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

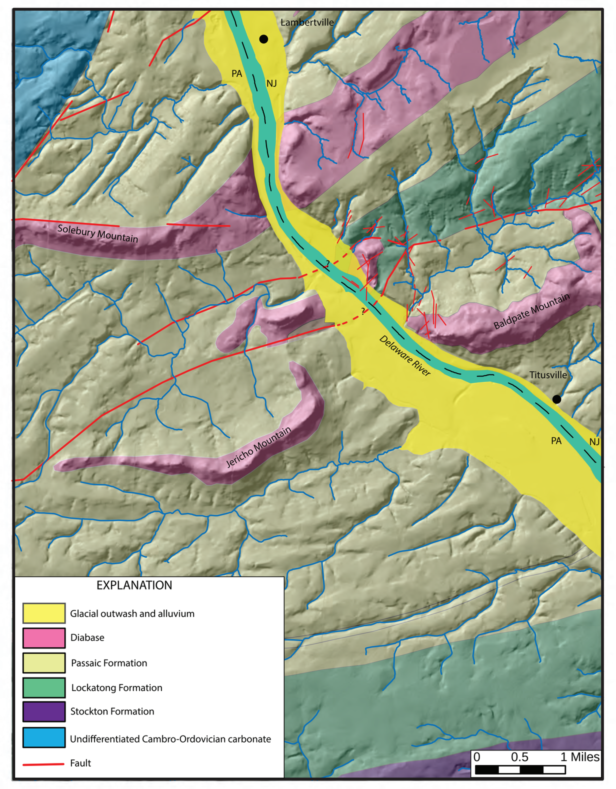


Figure 1. Hillshade and simplified bedrock map of the Lambertville, PA-NJ quadrangle. Pennsylvania geology modified from

