DEPARTMENT OF ENVIRONMENTAL PROTECTION
DIVISION OF SCIENCE AND RESEARCH
NEW JERSEY GEOLOGICAL SURVEY

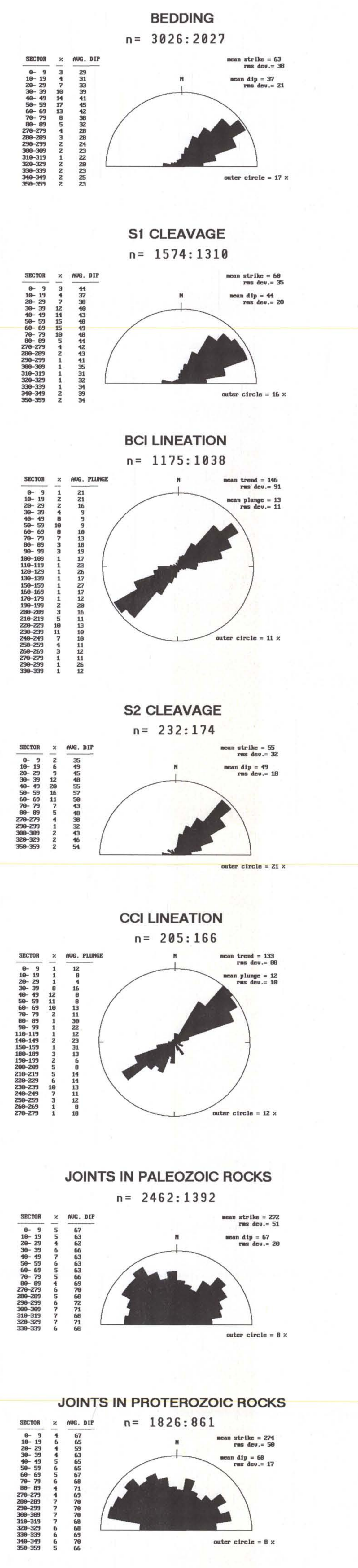

Figure. 1 - Circular histograms and statistical data for outcrop fractures and related lineations in Warren County, NJ. n = number of readings : number of outcrops. AVG. = average, rms dev. = root-mean-square deviation. See discussion on plate 2 for explanation of types of structures and methods of analysis.

LOCATION MAP

EXPLANATION

Where multiple measurements were taken, the station location is shown preferentially by S1 cleavage, S2 cleavage, then jointing.

MAP UNITS

PALEOZOIC

SILURIAN
- Sb — Bloomsburg Red Beds
- Ss — Shawangunk Conglomerate

ORDOVICIAN
- Omr — Martinsburg Formation, Ramseyburg Member
- Omb — Martinsburg Formation, Bushkill Member
- Oj — Jacksonburg Limestone
- Ow — Sequence at Wantage
- Ob — Beekmantown Group

CAMBRIAN
- OCa — Allentown Dolomite
- Clh — Leithsville Formation and Hardyston Quartzite

LATE PROTEROZOIC
- Zd — Diabase dikes
- Zch — Chestnut Hill Formation

MIDDLE PROTEROZOIC
- Ymr — Franklin Marble
- Yu — Middle Proterozoic rocks undivided

MAP SYMBOLS

CLEAVAGE
- S1 - inclined dip
- S1 - vertical dip
- S2 - inclined dip
- S2 - vertical dip

JOINTS
- inclined dip 0° - 29°
- inclined dip 30° - 59°
- inclined dip 60° - 89°
- vertical dip

- Fault
- Bedrock contact
- Proterozoic lithic contacts
- Axial surface trace of bedding or S1 cleavage fold
- 7-1/2 minute quadrangles

GEOGRAPHIC INFORMATION SYSTEM
N
NJDEP

SCALE 1:48000

2 MILES
14,000 FEET
2 KILOMETERS

Base generated from North America Datum (NAD) 1927 state plane coordinates

ENVIRONMENTAL GEOLOGY OF WARREN COUNTY, NEW JERSEY: MAP SHOWING FRACTURE SETS IN BEDROCK OUTCROPS

1994

by:

