Tracing the Fate and Transport of PFOA in the Bedrock Aquifer of Bennington, Vermont

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Marcel Belaval – EPA Region I

VERMONT AGENCY OF NATURAL RESOURCES Vermont Geological Survey

Middlebury 1800

UMASS geosciences

Center for EARTH & ENVIRONMENTAL SCIENCE SUNY Plattsburgh

BENNINGTON COLLEGE

EPA

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Outline

- Bennington PFOA Timeline
- Vermont Geological Survey Involvement Timeline
- Aquifer Characterization Retrospective
  - Where PFOA was not in groundwater
- Conceptual Site Model Summary

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A Bennington PFOA Timeline

- ~December 2015- PFOA discovered in Hoosic Falls, NY wells.
- January 2016- PFOA discovered in wells around Chemfab plant and testing expanded to a radius of ~1mile from this plant.
- Winter – Spring 2016- Bottled water supplied to those with contaminated wells
- 2016 - 2017 - Point of Entry Treatment (POET) Systems installed for contaminated wells.
- Summer 2017- First settlement between State of Vermont and St. Gobain to construct new water lines to the western ~half of the contamination area.
- April 2019- Second settlement between State of Vermont and St. Gobain to construct new water lines to the eastern ~half of the contamination area.
- 2019 – 2021- Replacement well policy formulated for wells too far from new public water lines.
- 2020 -2021- Class 4 groundwater classification proposed and approved for contamination area.

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VT Geological Survey Timeline

- GEOLOGY asked to participate- March 2016
- Begin Field Work- April 2016
- End Field Work- May 2019
- Preliminary Well Log Database- December 2016
- Maps (available to consultants from both sides):
  - Surficial Geology (2017)
  - Bedrock Geology (2017)
  - Spatial Analysis of Wells (2017)
  - Fracture Analysis (2017)
- Presentations of Integrated Work:
  - 2018 - 2020
  - Publication of Results (Ongoing 2022)

Vermont DEC/
Waste Mgt. Div.

Richard Spiese

John Schmeltzer

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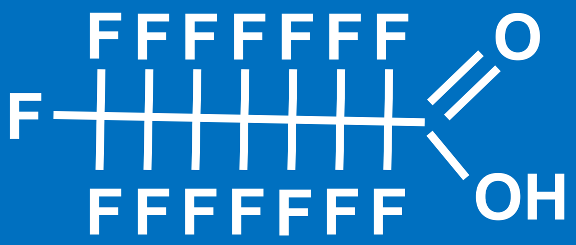
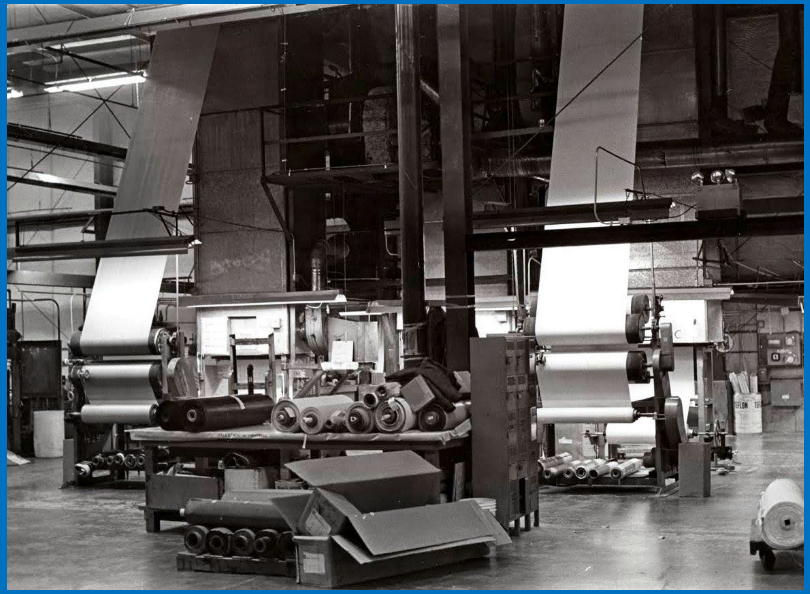
Product Manufacture Using PFOA:

What is PFOA?



U.S. Department of Health and Human Services, 2015



https://vtdigger.org/investigations/teflon-town-part-1/

Product Uses:

(First) Carrier Dome Roof (Syracuse University website)

Denver Airport Roof (from their website)

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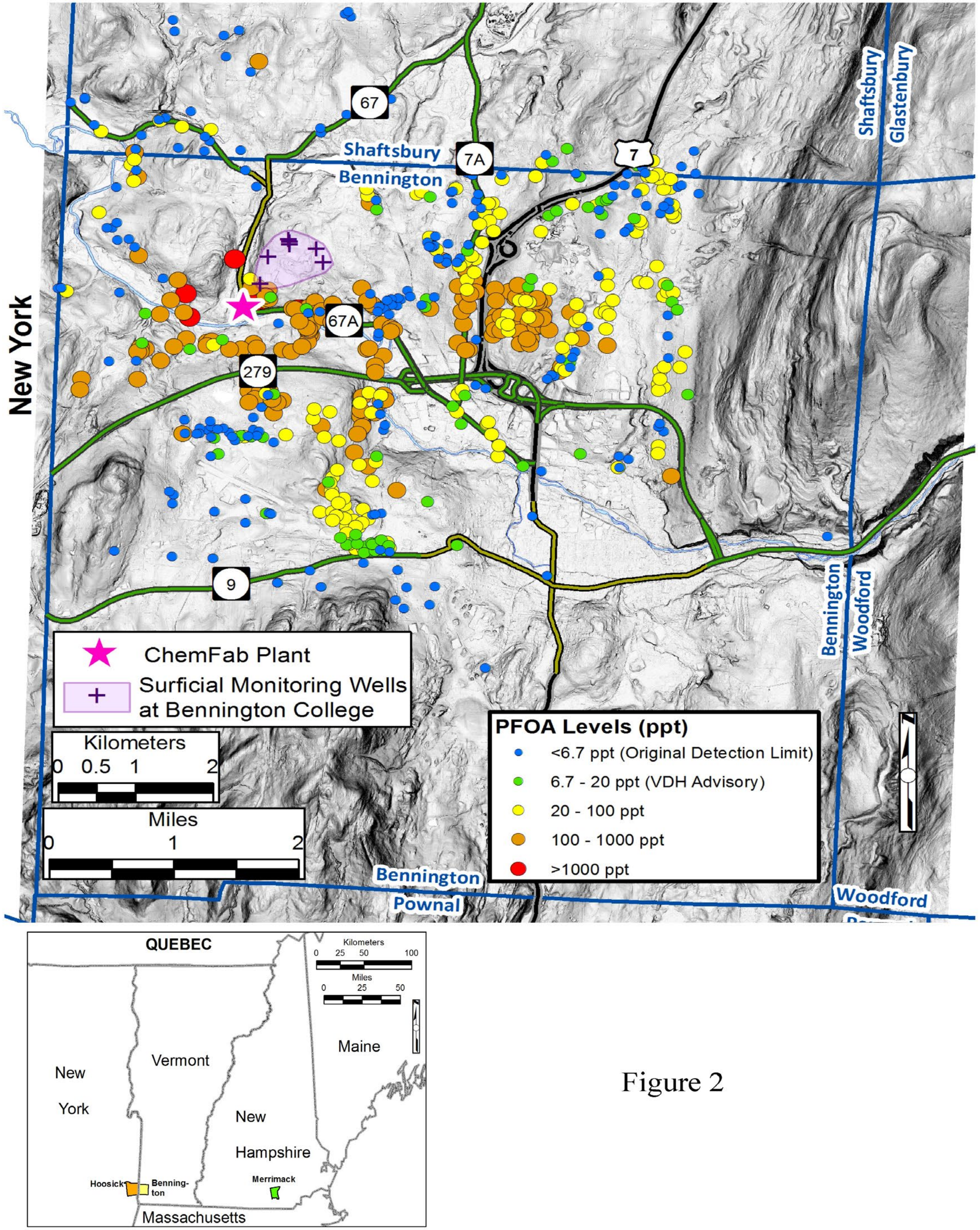

