Trip B-3

COMPARATIVE SEDIMENTOLOGY OF THE HELDERBERG GROUP IN CENTRAL NEW YORK

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INTRODUCTION

"What am I supposed to be looking at here?" The students have just assembled at the outcrop and, invariably, this question floats up from somewhere. This question drives some instructors wild, but most just chuckle to themselves. The answer to that question is, of course, the point of the field trip stop. If the stop is in sedimentary rocks (as on this trip) the immediate question: "what am I supposed to be looking at here?" breaks down into four questions: (1) what kind of rock is this, i.e. what was deposited?; (2) how did it get deposited?; (3) when did it get deposited?, and; (4) what happened after the sediments were deposited? A better way to phrase question two would be: what was the environment of deposition of these rocks? The answers to these questions are the core questions of *sedimentology*, the study of sediment, specifically the nature and origin of unconsolidated sediments and consolidated sedimentary rocks. The purpose of this trip is to show you how to systematically go about answering question two: the series of steps necessary to diagnose the *paleo-environment* of deposition.

PRELIMINARIES 1: STRATIGRAPHY (WHEN DID IT GET DEPOSITED?)

The question: "how old are these rocks?"; is the purview of a branch of sedimentology known as *stratigraphy*. One of the great scientific achievements of the nineteenth and early twentieth centuries was mapping and establishment of the relative age of all of the different rocks that cover the Earth, resulting in the *geologic column* or *stratigraphic column*. The stratigraphic column was assembled from information on: (1) the fossil content of sediments and sedimentary rocks, and; (2) application of a few common sense rules most important of which are that sediments and sedimentary rocks were deposited layer upon layer on gently inclined surfaces, and that discordances in the geologic record represent time gaps. In the early to mid twentieth century, development of radioactive isotopic dating techniques for rocks allowed the relative time scale based on fossils to be absolutely fixed in time. Moreover, rocks that did not contain fossils could now be dated within the limits of accuracy of the various radiometric dating techniques. This combination of relative and absolute age dating resulted in the *geological time scale*. There is no outcrop of rock anywhere on planet Earth whose position in the geologic column and geologic time scale is not known.

In particular, the rocks that are the subject of this field trip: the Helderberg Group, are Upper Silurian to Lower Devonian in age, or roughly 415 million years old (Fig. 1). The Helderberg Group of New York has been studied since the 1800s and is discussed in many historical geology and sedimentology text books. The classic work on the stratigraphy of the Helderberg was by Rickard (1962, 1973). Laporte (1967) provided an excellent early paleo-environmental interpretation that tackled many of the issues discussed here 40 years later.

In eastern New York, the Helderberg Group is up to 120 m thick and comprises five separate formations. Around Syracuse, the Helderberg comprises only one formation: the Manlius Limestone and is generally 10 m thick or less. The boundary between the underlying Rondout Formation and the Manlius Limestone occurs at each field trip site. East of Syracuse, at Chittenango Falls State Park (Stop 5 of the trip) a few meters of the Coeymans Limestone overlies the Manlius Limestone. The Manlius Limestone around Syracuse is reckoned to be younger than the Manlius Formation in the Hudson Valley and is divided into a number of members. However, the Manlius Limestone has only a few types of fossils and the true ages and stratigraphic relationships of the members of the Manlius Limestone and formations of the Helderberg Group is an area of active research in New York. Another interesting aspect of the Manlius Limestone around Syracuse is that there is a significant *unconformity* separating the Helderberg formations and the Oriskany Sandstone and another unconformity separating the Oriskany Sandstone from the Middle Devonian Onondaga Limestone. In all, a few millions of years of erosion and/or nondeposition are **not** recorded in these rocks. The Oriskany Sandstone itself is discontinuous in this part of the world and is difficult to find in some of the outcrops on this fieldtrip. The Middle Devonian Onondaga Limestone occurs at the top of the section at all of the stops in this trip.

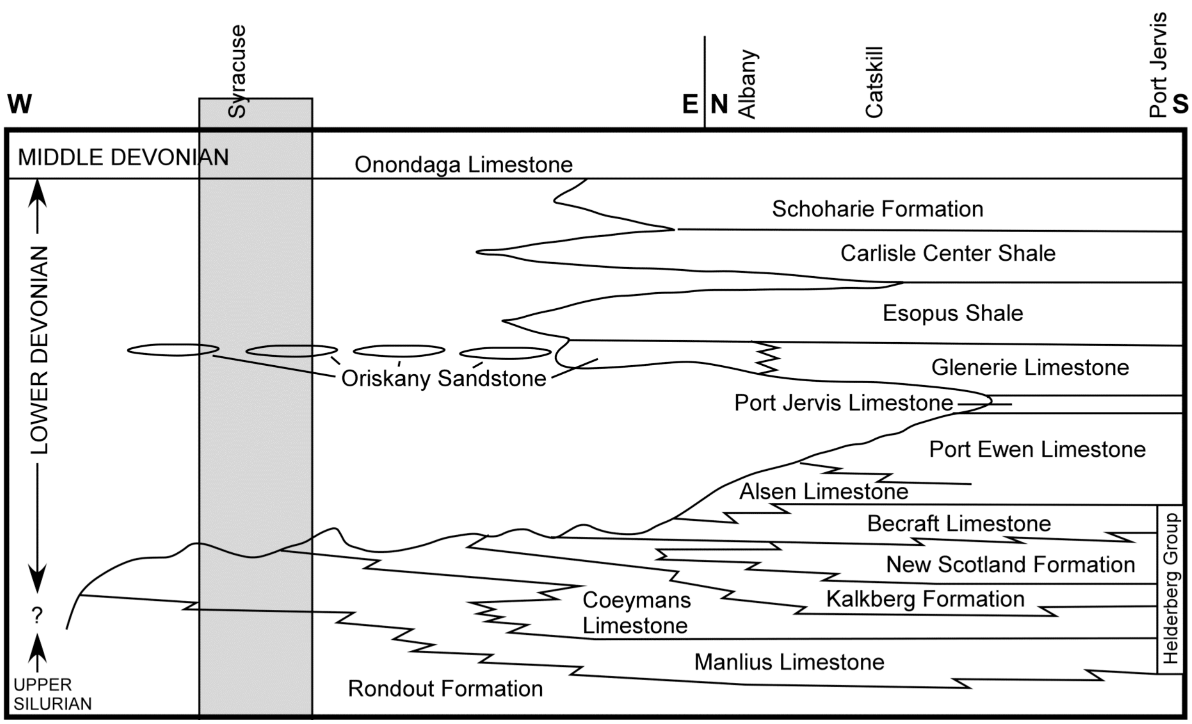

FIGURE 1—Stratigraphy of the Lower Devonian rocks in New York State showing Rickard's (1975) interpretation of the time-transgressive nature of the Helderberg Group rocks. The vertical axis here is time, so thicknesses of the formations are not determinant. The boundary between the Silurian and the Devonian is reckoned to be in the Manlius Limestone in eastern New York and in the Rondout Formation in western New York. The shaded area indicates the stratigraphy of the rocks in this field trip area.