Gregory C. Herman[1], Donald H. Monteverde[1], Richard A. Volkert[1], Avery A. Drake, Jr.[2], and Richard F. Dalton[1]

[1]New Jersey Geological Survey
[2]U. S. Geological Survey

Digital cartography by G. C. Herman

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INTRODUCTION

Warren County, New Jersey, occupies the southwest part of the Valley and Ridge province and most of the southwest part of the Highlands province, covering parts of fourteen 7-1/2 minute quadrangles (fig. 1). The bedrock is broken by many types of fractures resulting from tectonic deformation. These widespread breaks include bedding or foliation fractures, cleavage, and joints. They indicate low-temperature deformation mechanisms of intermediate scale.

Bedrock fractures store and transmit ground water in the near surface environment where the compressive stresses of rock pressure are minimal. Karst studies and pump-test data for New Jersey show that fractures in bedrock aquifers affect ground water flow paths (Dalton, 1976; Vecchioli and others, 1969; Spayd, 1985; Michalski, 1990; Boyle, 1993). However, little has been done in this region to quantify aquifer characteristics as related to specific sets of fractures. The purpose of this study is to delineate many common bedrock fractures in the county for use in studies of bedrock aquifers. Orientation analyses show sets of bedding fractures and related lineations mapped in rocks of Paleozoic age, and joints in rocks of Paleozoic and Proterozoic age. Orientation statistics for each set of fractures are based on circular histograms (rose diagrams), and include average strike and dip, or trend and plunge, with standard deviation values. The distribution and orientation of joints and cleavages are shown on plate 1. The length of joint symbols on the map is statistically weighted to emphasize dominant trends in each area.

Description of each type of fracture is generalized to simplify its representation on the maps. Groshong (1988) presents a more detailed classification of bedrock fractures, and includes a review of their origin, lithologic distribution, and other characteristics.

DATA COLLECTION AND COMPILATION

The N.J. Geological Survey maintains an inventory of geologic field data for approximately 3000 bedrock outcrops in Warren County. Structural data for the Paleozoic rocks and joint data for Proterozoic rocks in the northeast part of the county were compiled from recent (1985-1993) geologic mapping by the N.J. Geological Survey. Joint data for Proterozoic rocks in the southwest part of the Highlands were compiled from earlier mapping by the U.S. Geological Survey (A. A. Drake, Jr. written communication, 1993).

Multiple readings of structural trend or inclination were collected at individual sites wherever measurements varied by more than 5°. Multiple readings of a structure are included in the statistical analyses and the map to show how the distribution and orientation of bedrock fractures are related to lithologic contacts, faults, and folds.

The analyses of structural data are based on lithologic groups and structural domains. A lithologic group is a sequence of rocks possessing similar mechanical properties and therefore responding to tectonic stress by developing similar secondary structures. A list of geologic units that comprise the lithologic groups is shown in the EXPLANATION OF MAP UNITS (pl. 1). More stratigraphic details and thickness values for each geologic unit are given by Monteverde and others (1994). The distribution of a particular structure or set of structures within a lithologic group varies, depending upon the composition of the unit and the distribution of faults and folds. For example, slaty cleavage is regionally developed in the fine-grained claystone slate of the Martinsburg Formation whereas pressure solution cleavage is localized in the carbonate rocks of area close to large-scale reverse faults.

The division of a region into structural subregions, or domains, facilitates statistical analyses and representation of dominant structural trends in different parts of the map. A structural domain is a belt of similar rocks that can be separated from others by structural or stratigraphic boundaries. A domain normally contains a single group of rocks showing similar strain features, however, rock groups may be combined if data are inadequate to allow their separation. The designation of structural domains is arbitrary and may be modified in subsequent analyses. Figure 1 shows the distribution of structural domains and the layout of 7-1/2 minute quadrangles.

