This book is dedicated to my children, Debra and Brian Belowich, Brian and Baylene Feldman, and my grandchildren, Alexa and Talia Belowich.

CONTENTS

INTRODUCTION

The papers herein not only provide a database for taxonomists, biostratigraphers, sedimentologists, and paleobiogeographers but also enhance our knowledge of marine communities and depositional environments, especially in the Paleozoic. They also increase our ability to correlate Paleozoic formations in the northeastern United States. The Ordovician Martinsburg Formation can be traced into Pennsylvania as can the Silurian Shawangunk Formation, the correlatives of which can be found as far south as Virginia. The Devonian Onondaga Limestone provides insight into formations such as the Anderdon Limestone, Lucas Dolomite, Amhertsburg Dolomite, and Sylvania Sandstone of the Detroit River Group in the Michigan Basin.

The brachiopods from the Paleocene Hornerstown Formation of New Jersey that occur in a biostrome on the New Jersey Coastal Plain help elucidate topoclines, chronoclines, and morphologic variation in the genus *Oleneothyris*. In addition, paleoecological information provides us with information about how these brachiopods lived and under what environmental conditions.

Ordovician-Silurian

The Martinsburg Formation was formed due to Ordovician plate convergence that involved a collision between proto-North America and a Taconic Island Arc as the Iapetus Ocean closed. As the collision progressed, a deep basin formed, into which was deposited a thick sequence of muds and dirty sands that were subsequently consolidated into what we now recognize as the Martinsburg Formation (Feldman et al., 2012). The Martinsburg is generally considered to be representative of a synorogenic basin that deepened as a result of Taconic tectonism (Epstein, 1986). Epstein and Lyttle (1987) consider the Martinsburg Formation in the Wallkill Valley as parautochthonous and Middle to Upper Ordovician in age. However, they believe that the parautochthonous sequence west and southwest of Albany

is not contiguous with the rocks of the Wallkill Valley and thus the Shale Bank at Mohonk from which a moderately diverse fauna was collected.

The Martinsburg Formation in the lower mid-Hudson Valley has yielded a *Sowerbyella-Onniella* brachiopod community with the following faunal constituents:

Sowerbyella
Onniella
Dalmanella
Ectenocrinus
Deceptrix
Cryptolithus
Isotelus
Conularia sp.
Trocholites
Corals
Ostracodes

In addition, numerous sedimentary structures were found: oscillation and interference ripple marks, gutter casts, cross-stratification, and linear to sinusoidal burrows. Based on the fauna and sedimentology, the depositional environment appears to have been relatively shallow water. McBride (1962) suggested that the Martinsburg Formation in the Great Valley was probably deposited at a depth of less than 2,000 m.

The Middle Silurian Shawangunk Formation lies unconformably above the Ordovician shales and graywackes of the Martinsburg. It crops out from near Rosendale, south through Wurtsboro, New York, High Point State Park and the Delaware Water Gap in New Jersey, and at Lehigh Gap, Pennsylvania, after which it continues into Maryland and Virginia (Feldman et al., 2014). The depositional environment of the Shawangunk was one of braided streams with deposition on a coastal plain of alluviation, a linear source toward the southeast, and a marine basin toward the northwest (Epstein et al., 1987; Feldman et al., 2014). *Arthrophycus*, found on the Shawangunk Ridge at Mohonk, near New Paltz, New York, is normally found on the bottom of beds; however, these specimens occur on the top of a bed. The trace maker may have been terrigenous but it is likely that it was formed in a marine environment, possibly estuarine since the basin was just to the northwest. Rises in sea level or tidal ebbs and flows would have enabled marine burrowers to form traces in the conglomerate, a fact supported by the occurrence of (euryhaline) eurypterids in the formation that lived in a wide range of salinities.