It is our contention that the depositional paleoenvironments of the Manius Limestone can be diagnosed without worrying about the detailed stratigraphy at the various outcrops. In fact, the stratigraphy confuses the issue in some respects. The starting point of any study of sedimentary rocks is an analysis of the depositional environments represented.

PRELIMINARIES 2: PETROLOGY (WHAT WAS DEPOSITED?)

The first question posed in the introduction was: "what kind of rock is this?" The answer of for this field trip is fairly straightforward: carbonate rocks. Carbonate rocks are chemical and biochemical sediments composed of calcium (Ca^{2+}), magnesium (Mg^{2+}) and carbonate (CO_3^{2-}). In particular there are two minerals to worry about: calcite and dolomite. Calcite is most important in the Manlius Limestone and usually weathers a bluish gray to gray. Most sedimentary calcites older than Cenozoic have < ~ 4% magnesium in them and are technically known as low magnesium calcites ($Ca_{0.96}Mg_{0.04}CO_3$). Dolomite is a calcium, magnesium double salt ($CaCO_3$□$MgCO_3$) and in this part of the world commonly weathers tan to brownish due to a few percent iron in the lattice.

Two important features of modern chemogenic and biogenic carbonate sediments are: (1) they originate as either biochemical precipitates or as physico-chemical precipitates in the depositional environment where they accumulate, and; (2) the majority of the grains are subjected to physical transport and deposition, although some of the grains may remain at the precipitation site. In particular, tropical, shallow-water environments with low terrigenous-sediment supply host a veritable 'carbonate factory' of biogenic and non-biogenic carbonate sediment production, both today and in the past. Biochemical production of calcium carbonate is controlled mainly by water temperature, salinity, depth, water clarity and residence time.

There are several types of carbonate sedimentary grains that can be recognized in modern and ancient deposits: mud, skeletal grains, pellets, ooids, grapestones, and intraclasts. Much of the calcium-carbonate mud and sand on modern shallow marine tropical environments is aragonite (another $CaCO_3$ mineral) and is produced by *green algae* such as *Halimeda* and *Penicillus* that need warm, shallow, clear water. Macroscopic *skeletal grains* are also produced by hermatypic corals that typically occur in tropical shallow-water environments, and these have symbiotic photosynthetic unicellular microorganisms known as *Zooxanthellae* in their tissues. These are dinoflagellate protozoans and, like green algae, require warm, sunlit (i.e. shallow and clear) and siliciclastic-mud-free water to thrive. Modern tropical shelves also contain a wide range of other bottom-dwelling organisms, mainly molluscs, red algae, and foraminifera that also produce silt- to gravel-sized skeletal grains composed of aragonite and high magnesium calcite. High magnesium calcite has up to a few tens of percent magnesium in the lattice and is the most common calcite produced by modern organisms. The warm conditions of tropical, shallow seas also favor non-biogenic precipitation of calcium carbonate both as sedimentary particles and as early diagenetic cements. Calcium-carbonate precipitation as mud takes place in *whitings*, clouds of suspended aragonite needles ~ 4 microns long that occur in surface water on shallow-marine carbonate shelves (and in lakes). Whitings occur where deep ocean water rises onto a shallow platform, warms, begins to evaporate, and degasses CO_2. Whitings are perhaps triggered by blooms of unicellular photosynthetic organisms that also take CO_2 out of the water. *Ooids* are concentrically-laminated, sand-sized grains considered to be chemical precipitates created as sea-water warms, evaporates, and degasses as it washes onto a shallow platform. Ooids typically accumulate as tidal shoals or beaches at the shelf margin. Carbonate cementation on and just below the sea floor is also important in shallow, tropical-marine carbonate deposition. Carbonate mud on modern tropical shallow shelves is commonly aggregated into *pellets* by both deposit-feeding and filter feeding organisms. Some pellets become cemented on the sea floor and aggregated into lumps known as *grapestones*. Erosion of cohesive mud and cemented sediments results in various types of *intraclasts*.

The most important carbonate rocks are: (1) grainstones; (2) packstones; (3) wackestones, and; (4) mudstones. *Grainstones* comprise well-sorted sand- and gravel-sized components surrounded by calcite cements. As cements must be introduced after deposition, grainstones originally comprised mud-free accumulations of carbonate particles. In *packstones*, the sand- and gravel-sized components are in grain-to-grain contact but carbonate mud fills the space between the grains. In *wackestones*, the sand- and gravel-sized components 'float' in mud, whereas *mudstones* are composed of uniform crystals that cannot be seen in a hand lens. In other words, if you don't see grains it is most likely a mudstone. The rocks that contain sand- and gravel-sized debris can be further classified by adding one or two modifiers to the rock name based on the dominant sand- or gravel-sized components: e.g. *ooid grainstone*, *skeletal packstone*, or *intraclast wackestone*. It is commonly assumed that a mud-supported limestone was deposited in the absence of turbulent water currents, and *vice versa* for a mud-free limestone. However, the texture and fabric of biogenic and chemogenic grains are difficult to relate to transport mechanisms, because of the possibility of *in-situ* accumulation with little transport, and because of original rounded shapes. Furthermore, carbonate mud may be produced diagenetically (by a process known as 'micritization') and bioturbation commonly mixes separate sand and mud layers into packstones and wackestones. Classification is commonly made difficult by diagenetic modification of original textures and fabrics, which is especially true where limestones (rocks dominately composed of low magnesium calcite) have been altered into dolomite.

