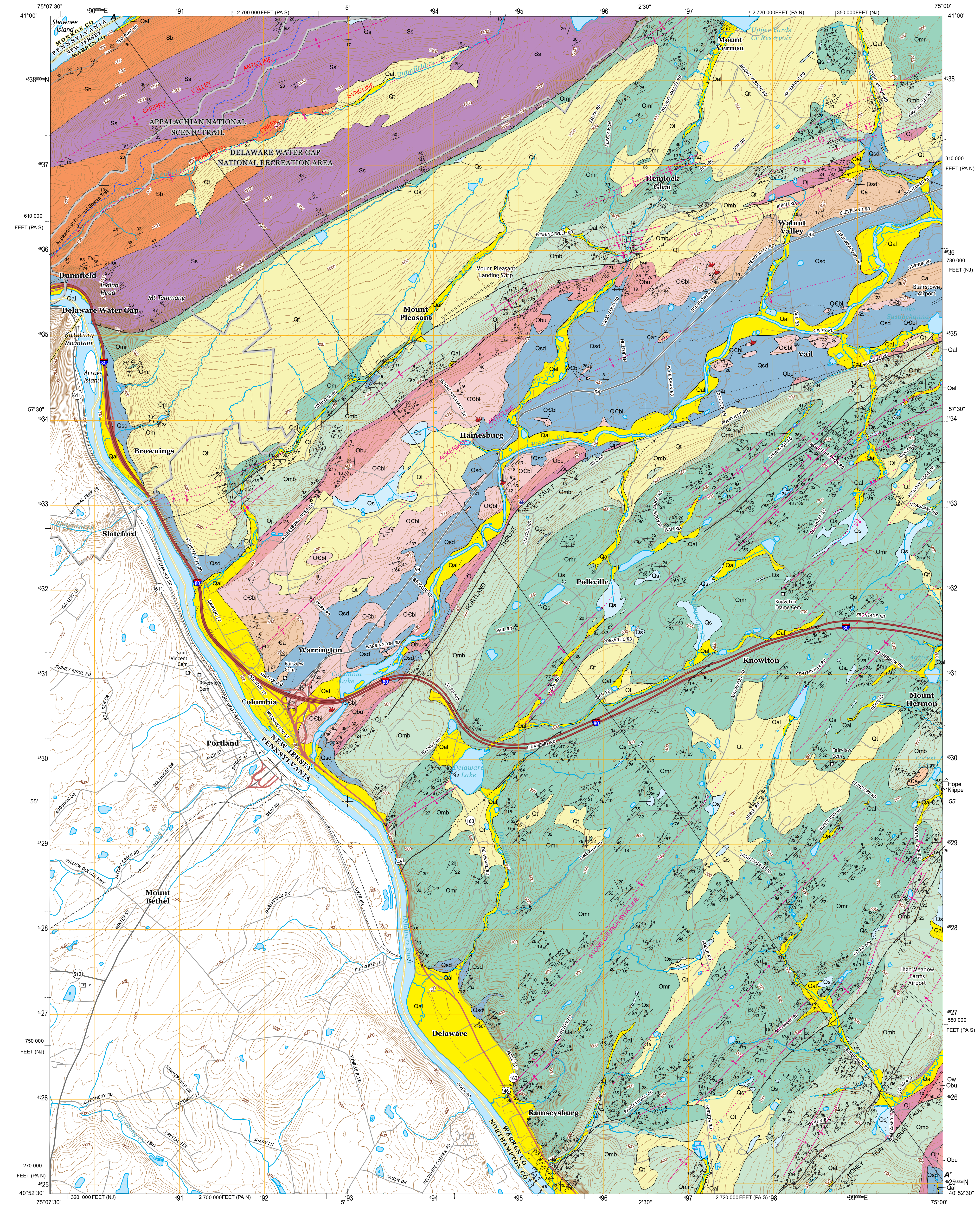
DEPARTMENT OF ENVIRONMENTAL PROTECTION
WATER RESOURCES MANAGEMENT
NEW JERSEY GEOLOGICAL AND WATER SURVEY

Prepared in cooperation with the
U.S. GEOLOGICAL SURVEY
NATIONAL GEOLOGIC MAPPING PROGRAM

GEOLOGIC MAP OF NEW JERSEY PORTIONS OF THE PORTLAND
QUADRANGLE, WARREN COUNTY, NEW JERSEY
GEOLOGIC MAP SERIES GMS 21-2

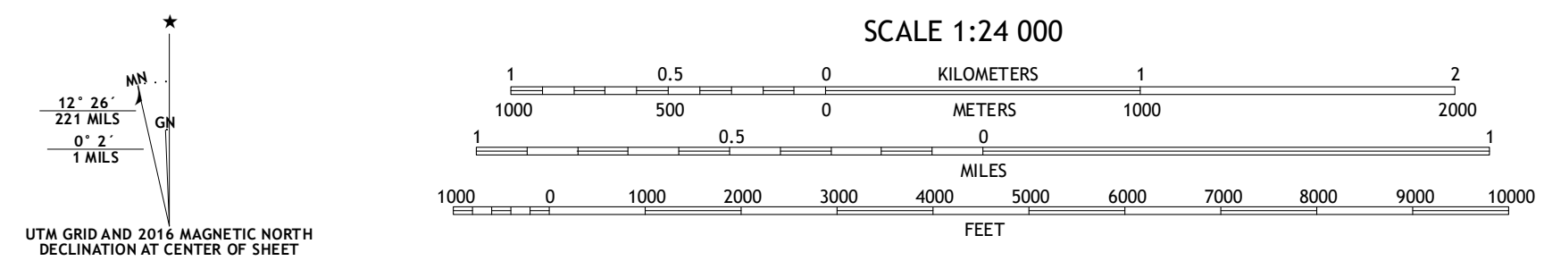


Produced by the United States Geological Survey
North American Datum of 1983 (NAD83)
World Geodetic System of 1984 (WGS84). Projection and
1 000-meter grid: Universal Transverse Mercator, Zone 18T
10 000-foot ticks: New Jersey Coordinate System of 1983,
Pennsylvania Coordinate System of 1983 (south and north zones)

This map is not a legal document. Boundaries may be generalized for this map scale. Private lands within government reservations may not be shown. Obtain permission before entering private lands.

