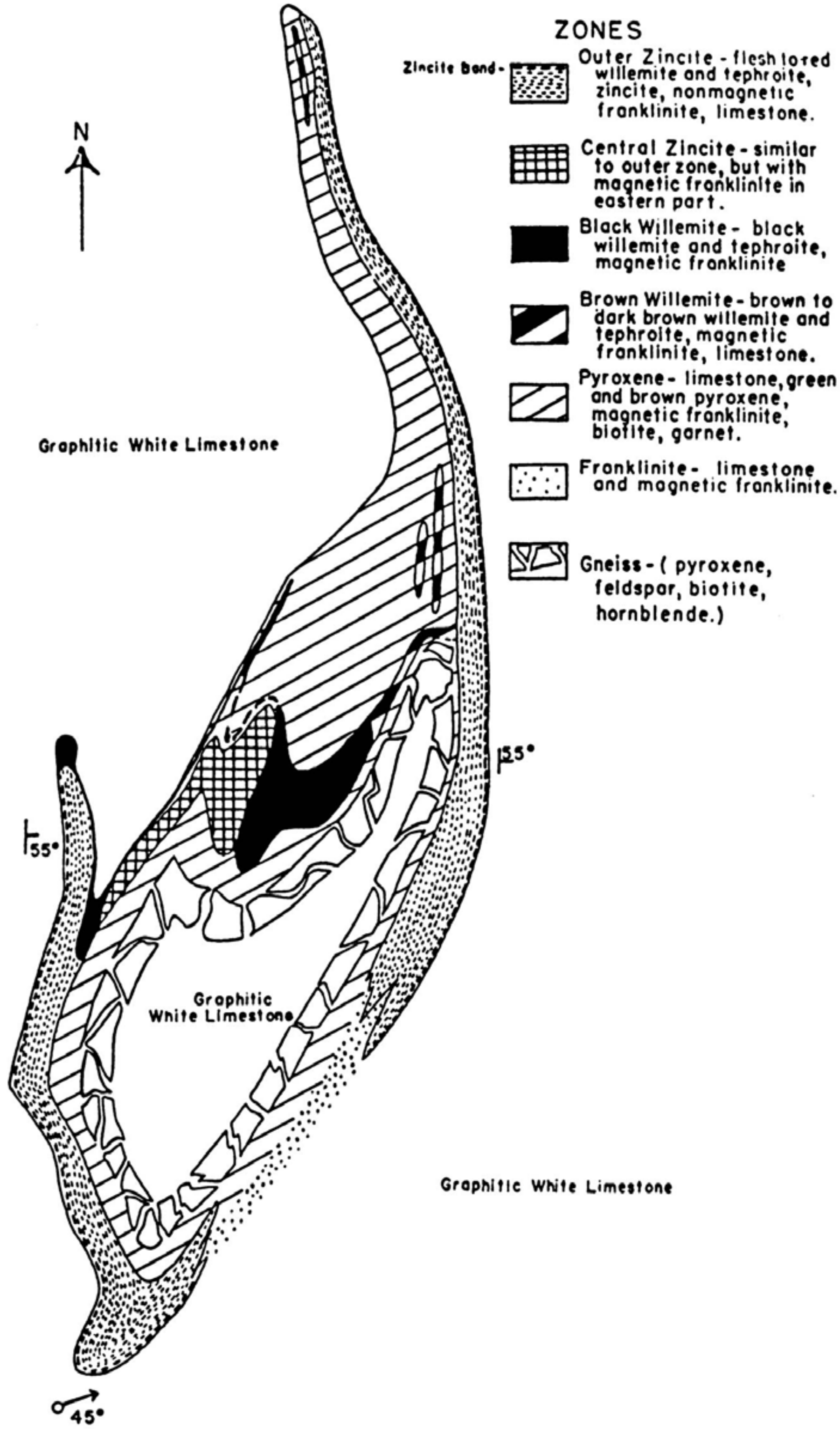


Figure 50. Geologic map of the Sterling Hill orebody. (R. W. Metsger, C. B. Tennant, and J. L. Rodda, 1958, fig. 1, p. 779.)

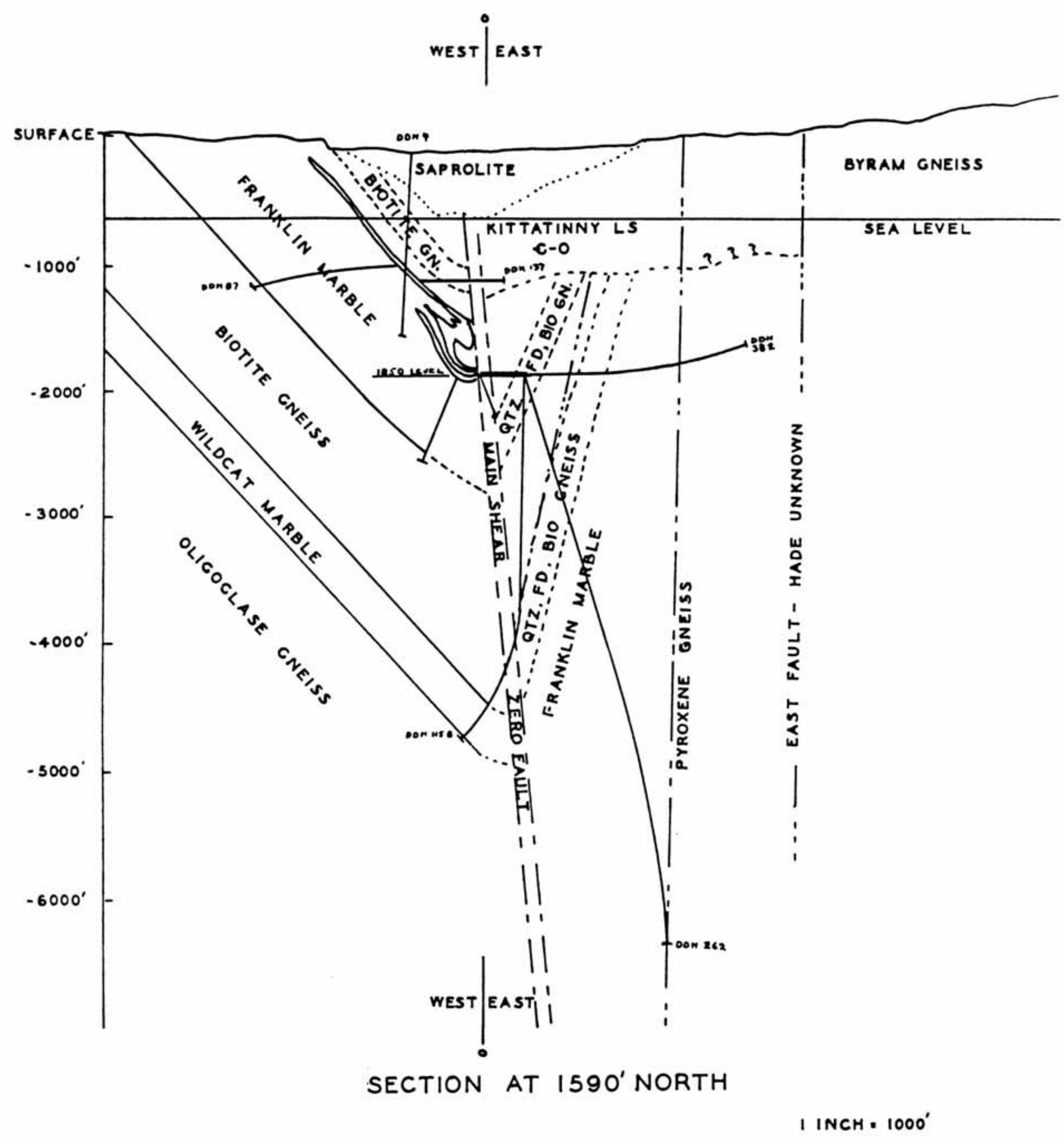


Figure 51. Vertical geologic section of the Sterling Hill Mine showing the location of the Zero Fault and bounding units. (R. W. Metsger, 1990, fig. 3, p. 45.)

CM strongly disagrees with this model, but appreciates the potential "need" for an active rift zone to concentrate the ore-bearing sediments. CM argues that the carbonates are not discontinuous and thin, but significant in dimension and areal extent (similar zinc- and magnetite-bearing carbonate deposits to the north in the Adirondacks, for example) to warrant embracing a passive margin interpretation. Perhaps much of the Proterozoic Y carbonate sequence is structurally buried by basement overthrusts as suggested by the marked distribution of thrust faults as shown in Figures 2, 24, and 35.

One fact is clear and undisputed, however. The Franklin Marble, which shows evidence of intense brecciation and perhaps Paleozoic dissolution collapse (Metsger 1990), was a highly reactive host for development of the unique, world-renowned Zn-Mn-Fe deposits found within it. Further, as discussed below and at Stop 5, the development of franklinite ore in the Franklin-Sterling Hill Mining District was accomplished under conditions of high oxygen fugacity during the Proterozoic Era and probably during the Proterozoic Y Grenville orogeny, roughly 1.1 Ga. We expect that Paleozoic orogenesis and intrusive activity strongly modified and amplified the type and numbers of minerals to their present outstanding variety, but maintain, along with most modern workers, that the major-element mineralogic framework was in place before the close of the Proterozoic Era as indicated by the presence of detrital franklinite and graphite in the Cambrian Hardyston Quartzite (Stop 5).

The genesis of the ores in the Franklin Marble remains a sticking point in the geologic history of the district. Moving far afield from earlier models involving mineralization from hot solutions related to intrusive igneous activity, most modern studies support the idea that the metalliferous deposits are syngenetic, meaning that they were deposited at the same time as the Proterozoic Y host rocks. Not a surprising interpretation as they are stratabound deposits, conformable with layering in the Franklin Marble. According to Drake (1990) and Metsger (1990), minerals grew as a consequence of rift-related volcanism at a spreading-ridge crest during the Proterozoic. At first glance, this explanation seems reasonable--Proterozoic X rocks stratigraphically beneath the Franklin Marble are volcanic and volcaniclastic, but the host rocks for the Franklin-Sterling Hill ores are massive (perhaps remobilized in a fluidal state?) carbonates that, for reasons mentioned earlier, may be a part of an extensive carbonate-platform sequence. What is more, oceanic rift-related metalliferous deposits, such as those found in the Ordovician of western New England (Abu-Moustafa and Skehan, 1976; Merguerian, 1980, 1981) and elsewhere in the world (Binstock, 1977; Kramm, 1976) are characterized by stratabound manganese-quartz granofels (coticules) and disseminated iron-oxide (typically hematite-rich, itabirite) deposits, together with podiform and disseminated Cu-Fe-Zn sulfide deposits, all intercalated with mafic rocks and dismembered ophiolitic material (Bonatti, 1975; Bonatti et al., 1976a,b; Corliss, 1971; Dumont, 1847; Merguerian, 1979, 1983; Renard, 1878; and Schiller and Taylor, 1965).

Such is not the case with the oxide- and silicate ores of the Franklin-Sterling Hill deposits. For one thing, the Franklin-Sterling Hill deposits are unique in terms of chemical composition with no known terrestrial counterpart (although the mineral deposits at Langban, Sweden are closest). They do not contain Cu-rich rocks, Fe-Zn sulfides are rare, and laminated itabirites and/or coticules are absent. Based on this negative evidence, CM argues that the absence of such distinctive deposits dismisses an oceanic rift environment as the genetic source of ore-bearing fluids. Because of the thermally induced leaching of these elements from fractured ocean crust by rising volcanic fluids adjacent to the rift, ocean-floor mineral deposits and associated rocks typically are rich in Cu-Fe-Zn sulfides. Thus, in CM's opinion, the ocean-rift model is probably "dead in the water". Rather, CM would cite the unique aspects of the Franklin-Sterling Hill deposits and argues for an active continental-margin environment that included significant carbonate-shelf sedimentation. CM, forever the contrarian, cites the metalliferous massive Proterozoic carbonates of India (the "Gondites" and "Kodurites" of Mitra, 1965; Mookherjee, 1961; Prasada Rao and Murty, 1956; and Roy, 1956, 1965) as a possible type example for the Franklin Marble Belt. Concentration of Zn-Fe-Mn sediment could have resulted from a unique geochemical buildup in a restricted basin with episodic precipitation of stratabound sulfides as a consequence of nearby, outer-shelf volcanism.

GLACIAL HISTORY AND DRAINAGE

The glacial history and drainage of Sussex County, New Jersey are closely related. Indeed, the modern drainage is of postglacial age and has developed as the latest glacier (known as the Woodfordian) melted and disappeared. We first mention the glacial deposits and then take up the drainage.

Glacial Deposits

As mentioned under the description of Layer VII, (the Quaternary sediments in Table 2), glacial deposits include several contrasting varieties. We will be especially interested in the characteristics of till and outwash. Till is a general name for any sediment deposited directly by the flowing ice of the glacier. Typically, till is not stratified and contains a wide range of particle sizes, from boulders to clay. Outwash is a general term for any sediment deposited by water melted from a glacier. Outwash includes such contrasting sediments as stream sands/gravels and lake clays. The key point about recognizing outwash is the stratification that resulted from the action of water. Another feature of some outwash is that it was deposited under, adjacent to, or on top of blocks of stagnant ice from a former glacier. Such outwash can be used to pinpoint the position of the ice front at the time the outwash was deposited.

An important point to be determined in studying a deposit of till is which way the glacier flowed. Because glaciers create scratches and even large grooves on solid bedrock, if any such bedrock is exposed, one can infer ice-flow direction in a simple, straightforward manner. The ice flowed along the trend of the linear grooves, striae, and other elongate features.

Direction of flow may also be inferred by studying provenance; that is, the source of the particles in the deposits. Because glaciers can transport stones long distances, one commonly finds a collection of glacial particles unlike the bedrock on which the glacial deposits rest. Such stones are known as erratics. If an erratic can be traced to a distinctive source, it becomes an indicator stone. The distinctive mineral deposits of the Franklin-Ogdensburg area have provided indicator stones in the local glacial deposits. Because these minerals fluoresce in ultraviolet light, mineral collectors have searched through the local glacial deposits for specimens. They prospect at night. Accordingly, the scheme JES once thought would be useful, that is scanning the till for fluorescent specimens from the distinctive zinc deposits, might be helpful if one happened to be the first to shine an ultraviolet light on a newly opened exposure of the glacial deposits. After that, the mineral collectors have probably removed the geologic evidence.

Use of striae and indicator stones shows that glaciers flowed across the New York region from several directions. The distribution of erratics derived from as far away as the anthractite district in eastern Pennsylvania and pebbles of the distinctive maroon-matrix, white pebble rock in the Green Pond Formation (Lower Silurian--the "Braunschweiger-sausage rock" of the late Barnard biology Professor Donald Ritchie) in the red- brown tills and -outwashes in New York City lends strong support to the interpretation that the striae and other directional indicators oriented NW-SE indicate regional ice flow from that direction, rather than SE deviation locally of a glacier whose main axis of flow was from NNE to SSW.

The stratigraphy of glacial deposits is worked out by noting the relationships among till, outwash, and sediments that have nothing at all to do with a glacier and, in fact, were deposited under a climate regime that is nonglacial. In a coastal area such as New York City, glacial deposits are interstratified with marginal-marine deposits. This has resulted from the relationship between growth of continental ice sheets and the volume of water in the ocean basins. Professor R. A. Daly, of Harvard, once described this relationships between glacial ice and the water of the oceans as one of "robbery and restitution." By robbery, he meant the locking up of the water in the glaciers. By restitution, he meant the return of the water to the oceans when glaciers melted. Although the exact climate settings involved in these changes are not as well known as one might suppose, it has been firmly established that when the glaciers reached their maximum extents, the sea was at its lowest stand, a level around 90 to 150 m lower than now.

In addition to ripping up individual fragments from the material over which it passes, a glacier may also deform the strata it over-rides. One of the Pleistocene glaciers profoundly affected some of the Upper Cretaceous strata: it stripped several large thin slabs (up to 0.5 km in one dimension and a few tens of meters thick) away from their pre-glacial positions and incorporated them as great thrust slices in the till (Sanders, Merguerian, and Okulewicz, 1995a, b).

Another aspect of glacial deposits dear to the heart of those who are Pleistocene geologists is use of sediments to infer the positions of the margin of a melting, retreating glacier. In many places, records of deglaciation are extensive; numerous ice-margin positions during the retreat can be established.

The deglacial record in the upper Wallkill Valley has recently been revised by Connally, Sirkin, and Cadwell (1989). Farther southwest, in the region of the headwaters of the Wallkill, several proglacial lakes (lakes in contact with a glacier) have been inferred (Figure 52). The lake-bottom deposits subsequently were covered by peat. In the peat are samples of the pollen from the surrounding vegetation, which enable specialists to reconstruct the changes in climate as the change took place from a glacial-type climate (the "ice house") to a non-glacial climate (the "greenhouse").

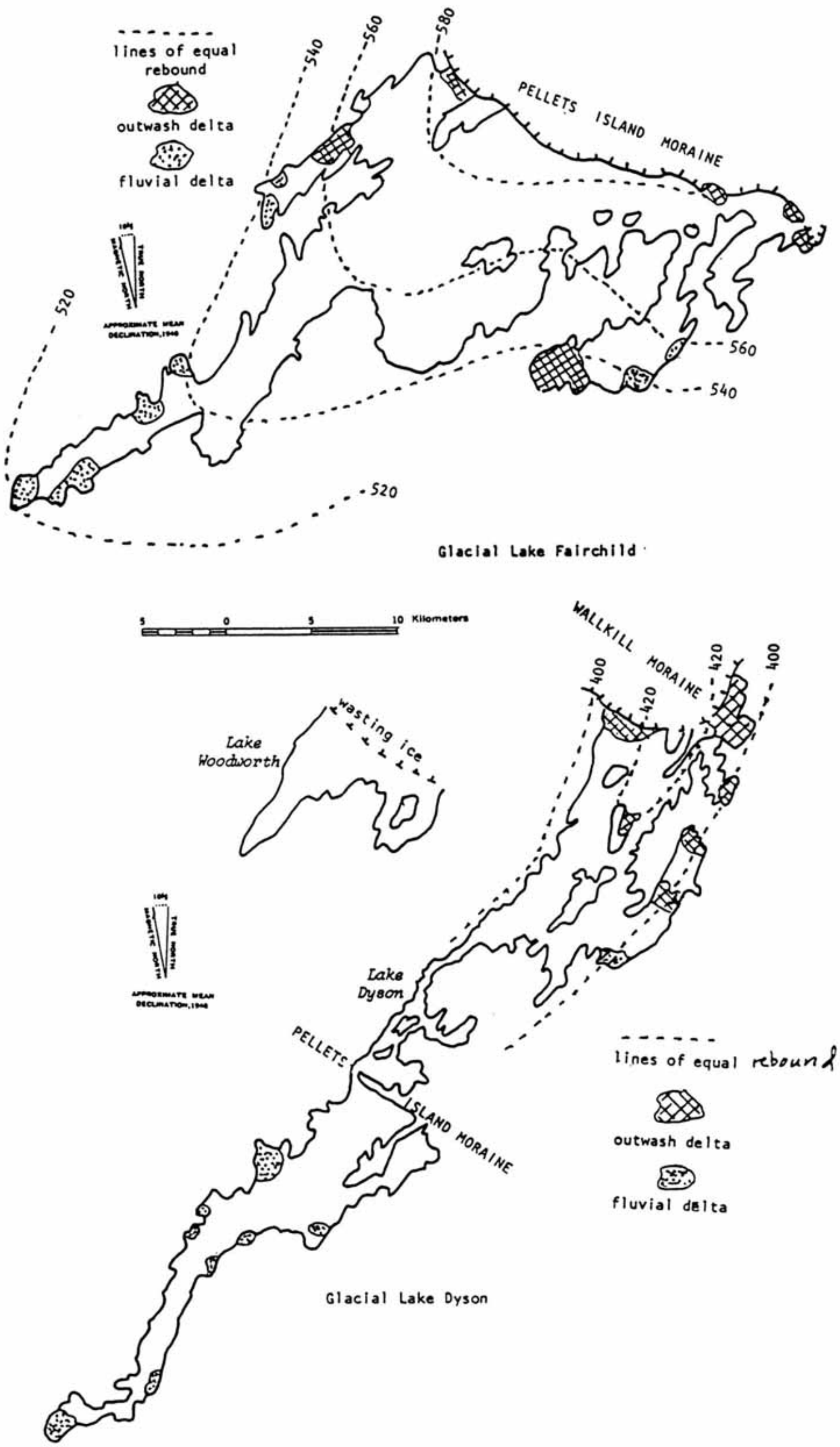


Figure 52. Maps showing distribution of glacial lakes Fairchild and Dyson. (G. G. Connolly, L. A. Sirkin and D. H. Cadwell, 1989, figs. 5 and 7, p. 214 and 218, respectively.)