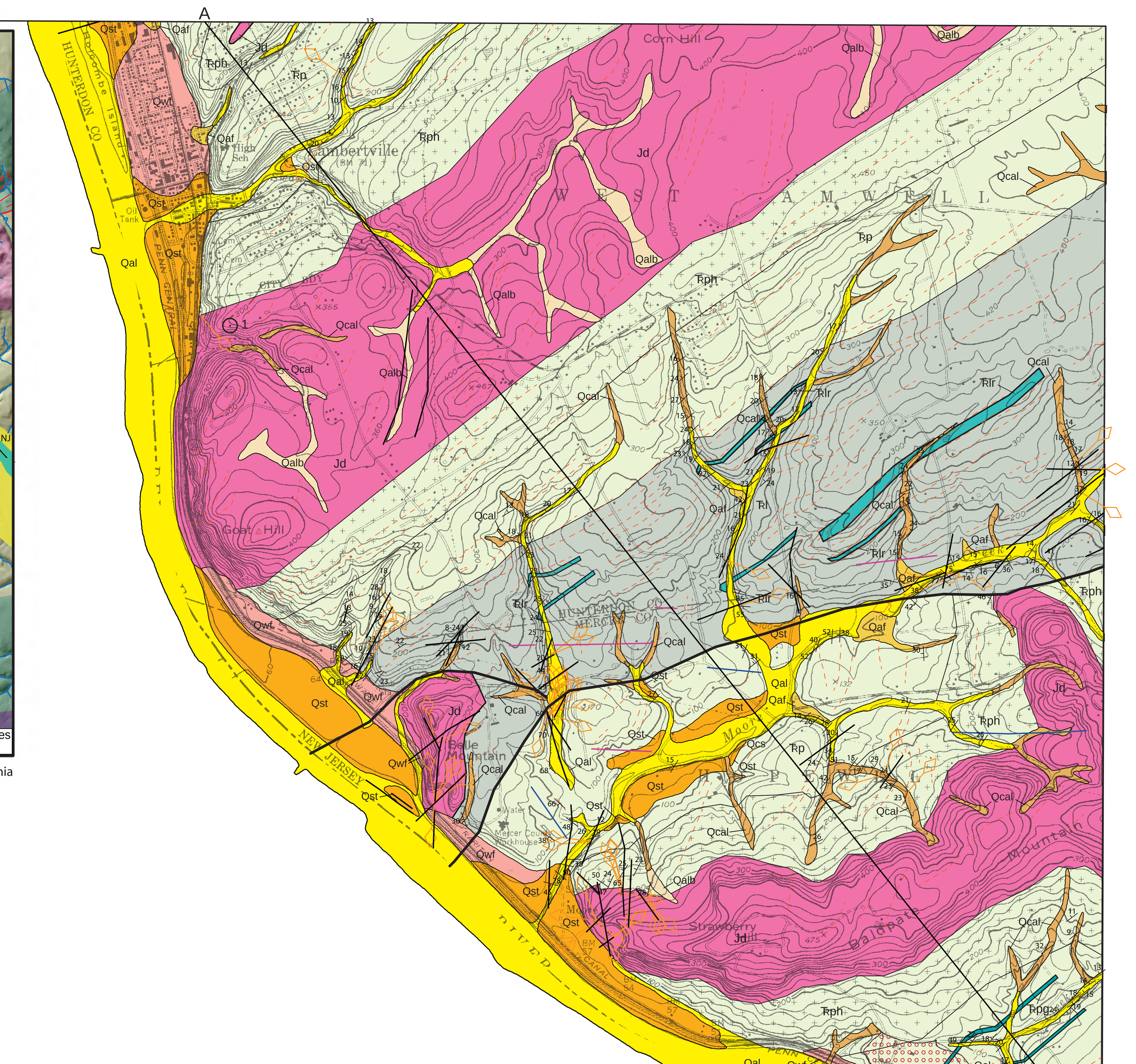


Figure 2. Thin bouldery diabase colluvium overlying Passaic Formation hornfels. Hammer lies along systematic joints striking 20° and dipping 63° SE.

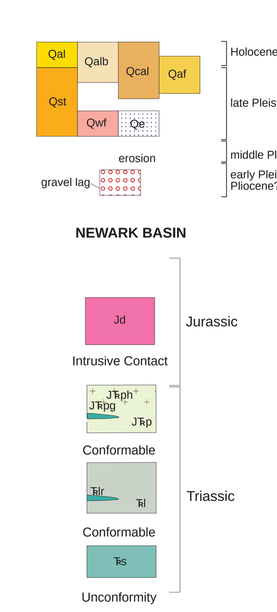
Figure 3. Ephemeral spring seepage eroding a small open-ended hollow in diabase colluvium on the west side of Baldpate Mountain. Tree near center of photograph is 12 inches in diameter.

Figure 5. Eastward view across a small fault in the Lockatong Formation, Moores Creek. Note folding of systematic joints into the fault showing right-lateral slip. Inset photo (westward view)shows part of a 3-meter wide fault breccia that trends about north - south.

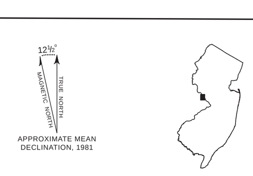
Figure 6. Brittle folding in the Lockatong Formation in the footwall of the Hopewell Fault about 800 feet from the fault trace. The pencil tip points downward along a fold axis that plunges 60° along a 095° trend.

Figure 7. Conjugate vertical joints in the Passaic Formation forming joint-block wedges along Fiddler Creek, Titusville, New Jersey.

CORRELATION OF MAP UNITS



Base from U.S. Geological Survey
Lambertville, 1942



SCALE 1:24 000

1 .5 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER

Bedrock geology mapped by H. F. Houghton, 1994, J. Mitchell, 1994, G.C. Herman, 2010 - 2013, D.H. Monteverde, 2012 -2013, and R.W. Witte in 2013. Surficial geology mapped by S.D. Stanford in 1990.

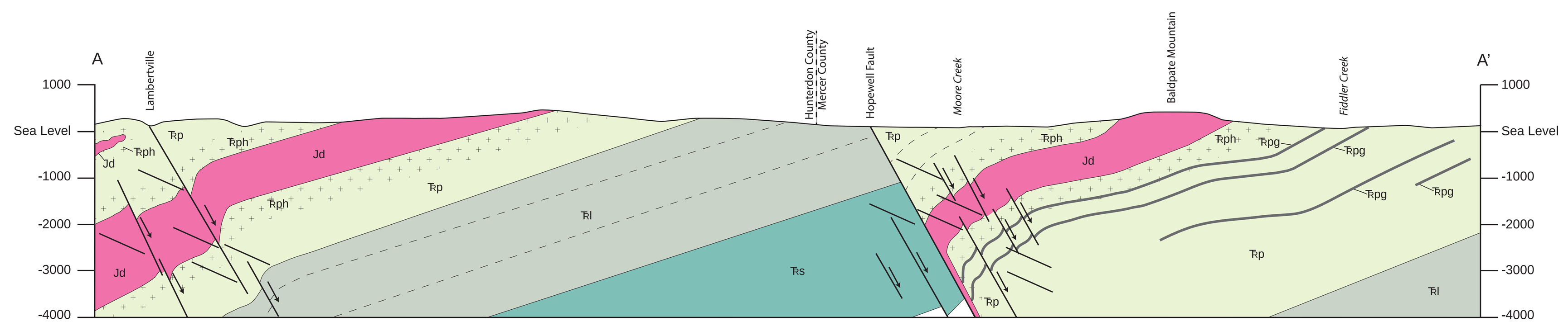
GIS application by Ron Pristas and digital cartography by R.W. Witte. Submitted in fulfillment of U. S. Geological Survey Award Number G12AC20227.

Following submission, map will be cartographically prepared, reviewed, edited, and published in digital format as a free download available on the N. J. Geological and Water Survey website.

