FIELD TRIP TO THE SOUTH CENTRAL NEWARK BASIN FOR 7th INTERNATIONAL WORKSHOP ON FISSION-TRACK THERMOCHRONOLOGY

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INTRODUCTION

The purpose of this field trip is to examine the classic outcrops of the Newark basin (Figures 1 and 2) along the Delaware River, which have been the subject of so many guidebooks. In this case, however we can directly compare the results of the newly recovered Newark basin cores with the outcrop. The similarity between the cores and the outcrops are remarkable because the two main areas in which they occur are in different sub-basins that were active during sedimentation, and are presently separated by 25 to 55 km. This brief guidebook is based largely on text and figures culled, with modification, from Olsen et al (1989), which includes the work of many authors. Complete attribution and references in this guidebook can be found in that source.

GEOLOGICAL CONTEXT

Eastern North America includes the classic Atlantic-type passive continental margin formed by the breakup of the supercontinent of Pangaea. The Triassic initiation of the breakup was marked by the formation of rifted crust all along the axis of the future Atlantic Ocean, from Greenland to Mexico. In eastern North America, nine major rift basins, mostly half-graben, and several minor basins are exposed from Nova Scotia to South Carolina, with many more buried below the coastal plain and continental shelf (Figure 1). The exposed rift basins, which closely follow the trend of the Appalachian orogen, filled with thousands of meters of continental sediments and basalt flows over a period of approximately 45 million years. Diabase plutons and dikes, apparently coeval with the basalt flows, extensively intruded and metamorphosed pre-existing strata. The faulted, tilted, and eroded rift strata are termed the Newark Supergroup.

GEOLOGY OF THE NEWARK BASIN

The Newark Basin (Figure 5.1) is the largest of the rift sequences exposed in the United States, covering over 7000 km^2 and with a preserved stratigraphic thickness of more than 6 km (Figures 2 and 3). It is a block-faulted, deeply eroded, half-graben (Figures 2a and 2b). Most strata dip 5°-15° NW. Most of the basin's northwestern margin is bound by normal faults, whereas the southeastern margin consists of an unconformable contact with Paleozoic rocks, or is marked by overlap of coastal plain sediments.

Nine formations are presently recognized in the Newark basin section (Figure 3). These are, from the bottom up: Stockton Formation, Lockatong Formation, Passaic Formation, Orange Mountain Basalt, Feltville Formation, Preakness Basalt, Towaco Formation, Hook Mountain Basalt, and Boonton Formation.

Fluvial red and buff sandstones and red and purple mudstones make up the Stockton Formation, the oldest formation in the basin. The succeeding lacustrine Lockatong and Passaic formations together make up a natural facies package united by repetitive and permeating lake level cycles. Because of the great thickness of the two formations, presence of very large exposures, relatively common small exposures, and a long history of detailed mapping, it is in these two formations that the evidence for Milankovitch-type climatic forcing is the strongest (see Stop 2 below). The hierarchy of Van Houten cycles of 21,000-year-duration and higher order cycles of 100,000- and 400,000-year-duration is obvious at virtually all relatively fine-grained outcrops, and even many of the coarsest (see Stop 4). The Orange Mountain Basalt, Feltville Formation, Preakness Basalt, Towaco Formation, and Hook Mountain Basalt are interbedded tholeiitic basalt and largely lacustrine sedimentary formations of Early Jurassic age. These are overlain by the lacustrine Boonton Formation, the youngest formation preserved in the basin. Sequences of sedimentary cycles similar to those in the Lockatong and Passaic formations occur throughout the Jurassic portions of the Newark basin.

GEOLOGICAL HISTORY

Eastern North America underwent a succession of accretion events during the Paleozoic that culminated with the condensation of Pangaea. The zone between the adjacent cratons was highly structured by compression and transpression and many brittle and ductile structures were reactivated as major normal and transtensional strike-slip faults during the onset of regional NW-SE extension somewhere near the beginning of the Late Triassic (~230 MA).

There is presently no direct date of the onset of sedimentation in the Newark basin. However, the older exposed strata of the Stockton Formation are at least early late Carnian in age, based on pollen and spores (~227 Ma). Because of the pattern of hanging wall onlap commonly occurring in half graben yet older strata are probably present, deeply buried along the axis of the basin ((Figure 2b).

The Late Triassic Stockton Formation is almost entirely fluvial in origin, and the transition from fluvial to lacustrine environments occurred very close to the top of the Stockton about 226 Ma, probably because of an increase in the area of the basin or by an increase in regional extension rate (Schlische and Olsen, 1989). The transition to the "deepest water" facies of the Lockatong Formation was rapid and maximum average depth was reached by the middle lower Lockatong Formation (~225 Ma). From the upper Lockatong, through the succeeding Passaic Formation the average depth of Newark basin lakes and the average accumulation rate very slowly decreased. Of course, the actual lake depth fluctuated dramatically all during this time, following the Milankovitch cyclicity. Near the top of the Passaic Formation, the accumulation rate and average water depth dramatically increased. The Triassic-Jurassic boundary (202 Ma) is in this zone. Within 40,000 years of the Triassic-Jurassic boundary and at the top of the Passaic Formation, the first of three lava lake formations (Orange Mt. Basalt) was extruded. Within about 600,000 years all three basalt formations had been extruded. Interbedded lacustrine strata are of deeper water facies than the underlying Passaic Formation and have the highest sedimentation rates of the preserved basin section (~1 mm/yr). Thereafter, sedimentation rates and average water depth slowly decline. The increase in accumulation rate, the deeper water lakes, and the basalt extrusion were probably the result of a short-lived, but dramatic increase in regional extension rate. At the top of the preserved basin section (e.g. Boonton Formation), the basin had accumulated at least 7 km of strata. Minimally 2 km of additional strata were deposited on top of that before deposition ceased (largely based on organic maturity data, but compatible with fission track data).

Tilting of the strata, and hence most deposition, was over by the Middle Jurassic (~175 Ma), during which time eastern North America witnessed a major hydrothermal fluid event. This event produced a strong magnetic overprint as well as resetting K-spars in the igneous rocks, and at least in some large areas, annealing fission tracks in zircons, sphenes and apatites. This fluid event may have been associated with the beginning of true sea-floor spreading and the production of the first Atlantic oceanic crust. The magnetic overprints of the sedimentary rocks of more northern Newark Supergroup basins appears considerably more complex than that of the Newark basin, however, suggesting additional and younger hydrothermal events, perhaps associated with the intrusion of the relatively near by White Mountain plutons.

The transition from regional NW-SE extension to NW-SE compression from ridge-push probably occurred somewhere near this time, and there may have been an interval of intervening NE-SW compression or shear. Because the basin was above sea level all during its preserved depositional history, erosion of the stratigraphic section probably began as basin subsidence slowed, somewhere after the Early Jurassic. Although uplift of eastern North America may have occurred during the initial phases of the production of oceanic crust or loading of the passive margin, the post-rift unconformity would have been produced any way as erosion proceeded towards sea level. By the Early Cretaceous (~ 135 Ma) a combination of thermal (cooling) subsidence and erosion brought the basin to near sea level and present erosional level. From at least the Cretaceous to the present, the basin, as well as most of eastern North America has been under mild regional NW-SE compression. The thickness of any coastal plain strata that might have been deposited prior to Neogene sea level drop and erosion must have been relatively small.

FIELD STOPS

STOP 1: QUARRY IN PRALLSVILLE MEMBER OF STOCKTON FORMATION, STOCKTON, NJ

(Adapted from Olsen and Schlische (in Olsen et al., 1989, pp. 89-90)

Highlights:

- *Basal fluvial portion of basin fill with large upward fining cycles.*
- *Correlates with lower part of Princeton # 1 core.*

The Stockton Formation comprises the oldest fill in the Newark rift basin and it is almost entirely fluvial. The Skeuse family quarry in upper part of the Prallsville Member of the Stockton Formation exposes about 60 m of section and begins about 760 m above the base of the formation (Figure 4) (Van Houten, 1969, 1980). We will examine an 18 m section in the most recently active part of the quarry. The interval exposed in the quarry probably correlates with from 2700 to 3500 ft in the Princeton # 1 core (Figure 5).