Devonian

The first serious attempt to study the fossils of the Onondaga Limestone (Eifelian) in New York was made by Eaton (1832) in which he mentioned twelve Onondagan species. In 1836 Governor Marcy established the Geological Survey of New York shortly after which detailed studies of the Devonian in the state began. In Vanuxem's Fourth Annual Report (1840), he referred to the "Corniferous Rock" of Eaton in which he noted the occurrence of *Cyrtoceras* from the Nedrow Member. In 1842, he published the first significant description of the Onondaga Limestone in which he included the outcrop belt in New York State's Third Geological District. In general the faunal constituents of the Onondaga, especially the brachiopods, were not very well known by workers in the nineteenth century. Hall (1840), in a discussion of the Fourth District, stated that his faunal list represents only a few of the most common and characteristic fossils and that the list will be greatly increased when we have succeeded in ascertaining the names of species.

The papers herein provide a thorough taxonomic treatment of Onondagan brachiopods from central New York through the lower mid-Hudson Valley.

Stratigraphy

Stratigraphically, the Onondaga consists of four members within the study area: Edgecliff, Nedrow, Moorehouse, and Seneca. In the mid-Hudson Valley, the Edgecliff Member can be recognized by abundant light-weathering chert seams with occasional crinoid stems present. It is finer-grained than in central New York and more than twice as thick in the eastern part of the state. Large crinoid stems are typical of the Edgecliff in the Syracuse area. The Nedrow Member in central New York is very shaly resulting in ledges on which brachiopods weather out. In the east, however, the Nedrow becomes thicker-bedded, less argillaceous and coarser-grained (Feldman, 1985). The Moorehouse Member in the Hudson Valley can be recognized by its dark-weathering chert seams and greater thickness. In central New York the Moorehouse is lighter in color with lighter chert. Silicified fossils are found in the east but not the central part of the state. The Seneca Member is an

argillaceous limestone with few fossils except for the chonetids found in the pink "Chonetes" (*Hallinetes*) Zone 10 ft above the base in central New York (Feldman, 1985). The Tioga Bentonite separates the Moorehouse from the Seneca in the Syracuse area. The Seneca Member does not crop out east of Cherry Valley, New York.

Community Ecology

The Onondaga Limestone was deposited in a low-energy environment (Feldman, 1980). The hard-shell component of the Onondaga (brachiopod) communities are closely representative of the living communities. There was little post-mortem transport and no significant destruction of the shells due to biopredation of diagenesis. Here I define community as a recurrent association of taxa that were presumably controlled by a set of environmental factors such as: temperature, pressure, current and/or wave action, light penetration, nutrients, water chemistry, dissolved oxygen, and miscellaneous factors (biotic relationships such as symbiosis; mechanical wear, etc.) (Feldman, 1980). It should be noted that there are many varying views on exactly what defines a community. MacArthur (1971), as cited in Boucot (1981), summarized the community definition question well by an appropriate quote from Lewis Carroll: "Humpty Dumpty told Alice, 'when I use a word, it means just what I choose it to mean—neither more nor less' (pp. 189-190)."

The communities described herein are named after the dominant brachiopod taxa. Nine brachiopod communities are recognized in the Onondaga Limestone:

Atrypa-Coelospira-Nucleospira
Atrypa-Megakozlowskiella
Atrypa
Leptaena-Megakozlowskiella
Pacificacoelia
Levenea Community I
Levenea Community II
Amphigenia?
"*Chonetes*" (now *Hallinetes*)

The communities named above belong to Benthic Assemblage 3. A Benthic Assemblage is a group of communities that occur repeatedly in parts of a region in the same position relative to shoreline (Boucot, 1975). Boucot (1975) noted that Benthic Assemblages are probably temperature controlled

and highly correlated with depth. Some of the Onondaga communities, such as the *Atrypa-Coelospira-Nucleospira* Community, closely resemble Wang et al.'s (1987) Eifelian *Atrypa-Xystostrophia* Community from the Shan States of Burma in faunal composition as well as depositional environment, that is, a normal, quiet water marine environment (Benthic Assemblage 3). The faunal composition of the *Atrypa-Coelospira-Nucleospira* Community (AMNH locality 3137), in order of abundance, is as follows:

1. *Atrypa*
2. *Coelospira*
3. *Nucleospira*
4. *Megakozlowskiella*
5. *Acrospirifer*
6. *Pentamerella*
7. *Dalejina*
8. *Pentagonia*
9. *Mucrospirifer*
10. *Schizophoria*
11. *Cyrtina*
12. *Elytha* (*Elita*)
13. *Athyris*
14. *Cupularostrum*

Paleocene

In the Paleocene Hornerstown Formation, central New Jersey, two species of large very well-preserved terebratulid brachiopods belonging to the genus *Oleneothyris* (*O. harlani* and *O. subfragilis*) can be found in a biostrome that occurs at the top of the formation. The Hornerstown Formation strikes in a northeasterly direction in a belt along New Jersey's coastal plain (Feldman, 1977a) and is in gradational contact with the overlying Vincentown Formation, whereas the lower contact varies geographically.