Imagery..........NAIP, July 2013
Roads..........U.S. Census Bureau, 2015 - 2016
Names..........GNIS, 2016
Hydrography..........National Hydrography Dataset, 2013
Contours..........National Elevation Dataset, 2000
Boundaries..........Multiple sources; see metadata file 1972 - 2016

Wetlands..........FWS National Wetlands Inventory 1977 - 2014



U.S. National Grid
100,000-m Square ID
VL
Grid Zone Designation
18T

CONTOUR INTERVAL 20 FEET
NORTH AMERICAN VERTICAL DATUM OF 1988

1	2	3
4		5
6	7	8

ADJOINING QUADRANGLES

1 East Stroudsburg
2 Bushkill
3 Flatbrookville
4 Stroudsburg
5 Blairstown
6 Bangor
7 Belvidere
8 Washington

ROAD CLASSIFICATION
Expressway
Secondary Hwy
Ramp
Local Connector
Local Road
4WD
Interstate Route
US Route
State Route

Bedrock geology mapped by D.H. Monteverde and G.C. Herman[1] in 1985-1988, 2018-2019
Surficial geology mapped by R.W. Witte and J. Ridge (in preparation)
Reviewed by Dr. Jeffery Webber, Stockton University
Digital cartography by D.H. Monteverde, R.S. Pristas and Nicole Malerba

Submitted in fulfillment of U.S. Geological Survey Award Number G18AC00178. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

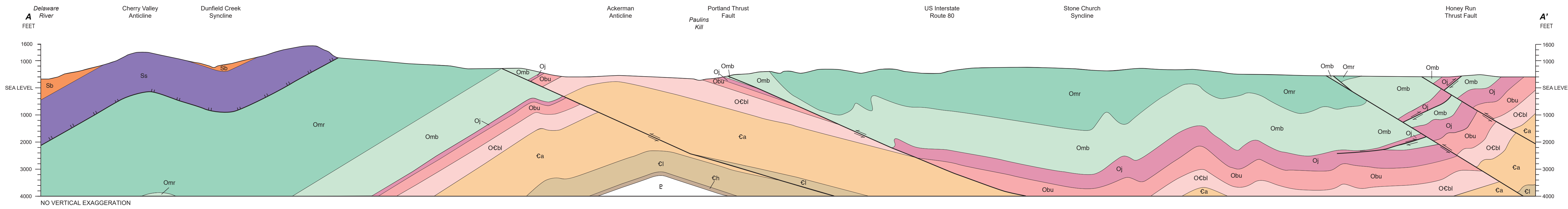
Geologic Map of the New Jersey portions of the Portland Quadrangle, Warren County, New Jersey

by

Donald H. Monteverde and Gregory C. Herman[1]

2021

[1] retired, New Jersey Geological and Water Survey



EXPLANATION OF MAP SYMBOLS

CONTACT - Long dashed where approximately located; short dashed where inferred; dotted where concealed, queried where questionable.

FAULT - Long dashed where approximately located; short dashed where inferred; dotted where concealed; queried where questionable.

Thrust fault - Sawteeth on upper plate.
Detachment fault - Identity questionable, location approximate. Hachures on upper plate.

FOLD - Shows trace of axial surface. Long dashed where approximately located; short dashed where inferred; dotted where concealed.

Anticline
Syncline
Overturned anticline
Overturned syncline

PLANAR FEATURES

Strike and dip of bedding
- Inclined
- Vertical
- Overturned

Strike and dip of slaty cleavage
- Inclined

Strike and dip of crenulation cleavage
- Inclined
- Vertical

LINEAR FEATURES

Bearing and plunge of intersection of bedding and slaty cleavage.
- Inclined
- Horizontal

Bearing and plunge of intersection of slaty cleavage and crenulation cleavage.
- Inclined
- Horizontal

OTHER FEATURES

Location of conodont age constraint equivalent to Stonehenge Formation (Beekmantown lower part (Harris and others, 1995).

Location of conodont age constraint equivalent to Jacksonburg Limestone (Harris and others, 1995).

Appalachian National Scenic Trail

National Park boundary

INTRODUCTION

The Portland quadrangle covers parts of New Jersey and Pennsylvania that are separated by the south flowing Delaware River. It lies within the Valley and Ridge Physiographic Province. Only the New Jersey portion of the quadrangle was geologically mapped. Northeast-trending Kittatinny Mountain dominates the topography of the region. Smaller bedrock ridges generally parallel the same northeastern trend as Kittatinny Mountain. More northerly trending ridges along the southern base of Kittatinny Mountain result from Pleistocene glaciation which locally left behind thick blankets of glacial and meltwater sediment (Witte and Ridge, in preparation). Fluvial drainage in this section of New Jersey trends southwestward into the Delaware River. The Paulins Kill and Dunnfield Creek are the largest tributaries feeding into the Delaware. Worthington State Forest and the Delaware Water Gap National Recreation Area (DEWA) cover a large area of the northern part of the quadrangle and offer public access for hiking, camping, hunting and boating. The Appalachian Trail winds through both Worthington State Forest and DEWA.

STRATIGRAPHY

Cambrian and Ordovician sediments underlie the topography south of Kittatinny Mountain. These rocks record the development of a passive continental margin following the initial breakup of the Supercontinent Rodinia and subsequent collision with an island arc complex of the Taconic orogenic event. The breakup of Rodinia led to a transgression and development of a broad carbonate passive margin; the Hardyston Quartzite and Leithsville Formation, only represented in cross section, mark the initial transgression and basal sedimentation of the carbonate-dominated passive margin. The Allentown Dolomite overlies the Leithsville and contains abundant stromatolites, oolites, and quartz sand lenses marking a shallow marine carbonate environment. The overlying carbonate deposits of the Beekmantown Group continued the development of the passive margin. An unconformity marks the beginning stages of the Taconic Orogeny which closed the Iapetus Ocean. Cambro-Ordovician carbonates have been almost completely dolomitized across New Jersey. Initially the subdivision of the Beekmantown Group rocks in New Jersey was based on the work of Hobson (1963) in the Reading, Pennsylvania area. Hobson correlated his units across eastern Pennsylvania to the Delaware River and just into New Jersey. From his work his basal unit, the Stonehenge Limestone, pinched out to the east toward New Jersey. He mapped his next younger unit, the Rickenbach Formation, as the basal section of the Beekmantown Group in New Jersey. It is overlain by the Epler Formation which is dominantly a dolomite with limited limestone interbeds. Drake (1965, 1969) followed this interpretation on early U.S. Geological Survey geologic maps of quadrangles in the southwestern Valley and Ridge and Highlands Physiographic Provinces in New Jersey. Later, Markewicz and Dalton (1977) further subdivided the New Jersey Beekmantown Group into various members traceable across northwestern New Jersey. These authors placed the few limestone beds found within the Beekmantown into either the Epler Formation or the younger Ontelaunee Formation which Hobson (1963) described as an alternating interbedded limestone and dolomite unit.