BEDDING AND FOLIATION FRACTURES

Bedding fractures are common throughout the sedimentary rocks of Paleozoic age. In contrast, foliation or layering fractures in the metamorphic rocks of Proterozoic age are not as systematically developed. However, of the metamorphic rocks, the metasedimentary ones locally display the most foliation fractures. Bedding and foliation strike are generalized on plate 1 using lithologic contacts for the Paleozoic rocks, and form lines derived from lithologic contacts for the Proterozoic rocks. Strike and dip values for bedding and foliation readings are available from Monteverde and others (1994).

Bedding fractures are common. Moreover, karst studies and pump-test data show that these fractures strongly affect ground water storage and flow. Less is known about how metamorphic foliation affects aquifer characteristics. Structural details for bedding and metamorphic foliation are available from previously published geologic maps (Monteverde and others, 1994; Drake, 1967a; Drake 1967b; Drake and others 1969, 1985; Drake and Lyttle, 1985; Epstein, 1973).

CLEAVAGE

Rock cleavage is the property or tendency of a rock to split along secondary, aligned fractures or other closely spaced, planar structures or textures, produced by deformation or metamorphism (Bates and Jackson, 1987). Cleavage commonly is subparallel to the axial planar surface of contemporaneous bedding folds. Therefore it commonly strikes subparallel to bedding strike but dips at moderate to high angles. In regions of high shear strain, bedding and cleavage planes are generally reoriented into subparallel alignment.

Various kinds of cleavage can form in different types of rocks and structural settings. Warren County has been a cleavage laboratory, with many studies illuminating cleavage relations in the Martinsburg Formation (Broughton, 1946; Maxwell, 1962; Drake, 1967a; 1967b; Drake and Epstein, 1967; Drake and other 1969; 1985; Epstein and Epstein, 1969; Epstein, 1973; Groshong, 1976; Beutner and others, 1977; Beutner, 1978; Beutner and Diegel, 1985; Drake and Lyttle, 1985, Herman and Monteverde, 1989). For this study, all cleavage is grouped into an early, regional set [S1], and a later, localized set [S2] which overprints bedding and S1 cleavage with structural discordance. The S1 set includes the spaced pressure solution cleavage in carbonate rocks of the Kittatinny Supergroup and Jacksonburg Limestone, the "rough", and "slaty" or " flow" cleavage in the Martinsburg Formation (Broughton, 1946; Drake and Epstein, 1967), and any cleavage in the Middle Paleozoic rocks. The S2 set includes all mapped secondary cleavages, such as the "fracture" or "false", "crenulation", and "slip" cleavage mapped in the Martinsburg Formation (Broughton, 1946; Maxwell, 1962; Drake and Epstein, 1967).

Cleavage is unevenly distributed throughout the Paleozoic rocks. The S1 set is extensively developed in slate, shale, and argillaceous limestone, where its close spacing of much less than an inch obscures bedding as the dominant fracture plane in outcrop. Cleavage is also well developed in siltstone, sandstone, conglomerate, and other limestone, but is more widely spaced, from less than an inch to a few inches. These rocks show a more equal distribution of bedding and cleavage fractures in outcrop. Dolomitic carbonate rocks are less commonly cleaved, but generally show well-developed S1 pressure-solution planes near reverse faults, and in the hinge area of tight bedding folds where spacing ranges from less than an inch to a few inches.