Geologic Map of the Lambertville Quadrangle, Hunterdon and Mercer Counties, New Jersey

By
Gregory C. Herman, Ron W. Witte, Donald H. Monteverde and Scott D. Stanford

DRAFT



DESCRIPTIONS OF MAP UNITS

Qal Alluvium -- Silt, pebble-to-cobble gravel, minor fine sand and clay. Moderately to well-sorted and stratified. Contains minor amounts of organic matter. Color of fine sediment is reddish-brown to brown, locally yellowish-brown. Gravel is dominantly flagstones and chips of red and gray shale and mudstone with minor pebbles and cobbles of basalt, diabase, sandstone, and hornfels. Silt, fine sand, and clay occur as overbank deposits on floodplains along low-gradient stream reaches. Overbank silts are sparse or absent along steeper stream reaches. Gravel is deposited in stream channels and is the dominant floodplain material along steeper stream reaches. Flagstone gravel typically shows strong imbrication. As much as 10 feet thick.

Qalb Alluvium and boulder lag -- Silt, sand, minor clay and organic matter, dark brown, brown, yellowish-brown, reddish-yellow, moderately sorted, weakly stratified, overlying and alternating with surface concentrations (lags) of rounded to subrounded diabase (and, in places, hornfels) boulders and cobbles. As much as 10 feet thick (estimated). Formed by washing of weathered diabase and hornfels by surface water and groundwater seepage.

Qcal Colluvium and alluvium, undivided -- Interbedded alluvium as in unit Qal and colluvium as in unit Qcs in narrow headwater valleys. As much as 10 feet thick (estimated).

Qaf Alluvial fan deposits -- Flagstone gravel as in unit Qal and minor reddish-brown silt and fine sand. Moderately sorted and stratified. As much as 15 feet thick. Form fans at mouths of steep tributary streams.

Qst Stream-terrace deposits -- Silt, fine sand, and pebble-to-cobble gravel, moderately sorted, weakly stratified. Deposits in the Neshanic River basin are chiefly reddish-yellow to reddish-brown silt with minor fine sand and trace of red and gray shale, mudstone, and sandstone pebble gravel, and are generally less than 10 feet thick. They form terraces 5 to 10 feet above the modern floodplain and are likely of late Wisconsinan age. Deposits along the Delaware River are chiefly yellowish-brown silt and fine sand as much as 25 feet thick that form a terrace 15 to 20 feet above the modern floodplain. They rest on a strath cut into the glaciofluvial gravel (unit Qwf) and so are of postglacial age. Deposits along Wickecheoke Creek are dominantly flagstone gravel and minor reddish-brown silt and fine sand. They are as much as 15 feet thick and form terraces 5 to 10 feet above the modern floodplain. They are likely of both late Wisconsinan and postglacial age.

Qe Eolian deposits -- Silt and very fine-to-fine sand, reddish yellow. Well-sorted, nonstratified. As much as 5 feet thick. These are windblown deposits blown from the glaciofluvial plain in the Delaware River valley.

Qwf Glaciofluvial deposit -- Pebble-to-cobble gravel and pebbly sand, moderately to well-sorted and stratified. Sand is yellowish-brown, brown, light gray. Gravel includes chiefly red and gray mudstone and sandstone, gray and white quartzite and conglomerate, and some gray and white gneiss, dark gray chert, and dark gray diabase. As much as 40 feet thick. Forms an eroded plain in the Delaware River valley with a top surface about 35-40 feet above the modern floodplain. Deposited by glacial meltwater descending the Delaware River valley during the late Wisconsinan glaciation.

Jd Diabase (Lower Jurassic) -- Fine-grained to aphanitic dikes (?) and sills and medium-grained, discordant, sheet-like intrusion of dark-gray to dark greenish-gray, sub-ophitic diabase; massive-textured, hard, and sparsely fractured. Composed dominantly of plagioclase, clinopyroxene, and opaque minerals. Contacts are typically fine-grained, display chilled, sharp margins and may be vesicular adja-cent to enclosing sedimentary rock. Exposed in map area in sills, southeast of Stockton and east of Lambertville, and in the Sourland Mountain diabase sheet on the southern edge of the mapped area. This sheet may be the southern extension of the Palisades sill. The thickness of the Rocky Hill diabase in the quadrangle, known mainly from drill-hole data, is approximately 1,325 feet.