Figure 2

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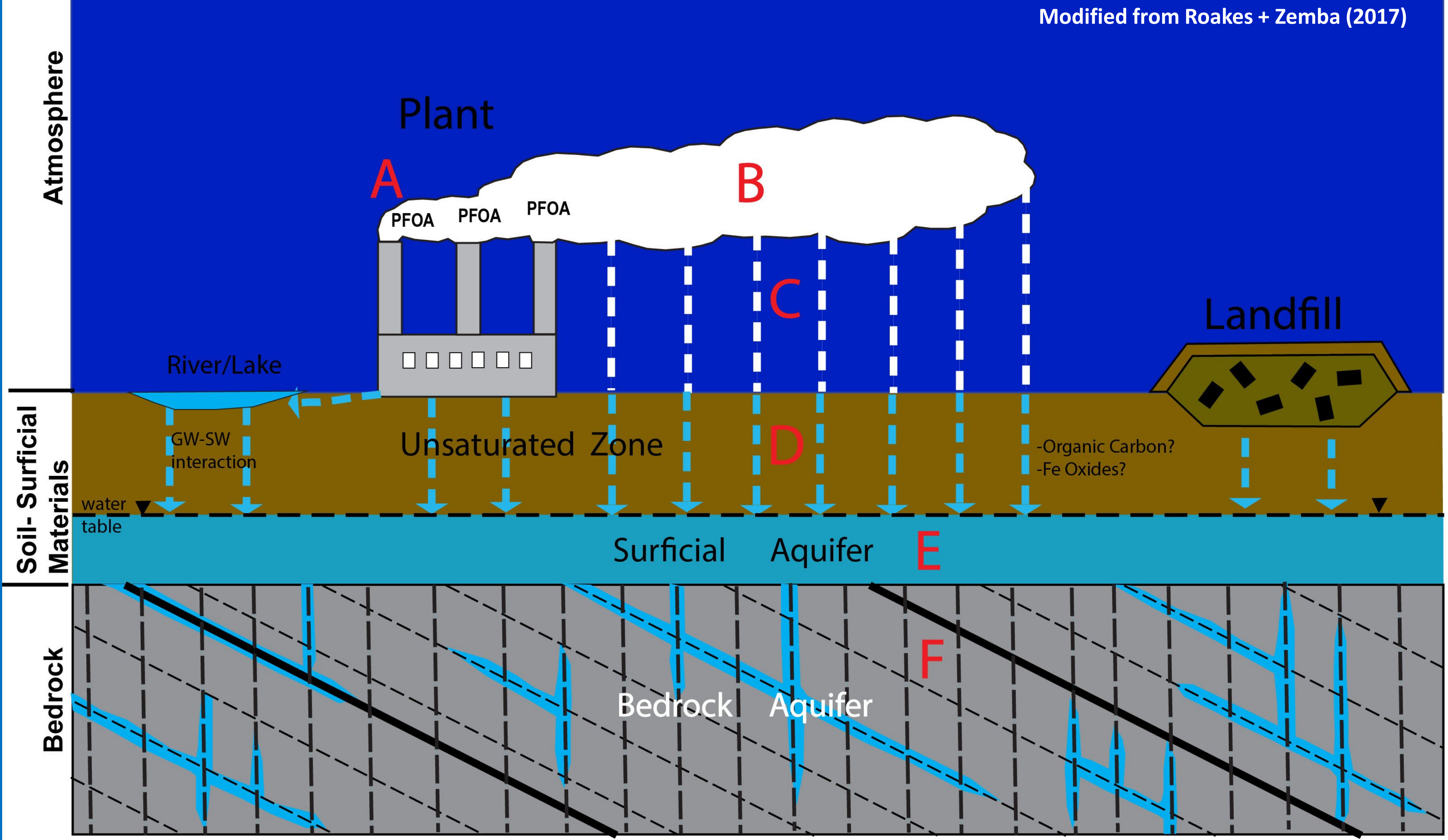
Fate and Transport of PFOA



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Aquifer Characterization Process

Physical

Geologic Mapping

Bedrock — Surficial

↓

Spatial Analysis of Wells

GPS Well-Locating — Hydrogeology Maps

↓

Geophysical Well Logging

Chemical

Ground- + Surface Water Chemistry

↓

PFAS Analysis

↓

Major + Trace Elements

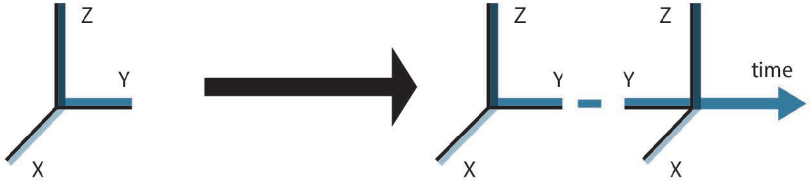
↓

Stable Isotopes

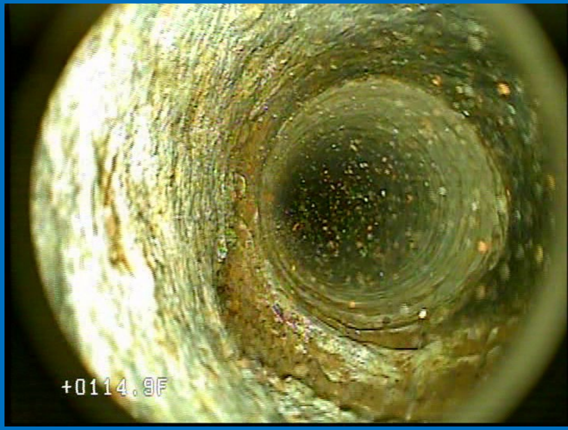
↓

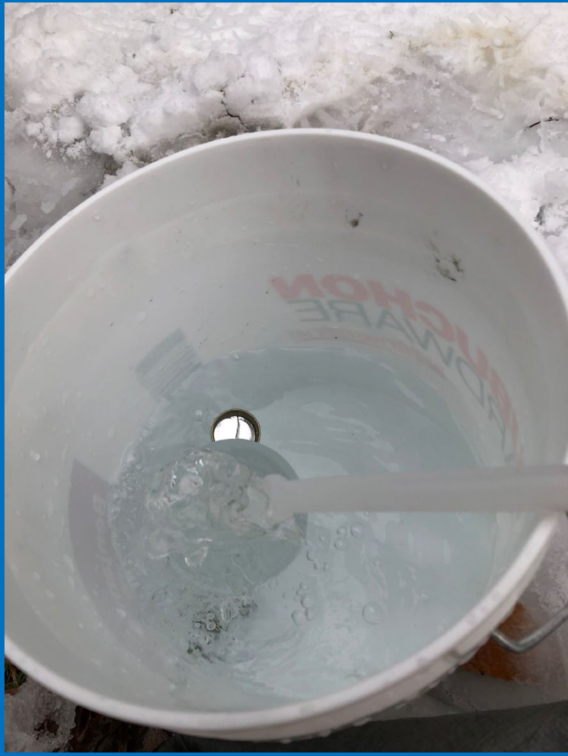
Recharge Ages

INTEGRATE



3-D → 4-D





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PFOA Contours in Groundwater + Air Deposition Envelope (Schroeder et al., 2021)

In Retrospect……..

-Low PFOA zones in the bedrock aquifer were critical for understanding the "plumbing"

