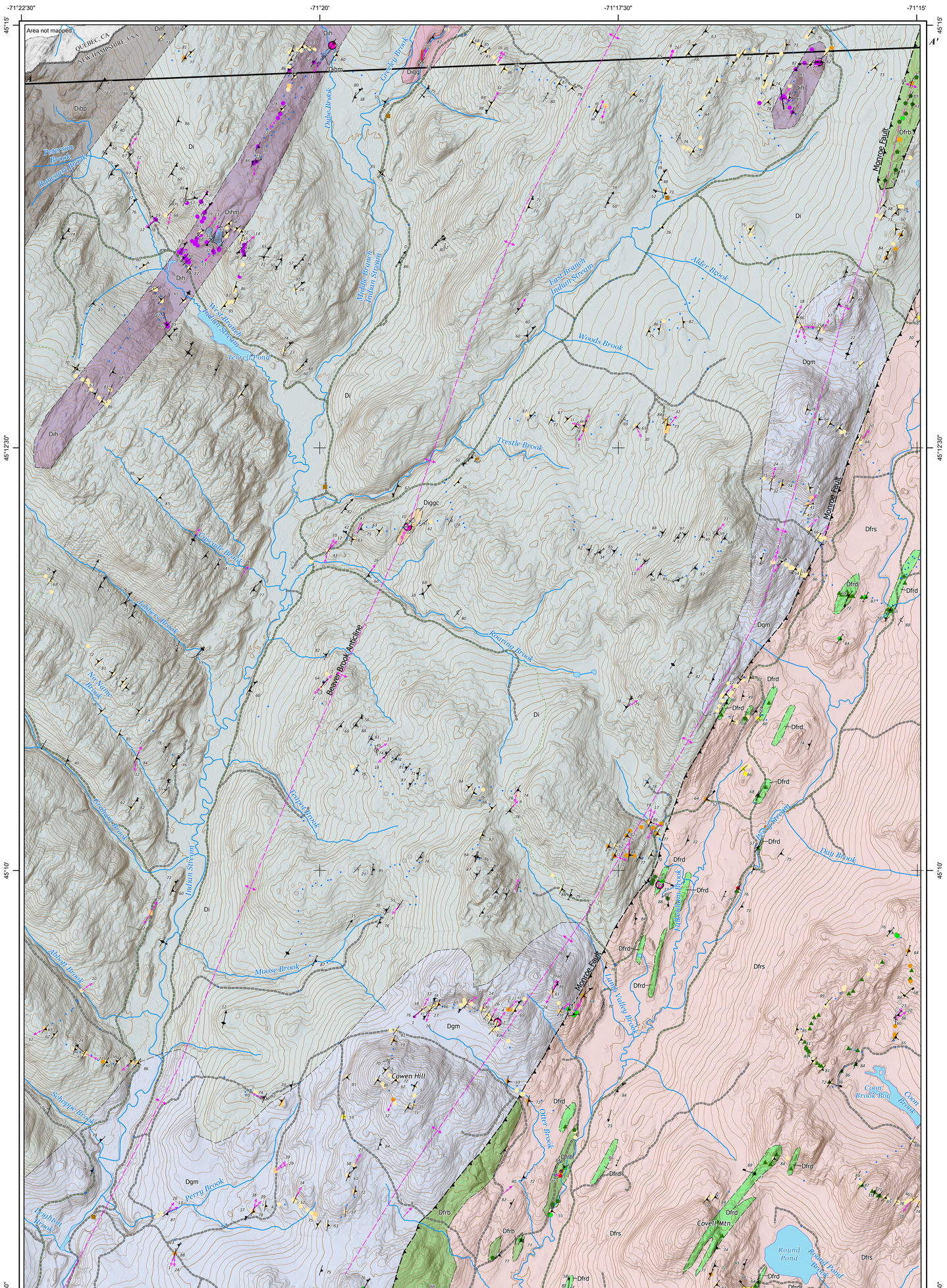
Bedrock Geologic Map of the Cowen Hill 7.5' Quadrangle, New Hampshire, 2022