In a recent article on deglaciation, Cotter, Ridge, Evenson, Sevon, Sirkin, and Stuckenrath (1985, 1986) interpreted evidence of contrasting flow directions in terms of lobes from the same Woodfordian glacier. Their map of erratics in the Great Valley glacial deposits that were derived from north of Kittatinny Mountain clearly demonstrates flow from NW to SE (Figure 51a), but they inferred that this flow had been by a Delaware Gap ice tongue of Woodfordian age (Figure 53b).

Numerous sand pits have been opened in the sandy-gravelly outwash. Many of these deposits were made by deltas in the proglacial lakes.

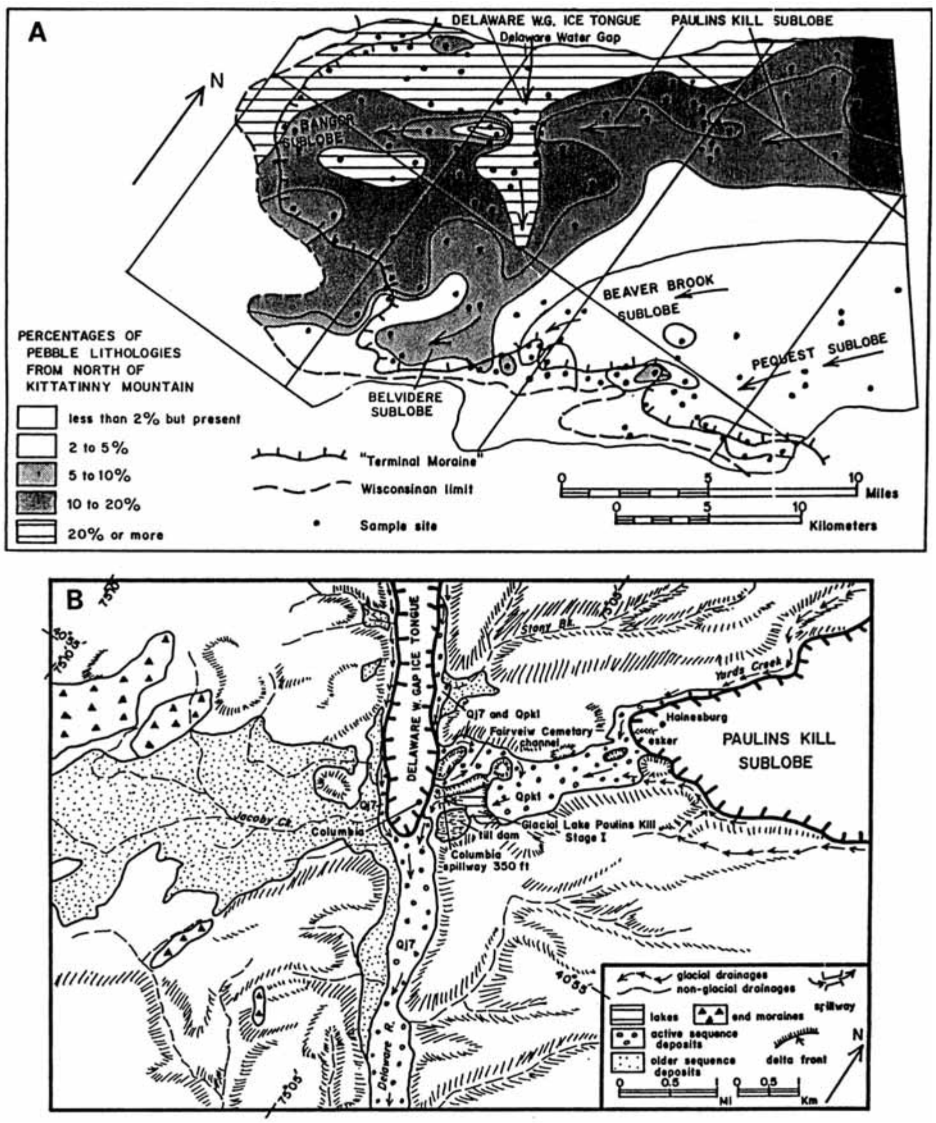


Figure 53. A. Provenance indications of ice flow from the NW to the SE, Kittatinny Mountain, Pennsylvania and New Jersey, but interpreted as the work of a lobe of the Woodfordian glacier.
B. Ice flow from the NW to the SE interpreted as a Delaware Gap ice tongue of a Woodfordian-age glacier, whose main flow direction was from the NNE to the SSW, as indicated by the Paulins Kill sublobe. (J. F. P. Cotter, J. C. Ridge, E. B. Evenson, W. D. Sevon, L. A. Sirkin, and R. Stuckenrath, 1985, figs. 9 and 10, p. 24 and 25, respectively.)

Drainage History

As mentioned, the modern rivers of the region we shall visit in Sussex County, New Jersey (See Figure 3.) are flowing in lowlands following courses that are of postglacial age.

The headwaters of the Wallkill River are in Mohawk Lake southwest of Ogdensburg. The waters flow northeastward and are augmented by waters from other NE-flowing tributaries. East of Rosendale, New York, the Wallkill is joined by another drainage network having headwaters in the Catskill, but flowing northeastward in the Siluro-Devonian strike valley. The combined Wallkill-Rondout flow drains into the Hudson River at Kingston. There, it forms a barbed tributary (tributary entering the main stream with the acute angle between them on the downstream side, with reference to the flow direction of the main stream). Barbed tributaries are distinctly rare. The usual arrangement is for the acute angle to be on the upstream side. As shown on the series of maps of Figures 54 and 55, The drainage from the melting glacier had to have been southward. No flow northward was possible until after the ice had melted away.

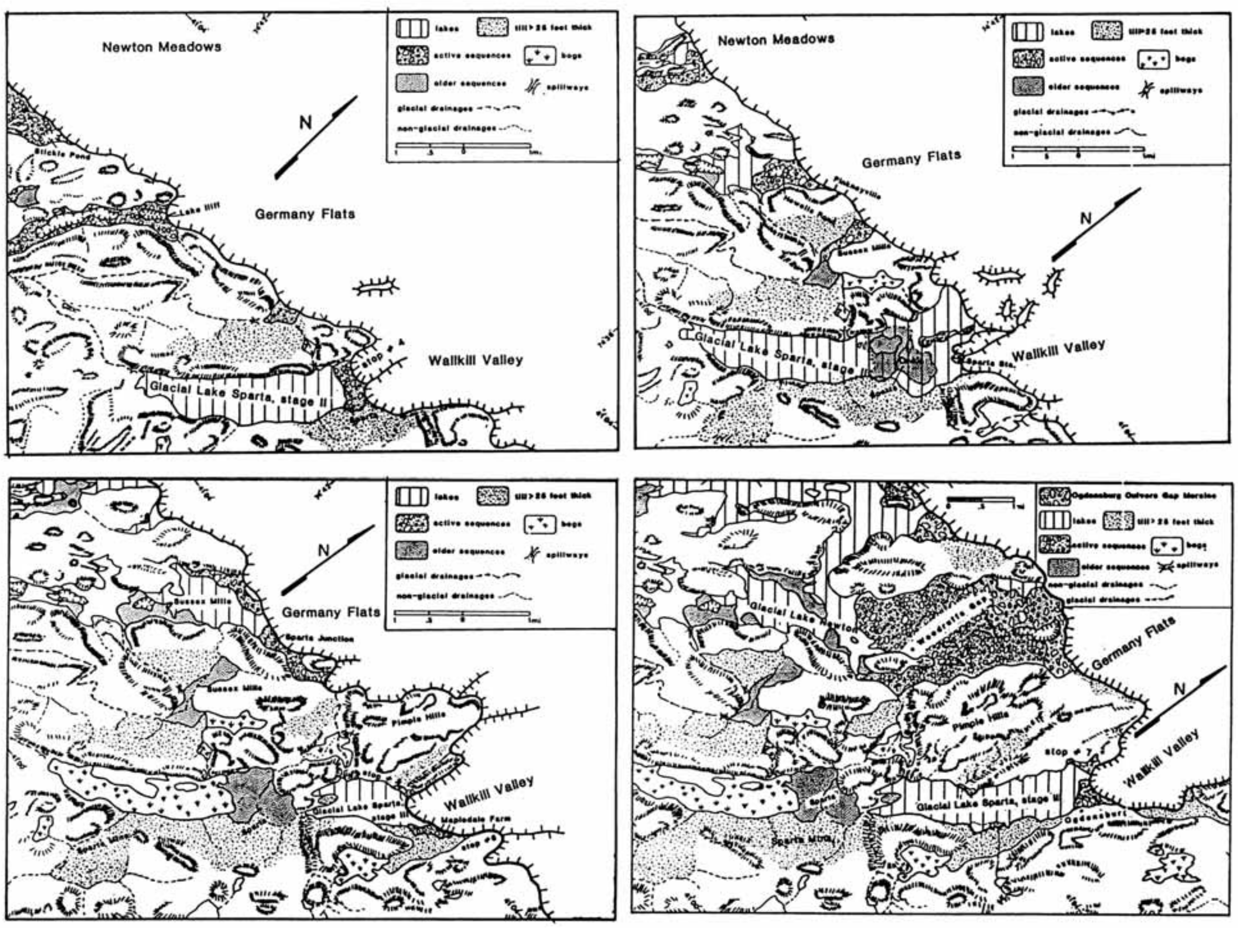


Figure 54. A series of maps showing retreat of the Woodfordian glacier in New Jersey from a position at the Franklin Grove-Turtle Pond Moraine to the Ogdensburg-Culvers Gap Moraine. (R. W. Witte, E. B. Evenson, and C. Koteff, 1985, figs. 3, 4, 5, and 6, p. 63-66, respectively.)

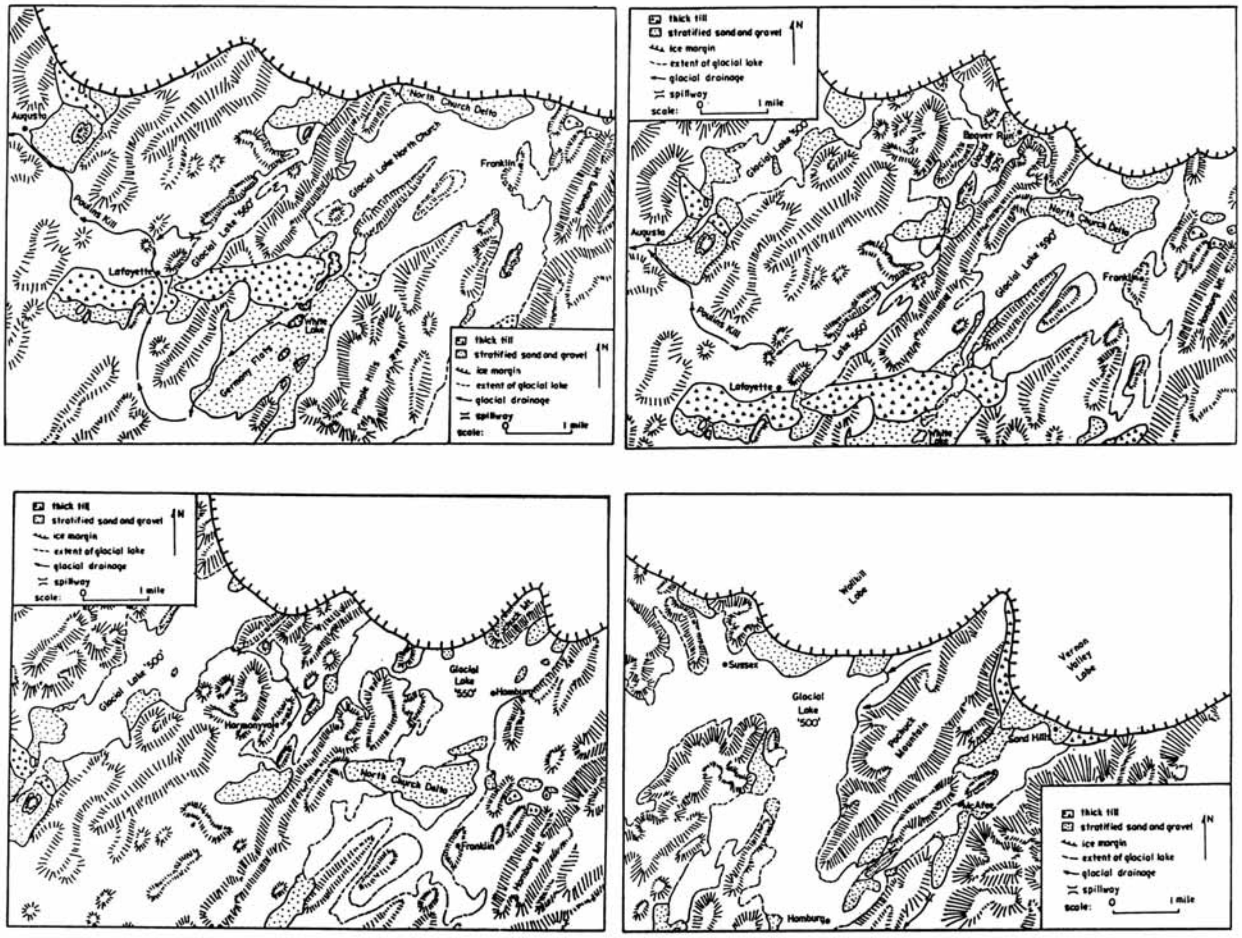


Figure 55. A series of maps showing retreat of the Woodfordian glacier in New Jersey from a position at the Ogdensburg-Culvers Gap Moraine to the Sussex Moraine. (S. Stanford and D. Harper, 1985, figs. 2, 3, 4, and 5, p. 73, 75, 76, and 79, respectively.)

Another factor working against postglacial drainage to the north is what is known as isostatic rebound. This comes about because the weight of the glacier displaces some of the sub-lithospheric material (within a layer known as the asthenosphere). This causes the top of the lithosphere to become depressed (it gets very sad!). After the ice has melted, the displaced parts of the asthenosphere flow back again, and the surface of the lithosphere is elevated. The amount of depression of the surface of the lithosphere is related to the thickness of the continental glacier. Where the glacier was thickest, the amount of lithosphere subsidence is greatest. As a result, after the ice has melted, the greatest amount of so-called glacial rebound likewise takes place where the ice was thickest.

Isostatic rebound has been demonstrated in the Hudson Valley by determining elevations on shoreline features built by postglacial lakes. These were horizontal initially but now are inclined toward the south. This inclination has resulted from greater amounts of rebound in the north, where the glacier was thicker. Comparable postglacial rebound has been inferred for northwestern New Jersey.

As far as postglacial drainage is concerned, therefore, both the residual effects from the meltwater channels and the isostatic rebound should have established a regional drainage toward the south. The authors of the deglacial history of Sussex County seem not to have been impressed with the northeastward course of the modern Wallkill drainage. JES thinks that something such as an active syncline pitching toward the northeast is needed as a mechanism for explaining the direction of the Wallkill drainage.

So much for geologic background. We now turn to the specifics of today's trip, starting with the objectives.

OBJECTIVES

1) To drive across and observe the Mesozoic rocks of the Newark Basin at 55 mph.

2) To examine the Cambro-Ordovician shelf deposits Kittitinny dolomitic carbonates of Passive Margin I.

3) To examine evidence for glaciation and glacial deposition in the Wallkill valley and discuss the drainage history of the region.

4) To contrast and compare the Paleozoic and Proterozoic marble units and to discuss their paleoenvironments.

5) To examine the Proterozoic rocks paying particular attention to the host rock for the Franklin-Sterling Hill orebodies and to discuss their genesis.

6) To visit the world-famous Sterling Hill Mine site and the Franklin Mineral Museum for guided tours and, time permitting collecting, and,

7) To get close and personal with folds, faults, and surfaces of unconformity.

ROAD LOG AND DESCRIPTIONS OF LOCALITIES ("STOPS")

Today's road log begins at the northeast corner of Fort Washington Avenue and 179 Street, Manhattan, by the Holy Rood Episcopal Church. For locations of the trip Stops, refer to Figure 56.

[0.0] Bear L for ramp to George Washington Bridge, upper level.
[1.5] Passing tollgate on L; keep L for I-80 and I-95.
[2.1] Bear R for I-80 local.
[2.3] Take ramp on L to I-80 local.
[2.7] Jones Road overpass; upper contact of Palisades sheet exposed on R.
[2.9] Top of intrusive sheet at road level. Note contact-metamorphosed Lockatong Formation. Ahead is the strike ridge underlain by a sandstone in the Passaic Formation.

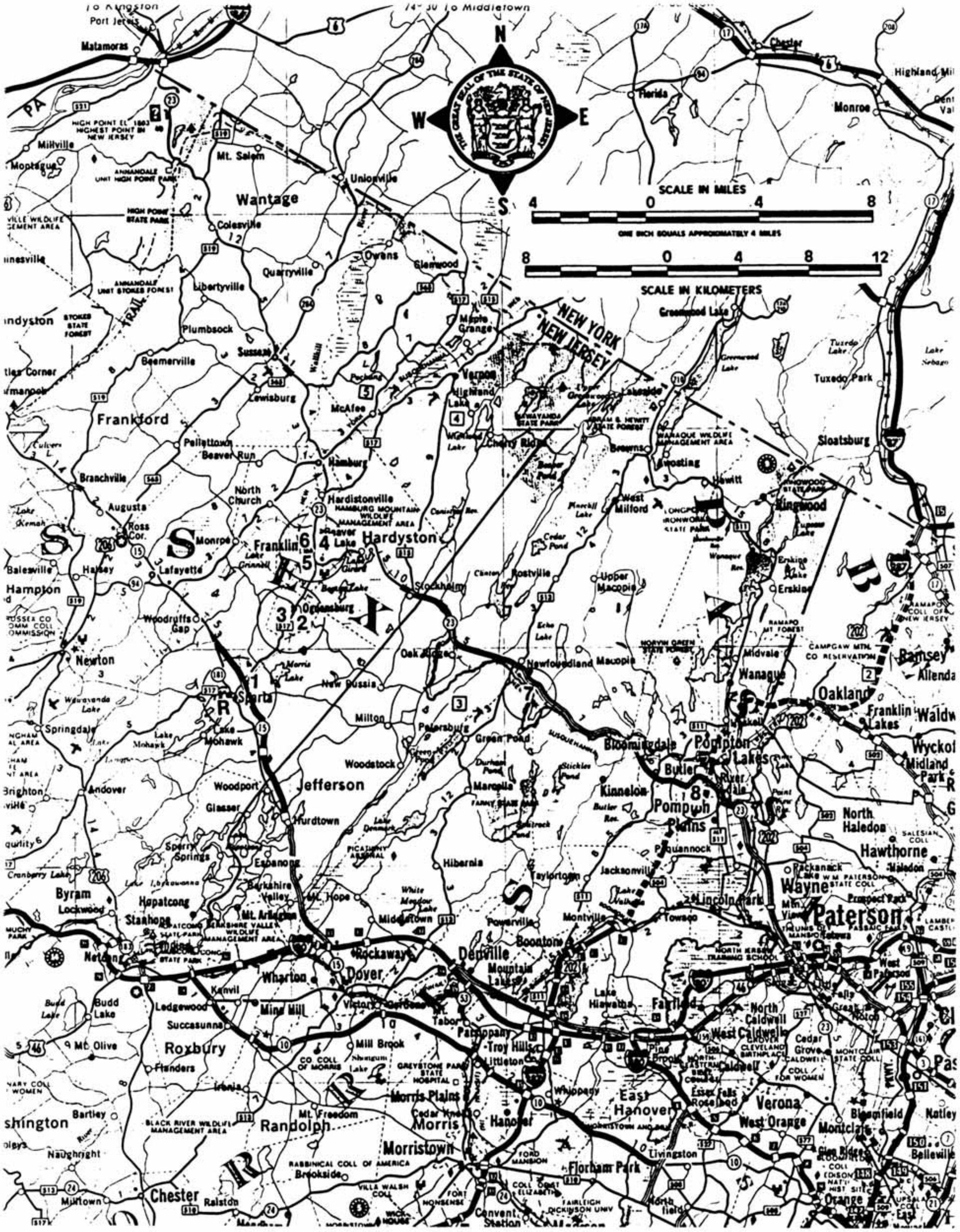


Figure 56. Road map showing numbered trip stops 1 through 8 (circled). (State of New Jersey, 1993-1994 Official Transportation Map and Guide.)