-Do not represent depositional extent of PFOA

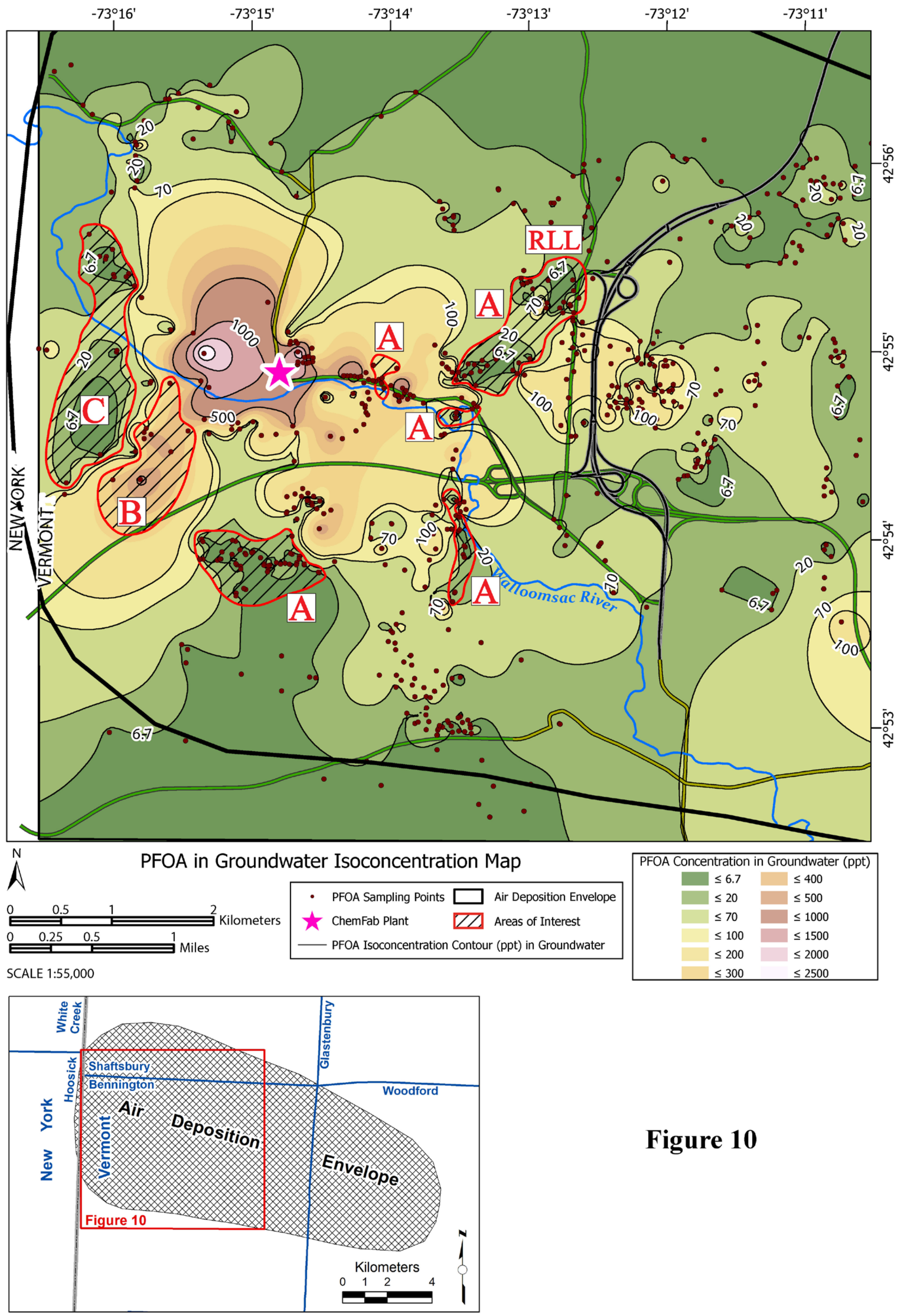

Figure 10

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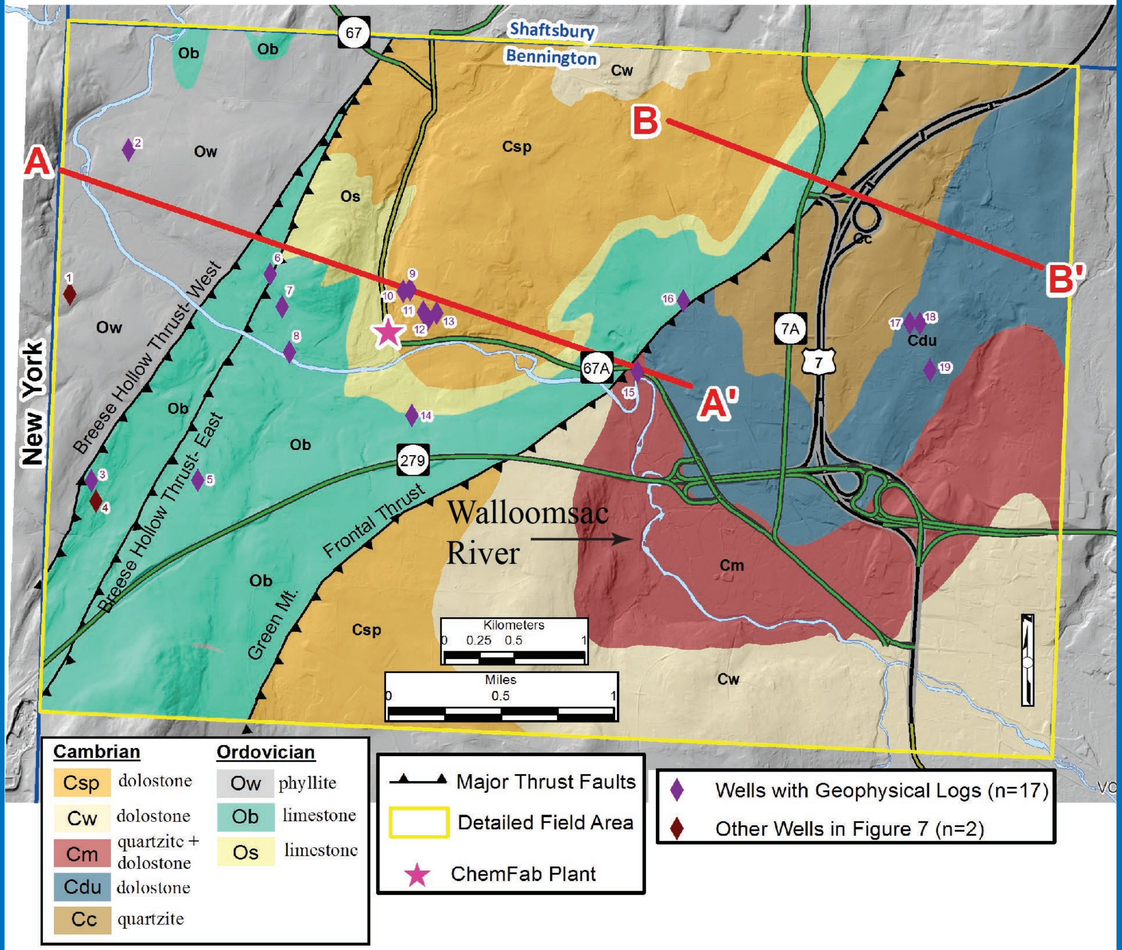
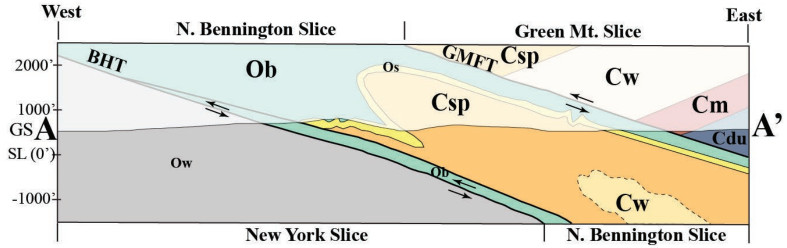
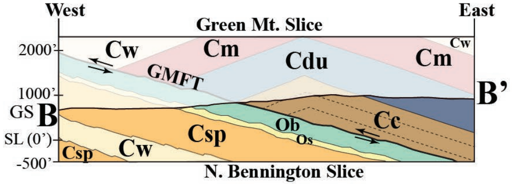
Groundwater Pathway Options:

