PAC STRATIGRAPHY OF THE HELDERBERG GROUP: CYCLE DEFINITION, ALLOGENIC SURFACES, HIERARCHY, CORRELATION AND RELATIONSHIP TO "VAIL" SEQUENCES

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ABSTRACT

Sections at Thacher Park and Schoharie demonstrate our method of defining 6th order rock cycles (PACs) on the basis of facies patterns (as opposed to key lithologies). Cycle boundaries are placed at surfaces where deeper facies abruptly overlie shallower facies in a disjunct relationship. Several genetically distinct kinds of stratigraphic surfaces are well illustrated in these sections, including PAC boundaries, intracycle surfaces (sea-level fall surfaces) and cryptic unconformities. Criteria for correlation of cycles (PACs) in the Manlius Formation between the two localities include: degree of facies change at PAC boundaries, tracing distinctive litho and bio facies, matching patterns of facies change through several cycles and matching the hierarchic pattern of cycles. In the Manlius Formation alone 14 or more 6th order cycles, as many as six 5th order cycles, parts of two 4th order cycles and an incomplete 3rd order B cycle are represented. The Manlius-Coeymans formational boundary is a cryptic unconformity that represents a 3rd order B "Vail" sequence boundary. The stratigraphic section at Schoharie from this unconformity to the Oriskany unconformity represents a nearly complete 3rd order B sequence and is tentatively divisible into a hierarchy of three 4th order and numerous 5th and 6th order sequences (rock cycles). In terms of systems tract analysis the section equivalent to the Coeymans and Kalkberg Formations is identified as shelf margin wedge, the lowermost New Scotland (equivalent) rocks are the transgressive systems tract and the remaining New Scotland and Becraft Formations are the highstand systems tract.

INTRODUCTION

Our purpose on this trip is to introduce participants to field application of allogenic, hierarchic cyclic stratigraphy. Participants are asked to begin with the assumption that the internal structure of the stratigraphic record is a product of a hierarchic set of cyclic processes that caused sea-level fluctuations. If this assumption is correct then the significant components of the stratigraphic record may include rock cycles arranged in a hierarchy, a variety of allogenic surfaces both within cycles and at their boundaries and a systematically arranged set of unconformities. We will attempt to provide a basis for discriminating the various types of cycles and surfaces and in doing so make the case that field analysis is dictated by assumed models. We would like to emphasize that our focus on these stratigraphic components of the rock record is different from the traditional focus on grains, laminations, beds and formations. New stratigraphic models therefore require new field methods and a different approach to recording data (see Anderson and Goodwin, 1990; Goodwin and Anderson, 1988 and Goodwin et al., 1986).

In this field exercise we will be applying a hierarchic stratigraphic model consisting of 5 orders of allogenic cycles:

3RD ORDER A (Supersequence)	8-10 million years
3RD ORDER B (Sequence)	1-2 million years
4TH ORDER (eccentricity)	400 thousand years
5TH ORDER (eccentricity)	100 thousand years
6TH ORDER (precession)	20 thousand years

Choice of this particular hierarchy is justified by the large number of sequence stratigraphic studies documenting the existence of the two "third order" natural groupings and by the growing number of studies confirming the presence of Milankovitch cyclicity throughout the stratigraphic record.

STOP 1, THACHER PARK

This locality has been selected to illustrate the fundamental, 6th order, meter-scale, allogenic cycle (fig. 1). This cycle is thought to be produced by the 20ky, precessional Milankovitch signal. At this locality these rock cycles range from less than one meter to almost three meters in thickness. Some of them are totally subtidal and others (e.g. PACs 9 and 12) have tidal flat facies at their tops. Cycle boundaries are placed at surfaces where deeper water facies abruptly overlie shallower water facies independent of the occurrence of specific facies. **Cycles are pattern-defined and do not require the presence of tidal flat facies or any other recurrent lithology.**

Five partially complete fifth order cycles are recognized at Thacher Park in the interval represented by the Rondout and Manlius Formations (PAC 3 by itself; PACs 5-6; PACs 7-9; PACs 10-12; PACs 13-14). In that fifth order cycles are thought to be the product of the 100ky eccentricity cycle this section at Thacher Park is incomplete in terms of the number of 6th order cycles within each 5th order cycle. Reasons that could explain this incompleteness include hiatus, vacuity, failure to recognize 6th order cycles and incorrectly designated 5th order boundaries. PACs 5-14 are potentially the record of a 4th order cycle, the product of the 400ky eccentricity cycle.