The most common rock types in the Manlius Limestone are mudstones and wackestones. Carbonate muds are renowned for preserving delicate sedimentary features unlike fissile siliciclastic mudstones. The exact reasons for preservation of such exquisite detail in carbonate muds is a matter of some debate and need not concern us here. The carbonate mudstones in the Manlius Limestone also contain various amounts of terrigenous mud (mostly comprising clay minerals). In some cases Manlius Limestone mudstones can be quite shale-like with fissility and cleavage development. In addition, the organisms that produced the skeletal grains in the Manlius Limestone were from quite different groups than those found on modern carbonate shelves. Skeletal grains in the Manlius Limestone included ostracod, brachiopod, and gastropod fragments. Stromatoporoids (a calcium-carbonate secreting sponge) can be quite common in some layers where corals also occur. The Coeymans Limestone (exposed at Stop 5 at Chittenango Falls State Park) is a skeletal grainstone to packstone. Common skeletal debris in the Coeymans Limestone includes crinoid and brachiopod fragments.

COMPARATIVE SEDIMENTOLGY:
DIAGNOSING ANCIENT ENVIRONMENTS

The only rational way of interpreting the origin of ancient sedimentary deposits is to compare them with modern sedimentary deposits: an approach referred to as *comparative sedimentology* by Robert Ginsburg (1974). An *environment* is a part of the Earth's surface where erosion and deposition are proceeding that has a distinctive association of physical, chemical and biological landforms and processes. Examples of environments are rivers and adjacent floodplains, glaciated regions, deserts, lakes, beaches, tidal flats, rocky coasts, continental shelves, coral reefs, and ocean basins. Environments, in turn, can be broken up into a series of smaller, more specific subenvironments. For example, a river can be divided into channel thalwegs (the deepest scoured areas), point bars, channel cross-over areas, partly to completely abandoned channels (sloughs), and levees. On the adjacent floodplains there are oxbow lakes, crevasse-splays, marshes or forests, and lakes. Tidal flat environments commonly can be subdivided into subtidal, intertidal and supratidal flats that are traversed by meandering tidal channels. In each case, the distinctive set of physical, chemical and biological processes operative in each subenvironment leaves behind a deposit with a distinctive set of physical, chemical and biologic sedimentary structures, sedimentary grain types, sedimentary textures (grain size, shape, sorting), body fossils, trace fossils and paleocurrent indicators. Understanding ancient environments from study of sedimentary rocks, using modern counterparts as comparative guides, is the essence of comparative sedimentology.

The most important step in interpreting the depositional paleoenvironment of ancient sedimentary rocks is accomplished by dividing the outcrop up into elemental rock units that are commonly referred to as *facies* or *lithofacies*. Facies are usually between a few tens of centimeters up to a few meters thick and in carbonate rocks are characterized first by their assemblages of physical, chemical and biogenic sedimentary structures and early diagenetic features and secondarily by the rock type, fossil content, grain size and shape, and paleocurrent indicators. Demicco and Hardie (1994) provide an introduction to sedimentary structures and early diagenetic features of shallow marine carbonate deposits. *Each facies ideally should represent the depositional record of an ancient subenvironment*. It is the lateral and vertical arrangement of facies at an outcrop that unambiguously point to the depositional environment of the rocks.

In order to interpret the depositional environment of a formation it is necessary to describe the three-dimensional distribution of the facies (commonly referred to as a *facies association*). In this part of the world, large, three-dimensional outcrops are rare. Instead, the three-dimensional details of facies distribution must be pieced together from widely-spaced, one- and two-dimensional outcrops that (we hope) can be correlated. This is a tricky business (see below). With this in mind, the description of an outcrop follows a logical sequence.

Step 1: Outcrop Reconnaissance (a.k.a. 'Scratch & Sniff')

The first thing you should do is a brief reconnaissance overview of the outcrop to gain an impression of the main rock types, sedimentary structures, and body and trace fossils. In deformed rocks, it will be necessary to establish which way is stratigraphic 'up' but in this part of the world the rocks are in place and become younger higher and higher in the section. For some purposes (and on many field trips) this step is all that is done, and, by the time you have walked through the outcrop, you will have a 'shopping list' of sedimentary features that will allow you to make a pretty good guess as to the broad depositional environment. For example, the 'shopping list' of common sedimentary features in the outcrops of the Manlius Limestone around Syracuse include: (1) laminated mudstones; (2) desiccation cracks; (3) 'ribbon rocks' - alternating thin beds of small-scale cross stratified grainstones alternating with dolomitic mudstones and shales; (4) wave ripple marks; (5) current ripple marks; (6) meter-thick layers rife with skeletons of the stromatoporoid sponge *Syringostroma barretti* nearly to the exclusion of other fossils; (7) microbial tufas; (8) stromatolites; (9) burrow-mottled skeletal-peloidal wackestones in thin-bedded sets of strata, and; (10) a low diversity of fossils including one or two species of brachiopods and ostracods. All these features have long been recognized as the hallmarks of carbonate tidal flat deposits. A useful descriptor for such rocks is 'peritidal': literally 'around the tides'.

In the reconnaissance walkthrough you will commonly notice that certain sedimentary features occur associated with each other, i.e. comprise facies. For example, one of the most famous facies of the Manlius Limestone comprises thick cosets of planar laminated mudstones, stromatolitic-laminated mudstones, millimeter thick lenses of intraclastic conglomerates, and desiccation cracks. The laminae commonly are very fine (less than one millimeter) alternations of limestone (calcite) and dolostone (dolomite). Another notable facies of the Manlius Limestone is the meter-thick stromatoporoid sponge wackestone beds. The emphasis of this field trip will be the recognition and interpretation of the facies of the Manlius Limestone.

Step 2: Measuring Sections and Constructing Photomosaics ('Getting Serious')

The only real way to interpret sedimentary rocks is to construct measured sections (also called stratigraphic logs) of the vertical succession of facies, and, where appropriate, construct two-dimensional scale drawings of the outcrops from photomosaics. Measuring the section forces you to come to grips with the problem of defining facies by putting your nose directly on the rocks. In addition, correlation between outcrops is impossible without a to-scale, detailed representation of the facies at the various outcrops (commonly referred to as *graphic logs*). Sedimentological logs normally include measurement of the upward variation through the sedimentary sequence of stratal thickness, texture, color, composition, fossils, sedimentary structures and paleocurrent directions. Measurement of true stratal thickness in dipping strata is accomplished using a level on a ranging pole. Location of positions in sedimentological logs can now be measured using differential GPS. Figure 2 illustrates how logged sedimentary features can be represented graphically. The legend for Figure 2 is a typical legend for sedimentological logs, but there are many other legend designs to suit specific needs. *We would like to encourage anyone interested in trying to measure a section to have a go at it at Stop 2 in Split Rock Quarry*.