[4.8] Bear R for Exit 69 to I-80 local (Paterson).
[5.8] Red sandstones and shales of Passaic Formation on R.
[6.2] More Passaic sandstones exposed on R.
[7.6] Pass Exit 65 on R.
[8.0] Pass Exit 64B on R.
[8.5-8.6] More Passaic strata dipping NW exposed on R.
[9.4] Pass ramp on R for Exit 63.
[9.7] More Passaic strata exposed on R.
[11.0] Pass ramp on R for Exit 52, Garden State Parkway.
[11.6] MP 62 on R.
[13.4] Passing ramp on R for Exit 59 to US Route 46 and NJ Route 20.
[13.7] MP 60 on R.
[14.4] View ahead to contact between top of red Passaic Formation and base of overlying Orange Mountain basalt (=First Watchung of pre-Paul Olsen terminology).
[15.9] Large cut on L of Orange Mountain basalt showing columnar joints cut by five sub-vertical faults.
[16.5] Passing Exit 56 ramp on R to Paterson.
[17.4] Bridge over Passaic River.
[18.4] Pass ramp on R for Exit 55B.
[18.7] Pass ramp on R for Exit 55A.
[20.1] Pass ramp on R for Exit 53, US Route 46 and NJ Route 23.
[21.1] Bridge over Passaic River (again).
[21.5] Pass ramp on R for Exit 52, Lincoln Park. View ahead to Second Watchung Basalt Ridge (Preakness Mountain basalt).
[23.0] MP 51.
[25.7] Bridge, entering Montville Township.
[26.2] MP 48; pass ramp on R for Exit 48.
[26.4] Cuts of Preakness (2nd Watchung) Basalt.
[27.7] Pass ramp for Exit 47 on R to US Route 46 (Westbound) toward Parsippany.
[28.0] Road divides. Keep L for I-80, do not veer R to I-287 (Morristown).
[31.3] MP 43.
[31.4] Pass ramp on R for US Route 202.
[33.1] Exposures on L of subvertical Proterozoic gneiss.
[33.4] Interlayered mafic and felsic gneisses.
[34.4] MP 40.
[35.0] Passing Exit 39 on R (Denville) to US Route 46 and NJ Route 59.
[36.5] MP 38.
[36.8] Entering Rockaway Township.
[36.9] Pass ramp on R for Exit 37.
[37.5] Proterozoic gneiss on R.
[39.0] Pass Exit 35B ramp on R. (to Mt. Hope).
[39.3] Pass Exit 35A ramp on R.
[40.2] Take Exit 34B ramp on R for NJ Route 15 (North) to Sparta.
[41.0] Traffic light. Road for trucks to Picatinny Arsenal.
[42.1] Entering Jefferson Township.
[42.4] Traffic light by powerline parallel to road.

[42.6] MP 4 on R.
[43.0] Pass road junction with Taylor Road (no light).
[44.0] Proterozoic pyroxene-bearing mafic gneiss in cut on R.
[44.1-44.2] Felsic quartz-oligoclase Proterozoic gneisses.
[44.55] Traffic light.
[44.6] MP 6 on R.
[45.6] Take exit on R for 181 N.
[45.8] Coming from NJ 15, take lst R turn onto 181 N.
[46.7] Proterozoic pyroxene-bearing granite gneiss in cut on R.
[46.9] MP 1. Lake on L ahead.
[47.2] Crossing bridge between lakes on L and R.
[47.6] Entrance on L to Hopatcong Crushed Stone Co.
[47.8] Proterozoic felsic gneisses on L.
[48.0-48.1] Iron-stained, mafic Proterozoic gneiss.
[49.0] MP 3 on R.
[49.1-49.3] Proterozoic gneisses on R.
[49.3] Sawmill Road on L followed by more gneisses.
[49.5] Junction with NJ 15 (Should have exited here). Lots of Proterozoic quartz-oligoclase gneiss and amphibolite around cloverleaf.
[50.1] Hunters Lane on L.
[50.9] Pull into Sparta Diner on L. Time for a driving break and Rest Stop.
[51.0] Leave parking lot by turning L.
[51.1] Stop sign at Stanhope Road, turn R.
[51.2] Traffic light; merge with NJ 181 N.
[51.3] Turn R on 181.
[51.4] Bear L on 181 toward Lafayette and Newton.
[51.5] Traffic signal; go straight toward Newton.
[51.9] Blinking light, bear R toward Lafayette.
[52.1] MP 6 on R.
[52.4] Proterozoic gneisses on L.
[52.6-52.8] More Proterozoic gneisses on L in long exposure. Scenic views of countryside ahead.
[53.6] U-turn onto NJ 15 (South).
[54.0] Proterozoic gneisses on R.
[54.7] Grenville (Proterozoic) marble and gneisses on R.
[54.8] MP 13 on R.
[55.2] Big exposure on R before and beneath overpass. Pull over for Stop 1.

STOP 1 - Folded- and Faulted Sauk Sequence Carbonates (Cambro-Ordovician) in new cuts on NJ Route 15. [UTM Coordinates: 530.7E / 4544.5N, Newton East quadrangle.]

New road cuts are the stuff geologist's dreams are made of. Here, in freshly opened roadcuts for new ramps on NJ 15, Paleozoic carbonate rocks (the blue limestone of the older literature or Kittatinny Dolostone and Limestone of modern usage) of Layer IIA(W) (See Table 2.) are exposed. At the extreme south end of the exposure note the well-bedded nearly vertical layers oriented N47°E, 75°NW with discontinuous black chert seams 3- to 4 cm thick. The bedding is subparallel to subvertical dissolution cleavage (stylolites) that indicate, along with the steep orientation, that some degree of deformation has affected these strata. These features are cut by subhorizontal cross fractures filled with calcite.

Grading northward, underneath the overpass, the carbonates are more massive. Here, crenulate folds with subhorizontal axial surfaces deform the dissolution cleavage and sedimentary layering. These second-generation (F_2) folds are geometrically, and possibly temporally, related to the calcite-filled fractures noted above. North of the overpass significant zones of breccia are present; clast sizes range from l cm to 1 m and many show significant internal cracking suggesting high pore pressures during brecciation of consolidated rock. In addition, some of the boulders are breccias within themselves! We interpret that most of the brecciation was stratigraphic (sinkhole- and collapse breccias) and compare them to the breccia zones found within the Pine Plains Formation of the Wappinger Group of New York State (Guo, Sanders, and Friedman, 1994). The possibility exists that some breccias are of tectonic origin, however, as northward-dipping low-angle faults are obvious above- and through the breccia zone. Channels cut into the bedding indicate that tops are to the south and thus the beds that dip 75° NW are overturned.

Above the breccias, north of the overpass, note how the carbonates take on a laminated appearance which is similar to, and thus in our view, correlative with, the Pine Plains Formation of New York. Just beyond the laminated rocks, the bedding begins to swing wildly in the axis of an isoclinal F_1 synform with axial surface parallel to bedding (and to dissolution cleavage at S end of outcrop). At the extreme N end, bedding is N28°E 20°NW. As such, a possible broad-wavelength anticlinal F_3 (or younger) fold is suggested, with a structural break in the outcrop at the axial surface. Such superposed folds are reminiscent of the Inwood Marble of New York City which is a direct lithostratigraphic correlative of these rocks.

[55.2] Continue S on NJ 15.
[55.5] Bridge over local road, Sparta.
[55.8] MP 12 on R. Sign for exit coming up to Sparta, Lake Mohawk.
[56.5] Proterozoic rocks exposed on L; steep foliation.
[56.8] More but with interlayered mafic gneiss and felsic dikes.
[56.9] Mostly granitic Proterozoic.
[57.4] Exit on R. for NJ 181; Sparta business district. Back to cloverleaf of earlier part of log. Bear R on NJ 181 N. Note that we duplicate earlier log for a little bit here as we try to see who is actually paying attention. Round in circles we go!.
[58.1] Saginaws Drive on R.
[58.3] Hunters Lane on L.
[58.4] Turn R on East Mountain Road.
[58.6] Pond on R; Proterozoic rocks exposed on L.
[58.9] Crossing above NJ 15.
[59.1] Morning Star Drive on R.
[59.4] Proterozoic rocks exposed in driveway on R.
[59.7] Stop at T-intersection; turn L on Sussex County Route 620, toward Ogdensburg.

[59.8] Highly jointed Proterozoic rocks.
[60.6] Traffic light. Junction with Sussex County Route 517 (Main Street) entering from Glen Road. Turn R onto 517.
[61.1] Crossing RR line.
[61.2] Station Road on L.
[61.6] West Mountain Road on L.
[62.9] Gravel pit on R.
[63.0] Village of Ogdensburg. The elongate valley on the L is the Wallkill Valley which is underlain primarily by the easily eroded Cambro-Ordovician Kittitinny dolostone (as seen at Stop 1). The lack of relief also results from the fact that the limestone belt here has been downdropped in a graben structure. Here, drill-core data disclose that the thickness of the Paleozoic strata exceeds 1,100 feet (Metsger, oral communication).
[63.5] Brooks Flat Road enters on L.
[63.7] MP 38 on R.
[63.8] Glenbrook Road on L.
[64.0] View on L of headframe, Sterling Hill Mine.
[64.25] Turn L on Passaic Avenue.
[64.8] Pull over to R onto shoulder leading into old gravel pit for Stop 2.

STOP 2 - Pleistocene Till and Gravel Body of Ogdensburg Moraine. [UTM Coordinates: 533.4E / 4548.0N, Franklin quadrangle.]

The Ogdensburg Moraine of Cotter and others (1985), occurs in a lowland east of the Sterling Hill Mine, New Jersey. This is an old gravel pit from which extensive amounts of outwash sand and gravel have been removed. Till forms the west wall. This locality has furnished erratics from the Franklin ore deposit to the north. As noted on a foregoing page, such erratics are easily to identify because of their fluorescence in ultraviolet light. Mineral collectors are well aware of this and use it to look for specimens at night among the stones. A considerable hole has been excavated in the gravel in search of Franklin erratics. According to Bob Metsger, part of the Sterling Mine lies 2000 feet beneath the small hole dug in the gravel.

Another feature of interest here is the precipitation by circulating ground water of a white calcite cement. Evidence of this cement consists of coarse sand-size particles attached to larger cobbles and of a thin, discontinuous white coating on the surfaces of cobbles and -boulders. If conditions are conducive to digging, we might scrape away at the face of till with the idea of exposing some fluorescent erratics that have not been spotted by zealous collectors.

[64.8] Continue ahead.
[64.9] Cork Hill Road on R; Plant Street on L. Go straight on Passaic Avenue, uphill, under old trestle.
[65.0] Turn L into Sterling Hill Mining Company entrance.
[65.1] Park in lot by office for Stop 3.

STOP 3 - Sterling Hill Mine, Ogdensburg. [UTM Coordinates: 532.9E / 4547.9N, Franklin quadrangle.]

Mr. Richard Houck, owner of the Sterling Hill Mining Company and tour guide/lecturer, re-opened the mine as a tourist attraction on 01 July 1990, about two years after it was closed in September of 1988. Of further benefit, Dr. Bob Metsger, former Chief Geologist (in the years 1949 to 1988) for the New Jersey Zinc Company at Sterling Hill and currently geologist for the New Jersey Geological Survey, has agreed to meet us at the mine and provide a guided tour of the mine area. As such, CM and JES have little to say here and will allow the area experts to provide the details. This is a great place for an outing with family and friends where a world-class mineral deposit is on display!

[65.1] Retrace route out of former mine area back to street.
[65.3] Turn R onto Passaic Avenue.
[65.3] Turn L onto Corkhill Road and pass through tunnel.
[65.5] At Y-intersection, bear L.
[65.7] Kennedy Avenue on R.
[65.9] Old RR grade crossing; track has gone bye bye.
[66.8] Another crossing for vanished RR.
[66.9] Large boulders of Franklin marble on R.
[67.1] Exposures of Franklin marble on L.
[67.4] Maple Road on L.
[67.5] Stop sign at T-intersection. Turn R on Sussex County Road 631 (Franklin Avenue).
[67.6] Road on L to Franklin Mineral Museum opposite dam to water supply on R.
[67.7] Grenville Marble exposed on L.
[68.1] Traffic light at intersection of NJ 23 and County Road 517. New shopping center ahead (Franklin Shopping Center). Turn L toward Sussex.
[68.4] Paleozoic carbonates on L with low dip to NW. At top of hill note Dunkin Donuts (a culinary marvel even without the hairs) on R.
[68.75] Turn R on gravel road just before McDonald's (a fine, world-class Scottish Restaurant).
[68.8] Drive through gate. Do Not Pass Go. Do not pay $200.
[68.9] Turn L toward rockface beyond big boulders ahead for Stop 4.

STOP 4 - Rutherford Cross Fault, Franklin. [UTM Coordinates: 535.5E / 4551.4N, Franklin quadrangle.]

In the large rock face in front of you, massive Cambro-Ordovician carbonates (to the right - SE) are in fault contact with mylonitic Grenville Marble (to the left - NW) along the Rutherford cross fault of Metsger. This area is actively being cleared by developers and as such the rock face may be unstable and may not last forever. The Paleozoic rocks are massive dark gray dolostones with black chert stringers on the SE side of the fault. According to Metsger (oral communication) drill-core data show that the thickness of the Paleozoic rocks exceeds 1300 ft. The Rutherford fault is sharp and strikes N57°E and dips 81°SE. Slickensides in the fault zone are marked by graphite smears in the Grenville Marble and indicate dominantly dip-slip normal motion (hanging wall down to SE) with some component of oblique slip. The fault zone is extremely sharp and marked by a clay- rich gouge zone 10 cm thick. Weathering of the clay gouge creates a recess that makes the fault all the more visible.

Even without the marked gouge zone, the difference in lithology across the fault is striking. Here, the footwall is composed of highly laminated graphitic marble with tight isoclinal and rootless folds of a well-developed mylonitic foliation in the marble defined by smeared graphitic lamellae. The folds of the mylonitic foliation (which may be related to faulting) plunge steeply toward the NE. The Grenvillian marble grades into iron-stained quartzo-feldspathic gneiss and a massive quartz-feldspar alaskitic intrusive away from the fault.

[68.9] Turn around and head back toward NJ 23.
[69.1] Turn R onto NJ 23 and then make immediate L onto Washington Avenue.
[69.2] Pass Franklin Elementary School.
[69.3] At Stop sign, turn L.
[69.35] Franklin marble exposed on R.
[69.65] Evans Street on R; the street leading to the Franklin Mineral Museum.
[69.7] Exposure of Franklin marble on R.
[69.8] Sharp turn to L into driveway of Franklin Rod & Rifle Club and bear L on gravel road.
[69.85] Park by shooting points at end of driveway for Stop 5.

STOP 5 - Proterozoic-Cambrian surface of nonconformity and camptonite dike in Franklin Marble. [UTM Coordinates: 534.65E / 4551.0N, Franklin quadrangle.]

Climb up on steep slope to R beside Franklin Revolver and Rifle Club building and note, where the rock was not quarried, the presence of a 1.5-m-thick camptonite dike oriented N40°E, 60°SE. The dike, which is an alkalic igneous rock similar to the Beemerville intrusives to the west, is intruded into the Franklin Marble and contains a thin vein of quartz along its SE side. The quarrying removed marble for lime.

Of further interest here, note the crack filling of quartzite of overlying Lower Cambrian Hardyston Formation. Look closely at the iron-stained quartzite and note the presence of detrital franklinite and graphite. This simple observation proves the Proterozoic age of ore formation and you've just sampled across the Proterozoic-Cambrian nonconformity at no extra charge. CM notes that the thin veneer of iron-stained quartzite here may be older than Cambrian as the lithology fits descriptions presented earlier for the Proterozoic Z Chestnut Hill Formation (Drake, 1984) which rests nonconformably above the Grenvillian Franklin Marble. More work needs to be done here to prove or disprove this idea.

[69.85] Turn around and head out the way we came.
[69.9] At the end of driveway; sharp R onto street to Mineral Museum. (Please watch traffic here as it is a dangerous curve).
[70.0] Turn L onto Evans Street.
[70.1] Turn L into Franklin Mineral Museum Parking lot for Stop 6.

STOP 6 - Franklin Mineral Museum Lecture, Tour, and (Time-Permitting) Collecting at Buckwheat Dump. [UTM Coordinates: 534.58E / 4551.26N, Franklin quadrangle.]

We have made an arrangement with Mrs. Carol Hunsinger (Manager) and Steve Sanford, curator of the Franklin Mineral Museum, to enjoy a guided tour and lecture of the museum. There are specimens for sale in his shop and a phenomenal collection of Franklin/Sterling Hill mineral specimens on view in the museum including the Bill Welsh collection. Time permitting (and for a $3.00 fee) you will be permitted to collect fluorescent minerals from the Buckwheat Dump immediately west of the museum.

Just behind here is the old open pit of the Franklin Mine. The underground workings of the mine (which form a labyrinth beneath the town of Franklin) were closed in 1954. In the distance is a narrow cut beyond which occurs a subvertical lamprophyre dike 20 ft thick, which encloses xenoliths of Franklin ore. Strangely, the willemite-bearing xenoliths still fluoresce despite the fact that high heat typically destroys the fluoresence of willemite.

[70.2] Turn R toward Sussex County Road 631.
[70.3] Turn L onto Sussex County Road 631.
[70.8] Turn R at traffic light junction with NJ 23 (Mobil Station).
[71.2] Traffic light; on R Sussex County Road 517 (road to Ogdensburg). Ahead are Hamburg Mountains, a block underlain by Proterozoic gneisses, exposed in cuts ahead. NJ 23 follows the valley of Franklin Pond Creek.
[72.2] Wide belt of Proterozoic gneisses; exposures on both sides of NJ 23.
[72.8] Bridge over Susquehanna and Western RR tracks; MP 30 on R by bridge.
[73.4] Start large curve to R.
[73.6] End curve on NJ 23.
[73.7] On L, Sussex County Road 625 (road to Silver Lake).
[73.9] Passing road on R to Lake Gerard.
[74.4] Passing road on R to Summit Lake and Tamarack Lake.
[74.9] MP 28 on R;, just past entry on L of Sussex County Road 625.
[75.8] Blinker light; road to Stockholm to L and Lake Stockholm to R.
[75.9] Begin 4-lane divided highway on NJ 23. Passing MP 27 on R.
[76.2] Traffic signal; road on R for Sussex County Road 515.
[76.6] Exposure of Proterozoic gneisses on R. Leave Sussex County, enter Morris County.
[76.9] MP 26 on R. Leave Franklin quadrangle, enter Newfoundland quadrangle.
[77.0] Passing sign on R indicating West Milford Township line. Here, N.J 23 follows valley of Pequannock River.
[77.2] Traffic light. Road on R for Canistear Road. Leads to Canistear Reservoir in NW corner of Newfoundland quadrangle.
[77.7] NJ 23 crosses creek. Leave Morris County, enter Passaic County.
[77.9] Oak Ridge Reservoir on R; Proterozoic rocks exposed on W shore.
[78.4] Traffic light; passing Reservoir Road on R.
[78.7] Bridge over Susquehanna and Western RR.
[78.9] Traffic light; passing Paradise Road. The glacial deposits here are thick and they mask a major fault, with the Proterozoic rocks of the Hamburg Mountains, just crossed, on the NW, and

a complexly folded belt of Silurian- and Devonian rocks, just ahead. In this belt of Silurian-Devonian rocks occur two prominent ridge-making formations: the Green Pond Conglomerate (L. Silurian; SE extension of the Shawangunk-Tuscarora) and the Schunnemunk Conglomerate (M. Devonian, a SE extension of the rocks underlying the Catskills).
[79.0] Passing MP 23 on R.
[79.2] Traffic signal; passing Oak Ridge Road (to Milton) on R.
[79.3] Sign on R indicates entering Newfoundland.
[79.8] Traffic signal; passing La Rue Road on R.
[80.3] Passing County Road 513 on R.
[80.5] Traffic signal Union Valley Road (County Road 513) on ramp on R for left turn. The high ridge on the R is Green Pond Mountain, the source of the name for the Green Pond Conglomerate.
[80.9] Passing median road for U turn (westbound) on L.
[81.0] Passing MP 21 on R; crossing Kanouse Brook.
[81.1] Median road for U turn (eastbound) on L. Pull over to R on R shoulder for Stop 7.

STOP 7 - Anticline and syncline in Lower Silurian Green Pond Formation, Newfoundland. [UTM Coordinates: 547.4E, 4542.7N, Newfoundland quadrangle.]

We have just come out of a continuous belt of Proterozoic gneisses and have passed over a fault that separates the older gneisses from an inlier of Silurian- and Devonian strata of Layer III. Presumably the Siluro-Devonian strata have been downdropped against the in-situ Proterozoic but modern interpretations, involving significant basement-over-basement overthrusting, allow for the possibility that the Proterozoic and Paleozoic rocks may have been downdropped from the upper plate. As such, this may be a down and in-lier (a new term not to be confused with down and out-lier).

The cuts on the SW side of NJ 23 expose a distinctive fine-pebble conglomerate with uniformly sized white quartz pebbles in a purplish fine-textured matrix interbedded with sandstone and siltstone. This distinctive rock forms erratics found on the beach at Princes Bay, Staten Island and thus provide a direct line provenance point-source that is a glacial- flow-direction indicator. After seeing such erratics, the late Professor Emeritus of Biology from Barnard College, Donald Ritchie, dubbed them "Braunschweiger-sausage" rocks. Once you have seen this rock, you will understand why he gave it this name.

Exposed in the roadcut are an asymmetric anticline and -syncline couple of sandstones with interbedded siltstones and shales. Compared to the sandstones, the shales are differentially strongly cleaved; cleavage has been "refracted" across bedding surfaces. The bedding/cleavage relationships indicate that the folds are upright. Slickensides within the more-competant sandstones indicate that they were lithified at the time of deformation with the axes of small folds parallel to the regional "Appalachian" trends. Take note, however, that the axial surfaces of the folds dip toward the northwest, a reversal of the typical southeast dip of most Appalachian folds in this area.