The degree of dolomitization in New Jersey exceeds that in the Reading area of Pennsylvania which later created different correlations between Hobson's initial work and later workers (Figure 1). The difference in interpretation arose from the introduction of conodont-based ages across this dolomitized terrain. These ages resulted in the New Jersey units mapped as the Rickenbach Formation and the overlying Epler Formation being age equivalent with the Stonehenge Limestone in its type area in Reading, Pennsylvania (Karlins and Repetski, 1989; Harris and others, 1995; Repetski and others, 1995). Harris and others (1995) list nine sites on the Portland quadrangle where conodonts were collected. Eight sites contain fossil conodonts that are age equivalent to the Stonehenge Limestone. Age dates of conodonts from the remaining sites was distinguished as belonging to the younger Jacksonburg Limestone (Figure 2). Drake and Lyttle (1985) started using the name Stonehenge Limestone but changed it to a Formation due to its degree of dolomitization in New Jersey. Dalton (personal communication, 1997) maintained the original breakdown of the carbonates in New Jersey as suggested by Hobson (1963). Drake and others (1996) divided the Beekmantown Group into an Upper and Lower Part. Both Drake and others (1996) and Markewicz and Dalton (1977) recognize the contact between the Upper and Lower Parts though they each use this boundary differently. Drake and others (1996) suggest the boundary lies between the Stonehenge and Rickenbach formations while Markewicz and Dalton (1977) and Dalton and others (2014) placed this same boundary between the Epler and younger Ontelaunee Formation. The current map returns to the subdivision of Drake and others (1996). Drake and Lyttle (1980) placed formations including the Hardyston, Leithsville, Allentown, and formations including Stonehenge, Rickenback, Epler and Ontelaunee that are mapped here as Beekmantown Lower and Upper Parts into the Kittatinny Valley Supergroup. Drake and others (1969) original map of parts of the Portland quadrangle predates the conodont ages of the carbonate rocks, therefore Stonehenge was not identified. Later work by Drake and others (1985) first identified the Stonehenge Limestone within the Portland quadrangle but still used the older stratigraphy over most of the carbonate mapped units.

The passive margin ends with the approach of an island arc and the Taconic Orogeny which resulted in the closing of the Iapetus Ocean in this region. A peripheral bulge formed due to thrust loading caused by the approaching island arc on an eastward dipping subduction zone (Jacobi, 1981; Quinlan and Beaumont, 1984). The westward migrating peripheral bulge uplifted, exposed and eroded the Beekmantown Group carbonates. This erosion accounts for the variable thickness of the Beekmantown Group Upper Part and local paleokarst features observed across the quadrangle (Monteverde and Herman, 1989). With the passing of the bulge the region subsided with a transgression and deposition of the Sequence at Wantage, a locally preserved unit of reworked residual material of the regolith from the erosional event. Marine waters deepened leading to the deposition of two facies within the Jacksonburg Limestone. The cement-lime facies, a highly fossiliferous limestone, developed under shallow to moderate water depths. The continued bulge migration and deepening water depths produced an argillaceous limestone known as the cement-rock facies which marks the change to a foreland basin. Down slope turbidite sediments of the Martinsburg Formation show the complete change to a foreland basin. Two members of the Martinsburg, both distal ribbon slates of the Bushkill Member and the more proximal graywacke silts and sands of the Ramseyburg Member, define a change in proximity of the sediment deposited into the basin. A third member, the Penn Argyl Formation, just to the west in Pennsylvania, consists of a thick sequence of slate beds that may cross the Delaware River into New Jersey at the base of Kittatinny Mountain. Further work is needed on this due to limited exposure. Continued closing of the Iapetus Ocean led to the deformational features that mark the Taconic Orogenic event.

Post-orogenic uplift led to subaerial erosion of the Martinsburg. Erosion and westward flowing rivers from the Taconic Mountains created a thick cover of molasse sediment over the eroded Martinsburg. These sediments mapped as the Shawangunk Formation were transported in braided steams and in transitional marine-continental environments (Epstein and Epstein, 1972). Gray and Zeitler, (1997) analyzed zircons in quartz clasts within the Shawangunk that yielded U/Pb ages ranging from 950-1200 Ma (million years) indicating a Grenville orogenic source and therefore a west directed transport for the Shawangunk. Local chert and shale clasts suggest provenance of some materials to be Lower Paleozoic in origin. Fluvial deposition continued in the overlying Bloomsburg Red Beds.

STRUCTURE

The Portland quadrangle shows evidence of both the Taconic and Alleghenian Orogenic events. Previous workers (Merchant and Teet, 1954; Offield, 1967; Herman and others, 1997) who studied rocks in the northern New Jersey and southern New York suggested that only broad open folds remain from the Taconic Orogeny with emergent Taconian faults much farther to the south. In their model, folds are over steepened to overturned near the Taconic faults. Stress decreased northward with the overturned folds gradually diminishing to broad open folds. Later Alleghanian deformation developed northwest verging thrust faults that subsequently deformed the Taconic folded cover sequence. Workers (Drake, 1967a, 1967b, 1969) who began work in the southern New Jersey Highlands Province developed a Taconic-aged nappe model for the Lower Paleozoic and Mesoproterozoic rocks of the region. Drake and others, (1969, 1985) applied the nappe model to explain the geology of the Portland quadrangle. Revised interpretations of the regional structure were advanced beginning with Herman and Monteverde (1988,1989), then Drake and others (1996), and Herman and others (1997).

The geology of the Portland quadrangle is dominated by a series of broad anticlines and synclines, small scale overturned folds and northwest directed thrust faulting. The broad folds allow a general subdivision characterized by different rock types that also follow age. A broad anticline, the Ackerman anticline (Drake and others, 1985) underlain by Cambrian and Ordovician carbonates, traverses the quad in an east-northeast direction. To the south is a broad syncline, the Stone Church syncline (Drake and others, 1985) marked by folded Ordovician turbidites of the Martinsburg Formation. The Paulins Kill Thrust Fault forming the boundary between these two folds continues approximately 30 miles to the northeast where it ends in the Branchville quadrangle (Drake and Monteverde, 1992). Northeast trending thrust faults occur in the southeast corner of the quadrangle. North of the Ackerman anticline a northern belt of Martinsburg turbidite units that generally dips westward is overlain by Silurian-aged clastic rocks. A single unnamed south-dipping thrust fault lies near the boundary between the carbonate-cored Ackerman anticline and the northern Martinsburg belt. Drake and others, (1969,1985) originally interpreted this fault as the west dipping continuation of the Paulins Kill Thrust Fault in the nappe structure. However, this thrust fault shows older rocks in the hanging wall over younger rocks of the footwall. This differs from the Paulins Kill Thrust Fault where younger rocks in the hanging wall were thrust over older rocks in the footwall. This suggests a possible interpretation of the Ackerman anticline as an older structure that was later cut by the two faults to the north and south. Lastly a small isolated klippe and an extension of the Hope Klippe (Drake and Lyttle, 1985), remnants of a northwest verging thrust fault along the base of Jenny Jump Mountain (Bayley and others, 1914) to the east in the Blairstown quadrangle, lie along the east central part of the quadrangle. They contain the Allentown Dolomite which over lies the Bushkill Member of the Martinsburg Formation.

Rocks of the Ackerman anticline display a mixed dip direction as equal exposure occurs on both sides of the axial surface trace. Using the Cylindrical Best Fit app on Stereonet software of Allmendinger and others (2013) and Cardozo and Allmendinger (2013) poles to bedding of the carbonate rocks (Figure 3) within the Ackerman anticline define a fold axis with a trend and plunge of 1/6 that best fits the great circle of 143/89 of poles to bedding (Figure 3). These trends compare well with the southern Martinsburg belt which has a trend and plunge fold axis of 2/047 and a best fit great circle to the poles of 136.8/88 (Figure 3). The northern Martinsburg belt has a similar trend, but the fold axis plunges to the southwest instead of the northeast as do the carbonate belt and southern Martinsburg. This change relates to the near vertical dip of the great circles of the different areas. Only a small change in dip will swing the fold axis to approximately 180 degrees. The northern belt has a fold axis of 2/240 on a great circle of 330/88.