Ʀp, Ʀpg, Ʀph Passaic Formation - (Lower Jurassic and Upper Triassic) (Olsen, 1980) - Interbedded sequence of reddish-brown to maroon and purple, fine-grained sandstone, siltstone, shaly siltstone, silty mudstone and mudstone, separated by interbedded olive-gray, dark-gray, or black siltstone, silty mudstone, shale and lesser silty argillite. Reddish-brown siltstone is medium- to fine-grained, thin- to medium-bedded, planar to cross-bedded, micaceous, locally containing mud cracks, ripple cross-lamination, root casts and load casts. Shaly siltstone, silty mudstone, and mudstone form rhythmically fining upward sequences up to 15 feet thick. They are fine-grained, very-thin- to thin-bedded, planar to ripple cross-laminated, fissile, locally bioturbated, and locally contain evaporate minerals. Gray bed sequences (JƦpg) are medium- to fine-grained, thin- to medium-bedded, planar to cross-bedded siltstone and silty mudstone. Gray to black mudstone, shale and argillite are laminated to thin-bedded, and commonly grade upwards into desiccated purple to reddish-brown siltstone to mudstone. Thickness of gray bed sequences ranges from less than 1 foot to several feet thick. Several inches of unit have been thermally metamorphosed along contact with Orange Mountain Basalt (Jo). Thicker thermally metamorphosed sections(JƦph) exist on the southern flank of Sourland Mountain, on the southern part of the mapped area. Unit is approximately 11,000 feet thick in the map area.

Ʀl, Ʀlr Lockatong Formation (Upper Triassic) (Kummel, 1897) - Cyclically deposited sequences of mainly gray to greenish-gray, and in upper part of unit, locally reddish-brown siltstone to silty argillite (Ʀlr) and dark-gray to black shale and mudstone. Siltstone is medium- to fine-grained, thin-bedded, planar to cross-bedded with mud cracks, ripple cross-laminations and locally abundant pyrite. Shale and mudstone are very thin-bedded to thin laminated, platy, locally containing desiccation features. Lower contact gradational into Stockton Formation and placed at base of lowest continuous black siltstone bed (Olsen, 1980). Maximum thickness of unit regionally is about 2,200 feet (Parker and Houghton, 1990).

Ʀs Stockton Formation (Upper Triassic) (Kummel, 1897) - Unit is interbedded sequence of gray, grayish-brown, or slightly reddish-brown, medium- to fine-grained, thin- to thick-bedded, poorly sorted to clast-imbricated conglomerate, planar to trough cross-bedded, and ripple cross-laminated arkosic sandstone, and reddish-brown clayey fine-grained, sandstone, siltstone and mudstone. Coarser units commonly occur as lenses and are locally graded. Fining upwards sequences are common, the finer grained beds are bioturbated. Conglomerate and sandstone layers are deeply weathered and more common in the lower half; siltstone and mudstone are generally less weathered and more common in upper half. Lower contact is an erosional unconformity. Thickness is approximately 4,500 feet. In subsurface only.

EXPLANATION OF MAP SYMBOLS

Surficial Map Symbols

Contact--Contacts of units Qal, Qst, and Qwf are well-defined by landforms and are drawn from 1:12,000 stereo airphotos. Contacts of other units are drawn at slope inflections and are feather-edged or gradational.

Gravel lag--Scattered cobbles of gray and white quartzite and quartzite-conglomerate left from erosion of fluvial deposits.

Strath--Erosional terrace cut into bedrock by fluvial action.

Bedrock Map Symbols

Contact - Dashed where approximately located; queried where uncertain; dotted where concealed

Faults - U, upthrown side; D, downthrown side. Ball and post indicates direction of dip
Dashed where approximately located; queried where uncertain; dotted where concealed
Arrows show relative motion
Motion is unknown

Anticline - showing trace of axial surface, direction and dip of limbs, and direction of plunge.

Syncline - showing trace of axial surface, direction and dip of limbs, and direction of plunge.

Strike and dip of inclined beds

Ridge form-line or scarp parallel to bedrock strike. Interpreted from a LIDAR-derived hillshade image.

Slickenline

Well 1 location

Abandoned rock quarry

Active rock quarry

INTRODUCTION

The Lambertville 7-1/2' topographic quadrangle straddles the New Jersey (NJ) – Pennsylvania (Pa) border at the Delaware River. The upper right quadrant of the quadrangle falls in the Newark basin part of the Piedmont Physiographic Province, and Hunterdon and Mercer Counties. The Delaware River flows southeast through the quadrangle within a narrow valley underlain by late Wisconsinan glacial outwash and postglacial stream deposits (fig. 1). Topographic relief varies within the quadrangle ranging from a high of 475 feet above sea level (a.s.l.) on Baldpate Mountain near Strawberry Hill to a low of about 50 feet a.s.l. along the river less than one mile away. This variable relief reflects the erosional differences between the various igneous and sedimentary bedrock of Early Mesozoic age (fig. 1). The highest elevations are underlain by intrusive igneous rocks (diabase) whereas those areas of lesser relief are underlain by red and gray shale and argillite. These areas are highly dissected by the Delaware's tributaries, with stream courses chiefly controlled by brittle faults and systematic tension and shear fractures in the bedrock.