S2 cleavage mostly occurs in the Martinsburg Formation within the fold and thrust belts (Stone Church syncline, and Musconetcong Valley; fig. 1 and pl. 1), and in carbonate rocks near faults (pl. 1). S2 cleavage locally crenulates S1 surfaces with close spacing of much less than an inch, or forms wider-spaced subparallel planes that sometimes offset S1 with visible shear slip and associated drag folds (Broughton, 1946; fig. 8; Drake, 1969, fig. 25.). The most common direction of shear movement on S2 planes is normal slip, although reverse slip also occurs (Broughton, 1946; Herman and Monteverde, 1989). S2 cleavage that shows shear slip is mapped separately from small faults, which commonly occur in coeval, rhombohedral and conjugate sets, and commonly show lineations of secondary mineralization or mechanical abrasion on the sides of the shear planes. In places, particularly near reverse faults, multiple sets of systematic cleavage planes require mapping S3 cleavage at the 1:24,000 scale. However, these relations are beyond the scope of this study; any cleavage that postdates the S1 set is referred to as S2. Outcrops show that close-spaced sets of S2 cleavage may coincide with zones of profuse ground water discharge, particularly within the Martinsburg Formation.

JOINTS

Joints are fracture planes aside from bedding, foliation, or cleavage fractures which show no visible displacement parallel to the surface. Joints may be continuous throughout rock outcrops, intersect, terminate against other joints or fractures, or just die out. Uncemented joints have been mapped separately from veins and partially vein-filled joints. Uncemented joints are the only ones analyzed for this study.

The orientation of joints was the sole characteristic analyzed because of the widely varying quality of outcrops. However, trace length and spacing are field guides in differentiating joints from cleavage; joints are typically more widely spaced, from a few inches to a few feet apart. They also occur in unevenly distributed sets of subparallel or conjugate planes, in "en echelon" arrays, or as isolated fractures. They typically are systematically oriented, most commonly at right angles to fold axes and subparallel to bed or foliation strike, but with complimentary dip angles (fig. 2 and pl. 1).

Much work has been done on the porosity and permeability of joints, especially for the petroleum industry. Groshong (1988) stated that maximum fracture porosity is generally less than 2 to 6 percent, and joint permeability ranges from nearly 0 to 400 millidarcys (0 to .334 meters/day) at the earth's surface. He also cites fractures with partial-vein filling as significantly contributing to fluid flow in low-porosity rocks.

LINEAR STRUCTURES

Other structures analyzed here are linear intersections of bedding with S1 cleavage (bci lineations) and cleavage sets S1 and S2 (cci lineations). These structures indicate regional fold-axis orientation, on the assumption that cleavage is subparallel to the axial surface of folds of the same tectonic generation. These data facilitate comparison between the orientation of planar fractures and those of accompanying folds.

DATA MANAGEMENT, STATISTICAL ANALYSES, AND PLOT AUTOMATION

Geological and geographical data for each outcrop were input for a personal computer (PC) program that provides routines for data sorting, printing, conversion, and circular-histogram (rose-diagram) analysis (Kaeding and Herman, 1988; G. C. Herman, Field Data Management System v. 2.1, unpublished computer program upgrade, on file at the N.J. Geological Survey, Trenton, N.J.). The program is MS-DOS compatible and produces output files that are used within an ARC/INFO Geographic Information System (GIS) program to automatically plot structural data on a map with user-specified structural symbols (Herman and others, 1993; M. A. French and G. C. Herman, MesoPlot v. 1.0, unpublished computer program, on file at the N.J. Geological Survey, Trenton, N.J.). Structural symbols are registered to digital geologic coverages for Warren County generated at the 1:24,000 and 1:48,000 scales for Paleozoic and Proterozoic rocks respectively.

Statistics are given for sets of structures from each structural domain (figs. 2, 3). Statistics include average strike, dip, trend, and plunge, with the root-mean-square (rms) deviation of the mean values relative to the set of structures. Strike, dip azimuth, and trend frequencies, dependant on the type of structure, are illustrated in either half- or full-rose diagrams for each structural domain. The diagrams show the total number of readings from the total number of outcrop locations, and the percentage of readings within each 10° sector. Sectors are arranged with north (0°) at the top and progress clockwise through either 180° (half-rose) or 360° (full-rose). Half-rose diagrams show strike frequencies for all readings of a particular structure within the county (pl. 1, fig. 1). Full-rose diagrams show the dip azimuth trends for planar structures, and the trend of linear structures (pls. 1, 2). For analyses primarily dealing with the strike of a feature, the cumulative percentage of strike within a sector, or range of sectors, is derived by adding percentage values for sectors containing dip azimuth values differing by 180°. It is reemphasized that strike is complementary to the dip azimuth, and where planes are plotted as dip-azimuth values, strike-parallel structures that dip in opposite directions are represented separately. For example, the cumulative percentage of bedding fractures striking between 40° and 49° in rocks of Middle Paleozoic age is 15 percent; 2 percent dip azimuth of 130° to 139°, and 13 percent dip azimuth of 310° to 319° (fig. 2).