Thick (~15 m) fining upward cycles are obvious at these outcrops (Figure 3), which consist of, from the bottom up: 1) pebbly trough cross bedded sandstone at base passing upwards into sandy compound cross-bed sets - units tend to be kaolinized and have small to large siltstone rip-up clasts; 2) thick interval of well sorted sandstone with climbing ripple cross lamination and planar lamination with bioturbation and siltstone partings increasing up section; 3) climbing ripple to massive siltstone with intense bioturbation by *Scoyenia* and roots, and slickensided dish structures. The 18 m section exposed in the part of the quarry we will visit (main quarry - Figure 4) exposes almost a complete cycle plus the basal portion of a succeeding cycle.

The sequence of structures in these fining-upward sequences are consistent with large, perennial meandering or anastamosing river deposits. In addition, lateral accretion surfaces of point bars are suggested by the lateral fining of cross-bedded structures in the up-dip direction. The large river systems implied by these outcrops are incompatible with a closed basin model for the Newark basin (Smoot, 1985) and indicate an open basin for this part of the basin's history. This is in accord with the predictions of the basin filling model outlined by Schlische and Olsen (1990) and Olsen and Schlische (1988a-d), and every basin in the Newark rift system has a similar basal through-draining fluvial unit.

This is a particularly good place to see the two main mutually perpendicular joint sets characteristic of the Newark basin (Figure 4). Such regional joint sets are characteristic of extensional systems with one set (NE-striking) being perpendicular to the extension direction and tending to be parallel with most of the Jurassic age dike sets in the Newark basin. The NW-striking set parallels the axes of fold systems in the basin, and may be related to the overall bending and downwarping of the Newark basin as a result of variable slip on the border fault system.

STOP 2: MIDDLE LOCKATONG FORMATION AT BYRAM, NJ

Highlights:

- *Byram Diabase Sill*
- *Example of deepest water facies in Newark basin, classic field locality of cyclic Lockatong lacustrine strata.*
- *Extremely close correlation with Nursery # 1 core.*

Exposed along the east side NJ 29 and along the ravine at its north end are more than 400 m of middle Lockatong Formation (Figure 6), which represents a shallower portion of the “deep lake” stage of the Newark rift. In this basin the lacustrine interval is characterized by extremely exaggerated lake level cycles that always have a phase showing signs of complete desiccation. These cycles were originally described by Franklyn Van Houten in the 1960’s, and these are the exposures on which he based most of his interpretations. These are also the lacustrine exposures most often seen by visiting geologists, although they are becoming increasingly overgrown in recent years. This outcrop correlates to the section cored in Nursery # 1 from 1280 to 2300 ft (Figure 7).

The Byram Sill is well exposed at the southeastern end of this series of outcrops. It is probably the lateral equivalent of the Palisades Sill of northern New Jersey and southeastern New York. Here the sill intrudes between the lower and middle Lockatong Formation. Igneous layering is apparent at several places in the diabase sill. The Byram sill may not extend down dip in this area, as revealed by the NORPACK # 1 line. The section above the sill is metamorphosed to a hornfels by the intrusion, although this entire outcrop is very thermally mature even at the top of the measured section ($R_o \sim 2.0$).

About 99% (405 m) of the sedimentary rock of this outcrop section consists of fine calcareous mudstone and claystone with the remaining 1% (5 m) consisting of very fine sandstone. These exposures include the Ewing Creek, Byram, Skunk Hollow, and Tohicken members. McLaughlin's (1944) "First Thin Red" makes up the upper part of the Skunk Hollow Member and the "First Thick Red" makes up the upper part of the Tohicken Member. These outcrops are typical of the middle and upper Lockatong Formation, with the deepest water stages of the Lockatong sequence being lower in the formation.

Fourier analysis of this depth-ranked section done in 1984 (Figure 6) and calibration by varve-based sedimentation rates and radiometric time scales show the main thickness and time periodicities typical of both the Lockatong and Passaic formations in this part of the basin. All of the periodic components predicted by the Milankovitch theory of climate change for monsoonal equatorial regions are present in the power spectrum. More details on this stop are provided in the Olsen et al. (1989) guidebook (pp.86-89).

STOP 3: BASAL PASSAIC FORMATION: MEMBER C AT DEVILS TEA TABLE

Highlights:

- *Red mudstone of lower Passaic Formation still showing characteristic cyclical pattern.*
- *Correlates with 2150 to 2300 in the Titusville # 1 core.*

The transition from Lockatong to Passaic Formation is marked by an increase in proportion of red massive mudstones over gray. The cyclical pattern remains intact through the transitions and through the entire Passaic Formation, however, the frequency with which deep lakes appeared was waning. These outcrops are stratigraphically the lowest in this part of the basin in which red rather than gray massive mudstones are dominant. The section illustrates the facies typical of much of the shallow lake phase of the Newark basin section, and it is similar to often desiccated, but still, lacustrine phases in other rift lakes as well.

Exposed along the east side NJ 29 are about 100 m of lower Passaic Formation (Figure 8) showing the classic cyclical alternation of thin black and gray shales and mudstones and much thicker packages of red mudstone. This outcrop section is amazingly similar to the section cored in Titusville # 1 from 2150 to 2300 ft. Outcrops on the southwest side of Devils Tea Table and Cains Run are of the gray and black portions of Member C, the stratigraphically lowest of many putatively 400,000 year cycles in the Passaic Formation. The dominant lithology in the gray beds is a massive mudcracked mudstone (breccia fabric) deposited in a playa. However, gray and black more fissile mudstones deposited in perennial lakes occur about every 5-7 m, outlining the same kind of cyclicity seen in the underlying Lockatong Formation (Stop 2). The thick sequence of red mudstones higher in Member C still follows this pattern, although the gray and black units are replaced by fissile red or purple siltstones.

Many gray and red massive mudstones at this locality are cut by dish-shaped, concave-upward clay-lined surfaces with radial slickenlines. These "dish structures" were described by Van Houten (1964, 1969) and interpreted as a possible gilgai-type soil feature (Van Houten, 1980). A mechanical analysis of these structures suggests they are coulomb fractures produced in relatively rigid, but not lithified, mud by more or less isotropic expansion in a three-dimensional analogue of Davis *et al.*'s (1983) "bulldozer" model for the development of thrust faults in accretionary wedges. The volume increase was probably due to eolian deposition of mud in desiccation cracks followed by rewetting. Because the bed was confined laterally, it fractured along listric, dish-shaped faults and compensated for increased volume by increasing in thickness. As a mechanical consequence of volume increase, the dish-structures are probably not specific to any particular environment in larger sense, but could be indicative of a limited range of environments in a particular basin setting such as the basal Passaic.

STOP 4: PEBBLE BLUFF, NEAR MILFORD, NJ

Highlights:

- *Interbedded conglomerates and lacustrine strata near the border fault.*
- *Correlates with from about 1900 to 2400 ft in the Rutgers # 1 core and from 30 to 300 ft in the Titusville # 2 core.*

These outcrops [described by Van Houten (1969, Stop 6; 1980, Stop 1) and Arguden and Rodolpho (1987), Olsen *et al.* (1988 and 1989)] consist of thick sequences (> 20 m) of red conglomerate and sandstones alternating with cylindrical black, gray, and red mudstone and sandstone. Dips average 10-15° NW, and there several faults, down-throwing to the east, between the largest outcrops. The gray beds seen in Figure 10 appear to be the basal Perkasie member. The outcrops shown in Figure 10 correlate with 2280 to 2320 ft in the Rutgers # 1 core and from 30 to 110 ft and are the facies equivalent of those fine grained strata near the border fault. The entire suite of outcrops at Pebble Bluffs span the intervals from about 1900 to 2400 ft in the Rutgers # 1 core and from 30 to 300 ft in the Titusville # 2 core (0 to 30 ft not cored in the latter).

Conglomerates at Pebble Bluffs occur in three basic styles. 1) Poorly-bedded boulder-cobble conglomerate with pebbly sandstone interbeds. Matrix rich conglomerates are in places matrix-supported. These appear to define lenses that are convex-upward and bounded by the largest clasts at their edges and tops. These lenses appear to be debris flow lobes, in which some of the matrix may have been partially washed out by rain during periods of non-deposition. If correctly identified, the flow lenses are typically less than 30 cm. thick and less than 5 m wide, similar to debris flows formed on mid to lower portions of steep fans. Pebbly sandstone and muddy sandstone include "trains" of isolated cobbles often oriented vertically. These cobble trains represent thin, low viscosity debris flows that are stripped of their matrix by shallow flash-flood streams. The sandstones appear to be broad, shallow stream deposits that may include hyperconcentrated flow as indicated by flat layering defined by the orientation of granules.