	Greeley Brook	Prospect Hill
Metallak Mountain	Cowen Hill	Second Connecticut Lake
Pittsburg	Lake Francis	Magalloway Mountain

Scale 1:24,000

0 0.5 1 2 Kilometers

0 1,500 3,000 6,000 Feet

0 0.25 0.5 1 Miles

Topographic basemap from The National Map (USGS) vector base data, Cowen Hill 7.5' quadrangle Projection: North American Datum 1983 New Hampshire State Plane Feet. Contour Interval 40 ft. Hillshade produced from high resolution (1 meter) LiDAR data.

MN GN 15°5' 268 MILS 17.35° 29 MILS

UTM GRID AND 2015 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

DESCRIPTION OF MAP UNITS

IGNEOUS AND META-IGNEOUS UNITS

Mesozoic White Mountain Plutonic-Volcanic Suite

Mzf — **Felsic dike —**Mzf – Light red brown to golden weathering 1-1.2m thick, dark gray fine-grained micro-porphyritic to sugary aplite dike cross-cutting thick-bedded Devonian graywacke in the Indian Stream Canyon (Middle Branch) – see Cross-Section A-A'. Feldspars are dominant, but much altered to form a fine-grained sericitic matrix. Potential sources are the Jurassic Monadnock Mountain (Vt) and the Cretaceous Mont Mégantic (Quebec).

Early Devonian Frontenac Formation meta-igneous units

The relationships between the Frontenac intrusive and extrusive metaigneous rocks can be complex and subtle. An outcrop with abundant pillow meta-basalts or lapilli tuffs that define extrusive activity, can also include coarse-grained metadiabase. Contacts between coarse-grained and finer-grained units may not have an apparent chill zone. Two metaigneous Frontenac members were observed in the Cowen Hill Quadrangle.

Dfrd — **Metadiabase —** Metadiabase: Dominantly coarser grained meta-diabases to metagabbros that are sometimes associated with meta-lapilli tuffs, pillow basalts, meta-volcaniclastic sediments and other extrusive features. Compositions are similar to the meta-basalt unit (Dfrb). Outcrops range from thin sills to thick bodies that form 30-40 m cliffs that extend up to 1-2 kilometers. It was not possible to map all occurrences due to access issues. Lapilli meta-tuffaceous sediment (DFR_MS) adjacent to metadiabase bodies yielded ages of 408 ± 6 and 415 ± 5 Ma.

Dfrb — **Meta-basalt —** Meta-basalt: Dominantly meta-basalts, common pillows, possibly associated exhalative horizons in thicker units just east of the Monroe Line. The pillows range from small, ≤ 30 cm to 2 m in length; tops can sometimes be determined. Compositions range from basalts and trachybasalts to basaltic andesites and basaltic trachyandesites. It seems likely that the meta-basalt sequence is not much older than nearby meta-volcaniclastic tuffaceous sediments with maximum depositional ages of 408 ± 6 and 415 ± 5 Ma.

METASEDIMENTARY ROCKS

Middle to Early Devonian

Di — **Ironbound Mountain Formation** – black, metamudstone, slate, and phyllite, variably graphitic and pyritic, commonly spotted with either weathered pyrite and/or ankerite; interfings with black metasiltstones. Thin interlayers of fine-grained, light gray to rusty metasiltstone sometimes preserve grading. Where graded beds are preserved, delicate crossbedding may be seen on cleavage surfaces cutting bedding at a shallow angle. Metasiltstone channels occur primarily in the Hall Stream and Graded Graywacke members, but an outcrop of a stacked channel complex was also observed (Diggc). Correlative with the Ironbound Mountain Formation in northwestern Maine (Marvinney et al., 2001). Correlative with Meetinghouse Slate member of the Gile Mountain Formation in Vermont and in part with the Ludger and Lac Drolet members of the Compton Formation in Quebec.