Ordovician Martinsburg rocks have a well-developed cleavage that is better developed in slate beds then the coarser-grained layers. Both the Silurian units, due to a coarser grain size, and the blocky Cambrian and Ordovician carbonate formations generally lack a cleavage. As deformation generally increases towards the south across the quadrangle an additional crenulation cleavage associated with thrusting is present in the southeastern part of the map. Cleavage trends differ slightly from the northern to the southern Martinsburg belts with a best fit great circle to the southern belt at 144/86 and the northern belt at 158/89 (right hand rule; figure 3). The best fit fold axis for the southern belt is 4/54 and for the northern belt is 1/68. The crenulation cleavage has a best fit great circle of 135/86 and best fit fold axis of 4/045.

Bedding-cleavage intersection lineations appear quite complimentary to each other, both north and south of the Ackerman anticline (Figure 4). Martinsburg rocks display both northeast and southwest plunge directions. The northern Martinsburg belt has similar trends with a higher concentration to the southwest. The southern Martinsburg belt data shows approximately equal trends both northeast and southweast with a similar trend for the crenulation cleavage.

Silurian Shawangunk Formation and Bloomsburg Red Beds, the only post Taconic sediments in the quadrangle, form a broad syncline-anticline pair, the Dunnfield Creek syncline and Cherry Valley anticline (Drake and others, 1969). Epstein and Epstein (1967, 1969) described disharmonic folding between the Martinsburg and the Silurian units on this quadrangle. They characterized the boundary separating these rocks as "décollements or zones of décollements". They suggest these décollement zones may be discrete surfaces but are more commonly zones of deformation that allow detachment between layers and or lithologies of different rheology as they react to the tectonic strain and thereby create the disharmonic folds. Epstein and Epstein (1967, 1969) model these décollements as generally northwest dipping and having an overall motion of tops to the northwest. Epstein (2001) described an example of shearing within a two-inch thick clay gouge at a possible décollement at Yards Creek to the north in the Bushkill quadrangle. Mapping of this boundary here and to the north would be better described as detachment faults which fade out to the northeast. No exposures of the Martinsburg-Shawangunk contact have been found in the mapped area to verify the existence of a similar slip surface as described by Epstein (2001). Shawangunk and Bloomsburg bedding trends mimic those of the northern Martinsburg belt with a best fit great circle for the Silurian beds as (strike/dip, right hand rule) 335/85 as compared to the Martinsburg at 330/88 (Figure 3). Trend and plunge of calculated cylindrical best fit is 245/2 for the Silurian units and 240 in the Martinsburg rocks.

DESCRIPTION OF MAP UNITS

Postglacial Deposits

Qal — **Stream deposits** (Holocene and late Wisconsinan) - Stratified, moderately- to poorly-sorted, yellowish-brown, brown, and brownish-gray sand, gravel, silt, and minor dark gray clay and dark brown organic material deposited by streams. Locally bouldery. Can form narrow, sheet like deposits on the floors of modern valleys and higher stream terraces that flank the course of modern streams. Includes stratified, moderately to poorly sorted sand, gravel, and silt in fan deposits that lie at the mouth of tributaries. As much as 40 feet thick. Thickest deposits are in the Delaware Valley.

Qs — **Swamp and bog deposits** (Holocene and late Wisconsinan) – Dark brown to black, partially decomposed remains of mosses, sedges, trees and other plants, and muck underlain by laminated organic-rich silt and clay. Accumulated in kettles, shallow postglacial lakes, glacially scoured bedrock basins, poorly-drained areas in uplands, in abandoned stream channels on alluvial plains, and hollows in ground moraine. Locally interbedded with alluvium and thin colluvium. In areas underlain by limestone and dolomite may contain calcareous marl. As much as 25 feet thick.

Glacial Deposits

Qt — **Till** (late Wisconsinan) – Yellowish-, reddish-, olive-brown, and grayish brown sandy, sandy-silty, and clayey-silty diamicton consisting of a very poorly sorted matrix of sand, silt, and clay and containing 5 to 35 percent pebbles, cobbles, and boulders. Deposited directly by or from glacial ice. Till is widespread, generally less than 20 feet thick and lies on bedrock. In areas of thin till, which are mapped here as bedrock formation, bedrock outcrops are abundant and most of these exhibit signs of glacial erosion. Thicker till forms aprons on the north facing hillslopes, drumlins, and ground and recessional moraine. In places overlain by thin, noncompact, poorly sorted silty sand to sand containing as much as 35 percent pebbles, cobbles, boulders, and interlayered with lenses of sorted sand, gravel, and silt. May be as much as 100 feet thick.

Qsd — **Meltwater deposits** (late Wisconsinan) - Stratified, well- to moderately-sorted sand, yellowish-brown, brown, and brownish-gray boulder-cobble to pebble gravel, pebbly sand and minor silt deposited by meltwater streams in valleys as outwash plains and fans and meltwater terraces and small glacial lakes as deltaic and lacustrine-fan deposits. In places includes light to dark gray, parallel-laminated, irregularly to rhythmically-bedded silt, clay, and very-fine sand; and minor cross-laminated silt, fine sand, and minor clay deposited on the floor of glacial lakes. As much as 150 feet thick.

Bedrock Formations

Sb — **Bloomsburg Red Beds** (Upper and Middle Silurian) - Pale red to grayish red, grayish red purple, and lesser medium gray and greenish gray, very fine to coarse grained, cross bedded to planar bedded, thin to thick bedded, partly conglomeratic sandstone with quartz grains as much as 0.4 in. long and flattened grayish red shale pebbles as much as 0.8 in. long. Also poorly bedded to laminated, pale red, light brown to moderate brown, and greenish gray shale and siltstone with scattered green reduction spots and with conspicuous cleavage, partly mud cracked and with scattered ferroan dolomite concretions about 0.5 in. in diameter. Fining upward cycles with basal channel sandstones are abundant. Minor medium gray, fine grained, planar bedded sandstone. Lower contact, placed at the base of the lowest red bed, is transitional. In some places a gray quartzite bed typical of the Shawangunk Formation is found interbedded with red beds less than 20 feet above the base. About 1,500 feet thick.