Paleoecology

The macrofauna of the Hornerstown Formation is very diverse and includes the following groups:

Porifera
Cnidaria
Brachiopoda
Bryozoa
Echinodermata
Annelida
Decapoda
Mollusca
    Cephalopoda
    Gastropoda
    Pelecypoda
Chordata

The presence of *Cardium* in the upper part of the Hornerstown Formation suggest a sandy bottom, as does the fact that there is an absence of clay-sized particles (Feldman, 1977a). Although deposition in the upper part of the formation was in shallow water with strong wave and current action, post-mortem transport was minimal. The brachiopod community was dominated by one trophic group but the next most dominant species belonged to a different trophic group. The *Oleneothyris* Community conforms to Recent Arctic and Boreal (see Turpaeva, 1957). Morphologic changes in *Oleneothyris* can be correlated with increased turbulence on the sea floor.

Feldman (1977b) described *Oleneothyris fragilis* (subsequently changed to *O. subfragilis* [Feldman, 1985]) also found in the Hornerstown Formation. The species is known only from the biostrome at the top of the formation in New Jersey (Feldman, 1977b) whereas *O. harlani* occurs in Delaware, Maryland, and Alabama.

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Finally, thanks to my family, who still wonders why I have so many "rocks" all over the house, garage, and garden. I recently found an essay written in sixth grade describing how I would become a paleontologist and I remember how my father strenuously argued that I keep paleontology as a hobby and get a "real" career.

It should be noted that a variety of traditional authorities and texts have dealt with the particular issues concerning the age of the universe, and have offered diverse approaches for resolving any apparent conflicts that might arise between Jewish tradition and modern science on this matter.[1] This author follows the lead of these traditional authorities in operating with the accepted principles of the science of paleontology.

[1] See, e.g., Babylonian Talmud, standard editions, Hagigah 13b; Midrash Bereshit Rabba, ed. J. Theodor and C. Albeck (Jerusalem, 1996), 3, 5; Rabbi Isaac of Akko, Ozar ha-Hayyim, Ms. Moscow-Russian State Library, Guenzburg 775, 86b-87b; Rabbi Yisrael Lifshitz, Derush Or Ha-Hayyim, in his Tiferet Yisrael on Mishnah, end of Nezikin (Danzig, 1845), 276b-279b.

NOTES ON THE GEOLOGY OF THE SHAWANGUNK RIDGE ON THE MOHONK PRESERVE AND ENVIRONS

ABSTRACT

The Shawangunk Formation, a quartz pebble conglomerate of Middle Silurian age, extends from the lower mid-Hudson Valley through New Jersey and into Pennsylvania. It overlies the Ordovician Martinsburg Formation, which is composed of shales and graywackes. The Martinsburg crops out on the Shawangunk Ridge and is quarried by Mohonk Mountain House in New Paltz, New York, in order to prevent erosion and provide good footing on the trails. The quarry, locally known as the "Shale Bank," contains a diverse marine fauna of brachiopods, crinoids, bivalves, ostracodes, corals, trilobites, and conulariids. In this community, the partition of feeding niches results in a reduced competitive trophic structure and therefore increased community stability. Within the Shawangunk Formation, there are rare "pods," domelike structures that are filled with a gray matrix of rounded quartz grains supported by a clay matrix. The pods appeared to have formed along cleavage surfaces. A previously unrecognized metal sulfide deposit has been discovered in the conglomerate along Eagle Cliff. This deposit consists of the Fe-sulfide phases pyrite and marcasite, lesser amounts of the Cu-Fe sulfide chalcopyrite, and trace amounts of anglesite (Pb-sulfate). An outcrop of the Middle Devonian Onondaga Limestone in the Port Jervis Trough contains large crinoid columnals, the coral *Amplexiphyllum,* trilobite fragments, and the brachiopod *Levenea subcarinata.* The Onondaga in this area is part of a carbonate ramp that was a shallow carbonate shelf in the Helderberg-Coxsackie area, a thick accumulation of shelf-margin bryozoan bafflestone between Leeds and Saugerties, and an even thicker accumulation of sparse to packed biocalcisiltites deposited on a carbonate ramp dipping southward into the Port Jervis area.