- -Lithologic Contacts
- -Bedding
- -Cleavage(s)
- -Thrust Faults
- -Fold Plunge







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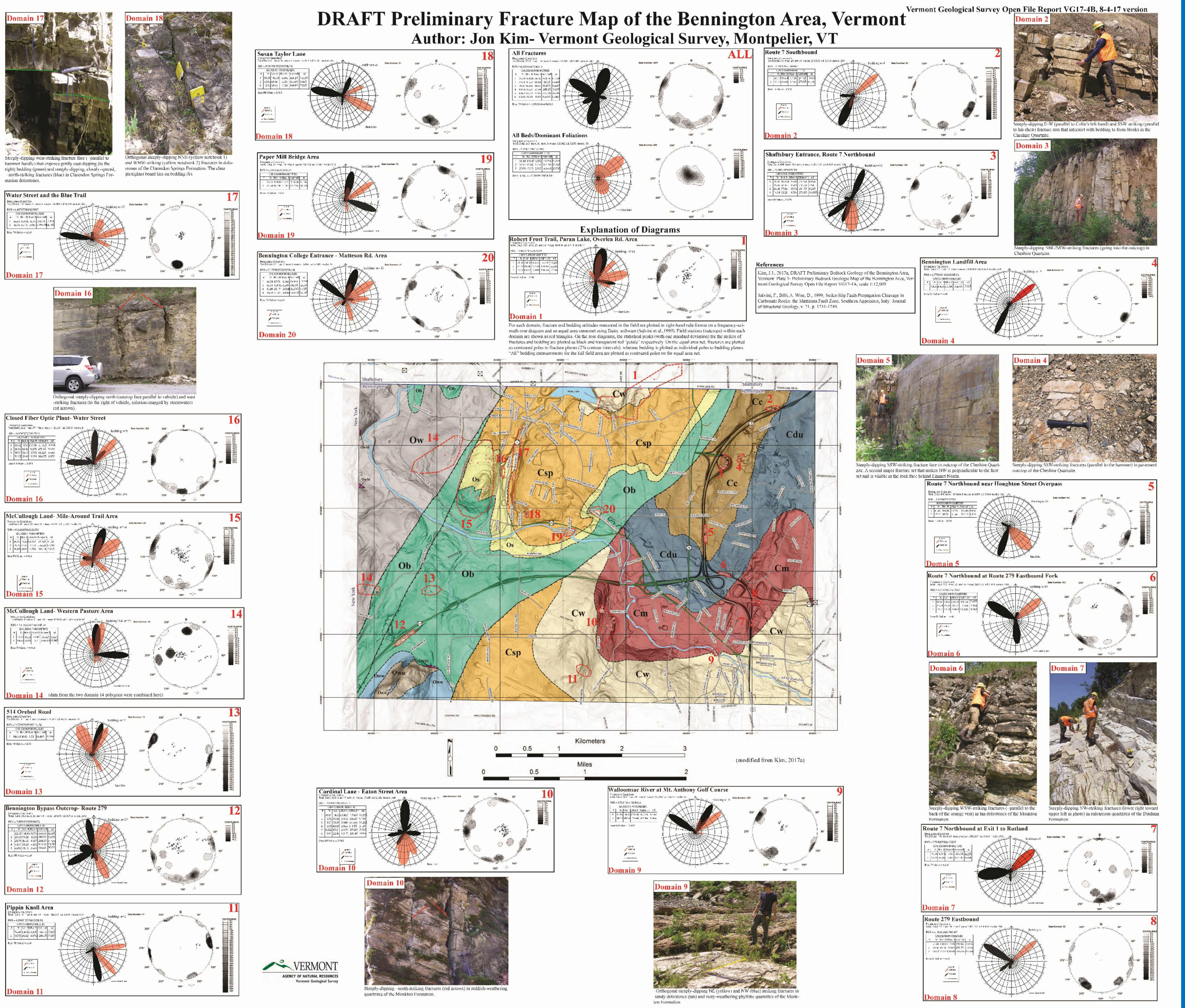
Fracture Analysis



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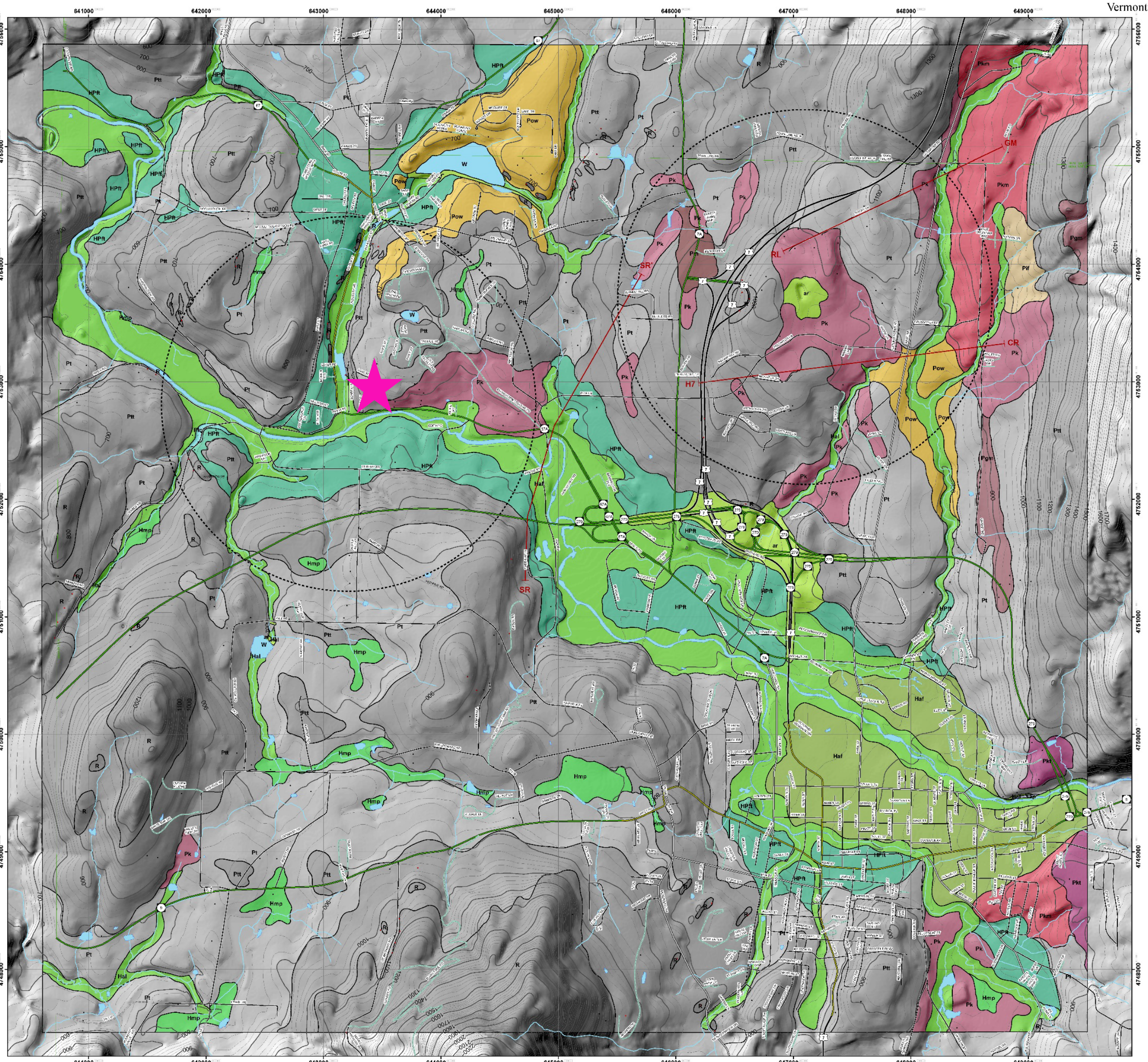


Description of Map Units

Recent

ar Artificial Fill. Variable materials used as artificial fill along rail beds, road beds, embankments and low lying areas. Large areas of fill are commonly shown on the map. Small areas of fill and areas along rail lines are not shown.

Holocene

Hmp Muck-Peat. Organic sediment. Primarily silt and clay in wetlands and swamps. Deposits are located in low lying flat lands that are prone to flooding.

Hal Alluvium. Fine sand, silt and gravel, stream flood plain deposits of river channel, bar, and overbank areas. Deposits usually have intermediate to lov permeability but can be a good aquifer if sufficiently thick. Surface sedimen may be poorly drained overbank silt or well drained channel and bar sand and gravel.

Haf Alluvial Fan. Gravel, silt and sand, often poorly sorted, includes diamicton. Moderately sloping tributary stream deposits located at the base of steep slopes and at stream junctions. Deposits usually have intermediate to low permeability but can be a fair aquifer if sufficiently thick and permeable.

Holocene/Pleistocene

HPft Fluvial Terrace. Fine sand, silt and gravel generally less than 5 meters thick overlying other material. Flat to gently sloping old flood plain deposits. Deposits have variable permeability but usually intermediate. Usually serve as a fair aquifer. Banks above streams may be prone to failure.

Pleistocene

Plc Lake Clay-Silt. Fine grained varved or thinly laminated deposits of silt and clay accumulated in the deeper portions of lake basins. Gravel and sand lenses may be present within the sequence but especially toward the bottom. Deposits are poorly drained and form an aquitard to an aquiclude. Deposits are also are prone to landsliding and gullying.

Pif Inwash Fan. Stratified fluvial sand, sand and gravel, or gravel. Deposited in topographic setting similar to alluvial fans but lower distal position was glacial ice and not solid ground. Deposits are well drained and, if thick, a good unconfined aquifer.

Pow Outwash. Well sorted gravel and sand typically greater than 5 meters thick. Deposits form gently sloping to flat lands which may be pitted due to melte ice blocks. Deposits have intermediate to high permeability and are an excellent aquifer with high gravel-sand resource potential.

Pk Kame. Stratified and unstratified sand, gravel and boulders with variable silt Deposits form undifferentiated hummocky terrain. Comprised of glacial deposits from streams, slumps, and deposition by ice. Deposits have intermediate to high permeability, high gravel-sand resource potential, and are a fair to good unconfined aquifer, limited by variable thickness and aeria extent, which may be recharge to confined aquifer on valley floor.