Joint symbols are statistically weighted on the map (pl. 1). The lengths of the joint symbols are based on the sector percentage values from the dip-azimuth rose diagrams for each structural domain (fig. 2). The sector with the highest percentage value is assigned a length of 0.2 inch. The remaining lengths are then scaled proportionally to the maximum. The minimum length of a weighted plot symbol is 0.075 inch, anything smaller is obscure on the map. Owing to the crowding, joints are represented by symbols indicating dip ranges rather than conventional numerical values. The joint symbols correspond to ranges of dip with low- (0° to 29°), moderate- (30° to 59°), and high- (60° to 89°) angle values (pl. 1).

RESULTS

The distribution of mapped joints, cleavage in Paleozoic rocks, faults, folds and a statistical data summary for the county are shown on plate 1. The index map, and statistical data for each set of structures in each structural domain, are summarized on plate 2.

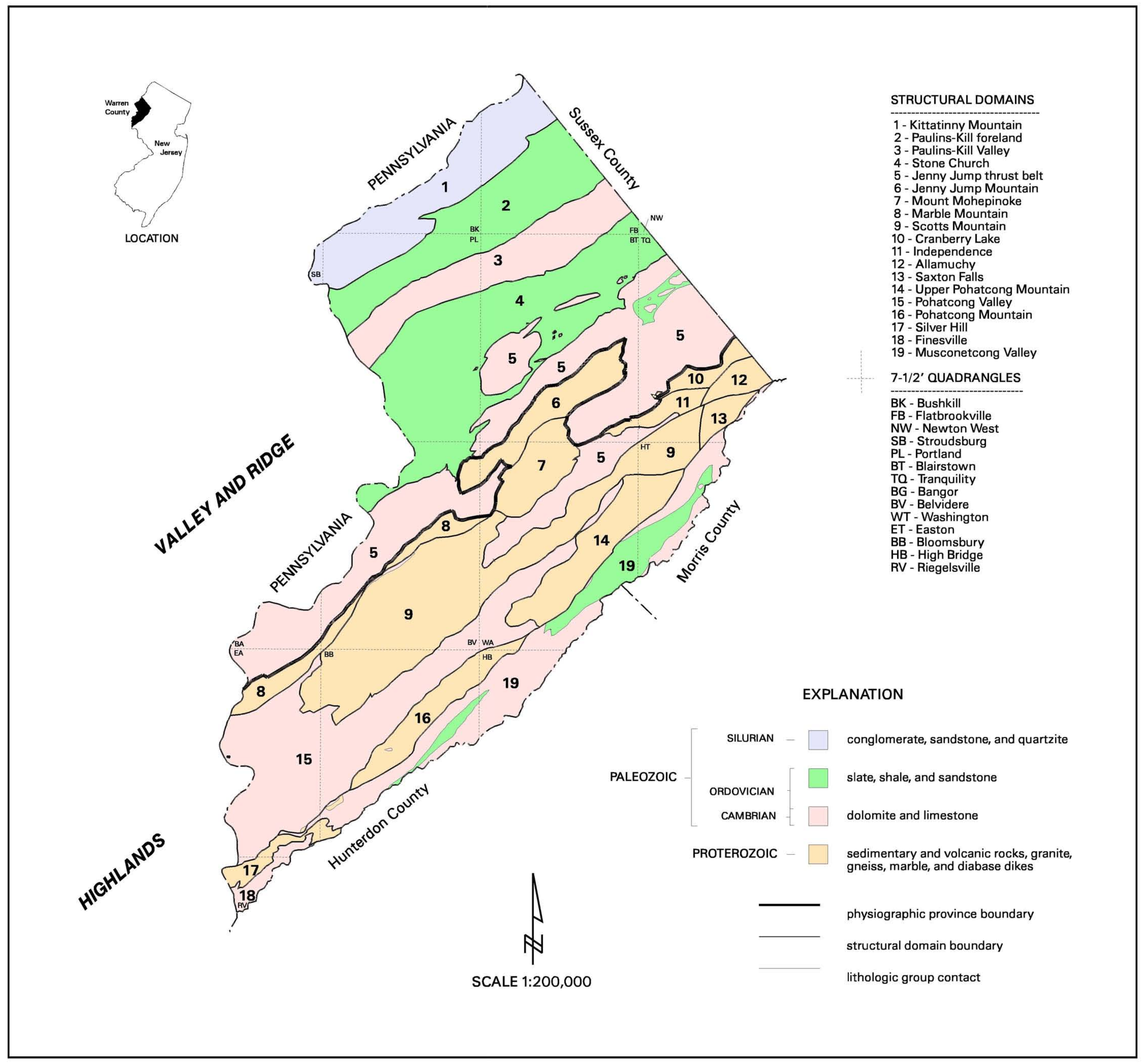

Figure 1. Index map for Warren County showing generalized bedrock geology, structural domains, physiographic provinces, and 7-1/2 minute quadrangles.

Paleozoic structural trends are generally consistent among structural domains (fig. 1). Approximately 60 percent of the regional strike of bedding and cleavage fractures, and regional trends of bci and cci-lineations cluster between 30° and 70° (210° to 250°); the maximums center between 40° and 60° (220° to 240°) (pl. 1, fig. 1). The greatest range in strike for S1 cleavage occurs in the foreland domains containing exposed faults. The dip of bedding generally ranges from 20° to 45° and averages 37°. Northwest-dipping beds are most abundant in the northwest Valley and Ridge; the proportion dipping southeast increases southeastward. S1 cleavage mostly dips southeast 31° to 49°, and averages 44°. The