Dibp — **Black Phyllite —** Metamorphosed black, mudstone, slate and phyllite member has very little siltstone and represents deposition in a quiescent euxinic environment. Dibp transitions to siltier facies to the east and is correlative with the Ludger member of the Compton Formation in southern Quebec. No known fossils or age dates.

Dih — **Halls Stream Grits —** Discontinuous lenses up to a few km long and few hundred meters wide. May occur in layers a few cm to tens of meters thick and is characterized by abundant feldspar grains (laths) occurring in black phyllite or metasiltstone matrices, including siltstone channels. In some locations, composed dominantly of feldspars and grades from thin-bedded unit (10-15 cm thick) to a massive unit without obvious bedding (Dihm). Traverses along the Dih unit north of Terrell Pond show highly variable interlayering or interfingering of the feldspar-rich units with black phyllites and siltstones. Coarser grit is composed of randomly oriented, euhedral, frequently fractured twinned plagioclase, variable amounts of clear quartz grains, and rare rock fragments in slaty/silty matrix. Maximum depositional ages vary between 413 to 425 ± 7 Ma and may be older than the actual age (see following Dihm description).

Dihm — **Halls Stream Grits - massive —** a sub-member that is a massive feldspar-rich unit that forms both small and large cliffs, which in places do not exhibit obvious bedding. Possible interpretation of the lack of bedding is due to its origin as a submarine debrite. Present in the ridge to the north of Terrell Pond and in the Pittsburg Quadrangle. Age dating of a sample exhibited a single well-defined "maximum depositional age" of 391 ± 8 Ma. Possible origin as a very rich tuffaceous sediment.

Digg — **Graded Graywacke —** Bands of rhythmically graded, gray weathering, fine-grained micaceous feldspathic meta-sandstone and dark gray meta-shale member of the Ironbound Mountain Formation. Beds range are typically only 0.5 cm to several meters thick (e.g., Indian Stream Canyon). Quartz, feldspar, white mica and opaque are dominant phases. Interpreted to equate with Dgg in Vermont (Ratcliffe et al., 2011) and the Lac Drolet member of the Compton Formation (Dcd) in nearby Quebec where Perrot et al. (2018) reported a maximum depositional age of 413 ± 7 Ma from U/Pb analyses of detrital zircons.

Diggc — **Graded Graywacke Channel Complex —** Thick-bedded meta-siltstone – meta-sandstone in an apparent stacked channel complex.

Dgm — **Gile Mountain Formation** — Gray to light brown weathering, variably calcareous feldspathic metasandstone in beds 0.5 – 3 m thick, meta-siltstone and dark gray phyllite. These units often carry ankerite and/or pyrite cubes up to 1 cm across, alteration of both minerals produces a reddish-brown weathering surface. Graded bedding is rarely preserved; brown weathering carbonate-rich lenses are present locally. Two detrital zircon samples (Lake Francis Quad yielded maximum depositional ages of 413 ± 8 Ma and 411 – 414 ± 10 Ma respectively. Just north of Cowan Hill, detrital zircon analyses yielded several young age clusters: 388 ± 8, 411 ± 6 and 426 ± 7 Ma and a crystallization age (basaltic andesite) yielded an age of 40 3± 6 Ma. Correlated the Milan member (maximum depositional age of 413 ± 7 Ma along the Quebec-NH border - Perrot, 2018) of the Compton Formation and the Gile Mountain Formation (Dgqs) in nearby Vermont (maximum depositional age of 401 ± 6 Ma near St. Johnsbury (Perrot, 2018)).