The Early Mesozoic sediment and igneous material were deposited within the Newark rift basin, one of a number of extensive continental basins that formed on the Atlantic margin of North America during an early phase of breakup and separation of the Pangaea supercontinent into today's continents. The Newark basin is filled with Triassic-Jurassic sedimentary and igneous rocks that have been tilted NW, faulted, and locally folded (see recent summaries in Schlische, 1992; and Olsen and others, 1996). Most tectonic deformation is probably Late Triassic to Middle Jurassic age (Lucas and others, 1988; de Boer and Clifford, 1988). Southeast-dipping normal faults along the basin's northwestern margin primarily influenced the basin morphology, sediment deposition patterns, and the orientation of secondary structures within the basin. Differential fault slip along individual segments of border and intrabasinal splay faults resulted in folding of bedding with axes oriented sub-parallel and sub-normal to the main fault traces (Schlische, 1995). Both border and intrabasinal faults were active during sediment deposition with thicker strata located in synclines. Tectonic deformation and synchronous sedimentation continued into the Middle Jurassic at which time extensional faulting and associated tilting and folding ceased. Current thinking is that the basin likely experienced a period of post-rift contraction deformation and localized basin inversion, which have been recognized in other Mesozoic rift basins (de Boer and Clifford, 1988; Withjack and others, 1998). Subsequent erosion of Mesozoic rocks was followed by flexural loading of the passive margin by Cretaceous sediments of the coastal plain sequence.

The compilation of bedrock structures through the entire quadrangle requires integrating geological maps between neighboring states. Only brief geological mapping was done in Pennsylvania for this effort that mostly relied upon mapping by Willard and others (1959) at the 1:62,500 scale as a basis for compiling continuous, interstate structures. During this compilation, we recognized that the nearby Buckingham window represents a structural dome where Proterozoic and Paleozoic basement crop out in the footwall of the Chalfont fault. Having Precambrian and Paleozoic strata cropping out in the center of the basin requires at least 2-3 miles (3-5 km) of positive structural relief adjacent to flanking depositional centers including the Jacksonwald, Sand Brook, and Flemington synclines. The 'Buckingham dome' contains conjugate diabase dikes that probably merge and feed sills that step down off the dome into flanking areas such as those in the Lambertville quadrangle. The occurrence of a structural dome that is at least coeval with, and perhaps predates diabase intrusion into basin strata requires further evaluation and reconsideration of the timing and structural evolution of the basin, particularly with respect to the timing of basin inversion and the map geometry of the large, intrabasinal faults. Although the scope and details associated with this crustal dome are beyond the scope of the mapping presented here, recognition of this structure stemmed from this work and is therefore introduced here for further consideration.

STRATIGRAPHY

Strata in the New Jersey part of the Lambertville quadrangle include recent (Quaternary) surficial deposits and Mesozoic (Lower to upper Triassic) fractured sedimentary and igneous bedrock. Surficial deposits include fluvial, colluvial, and windblown sediment. The oldest surficial material in the map area is a lag of quartzite cobbles on a bedrock bench about 100 feet above the Delaware River near Titusville. These cobbles are erosional remnants of fluvial gravel laid down by the Delaware that may be equivalent to the Pensauken Formation, a Pliocene fluvial deposit in central New Jersey that formerly extended up the Delaware valley from the Trenton area. After deposition of these gravels, the Delaware River and its tributaries deepened their valleys by 50 to 100 feet into bedrock, in the early and middle Pleistocene (2.5 Ma to 125 ka). During the late Wisconsinan glaciation, which reached its maximum extent at about 25 ka, glaciofluvial gravel was laid down in the Delaware valley (unit Qwf). This gravel was deposited between about 30 and 20 Ka as the glacier advanced into, and then retreated from, the Delaware Valley, reaching its terminal position just south of Belvidere, N.J. At the same time, sediment aggraded in tributary valleys (units Qst, Qaf), colluvium (fig. 2) collected on footslopes (not shown on map), and silt and fine sand were blown off of terraces in the Delaware valley (unit Qe). Between about 20 and 15 ka, the Delaware, no longer transporting glacial gravel, incised into the glaciofluvial deposit and cut a lower terrace on which it laid down sand and silt (unit Qst in the Delaware valley). By 10 ka, continued downcutting had formed the present floodplain and channel of the Delaware River and tributary streams. Channel and overbank deposits have aggraded in these floodplains within the past 10 ka (unit Qal). In headwater areas during this period, and earlier, colluvium and weathered rock material have been incised, washed, and winnowed by runoff and groundwater seepage (fig. 3, units Qcal, Qalb).