The final purpose of using this section is to illustrate our approach to correlation at the level of 6th order cycles. For example, distinctive widespread lithologies are introduced at the bases of two PACs in the sequence of PACs at Thacher Park. A subtidal well-sorted calcarenite appears in PAC 7 at all localities (fig. 1) and at all localities PAC 11 is thick bedded and contains well developed stromatoporoids. These two PACs in which relatively large facies changes occur represent the response to larger deepening events in the basin. PAC 7 is the first 6th order cycle in a 5th order sequence of cycles and PAC 11 contains the deepest facies in its 5th order sequence. In summary distinctive lithologies in certain cycles, the magnitude of facies change at cycle boundaries and the sequential pattern of cycles are all keys to correlation.

STOP 2, SCHOHARIE A, I-88

This locality illustrates a record of 6th order cycles in a different, slightly more offshore set of Manlius facies than those seen at Thacher Park. For example, PACs 9 and 12, in which high tidal-flat facies were developed at Thacher Park, are here represented by nearly all subtidal facies. Second the record of 6th order cycles associated with unconformities is more complete. PAC 2 (actually a 5th order sequence), PAC 6b and PAC 15, recognized here at Schoharie, are missing in the more onshore Thacher area. PAC 2 and 6b are missing owing to hiatus (non-deposition) at Thacher; PAC 15 is missing due to erosion (i.e. vacuity).

In addition to PAC boundaries and unconformable surfaces, the section at Schoharie contains good examples of intracycle allogenic surfaces. Whereas PAC boundary surfaces are thought to be produced by the eustatic sea-level rise forced by the precessional (20ky) cycle, intracycle allogenic surfaces are produced by the complementary sea-level fall on the precessional eustasy curve. Thus each 6th order cycle potentially may be composed of a set of sea-level highstand facies overlain abruptly by a set of lowstand facies. **The surface between the two facies sets is thus an intracycle allogenic stratigraphic surface.** Such surfaces are well illustrated in PACs 9, 11 and 12, in which massive ostracod bearing calcarenites sharply overlie thin bedded ribbon calcarenites.

Finally the Manlius-Coeymans boundary is an erosional unconformity. At Syracuse, 100km to the west, an additional two 6th order cycles are preserved below this erosion surface (PACs 16 and 17) while at Kingston, 100km to the southeast, PACs 14 and 15, present at Schoharie, have been removed by erosion (fig. 1). This major erosion surface is the basis for defining this surface as a third order "Vail" sequence boundary. The section from the Brayman-Cobleskill unconformity to this unconformity represents the second 3rd order B sequence in the Helderberg