INTRODUCTION

The Middle Silurian Shawangunk formation lies unconformably above Ordovician graywackes and shales of the Martinsburg Formation. Near Otisville and Port Jervis, the Shawangunk is overlain by the Bloomsburg Red

Beds, which crop out to the west in Pennsylvania and New Jersey (Epstein, 1993). The fluvial deposits of the Tuscarora and Shawangunk formations accumulate to the northwest of uplands lifted during the Taconic Orogeny. Thus, the source area lays to the southeast, and the marine basin lays to the west of the Shawangunk/Bloomsburg fluvial plains. The Shawangunk Formation gradually thins from Port Jervis to its disappearance just north of New Paltz. In the early Paleozoic Era, carbonate banks lay along the east coast of proto-North America. Ordovician plate convergence involving proto-North America formed a deep basin into which a thick sequence of muds and dirty sands accumulated. These deposits were subsequently consolidated to form the Martinsburg Formation. The Martinsburg was deformed during the mountain-building episode known as the Taconic Orogeny. The trend, or strike, of these rocks in southeastern New York is approximately 20 degrees toward the northeast. The intensity of deformation diminishes to the west. The Taconic Mountain system shed coarse sediment that was transported westward as fluvial conglomerates and sandstones of the Shawangunk Formation over beveled folds of the Martinsburg Formation. To the northwest, erosion of the source area was intense and the climate, based on the mineralogy of the rocks, was warm and at least semiarid (Epstein and Lyttle, 1987). The source was composed predominantly of sedimentary and low-grade metamorphic rocks that hosted abundant quartz veins and local occurrences of gneiss and granite. Progressive erosion of the source regions caused the steep, braided streams of the Shawangunk to give way to the lower-gradient meandering streams from which the Bloomsburg Red Beds accumulated. The abundance of vein quartz could explain the abundant conglomerate of the Shawangunk Formation. A thin diamictite (a poorly sorted, noncalcareous, land-derived sedimentary rock that contains a wide range of particle sizes) with exotic pebbles records a brief geologic episode of colluvial deposition that occurred during the Taconic hiatus (Epstein, 1989). As the mountains eroded, finer clastic sediments and even carbonates accumulated more or less continuously through the Middle Devonian Period. Clastic influx during the Middle Devonian records another, later mountain-building episode, the Acadian Orogeny.

REGIONAL OVERVIEW

The highest point in the Shawangunk Mountains (698 m [2289 ft]) lies near Sam's Point (Figure 1). On a clear day, one can see (from southeast to

north) the New York highlands underlain by Precambrian rocks thrust on top of Cambrian and Ordovician carbonates and shales of the Wallkill Valley. West of the highlands are Schunnemunk and Bellvale mountains underlain by conglomerates and sandstones of the Middle Devonian Schunnemunk Conglomerate in the Green Pond Outlier. The rocks of the outlier are in fault and sedimentary contact with the Precambrian. The Shawangunk and Kittatinny mountains, held up by the Shawangunk Formation, trend to the southwest, with Tristates Monument marking the highest elevation in New Jersey at High Point (550 m [1803 ft]). The Shawangunk at Sam's Point dips very gently to the northeast, near the broad crest of the Ellenville Arch. Tough cross-bedding is well exposed and indicative of current trends ranging between 80SW and 70NW. Glacial striae with chattermarks on the bedding surfaces indicate that the Wisconsinan glacier flowed over the mountains moving 16SW. The lower 24 m (80 ft) of the Shawangunk here consists of medium- to thick-bedded conglomerate with quartz pebbles as much as 5 cm (2 inches) long. Channel cuts are common. Nowhere do we see any pebbles from the underlying Martinsburg, a peculiarity that exists throughout New York, New Jersey, and eastern Pennsylvania, and one that eludes a good sedimentologic explanation. The Shawangunk is separated into blocks tens of feet wide that have moved apart along the soft shales of the underlying Martinsburg, probably forced apart by gelifraction, wedging of boulders that fall into the cracks, and block sliding. At the Ice Caves, 0.8 km (0.5 mi) to the east, the joints parallel the cliff face of the mountain (Feldman and Thompson, 2008), and cold air trapped in the maze of blocks and snow may persist throughout the summer, hence their name.