NJ 23 follows through a gap in the strike ridges underlain by the resistant Green Pond Conglomerate. To the NE, the ridge is Kanouse Mountain; to the SW, it is Copperas Mountain. Just beyond Copperas Mountain to the SE is a new reservoir formed by the damming of Pequannock River.

[81.1] Continue east on NJ 23.
[81.7] Traffic signal, Echo Lake Road.
[82.0] MP 20. Start Proterozoic rocks of Ramapo block.
[82.4] Exposures on L of Proterozoic gneisses.
[82.6] Median road for U turn; continue on NJ 23.
[82.8] Macopin Reservoir in median lowland between divided lanes of NJ 23.
[83.1] End of Macopin Reservoir; US Geological Survey stream-gaging station on Pequannock River at SE end of the reservoir.
[83.2] Passing median U-turn road on L.
[83.9] Crossing Pequannock River. On L is a large borrow pit where glacial sediments have been removed, exposing the underlying Proterozoic gneisses.
[84.4] End divided highway.
[84.8] Leave Newfoundland quadrangle, enter Wanaque quadrangle.
[85.0] Crossing Pequannock River, leave Passaic County, enter Morris County.
[85.9] Traffic light, Kinnelon Road (County Road 511) on R. County Road 515 to Butler on L.
[86.1] Leave Wanaque quadrangle, enter Pompton Plains quadrangle.
[87.9] Passing road on L to Nee's Plaza, Butler.
[88.9] Passing Suntan Lake on L and begin curve to L.
[89.2] End curve on NJ 23. Valley Spring Lake downhill to L.
[89.4] Begin curve to R on NJ 23.
[89.6] End curve; logging operation on R.
[90.0] Passing MP 13 on R; crossing Ramapo fault and entering Newark basin.
[90.5] Start traffic circle. A bit of freelancing may take place here in order to take a look at the large new cuts exposing the Proterozoic rocks in the Ramapo fault zone on I-287 for Stop 8.

STOP 8 - Ramapo Border Fault, Exposed in New Cuts, I-287. [UTM Coordinates: 558.0E / 4537.6N, Pompton Plains quadrangle.]

This is a free-form *(read that as, sorry guys but we really haven't looked too closely at this one!)* stop where we will examine new exposures of the Ramapo Fault. Here, the Proterozoic gneisses consist of quarto-feldspathic, amphibolitic, and granitoid gneisses that are strongly retrograded to epidote-rich rocks. The exposure is cut by surprisingly few brittle faults. Thus, despite the fact that we are within the Ramapo fault zone only a few faults have been observed. These faults dip steeply toward the east and contain slickensides that plunge toward the northeast. We have not examined these rocks in detail, however, and will discover and discuss our findings On-The-Rocks. As such, any new data will be truly new and open for scientific discussion. JES and CM will be offering On-The-Rocks franchises for those of you who would like to write the newer version of this guidebook.

-------------------------End of Trip---------------------------

Driving Directions Back to NYAS

Continue south on I-287 and east on I-80 to I-95 across the George Washington Bridge. Take Harlem River Drive south to FDR Drive to 63rd Street exit back to the Academy. We hope you've enjoyed the trip ---- ;)

ACKNOWLEDGEMENTS

We would like to thank Bob Metsger for joining us on our 1990 pre-field trip investigation of the trip and for his willingness, in May of 1990 and on this retrip, to share his experience on the mining history and geology of the Sterling Hill Mine. Thanks also to Dick and Elna Houck of the Sterling Hill Mining Company for allowing access to the Sterling Hill Mine. Thanks also to Carol Hunsinger and Steve Sanford for agreeing to conduct a special tour of the Franklin Mineral Museum for the On-The-Rocks Field Trip Series. Hofstra student Jessica Levine assisted in compilation and xerography of illustrations. Matt Katz and Marcie Brenner of the Academy were, as usual, most helpful in the logistical support necessary for such an undertaking.

TABLES

Table 01 - GEOLOGIC TIME CHART

(with selected major geologic events from southeastern New York and vicinity)

ERA Periods (Epochs)	Years (Ma)	Selected Major Events
CENOZOIC		
(Holocene)	0.1	Rising sea forms Hudson Estuary, Long Island Sound, and other bays. Barrier islands form and migrate.
(Pleistocene)	1.6	Melting of last glaciers forms large lakes. Drainage from Great Lakes overflows into Hudson Valley. Dam at The Narrows suddenly breached and flood waters erode Hudson shelf valley. Repeated continental glaciation with five? glaciers flowing from NW and NE form moraine ridges on Long Island.
(Pliocene)	6.2	Regional uplift, tilting and erosion of coastal-plain strata; sea level drops. Depression eroded that later becomes Long Island Sound.
(Miocene)	26.2	Fans spread E and SE from Appalachians and push back sea. Last widespread marine unit in coastal-plain strata.
MESOZOIC	66.5	
(Cretaceous)		
	96	Passive eastern margin of North American plate subsides and sediments (the coastal-plain strata) accumulate.
	131	(**Begin Atlantic Passive-Margin Stage II**).
(Jurassic)		Baltimore Canyon Trough forms and fills with 8,000 feet of pre-Cretaceous sediments.
		Atlantic Ocean starts to open. Newark basins deformed, arched, eroded.
	190	Continued filling of subsiding Newark basins and mafic igneous activity both extrusive and intrusive.
(Triassic)		Newark basins form and fill with non-marine sediments.

PALEOZOIC	245	
(Permian)		Pre-Newark erosion surface formed.
	260	**Appalachian orogeny.** (Terminal stage.) Folding, overthrusting, and metamorphism of Rhode Island coal basins; granites intruded.
(Carboniferous)		Faulting, folding, and metamorphism in New York City area. Southeastern New York undergoes continued uplift and erosion.
(Devonian)	365	**Acadian orogeny.** Deep burial of sedimentary strata. Faulting, folding, and metamorphism in New York City area. Peekskill Granite and Acadian granites intruded.
(Silurian)		
	440 450	**Taconic orogeny.** Intense deformation and metamorphism. Cortlandt Complex and related rocks intrude Taconian suture zone. (Cameron's Line and St. Nicholas Thrusr Zone). Arc-continent collision. Great overthrusting from ocean toward continent. Taconic deep-water strata thrust above shallow-water strata.
(Ordovician)		Ultramafic rocks (oceanic lithosphere) sliced off and transported structurally above deposits of continental shelf. Shallow-water clastics and carbonates accumulate in west of basin. (= **Sauk Sequence**; protoliths of the Lowerre Quartzite, Inwood
(Cambrian)		Marble, Walloomsac Schist). Transitional slope/rise sequence (Manhattan Schist) and deep-water terrigenous strata (Hartland Formation) form to east. (= **Taconic Sequence**).
PROTEROZOIC		
	570	Period of uplift, rifting,and erosion followed by subsidence of margin and development of **Iapetan Passive-Margin Stage I**.
(Z)	600	Rifting with rift sediments, volcanism, and intrusive activity. (Ned Mountain, Pound Ridge, and Yonkers gneiss protoliths).
(Y)	1100	**Grenville orogeny.** Sediments and volcanics deposited, compressive deformation, intrusive activity, and granulite facies metamorphism. (Fordham Gneiss, Hudson Highlands and related rocks).
ARCHEOZOIC		
	2600	No record in New York.
	4600	Solar system (including Earth) forms.

Table 02

Generalized Descriptions of Major Geologic "Layers", SE New York State and Vicinity

This geologic table is a tangible result of the On-The-Rocks Field Trip Program conducted by Drs. John E. Sanders and Charles Merguerian between 1988 and 1998. In Stenoan and Huttonian delight, we here present the seven layer cake model that has proved so effective in simplifying the complex geology of the region. Under continual scrutiny and improvement, we provide this updated web-based information as a public service to all students and educators of geology. We encourage any comments, additions, or corrections. References cited can be sought by following this link.

LAYER VII - QUATERNARY SEDIMENTS

A blanket of irregular thickness [up to 50 m or more] overlying and more or less covering all older bedrock units. Includes four or five tills of several ages each of which was deposited by a continental glacier that flowed across the region from one of two contrasting directions: (1) from N10°E to S10°W (direction from Labrador center and down the Hudson Valley), or (2) from N20°W to S20°E (direction from Keewatin center in Hudson's Bay region of Canada and across the Hudson Valley). The inferred relationship of the five tills is as follows from youngest [I] to oldest [V]. [I] - Yellow-brown to gray till from NNE to SSW, [II] - red-brown till from NW to SE, [III] - red-brown till from NW to SE, and [IV] - yellow-brown to gray till from NNE to SSW, and [V] - red-brown till from NW to SE containing decayed stones (Sanders and Merguerian, 1991a,b, 1992, 1994a, b; Sanders, Merguerian, and Mills, 1993; Sanders and others, 1997; Merguerian and Sanders, 1996). Quaternary sediments consist chiefly of till and outwash. On Long Island, outwash (sand and gravel) and glacial lake sediment predominates and till is minor and local. By contrast, on Staten Island, tills and interstratified lake sediments predominate and sandy outwash appears only locally, near Great Kills beach.

[Pliocene episode of extensive and rapid epeirogenic uplift of New England and deep erosion of major river valleys, including the excavation of the prominent inner lowland alongside the coastal-plain cuesta; a part of the modern landscape in New Jersey, but submerged in part to form Long Island Sound].

~~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~~

LAYER VI - COASTAL-PLAIN STRATA (L. Cretaceous to U. Miocene; products of Passive Continental Margin II - Atlantic).

Marine- and nonmarine sands and clays, present beneath the Quaternary sediments on Long Island (but exposed locally in NW Long Island and on SW Staten Island) and forming a wide outcrop belt in NE New Jersey. These strata underlie the submerged continental terrace. The basal unit (L. Cretaceous from Maryland southward, but U. Cretaceous in vicinity of New York City) overlaps deformed- and eroded Newark strata and older formations. Also includes thick (2000 m) L. Cretaceous sands and shales filling the offshore Baltimore Canyon Trough. At the top are Miocene marine- and coastal units that are coarser than lower strata and in many localities SW of New Jersey, overstep farther inland than older coastal-plain strata. Capping unit is a thin (<50 m) sheet of yellow gravel (U. Miocene or L. Pliocene?) that was prograded as SE-directed fans from the Appalachians pushed back the sea. Eroded Newark debris is present in L. Cretaceous sands, but in U. Cretaceous through Miocene units, Newark-age redbed debris is conspicuously absent. This relationship is considered to be proof that the coastal-plain formations previously buried the Newark basins so that no Newark-age debris was available until after the Pliocene period of great regional uplift and erosion. The presence of resistant heavy minerals derived from the Proterozoic highlands part of the Appalachians within all coastal-plain sands indicates that the coastal-plain strata did not cover the central highlands of the Appalachians.

[Mid-Jurassic to Late Jurassic episode of regional arching of Newark basin-filling strata and end of sediment accumulation in Newark basin; multiple episodes of deformation including oroclinal "bending" of entire Appalachian chain in NE Pennsylvania (Carey, 1955), and one or more episodes of intrusion of mafic igneous rocks, of folding, of normal faulting, and of strike-slip faulting (Merguerian and Sanders, 1994b). Great uplift and erosion, ending with formation of Fall-Zone planation surface].

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

LAYER V - NEWARK BASIN-FILLING STRATA (Upper Triassic and Lower Jurassic)

Newark-age strata unconformably overlie folded- and metamorphosed Paleozoic strata of Layer II and some of the Proterozoic formations of Layer I; are in fault contact with other Proterozoic formations of the Highlands complex. Cobbles and boulders in basin-marginal rudites near Ramapo Fault include mostly rocks from Layers III, IIB, and IIA(W), which formerly blanketed the Proterozoic now at the surface on the much-elevated Ramapo Mountains block. The thick (possibly 8 or 9 km) strata filling the Newark basin are nonmarine.

In addition to the basin-marginal rudites, the sediments include fluvial- and varied deposits of large lakes whose levels shifted cyclically in response to climate cycles evidently related to astronomic forcing. A notable lake deposit includes the Lockatong Formation, with its analcime-rich black argillites, which attains a maximum thickness of about 450 m in the Delaware River valley area. Interbedded with the Jurassic part of the Newark strata are three extrusive complexes, each 100 to 300 m thick, whose resistant tilted edges now underlie the curvilinear ridges of the Watchung Mountains in north-central New Jersey. Boulders of vesicular basalt in basin-marginal rudites prove that locally, the lava flows extended northwestward across one or more of the basin-marginal faults and onto a block that was later elevated and eroded. The thick (ca. 300 m) Palisades intrusive sheet is concordant in its central parts, where it intrudes the Lockatong at a level about 400 m above the base of the Newark strata. To the NE and SW, however, the sheet is discordant and cuts higher strata (Merguerian and Sanders, 1995a). Contact relationships and the discovery of clastic dikes at the base of the Palisades in Fort Lee, New Jersey, suggest that the mafic magma responsible for the Palisades was originally intruded at relatively shallow depths (roughly 3 to 4 km) according to Merguerian and Sanders (1995b).

Xenoliths and screens of both Stockton Arkose and Lockatong Argillite are present near the base of the sill. Locally, marginal zones of some xenoliths were melted to form granitic rocks (examples: the trondhjemite formed from the Lockatong Argillite at the Graniteville quarry, Staten Island, described by Benimoff and Sclar, 1984; and a "re-composed" augite granite associated with pieces of Stockton Arkose at Weehawken and Jersey City, described by J. V. Lewis, 1908, p. 135-137).

[**Appalachian terminal orogeny**; large-scale overthrusts of strata over strata (as in the bedding thrusts of the "Little Mountains east of the Catskills" and in the strata underlying the NW side of the Appalachian Great Valley), of basement over strata (in the outliers NW of the Hudson Highlands, and possibly also in many parts of the Highlands themselves), and presumably also of basement over basement (localities not yet identified). High-grade metamorphism of Coal Measures and intrusion of granites in Rhode Island dated at 270 Ma. Extensive uplift and erosion, ending with the formation of the pre-Newark peneplain].

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

LAYER IV - COAL MEASURES AND RELATED STRATA (Carboniferous)

Mostly nonmarine coarse strata, about 6 km thick, including thick coals altered to anthracite grade, now preserved only in tight synclines in the Anthracite district, near Scranton, NE Pennsylvania; inferred to have formerly extended NE far enough to have buried the Catskills and vicinity in eastern New York State (Friedman and Sanders, 1982, 1983).

[**Acadian orogeny**; great thermal activity and folding, including metamorphism on a regional scale, ductile deformation, and intrusion of granites; dated at ~360 Ma].

LAYER III - MOSTLY MARINE STRATA OF APPALACHIAN BASIN AND CATSKILLS (Carbonates and terrigenous strata of Devonian and Silurian age)

(Western Facies)	**(Eastern Facies)**
Catskill Plateau, Delaware Valley monocline, and "Little Mountains" NW of Hudson-Great Valley lowland.	SE of Hudson-Great Valley lowland in Schunnemunk-Bellvale graben.
Kaaterskill redbeds and cgls.	Schunnemunk Cgl.
Ashokan Flags (large cross strata)	Bellvale Fm., upper unit
Mount Marion Fm. (graded layers, marine)	Bellvale Fm., lower unit (graded layers, marine)
Bakoven Black Shale	Cornwall Black Shale
Onondaga Limestone	

Schoharie buff siltstone	Pine Hill Formation
Esopus Formation	Esopus Formation
Glenerie Chert	
Connelly Conglomerate	Connelly Conglomerate
Central Valley Sandstone	
Carbonates of Helderberg Group	Carbonates of Helderberg Group
Manlius Limestone	
Rondout Formation	Rondout Formation
Decker Formation	
Binnewater Sandstone	Poxono Island Formation
High Falls Shale	Longwood Red Shale
Shawangunk Formation	Green Pond Conglomerate

[**Taconic orogeny**; 480 Ma deep-seated folding, dynamothermal metamorphism and mafic- to ultramafic (alkalic) igneous intrusive activity (dated in the range of 470 to 430 Ma) across suture zone (Cameron's Line-St. Nicholas thrust zones). Underthrusting of shallow-water western carbonates of Sauk Sequence below supracrustal deep-water eastern Taconic strata and imbrication of former Sauk-Tippecanoe margin. Long-distance transport of strata over strata has been demonstrated; less certain locally is proof of basement thrust over strata and of basement shifted over basement. In Newfoundland, a full ophiolite sequence, 10 km thick, has been thrust over shelf-type sedimentary strata]. In NYC and throughout New England, dismembered ophiolite is common (Merguerian 1979; Merguerian and Moss 2005, 2007).

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

LAYER II - CAMBRO-ORDOVICIAN CONTINENTAL-MARGIN COVER (Products of Passive Continental Margin I - Iapetus). Subdivided into two sub layers, IIB and IIA. Layer IIA is further subdivided into western- and eastern facies.

LAYER IIB - TIPPECANOE SEQUENCE - Middle Ordovician flysch with basal limestone (Balmville, Jacksonburg limestones).

Not metamorphosed / Metamorphosed
Martinsburg Fm. / Walloomsac Schist
Normanskill Fm. / Annsville Phyllite

Subaerial exposure; karst features form on Sauk (Layer IIA[W]) platform.

~~~~~~~~~~~~~~~~~~~~Surface of unconformity~~~~~~~~~~~~~~~~~~~~

LAYER IIA [W] - SAUK SEQUENCE

Western shallow-water platform
(L. Cambrian - M. Ordovician)

Copake Limestone (Stockbridge,
Rochdale Limestone (Inwood Marble)
Halcyon Lake Fm.
Briarcliff Dolostone
Pine Plains Fm.
Stissing Dolostone
Poughquag Quartzite
Lowerre Quartzite
Ned Mtn Fm.

LAYER IIA [E] - TACONIC SEQUENCE

Eastern deep-water zone
(L. Cambrian-M. Ordovician)

(Ꞓ-Oh) Hartland Fm.
(Ꞓ-Om) Manhattan Fm.

[**Pre-Iapetus Rifting Event**; extensional tectonics, volcanism, rift-facies sedimentation, and plutonic igneous activity precedes development of Iapetus ocean basin. Extensional interval yields protoliths of Pound Ridge Gneiss, Yonkers granitoid gneisses, and the Ned Mountain Formation (Brock, 1989, 1993). In New Jersey, metamorphosed rift facies rocks are mapped as the Chestnut Hill Formation of A. A. Drake, Jr. (1984)].

~~~~~~~~~~~~~~~~~~~~**Surface of unconformity**~~~~~~~~~~~~~~~~~~~~

LAYER I - PROTEROZOIC BASEMENT ROCKS

Many individual lithologic units including Proterozoic Z and Y ortho- and paragneiss, granitoid rocks, metavolcanic- and metasedimentary rocks identified, but only a few attempts have been made to decipher the stratigraphic relationships; hence, the three-dimensional structural relationships remain obscure. Followed by a period of uplift and erosion.

~~~~~~~~~~~~~~~~~~~~**Surface of unconformity**~~~~~~~~~~~~~~~~~~~~

[**Grenville orogeny**; deformation, metamorphism, and plutonism dated about 1,100 Ma. After the orogeny, an extensive period of uplift and erosion begins. Grenville-aged (Proterozoic Y) basement rocks include the Fordham Gneiss of Westchester County, the Bronx, and the subsurface of western Long Island (Queens and Brooklyn Sections, NYC Water Tunnel #3), the Hudson Highland-Reading Prong terrane, the Franklin Marble Belt and associated rocks, and the New Milford, Housatonic, Berkshire, and Green Mountain Massifs.]