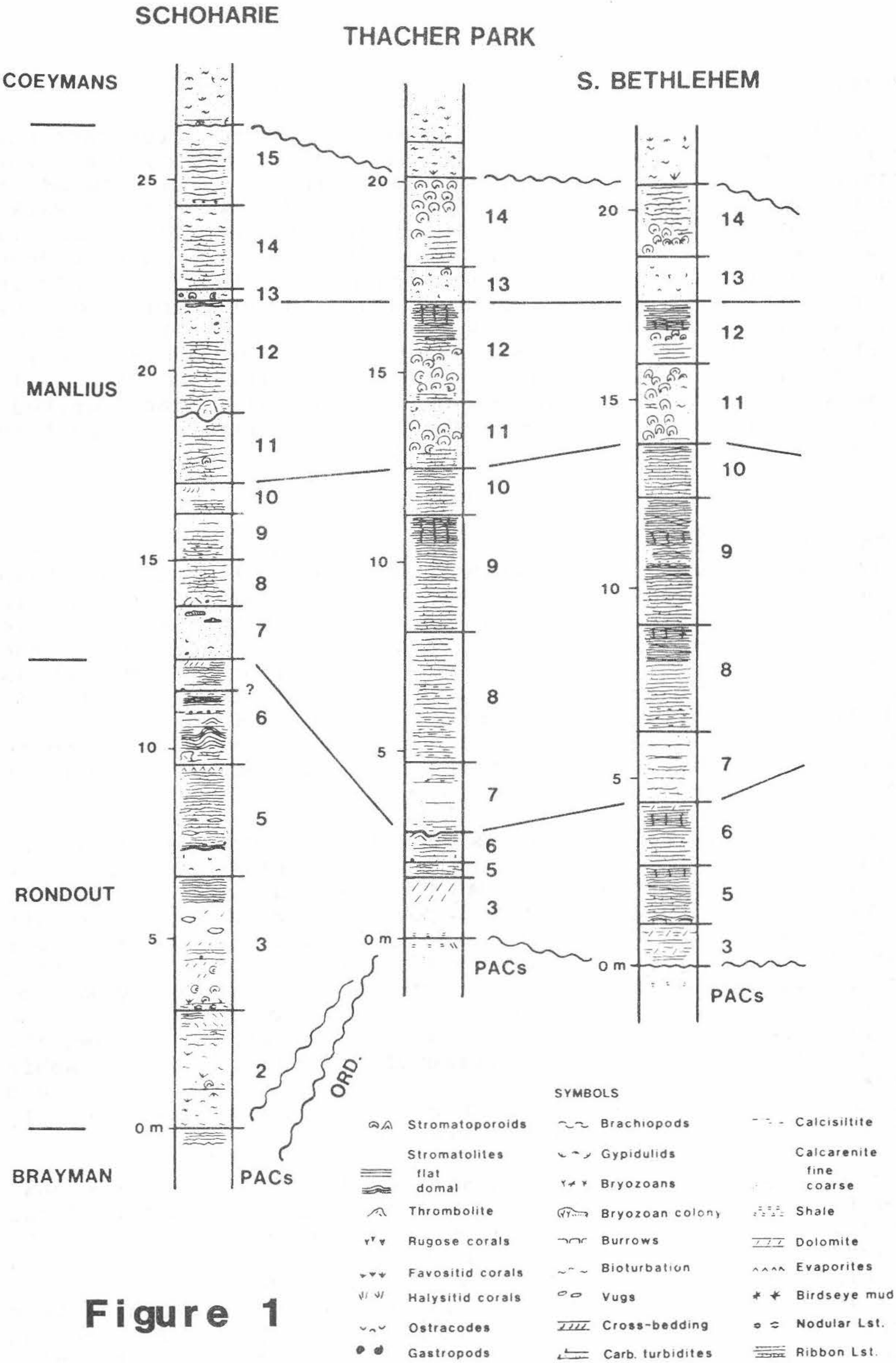