2) Well-defined lenticular beds of pebble-cobble conglomerate separated by pebbly muddy sandstones with abundant root structures. The conglomerate beds are channel-form with abundant imbrication. Some internal coarsening and fining sequences are consistent with longitudinal bars (Bluck, 1982). Finer grained deposits resemble less incised channels and overbank deposits. There are some hints of thin debris flow sheets. Abundant root structures filled with nodular carbonate (caliche?) suggest soil development.

3) Grain-supported cobble-pebble conglomerate with sandy matrix. Granules and coarse sand show a high degree of sorting suggestive of wave reworking of finer fractions (LeTourneau and Smoot, 1985). These are associated with the gray and black shales and oscillatory-rippled sandstones in the Van Houten cycles of the Perkasie at this locality.

Laterally continuous black and gray siltstones and claystones within division 2 of Van Houten cycles (Figure 10) contain pinch-and-swell laminae, abundant burrows, and rare clam shrimp. These perennial lacustrine deposits are clearly the coarser facies of strata represented in the more central Newark basin, such as seen in the Titusville and Rutgers cores. These lakes were evidently deep enough to transgress over the relief caused by the toes of alluvial fans, as represented by the debris flow deposits at this outcrop.

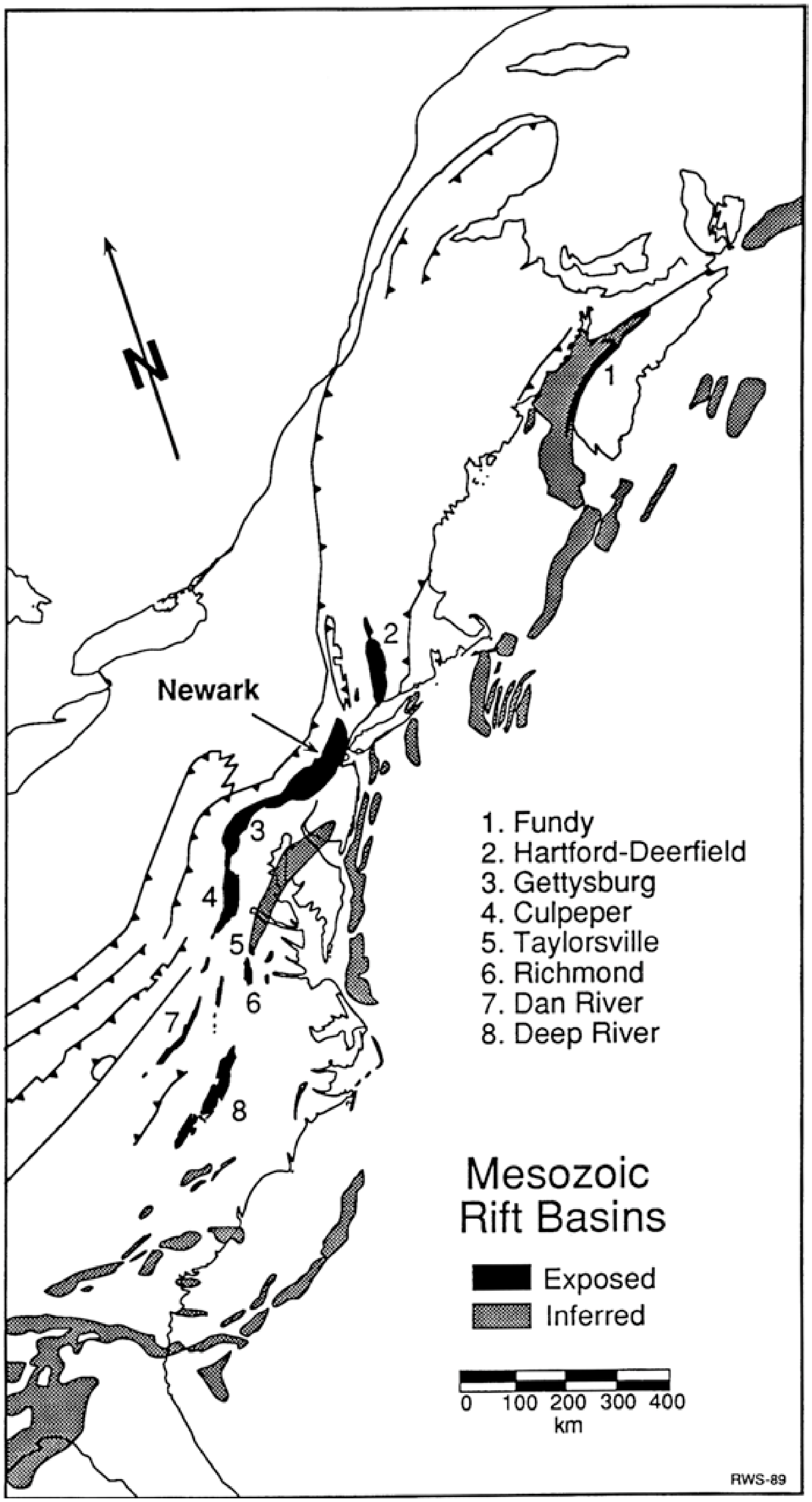

N
Newark
1
2
3
4
5
6
7
8
1. Fundy
2. Hartford-Deerfield
3. Gettysburg
4. Culpeper
5. Taylorsville
6. Richmond
7. Dan River
8. Deep River
Mesozoic Rift Basins
Exposed
Inferred
0 100 200 300 400
km
RWS-89

Figure 1.