~~~~~~~~~~~~~~~~~~~~**Surface of unconformity**~~~~~~~~~~~~~~~~~~~~

In New Jersey and Pennsylvania rocks older than the Franklin Marble Belt and associated rocks include the Losee Metamorphic Suite. Unconformably beneath the Losee, in Pennsylvania, Proterozoic X rocks of the Hexenkopf Complex crop out.
~~~~~~~~~~~~~~~~~~~~

Table 03 - Fluorescent Minerals of Franklin and Sterling Hill
(R. C. Bostwick, 1982, Table 1, p. 198.)

FLUORESCENT MINERALS OF FRANKLIN AND STERLING HILL

Species in italics are those which fluoresce more intensely under long wave ultraviolet radiation; most Franklin fluorescent species are much more brightly fluorescent under short wave ultraviolet radiation. Listed colors are fluorescent colors. (Compiled May, 1982.)

Aragonite — white, cream, green
Barite — white, cream, blue-white, tan
Barylite — pale blue
Bustamite — red
Cahnite — cream
Calcite — white, cream, yellow, orange, red, green, pink
Celestite — cream
Cerussite — yellow
Chrondrodite — yellow
Clinohedrite — orange
Corundum — red
Diopside — blue, cream
Dypingite — blue
Edenite — blue, greenish-blue
Epsomite — cream
Esperite — yellow
Ettringite — cream
Fluoborite — cream
Fluorapatite — blue, violet-blue, orange
Fluorite — green, blue-green, violet
Guerinite — white
Gypsum — blue
Hardystonite — blue-violet
Hedyphane — orange, cream
Hemimorphite — white, green
Hodgkinsonite — red
Hyalophane — red
Hydrotalcite — cream
Hydrozincite — blue
Johnbaumite — orange
Manganaxinite — red
Margarite — blue
Margarosanite — blue, red, cream, orange
Microcline — blue, red
Mimetite — orange
Monohydrocalcite — green
Norbergite — yellow
Oyelite — violet, white
Pectolite — orange
Phlogopite — yellow
Picropharmacolite — white
Powellite — yellow
Prehnite — pink
Scapolite group — red, cream, yellow, pink
Scheelite — yellow
Smithsonite — yellow
Sphalerite — orange, yellow, blue
Svabite — orange
Talc — cream
Thomsonite — white, cream
Tilasite — yellow
Titanite — tan
Tremolite — blue, cream
Uranospinite — green
Uvite — yellow
Willemite — green, yellow-orange, yellow
Wollastonite — orange, yellow
Xonotlite — blue
Zincite — yellow
Zircon — yellow-orange

Table 4 - The Fluorescent Minerals of Franklin and Sterling Hill Tabulated by Fluorescent Color.
(R. C. Bostwick, 1982, Table 2, p. 199-200.)

THE FLUORESCENT MINERALS OF FRANKLIN AND STERLING HILL TABULATED BY FLUORESCENT COLOR

Although fluorescent minerals exhibit a remarkable diversity of color, here they are categorized as red, pink, orange, yellow/tan, green, blue, violet, and white/cream. Fluorescent intensity is described as strong, moderate, weak, or very weak. All listings are based on first-hand observations made by the author.

Fluorescent mineral occurrence relative to the various mineral assemblages at Franklin and Sterling Hill is noted parenthetically. A typical notation (O, C: F, SH), means that the mineral may be found with the ore and calc-silicate assemblages at both Franklin and Sterling Hill.

Abbreviation of Terms

AC = altered calc-silicate occurrence
C = calc-silicate occurrence
F = Franklin location
F M = Franklin marble occurrence
L W = long wave ultraviolet radiation (366 nanometers)
O = ore occurrence
P = "pegmatite" occurrence
S H = Sterling Hill location
S W = short wave ultraviolet radiation (254 nanometers)
V = vein mineral occurrence
W = weathering mineral occurrence

Red Fluorescence

Bustamite: Moderate red fluorescence LW; weak SW. (C: F)
Calcite: Strong orange-red fluorescence, brief phosphorescence SW; weaker LW. (O, C, AC, V, P when associated with ore bodies: F, SH) (very rarely FM)
Corundum: Moderate red fluorescence LW; weak SW. (FM)
Hodgkinsonite: Weak red fluorescence LW. (V: F, SH)
Hyalophane: Weak red fluorescence SW. (C,AC: F)
Manganaxinite: Strong to weak orange-red fluorescence SW; weaker LW, very weak phosphorescence. Lack of obvious phosphorescence distinguishes it from calcite. (AC: F)
Margarosanite: Weak red, orange, or cream fluorescence LW. Strong blue, often with zoned red fluorescence SW. (Platy masses or disseminated in feldspar, AC: F)
Microcline: Weak red fluorescence SW. (C, AC, P: F, SH)
Scapolite group: Moderate red fluorescence SW. (P, FM)

Pink Fluorescence

Apatite group: Moderate dull orange-pink fluorescence SW. Also see fluorapatite listing under orange fluorescence. (O, C: F, SH)
Calcite: Moderate pink fluorescence, brief orange-red phosphorescence SW and LW. Rare. (V, W: F, SH)
Prehnite: Moderate creamy orange-pink or "peach" fluorescence SW. (White platy form often associated with pectolite and margarosanite, AC: F)
Scapolite group: Moderate pink fluorescence SW. Rare. (C, SH)

Orange Fluorescence

Calcite: Moderate orange fluorescence and phosphorescence SW. (A rare vein coating associated with fluorescent zincite: SH)
Clinohedrite: Strong orange fluorescence, persistant phosphorescence SW; weaker variations of intensity LW. (Coatings on hardystonite, several other forms, C, AC, V: F)
Fluorapatite: Strong to weak fluorescence SW; very weak (if any) fluorescence LW. Dominant member of apatite groups but not necessarily distinguished by fluorescence from svabite, hedyphane, mimetite, and johnbaumite. (O, C, V, P: F, SH)
Hedyphane: Moderate orange fluorescence SW; weak cream fluorescence LW. (Rare vein mineral with manganaxinite, rhodonite: F)
Johnbaumite: Moderate orange fluorescence SW. Rare. See fluorapatite listing. (F)
Margarosanite: Weak orange, red, or cream fluorescence LW; strong blue, often with zoned red fluorescence SW. (Platy masses or disseminated in feldspar, AC: F)
Mimetite: Moderate orange fluorescence SW. See fluorapatite listing. (F)
Pectolite: Moderate orange fluorescence and phosphorescence SW; weaker LW. White fibrous material labelled "pectolite" is probably wollastonite. (Glassy grains associated with prehnite, AC: F)
Sphalerite: Moderate, various hues of orange often flecked with blue fluorescence, phosphorescent LW; weaker SW. (O, C, V: abundant SH, less of F)
Svabite: Moderate orange fluorescence SW. See fluorapatite listing. (F)
Willemite: Moderate yellow-orange to pale greenish-yellow fluorescence and phosphorescence SW. Often misnamed "beta-willemite." (Small crystals, powdery coatings, W: SH)
Wollastonite: Strong orange to yellow fluorescence, often with red-orange phosphorescence SW; weaker LW. (Massive and grains, C: F, SH) (Fibrous, AC: F)
Zircon: Moderate yellow-orange fluorescence SW. Rare. (Crystals, P)

Yellow or Tan Fluorescence

Barite: Moderate tan fluorescence and phosphorescence SW and LW. Rare. (V: SH)
Calcite: Moderate yellow to orange yellow fluorescence LW; weak, redder fluorescence SW, some phosphorescence. (Variety of forms, V, W: F, SH)
Cerussite: Moderate yellow fluorescence LW; weak SW. (Crystals, W: SH)
Chrondrodite: Moderate yellow fluorescence SW; weak LW. Fluoresces same as norbergite. (FM)
Esperite: Strong lemon-yellow fluorescence, very weak phosphorescence SW; weak fluorescence LW. (C: F)
Norbergite: Moderate yellow fluorescence SW; weak LW. Fluoresces same as chondrodite. (FM)
Phlogopite: Moderate yellow fluorescence SW. (FM)
Powellite: Moderate yellow fluorescence SW; weak LW. (Associated with molybdenite, W: F, SH)
Scapolite group: Moderate to weak yellow to orange-yellow fluorescence and phosphorescence LW and SW. (FM)
Scheelite: Moderate yellow fluorescence SW; weak LW. (P: F)
Smithsonite: Moderate yellow to orange-yellow fluorescence LW; weak SW. (Coatings, poorly characterized, W: SH, F)
Sphalerite: Moderate orange-yellow fluorescence and phosphorescence LW. Rare. (O, C, V, W: F, SH)
Tilasite: Moderate creamy-yellow fluorescence SW. Very rare. (White crystalled vein material: SH)

Table 4 (cont'd)

Titanite: Weak tan fluorescence LW. (Brown crystals, FM)
Uvite: Moderate yellow fluorescence SW; weak LW. (FM)
Willemite: Moderate pale greenish yellow to orange fluorescence and phosphorescence SW; weak LW. Often misnamed "beta-willemite." (Small crystals, powdery coatings, W: SH)
Wollastonite: Moderate yellow to orange fluorescence, with a redder hued phosphorescence SW; weak fluorescence LW. (C: SH)
Zincite: Moderate pale yellow fluorescence LW, weaker SW. (Yellow veins and pods in ore: SH) This is a classic occurrence; most zincite does not fluoresce.

Green Fluorescence

Aragonite: Moderate green or cream fluorescence and cream phosphorescence LW: rarely green fluorescence SW. (W: SH)
Calcite: Moderate green or cream fluorescence, may phosphoresce cream LW; rarely green fluorscence SW. (FM) (W: SH)
Fluorite: Moderate pale green to bluish green fluorescence and phosphorescence LW, SW, and after exposure to incandescent light. Overexposure to light destroys greenish fluorescence; weak violet fluorescence remains. (O, C: F, SH)
Hemimorphite: Moderate green fluorescence, rare SW; weak white fluorescence LW. (W: SH)
Monohydrocalcite: Moderate green fluorescence SW and LW. Some phosphorescence LW. Rare. (Shiny yellow coating, W: SH)
Uranospinite: Moderate green fluorescence SW and LW. Rare. (Dull yellow coating, W: SH)
Willemite: Strong green fluorescence, often with strong phosphorescence SW; intensity variable LW. (Many forms, O, C, AC, V and rarely P: F, SH)

Blue Fluorescence

Barylite: Moderate pale blue fluorescence under the iron-arc spark; weak pale blue SW; weaker LW. Possible very weak phosphorescence. Almost all material labelled "barylite" is margarosanite disseminated in feldspar. (Hard, brittle white plates occurring with red-fluorescing calcite, serpentine, C: F)
Diopside: Moderate blue fluorescence SW; cream fluorescence LW. (FM)
Dypingite: Moderate blue fluorescence and phosphorescence SW and LW. (Coatings of white hemispheres, W: SH)
Edenite: Moderate blue to greenish-blue fluorescence SW. (Green, imperfectly characterized, FM)
Ettringite: Moderate pale blue fluorescence and phosphorescence SW and LW. Due to alteration coating of gypsum, the fluorescence of unaltered ettringite is difficult to observe. (AC: F)
Fluorapatite: Moderate to weak blue fluorescence SW; weak pale violet-blue fluorescence LW. (Greenish-blue crystals, FM)
Gypsum: Moderate pale blue to white fluorescence SW; weaker LW. (W: SH)
Hydrozincite: Strong blue fluorescence SW. (White powdery coating, W: SH)
Margarite: Weak pale blue fluorescence SW and LW. (Blue "brittle mica," FM)
Margarosanite: Strong blue, often with zoned red fluorescence SW; may fluoresce weaker red, cream, or orange LW. (Platy masses or disseminated in feldspar, AC: F)
Microcline: Moderate blue fluorescence SW. (C, P: F, SH)
Sphalerite: Moderate orange (with blue flecks) fluorescence and phosphorescence LW; weaker SW. Rarely moderate blue fluorescence and phosphorescence LW; weaker SW. (O, C, V: F, SH)
Tremolite: Moderate blue fluorescence SW; cream fluorescence LW. (Typically as prismatic crystals, FM)
Xonotlite: Moderate blue fluorescence SW; weak LW. (White, acicular, AC: F)

Violet Fluorescence

Fluorite: Moderate blue-violet fluorescence LW; weak SW. Such fluorite probably once fluoresced green but has been overexposed to light. (O, C: F, SH)
Hardystonite: Moderate blue-violet fluorescence SW; variable in intensity and occasionally brighter LW. (C: F)
Oyelite: Moderate violet, edged with white fluorescence SW; weaker LW. White fluorescing areas phosphoresce. Extremely rare. (Pink radiating masses edged with white fibers in red-fluorescing bladed manganaxinite matrix, AC: F).

White or Cream Fluorescence

Aragonite: Moderate cream to white fluorescence and phosphorescence LW; weaker SW. (V, W:F, SH)
Barite: Moderate white, blue-white, or cream fluorescence SW; weak LW. (C, AC, V: F, SH)
Cahnite: Moderate cream fluorescence and phosphorescence LW and SW. (Rare crystallized vein mineral: F)
Calcite: Moderate white or cream fluorescence and phosphorescence SW and LW. (V, W: F, SH)
Celestite: Moderate to weak cream fluorescence LW and SW. (V: SH)
Diopside: Moderate cream fluoresence LW; blue fluorescence SW. (FM)
Epsomite: Moderate cream fluorescence LW; weak SW. (White powdery coating, W: SH)
Fluoborite: Moderate cream fluorescence SW. (Resembles grains of rice; Bodnar-Edison quarry) Weak cream fluorescence SW. Rare. (Fibrous vein material: SH)
Guerinite: Weak white fluorescence SW and LW. Rare. (Lath-shaped crystals in red-fluorescing calcite, W: SH)
Hedyphane: Weak cream fluorescence LW; moderate orange fluorescence SW. Rare. (Vein mineral with manganaxinite and rhodonite: F)
Hemimorphite: Weak white fluorescence and phosphorescence LW and SW. (Thick crystal crusts, W: SH) Very rare. (F)
Hydrotalcite: Moderate cream fluorescence LW. Rare. (Microcrystals associated with gahnite and hodgkinsonite, V: F)
Margarosanite: Weak cream, red, or orange fluorescence LW; strong blue, often with zoned red fluorescence SW. (Platy masses or disseminated in fledspar, AC: F)
Oyelite: Moderate white-edging around violet fluorescence SW; weaker LW. White fluorescing areas phosphoresce. Extremely rare. (Pink radiating masses edged with white fibers in red-fluorescing bladed manganaxinite matrix, AC: F)
Picropharmacolite: Moderate to weak white fluorescence SW and LW. Rare. (Acicular crystals on red-fluorescing calcite, W: SH)
Scapolite group: Moderate cream fluorescence and phosphorescence SW and LW. (FM)
Talc: Moderate cream fluorescence LW; weak SW. (O, C, V: F, SH)
Thomsonite: Weak white-to-cream fluorescence SW and LW. Most specimens labelled "thomsonite" or "calciothomsonite" are believed to be xonotlite. Very rare. (Radiating acicular masses with prehnite and feldspar, AC: F)
Tremolite: Moderate cream fluorescence, rare LW; blue fluorescence, typical SW. (Typically as prismatic crystals, FM)

REFERENCES CITED

Aaron, J. M., 1969, Petrology and origin of the Hardyston Quartzite (Lower Cambrian) in eastern Pennsylvania and western New Jersey, p. 21-34 in Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: Geological Society of America Annual Meeting, 1969, Atlantic City: New Brunswick, NJ, Rutgers University Press, 382 p.

Abu-Moustafa, A.; and Skehan, J., 1976, Petrography (sic) and geochemistry of the Nashoba Formation, east-central Massa-chusetts, p. 31-70 in Page, L. R., ed., Contributions to the stratigraphy of New England: Boulder, CO, Geological Society of America Memoir 148, 445 p.

Adams, G. F., 1934 ms., Glacial waters in the Wallkill Valley: New York, NY, Columbia University Department of Geology Master's Thesis, 43 p.

Alger, Francis, 1845, On the zinc mines of Franklin, Sussex County, New Jersey: American Journal of Science, 1st series, v. 48, p. 252-264.

Ando, C. J.; Cook, F. A.; Oliver, J. E.; Brown, L. D.; and Kaufman, Sidney, 1983, Crustal geometry (sic) of the Appalachian orogen from seismic-reflection studies, p. 83-101 in Hatcher, R. D., Jr.; Williams, Harold; and Zietz, Isidore, eds., Contributions to the tectonics (sic) and geophysics of mountain chains: Geological Society of America Memoir 158, 223 p.

Ando, C. J.; Czuchra, B. L.; Klemperer, S. L.; Brown, L. D.; Cheadle, M. J.; Cook, F. A.; Oliver, J. E.; Kaufman, Sidney; Walsh, T.; Thompson, J. B., Jr.; Lyons, J. B.; and Rosenfeld, J. L., 1984, Crustal profile of mountain belt: COCORP deep seismic-reflection profiling in New England Appalachians and implications for architecture of convergent mountain chains: American Association of Petroleum Geologists Bulletin, v. 68, p. 819-837.

Andrews, J. T., 1973, The Wisconsin Laurentide ice sheet: dispersal centers (sic) problems or rates of retreat and climatic implications: Arctic and Alpine Research, v. 5, p. 185-199.

Armstrong, R. L., and Dick, H. J. B., 1974, A model for the development of thin overthrust sheets of crystalline rock: Geology, v. 2, no. 1, p. 35-40.

Baker, D. R., and Buddington, A. F., 1970, Geology (sic) and magnetite deposits of the Franklin quadrangle and part of the Hamburg quadrangle, New Jersey: United States Geological Survey Professional Paper 638, 73 p.

Baum, J. L., 1957, Precambrian geology and structure of the Franklin-Sterling area, New Jersey, p. 100-111 in Dorf, Erling, ed., Geological Society of America Annual Meeting, Atlantic City, Guidebook for field trips, 250 p.

Baum, J. L., 1973, Three hundred years of mining in Sussex County, New Jersey: Newton, NJ, Sussex County Historical Society, 14 p.

Bayley, W. S., 1910, Iron mines and mining (sic) in New Jersey: New Jersey Geological Survey, Final Report Series, volume VII.

Bayley, W. S., 1941, Precambrian geology and mineral resources of the Delaware Water Gap and Easton quadrangles, New Jersey and Pennsylvania: United States Geological Survey Bulletin 920, 98 p. (maps).

Bayley, W. S., Salisbury, R. D., and Kümmel, H. B., 1914, Description of the Raritan quadrangle: United States Geological Survey, Geologic Atlas of the United States, Raritan Folio, No. 191, 32 p.

Beach, A., 1975, The geometry (sic) of en-echelon vein arrays: Tectonophysics, v. 28, p. 245-163 (one is wrong!).

Benimoff, A. I., and Sclar, C. B., 1984, Coexisting silicic (sic) and mafic melts resulting from marginal fusion of a xenolith of Lockatong Argillite in the Palisades sill, Graniteville, Staten Island, New York: American Mineralogist, v. 69, nos. ll/12, p. 1005-1014.

Berthier, Pierre, 1819, Analyse de deux mineraux zinciferes des □tats-Unis de l'Am,rique: Annales des mines, 1st series, v. 4, p. 483-494. (Translated into English by Benjamin Silliman, 1820, American Journal of Science, 1st series, v. 2, p. 319-326.)

Betancourt, P. P., 1982, Franklinite from Franklin, New Jersey: Rocks and Minerals, v. 57, no. 5, p. 195 (only).

Binstock, J., 1977, Petrology (sic) and sedimentation of Cambrian manganese-rich sediments of the Harlech Dome, North Wales: Cambridge, MA, Harvard University Department of Geological Sciences, Ph. D. dissertation, 325 p.

Bonatti, Enrico, 1975, Metallogenesis at oceanic spreading centers, p. 401-431 in Donath, F. A., ed., and Stehli, F. G., and Wetherill, G. W., assoc. eds.,, Annual Review of Earth and Planetary Sciences: Palo Alto, CA, Annual Reviews, Inc., v. 3, 466 p.

Bonatti, E., Honnorez-Guerstein, M., et al., 1976a, Hydrothermal pyrite concretions from the Romanche Trench (Equatorial Atlantic): Metallogenesis in oceanic fracture zones: Earth and Planetary Science Letters, v. 32, p. 1-10.

Bonatti, E., Guerstein-Honnorez, B., and Honnorez, J., 1976b, Copper-iron sulfide mineralizations from equatorial mid-Atlantic ridge: Economic Geology, v. 71, p. 1515-1525.

Bostwick, R. C., 1982, A brief review of mineral fluorescence at Franklin and Sterling Hill: Rocks and Minerals, v. 57, no. 5, p. 196-201.

Brock, P. J. C., 1989, Stratigraphy of the northeastern Manhattan Prong, Peach Lake quadrangle, New York-Connecticut, p. 1-27 in Weiss, Dennis, ed., New York State Geological Association Annual Meeting, 61st, Field trip guidebook: Middletown, NY, Orange County Community College, Department of Science and Engineering, 302 p.

Brock, P. J. C., 1993 ms., Geology of parts of the Peach Lake and Brewster quadrangle, southeastern New York and adjacent Connecticut, and basement blocks of the north-central Appalachians: New York, NY, City University of New York Graduate Faculty in Earth and Environmental Sciences, Ph. D. Dissertation, 494 p., 6 plates.

Brown, L. D.; Ando, C. J.; Klemperer, S. L.; Oliver, J. E.; Kaufman, Sidney; Czuchra, B. L.; Walsh, T.; and Isachsen, Y. W., 1983, Adirondack-Appalachian crustal structure: the COCORP northeast traverse: Geological Society of America Bulletin, v. 94, p. 1173-1184.

Buddington, A. F., 1956, Correlation of rigid units, types of folds, and lineation in a Grenville belt, [N. J.- N. Y.], p. 99-118 in Thomson, J. E., ed., The Grenville problem: Royal Society of Canada Special Publication No. 1, 119 p. (maps).