Dfrs — **Metasediments of the Frontenac Formation**Frontenac metasediments consist of metasiltstones, sparse metasandstones, phyllites and a wide range of volcaniclastic metasediments. Homogenous metasiltstone bed thicknesses can exceed 1-2 m thick. In some places, there are graded beds that preserve Bouma couplets, which occasionally provide top directions, and rare calcareous lenses up to a meter in length. A distinct characteristic of much of the Frontenac metasediments is the presence of sufficient chlorite to provide a green color that is uncommon in the Gile Mountain metasediments.

Two U-Pb zircon analyses from meta-volcaniclastic sediments / lapilli tuffs in the Lake Francis Quadrangle yielded maximum depositional ages of ca. 408 ± 6 Ma and 415 ± 6 (new) Ma. A third analysis of very-fine grained metasediment recovered a limited number of zircons yielded a maximum depositional age of 443 ± 16 Ma that is likely significantly older than the depositional age. In the Cowen Hill Quadrangle, a metasediment yielded a maximum depositional age of 434 ± 4 Ma. Comparison of the age distributions of zircon grains in the Frontenac and the Gile Mountain metasediments shows that most Frontenac metasediments have a unique peak around 580 Ma, suggesting a different sediment source at that time.

Dwrs — **Waits River Formation** — Is shown at depth in Cross-Section A-A'. Interbedded brown weathering metasiltstone, dark gray phyllite, and brown lenses of meta-limestone and thin, intensely foliated dark gray to black limey metasiltstone as along West Road, Clarksville, NH. Previously interpreted as a calcareous member of the Frontenac Formation (Lyons et al. 1997). Correlated with parts of the Ayers Cliff Formation of Quebec (Perrot et al., 2018). Hatch (1963) suggested that the Waits River could be a calcareous facies of the Gile Mountain. Perrot (2019) presented detrital zircon age dates for the Waits River in northern Vermont near St. Johnsbury, indicating a maximum depositional age of 406 ± 9 Ma. McWilliams et al. (2010) determined two ages in Vermont: 418 ± 7 Ma and 415 ± 2 Ma. Aleinikoff and Karabinos (1990) reported an age of ca. 423 ± 4 Ma on a felsic dike that crosscut the Standing Pond Volcanics Member.

EXPLANATION OF MAP SYMBOLS

Contacts and faults
- Contact, certain
- Contact, approximate
- Thrust Fault, location approximate. Teeth on upper plate.
- Fault, showing strike and dip

Planar dikes and veins
- Felsic dike, vertical
- Quartz vein

Linear features
- F1 fold axis
- F2 fold axis
- Lineation

Fold hinge traces
- Asymmetric Anticline, showing shorter arrow on steeper limb
- Symmetrical Anticline

Bedding
- Bedding, inclined, showing dip
- Bedding, vertical
- Inclined graded bed, showing topping direction and dip
- Vertical, ball indicates topping direction
- Bedding, overturned, showing dip
- Bedding, inclined, for stations with multiple measurements, showing dip

Brittle Structure
- Joint, showing strike and dip
- Joint, vertical
- Joint, for stations with multiple measurements, showing dip
- Fracture

Foliation
- Foliation, S1, showing strike and dip
- Foliation, S1, vertical
- Foliation, inclined, S1, for stations with multiple measurements, showing dip
- Indeterminate bedding and/or S1 foliation, showing dip
- Indeterminate bedding and/or S1 foliation, vertical
- Indeterminate bedding and/ or S1 foliation, for stations with multiple measurements, showing dip
- Foliation, S2, showing strike and dip
- Foliation, S2, vertical
- Foliation, S2, inclined, for stations with multiple measurements, showing dip
- Foliation, S2, vertical, for stations with multiple measurements
- Foliation, S3, showing strike and dip
- Foliation, S3, for stations with multiple measurements, showing dip
- Foliation, unknown age