It is not uncommon to encounter rocks where the sedimentary features cannot be resolved at the outcrop. The rocks may be covered by mosses or lichens, or poorly weathered. In these cases, oriented samples of the rocks are taken back to the laboratory where they can be sawn, polished and etched in acids to bring out the sedimentary details. We have a number of slabs of some Manlius Limestone facies from poorly weathered portions of the outcrops. This iterative process of measuring, sampling, and laboratory study ultimately results in a complete, detailed graphical log of the outcrops. We find that graphical logs are best where drawn by hand, that the symbols for the different rock types look like the outcrop rocks, and that annotation of important features be made directly on the logs.

With large, continuous exposures of unconsolidated sediments and sedimentary rocks, a series of two-dimensional sections can be produced using photomosaics in combination with detailed logs of the sedimentary features. Figure 3 provides an example from Stop 4 of this field trip (Clockville). When constructing photomosaics, it is necessary to minimize the distortion in the photos related to varying distance of the outcrop from the camera. As a rule, the line of sight of the camera should be normal to the outcrop face, there should be 50% overlap of adjacent photos, and two ranging poles should be included in each frame for scale and to facilitate aligning the photos. In order to assemble photomosaics, it is necessary to establish a datum that should be surveyed during photography, possibly using a level or GPS and a laser range-finder for proper positioning of outcrop images. Digital photographs or scanned photos can be assembled into photomosaics using computer software. Photomosaics are analyzed in the laboratory and in the field, and it is common to construct overlays for marking surfaces and sedimentary facies.

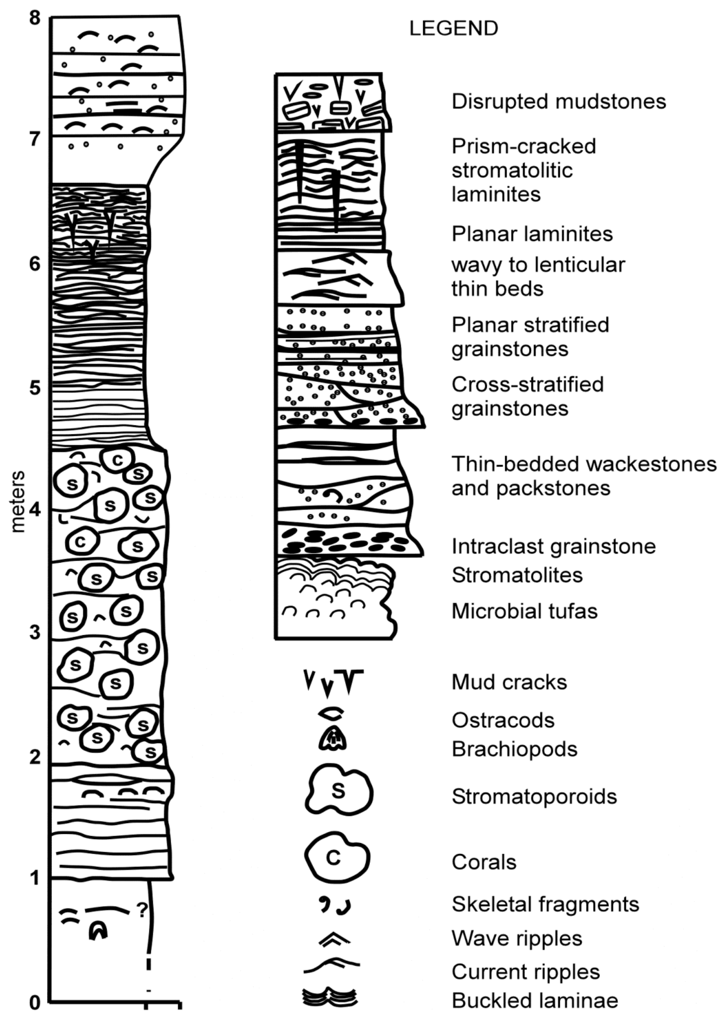

FIGURE 2—The right column is a graphic log of measured stratigraphic section at Nedrow, New York (Stop 1). Legend for the measured sections in this guidebook shown on right

Sedimentary rocks tend to occur in repetitive sequences of facies (this point is further discussed below). In the Hudson Valley, the Manlius Limestone is famous for its repetitive sequences. Thus, after the initial stages, it is not necessary to determine all of the sedimentary features that occur in facies. Indeed, once the facies have been established for a formation, it is easier to note the differences in facies within an outcrop or from outcrop to outcrop. Unfortunately, in this part of the world, the outcrops of the Manlius Formation are fairly thin and generally do not show repetitive sequences of facies (although there are some!). For this field trip then, we will be looking for different facies to recur from outcrop to outcrop instead of repetitively in the same outcrop.