Ss — **Shawangunk Formation** (Middle and Lower Silurian) - Very light to medium dark gray, and greenish gray to medium greenish gray, very fine to coarse grained, thin to thick bedded, planar bedded, cross bedded, and ripple bedded, light gray to light olive gray and moderate yellowish brown to moderate reddish orange and moderate brown weathering, conglomeratic quartzite with rounded to subangular quartz and lesser chert pebbles as much as 2.25 in. long, but averaging about 0.25 in. long, and dark gray to grayish black silty shale pebbles averaging about 2 in. long, cobbles may be as much as 10 in. long. Medium dark to dark gray, thin to thick bedded siltstone and shale is interbedded with the sandstone and conglomerate in a zone about 300 feet thick lying about 350 feet above the base of the formation in the western part of the quadrangle, and thins to about 110 feet and lies about 175 feet above the base in the eastern part. These shales and siltstones may be the Lizard Creek Member of the Shawangunk Formation separating the Tammany Member above from the Minsi Member below. These shales and siltstones are found in scattered outcrops along the steep east-facing cliff of Kittatinny Mountain. The members are not readily mapped in this quadrangle. Shales and siltstones ascribed to the Lizard Creek Member in eastern Pennsylvania thin northeastward through New Jersey and are represented by thin scattered intervals in southeastern New York (Epstein, 1993). The lower unconformable contact is covered by talus along the south slope of Kittatinny Mountain. About 1,400 feet thick

Omr — **Ramseyburg Member of Martinsburg Formation** (Upper Ordovician) – Interbedded medium- to dark-gray to brownish-gray, fine- to medium-grained, thin- to thick-bedded quartzose to graywacke sandstone and siltstone and medium- to dark-gray, laminated to thin-bedded shale and slate. Unit forms fining upward sequences characterized by basal cross-bedded sandstone to siltstone grading upward through planar laminated siltstone into shale or slate. Locally, fining upward cycles may have a lower, medium- to thick-bedded, graded-bedded sandstone overlain by planar laminated sandstone to siltstone beneath the cross-bedded layer. Complete cycles may be an inch to several feet thick. Basal scour, sole marks, and soft-sediment deformation of beds are common in quartzose and graywacke sandstones. Lower contact placed at bottom of lowest thick- to very-thick-bedded graywacke but contact locally grades upwards through a sequence of dominantly thin-bedded slate and minor thin- to medium-bedded discontinuous and lenticular graywacke beds in the Bushkill Member. Parris and Cruikshank (1992) correlate unit with *Orthograptus ruedemanni* zone to lowest part of *Climacograptus spiniferus* zone of Riva (1969, 1974). Unit is as much as 3,600 feet thick.

Omb — **Bushkill Member of Martinsburg Formation** (Upper Ordovician) – Medium- to medium-dark-gray-weathering, dark-gray to black, thinly laminated to medium-bedded shale and slate; less abundant medium-gray- to brownish-gray-weathering, dark-gray to black, laminated to thin-bedded, graywacke siltstone. Unit forms fining upward sequences characterized by either basal cross-bedded siltstone grading upward through planar laminated siltstone into slate, or laminated siltstone grading upward into slate. Locally, fining upward cycles may have a lower graded sandstone to siltstone overlain by planar laminated siltstone beneath the cross-bedded layer. Complete cycles may be an inch to several feet thick with slate comprising the thickest part. Lower contact with Jacksonburg Limestone gradational. Parris and other (2001) show that the unit is no older than the *Corynoides americanus* subzone of *Orthograptus amplexicaulis* zone (Berry, 1960; 1971; 1976). Thicknesses here is 1,500 ft but can range from about 1,000 to 1,500 feet regionally.

Oj — **Jacksonburg Limestone** (Upper Ordovician) – Medium-dark-gray-weathering, medium-dark to dark-gray, laminated to thin-bedded, argillaceous limestone (cement-rock facies) and minor arenaceous limestone. Grades downward into medium-bluish-gray-weathering, dark-gray, very thin- to medium-bedded, commonly fossiliferous, interbedded fine- and medium-grained limestone and pebble-and-fossil limestone conglomerate (cement-limestone facies). Elsewhere, thick- to very thick-bedded dolomite cobble conglomerate occurs within basal sequence. Lower contact unconformable on Beekmantown Group, and on clastic facies of "Sequence at Wantage," and conformable on carbonate facies of "Sequence at Wantage." Unit contains long ranging North American Midcontinent province conodont zones *Phragmodus undatus* to *Aphelognathus shatzeri* indicating Rocklandian to Richmondian and possibly Kirkfieldian (Caradocian) ages (Sweet and Bergstrom, 1986). Thickness ranges from 150 feet to 1,000 ft. regionally.

Ow — **"Sequence at Wantage"** (Middle Ordovician) – Interbedded, very-thin- to medium-bedded limestone, dolomite, siltstone, and argillite. Upper carbonate facies is moderate-yellowish-brown to olive-gray weathering, medium- to dark-gray, very-fine- to fine-grained, laminated to medium-bedded limestone and dolomite. Rounded quartz sand occurs locally as floating grains and in very thin lenses. Lower clastic facies contain medium-gray, grayish-red to grayish-green, thin- to medium-bedded mudstone, siltstone, and fine-grained to pebbly sandstone. Fine-grained beds commonly contain minor disseminated subangular to subrounded, medium-grained quartz sand and pebble-sized chert. Some coarse-grained beds are cross-stratified. Unit is preserved in geographic low-lying surfaces on the Middle Ordovician unconformity erosional surface. North American Midcontinent province conodonts have been identified by Harris and others (1995, p. 6) within the carbonate facies. Unit may be as much as 150 feet thick in the quadrangle.

Obu — **Beekmantown Group, upper part** (Lower Ordovician) – Light- to medium-gray- to yellowish-gray-weathering, medium-light to medium-gray, aphanitic to medium-grained, thin- to thick-bedded, locally laminated, slightly fetid dolomite. Locally a light-gray- to light-bluish-gray- weathering, medium- to dark-gray, fine-grained, medium-bedded limestone occurs near the top of unit. Grades downward into medium- to dark-gray on weathered surface, medium- to dark-gray where fresh, medium- to coarse-grained, medium- to thick-bedded, strongly fetid dolomite. Contains pods, lenses and layers of dark-gray to black rugose chert. Lower contact conformable and grades into the fine-grained, laminated dolomite of Beekmantown Group, lower part. Contains conodonts of North American Midcontinent province *Rossodus manitouensis* zone to *Oepikodus communis* zone (Karklins and Repetski, 1989), so unit is Ibexian (Tremadocian to Arenigian) as used by Sweet and Bergstrom (1986). In map area, unit correlates with the Epler and Rickenbach Dolomite of Drake and others (1985) and the Ontelaunee Formation of Markewicz and Dalton (1977). Thickness averages about 400 feet but locally is as much as 800 feet.

O€bl — **Beekmantown Group**, lower part (Lower Ordovician to Upper Cambrian) – Consists of an upper, middle and lower stratigraphic subdivisions. Upper sequence is light- to medium-gray- to dark-yellowish-orange-weathering, light-olive-gray to dark-gray, fine- to medium-grained, very thin- to medium-bedded locally laminated dolomite. Middle sequence is olive-gray- to light-brown- and dark-yellowish-orange-weathering, medium- to dark-gray, aphanitic to medium-grained, thin-bedded, locally well laminated dolomite which grades into discontinuous lenses of light-gray- to light-bluish-gray-weathering, medium- to dark-gray, fine-grained, thin- to medium-bedded limestone. Limestone has "reticulate" mottling characterized by anastomosing light-olive-gray- to grayish-orange-weathering, silty dolomite laminae surrounding lenses of limestone. Limestone may be completely dolomitized locally. Grades downward into medium dark- to dark-gray, fine-grained, well laminated dolomite having local pods and lenses of black to white chert. Lower sequence consists of medium- to medium-dark-gray, aphanitic to coarse-grained, thinly-laminated to thick-bedded, slightly fetid dolomite having quartz-sand laminae and sparse, very thin to thin, black chert beds. Individual bed thickness decreases, and floating quartz sand content increases toward lower gradational contact. Contains conodonts of North American Midcontinent province *Cordylodus proavus* to *Rossodus manitouensis* zones (Karklins and Repetski, 1989) as used by Sweet and Bergstrom (1986), so that unit is Ibexian (Tremadocian). Entire unit is Stonehenge Limestone of Drake and others (1985) and Stonehenge Formation of Volkert and others (1989). Markewicz and Dalton (1977) correlate upper and middle sequences as Epler Formation and lower sequence as Rickenbach Formation. Unit is about 600 feet thick.