highest values are mostly in the foreland, and the lowest are generally in the hinterland, reflecting the tendency of axial surfaces of folds to incline more steeply southeastward. However, anomalously low cleavage dips in the Paulins Kill foreland directly adjacent to the base of Kittatinny Mountain have been mapped by Epstein and Epstein (1969). S2 cleavage varies more in strike among domains; its maximums commonly range from 80° to 110°, in addition to the more common range of 30° to 40° (fig. 1). S2 cleavage generally dips at slightly higher angles; both regional and domain dips average about 50°.

The trends of bci lineations vary most widely within those domains containing the exposed thrust belts, thus resembling the aforementioned strike variation of related S1 cleavage. Average plunge among structural domains ranges from 7° to 22°, its regional average is 13° (pl. 1, fig.1). The trends of cci lineations are less variable than the strike of related S2 cleavages; most maximums follow regional trends of 40° to 59°, and 230° to 239°. However, the trend of other maximums is between 160° and 189°, corresponding to the secondary strike maximums of related S2 cleavage.

Joints in Paleozoic rocks are more abundant in Cambrian-Ordovician carbonates and Silurian rocks than in the Ordovician Martinsburg Formation, where cleavage is prevalent (fig. 2 and pl. 1). The most common are cross joints striking 110° to 159° (290° to 339°), and joints subparallel to bedrock striking 30° to 59°. Both sets dip at moderate to high angles. Average dips of Paleozoic joints are very consistent among structural domains, ranging from 65° to 69°, and averaging 67°. The maximums of dip azimuth in each structural domain are highly variable; they commonly reflect strike orientations that are either parallel to or normal to the trends of fold axes, based on bci and cci lineations.