In Devonian times, there was a shallow carbonate shelf in the Helderberg-Coxsackie area that graded into a shelf-margin bryozoan bafflestone near Leeds and Saugerties. Further southwest toward Port Jervis, the sediments consisted of sparse to packed biocalcisiltites deposited on a carbonate ramp. This ramp occupied the northern margin of a structural basin depocenter, located to the east of and not directly related to the topographic basin of central New York, which was centered in the Tristates vicinity from the Late Silurian until the early Middle Devonian (Lindemann and Feldman, 1987).

THE "SHALE BANK"

The Martinsburg Formation (Figures 2-3) crops out about 1.6 km (1 mi) from the entrance to Mohonk Mountain House (on Mountain Rest Road).

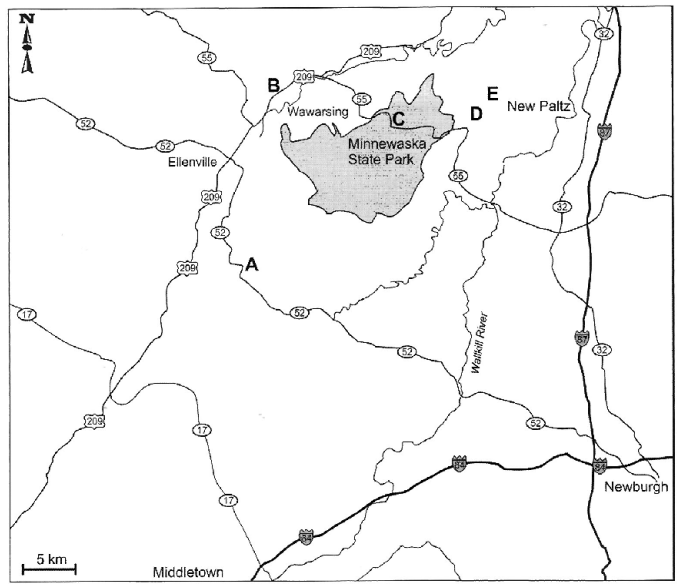

FIGURE 1. Locality map of the mid-Hudson Valley. A) Sam's Point; B) Onondaga Limestone in Wawarsing, NY; C) Mysterious "pods" in Minnewaska State Park; D) The "Shale Bank"; E) Eagle Cliff Road just to the west of Lake Mohonk.

Mohonk workers quarry and crush the shale in order to provide good footing and slow down erosion on the carriage roads. The outcrop consists of 14 m (45 ft) of predominantly dark gray shales and siltstones interbedded with fine-grained graywacke beds, occasional prominent pyrite layers, and disseminated sphalerite, chalcopyrite, and galena. Oscillation ripples can be observed on some bedding surfaces. Carbonaceous material occurs mostly as fine-grained patches throughout the matrix. The studied exposure illustrates a high degree of strain, mostly manifested by shiny quartz slickensided surfaces, small-scale cross-laminated and parallel-laminated strata, and ripple marks. Crinoid stems, some slightly disarticulated, and free columnals occur on different bedding surfaces, indicating a possible change in current regime. Scattered linear to sinusoidal horizontal burrow structures ranging in diameter from 0.5 to 3 cm are found on silty beds; some of the burrows are infilled with course quartz grains. Gutter casts are scattered throughout the section. The faunal constituents of this *Sowerbyella-Onniella* Community (Figure 4) include brachiopods (93%), crinoids (*Ectenocrinus*; 3%), bivalves (*Deceptrix?*; 3%), ostracodes (<1%), corals (<1%), trilobites (*Cryptolithus, Isotelus*; <1%), conulariids (<1%)