Buddington, A. F., 1957, Magnetite iron ore (sic) deposits of the New Jersey Highlands, p. 77-86 in Dorf, Erling, ed., Geological Society of America Annual Meeting, Atlantic City, Guidebook for field trips, 250 p.

Buddington, A. F., 1966, The Precambrian magnetite deposits of New York and New Jersey: Economic Geology, v. 61, p. 484-510.

Buddington, A. F., and Baker, D. R., 1961, Geology of the Franklin and part of the Hamburg quadrangles, New Jersey: United States Geological Survey Miscellaneous Geological Investigations, Map I-346.

Callahan, W. H., 1966, Genesis of the Franklin-Sterling, New Jersey orebodies: Economic Geology, v. 61, p. 1140-1141.

Carey, S. W., 1953, The orocline concept in geotectonics: Royal Society of Tasmania, Proceedings, v. 89, p. 255-288.

Chamberlin, T. C., 1882, Preliminary paper on the terminal moraine of the second glacial epoch: United States Geological Survey Annual Report, 3rd, p. 295-402.

Chamberlin, T. C., 1888, The rock scorings of the great Ice Age: United States Geological Survey Annual Report, 7th (1885-1886), p.

Chamberlin, T. C., 1895, Glacial phenomena of North America, p. 724-775 in Geikie, James, The great ice age: New York, D. Appleton and Company, 545 p.

Collins, L. G., 1969, Regional recrystallization and the formation of magnetite concentrations, Dover magnetite district, New Jersey: Economic Geology, v. 61, p. 17-33.

Connally, G. G., 1973, Regional deglacial sequences in northeastern Pennsylvania (abstract): Geological Society of America Abstracts with Programs, v. 5, p. 150 (only).

Connally, G. G., and Sirkin, L. A., 1970, Late glacial history of the upper Wallkill Valley, New York: Geological Society of America Bulletin, v. 81, no. 11, p. 3297-3305.

Connally, G. G., and Sirkin, L. A., 1973, The Wisconsinan history of the Hudson-Champlain lobe, p. 47-69 in Black, R. F., Goldthwait, R. P., and Willman, H. B., eds., The Wisconsinan Stage: Boulder, CO, Geological Society of America Memoir 136, 334 p.

Connally, C. G., Sirkin, L. A., and Cadwell, D. H., 1989, Deglacial history and environments of the upper Wallkill valley, p. 205-229 in Weiss, Dennis, ed., New York State Geological Association, Annual Meeting 61st, 13-15 October 1989, Middletown, New York, Field trip (sic) guidebook, 302 p.

Cook, F. A.; Albaugh, D. S.; Brown, L. D.; Kaufman, Sidney; Oliver, J. E.; and Hatcher, R. D., Jr., 1979, Thin-skinned tectonics in the crystalline southern Appalachians; COCORP seismic-reflection profiling of the Blue Ridge and Piedmont: Geology, v. 7, no. 12, p. 563-567.

Cook, F. A., Brown, L. D., and Oliver, J. A., 1980, The southern Appalachians and the growth of continents: Scientific American, v. 243, no. 4, p. 156-157, 159-168.

Cook, F. A., and Oliver, J. E., 1981, The Late Precambrian-Early Paleozoic continental edge in the Appalachian orogen: American Journal of Science, v. 281, p. 993-1008.

Cook, G. H., 1861, Note on the probable age of the white limesone at Sussex and Franklin zinc mines, New Jersey: American Journal of Science, 2nd series, v. 32, p. 208-209.

Cook, G. H., 1878, Exploration of the portion of New Jersey which is covered by the glacial drift: New Jersey Geological Survey Annual Report for 1877, p. 9-22.

Cook, G. H., 1879a, On the glacial and modified drift: New Jersey Geological Survey Annual Report for 1878, p. 8-23.

Cook, G. H., 1879b, On the southern limit of the last glacial drift across New Jersey and the adjacent parts of New York and Pennsylvania: American Institute of Mining Engineering Transactions, v. 6, p. 467-469.

Cook, G. H., 1881, Glacial drift: New Jersey Geological Survey Annual Report for 1880, p. 16-97.

Corliss, J., 1971, The origin of metal-bearing submarine hydrothermal solutions: Journal of Geophysical Research, v. 76, p. 8128-8138.

Cotter, J. F. P., Ridge, J. C., Evenson, E. B., Sevon, W. D., Sirkin, L. A., and Stuckenrath, R., 1985, The Wisconsinan history of the Great Valley, Pennsylvania and New Jersey, and the age of the "terminal moraine," p. 1-58 in Evenson, E. B., ed., Woodfordian deglaciation of the Great Valley, New Jersey: Friends of the Pleistocene Field Conference, 48th, 3-5 May 1985, McAfee, NJ, Guidebook: Bethlehem, PA, Lehigh University, and New Jersey Geological Survey, 119 p.

Cotter, J. F. P., Ridge, J. C., Evenson, E. B., Sevon, W. D., Sirkin, L. A., and Stuckenrath, R., 1986, The Wisconsinan history of the Great Valley, Pennsylvania and New Jersey, and the age of the "terminal moraine,: p. 22-49 in Cadwell, D. H., ed., The Wisconsinan Stage of the First Geological District, eastern New York: New York State Museum Bulletin 455, 191 p.

Crowl, G. H., 1980, Woodfordian age of the Wisconsinan glacial border in northeastern Pennsylvania: Geology, v. 8, p. 51-55.

Darton, N. H., Bayley, W. S., Salisbury, R. D., and Kümmel, H. B., 1908, Description of the Passaic quadrangle, New Jersey-New York: United States Geological Survey Geologic Atlas of the United States Passaic Folio, No. 157, 27 p.

Dallmeyer, R. D., 1974, Tectonic setting of the northeastern Reading Prong: Geological Society of America Bulletin, v. 85, p. 131-134.

Denny, C. S., 1982, Geomorphology of New England: United States Geological Survey Professional Paper 1208, 18 p.

Dorf, Erling, 1952, Critical analysis of Cretaceous stratigraphy and paleobotany of Atlantic Coastal Plain: American Association of Petroleum Geologists, Bulletin, v. 36, no. 11, p. 2161-2184.

Dott, R. H., Jr.; and Bourgeois, Joanne, 1982, Hummocky strataification: Significance of its variable bedding sequences: Geological Society of America Bulletin, v. 93, no. 8, p. 663-680.

Drake, A. A., Jr., 1969, Precambrian and lower Paleozoic geology of the Delaware Valley, New Jersey-Pennsylvania, p. 51-131 in Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: Geological Society of America, Annual Meeting, 1969, Atlantic City: New Brunswick, New Jersey, Rutgers University Press, 382 p.

Drake, A. A., Jr., 1970, Structural geology of the Reading Prong, p. 271-291 in Fisher, G. W.; Pettijohn, F. J.; Reed, J. C., Jr.; and Weaver, K. N., eds., Studies of Appalachian geology: central and southern (Cloos volume): New York, Wiley-Interscience, 460 p.

Drake, A. A., Jr., 1984, The Reading Prong of New Jersey and eastern Pennsylvania; an appraisal of rock relations (sic) and chemistry of a major Proterozoic terrane in the Appalachians, p. 75-109 in Bartholomew, M. J., ed., The Grenville event in the Appalachians and related topics: Boulder, CO, Geological Society of America Special Paper 194, 287 p.

Drake, A. A., Jr., 1990, The regional geologic setting of the Franklin-Sterling Hill district, p. 14-31 in Sclar, C. B., ed., Character (sic) and origin of the Franklin-Sterling Hill orebodies: Bethlehem, Pennsylvania, symposium held at Lehigh University, 19 May 1990, Proceedings: Lehigh University, Department of Geological Sciences and the Franklin-Ogdensburg Mineralogical Society, 118 p.

Drake, A. A., Jr., ed., 1991a, Contributions to New Jersey geology: U. S. Geological Survey Bulletin Report No. B, 42 p.

Drake, A. A., Jr.; Aleinikoff, J. N.; and Volkert, R. A., 1991a, The Mount Eve Granite (Middle Proterozoic) of northern New Jersey and southeastern New York, p. C1-C10 in Drake, A. A., Jr., ed., Contributions to New Jersey geology: U. S. Geological Survey Bulletin Report No. B, 42 p.

Drake, A. A., Jr.; Aleinikoff, J. N.; and Volkert, R. A., 1991b, The Byram intrusive suite of the Reading Prong; age and tectonic environment, p. D1-D14 in Drake, A. A., Jr., ed., Contributions to New Jersey geology: U. S. Geological Survey Bulletin Report No. B, 42 p.

Drake, A. A., Jr., Hall, L. M., and Nelson, A. E., 1988, Basement (sic) and basement-cover relation (sic) map of the Appalachian orogen in the United States: United States Geological Survey, Miscellaneous Investigations Map I-1655 (scale 1:1,000,000).

Drake, A. A., Jr.; and Lyttle, P. T., 1980, Alleghanian thrust faults in the Kittatinny Valley, New Jersey, p. 92-114 in Manspeizer, Warren, ed., Field studies of New Jersey geology and guide to field trips: New York Geological Association, Annual Meeting, 52nd, Newark, New Jersey, 10-12 October 1980: Newark, NJ, Rutgers University Newark College of Arts and Sciences Geology Department, 398 p.

Drake, A. A., Jr.; and Monteverde, D. H., 1992a, Bedrock geologic map of the Unionville Quadrangle, Orange County, New York, and Sussex County, New Jersey: U. S. Geological Survey Geologic Quadrangle Map GQ-1699, 1 sheet, colored geologic map on scale of 1/24,000.

Drake, A. A., Jr.; and Monteverde, D. H., 1992b, Bedrock geologic map of the Branchville Quadrangle, Sussex County, New Jersey: U. S. Geological Survey Geologic Quadrangle Map GQ-1700, 1 sheet, colored geologic map on scale of 1/24,000.

Drake, A. A., Jr.; and Volkert, R. A., 1991, The Lake Hopatcong Intrusive Suite (middle Proterozoic of the New Jersey Highlands, p. A1-A9 in Drake, A. A., Jr., ed., Contributions to New Jersey geology: U. S. Geological Survey Bulletin Report No. B, 42 p.

Dreimanis, Alexis; and Goldthwait, R. P., 1973, Wisconsin glaciation in the Huron, Erie, and Ontario lobes, p. 71-106 in Black, R. F., Goldthwait, R. P., and Willman, H. B., eds., The Wisconsinan Stage: Boulder, CO, Geological Society of America Memoir 136, 334 p.

Dumont, A., 1847, Memoire sur les tarraines Ardennais et Rh,nan de L'Ardenne, du Rhin, du Brabant, et du Condros. Memoirs de la Acad,m, de Royale Science de Belgique, XX:163p.

Epstein, J. B.; and Epstein, Anita, 1969, Geology of the Valley and Ridge Province between Delaware Water Gap and Lehigh Gap, Pennsylvania, p. 132-205 in Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: Geological Society of America Annual Meeting, 1969, Atlantic City: New Brunswick, NJ, Rutgers University Press, 382 p.

Epstein, J. B., and Lyttle, P. T., 1987, Structure (sic) and stratigraphy above (sic), below (sic) and within the Taconic unconformity, southeastern New York, P. C1-C78 in Waines, R. H., ed., New York State Geological Asociation, Annual Meeting, 59th, New Paltz, New York, Guidebook to field trips, not consecutively paginated.

Evenson, E. B., ed., 1985, Woodfordian deglaciation of the Great Valley, New Jersey: Friends of the Pleistocene Field Conference, 48th, 3-5 May 1985, McAfee, NJ, Guidebook, Bethlehem, PA, Lehigh University, and New Jersey Geological Survey, 119 p.

Fenner, C. N., 1914, The mode of formation of certain gneisses in the highlands of New Jersey: Journal of Geology, v. 22, p. 594-612; 694-702.

Fisher, D. W., Isachsen, Y. W., and Rickard, L. V., 1971, Geologic map of New York, 1970: New York State Museum and Science Service, Geological Survey, Map and Chart Series, No. 15.

Fisher, D. W., Isachsen, Y. W., Rickard, L. V., Broughton, J. G., and Offield, T. W., 1962, Geologic map of New York, 1961: New York State Museum and Science Service, Geological Survey, Map and Chart Series, No. 5.

Flint, R. F., 1943, Growth of North American ice sheet during the Wisconsin Age: Geological Society of America Bulletin, v. 54, no. 3, p. 325-362.

Flint, R. F., 1951, Highland centers of former glacial outflow in northeastern North America: Geological Society of America Bulletin, v. 62, no. 1, p. 21-37.

Flint, R. F., 1957, Glacial and Pleistocene geology: New York, NY, John Wiley and Sons, Inc., 553 p.

Flint, R. F., 1961, Two tills in southern Connecticut: Geological Society of America Bulletin, v. 72, no. 11, p. 1687-1691.

Flint, R. F., 1963, Status of the Pleistocene Wisconsin stage in central North America: Science, v. 139, p. 402-404.

Flint, R. F.; and Gebert, Jeffrey, 1974, End moraines on and off the Connecticut shore (abstract): Geological Society of America Abstracts with Programs, v. 6, no. 7, p. 738-739.

Friedman, G. M., and Sanders, J. E., 1978, Principles of Sedimentology, John Wiley and Sons, New York, NY, 792 p.

Friedman, G. M., Sanders, J. E., and Kopaska-Merkel, D. C., 1992, Principles of sedimentary deposits. Stratigraphy and sedimentology: New York, NY, Macmillan Publishing Company, 717 p.

Friedman, G. M., and Sanders, J. E., 1982, Time-temperature-burial significance of Devonian anthracite implies former great (ca. 6.5 km) depth of burial of Catskill Mountains, New York: Geology, v. 10, no. 2, p. 93-96. (Also, reply to discussion, 1983, ibid., v. 11, no. 2, p. 123-124.)

Friedman, G. M., Sanders, J. E., Martini, I. P., and others, 1982, Excursion 17A: Sedimentary facies: products of sedimentary environments in a cross section of the classic Appalachian Mountains and adjoining Appalachian basin in New York and Ontario: International Congress on Sedimentology, 11th, 22-27 August 1982, Hamilton, Ontario, Field Excursion Guidebook: International Association of Sedimentologists, not consecutively paginated.

Frondel, Clifford, 1972, The minerals of Franklin and Sterling Hill: a check list: New York, NY, Wiley-Interscience, 94 p.

Frondel, Clifford, 1989, History of a classic: Charles Palache's monograph on the minerals of Franklin and Sterling Hill: The Picking Table, v. 30, p. 2-7.

Frondel, Clifford, 1990, Historical overview of the development of mineralogical science at Franklin and Sterling Hill, Sussex County, New Jersey, p. 3-13 in Sclar, C. B., ed., Character (sic) and origin of the Franklin-Sterling Hill orebodies: Bethlehem, Pennsylvania, symposium held at Lehigh University, 19 May 1990, Proceedings: Lehigh University, Department of Geological Sciences and the Franklin-Ogdensburg Mineralogical Society, 118 p.

Frondel, Clifford; and Baum, J. L., 1974, Structure (sic) and mineralogy of the Franklin zinc-iron-manganese deposit, New Jersey: Economic Geology, v. 69, p. 157-180.

Frye, J. C., Willman, H. B., Rubin, M., and Black, R. F., 1968, Definition of Wisconsinan Stage: United States Geological Survey Bulletin 1274-E, p. E1-E22.

Gager, C. S., 1932, The story of our boulders: Brooklyn Botanical Garden, Records, v. 21, no. 8, p. 165-207.

Gale, L. D., 1829, Geology of New York island: in Mather, W. W., 1843, Geology of New York. Part I. Comprising (sic) the geology of the First Geological District: Albany, Carroll & Cook, Printers to the Assembly, 653 p., 46 pl.

Gentilli, Joseph, 1967a, Intertropical convergence zone (ITCZ) and intertropical front, p. 496-497 in Fairbridge, R. W., ed., The encyclopedia of atmospheric sciences and astrogeology: The Encyclopedia of the Earth Sciences, v. 2: New York, NY, Reinhold Publishing Corporation, 1200 p.

Gentilli, Joseph, 1967b, Monsoons, p. 613-617 in Fairbridge, R. W., ed., The encyclopedia of atmospheric sciences and astrogeology: The Encyclopedia of the Earth Sciences, v. 2, New York, NY, Reinhold Publishing Corporation, 1200 p.

Gries, R., 1983, Oil (sic) and gas prospecting beneath Precambrian of foreland thrust plates in Rocky Mountains: American Association of Petroleum Geologists Bulletin, v. 67, p. 1-28.

Gleason, S., 1972, Ultraviolet guide to minerals--with identification charts: San Gabriel, CA, Ultraviolet Products, Inc., 244 p.

Gratacap, L. P., 1902, Geology of the city of New York, 2nd ed.: New York, NY, Henry Holt and Company, 119 p.

Guo, Baiying; Sanders, J. E., and Friedman, G. M., 1994, Sedimentary breccias in the Pine Plains Formation (U. Cambrian, Sauk Sequence), SE New York: Sequence-stratigraphic implications (abstract): Geological Society of America Abstracts with Programs, v. 26, no. 3, p. 26 (only).

Hager, A. F., Collins, L. G., and Clemency, C. V., 1963, Host rock as a source of magnetite ore, Scott Mine, Sterling Lake, New York: Economic Geology, v. 58, p. 730-768.

Hague, J. M., Baum, J. L., Hermann, L. A., and Pickering, R. J., 1956, Geology (sic) and structure of the Franklin-Sterling area, New Jersey: Geological Society of America Bulletin, v. 67, p. 435-474.

Haight, C. M., and Tillson, B. F., 1918, Zinc mining at Franklin, New Jersey: American Institute of Mining Engineering, Transactions, v. 57 (for 1917), p. 720-825.

Hall, C. E., 1876, Notes on glacial action visible along the Kittatinny or Blue Mountain, Carbon, Northampton and Monroe counties, Pennsylvania: American Philosophical Society Proceedings, v. 14, p. 620-621.

Harding, T. P., 1985, Seismic characteristics (sic) and identification of negative flower structures, positive flower structures, and positive structural inversion: American Association of Petroleum Geologists Bulletin, v. 69, no. 4, p. 582-600.

Hatcher, R. D., Jr., 1990, Structural geology. Principles, concepts, and problems: Columbus-Toronto-London-Melbourne, Merrill Publishing Co., 531 p.

Helenek, H. L., 1987, Possible Late Proterozoic wrench tectonics in the Reading Prong, New York-New Jersey-Pennsylvania: Northeastern Geology, v. 9, p. 211-223.

Helenek, H. L., and Mose, D. G., 1984, Geology and geochronology of Canada Hill Granite and its bearing on the timing of Grenvillian events in the Hudson Highlands, New York, p. 57-73 in Bartholomew, M. J., ed., The Grenville event in the Appalachians and related topics: Boulder, CO, The Geological Society of America Special Papers 194, 287 p.

Herpers, H., 1961, The Ogdensburg-Culvers Gap recessional moraine and glacial stagnation in New Jersey: New Jersey Geological Survey Report Series, No. 6, 15 p.

Herpers, H., and Barksdale, H. C., 1951, Preliminary report on the geology and ground water (sic) supply of the Newark, New Jersey, area: New Jersey Water Policy and Supply Division, Special Report 10, 52 p.

Hinds, N. E. A., 1921, An alkali gneiss from the Precambrian of New Jersey: American Journal of Science, 5th series, v. 1, p. 355-364.

Hotz, P. E., 1953, Magnetite deposits of the Sterling Lake, New York, Ringwood, New Jersey area: United States Geological Survey Bulletin 982-F, p. 153-244.

Hull, J.; Koto, R.; and Bizub, R., 1986, Deformation zones in the Highlands of New Jersey: Geological Association of New Jersey Guidebook 3, p. 19-66.

Hutton, James, 1795, Theory (sic) of the Earth with proofs and illustrations: Edinburgh, W. Creech, 2 vols. (Facsimile reprint, 1959, New York, Hafner), 000 p.

Isachsen, Y. W., 1964, Extent (sic) and configuration of the Precambrian in the northeastern United States: New York Academy of Sciences, Transactions, series II, v. 26, no. 7, p. 812-829.

Jahns, R. H., 1941, Outwash chronology of northeastern Massachusetts (abstract): Geological Society of America Bulletin, v. 52, no. 12, part 2, p. 1910 (only).

Johnson, C. A., Rye, D. M., and Skinner, B. J., 1990, Unusual oxygen isotopic (sic) compositions in and around the Sterling Hill and Franklin Furnace ore deposits, p. 63-76 in Sclar, C. B., ed., Character (sic) and origin of the Franklin-Sterling Hill orebodies: Bethlehem, Pennsylvania, symposium held at Lehigh University, 19 May 1990, Proceedings: Lehigh University, Department of Geological Sciences and the Franklin-Ogdensburg Mineralogical Society, 118 p.

Jones, R. W., Jr., 1982, Franklin. Fluorescent mineral (sic) capital of the world: Rocks and Minerals, v. 57, no. 5, p. 190-194.

Kay, G. M., 1951, North American geosynclines: Geological Society of America Memoir 48, 143 p.

Kay, G. M., and Colbert, E. H., 1965, Stratigraphy and life history: New York-London-Sydney, John Wiley and Sons, Inc., 736 p.

Kemp, J. F., 1893a, The ore-deposits (sic) at Franklin Furnace and Ogdensburg, New Jersey: New York Academy of Sciences, Transactions, v. 13, p. 76-96.

Kemp, J. F., 1893b, A basic dike near Hamburg, Sussex County, New Jersey, which has been thought to contain leucite: American Journal of Science, 3rd series, v. 45, p. 298-305.