Bedrock units range in age from the Late Triassic to Early Jurassic (Olsen, 1980) and consist of Triassic alluvial to lacustrine sedimentary rocks that are locally cut and intruded by Early Jurassic diabase dikes and sills. Argillite and shale underlie the majority of the area. The sedimentary sequence here includes the uppermost alluvial beds of the Stockton Sandstone (alluvial) that is conformably overlain by thick, gray and black (deep lacustrine) argillite of the Lockatong Formation, then progressively more abundant red argillite and shale (shallow lacustrine to playa) of the Passaic Formation. The uppermost part of the Stockton Formation is mapped in the northeast where it is pinched out in the footwall of the Hopewell fault before reaching the Delaware River. The Stockton is poorly exposed here, but elsewhere in the area, the upper part is red, light brown and white sandstone, and lesser red and gray siltstone and mudstone (Moneteverde and others, in press). A more complete section of the Stockton is represented in the subsurface in cross-section A-A'. The black, gray, and red argillite and shale beds of the Lockatong and Passaic Formations display a cyclical pattern of wet and dry depositional environments encompassing four different periods of time spanning thousands to millions of years that reflect systematic climate variations tied to celestial mechanics (Olsen and others; 1996). The shortest of the recognized cycles has been identified as generally resulting in about 20 feet of lacustrine sediment over a 20,000-year time period (Van Houten, 1962).

The igneous (diabase) sills and dikes in the NJ part of the Lambertville quadrangle have been associated with the Orange Mountain Basalt based on geochemical (Husch, 1988; Houghton and others, 1992) and paleomagnetic data (Hozik and Colombo, 1984). Each intrusive body is surrounded by thermally metamorphosed argillite and shale (hornfels) of the Lockatong and Passaic Formations. Spectacular samples of secondary sulphides minerals and subhedral tourmaline crystals were collected in Passaic hornfels from the bench excavations of the Moore's Station Trap Rock mine at the western reaches of Baldpate Mountain. We thank Trap Rock Industries for the permission to access their facility while mapping this area.

STRUCTURE

Discussion of the structural setting and mapped structures is restricted to the NJ part of the quadrangle unless explicitly stated otherwise in order to avoid repetition. Parts of the two, major intrabasinal fault systems (Flemington and Hopewell) in the Newark basin occur in the NE part of the quadrangle. Isolated splay faults mapped near Lambertville stem from the Flemington fault to the north where branching and reconnecting faults have been mapped splaying southward through Dilt's Corner in the Stockton quadrangle to the north (Monteverde and others, in press). This is the area where the Flemington fault bends to overlap with the Chalfont fault in Pa (Houghton and others, 1992). However, most of the map is dominated by structures developed along the Hopewell fault system. The main trace of the Hopewell fault snakes through the area along a general N60º E trend that reflects the coalescence of smaller fault segments varying in strike between N20ºE to N80ºE. Early, isolated, en echelon fault segments of the general trend are cross-cut and joined by later fault segments to form systematic, interconnected, rhombohedral planes that accommodate early tensional dip-slip strains and later, oblique-normal, (transtentional) slip strains. There is early dip slip on faults striking N40º to N65ºE (S1 fracture phase of Herman, 2010) that were cross-cut, sheared, and tilted from later, steeply-dipping normal faults striking between N5º W to N20º E (S3 fracture phase of Herman, 2010), and by a complimentary late set striking about + 10º about E-W (fig. 4A) Those striking nearly N-S show late-stage, right-lateral (sinistral) components of oblique, normal dip slip and those striking about E-W show left-lateral (dextral) dip-slip strains.

Bedrock outcrops along and in tributaries to Moore's Creek (figs. 5 and 6) commonly contain, fractured, sheared, and folded strata on both sides of the main fault trace for distances approaching one mile. Localized outcrops of brecciated argillite, shale, diabase, and hornfels are found closer to the main fault trace. Brittle fractures include ordinary joints sets lacking any visible shear separation or evidence of slip in the form a mechanical or mineralized strain-slip features. Joints include mineralized (commonly with calcium carbonate) and unmineralized varieties that were all probably once filled with secondary minerals, some of which was removed through exhumation and near-surface erosion. Those having slip evidence were mostly measured on exposed, parted surfaces where strain features stemmed from mechanical abrasion, plucking, and polishing rather than those formed by overlapped, stepping mineral fibers.

The general strikes and dips of the most common groups of mapped structures were analyzed using circular histograms and stereographic-projection diagrams (fig. 4B) They show that the mean strike of sedimentary beds in the quadrangle is N25ºE with an average dip of 16o toward the NW (dip/dip azimuth of 16-295). The most frequent joint strike (N58ºE) falls within 7o of striking parallel with the aforementioned general strike of the Hopewell fault (N65ºE). Joints fan about this prominent strike through acute angles and most dip steeply E to SE. Subordinate sets of steeply-dipping cross-strike joints strike normal to the most frequent joint set. Small faults show more dispersed strike maximums, with most frequent sets striking N40ºE to N50ºE and N to N10ºE. These two sets are bracketed by less-common sets striking at acute angle to the primary trends. Most of the small faults dip to the S and SE, but a proportionally larger fraction of small faults dip NW in comparison to the composited joint sets. Measured slip lineation show a pronounced distribution falls within an N-S girdle with plunges dominantly skewed to the S, but also with scattered detached clusters of lesser slip directions trending toward E-W and NW directions.