€a — **Allentown Dolomite** (Upper Cambrian) - Unit is subdivided into an upper and lower unit (Markewicz and Dalton, 1977). Upper sequence is light-gray- to medium-gray-weathering, medium-light- to medium-dark-gray, fine- to medium-grained, locally coarse-grained, medium- to very thick-bedded dolomite, local shaly dolomite near the bottom. Floating quartz sand and two series of medium-light- to very light-gray, medium-grained, thin-bedded quartzite and discontinuous dark-gray chert lenses occur directly below upper contact. Lower sequence is medium- to very-light-gray-weathering, light- to medium dark-gray, fine- to medium-grained, thin- to medium-bedded dolomite and shaly dolomite. Weathered exposures characterized by alternating light- and dark-gray beds. Ripple marks, oolites, algal stromatolites, cross-beds, edgewise conglomerate, mud cracks, and paleosol zones occur throughout but are more abundant in lower sequence. Lower contact gradational into Leithsville Formation. Unit contains a trilobite fauna of Dresbachian (early Late Cambrian) age (Weller, 1903; Howell, 1945). Approximately 1,800 feet thick.

€l — **Leithsville Formation** (Middle to Lower Cambrian) - Shown in section only - Unit is subdivided into an upper, middle and lower unit (Markewicz and Dalton, 1977). Upper sequence, rarely exposed, is mottled, medium-light- to medium-dark-gray-weathering, medium- to medium-dark-gray, fine- to medium-grained, medium- to thick-bedded, locally pitted and friable dolomite. Middle sequence is grayish-orange or light- to dark-gray, grayish-red, light-greenish-gray- or dark-greenish-gray-weathering, aphanitic to fine-grained, thin- to medium-bedded dolomite, argillaceous dolomite, dolomitic shale, quartz sandstone, siltstone, and shale. Lower sequence is medium-light- to medium-gray-weathering, medium-gray, fine- to medium-grained, thin- to medium-bedded dolomite. Quartz-sand lenses occur near lower gradational contact with Hardyston Quartzite. Archaeocyathids of Early Cambrian age are present in formation at Franklin, New Jersey, suggesting an intraformational disconformity between Middle and Early Cambrian time (Palmer and Rozanov, 1967). Unit also contains *Hyolithellus micans* (Offield,1967; Markewicz, 1968). Approximately 800 feet. thick regionally.

€h — **Hardyston Quartzite** (Lower Cambrian) - Shown in section only - Medium- to light-gray, fine- to coarse-grained, medium- to thick-bedded quartzite, arkosic sandstone and dolomitic sandstone. Contains Scolithus linearis (?) and fragments of the trilobite *Olenellus thompsoni* of Early Cambrian age (Nason, 1891; Weller, 1903). Thickness ranges from 0 feet to a maximum of 100 feet regionally.

Ꝑ — **Proterozoic Undivided** - Shown in section only - composed dominantly of orthogneiss and paragneiss of Grenville age and post Grenville granitic intrusions.

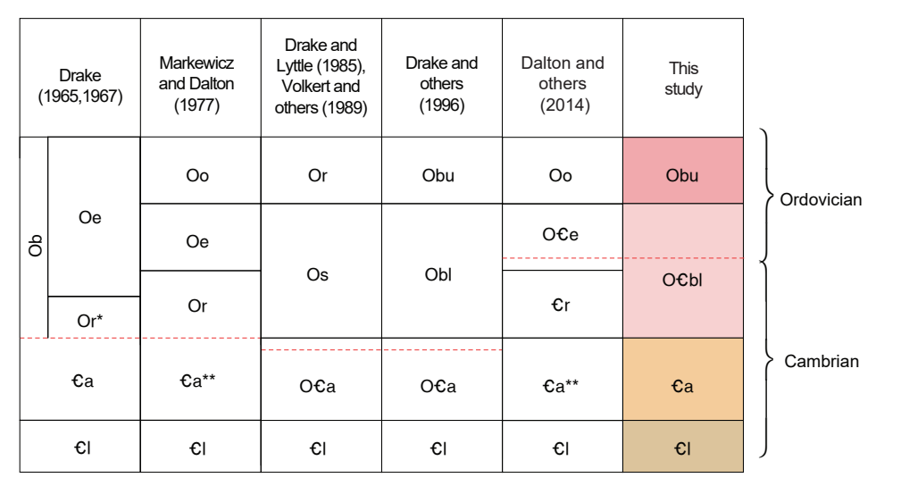
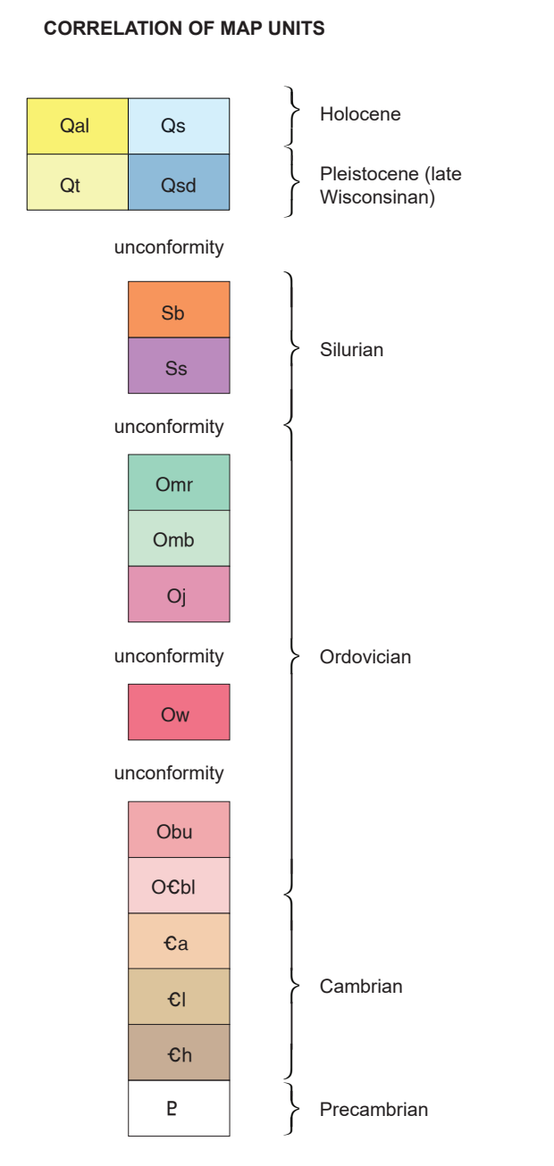


Figure 1. Evolution of Paleozoic carbonate rock nomenclature.