Kerr, P. F., 1933, Zinc-deposits (sic) near Franklin, New Jersey: International Geological Congress, 16th, United States, Guidebook 8, p. 2-13.

King, P. B., 1960, The anatomy (sic) and habitat of low-angle thrust faults, p. 115-125 in Rodgers, John; and Gregory, J. T., eds., American Journal of Science, v. 258A (Bradley volume), p.

Kitchell, W., 1856, Report on the geological department: northern division of the State: New Jersey Geological Survey, Annual Report (for 1855), 2nd, p. 111-248.

Klemic, H., Heyl, A. A., Jr., Taylor, A. R., and Stone, J., 1959, Radioactive rare-earth deposits at Scrub Oaks mine, Morris County, New Jersey: United States Geological Survey Bulletin 1082-B, p. 29-59.

Koteff, C., 1974, The morphologic sequence (sic) concept and deglaciation of southern New England, p. 121-144 in Coates, D. R., ed., Glacial geomorphology: Binghamton, NY, SUNY Binghamton Publications in Geomorphology.

Koteff, C., and Pessl, F., 1981, Systematic ice retreat in New England: United States Geological Survey Professional Paper 1179, 20 p.

Kozykowski, B. T., 1982, An introduction to the Franklin and Sterling Hill, New Jersey, mineral deposits: Rocks and Minerals, v. 57, no. 5, p. 188-189.

Kramm, U., 1976, The coticule rocks (spessartine quartzites) of the Venn-Stavelot Massif, Ardennes, a volcanoclastic metasediment?: Contributions to Mineralogy and Petrology, v. 56, p. 135-155.

Kummel, H. B., 1906, The chemical composition of the white crystalline limestones of Sussex and Warren counties: New Jersey Geological Survey, Annual Report for 1905, p. 173-191.

Kummel, H. B., 1940, The geology of New Jersey: New Jersey Geological Survey Bulletin 50, 203 p.

Kummel, H. B., and Weller, S., 1901a, Paleozoic limestones of the Kittatinny Valley, New Jersey: Geological Society of America Bulletin, v. 12, p. 147-161.

Kummel, H. B., and Weller, S., 1902, The rocks of the Green Pond Mountain region, Morris and Passaic counties: New Jersey Geological Survey, Annual Report of the State Geologist for 1902, p. 1-51.

Leavens, P. B., and Nelen, J. A., 1990, Franklinites from Franklin and Sterling Hill, New Jersey and oxygen fugacities of the deposits, p. 49-62 in Sclar, C. B., ed., Character (sic) and origin of the Franklin-Sterling Hill orebodies: Bethlehem, Pennsylvania, symposium held at Lehigh University, 19 May 1990, Proceedings: Lehigh University, Department of Geological Sciences and the Franklin-Ogdensburg Mineralogical Society, 118 p.

Leighton, M. M., 1960, The classification of the Wisconsin glacial stage of north-central United States: Journal of Geology, v. 68, p. 529-551.

Leith, C. K., 1909, Magnetite (sic) and zinc ores of Franklin Furnace quadrangle: Economic Geology, v. 4, p. 265-269.

Leverett, F., 1934, Glacial deposits outside the Wisconsinan terminal moraine in Pennsylvania: Pennsylvania Geological Survey, 4th series, General Geology Report G-7, 123 p.

Levine, E. R., and Ciolkosz, E. J., 1983, Soil development in till of various ages in northeastern Pennsylvania: Quaternary Research, v. 19, p. 85-89.

Lewis, H. C., 1883a, The great ice ages in Pennsylvania: Franklin Institute, Journal, v. 115, p. 287-307.

Lewis, H. C., 1883b, The great terminal moraine across Pennsylvania (abstract): Science, v. 2, p. 163-167.

Lewis, J. V., 1908a, Petrography of the Newark igneous rocks of New Jersey. Part IV, p. 97-167 in Geological Survey of New Jersey, Annual Report of the State Geologist for the year 1906: Trenton, New Jersey, MacCrellish & Quigley, State Printers, 192 p.

Lewis, J. V., 1908b, The Palisades diabase of New Jersey: American Journal of Science, v. 176, p. 155-162.

Lewis, J. V., and Kümmel, H. B., 1915, The geology of New Jersey; a summary to accompany the geologic map (1910-1912) on the scale of 1:250,000: New Jersey Geological Survey Bulletin 14, 146 p.

Lobeck, A. K., 1939, Geomorphology. An introduction to the study of landscapes: New York and London, McGraw-Hill Book Company, Inc., 731 p.

Longwell, C. R., 1933, Geology of western Vermont and northwestern Massachusetts, p. 61-63 in Longwell, C. R. ed., Eastern New York and western New England: International Geological Congress, 16th, United States 1933, Guidebook 1, Excursion A-1: Washington, D. C., U. S. Government Printing Office, 118 p.

Longwell, C. R., Flint, R. F., and Sanders, J. E., 1969, Physical geology: New York, John Wiley and Sons, 685 p.

Lovegreen, J. R., 1974 ms., Paleodrainage history of the Hudson Estuary: New York, NY, Columbia University Department of Geological Sciences Master's Thesis, 151 p., 8 pl.

Makovicky, E., Skinner, B. J., 1990, Luminescence (sic) and composition studies on primary, altered, and secondary willemites from the Sterling Hill mineral deposit, New Jersey, p. 93-104 in Sclar, C. B., ed., Character (sic) and origin of the Franklin-Sterling Hill orebodies: Bethlehem, Pennsylvania, symposium held at Lehigh University, 19 May 1990, Proceedings: Lehigh University, Department of Geological Sciences and the Franklin-Ogdensburg Mineralogical Society, 118 p.

Malizzi, L. D., and Gates, A. E., 1989a, An Alleghanian positive flower structure in the New Jersey Highlands (abstact): EOS American Geophysical Union, Transactions, v. 7, p. 462.

Malizzi, L. D., and Gates, A. E., 1989b, Late Paleozoic deformation in the Reservoir fault zone and Green Pond outlier, New Jersey Highlands, p. 75-91 in Weiss, Dennis, ed., Field trip (sic) guidebook: New York State Geological Association, Annual Meeting, 61st, Middletown, New York, 13-15 October 1989, 302 p.

Manchester, J. G., 1931, Minerals of New York City and its environs: New York Mineralogical Club Bulletin, v. 3, no. 1.

Marshak, R. Stephen; and Geiser, Peter, 1980, Penrose Conference on Pressure Solution and Dissolution, Guidebook to pressure-solution (sic) phenomena in the Hudson Valley, 49 p.

Marshak, R. Stephen; and Mitra, Gautam, eds., 1988, Basic methods of structural geology: Englewood Cliffs, NJ, Prentice-Hall, Inc., 446 p.

Mather, W. W., 1843, Geology of New York. Part I. Comprising (sic) the geology of the First Geological District: Albany, Carroll & Cook, Printers to the Assembly, 653 p., 46 pl. (Includes report of Prof. L. D. Gale on New York island in 1828-1829.)

Maxwell, J. C., 1962, Origin of slaty (sic) and fracture cleavage in the Delaware Water Gap area, New Jersey and Pennsylvania, p. 281-311 in Engel, A. E. J., James, H. L., and Leonard, B. F., eds., Petrologic studies: a volume in honor of A. F. Buddington: Geological Society of America, 660 p.

McSween, H. Y., Jr., 1976, Manganese-rich ore assemblages from Franklin, New Jersey: Economic Geology, v. 71, no. 4, p. 814-817.

Merguerian, C., 1979, Dismembered ophiolite along Cameron's Line, West Torrington, Connecticut (abstract): Geological Society of America Abstracts with Programs, v. 11, p. 45 (only).

Merguerian, C., 1980, Metamorphosed manganiferous sediments (coticules) in the Ordovician of southern New England (abstract): Geological Society of America Abstracts with Programs, v. 12, p. 73 (only).

Merguerian, C., 1981, Coticules in New England - Ancient examples of metalliferous sediments (abstract): Transactions of the American Geophysical Union, v. 62, p. 310 (only).

Merguerian, C., 1983a, Tectonic significance of Cameron's Line in the vicinity of the Hodges Complex--an imbricate thrust model for Western Connecticut: American Journal of Science, v. 283, p. 341-368.

Merguerian, Charles, 1983b, The structural geology of Manhattan Island, New York City (NYC), New York (abstract): Geological Society of America Abstracts With Programs, v. 15, no. 3, p. 169 (only).

Merguerian, Charles, 1988, Annealed mylonitic textures in polyphase deformed metamorphic terrains (abstract): Geological Society of America Abstracts with Programs, v. 20, no. 7, p. A214.

Merguerian, Charles, 1995, The Taconic problem--alive and well in New York City (NYC) (abstract): Geological Society of America Abstracts with Programs, v. 27, no. 1, p. 68 (only).

Merguerian, Charles; and Baskerville, C. A., 1987, The geology of Manhattan Island and the Bronx, New York City, New York, p. 137-140 in Roy, D. C., ed., Northeastern Section of the Geological Society of America, Centennial Fieldguide, v. 5, 481 p.

Merguerian, Charles; and Sanders, J. E., 1988, Trip 03: Geology of Manhattan and the Bronx, 20 November 1988: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 29 p.

Merguerian, Charles; and Sanders, J. E., 1989a, Trip 08: Geology of the Taconic range of eastern New York, 21-22 October 1989: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 98 p.

Merguerian, Charles; and Sanders, J. E., 1989b, Trip 09: Geology of the Shawangunks and Bellvale Mountain: 11 November 1989: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 56 p.

Merguerian, Charles; and Sanders, J. E., 1990a, Trip 11: Geology of the Little Appalachians and the Catskills, 26-27 May 1990: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 90 p.

Merguerian, Charles; and Sanders, J. E., 1990b, Trip 12: Geology of Franklin Furnace, New Jersey, 17 June 1990: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 83 p.

Merguerian, Charles; and Sanders, J. E., 1991a, Variations in style of Paleozoic fold-fault deformation in the southern New England Appalachian foreland of New York and New Jersey--A case for basement control of structures (abstract): Geological Society of America Abstracts with Programs, v. 23, no. 1, p. 103 (only).

Merguerian, Charles; and Sanders, J. E., 1991b, Trip 16: Geology of Manhattan and the Bronx, 21 April 1991: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 141 p.

Merguerian, Charles; and Sanders, J. E., 1991c, Trip 21: Cameron's Line and the Bronx parks, 24 November 1991: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks, Guidebook, 141 p.

Merguerian, Charles; and Sanders, J. E., 1992, Trip 23, Geology of the Delaware Water Gap and vicinity, 20 June 1992: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 109 p.

Merguerian, Charles; and Sanders, J. E., 1993a, Trip 26, Cameron's Line and The Bronx parks, 08 May 1993 (revision of Trip 21, 24 November 1991): New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 126 p.

Merguerian, Charles; and Sanders, J. E., 1993b, Trip 27, Geology of the Newark basin in the Delaware Valley, 19 June 1993: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 90 p.

Merguerian, Charles; and Sanders, J. E., 1993c, Trip 28, Geology of southern Central Park, New York City, 26 September 1993: New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 143 p.

Merguerian, Charles; and Sanders, J. E., 1994a, Post-Newark folds and -faults: implications for the geologic history of the Newark Basin (extended abstract), p. 57-64 in Hanson, G. N., chm., Geology of Long Island and metropolitan New York, 23 April 1994: Stony Brook, NY: Stony Brook, NY, Long Island Geologists Program with Abstracts, 165 p.

Merguerian, Charles; and Sanders, J. E., 1994b, Trip 32: Geology of the Little Appalachians and the Catskills, 24-25 September 1994; revision of Trip 11, 26-27 May 1990): New York Academy of Sciences Section of Geological Sciences Trips on the Rocks Guidebook, 103 p.

Merguerian, Charles; and Sanders, J. E., 1995a, Late syn-intrusive clastic dikes at the base of the Palisades intrusive sheet, Fort Lee, NJ, imply a shallow (~3 to 4 km) depth of intrusion (extended abstract): p. 54-63 in Hanson, G. N., chm., Geology of Long Island and metropolitan New York, 22 April 1995: Stony Brook, NY: Stony Brook, NY, Long Island Geologists Program with Abstracts, 135 p.

Merguerian, Charles; and Sanders, J. E., 1995b, NE-, not SE-, (sic) directed paleoflow of the Palisades magma: new evidence from xenoliths and contact relationships (extended abstract): p. 64-77 in Hanson, G. N., chm., Geology of Long Island and metropolitan New York, 22 April 1995: Stony Brook, NY: Stony Brook, NY, Long Island Geologists Program with Abstracts, 135 p.

Merrill, F. J., H., 1891a, Quaternary geology of the Hudson Valley: New York State Geologist, Annual Report, v. 10, p. 103-109.

Merrill, F. J. H., 1891b, On the postglacial history of the Hudson River Valley: American Journal of Science, 3rd series, v. 41, p. 460-466.

Metsger, R. W., 1980, The geologic setting of the Sterling Hill zinc-iron-manganese deposit, p. 210-214 in Manspeizer, Warren, ed., Field studies of New Jersey geology and guide to field trips: New York State Geological Association, Annual Meeting, 52nd, Newark, New Jersey: Rutgers University, Newark College of Arts and Sciences, Department of Geology, 398 p.

Metsger, R. W., 1990, Geology of the Sterling Hill Zn, Fe, Mn, deposit, p. 32-48 in Sclar, C. B., ed., Character (sic) and origin of the Franklin-Sterling Hill orebodies: Bethlehem, Pennsylvania, symposium held at Lehigh University, 19 May 1990, Proceedings: Lehigh University, Department of Geological Sciences and the Franklin-Ogdensburg Mineralogical Society, 118 p.

Metsger, R. W., Skinner, B. J., and Barton, P. B., Jr., 1969, Structural interpretation of the Sterling Hill ore body, Ogdensburg, New Jersey (abstract): Geological Society of America Abstracts with Programs, v. 7, p. 150 (only).

Metsger, R. W., Tennant, C. B., and Rodda, J. L., 1958, Geochemistry of the Sterling Hill zinc deposit, Sussex Couny, New Jersey: Geological Society of America Bulletin, v. 69, p. 775-788.

Mills, H. C., and Wells, P. D., 1974, Ice-shove deformation and glacial stratigraphy of Port Washington, Long Island, New York: Geological Society of America Bulletin, v. 85, no. 3, p. 357-364.

Minard, J. P., 1961, End moraines on Kittatinny Mountain, Sussex County, New Jersey: United States Geological Survey Professional Paper 424-C, p. C61-C64.

Minard, J. P., and Rhodehamel, E. C., 1969, Quaternary geology of part of northern New Jersey and the Trenton area, p. 279-313 in Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: Geological Society of America Annual Meeting, 1969, Atlantic City: New Brunswick, NJ, Rutgers University Press, 382 p.

Mitra, F., 1965, Genesis and mineralogenetic trend of the manganese ore bodies at Chikla, Sitasongi and Dongri Buzurg, Bhandara District, Maharashtra, India: Economic Geology, v. 60, p. 299-316.

Mitra, Gautam; and Marshak, R. Stephen, 1988, Description of mesoscopic structures, Part II, Special Topics, Chap. 11, p. 213-247 in Marshak, R. Stephen; and Mitra, Gautam, eds., Basic methods in structural geology: Englewood Cliffs, NJ, Prentice Hall, 446 p.

Mookherjee, A., 1961, Distribution of minor elements in the gonditic manganese ore and its geochemical significance: Economic Geology, v. 56, p. 723-729.

Moore, P. B., and Swihart, G. H., 1990, Origin, boron isotope (sic) geochemistry and mineralogy of the Franklin Marble, p. 77-80 in Sclar, C. B., ed., Character (sic) and origin of the Franklin-Sterling Hill orebodies: Bethlehem, Pennsylvania, symposium held at Lehigh University, 19 May 1990, Proceedings: Lehigh University, Department of Geological Sciences and the Franklin-Ogdensburg Mineralogical Society, 118 p.

Mose, D. G.; and Merguerian, Charles, 1985, Rb-Sr whole-rock age determination on parts of the Manhattan Schist and its bearing on allochthony in the Manhattan Prong, southeastern New York: Northeastern Geology, v. 7, no. 1, p. 20-27.

Muller, E. H., 1964, Quaternary geology of New York, p. 99-112 in Wright, H. E., and Frey, D. G., eds., The Quaternary of the United States: Princeton, NJ, Princeton University Press, 922 p.

Nason, F. L., 1891, The post-Archean age of the white limestones of Sussex County, New Jersey: New Jersey Geological Survey Annual Report for 1890, p. 25-50.

Newman, W. S.; Thurber, D. H.; Zeiss, H. S.; Rokach, A.; and Musich, L., 1969, Late Quaternary geology of the Hudson River estuary: a preliminary report: New York Academy of Sciences Transactions, series 2, v. 31, p. 548-570.

Offield, T. W., 1967, Bedrock geology of the Goshen-Greenwood Lake area, New York: New York State Museum and Science Service, Geological Survey, Map and Chart Series, No. 9, 77 p.

Olsen, P. E., 1980a, The latest (sic) Triassic and Early (sic) Jurassic formations of the Newark basin (eastern North America, Newark Supergroup): Stratigraphy, structure, and correlation: New Jersey Academy of Science Bulletin, v. 25, p. 25-51.

Olsen, P. E., l980b, Triassic and Jurassic formations of the Newark Basin, p. 2-39 in Manspeizer, Warren, ed., Field studies of New Jersey geology and guide to field trips: New York State Geological Association, 52nd Annual Meeting, Newark, New Jersey, Rutgers University, Newark College of Arts and Sciences, Geology Department, 398 p.

Page, L. R., 1950, Uranium in pegmatites: Economic Geology, v. 45, p. 12-34.

Palache, Charles, 1910, Contributions to the mineralogy of Franklin Furnace, New Jersey: American Journal of Science, 4th series, v. 29, p. 177-187.

Palache, Charles, 1928, Mineralogical notes on Franklin and Sterling Hill, New Jersey: American Mineralogist, v. 13, p. 297-329.

Palache, Charles, 1929, Paragenetic classification of the minerals of Franklin, New Jersey: American Mineralogist, v. 14, p. 1-18.

Palache, Charles, 1935, The minerals of Franklin and Sterling Hill, Sussex County, New Jersey: United States Geological Survey Professional Paper 180, 135 p.

Palmer, D. F., 1970, Geology (sic) and ore deposits near Benson Mines, New York: Economic Geology, v. 65, p. 31-39.

Peet, C. E., 1904, Glacial and post-glacial history of the Hudson and Champlain valleys: Journal of Geology, v. 12, p. 415-469; 617-660.

Perlmutter, N. M., 1959, Geology (sic) and ground-water resources of Rockland County, New York, with special emphasis on the Newark Group (Triassic): New York State Water Power and Control Commission, Bulletin GW-42, 133 p.

Perlmutter, N. M., and Arnow, T., 1953, Ground water in Bronx, New York, and Richmond counties with summary data on Kings and Queens counties, New York City, New York: New York State Water Power and Control Commission Bulletin GW-32, 86 p.

Perlmutter, N. M., and Geraghty, J. J., 1963, Geology and ground-water conditions in southern Nassau and southeastern Queens counties, Long Island, New York: United States Geological Survey Water-Supply Paper 1613-A, 205 p.

Pinger, A. W., 1950, Geology of the Franklin-Sterling Hill area, Sussex County, New Jersey: p. 77-87 in Dunham, K.C., ed., Symposium on lead and zinc: International Geological Congress, 18th, Great Britain, 1948, Reports, Part 7.

Platt, J. C., Jr., 1877, The franklinite (sic) and zinc litigation concerning the deposits of Mine Hill, at Franklin Furnace, Sussex County, New Jersey: American Institute of Mining Engineering Transactions, v. 5, p. 580-584.

Potter, P. E., and Pettijohn, F. J., 1977, Paleocurrents and basin analysis (2nd, corrected and updated ed.): Berlin-Heidelberg-New York, Springer-Verlag, 425 p.

Prasada Rao, G., and Murty, Y., 1956, Manganese-ore deposits, of Orissa and Bihar, India: International Geological Congress, 20th, Mexico City, Symposium on Manganese, v. 4, p. 115-131.

Puffer, J. H., 1975, Some North American iron-titanium oxide bearing (sic) pegmatites: American Journal of Science, v. 275, p. 708-730.

Puffer, J. H., Precambrian rocks of the New Jersey Highlands, p. 42-52 in Manspeizer, Warren, ed., Field studies of New Jersey geology and guide to field trips: New York State Geological Association, Annual Meeting, 52nd, Newark, NJ: Rutgers University, Newark College of Arts and Sciences, Department of Geology, 398 p.

Puffer, J. H., and Volkert, R. A., 1991, Generation of trondhjemite from partial melting of dacite under granulite facies (sic) conditions: An example from the New Jersey Highlands: Precambrian Research, v. 51, p. 115-125.