Pkt Kame Terrace. Stratified and unstratified gravel, sand, boulders and some silty sand with gravel. Ice contact melt water and sediment flow deposits that typically exceed 10 meters in thickness and form flat to nearly flat land Deposits have intermediate to high permeability and serve as an excellent unconfined aquifer that may be recharge to the valley floor confined aquife Deposits also have high gravel-sand resource potential, and slopes at edges of these areas may pose a stability problem.

Pkm Kame Moraine. Stratified and unstratified gravel and sand with silt and boulders. Ice contact melt water and sediment flow deposits that form rolling, hilly ridged lands with local flat areas. Deposits have intermediate tc high permeability, high gravel-sand resource potential, and local steep slope pose a slope stability problem.

Pgm Ground Moraine. Hummocky till with sand and gravel ranging from stratifie and well-sorted gravel and sand to unstratified and poorly sorted silt, sand, gravel and boulders (diamicton). Ice contact sediment flow, meltwater, and ice deposited sediments of variable texture that may form gently rolling or elongate hills. Deposits have low to high permeability and limited local slop stability problems.

Pm Moraine. Unstratified and stratified silt, sand, gravel and boulders that may form a ridged or smoothly undulating landform. Ice contact, ice deposited, sediment flow, and meltwater deposited materials that form broad ridges and swales with rolling low hills. Deposits have variable permeability and local slopes may pose a stability problem.

Pt Till. Ice-derived, unsorted, and unstratified hardpan silt, boulders, gravel ar sand greater than 3 meters in thickness. Material was deposited beneath th glacier and may contain deformed stratified units that may be re-deposited diamictons from subaqueous or subglacial flows. Deposits form smoothed and streamlined hills and drumlins in the valley and gently undulating slope on the lower mountain flanks, to nearly flat plains dotted with erratics. Deposits have low permeability and retard infiltration to bedrock aquifer. Slopes are often unstable in excavations and prone to significant slope failures along stream banks.

Ptt Thin Till. Ice-derived, unsorted, and unstratified hardpan silt, boulders, grav and sand less than 3 meters thick with rock outcrops or ledge frequent. Surface boulders or erratics are common. Deposits are located on moderate to steep mountain slopes and summit areas. Deposits have low permeabilit however, soil formation typically improves permeability and enables recharge to bedrock aquifer. Steep slopes are unstable and slides are common.

Pre-Pleistocene

sap Saprolite. Deeply, thoroughly weathered bedrock altered under climatic conditions much different than today. Saprolite was observed along the Walloomsac River in several exposures opened up by Hurricane Irene. Slumping has covered some of these preserved weathering profiles.

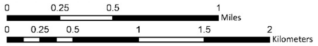
R Rock Outcrop. Areas of predominantly outcrop with patches of till or slump or slide debris. Outcrop areas serve to recharge bedrock units with groundwater. Slopes are generally stable except steep slopes where rock slides and rock falls may occur.

Surficial Geologic Map of the Bennington Area, Vermont

Vermont Geological Survey Open File Report VG2017-1: Plate 1

Scale 1:12,000

Contour Interval = 20 ft



David J. DeSimone, PhD
2017

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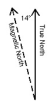
Published by:
Vermont Geological Survey
Marjorie H. Gale, State Geologist
Department of Environmental Conservation
Agency of Natural Resources
1 National Life Drive, Main 2
Montpelier, VT 05620-3902
http://dec.vermont.gov/geological-survey
Digital Cartography by Colin Dowey



Description of Map Symbols

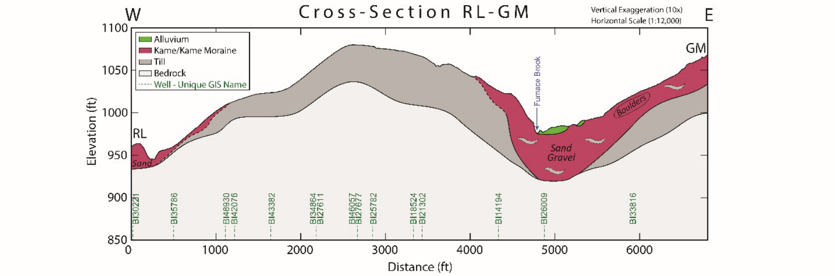
·	Field Locations (Bedrock Outcrops)	▭	Lakes/Ponds
·	Field Locations	—	Rivers
◌	Area Analyzed for Recharge Potential	⊢⊣	Cross-Section
—	Town Boundaries		

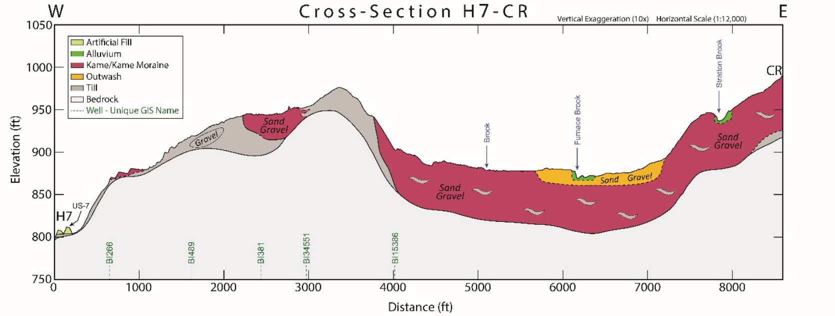
Grid Overlay: NAD 1983 UTM Zone 18N
Basemap and Contours derived from USGS 10m National Elevation Dataset.

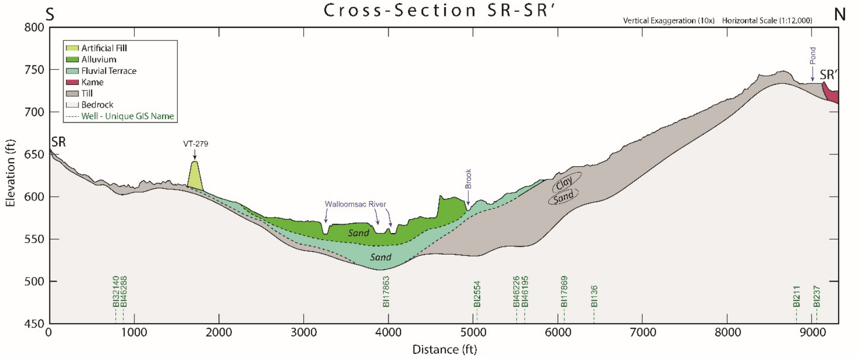
Suggested Reference: DeSimone, D. J., 2017, Surficial Geology of the Bennington Area, Vermont: Surficial Geologic Map, Vermont Geological Survey Open File Report VG2017-1, Plate 1 of 3, Scale 1:12,

Surficial Geology of the Bennington Area, Vermont: Cross Sections

Authors: David J. DeSimone, PhD and Colin Dowey







Land surface elevation derived from
VT Lidar Hydro-flattened DEM (2 meter) - 2012 - Bennington
from the Vermont Center for Geographic Information.
Bedrock surface elevation derived from Lidar Data,
Outcrop Locations, and Well Completion Reports.

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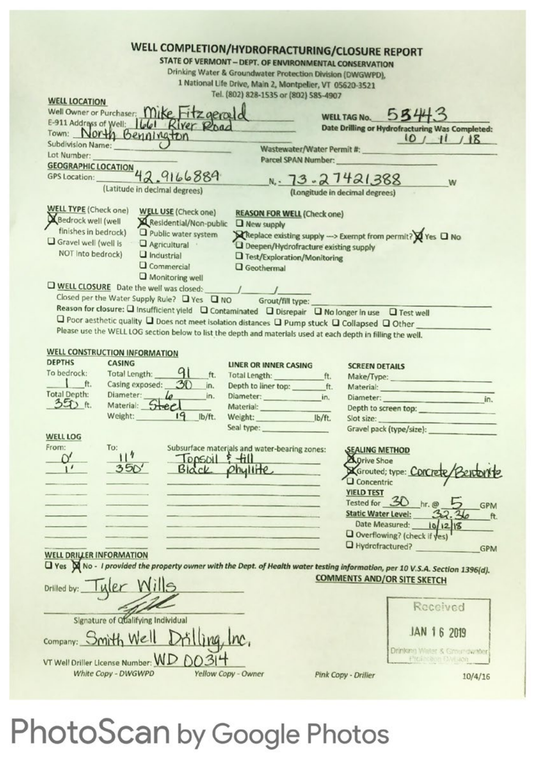
Suggested Reference: DeSimone, D. J., & Dowey, C., 2017, Surficial Geology of the Bennington Area, Vermont: Cross Sections,
Vermont Geological Survey Open File Report VG2017-1: Plate 3 of 3, Scale 1:12,000.