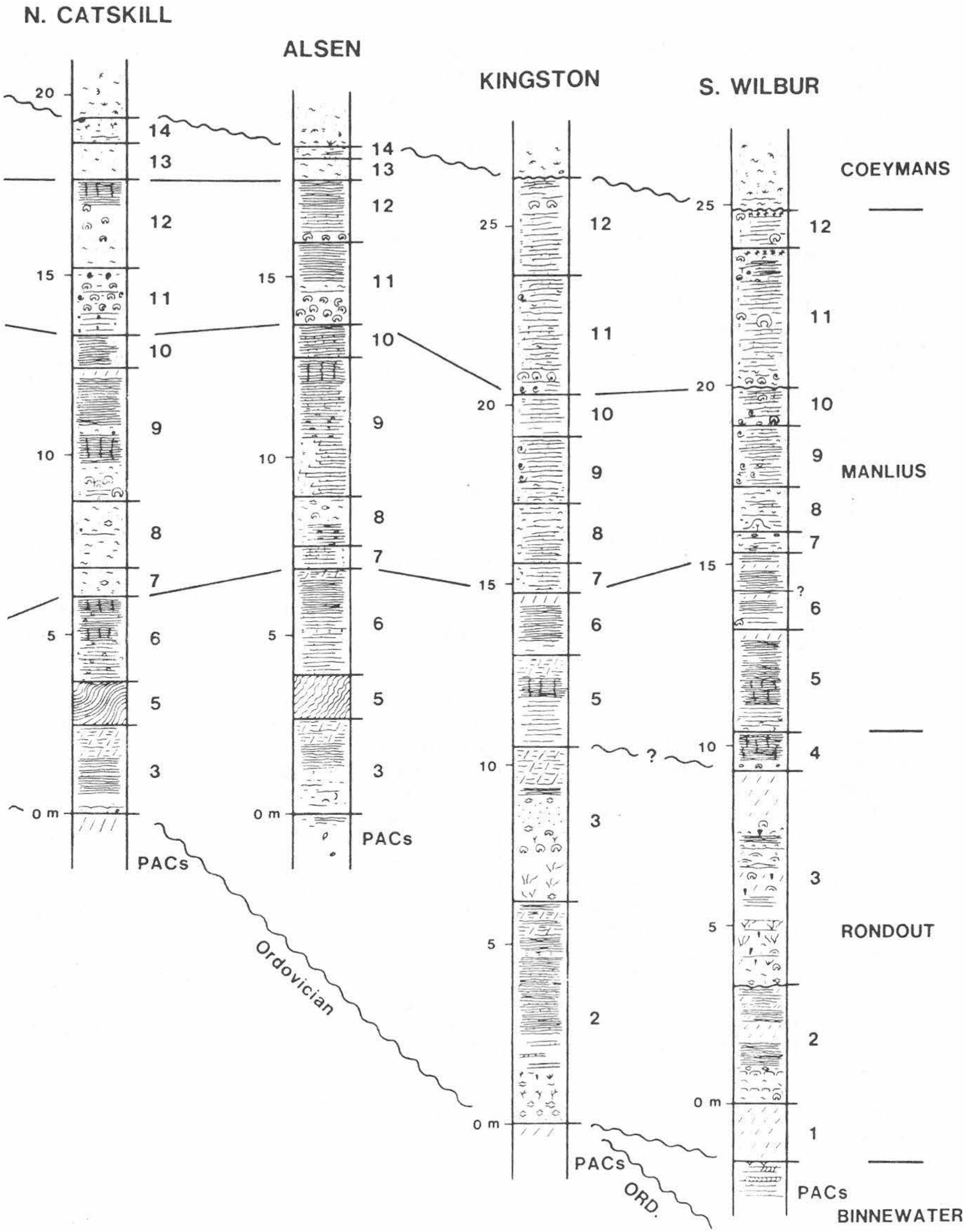