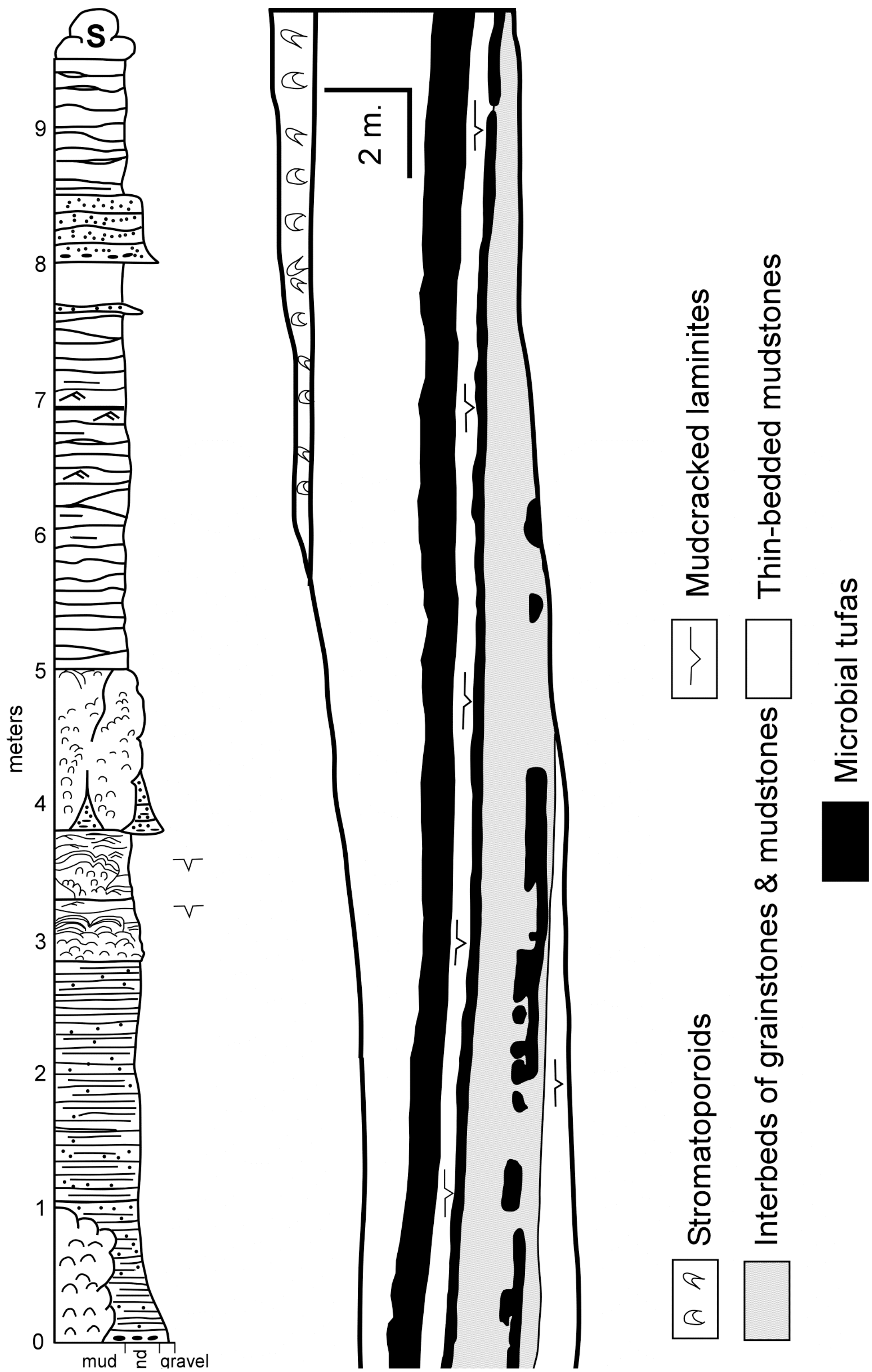

FIGURE 3—Measured section (left) and scaled outcrop diagram (prepared from photomosaics) of the Manlius Limestone at Clockville, New York (field trip Stop 4). Horizontal and vertical scales are the same. Modified from Browne (1986) and Browne and Demicco (1987).

Step 3: Interpretations (Walther's Law of Facies)

The link between the vertical and lateral arrangement of facies in an outcrop and ancient subenvironments that comprised the ancient environment is Walther's Law of Facies (Fig. 4). Walther's Law of Facies states that only those deposits that were laterally adjacent can be superimposed conformably one upon the other. Said another way, if there are no erosional breaks between strata, a vertical succession of facies represents an original horizontal distribution of subenvironments. Figure 2 shows the distribution of facies in the Manlius Formation at Stop One along U.S. Route 11 just south of Nedrow, New York. Here the Manlius can be divided up into three facies: (1) approximately 2 m of thin interbeds of packstones and grainstones with rare stromatoporoids; (2) 2.5 m of stromatoporoid – coral wackestone, and; (3) 2 m of planar-laminated to wavy-laminated mudstones. The laminated mudstones have rare desiccation mud-cracks. Note that: (1) there are no clear erosional breaks; (2) fossil-bearing beds are overlain by laminated mudstones with very rare fossils, and; (3) desiccation features are restricted to the top of the section. These observations suggest that the section records increasing exposure upwards and less habitable subenvironments. Figure 5 is a core taken through a tidal flat island in Florida Bay. Note that, aside from the stromatoporoids, this core has most of the features of this outcrop and we use it to guide us in our interpretation of this outcrop. We interpret this outcrop to represent subtidal pond (thin-bedded facies) and intertidal to supratidal mud flat covered by a cyanobacterial mat (laminated mudstones). The exact depositional subenvironment of the stromatoporoid wackestones is controversial and they may represent either: (1) patch reefs, or; (2) migrating tidal channels. However, the fact that it occurs within this shallowing-upwards succession radically restricts the subenvironment of deposition of this facies.

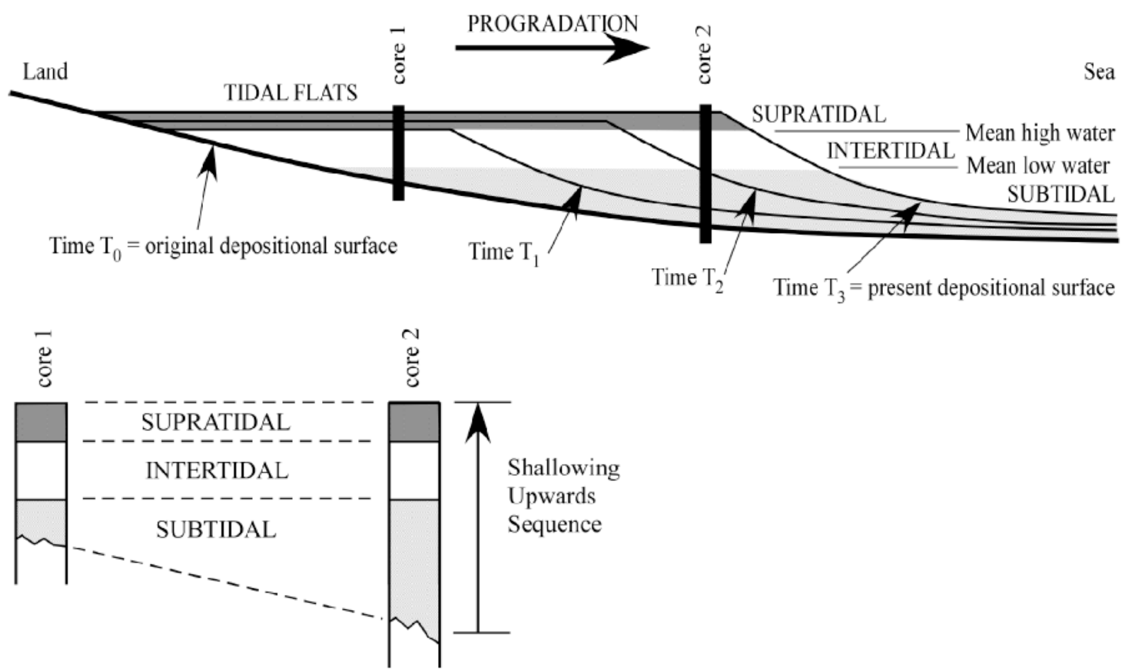

FIGURE 4—Walther's Law of Facies and the generation of shallowing-upwards sequences by tidal flat progradation (from Demicco and Hardie, 1994). We will follow this same approach at each outcrop. We have a number of samples from modern carbonates (including the core shown in Figure 5) that have been embedded in epoxy that we will use at the various outcrops to guide our subenvironmental interpretations.