Correlated Well Logs



WELL COMPLETION/HYDROFRACTURING/CLOSURE REPORT
STATE OF VERMONT – DEPT. OF ENVIRONMENTAL CONSERVATION
Drinking Water & Groundwater Protection Division (DWGWPD),
1 National Life Drive, Main 2, Montpelier, VT 05620-3521
Tel. (802) 828-1535 or (802) 585-4907

WELL LOCATION
Well Owner or Purchaser: Mike Fitzgerald
E-911 Address of Well: 1661 River Road
Town: North Bennington
Subdivision Name:
Lot Number:

WELL TAG No. 53443
Date Drilling or Hydrofracturing Was Completed: 10 / 11 / 18
Wastewater/Water Permit #:
Parcel SPAN Number:

GEOGRAPHIC LOCATION
GPS Location: 42.9166889 N, -73.27421388 W
(Latitude in decimal degrees) (Longitude in decimal degrees)

WELL TYPE (Check one)
☒ Bedrock well (well finishes in bedrock)
☐ Gravel well (well is NOT into bedrock)

WELL USE (Check one)
☒ Residential/Non-public
☐ Public water system
☐ Agricultural
☐ Industrial
☐ Commercial
☐ Monitoring well

REASON FOR WELL (Check one)
☐ New supply
☒ Replace existing supply —> Exempt from permit? ☒ Yes ☐ No
☐ Deepen/Hydrofracture existing supply
☐ Test/Exploration/Monitoring
☐ Geothermal

☐ **WELL CLOSURE** Date the well was closed: ___/___/___
Closed per the Water Supply Rule? ☐ Yes ☐ NO Grout/fill type:
Reason for closure: ☐ Insufficient yield ☐ Contaminated ☐ Disrepair ☐ No longer in use ☐ Test well ☐ Poor aesthetic quality ☐ Does not meet isolation distances ☐ Pump stuck ☐ Collapsed ☐ Other
Please use the WELL LOG section below to list the depth and materials used at each depth in filling the well.

WELL CONSTRUCTION INFORMATION

DEPTHS
To bedrock: 1 ft.
Total Depth: 350 ft.

CASING
Total Length: 91 ft.
Casing exposed: 30 in.
Diameter: 6 in.
Material: Steel
Weight: 19 lb/ft.

LINER OR INNER CASING
Total Length: ft.
Depth to liner top: ft.
Diameter: in.
Material:
Weight: lb/ft.
Seal type:

SCREEN DETAILS
Make/Type:
Material:
Diameter: in.
Depth to screen top:
Slot size:
Gravel pack (type/size):

WELL LOG

From:	To:	Subsurface materials and water-bearing zones:
0'	1'	Topsoil & fill
1'	350'	Black phylite

SEALING METHOD
☒ Drive Shoe
☒ Grouted; type: Concrete/Bentonite
☐ Concentric

YIELD TEST
Tested for 30 hr. @ 5 GPM
Static Water Level: 32.36 ft.
Date Measured: 10/12/18
☐ Overflowing? (check if yes)
☐ Hydrofractured? GPM

WELL DRILLER INFORMATION
☐ Yes ☒ No - *I provided the property owner with the Dept. of Health water testing information, per 10 V.S.A. Section 1396(d).*

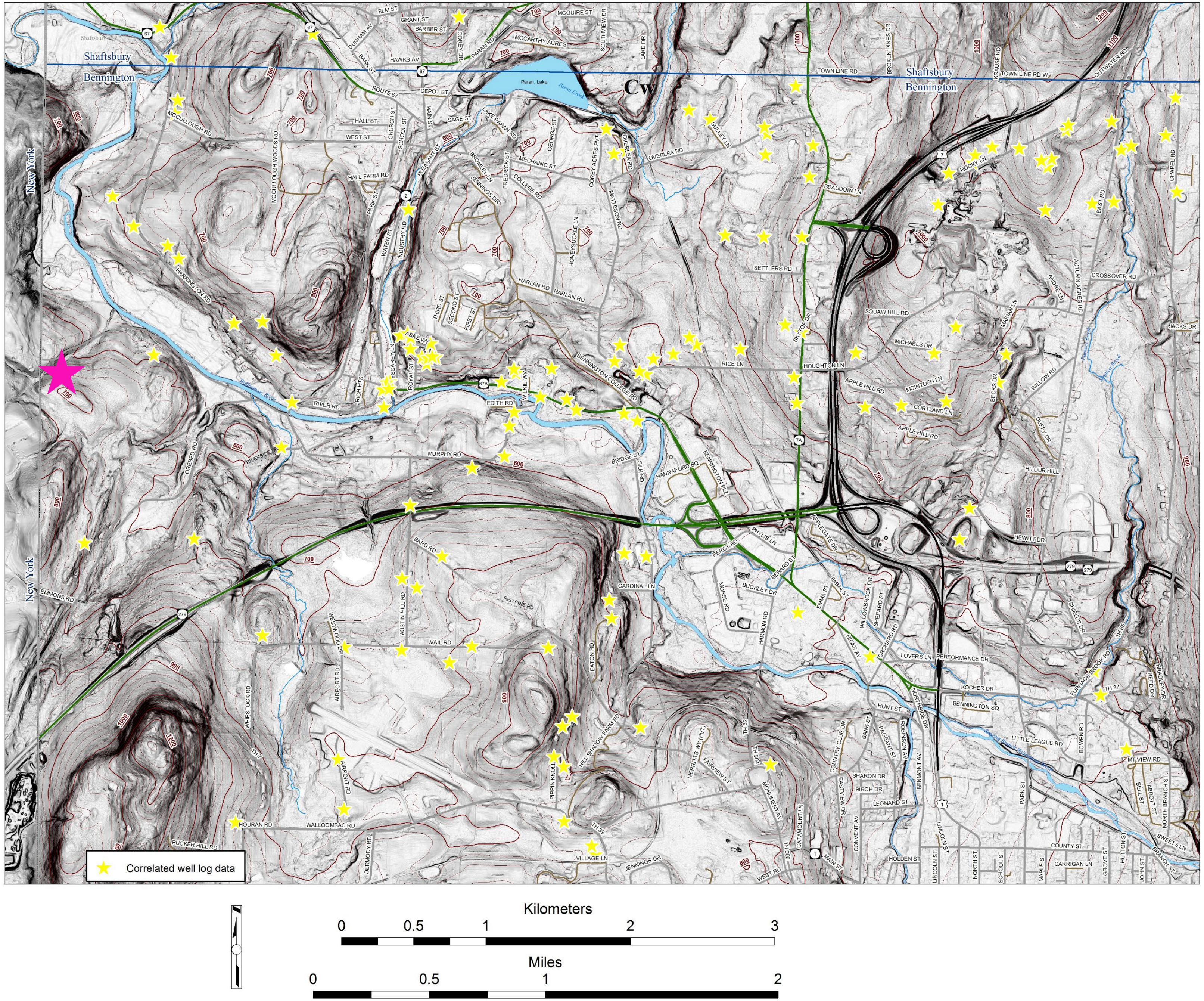
Drilled by: Tyler Wills
Signature of Qualifying Individual
Company: Smith Well Drilling, Inc.
VT Well Driller License Number: WD 00314