SCHOHARIE
THACHER PARK
S. BETHLEHEM
COEYMANS
MANLIUS
RONDOUT
BRAYMAN
PACs
ORD.
SYMBOLS
Stromatoporoids
Stromatolites
flat
domal
Thrombolite
Rugose corals
Favositid corals
Halysitid corals
Ostracodes
Gastropods
Brachiopods
Gypidulids
Bryozoans
Bryozoan colony
Burrows
Bioturbation
Vugs
Cross-bedding
Carb. turbidites
Calcisiltite
Calcarenite
fine
coarse
Shale
Dolomite
Evaporites
Birdseye mud
Nodular Lst.
Ribbon Lst.

Figure 1


N. CATSKILL
ALSEN
KINGSTON
S. WILBUR
COEYMANS
MANLIUS
RONDOUT
BINNEWATER
PACs
Ordovician
ORD.
0 m
5
10
15
20
25
1
2
3
4
5
6
7
8
9
10
11
12
13
14

supersequence. The section from this surface up to the top of the Becraft Formation (seen in the next two stops) is the third 3rd order B sequence. Erosion associated with the Oriskany unconformity (last stop) removes most of a fourth 3rd order B sequence in the Schoharie area.

STOP 3, SCHOHARIE B, I-88

This final stop is in three parts. The first and stratigraphically lowest part is on the north side of I-88 two miles west of STOP 2. The lower 25 feet of this exposure are equivalent to the upper half of the Hannacroix Member of the Kalkberg Formation in the Kingston-Catskill area and the upper five feet are equivalent to the lower part of the Broncks Lake Member (fig. 2). The base of this section is 2-3 feet stratigraphically above the top of rocks exposed in the section seen at STOP 2. The section continues in the large road cut on the south side of I-88. There is a seven foot covered interval between the two exposures. The thickness of these two covered intervals can be exactly determined because the entire stratigraphic interval is continuously exposed three miles to the east in the Schoharie Quarry and all exposed cycles and bounding surfaces can be correlated between the two localities. The Becraft and Oriskany Formations are exposed at the top of the large roadcut; however a more accessible exposure of the upper Becraft and Oriskany rocks occurs in I-88 roadcuts one mile farther west.

Our purpose in looking at the stratigraphic interval between the Manlius-Coeymans unconformity and the top of the Becraft is to lay out a tentative interpretation of the hierarchic cyclic structure of a fairly complete 3rd order B sequence representing 1-2 million years of accumulation. The entire section is in subtidal shallow to deep ramp facies. It is divisible into three 4th order sequences associated with the 400ky eccentricity cycle. These sequences in turn are each divided into four 5th order cycles related to 100ky eccentricity. Examples of 6th order cycles (PACs) in these facies will be pointed out, but analysis at this level is incomplete. Analysis of 4th and 5th order cycles is based on pattern and magnitude of facies changes and depends on correlation of those patterns to other localities. In this case larger scale cycle boundaries have been correlated to the Cherry Valley area to the west and to localities at Broncks Lake, Catskill and Kingston in the Hudson Valley. In short 3rd, 4th and 5th order cycle boundaries in the Schoharie sections have been correlated with prominent surfaces in sections over 100km away.

<u>4th Order Cycle I</u>

This cycle begins at the Manlius-Coeymans unconformity, also a 3rd order B boundary, and ends at the 161 foot mark on the log (fig. 2). The upper boundary is a surface between massive calcarenite and chert bearing calcisiltite (near the base of the large cut on the south side of I-88. A prominent shale occurs on the surface. The same surface is found on top of the shallowest facies in the Broncks Lake Member in the Hudson Valley (e.g. 16 feet below the New Scotland at Kingston). In systems tract analysis this 4th order cycle represents the shelf margin wedge of the third order B sequence. Fourth order cycle I can be divided into four 5th order cycles:

5th Order Cycle 1 ends at 108.5 feet on the log at the shallowest point in Coeymans facies. This surface is the Coeymans-Kalkberg Boundary at Kingston and Catskill.

5th Order Cycle 2 ends at 135 feet on the log at a surface separating coarser favositid rich calcarenites from gypidulid bearing, more argillaceous calcarenites.

5th Order Cycle 3 ends at 140 feet on the log at a surface just below a one foot thick shale interval with lime turbidite beds. This surface is the base of the Broncks Lake Member in the Hudson Valley.

5th Order Cycle 4 ends at the 4th order boundary.

4th Order Cycle II

This cycle contains the deepest facies in the third order sequence and at Schoharie its thickness is highly condensed (32 feet versus 66 feet at Kingston). The lower boundary (described above) is at 161 feet; the upper boundary, at 193 feet on the log, is the surface at the top of a six-foot-thick massive calcisiltite unit. In systems tract analysis of the third order B sequence the lower two 5th order cycles in this 4th order cycle represent the transgressive systems tract and the 5th order boundary at 181 feet would be the maximum flooding surface. Fourth order cycle II is divisible into four 5th order cycles:

5th Order Cycle 1 is 10.5 feet thick and in the lower part is charcterized by several amalgamated lime turbidites with cherts. These amalgamated units are thought to represent 6th order cycles. The upper 6th order unit is represented by 2.5 feet of calcisiltites in dicontinuous lenses. The top surface of this first 5th order cycle is correlated to the Kalkberg-New Scotland formational boundary in the Hudson Valley.