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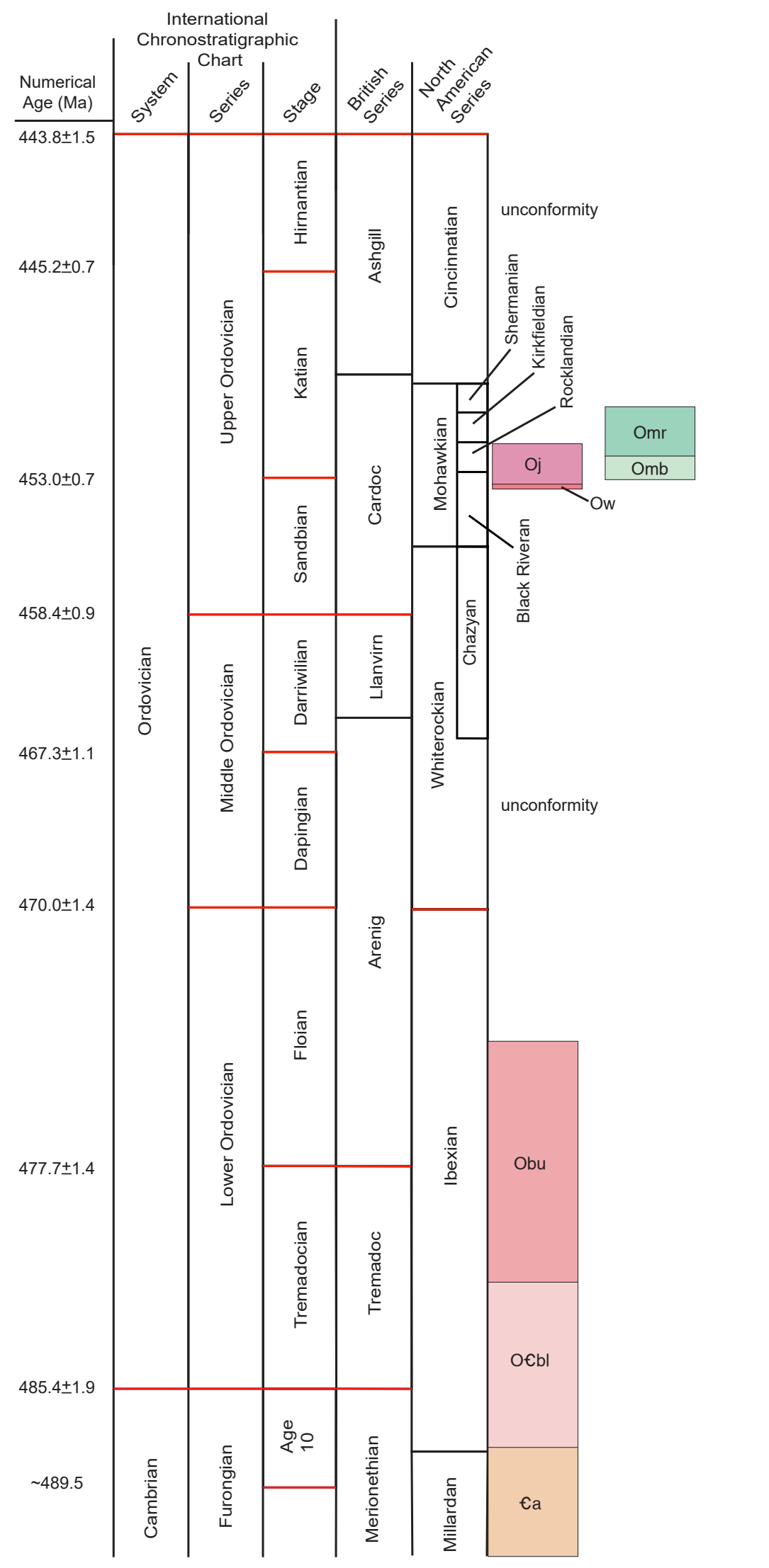

Figure 2. Correlation of Ordovician carbonate units mapped in the New Jersey portion of the Portland quadrangle. International Chronostratigraphic Chart including numerical ages in million years (Ma) is from Cohen and others (2013, updated). Red lines correspond to numerical age dates.