Ratcliffe, N. M., 1981, Cortlandt-Beemerville magmatic belt: a probable late Taconian alkalic cross trend in the central Appalachians: Geology, v. 9, no. 7, p. 329-335.

Reeds, C. A., 1933, The varved clays and other features in the vicinity of New York City, p. 52-63 in Berkey, C. P., ed., New York City and vicinity: International Geological Contress, 16th, United States, Guidebook 9, New York excursions, 151 p.

Reineck, H. E., and Singh, I. B., 1980, Depositional sedimentary environments, with reference to terrigenous clastics, 2nd revised and updated ed.: Berlin-Heidelberg-New York, Springer-Verlag, 549 p.

Renard, A., 1878, Sur la structure et la composition mineralogique du coticule: Mem. Cour. et Mem. des Sav. Etr. Acad. Roy. de Belgique, XLI:.

Rich, J. L., 1934, Mechanics of low-angle overthrust faulting as illustrated by Cumberland thrust block, Virginia, Kentucky, and Tennessee: American Association of Petroleum Geologists Bulletin, v. 18, no. 12, p. 1584-1596.

Ries, H., and Bowen, W. C., 1922, Origin of the zinc ores of Sussex County, New Jersey: Economic Geology, v. 17, p. 517-571.

Rodgers, John, 1949, Evolution of thought on structure of middle and southern Appalachians: American Association of Petroleum Geologists Bulletin, v. 33, no. 10, p. 1643-1654.

Rodgers, John, 1950, Mechanics of Appalachian folding as illustrated by Sequatchie anticline, Tennessee and Alabama: American Association of Petroleum Geologists Bulletin, v. 34, no. 4, p. 672-681.

Rodgers, John, 1953, The folds and faults of the Appalachian Valley and Ridge province, p. 150-166 in McGrain, Preston, ed., Techniques of mineral resources (sic) exploration and evaluation: Southeastern Mineral Symposium 1950, Proceedings: Kentucky Geological Survey, series 9, Special Publication No. 1, 166 p.

Rodgers, John, 1963, Mechanics of Appalachian foreland folding in Pennsylvania and West Virginia: American Association of Petroleum Geologists Bulletin, v. 47, no. 8, p. 1527-1536.

Rodgers, John, 1964, Basement and no-basement hypotheses in the Jura and the Appalachian Valley and Ridge, p. 71-80 in Lowry, W. D., ed., Tectonics of the Southern Appalachians: Blacksburg, Virginia, Virginia Polytechnic Institute, Department of Geological Sciences, Memoir 1, 114 p.

Rodgers, John, 1967a, Chronology of tectonic movements in the Appalachian region of eastern North America: American Journal of Science, v. 265, p. 408-427.

Rodgers, John, 1967b, Unusual features of the New York sector of the Appalachian Mountains, p. 1-4 in Waines, R. H., ed., New York State Geological Association, Annual Meeting, 39th, New Paltz, New York, 5-7 May 1967, Guidebook to field trips: New Paltz, New York, State University College at New Paltz, Division of Physical Sciences, not consecutively paginated.

Rodgers, John, 1970, The tectonics of the Appalachians: New York, Interscience Publishers, Inc., 271 p.

Roering, C., 1968, The geometrical significance of natural enechelon crack arrays: Tectonophysics, v. 5, p. 107-123.

Roy, B., 1956, Manganese-ore deposits of Bombay State, India: XX International Geological Congress, Mexico, Symposium on Manganese, v. 4, p. 41-61.

Roy, S., 1965, Comparative study of the metamorphosed manganese protores of the world--the problem of the nomenclature of the gondites and kodurites: Economic Geology, v. 60, p. 1238-1260.

Salisbury, R. D., 1892a, Certain extramorainic drift phenomena of New Jersey: Geological Society of America Bulletin, v. 3, p. 173-182.

Salisbury, R. D., 1892b, Preliminary paper on drift or Pleistocene formations of New Jersey: New Jersey Geological Survey, Annual Report for 1891, p. 35-108 (plus maps).

Salisbury, R. D., 1893, Distinct glacial epochs and the criteria for their recognition: Journal of Geology, v. 1, p. 61-84.

Salisbury, R. D., 1902, Pleistocene formations, p. 11-17 in Merrill, F. J. H., and others, Description of the New York City district: U. S. Geological Survey, Geologic Atlas of the United States, New York City Folio, No. 83, 19 p.

Salisbury, R. D., assisted by H. B. Kümmel, C. E. Peet, and G. N. Knapp, 1902, The glacial geology of New Jersey: Geological Survey of New Jersey Final Report of the State Geologist, v. 5: Trenton, NJ, MacCrellish and Quigley, Book and Job Printers, 802 p.

Salisbury, R. D., and Peet, C. E., 1894, Section V. Drift phenomena of the Palisade ridge, p. 157-224 in Geological Survey of New Jersey, Annual Report of the State Geologist for the year 1893: Trenton, NJ, The John L. Murphy Publishing Company Printers, 457 p.

Sampson, E., 1957, The zinc-manganese deposits of the Franklin-Sterling region, p. 87-94, in Dorf, Erling, ed., Geological Society of America Annual Meeting, Atlantic City, Guidebook for field trips, 250 p.

Sanders, J. E., 1962a, Strike-slip displacement on faults in Triassic rocks in New Jersey: Science, v. 136, p. 40-42.

Sanders, J. E., 1962b, Relationships of folds to faults in Upper Triassic rocks, northeast of the Schuylkill (Pennsylvania to Massachusetts) (abstract): Geological Society of America, Special Papers, No. 68, Abstracts for 1962, p. 260-261.

Sanders, J. E., 1963, Late Triassic tectonic history of northeastern United States: American Journal of Science, v. 261, p. 501-524.

Sanders, J. E., 1969, Bedding thrusts and other structural features in cross section through "Little Mountains" along Catskill Creek (Austin Glen and Leeds Gorge), west of Catskill, New York, Trip 19 p. 19-1 to 19-38 in Bird, J. M., ed., New England Intercollegiate Geological Conference, Annual Meeting, 61st, Albany, New York, 10-12 October 1969, Guidebook for field trips in New York, Massachusetts, and Vermont: Albany, State University of New York at Albany, not consecutively paginated.

Sanders, J. E., 1971, Triassic rocks, northeastern North America: regional tectonic significance in light of plate tectonics (extended abstract): Geological Society of America, Abstracts With Programs, v. 3, no. 7, p. 781-783.

Sanders, J. E., 1974a, Geomorphology of the Hudson Estuary, p. 5-38 in Roels, Oswald, ed., Hudson River Colloquium: New York Academy of Sciences Annals, v. 250, 185 p.

Sanders, J. E., 1981, Principles of physical geology: New York, John Wiley and Sons, 624 p.

Sanders, J. E., 1983, Reinterpretation of the subsurface structure of the Middletown gas well (Crom-Wells, Inc. 1 Fee) in light of concept of large-scale bedding thrusts: Northeastern Geology, v. 5, no. 3/4, p. 172-180.

Sanders, J. E., Friedman, G. M., and Sternbach, C. A., 1981, Extinct (sic) and active continental margin (sic) deposits and their tectonic-switchover products: Appalachian orogen ("Eastern overthrust belt")-Catskill Plateau-Newark basin-Atlantic Coastal Plain, p. 104-232 in Hobbs, G. W., ed., Field guide to the geology of the Paleozoic, Mesozoic, and Tertiary rocks of New Jersey and the central Hudson Valley: American Association of Petroleum Geologists, 1981 Eastern Section Meeting, Atlantic Margin Energy Symposium, Atlantic City, New Jersey, 4-6 October 1981: New York, N. Y., Petroleum Exploration Society of New York, 232 p.

Sanders, J. E., and Merguerian, Charles, 1991, Pleistocene tills in the New York City region: New evidence confirms multiple (three and possibly four) glaciations from two directions (NNE to SSE (sic) and NW to SE) (abs.): Geological Society of America Abstracts with Programs, v. 23, no. 1, p. 123.

Sanders, J. E.; and Merguerian, Charles, 1994a, Fitting newly discovered north-shore Gilbert-type lacustrine deltas into a revised Pleistocene chronology of Long Island (extended abstract), p. 103-113 in Hanson, G. N., chm., Geology of Long Island and metropolitan New York, 23 April 1994, Stony Brook, NY: Stony Brook, NY, Long Island Geologists Program with Abstracts, 165 p.

Sanders, J. E.; and Merguerian, Charles, 1994b, Glacial geology of the New York City region, p. 93-200 in Benimoff, A. I., ed., The geology of Staten Island, New York: Geological Association of New Jersey Annual Meeting, 11th, Somerset, NJ, 14-15 October 1994, Field guide and proceedings, 296 p.

Sanders, J. E. and Merguerian, Charles, 1995, Evidence for pre-Woodfordian ages of Long Island's terminal moraines (extended abstract), p. 91-106 in Hanson, G. N., chm., Geology of Long Island and metropolitan New York, 22 April 1995, Stony Brook, NY: Stony Brook, NY, Long Island Geologists Program with Abstracts, 135 p.

Sanders, J. E.; Merguerian, Charles; and Okulewicz, S. C., 1995a, Glacio-tectonic evidence for SE-directed glacial flow in displaced slab of Upper Cretaceous sediments exposed in the Harbor Hill Moraine, Princes Bay, Staten Island, New York (abstract): Geological Society of America Abstracts with Programs, v. 27, no. 1, p. 79-80.

Sanders, J. E.; Merguerian, Charles; and Okulewicz, S. C., 1995b, Recembent fold in displaced slab of Upper Cretaceous sediments, Princes Bay, Staten Island, New York: Further evidence that ice flowing southeastward deposited the Harbor Hill Moraine (extended abstract), p. 107-117 in Hanson, G. N., chm., Geology of Long Island and metropolitan New York, 22 April 1995, Stony Brook, NY: Stony Brook, NY, Long Island Geologists Program with Abstracts, 135 p.

Sanders, J. E., and Rampino, M. R., 1978, Wisconsinan stratigraphy, New York metropolitan area: interpretation of newly recognized units does not support modern concepts of the "Laurentide" ice sheet (abstract): Geological Society of America Abstracts with Programs, v. 10, no. 2, p. 84 (only).

Schiller, E., and Taylor, F., 1965, Spessartite-quartz rocks (coticules) from Nova Scotia: American Mineralogist, v. 50, p. 1477-1481.

Schuberth, C. J., 1968, The geology of New York City and environs: Garden City, NY, Natural History Press, 304 p.

Sclar, C. B., 1990, Geothermometry at the Sterling Hill zinc deposit, Sussex County, N. J. (just how hot did it get at Sterling Hill?), p. 110-117 in Sclar, C. B., ed., Character (sic) and origin of the Franklin-Sterling Hill orebodies: Bethlehem, Pennsylvania, symposium held at Lehigh University, 19 May 1990, Proceedings: Lehigh University, Department of Geological Sciences and the Franklin-Ogdensburg Mineralogical Society, 118 p.

Shilts, W. W., Cunningham, C. M., and Kaszycki, C. A., 1979, Keewatin Ice Sheet--re-evaluation of the traditional concept of the Laurentide Ice Sheet: Geology, v. 7, no. 11, p. 537-541.

Shrock, R. R., 1948, Sequence in layered rocks. A study of features and structures useful for determining top and bottom or order of succession in bedded (sic) and tabular rock bodies: New York-Toronto-London-McGraw-Hill Book Company, Inc., 507 p.

Sibson, R., 1977, Fault rocks and fault mechanisms: Geological Society of London Journal, v. 133, p.191-213.

Sims, P. K., 1953, Geology of the Dover magnetite district, Morris County, New Jersey: United States Geological Survey Bulletin 982-G, p. 245-305.

Sims, P. K., 1958, Geology and magnetite deposits of the Dover district, Morris County, New Jersey: United States Geological Survey Professional Paper 287, 162 p.

Sims, P. K., and Leonard, B. F., 1952, Geology of the Andover mining district, Sussex County, New Jersey: New Jersey Department of Conservation and Development Bulletin 62, 46 p., (plus maps).

Sirkin, L. A., 1967, Late (sic) Pleistocene pollen stratigraphy of western Long Island and eastern Staten Island, p. 249-274 in Cushing, E., and Wright, H. E., Jr., eds., Quaternary paleoecology: International Association for Quaternary Research, Congress, 7th, 1965, Proceedings, v. 7, New Haven, CT, Yale University Press, 433 p.

Sirkin, L. A., 1982, Wisconsinan glaciation of Long Island, New York to Block Island, Rhode Island, p. 35-59 in Larson, G. J., and Stone, B. D., eds., Late Wisconsinan glaciation of New England. A symposium: Dubuque, IA, Kendall/Hunt Publishing Company, 242 p. (Symposium held at Northeastern section of Geological Society of America, 13 March 1980, Philadelphia, PA.)

Sirkin, L. A., and Minard, J. P., 1972, Late Pleistocene glaciation and pollen stratigraphy in northwestern New Jersey: United States Geological Survey Professional Paper 800-D, p. D77-D87.

Sloss, L. L., 1963, Sequences in the cratonic interior of North America: Geological Society of America Bulletin, v. 74, no. 2, p. 93-114.

Smith, B. L., 1957, Summary of the Precambrian geology of the New Jersey Highlands, p. 70-76, in Dorf, Erling, ed., Geological Society of America, Annual Meeting, Atlantic City, Guidebook for field trips, 250 p.

Smith, B. L., 1969, The Precambrian geology of the central (sic) and northeastern parts of the New Jersey Highlands, p. 51-131 in Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: Geological Society of America, Annual Meeting, 1969, Atlantic City: New Brunswick, New Jersey, Rutgers University Press, 382 p.

Spencer, A. C., 1909, The Mine Hill and Sterling Hill zinc deposits of Sussex County, New Jersey: New Jersey Geological Survey Annual Report for 1908, Part 2, p. 23-52.

Spencer, A. C., Kümmel, H. B., Wolff, J. E., Salisbury, R. D., and Palache, C., 1908, Description of the Franklin Furnace quadrangle: United States Geological Survey, Geologic Atlas of the United States, Franklin Furnace folio (No. 161), 27 p.

Spurr, J. E., and Lewis, J. V., 1925, Ore deposition at Franklin Furnace, New Jersey: Engineering and Mining Journal-Press, v. 119, p. 317-328.

Stanford, S., and Harper, D., 1985, Late Wisconsinan deglaciation from the Ogdensburg-Culvers Gap Moraine to the Sussex Moraine, p. 70-80 in Evenson, E. B., ed., Woodfordian deglaciation of the Great Valley, New Jersey: Friends of the Pleistocene Field Conference, 48th, 3-5 May 1985, McAfee, NJ, Guidebook, Bethlehem, PA, Lehigh University and New Jersey Geological Survey, 119 p.

Tarr, W. A., 1929, The origin of the zinc deposits at Franklin and Sterling Hill, New Jersey: American Mineralogist, v. 14, p. 207-221.

ten Haaf, Ernst, 1959, Graded beds of the northern Apennines: Groningen, The Netherlands, Rijks University of Groningen Department of Geology Ph. D. Dissertation, 102 p.

Tilton, G. R., Wetherill, G. W., Davis, G. L., and Bass, M. N., 1960, 1000-million-year-old minerals from the eastern United States and Canada: Journal of Geophysical Research, v. 65, p. 4173-4179.

Troost, G., 1824, Observations on the zinc ores of Franklin and Sterling, Sussex County, New Jersey: Academy of Natural Sciences in Philadelphia, Journal, v. 4 (for 1824), p. 220-231.

Twiss, R. J., and Moores, E. M., 1992, Structural geology: New York, NY, W. H. Freeman and Company, 532 p.

United States Geological Survey, 1967, Engineering geology of the northeast corridor, Washington, D. C., to Boston, Massachusetts: United States Geological Survey, Miscellaneous Investigations Map I-514 A, B, and C.

Upham, W., 1895, Discrimination of glacial accumulation and invasion: Geological Society of America Bulletin, v. 6, p. 343-352.

Upham, W., 1914, Fields of outflow of the North American ice sheet: International Geological Congress, 12th, Canada (1913), Compte Rendu, p. 516-522.

Upson, J. E., and Spencer, C. W., 1964, Bedrock valleys of the New England coast as related to fluctuations of sea level: United States Geological Survey Professional Paper 454-M, p. M1-M44.

Vanuxem, L., and Keating, W. H., 1822, On the geology (sic) and mineralogy of Franklin, in Sussex County, New Jersey: Academy of Natural Sciences in Philadelphia, Journal, v. 2, p. 277-288.

Vogel, T. A., Smith, B. L., and Goodspeed, R. M., 1968, The origin of antiperthites from some charnokitic rocks in the New Jersey Precambrian: American Mineralogist, v. 53, p. 1696-1708.

Volkert, R. A., 1993, Geology of the Middle Proterozoic rocks of the New Jersey Highlands, p. 23-55 in Puffer, J. H., ed., Geologic traverse across the Precambrian rocks of the New Jersey Highlands: Geological Association of New Jersey Annual Meeting, 10th, Field Guide and Proceedings, xxx p.

Volkert, R. A., 1995, The Byram (sic) and Lake Hopatcong Intrusive Suites: Geochemistry and petrogenetic relationships of A-type granites from the New Jersey Highlands: Northeastern Geology and Environmental Sciences, v. 17, no. 3, p. 247-258.

Ward, F., 1938, Recent geological history of the Delaware Valley below the Water Gap: Pennsylvania Geological Survey, General Geology Report G-10, 65 p.

Warthin, A. S., Jr., and Pack, A. G., 1956 ms., Correlation of samples from a well in Orange County, New York: New York State Geological Survey Open-file report, 6 p.

Westgate, L. G., 1894, The age of the crystalline limestones of Warren County, New Jersey: American Geologist, v. 14, p. 369-379.

Wetherill, J. P., 1897, The Mine Hill ore deposits in New Jersey and the Wetherill concentrating plant: Engineering and Mining Journal, v. 64, p. 65-66, 98-100.

Widmer, K., 1964, The geology (sic) and geography of New Jersey: Princeton, New Jersey, Van Nostrand Company, Inc., 193 p.

Williams, E. H., Jr., 1895, Notes on the southern ice limit in eastern Pennsylvania: American Journal of Science, 3rd series, v. 49, p. 174-185.

Williams, E. H., Jr., 1920, Deep Kansan pondings in Pennsylvania and the deposits therein: American Philosophical Society, Proceedings, v. 19, p. 49-84.

Witte, R. W., Evenson, E. B., and Koteff, C., 1985, Late Wisconsinan deglaciation from the franklin Grove-Turtle Pond Moraine to the Ogdensburg-Culvers Gap Moraine, p. 59-69 in Evenson, E. B.. ed., Woodfordian deglaciation of the Great Valley, New Jersey: Friends of the Pleistocene Field Conference, 48th, 3-5 May 1985, McAfee, NJ, Guidebook, Bethlehem, PA, Lehigh University and New Jersey Geological Survey, 119 p.

Wolfe, P. E., 1977, The geology (sic) and landscapes of New Jersey: Crane and Russak.

Wolff, J. E., 1898, Occurrence of native copper at Franklin Furnace, New Jersey: American Academy of Arts and Sciences, Proceedings, v. 33, p. 429-430.

Wolff, J. E., 1903, Zinc (sic) and manganese deposits of Franklin Furnace, New Jersey: United States Geological Survey Bulletin 213, p. 214-217.

Wolff, J. E., and Brooks, A. H., 1898, The age of the Franklin white limestone of Sussex County, New Jersey: United States Geological Survey Annual Report, 18th, Part 2, p. 425-457.

Woodcock, N. H.; and Schubert, C., 1994, Continental strike-slip teconics, Chapter 12, p. 251-263 in Hancock, P. L., ed., Continental deformation: Oxford-New York-Seoul-Tokyo, 421 p.

Woodworth, J. B., 1901a, Pleistocene geology of portions of Nassau County and Borough of Queens (N. Y.): New York State Museum Bulletin 48, p. 618-670 (includes geologic map).

Woodworth, J. B., 1901b, Original micaceous cross banding of strata by current action: American Geologist, v. 27, p. 281-283.

Worner, H. K., Chenhall, B. E., and Jones, J., 1990, Synthesis of Franklin and Sterling Hill minerals using a microwave oven, p. 81-92 in Sclar, C. B., ed., Character (sic) and origin of the Franklin-Sterling Hill orebodies: symposium held at Lehigh University, Bethlehem, Pennsylvania, 19 May 1990, Proceedings: Bethlehem, PA, Lehigh University Department of Geological Sciences and the Franklin-Ogdensburg Mineralogical Society, 118 p.

Wright, G. F., 1882, The terminal moraine in Pennsylvania: Salem, Massachusetts, Essex Institute, Bulletin, v. 14, p. 71-73.

Wright, G. F., 1893, Extra-morainic drift in the Susquehanna, Lehigh, and Delaware valleys: Academy of Natural Sciences of Philadelphia, Proceedings, v. 44, p. 464-484.

Young, D. A., 1978, Precambrian salic intrusive rocks of the Reading Prong: Geological Society of America Bulletin, v. 89, p. 1502-1514.

Filename: OTR11 Franklin Furnace.doc