5th Order Cycle 2 ends at 181 feet on the log; a concentration of chert and a thick shale occur at this boundary.

5th Order Cycle 3 ends at 187 feet on the log; beds representing condensed 6th order cycles thicken up through this 5th order cycle.

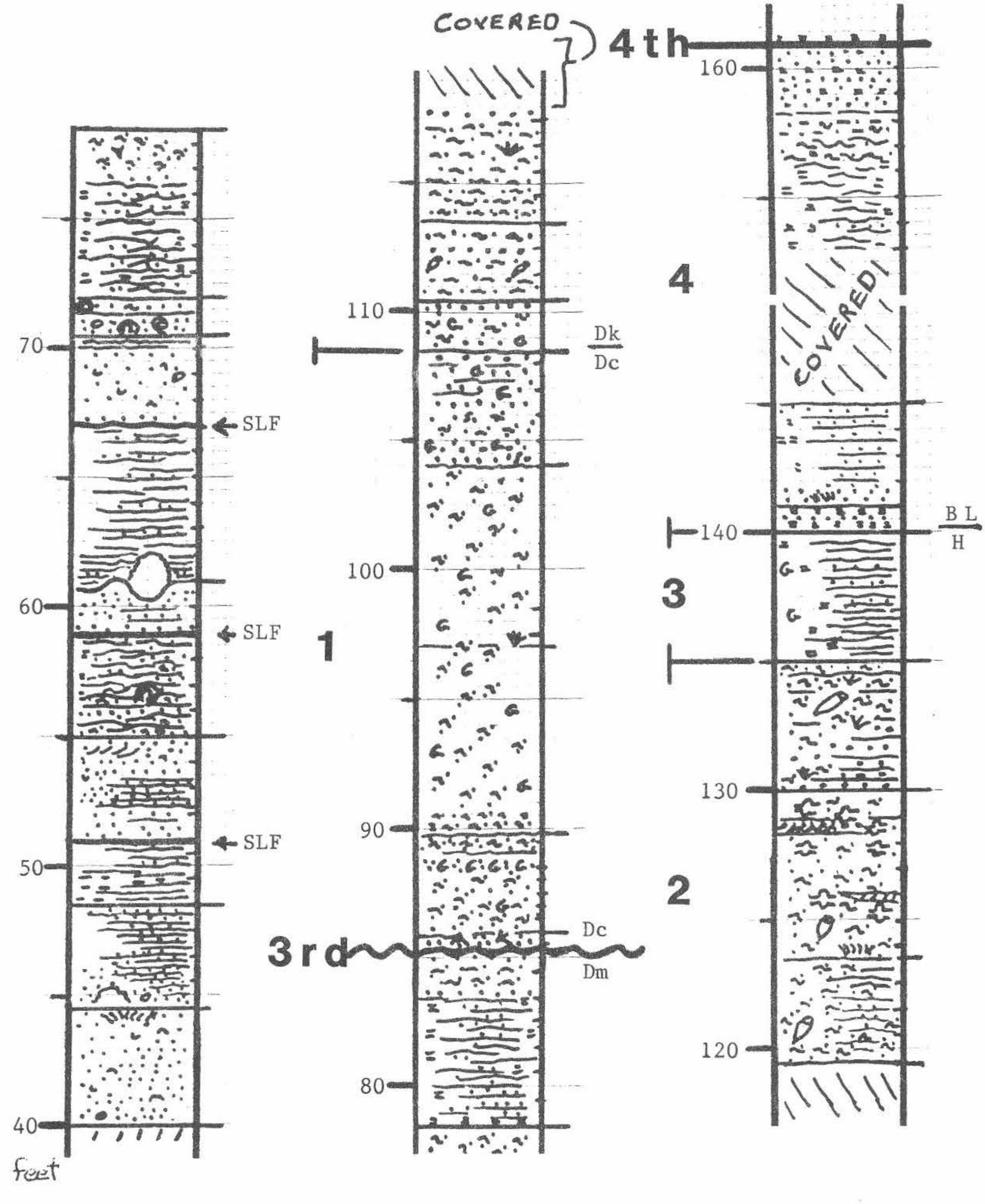
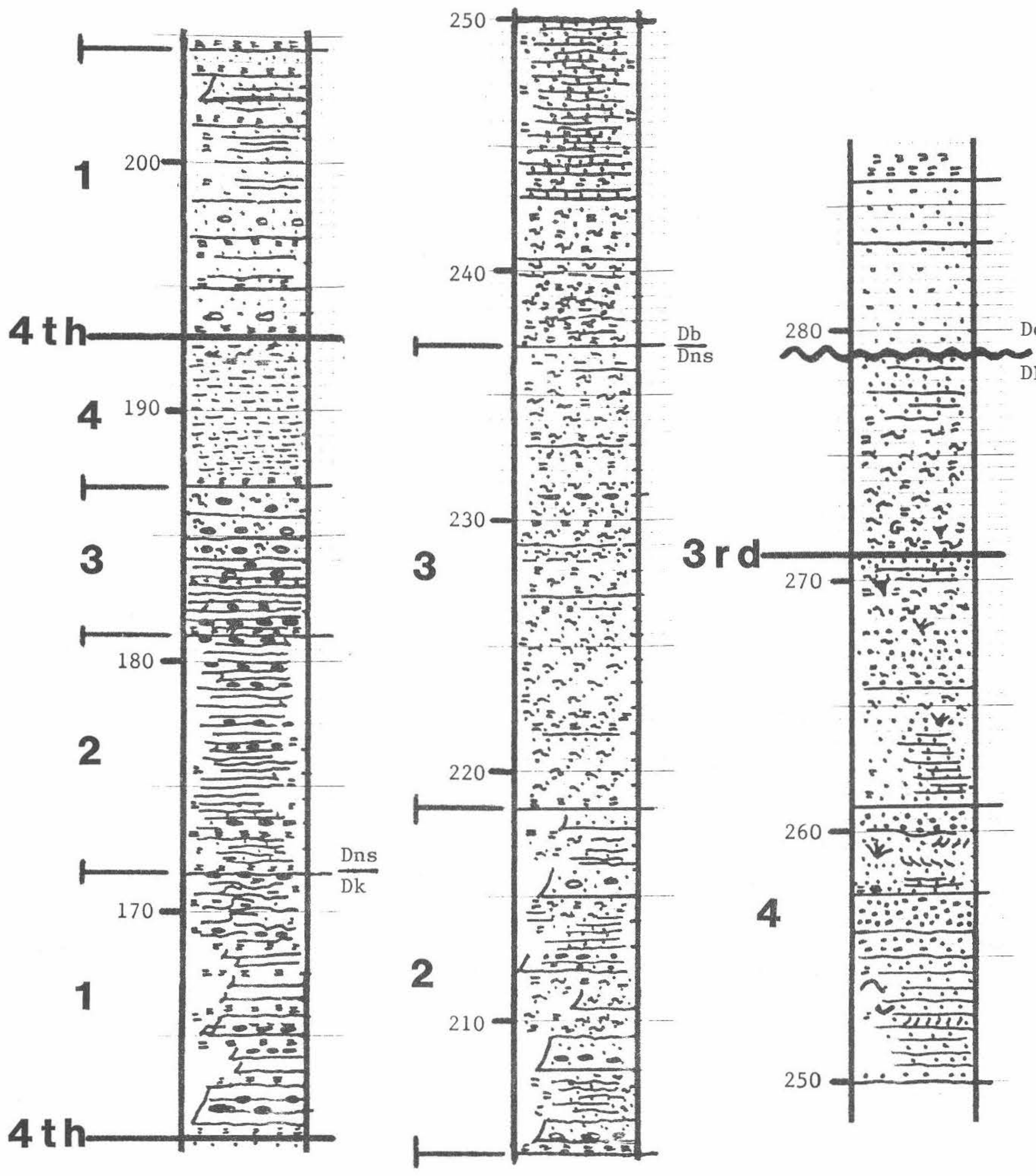


Figure 2 Log I-88 Schoharie

SLF = Sea level fall Dm = Manlius Fm. Dc = Coeymans Fm.