and unidentified burrowers (<1%). Brachiopods are represented by a low-diversity assemblage of *Sowerbyella* and *Onniella* with occasional *Dalmanella.* The fauna can be classified into distinct trophic groups: (1) high-level suspensions feeders (crinoids, corals); (2) low-level suspension feeders (brachiopods, bivalves); (3) animals that collect food from the sediment surface (ostracodes, trilobites); and (4) animals that feed within the sediment (burrowers). This partition of feeding niches leads to a reduced competitive trophic structure and therefore increased community stability. The community appears twice in the section, separated by about 4.9 m (16 ft) and thus appears to be stable. The depositional environment of this fauna may have been in relatively deep water as evidenced by gutter casts, at the bottom of which are shell accumulations, as well as a lack of bioturbation in the sediments. However, the moderately diverse fauna and oscillation ripples indicate a shallower environment. In addition, there are auriculate nuculoid bivalves that were shallow infaunal and deposit-feeding organisms. The sediments were probably not deposited at depths of greater than 2000 m, as suggested by McBride (1962), in the Martinsburg Formation at the Great Valley. Lehman and Pope (1990) noted that Bretsky (1970) divided the Reedsville and Martinsburg formations of the central Appalachians into three paleocommunities, one of which was the *Sowerbyella-Onniella* Community. This community, according to Bretsky (1970), corresponds to a deep-water depositional environment. The fauna at the "Shale Bank" very closely resembles the *Sowerbyella-Onniella* communities of Lehman and Pope at Swatara Gap and Bretsky's community of the central Appalachians, although the *Sowerbyella-Onniella* Community along the Shawangunk Ridge is much less diverse than the other two and was most likely deposited in shallower water. Bretsky never defined the absolute depth of his communities (Bretsky, 1970; Lehman and Pope, 1990).

"PODS" OF UNKNOWN ORIGIN

Within the Shawangunk Formation, we note occurrences of what we term "pods" that are domal in cross section with a flat base, the bottoms of which often contain quartz pebbles. The matrix is dark gray and consists of interstitial quartz ranging in size from fine (0.25-0.125 mm) to coarse (1.00-0.5 mm) sand and muscovite mica (Figure 5). The pods are aligned along bedding and, in many cases, crossbedded foresets, and range in size from 0.2 to 7 cm in diameter (at the base) and 0.2 to 6 cm in height. The rock that hosts

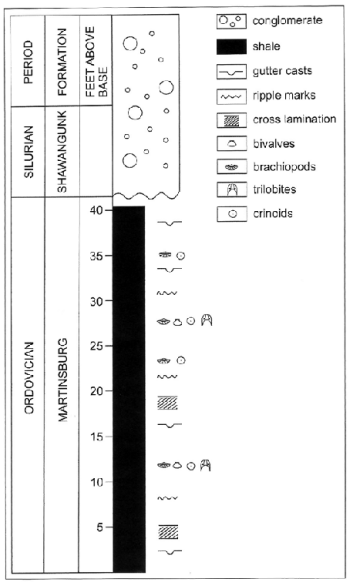

FIGURE 2. Columnar stratigraphic section of the Martinsburg and Shawangunk formations in the "Shale Bank" at Mohonk. The Martinsburg Formation, estimated to be between 3048-3658 m (10,000-12,000 ft) thick in the mid-Hudson Valley, is highly deformed. Based on field relations, the "Shale Bank" is considered to be near the top of the Martinsburg, but due to repetition of beds in the area, it is difficult to precisely determine exactly how close to the top of the formation it lies.

FIGURE 3. The steeply dipping Ordovician Martinsburg Formation in the "Shale Bank" on the Shawangunk Ridge.

the pods is composed of pressure solution welded quartz grains consistent with the quartzitic nature of the formation. There is no evidence of stratification. The origin of the pods is under investigation (Feldman et al., 2009), and possibilities include microbial mounds, sponges, or mud balls. Pods are similar in outline to some thrombolites in that the internal texture is nonlaminated; however, there is no indication of microbial activity such as clotting. Though the pods may represent algal mats, their association with braided fluvial deposit renders this interpretation doubtful. It is possible that they are the remains of sponges, since the braided streams drained into a marine basin and the resulting tidal incursions may have supported sponges in an estuarine