Joints (fig. 7) show strike maximums ranging about N40ºE from N20ºE to N60ºE, with complimentary sets of subordinate cross joints (fig. 4B) These trends agree with the early (S1 and S2) fracture systems noted by Herman (2010?) elsewhere in the NJ part of the basin. In contrast, the small faults show distinct maximums striking between N40º to N50º E (S1) and N-N20ºE (S3), but a wide span of slip planes striking between N10ºW to N80ºE (fig. 4A). These groups collectively span a 90-degree sector striking about N-S to E-W. (fig. 4B) Slip on these planes is complex with indicators of both dip slip and strike slip motions that reflect overlapping, incremental, and progressive strains including early dip-slip motion on small faults sipping southeast, and later left-lateral (sinistral) strike slip on slip planes striking about N45ºE to E-W, and right-lateral (dextral) strike slip motion on small faults striking about N-S to N20ºE (fig. 4A). Overall, the outcrop-scale structures show that the bedrock here was first stretched southeastward, then later eastward. Small folds mapped in the fault system commonly trend E-W, plunging gently-to moderately, westward and eastward. These folds may have originated as drag folds associated with late-stage, strike slip movement along the Hopewell fault system that eventually merges with the Chalfont fault in Pennsylvania. The Chalfont shows about four miles of apparent, sinistral, stratigraphic separation based on the offset of a Jurassic dike in nearby Bucks County, Pennsylvania.

NOTES

The map includes a set of surface lineaments that are interpreted to represent bedrock ridges stemming from differential erosion of the layered strata having as little as a few feet of topographic relief. The lineament analysis used proprietary hillshade-relief themes based on digital terrain models derived from airborne ground surveys using laser ranging and detection methods (LIDAR). These data were generated by various interests, and are currently being compiled and integrated by NJ State programs for public access.

The location of a 370-ft deep bedrock well is included on the map that was drilled into the top of the Lambertville diabase sheet about one-mile North of Goat Hill. Stratigraphic, structural, and hydrogeological details for this well are reported by Herman and Curran (2010) based on the interpretation of a comprehensive set of geophysical logs, including an optical borehole televiewer (BTV) interpretation. A structural analysis of the compositional layering and tectonic fractures derived from the BTV data are included here as figure 4D as a basis to compare orientations of compositional layering and tectonic fractures mapped in outcrop (fig. 4C) versus the subsurface, and between the different diabase sills in the two major fault blocks. A comparison of compositional layering in the upper sections of both sills shows that layers in the Lambertville sill dip gently westward, whereas layers in Baldpate Mountain dip moderately eastward. Both sets of layers show bimodal distributions with fold (Beta) axes trending about E-W. This contrast in layering dip implies that the sills within the different fault blocks were at least, in part, injected from opposing directions. Baldpate Mountain has similar sill morphology to other nearby sills that reside within the Passaic Formation and the hanging wall of the Hopewell fault including Jericho Mountain across the Delaware River in Pa. to the west (fig. 1), and Pennington Mountain to the East (Herman and others, 2010). Each of these intrusions is predominantly sill-like in form, but includes a funnel-like dike segment that veers northward from each sill and heading toward the trace of the nearby Hopewell fault. We interpret this geometry as indicator that the sills are being sourced by dikes that locally ascend along the Hopewell fault (see cross section), probably during a late transtentional phase, or phases, of basin growth (S2 and/or S3 phases of Herman, 2010). Magma probably ascended at places along the fault system where strains were dilatational, and feeders followed linear avenues along interstices of misfit fault blocks in contrast with other areas where fault strains are high, blocks were impinged upon, restrained, and compressed. Based on these criteria, the western limb of the Baldpate Mountain sill was probably injected into the Passaic Formation from E to W, which then implies that the upper section of the Lambertville sill may have been injected from W to E based on the demonstrated differences in layering dip.

This map also addresses problems that arose from edge matching geological contacts and the main trace of the Hopewell fault along the Delaware River and between states in the vicinity of Belle Mountain. As previously mapped by Drake and others (1996), both the upper Lockatong contact with the Passaic Formation and the main trace of the Hopewell fault ran north of Belle Mountain. Here we map the main fault trace to swing south of the mountain to connect with a comparatively large fault mapped in Bucks County by Willard and others (1950), in contrast to a smaller fault segment that it was previously tied to. Similarly, the Lockatong-Passaic contact now swings from the more regional SW-NE strike to a N-S strike north of Belle Mountain and is cut by the fault trace before reaching the river. This restricts the Passaic Formation to crop out in the hanging wall and the Lockatong Formation in the footwall respectively. The Lockatong-Passaic contact is mapped about 1000 ft north of Belle Mt where Van Houten (1980) identified his "first Big Red unit" within the Lockatong. This section is well exposed and marks the change to having mostly red beds progressing upward through the composite section in comparison to having mostly gray and black beds below. Olsen and others (1996) places the Lockatong-Passaic contact at the base of a thick red section in the upper part of the Walls Island Member. Based on our mapping, we interpret Van Houten's 'first Big red unit' as Olsen and others (1996) first, thick red section of the basal Passaic Formation.