Dip azimuth orientations of Proterozoic joints also vary substantially among structural domains (fig. 3) reflecting variable foliation strike (pl. 1). However, the most abundant joint-strike orientations in the region are exhibited by cross joints striking 100° to 139° (280° to 319°) (pl. 1, fig. 1). Secondary in abundance are joints subparallel to regional foliation maximums, they strike 10° to 79°. Average dips of Proterozoic joints in the various structural domains range from 60° to 73°, and average 68°.

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ENVIRONMENTAL GEOLOGY OF WARREN COUNTY, NEW JERSEY:
BEDROCK FRACTURE MAP, PLATE 2 ;
INDEX MAP, STATISTICAL DATA, AND METHODS OF FRACTURE ANALYSIS

1994

by

Gregory C. Herman[1], Donald H. Monteverde[1], Richard A. Volkert[1],
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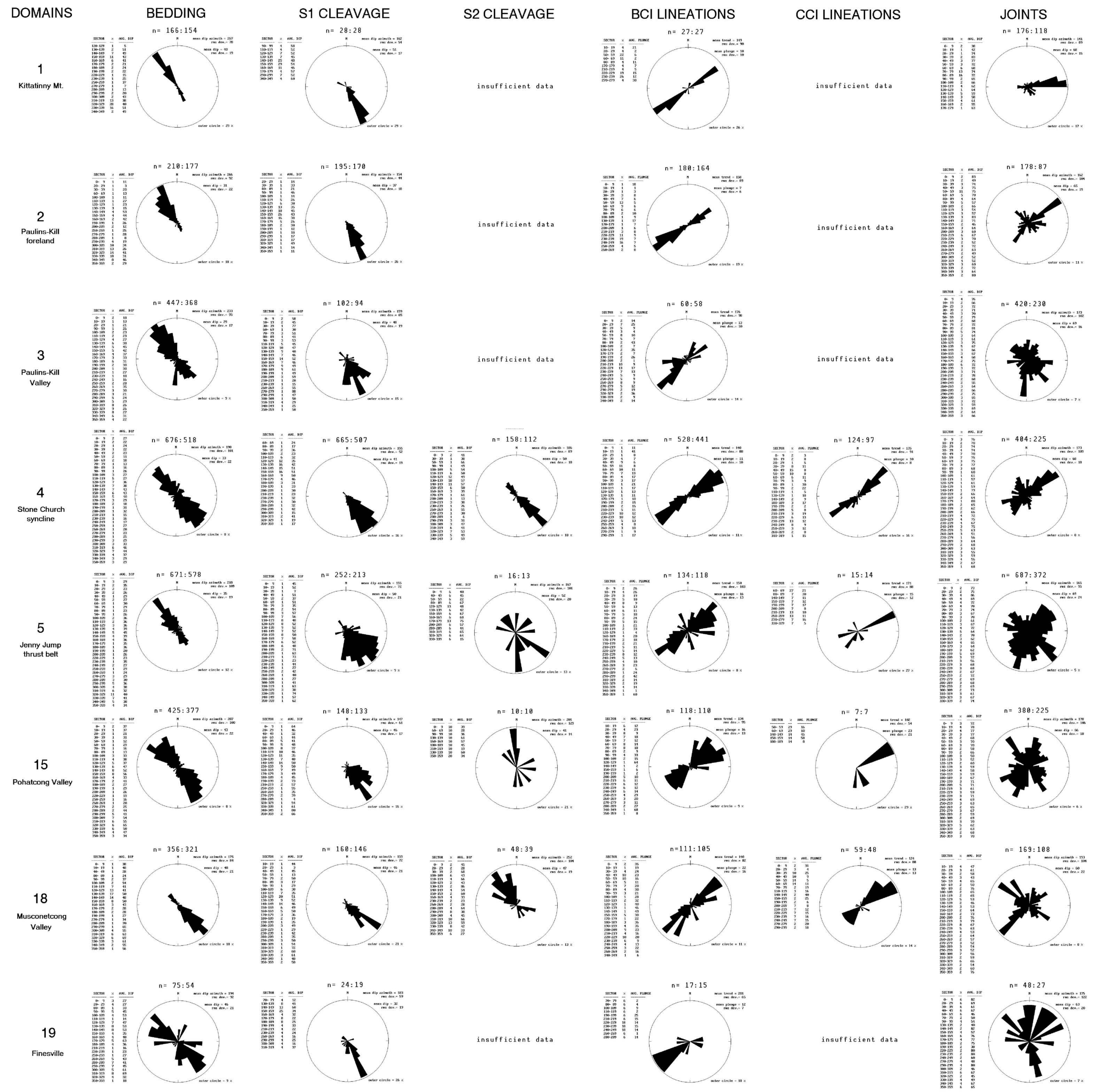