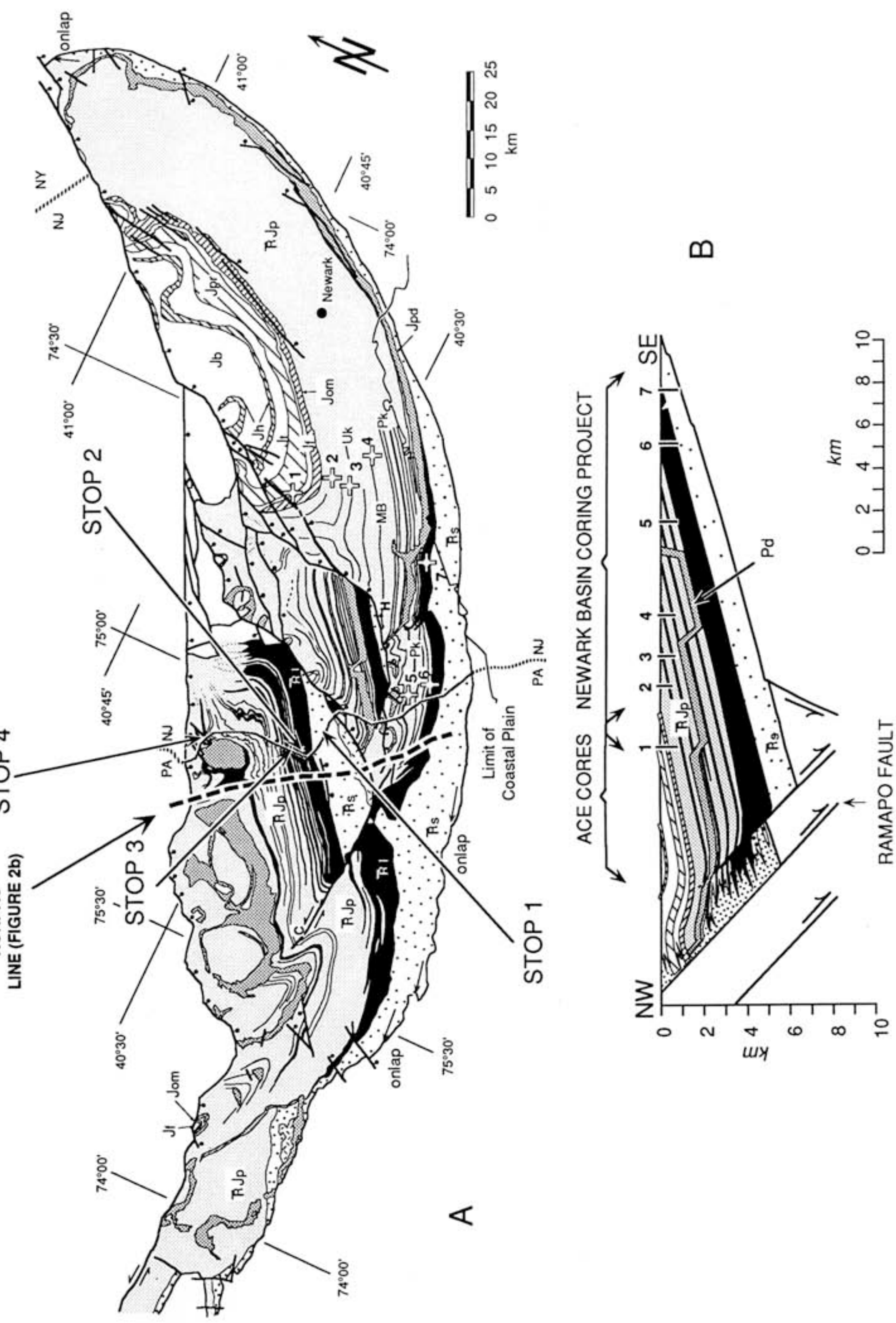
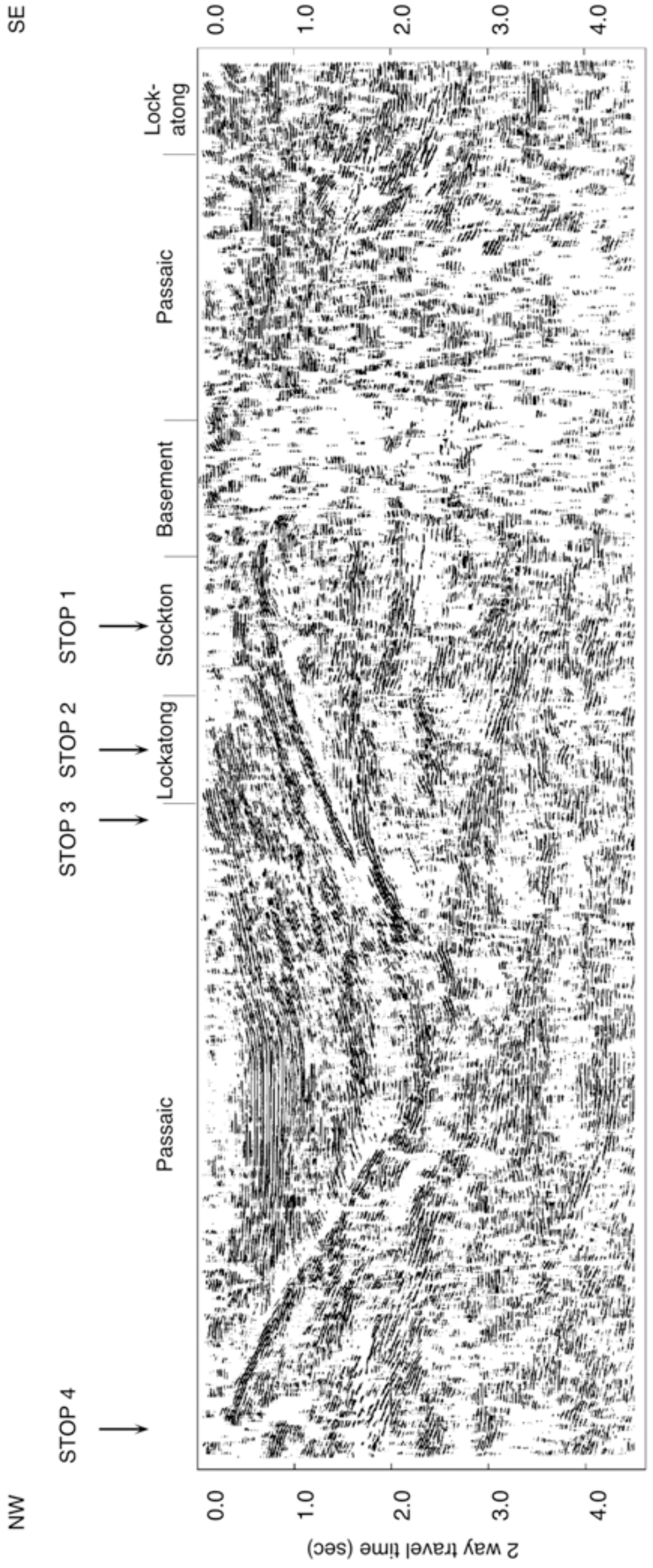

NORPAC LINE (FIGURE 2b)
STOP 1
STOP 2
STOP 3
STOP 4
A
B
NY
NJ
PA
Newark
Limit of Coastal Plain
onlap
0 5 10 15 20 25 km
74°00'
74°30'
75°00'
75°30'
40°30'
40°45'
41°00'
T̶RJp
T̶Rs
T̶Rl
Jb
Jh
Jom
Jpr
Jpd
Jf
Pk
Uk
MB
H
1 2 3 4 5 6 7
ACE CORES
NEWARK BASIN CORING PROJECT
NW
SE
RAMAPO FAULT
Pd
km
0 2 4 6 8 10

Figure 2a.



NORPAC LINE NB-1 AUTOMATED LINE DRAWING MODIFIED FROM COSTAIN AND ÇORUH, 1990
see Figure 2a for position in basin

Figure 2b.

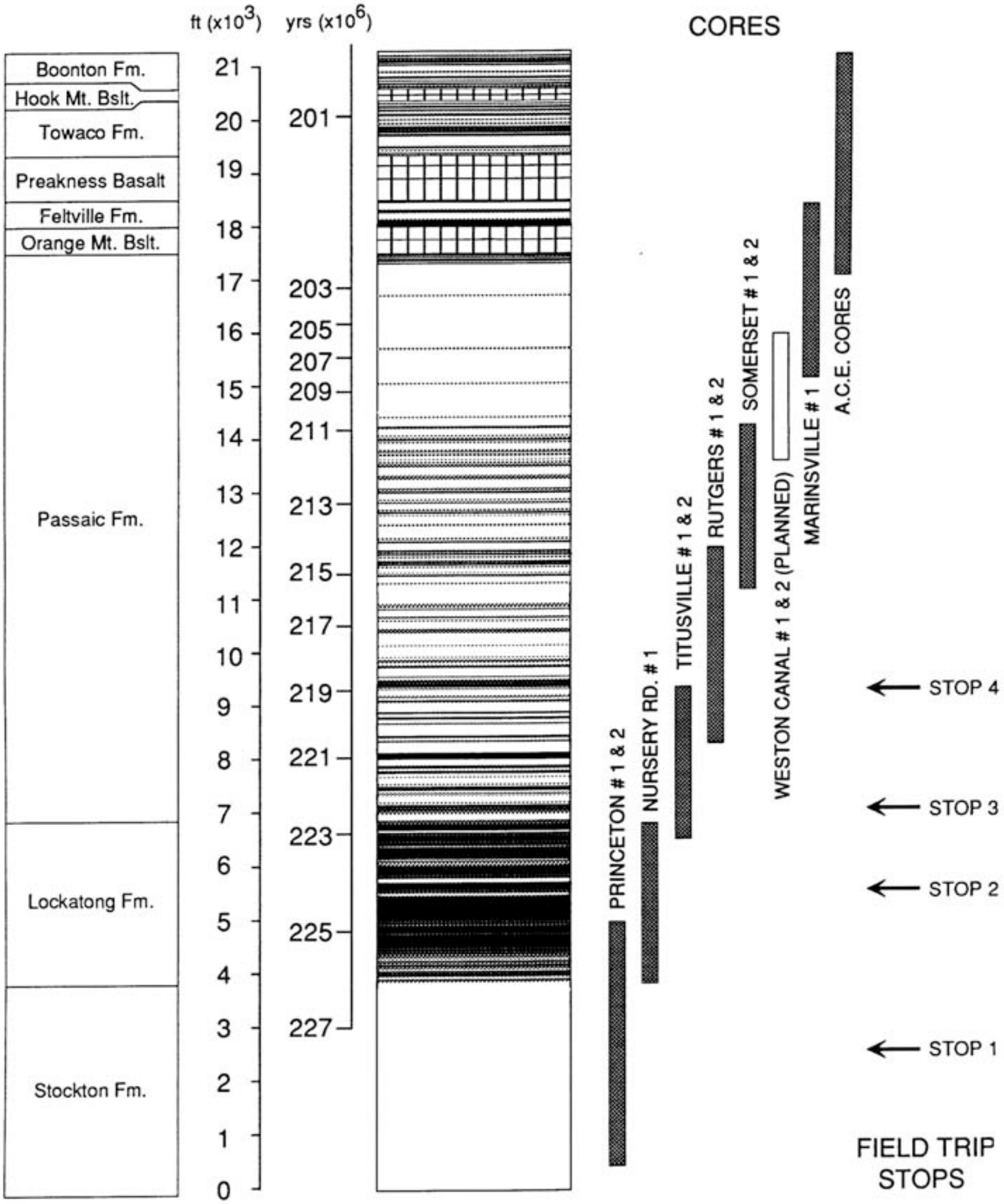

ft (x10^3)
yrs (x10^6)
CORES
Boonton Fm.
Hook Mt. Bslt.
Towaco Fm.
Preakness Basalt
Feltville Fm.
Orange Mt. Bslt.
Passaic Fm.
Lockatong Fm.
Stockton Fm.
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
201
203
205
207
209
211
213
215
217
219
221
223
225
227
PRINCETON # 1 & 2
NURSERY RD. # 1
TITUSVILLE # 1 & 2
RUTGERS # 1 & 2
SOMERSET # 1 & 2
WESTON CANAL # 1 & 2 (PLANNED)
MARINSVILLE # 1
A.C.E. CORES
STOP 4
STOP 3
STOP 2
STOP 1
FIELD TRIP STOPS

Figure 3

STOP 1
FLUVIAL SEQUENCES IN PRALLSVILLE MEMBER OF STOCKTON FORMATION, PRALLSVILLE, PA.