COMMENTS AND/OR SITE SKETCH

Received
JAN 16 2019
Drinking Water & Groundwater Protection Division

White Copy - DWGWPD *Yellow Copy - Owner* *Pink Copy - Driller* 10/4/16

PhotoScan by Google Photos



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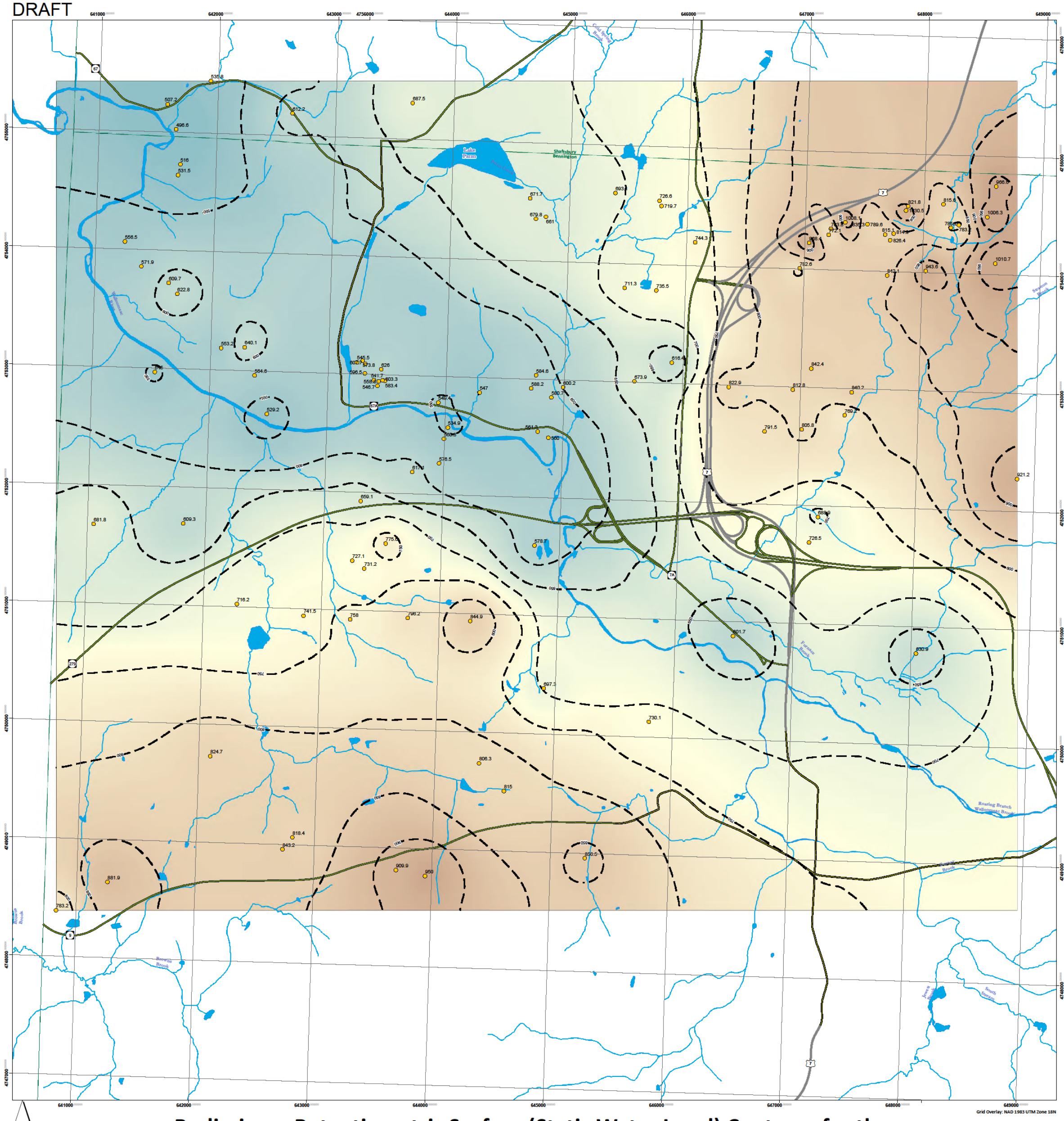

N

1:12,000

0 0.25 0.5 1 Kilometers

0 0.25 0.5 1 Miles

Preliminary Potentiometric Surface (Static Water Level) Contours for the Bedrock Aquifer in the Bennington Area, Vermont (feet, smoothed)

Vermont Geological Survey Open-File Report 2017-3D 06-02-17 Version

Authors: Jonathan Kim and Colin Dowey
Vermont Geological Survey
Montpelier, Vermont

Legend

Wells with Static Water Level Data

(Labels = SWL Elevation)

- Bedrock Well (Kim, 2017a) (n = 105)
- Town Boundary
- Study Area

Generalized GIS Outputs derived from raster contouring of well data

- Static Water Level Contours (50 ft Interval)

Static Water Level (ft)

High : 996

Low : 501

This map was produced at a scale of 1:12,000 and is designed to show general static water levels for the entire Bennington field area. It is not suitable for any detailed evaluation of the Bennington landfill area, for which McLaren-Hart (1997) should be consulted.

This map includes a Static Water Level Elevation raster and contours (50 ft) derived from the Static Water Level data in the (Kim, 2017a) database. Only wells with Static Water Level data were included in the interpolation, and where GL_SWL data was available this was used instead of DL_SWL. IDW parameters: Output cell size = 2, Power = 2, Search radius = variable, Number of points = 12. The resulting raster was smoothed using the FOCAL STATISTICS tool. FOCAL STATISTICS parameters: Neighborhood = Circle, Radius = 50 cell units, Statistics type = Mean. The Static Water Level contours were constructed using the CONTOUR tool with a 50 foot contour interval. Some contours were hand edited to more accurately portray water well data.

Software: ArcGIS10.3.1, Spatial Analyst Tools 10.3.1
Coordinate System = NAD 1983 StatePlane Vermont FIPS 4400 (m)

References:

DeSimone, D. J., 2017, Surficial Geology of the Bennington area, Vermont: Vermont Geological Survey Open-File Report VG2017-1, Plates 1 - 3, scale 1:12,000.

Kim, J. J., 2017a, "DRAFT Bennington correlated well logs, J. Kim, VT Geo. Survey 2-09-17", Unpublished, Data derived from anrweb.vt.gov/DEC/WellDrillerReports/Default.aspx and other sources.

Kim, J. J., 2017b, DRAFT Preliminary Bedrock Geologic Map of the Bennington area, Vermont: Vermont Geological Survey Open-File Report VG2017-4, 1 sheet, scale 1:12,000.

McLaren-Hart Environmental Engineering Corp., 1997, Final Draft, Remedial Investigation Report, Bennington Landfill Site, Bennington Vermont: Submitted to U. S. EPA Region 1, 483 p.

Potter, D.B., 1971, Stratigraphy and structure of the Hoosic Falls area, New York-Vermont, east-central Taconics: New York State Museum and Science Service Map and Chart Series, no. 19, 71 p., scale 1:24,000.

Vermont Center for Geographic Information, 2012, VT Lidar Hydro-flattened DEM (2 meter) - 2012 - Bennington. Accessed 01/2017 from http://geodata.vermont.gov/.

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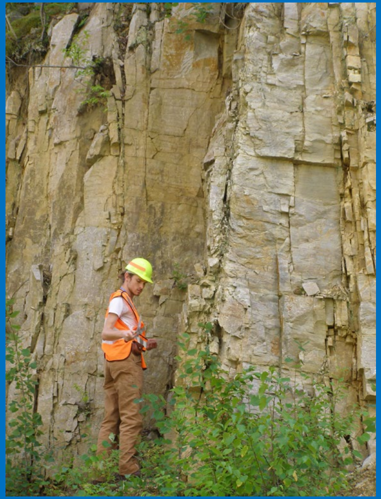
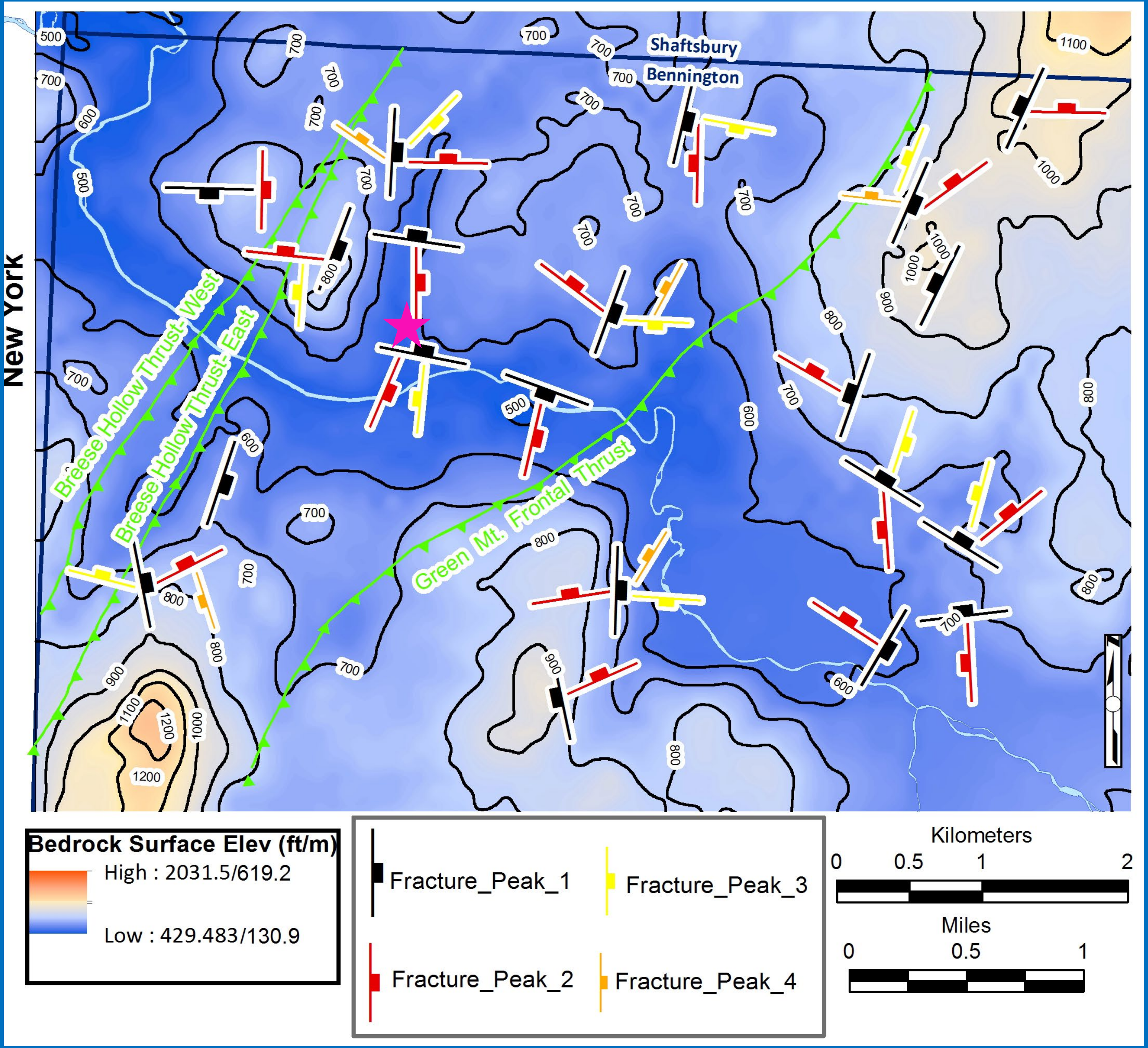
Bedrock Surface Elevation, Thrust Faults, and Fractures