It is interesting to note that the E-W orientation of late-stage, map-scale folds in the Hopewell fault zone parallel the E-W strike of the Chalfont fault and the plunge of Beta axes derived from the bimodal distributions of compositional layering in diabase sills from both fault blocks. The tectonic link between these features is uncertain, but each set of structures is consistent with having the axis of least principal tectonic compression oriented E-W at some tectonic stage. Whether these trends reflect only E-W tectonic extension or overlapped phases of E-W extension followed by subsequent N-S compression is uncertain.

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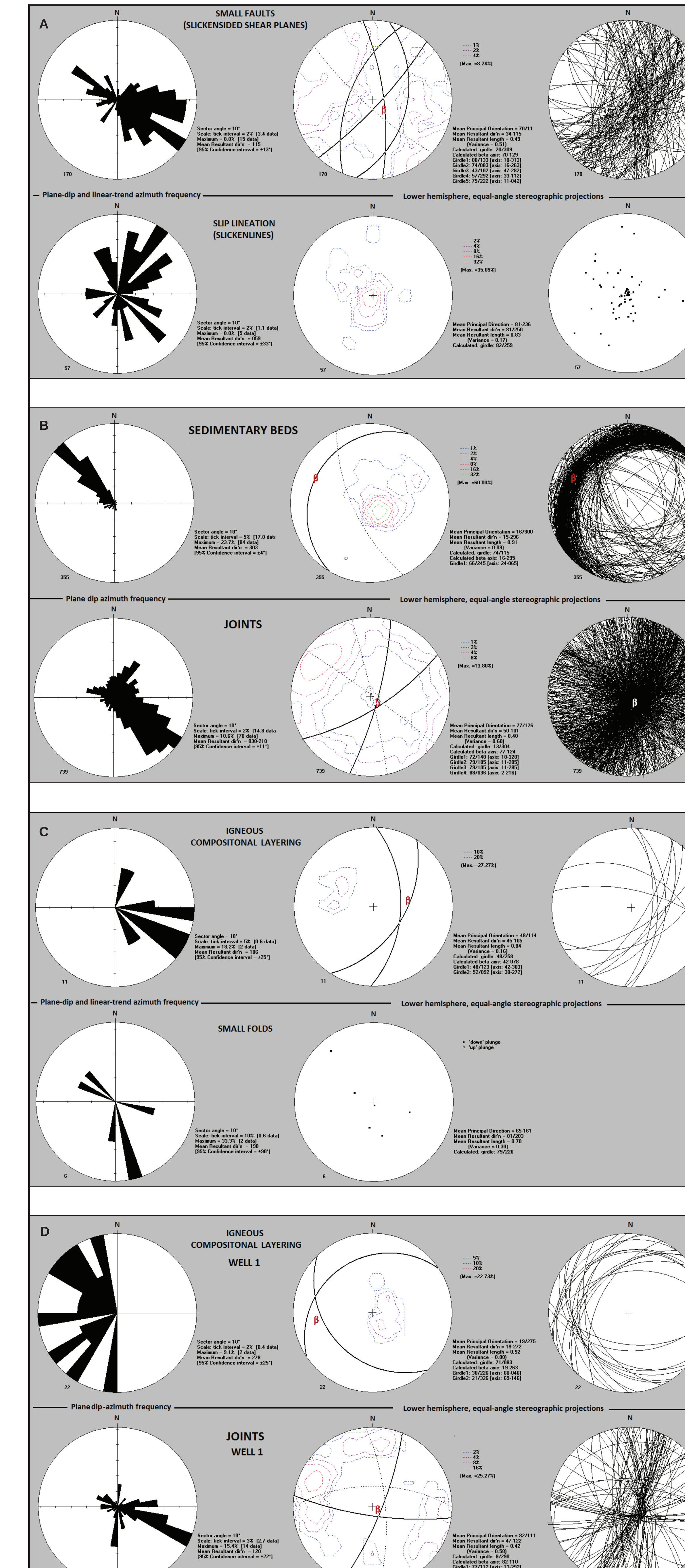

Figure 4. Structural analyses of primary and secondary structures. Primary structures include sedimentary beds and compositional layering in diabase. Secondary structures are grouped as joints, small faults (slickensided shear planes) and slip lineation (slickenlines). Data for figs 5A – C stem from outcrop data whereas 5D stems from subsurface data collected using a borehole televiewer (Herman and Curran, 2010). Circular histograms show relative frequencies of plane dip azimuths and lineation trends using 10o sectors. The stereographic diagrams are lower-hemisphere, equal-angle projections showing the composite distribution of features for each set of structures and the most common plane orientations for the planar structures.

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