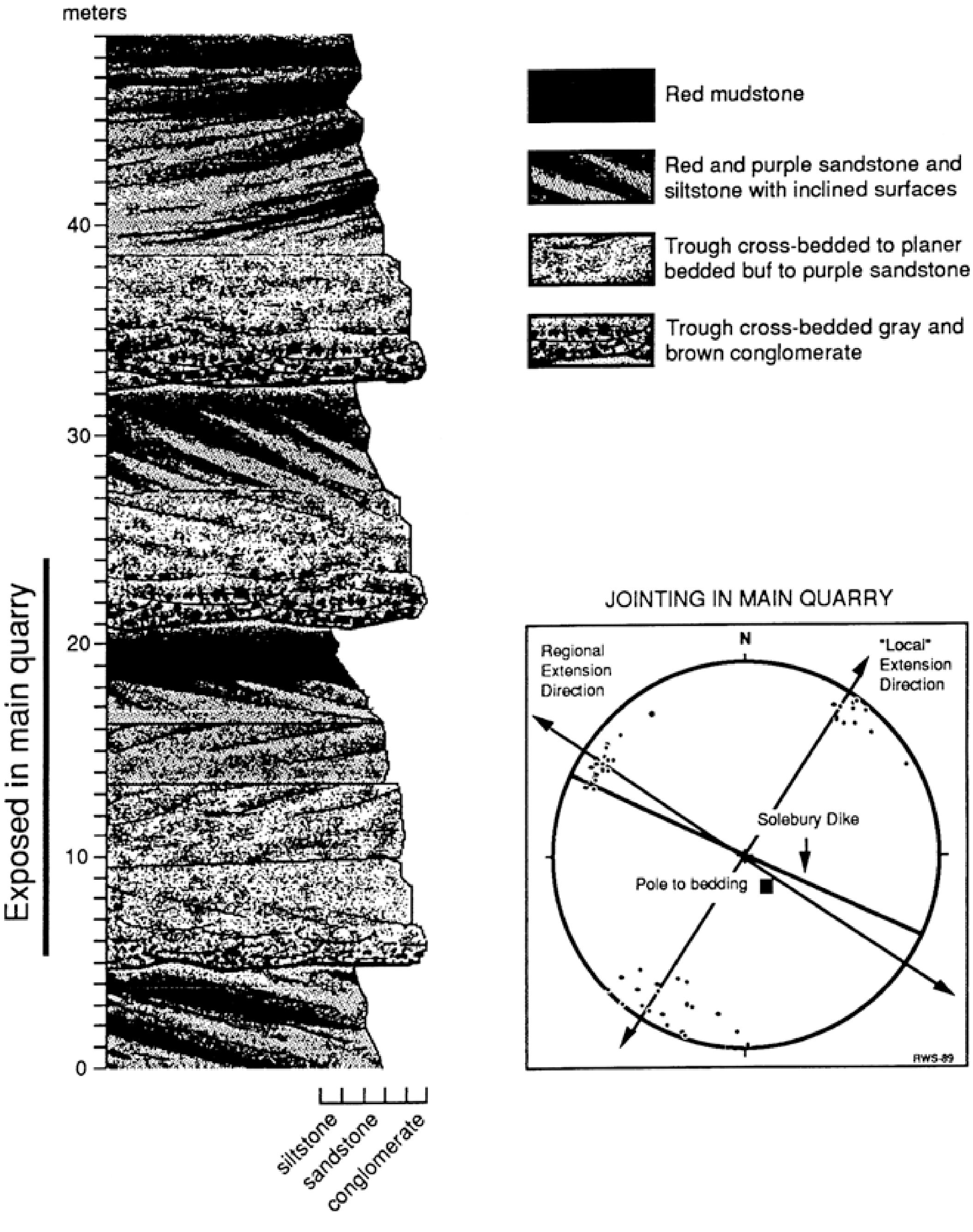


Figure 4.

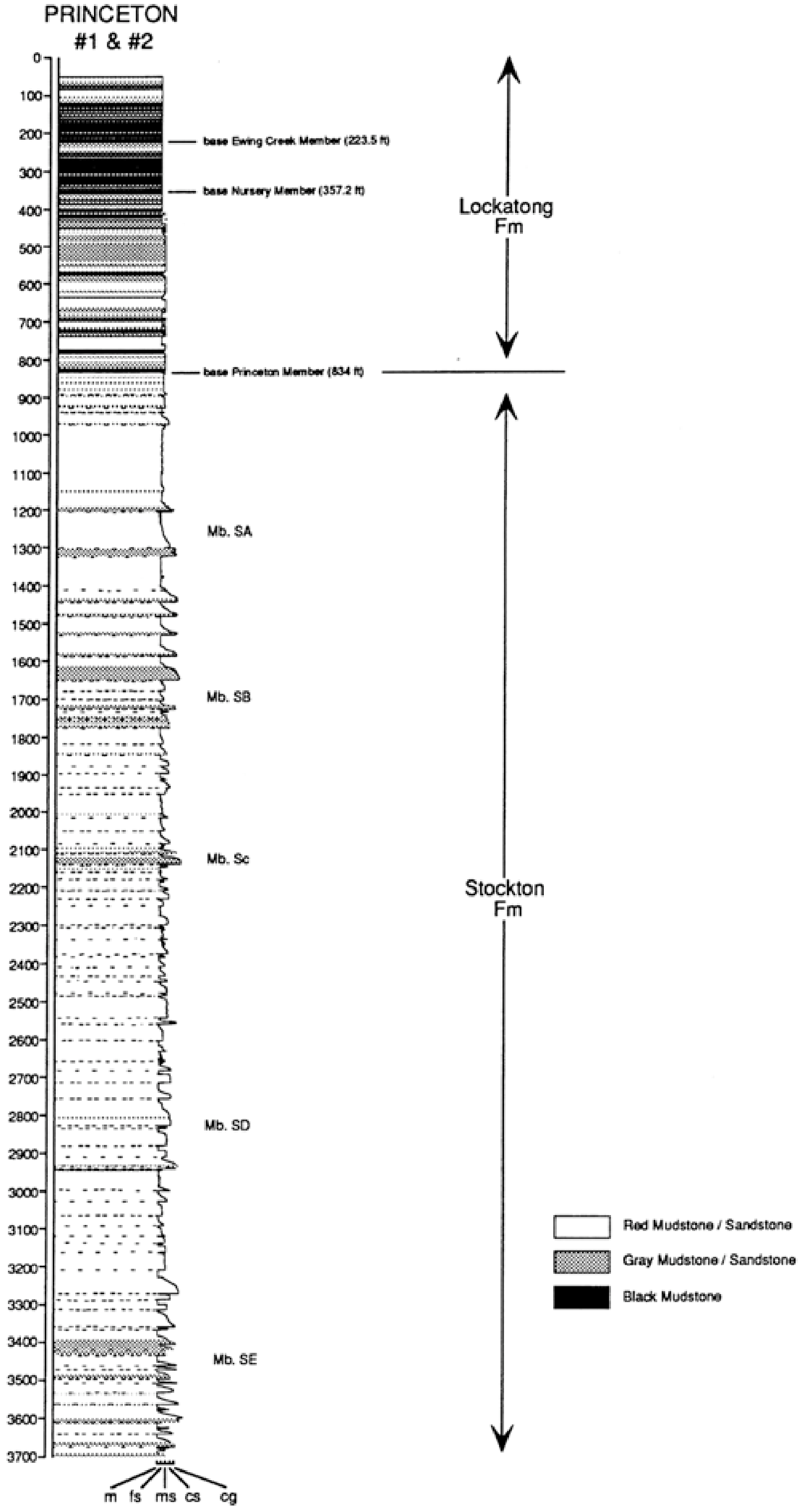

PRINCETON
#1 & #2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400
3500
3600
3700
base Ewing Creek Member (223.5 ft)
base Nursery Member (357.2 ft)
base Princeton Member (834 ft)
Lockatong Fm
Mb. SA
Mb. SB
Mb. Sc
Mb. SD
Mb. SE
Stockton Fm
Red Mudstone / Sandstone
Gray Mudstone / Sandstone
Black Mudstone
m
fs
ms
cs
cg

Figure 5.