Step 4: Correlations ('The Big Picture')

Once individual outcrops have been logged and their vertical and lateral associations of facies interpreted, it is time to move up to the next step; correlation of the graphic logs among the outcrops. It cannot be stressed enough that, unless you can actually walk layers out between outcrops, any correlation of facies between outcrops is *an interpretation*. Indeed, for most formations, the outcrop (or well) information that is used to diagnose the depositional environments and correlate facies among outcrops is only a tiny fraction of the formation! In the absence of: (1) reliable biostratigraphic data; (2) continuous exposure to walk out facies relationships, or; (3) or discreet 'event' beds, such as ash fall layers, *all* correlations (including those in Figure 1) are interpretations.

Compare our measured section from Stop 1 (Nedrow) to your measured section from Stop 2 (Split Rock Quarry) a distance of some 10 km. It is rarely possible to correlate facies from outcrop to outcrop in the Manlius Limestone either locally or across the state, a fact recognized by Leo Laporte (1967) some 40 years ago. However, the lack of correlation among outcrops itself may actually provide a clue as to the bigger depositional picture. Clearly, during deposition of the Manlius Limestone in central New York, we did not have

areas where large tidal flat coastlines prograded laterally for hundreds of kilometers leaving behind sheet-like tidal flat deposits correlative from outcrop to outcrop. Modern areas where this style of deposition occurs include tidal flats of southwestern Andros Island in the Bahamas and the famous 'sabkhas' of the Arabian Gulf that comprise the United Arab Emirates. Instead, we picture the Manlius Limestone around Syracuse as analogous to the modern Florida Bay (Fig. 6). Florida Bay comprises a restricted area of linear mudbanks, ornamented with tidal flat islands that separate the shallow subtidal areas into semi-circular areas known as 'lakes'. Mud banks in the eastern parts of Florida Bay (Fig. 6A) are linear features a few hundred meters across, 1 -2 m high, and up to kilometers long, that run between tidal-flat islands. The tidal-flat islands are up to a few square kilometers in area and mostly covered in mangroves, although many have open intertidal to supratidal ponds covered with cyanobacterial mats (Fig. 6C). In the western portions of Florida Bay, the mud banks are larger and more irregular in shape, and the islands are scattered on them. Florida Bay mud banks were once thought to be a product of baffling and subsequent deposition of transported sediment by the sea grasses on the banks, with additional sediment produced in place by a host of small, calcareous organisms (known as epibionts) that lived on the grass. However, it appears likely that the mud mounds in Florida Bay are tombolos and spits that are influenced by wave refraction around the tidal-flat islands.

Cores taken from the banks reveal bioturbated mud with sand- and gravel-sized skeletal fragments and the rhizomes of sea grasses (Fig. 6B). Cores through the tidal-flat islands (Fig. 5) show that they are mostly underlain by thin-bedded pond deposits and cyanobacterially-laminated muddy tidal-flat deposits, indicating that they have always been tidal flats that have migrated laterally perhaps a few hundred meters at most (Enos and Perkins, 1979). Mud banks in Florida Bay comprise tombolos that generally run between mangrove-covered tidal flat islands. These mud banks are probably related to longshore transport of mud controlled by wave refraction around the islands.

The deposits of an area like Florida Bay would comprise isolated tidal flat islands that develop by in place vertical growth (aggradation) as well as some lateral progradation. The deposits of such an area would produce a complicated three-dimensional mosaic of facies that could not be correlated over areas greater than 10 kilometers or so. This is exactly the situation of the facies of the Manlius Limestone in central New York. The restricted fauna of the Manlius Limestone suggests that the waters of the basin were inimical to invertebrates; i.e. they were either too salty, or too brackish. Florida Bay is brackish, and is backed up by the Everglades, a vast area of fresh-water carbonate deposition in periphyton marshes. It would not be at all surprising if some of the more exotic facies of the Manlius Limestone (such as the microbial tufas we shall visit at Stop 4 in Clockville) were, in fact, fresh water deposits.