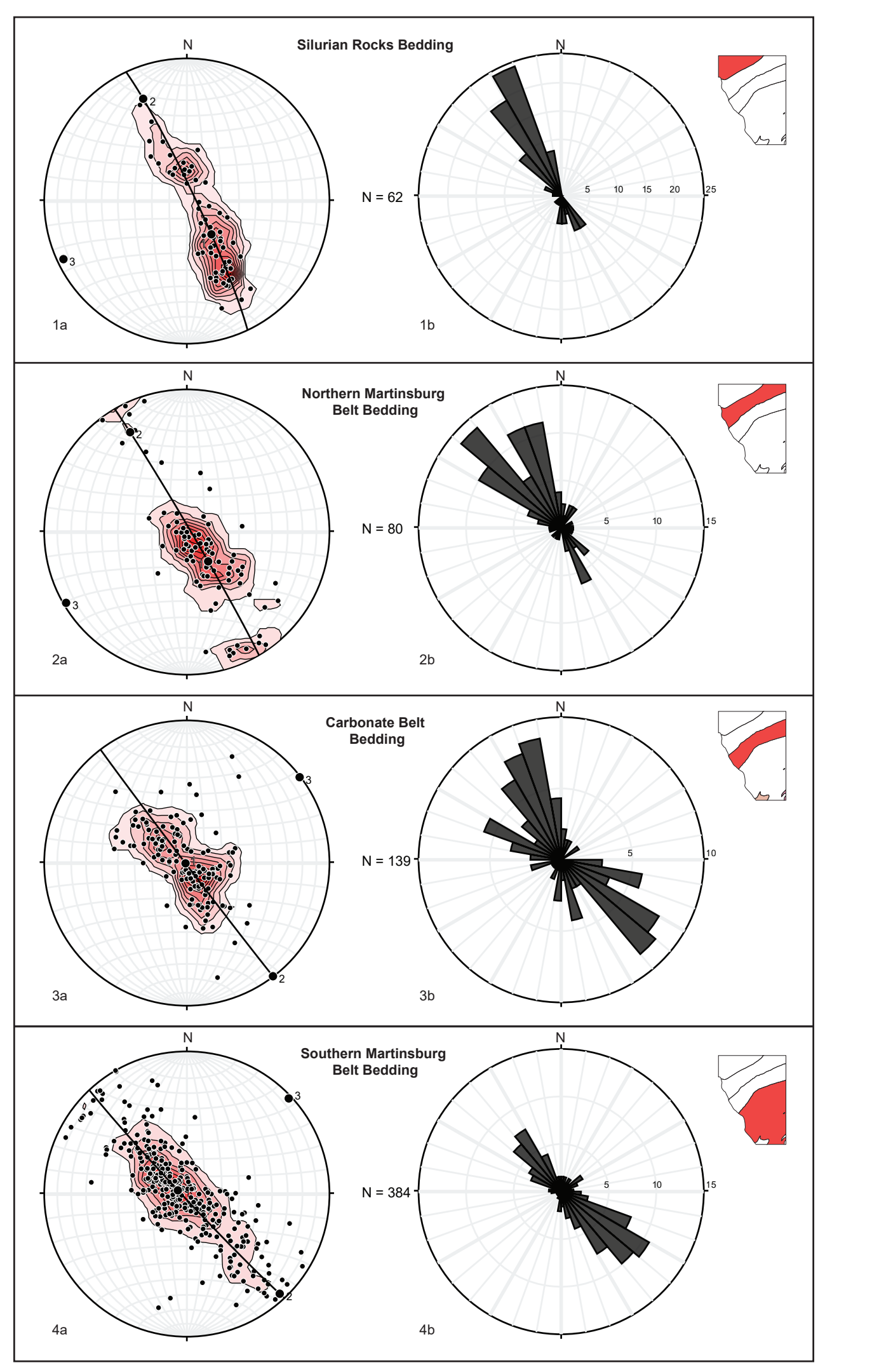

Figure 3. Equal area lower hemisphere spherical projection and rose diagram plots of bedding of the different structural regions where Row 1 displays data from the Silurian units; Row 2 is the northern Martinsburg belt; Row 3 is the carbonates in the Ackerman anticline and Row 4 is the southern Martinsburg belt and limited carbonates. Orientations both as poles to planes on lower hemisphere, equal area projections (1a, 2a, 3a and 4a) and as dip directions on rose diagram (1b, 2b, 3b and 4b). Maps to the right in the figure show the areal location where the data was collected. Data density contours use 1% area with a 2% contour interval. N represents the number of readings analyzed in the plot. Bold dots labeled 1, 2 and 3 represent calculated eigenvectors with 1 being the largest eigenvalue and 3 the smallest. Great circle represents cylindrical fold axis of data defined by the plane to circle 3, the smallest eigenvalue. Eigenvalues and fold axis are defined using the cylindrical best fit option in stereonet software described in Allmendinger and others (2013) and Cardozo and Allmendinger (2013).

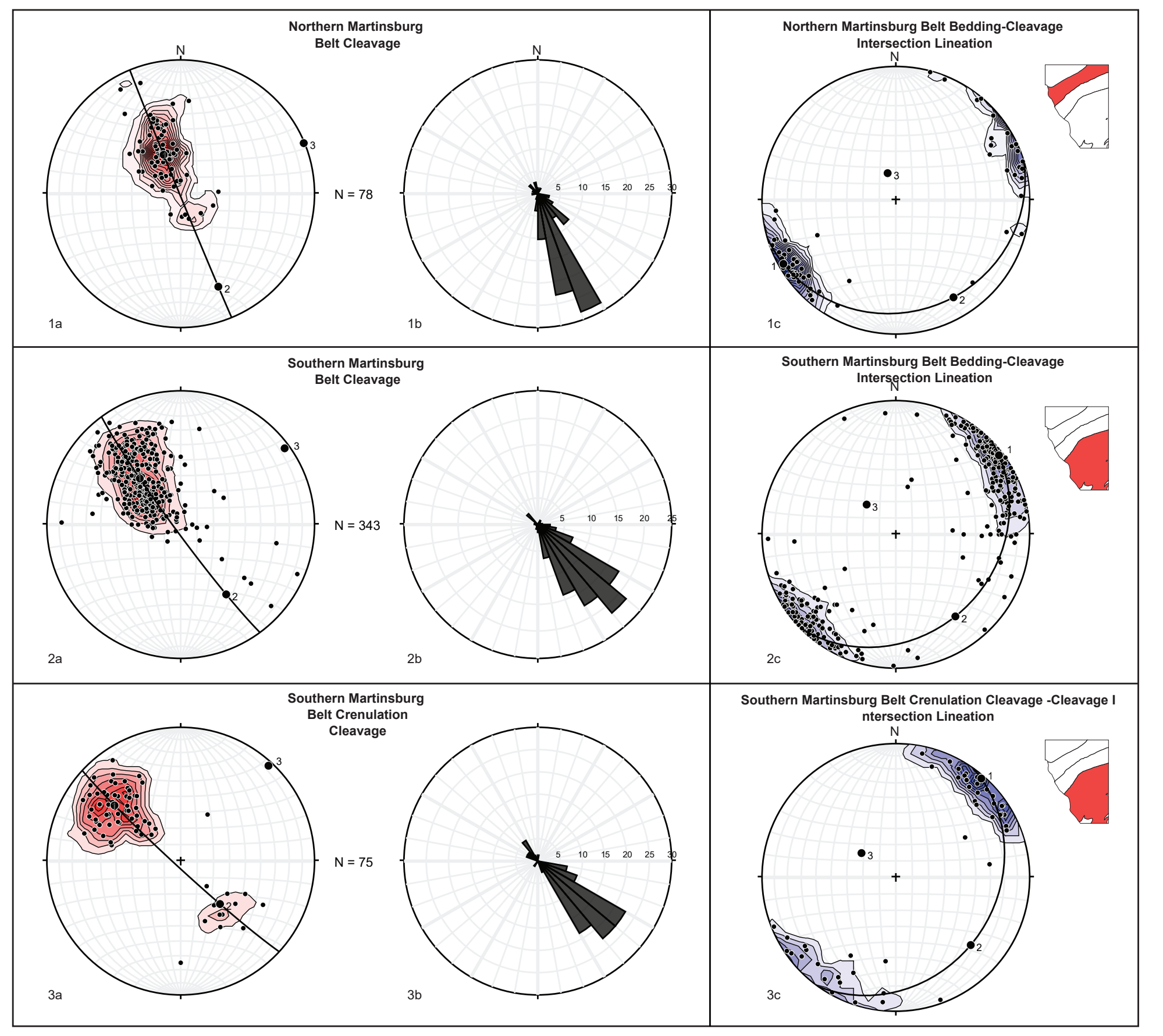

Figure 4. Rows 1 and 2 plot Martinsburg cleavage orientations both as poles to planes on lower hemisphere, equal area projections (1a and 2a) and as dip directions on rose diagram (1b and 2b). Plots 1c and 2c plot bedding cleavage intersection lineations. Row 3 presents similar plots as rows 1 and 2 but depicts crenulation cleavage data which was only found in the southeast section of the quadrangle. Maps to the right in the figure show the areal location where the data was collected. Data density contours use 1% area with a 2% contour interval. N represents the number of readings analyzed in the plot. Circles labeled 1, 2 and 3 represent calculated eigenvectors with 1 being the largest eigenvalue and 3 the smallest. Great circle represents cylindrical fold axis of data defined by the vector to circle 3, the smallest eigenvalue. Eigenvalues and fold axis are defined using the cylindrical best fit option in stereonet software described in Allmendinger and others (2013) and Cardozo and Allmendinger (2013).