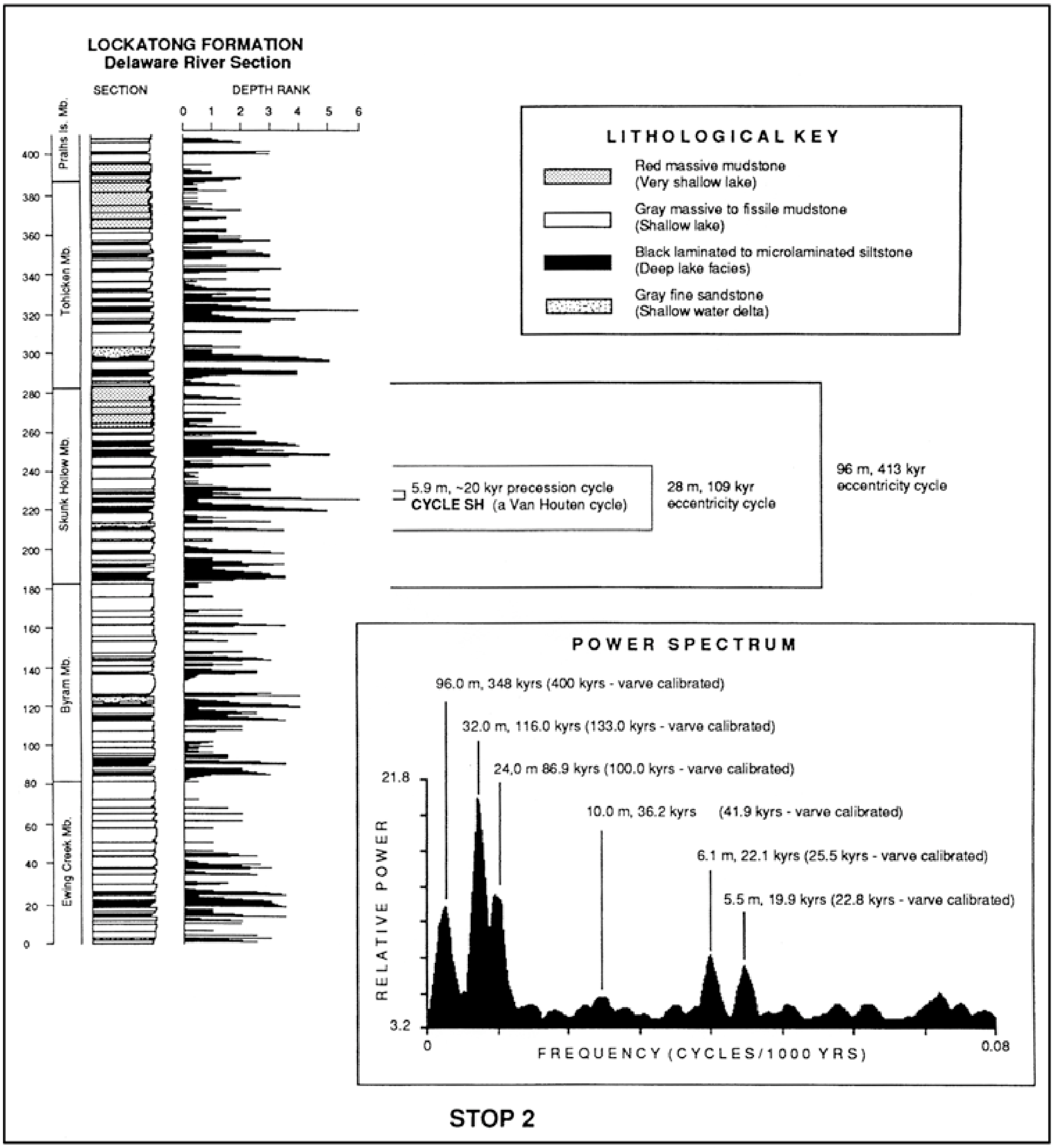


Figure 6: Measured section of Lockatong Formation at Byram along the Delaware River with depth ranks and power spectrum derived from them. Power spectrum yields periods in thickness that are converted to time by assigning the two high-frequency peaks to an average period of 20,000 years. Periods in parentheses are based on varve-calibration with an accumulation rate of 0.24 mm/yr. Adapted from Olsen (1986).

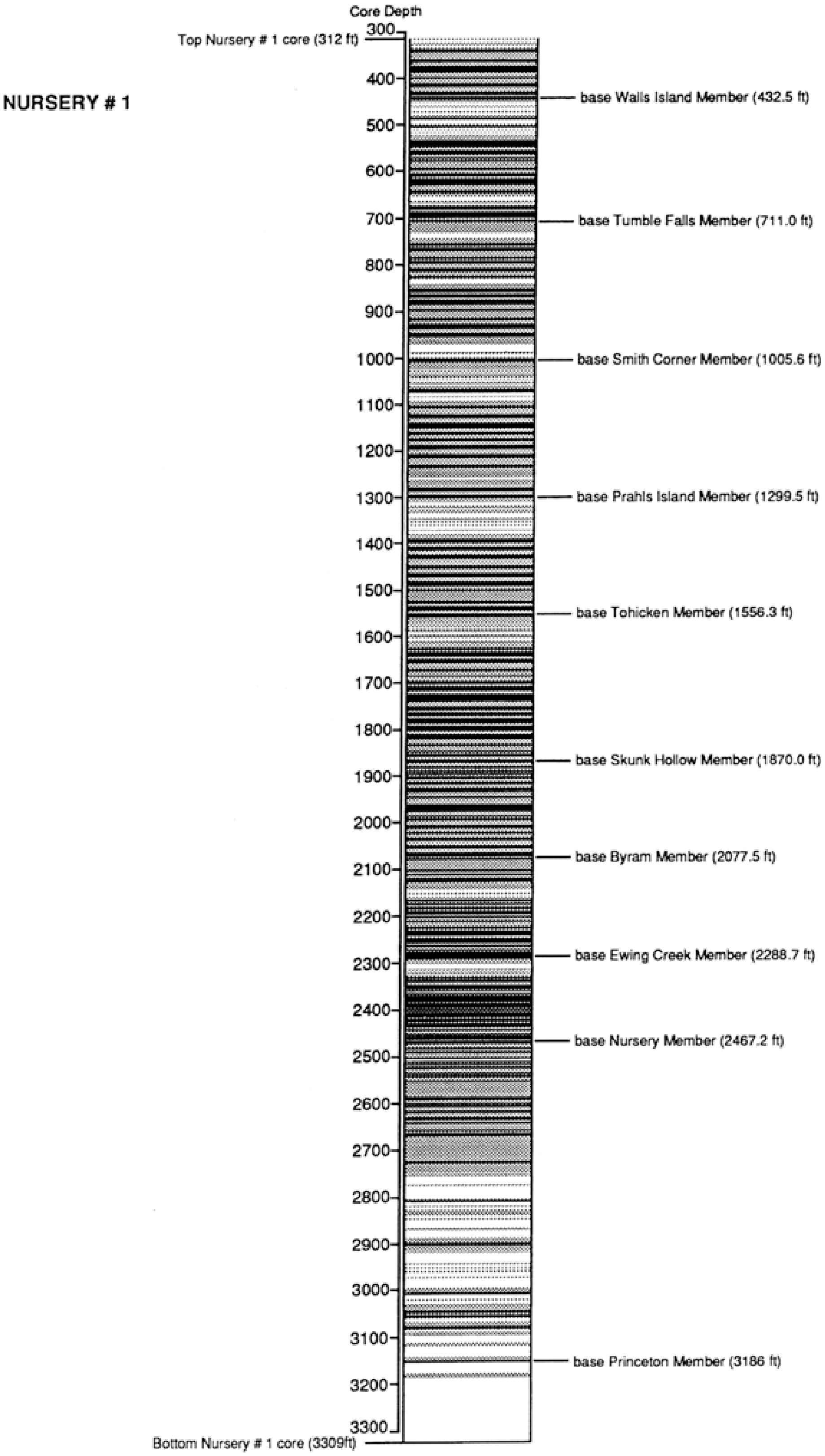

NURSERY # 1
Core Depth
Top Nursery # 1 core (312 ft)
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
3100
3200
3300
Bottom Nursery # 1 core (3309ft)
base Walls Island Member (432.5 ft)
base Tumble Falls Member (711.0 ft)
base Smith Corner Member (1005.6 ft)
base Prahls Island Member (1299.5 ft)
base Tohicken Member (1556.3 ft)
base Skunk Hollow Member (1870.0 ft)
base Byram Member (2077.5 ft)
base Ewing Creek Member (2288.7 ft)
base Nursery Member (2467.2 ft)
base Princeton Member (3186 ft)

Figure 7.