Other points
- Observation
- Gravel pit

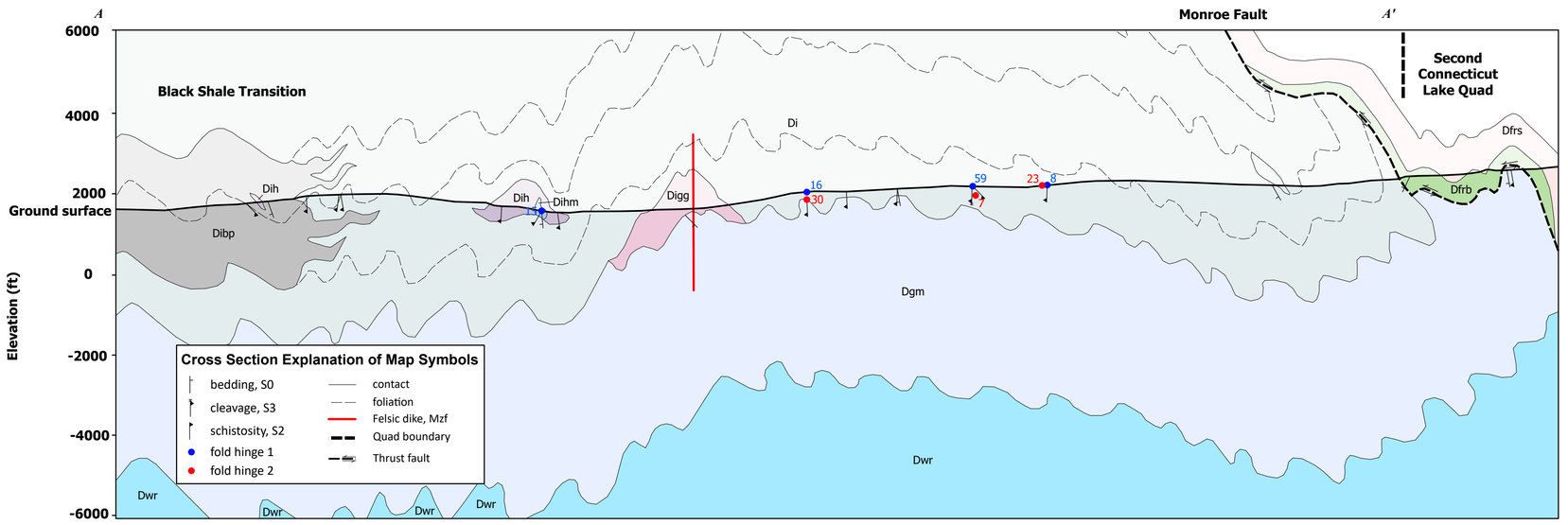
Samples
- Preliminary Zircon U-Pb age (this study)

Basemap features
- State Boundary
- US Route
- Local Road
- Not Maintained
- Railroad
- Lidar Contours (20-foot intervals)
- Stream
- Trail

EXPLANATION OF LITHOLOGY POINT SYMBOLS

- Black Phyllite
- Bull Quartz
- Gray-brown Phyllite
- Gravel
- Metagraywacke
- Halls Stream Grits
- Metabasalt
- Felsic metavolcanic
- Mafic Intrusive
- Metasiltstone
- Metasiltstone and Phyllite
- Metasandstone
- Metatuff and Pyroclastics
- Metavolcaniclastics
- Unmetamorphosed felsic dike (Mesozoic)

Interpretive Cross Section A - A' (No Vertical Exaggeration)



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Geology by D.R. Converse, W.A. Bothner, C.E. Jahring, II, and P.S. Koch, 2022
Digital Compilation by D.R. Converse, and J.A. Keeley, 2022

New Hampshire State Geologist: S. Csiki, Ph.D.

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Maps and map pamphlets can be found at https://www.des.nh.gov/land/geology

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New Hampshire Geological Survey
NH Department of Environmental Services
29 Hazen Drive, P.O. Box 95
Concord, NH 03302-0095
Phone: 603-271-1976
E-mail: geology@des.nh.gov