Dk = Kalkberg Fm. H = Hannacroix Mbr. BL = Bronk's Lake Mbr.

Dns = New Scotland Fm. Db = Becraft Fm. Do = Oriskany Fm.



1
200
4th
4
190
3
180
2
Dns
Dk
170
1
4th
250
240
Db
Dns
3
230
220
2
210
280
Do
Db
3rd
270
260
4
250

<u>5th Order Cycle 4</u> is the thick calcisiltite unit.

<u>4th Order Cycle III</u>

This is the thickest of the three 4th order sequences at Schoharie. It is 66.5 feet thick and in general a regressive sequence of 5th order cycles, beginning in deep ramp and ending in shoreface facies. This unit is equivalent to the highstand systems tract of sequence stratigraphy. The top of the cycle is placed at a surface above the coarsest calcarenite facies in the Becraft, at 271 feet on the log. This surface is also a third order B sequence boundary. The Oriskany unconformity, 8 feet above this surface, has eliminated most of the last 3rd order sequence of the Helderberg supersequence (third order A). At Kingston the upper 3 feet of the Becraft and the Alsen-Port Ewen Formations comprise this 3rd order sequence. Fourth order cycle III consists of four 5th order cycles:

<u>5th Order Cycle 1</u> ends at 204.5 feet on the log and is an 11.5 foot thick set of amalgamated lime turbidites.

<u>5th Order Cycle 2</u> ends at 218.5 feet on the log just below a 4-6 inch shale and like the cycle just below, is a 14 foot thick set of amalgamated turbidites.

<u>5th Order Cycle 3</u> ends at 237 feet on the log just above a massive calcisiltite bed. Rocks above this surface are coarser and would generally be described as Becraft.

<u>5th Order Cycle 4</u> extends to the top of the 3rd order sequence and consists of five coarsening upward, calcarenite shallow ramp cycles and is the thickest of the 5th order cycles in the set.

The last part of STOP 3 is one mile farther west on I-88. Here the surface between Becraft/Alsen calcarenite and fossiliferous quartz sandstone of the Oriskany represents superimposed 2nd (i.e. Sloss sequences), 3rd, 4th, 5th and 6th order boundaries. There are two 6th order cycles in the Oriskany followed by a major deepening into basinal Esopus facies.

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Lengthy reference lists including other peoples work on the Helderberg Group and on cyclic stratigraphy are presented in the above papers.

ROAD LOG

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	Start at the central Oneonta entrance to I-88
39.0	39.0	Cobleskill Exit I-88
39.3	.3	Oriskany/Esopus, STOP 3B
40.0	.7	Kalkberg to Becraft, STOP 3A
42.5	2.5	Rondout to Coeymans, STOP 2
44.0	1.5	Schoharie Exit I-88, turn south on Route 30A
44.9	.9	End Route 30A, continue south on Route 30
46.2	1.3	Intersection with Route 443, turn east on Route 443
50.2	4.0	The village of Gallupville, continue east on Route 443

CUMMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
51.4	1.2	Quarry in the Manlius-Coeymans on the south side of road (Rickard Locality 67)
53.8	2.4	The village of West Berne
56.6	2.8	The village of Berne, continue easat on Route 443
60.1	3.5	The village of East Berne, turn left on Route 157A
60.5	.4	Warner Lake, turn east on Route 157A toward Thacher Park
62.3	2.3	Intersection with Route 157, Thompson Lake,Continue straight northeast on Route 157
63.8	1.5	Thacher State Park, pool and recreation area on left
64.4	.6	Turn left into parking lot for Mine Lot Falls, STOP 1

Return by same route to I-88 Schoharie, go to STOP 2 and then STOP 3 as located above on the interstate.