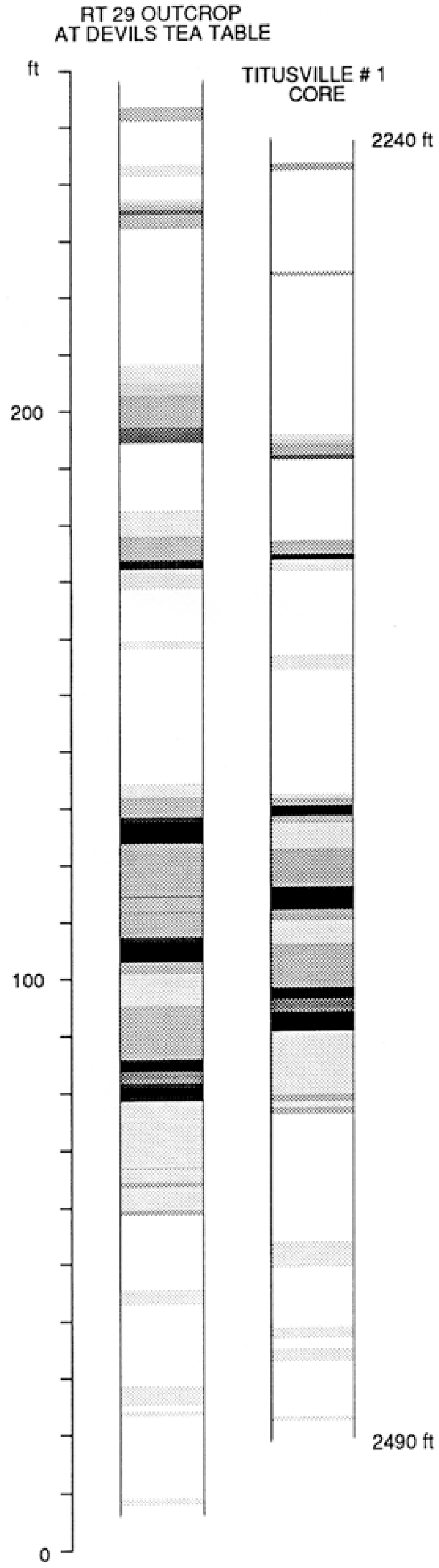

RT 29 OUTCROP
AT DEVILS TEA TABLE
ft
200
100
0
TITUSVILLE # 1
CORE
2240 ft
2490 ft

Figure 8.

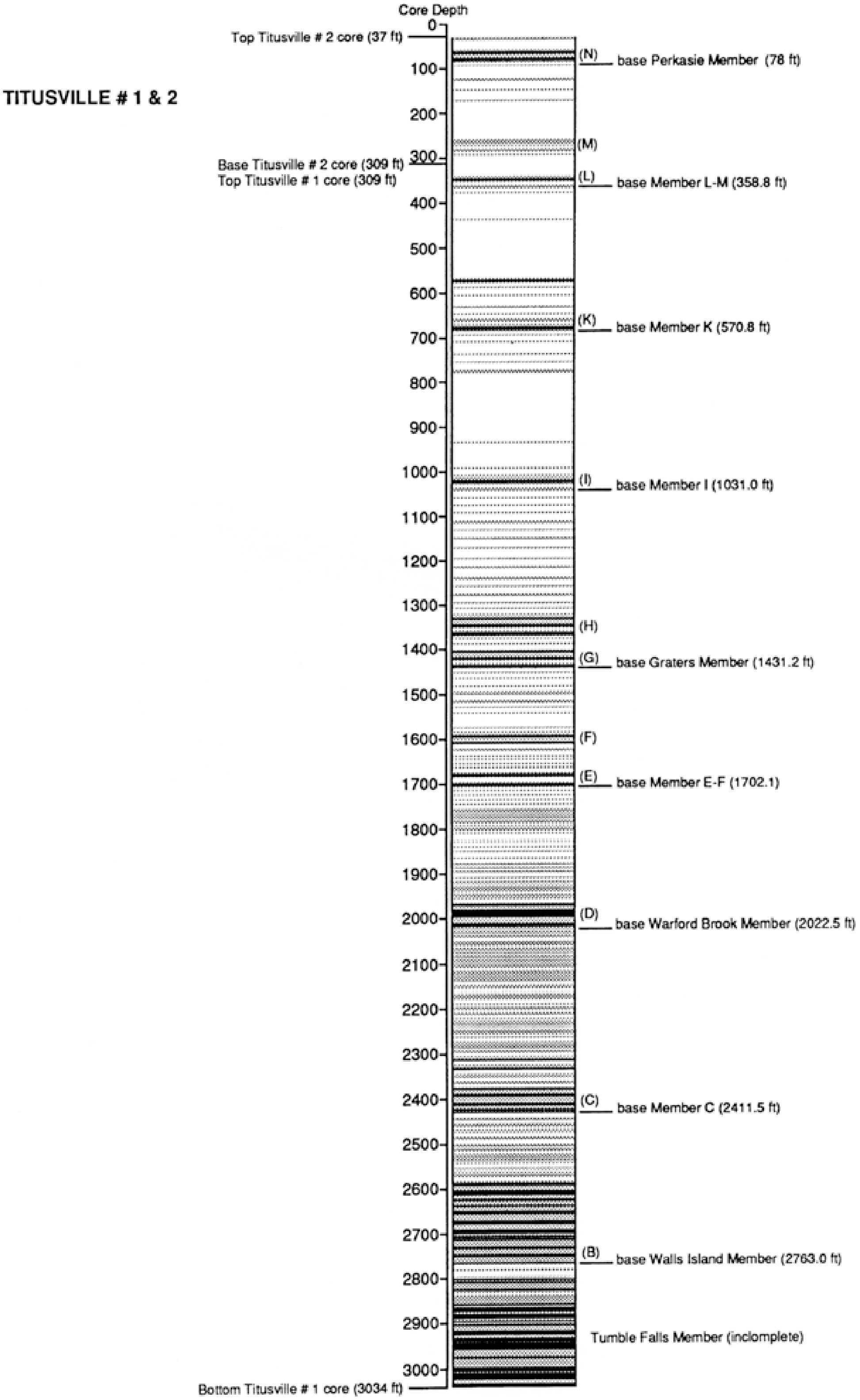

TITUSVILLE # 1 & 2
Core Depth
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
Top Titusville # 2 core (37 ft)
Base Titusville # 2 core (309 ft)
Top Titusville # 1 core (309 ft)
Bottom Titusville # 1 core (3034 ft)
(N) base Perkasie Member (78 ft)
(M)
(L) base Member L-M (358.8 ft)
(K) base Member K (570.8 ft)
(I) base Member I (1031.0 ft)
(H)
(G) base Graters Member (1431.2 ft)
(F)
(E) base Member E-F (1702.1)
(D) base Warford Brook Member (2022.5 ft)
(C) base Member C (2411.5 ft)
(B) base Walls Island Member (2763.0 ft)
Tumble Falls Member (inclomplete)

Figure 9.