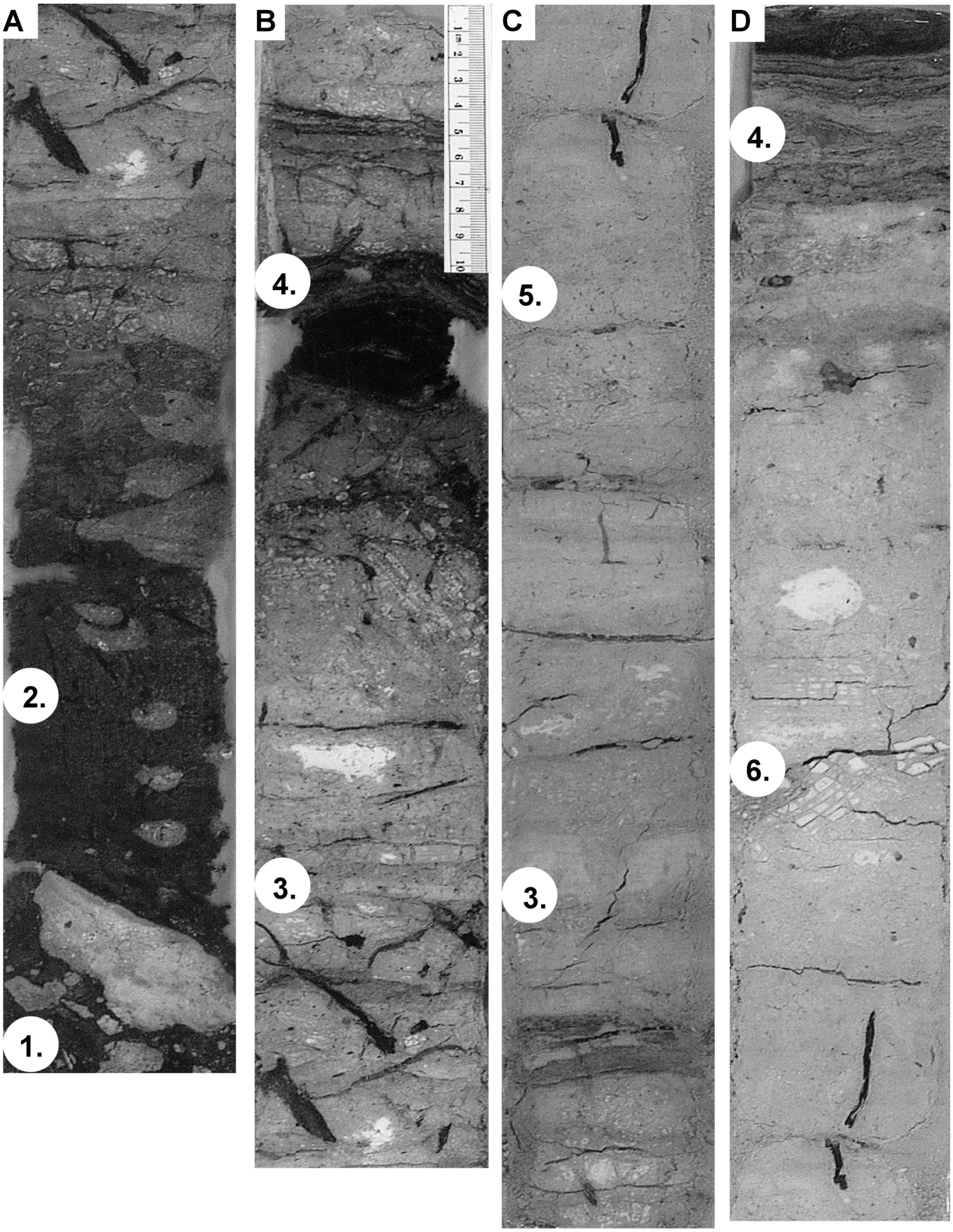

FIGURE 5—Epoxy embedded core 1.7 m thick through tidal flat island from Florida Bay. Base of core in A top of core in D. Circled numbers denote: (1) pieces of Pleistocene rock; (2) freashwater peat; (3) thin-bedded intertidal pond sediments; (4) two layers of cyanobacterial laminated muds of supratidal marsh; (5) burrowed mud of intertidal pond with indistinct thin beds; (6) high magnesium calcite (so-called protodolomite) cemented crust broken up during coring.

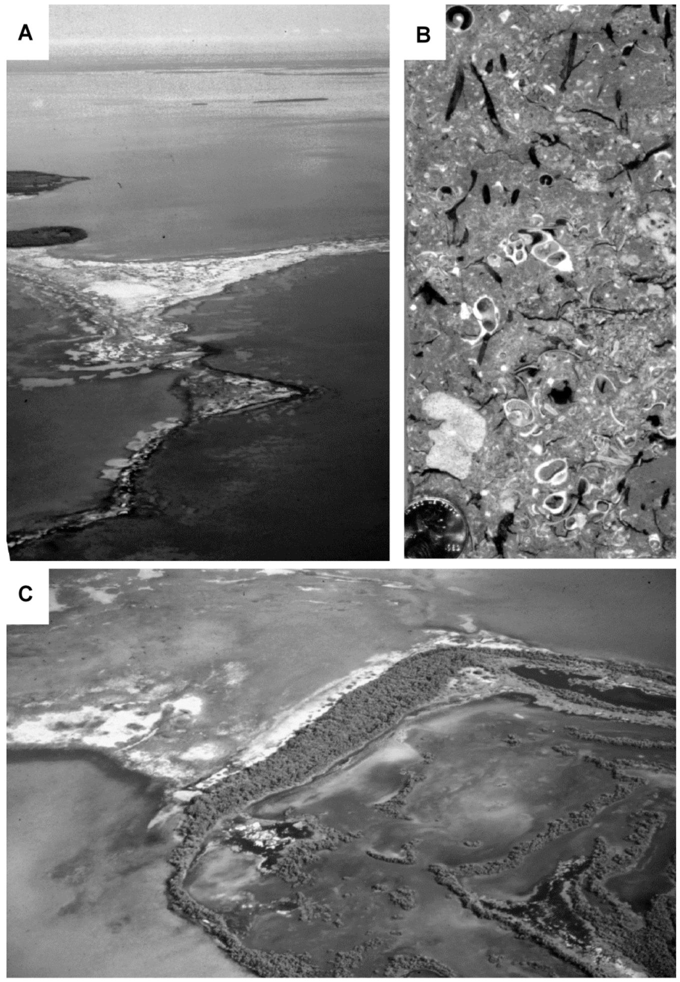

FIGURE 6—(A) Linear subidal mud banks of Florida Bay connecting tidal-flat islands. The freshwater marl prairie of the Everglades is in the far distance. (B) Epoxy embedded core of coarse skeletal wackestone from mud bank seen in A. (C) Tidal-flat island in Florida Bay showing open intertidal pond covered by cyanobacterial mats. Adjacent mud bank runs off to the upper right.

CONCLUDING REMARKS

It is our contention that understanding of the origin and significance of primary sedimentary structures and early diagenetic features is vital to unraveling the origin and significance of carbonate deposits in the geologic record. Without such an understanding at the individual sedimentary structure scale, we cannot hope to accurately reconstruct the large scale accumulation history of carbonate deposits or to decipher the roles of sea-level changes, sedimentation rates, subsidence rates, and tectonics in determining the facies stratigraphy, cyclostratigraphy, and sequence stratigraphy of these buildups. The message seems crystal clear, if we do not get the little things right we may not be able get the big things right (Demicco and Hardie, 1994, p. 242).