Figure 2. Fractures and related lineations in Paleozoic rocks. AVG. = average, rms dev. = root-mean-square deviation, n = number of readings : number of outcrops.

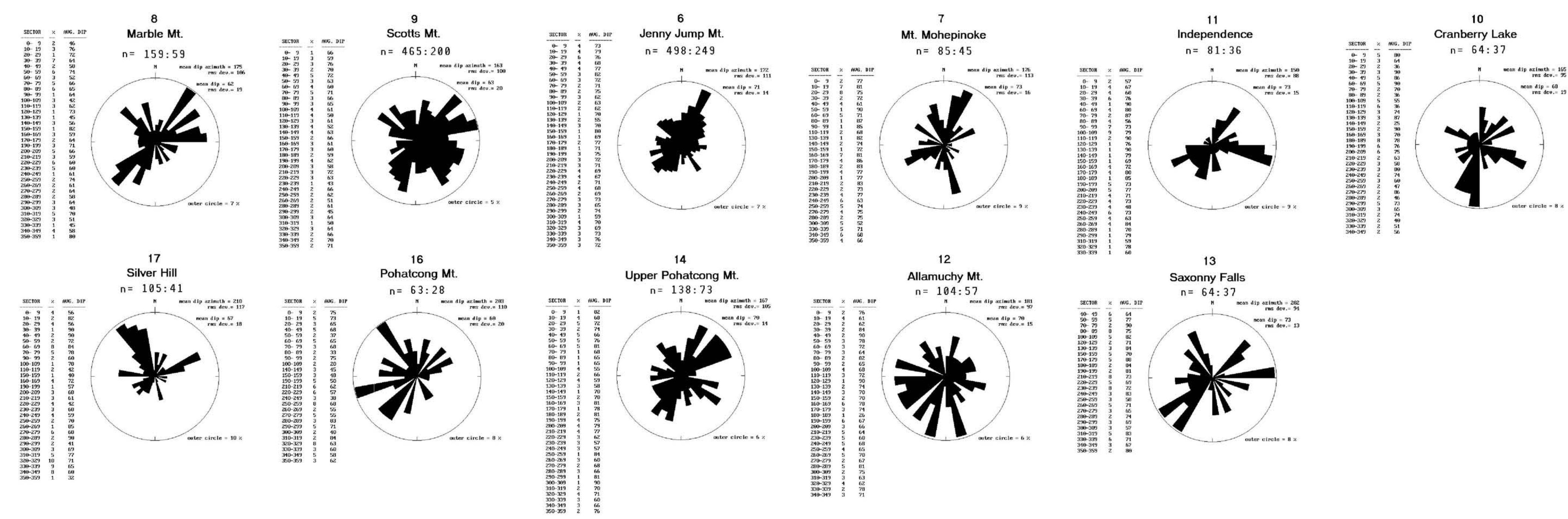

Figure 3. Joints in Proterozoic rocks. AVG. = average, rms dev. = root-mean-square deviation, n = number of readings : number of outcrops.

The interpretations presented here
are provisional pending peer review.
There may be revisions prior to publication.

Digital cartography by G. C. Herman