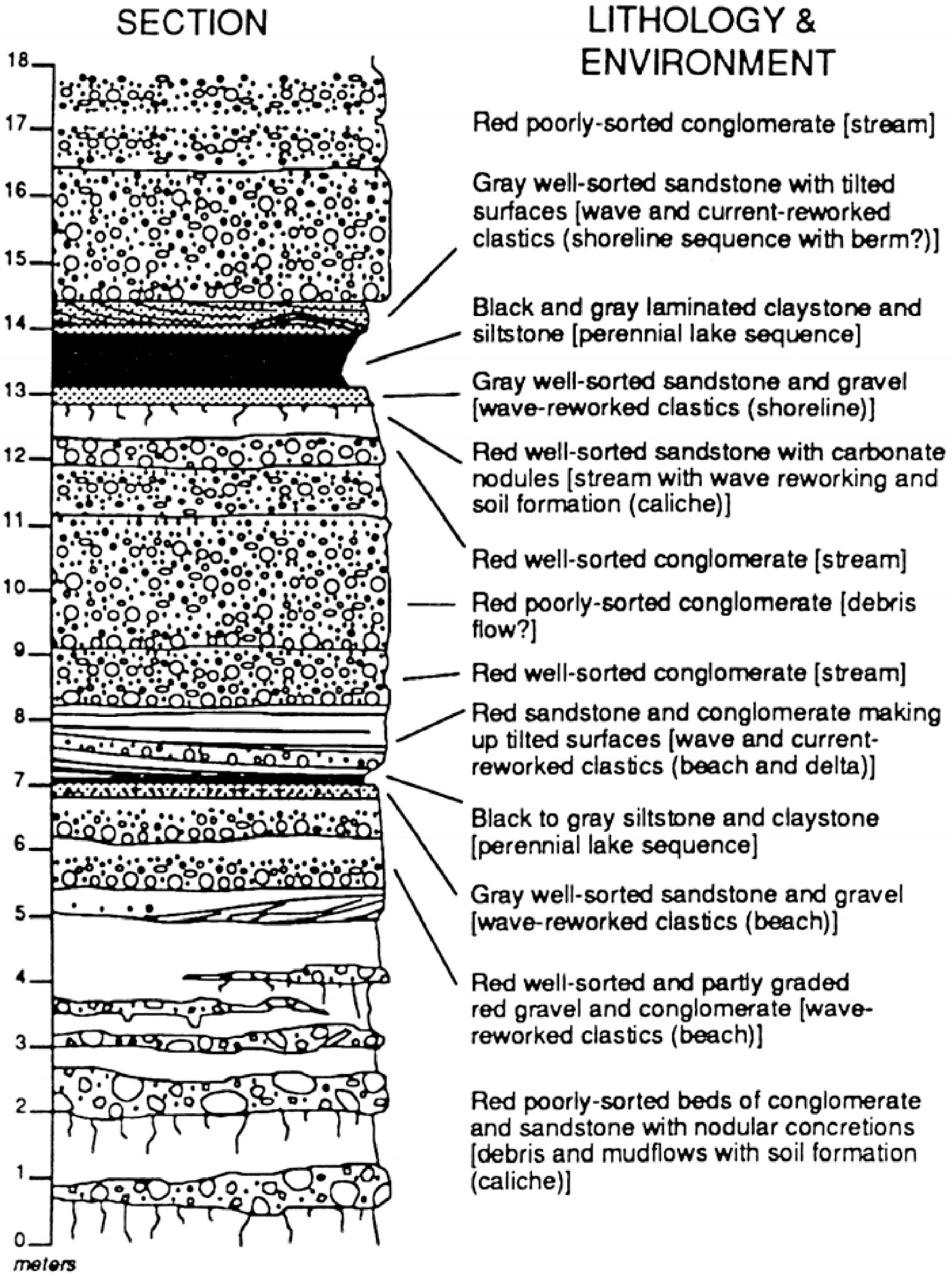


Figure 10: Measured section of the Passaic Formation (lower part of the Perkasie Member) at Stop 4 showing the alternation of alluvia and lacustrine deposits (after Olsen et al., 1986).

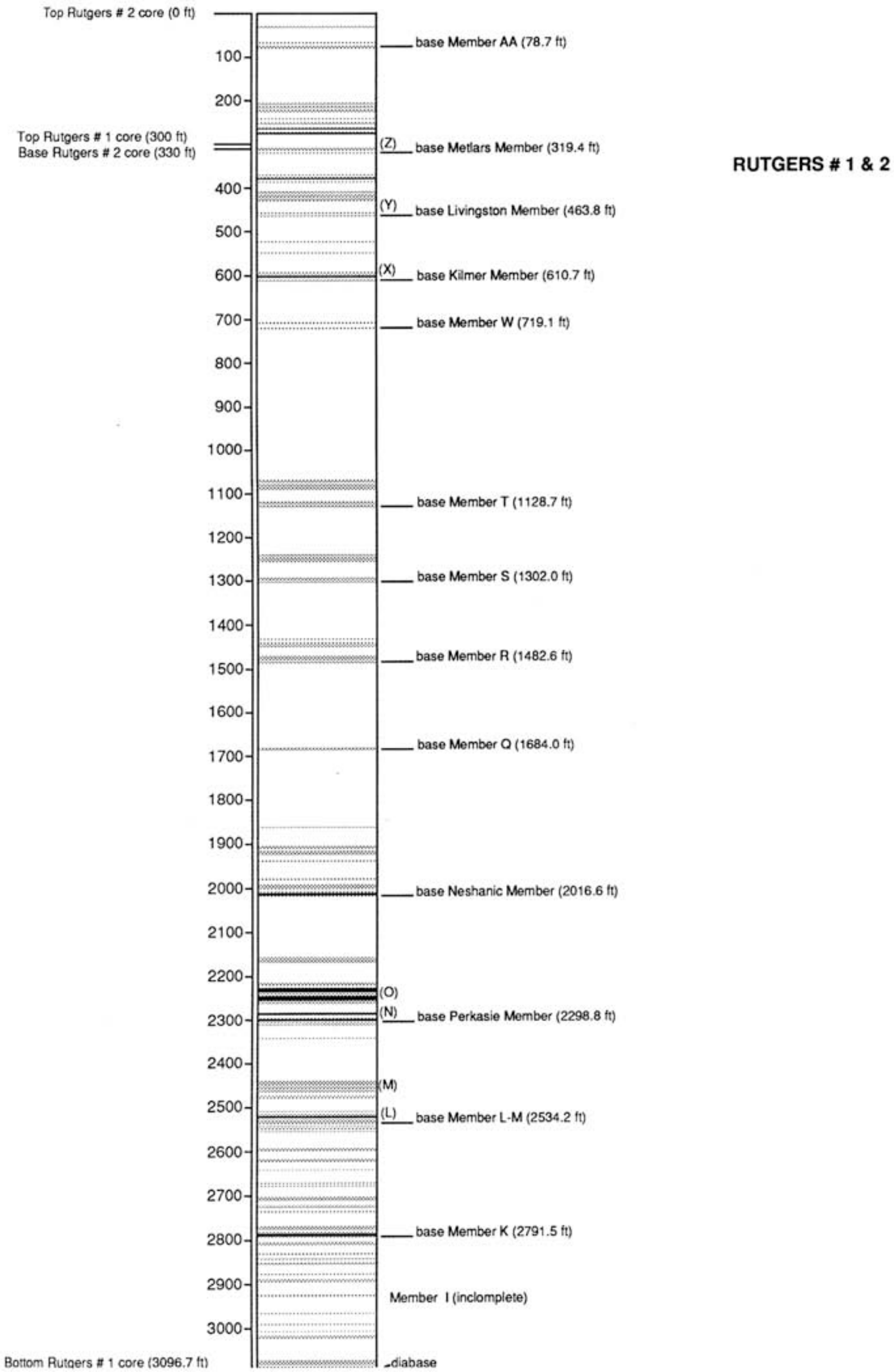

RUTGERS # 1 & 2
Top Rutgers # 2 core (0 ft)
Top Rutgers # 1 core (300 ft)
Base Rutgers # 2 core (330 ft)
Bottom Rutgers # 1 core (3096.7 ft)
100
200
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
base Member AA (78.7 ft)
(Z) base Metlars Member (319.4 ft)
(Y) base Livingston Member (463.8 ft)
(X) base Kilmer Member (610.7 ft)
base Member W (719.1 ft)
base Member T (1128.7 ft)
base Member S (1302.0 ft)
base Member R (1482.6 ft)
base Member Q (1684.0 ft)
base Neshanic Member (2016.6 ft)
(O)
(N) base Perkasie Member (2298.8 ft)
(M)
(L) base Member L-M (2534.2 ft)
base Member K (2791.5 ft)
Member I (inclomplete)
diabase

Figure 11.