ACKNOWLEDGEMENTS

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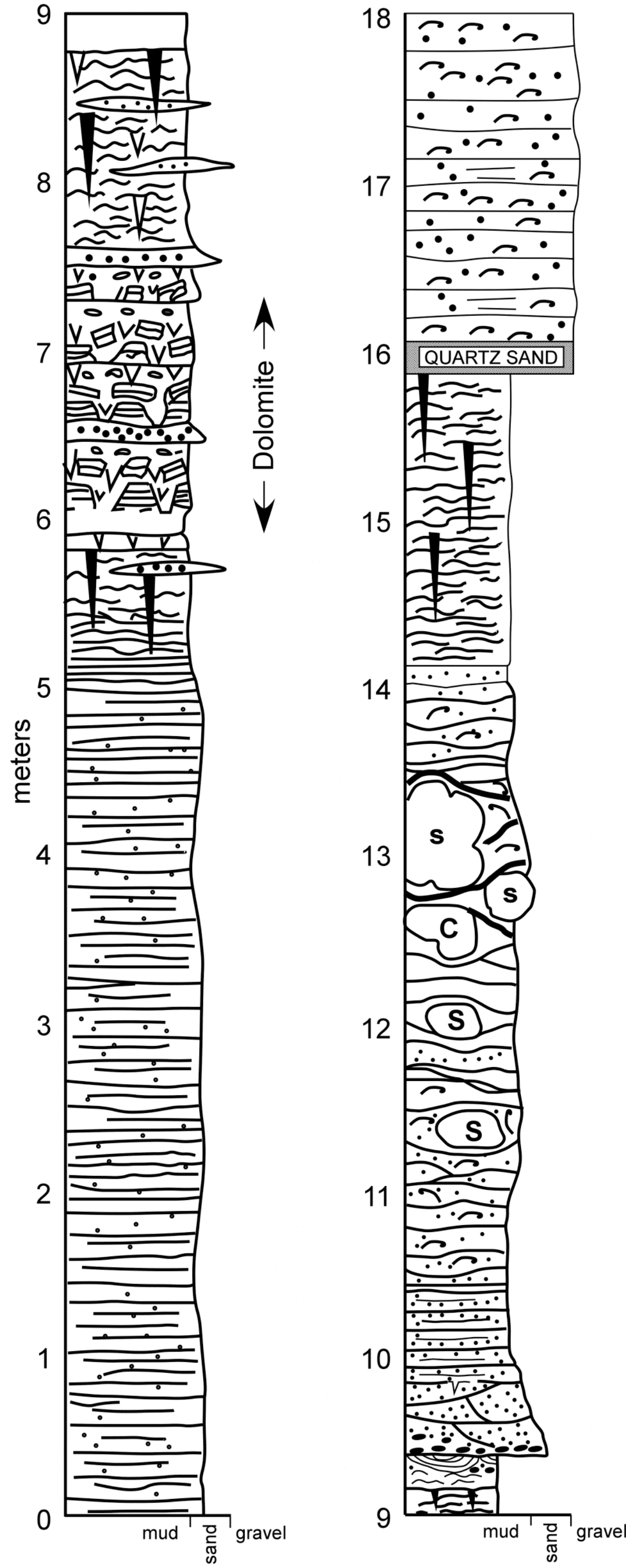

FIGURE 7—Measured section from Clark Reservation, New York (field trip stop 3).

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ROAD LOG FOR TRIP B-3

COMPARATIVE SEDIMENTOLOGY OF THE HELDEBERG GROUP OF CENTRAL NEW YORK

CUMULATIVE MILEAGE	MILES FROM LAST POINT	ROUTE DESCRIPTION
0.0	0.0	Enter I-81 northbound from NY St. Rte. 11 in Cortland
24.4	24.4	Exit I-81 at Exit 16 to U.S. Rte 11 at Nedrow, NY
24.5	0.1	Turn left at end of exit ramp onto Rte. 11 toward Nedrow, NY
25.0	0.5	Pull off Rte 11 on right – outcrop along east side of Rte. 11

STOP 1. NEDROW (Graphic Log Figure 2)

25.0	0.0	Proceed north on Rte. 11 through Nedrow into Syracuse, NY
27.7	2.7	Turn left (west) onto West Seneca Turnpike (NY St. Rte 173)
29.5	1.8	Junction NY 173 and NY 175 - bear right on 173 now called Onondaga Road
32.4	2.9	Turn left (south) on Onondaga Blvd.
33.1	0.7	Park at dead end – at top of access road take path to left into old quarry

STOP 2. SPLIT ROCK QUARRY (Do it yourself?)

33.1	0.0	Return north on Onondaga Blvd.
33.8	0.7	Turn right (east) on NY 173 and retrace route back into Syracuse
38.5	4.7	Intersection of NY 173 and US 11 – continue straight on NY 173 now called East Seneca Turnpike
39.0	0.5	Cross under I-81
39.2	0.2	At light, turn right (south) on 173 (East Seneca Tpk.) toward Jamesville, NY
41.0	1.8	Turn left (north) into Clark Reservation State Park – go to entry kiosk.
41.2	0.2	Park in lot, walk right to trial down to 'glacial' lake

STOP 3. CLARK RESERVATION STATE PARK (Graphic Log Figure 7)

41.2	0.0	Return out entry road
41.4	0.2	Turn left (east) on NY 173 (East Seneca Tpk.) and proceed through Jamesville
42.8	1.4	Intersection NY 173 and NY 91 – stay on NY 173 east
44.7	1.9	Junction NY 92 and NY 173 in Manlius – continue east on NY 173 (now Brinkerhoff Hill Rd.)
53.8	9.1	End of NY 173– proceed straight (east) on NY 5 & US 11 through Chittenango
54.6	0.8	Bear right NY 5 (east) & US 13 (north) (E. Genessee St.)
60.2	5.6	Turn right (south) on Oxbow Road in Canastota
63.0	2.8	Pull out into parking area going up the hill

STOP 4. CLOCKVILLE (Interpretive photomosaic and graphic log Figure 3)

63.0	0.0	Return north on Oxbow Road to Canastota
65.8	2.8	Turn left (west) onto NY 5 (west) & US 13 (south) (E Genessee St.)
71.4	5.6	Turn left (south) on NY 5 (west) & US 13 (south) into Chittenango, NY
72.1	0.7	Turn left (south) on US 13
77.3	5.2	Turn right into Chittenango Falls State Park – go to entry kiosk
77.4	0.1	Pull into parking lot and stop

STOP 5 – CHITTENANGO FALLS STATE PARK

Return out access road and turn right (south) – follow US 13 ~ 6.5 miles back to intersection of I-81 and US 13 (starting point of trip).

END OF FIELD TRIP