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HQ40d
multi
HACH
110119-5A
110119-5B
110119-5C
110119-5
110119-5
110119-5

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Chemical Hydrogeology Sample Locations

PFOA Tests

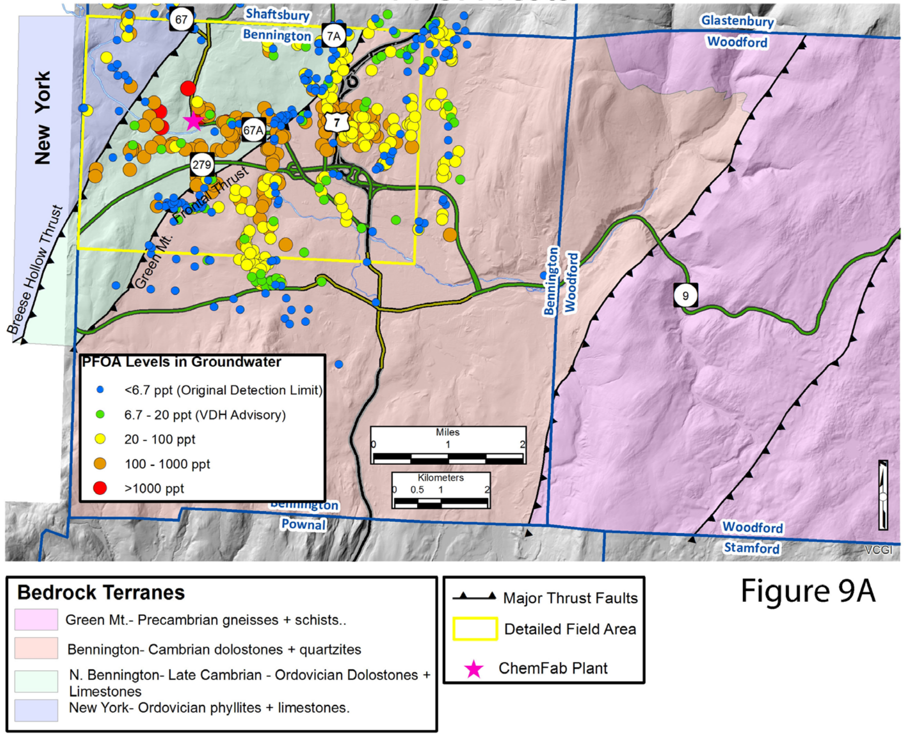

Figure 9A

Major + Trace Element Samples

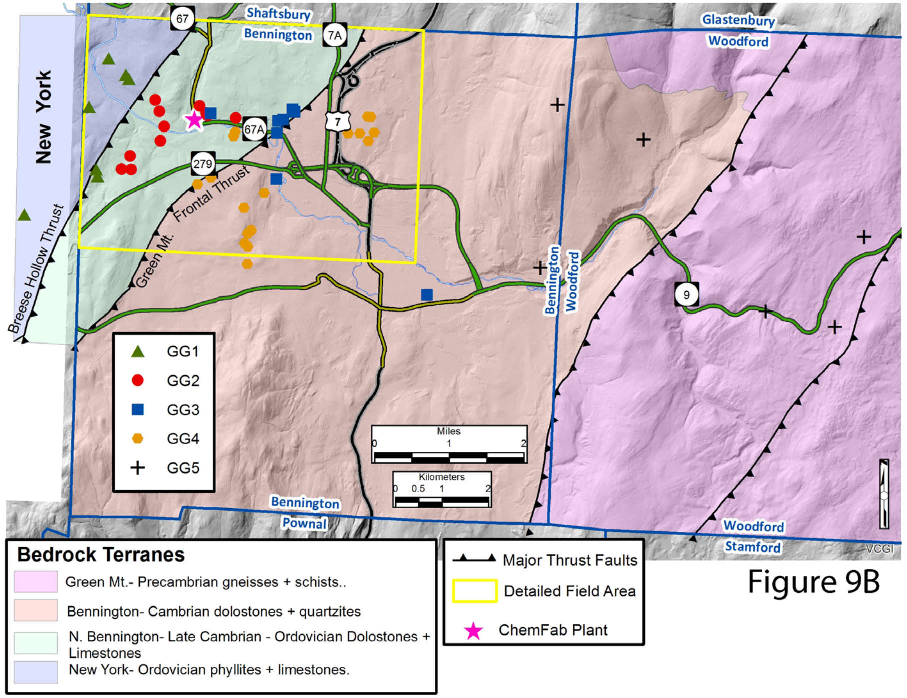

Figure 9B

Stable Isotope Samples

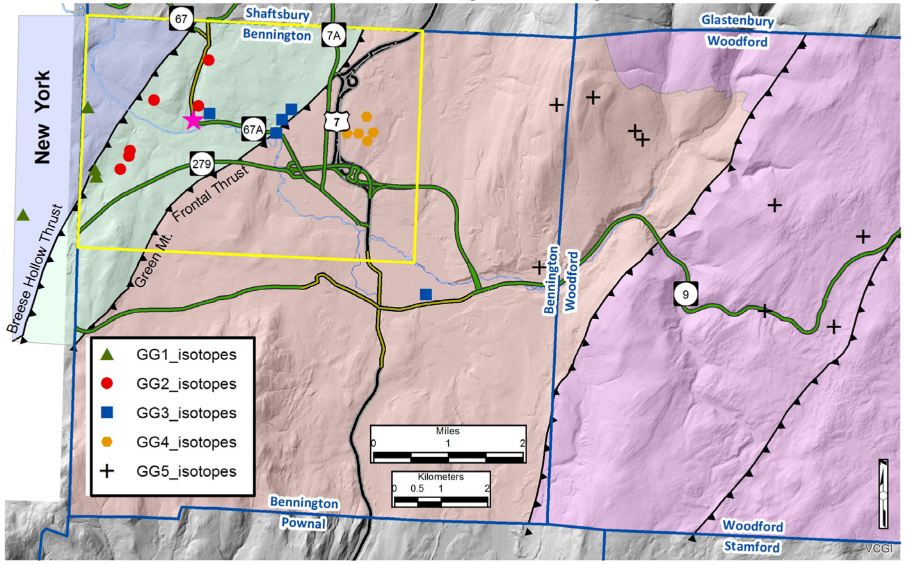

Figure 9C

Recharge-Age Samples

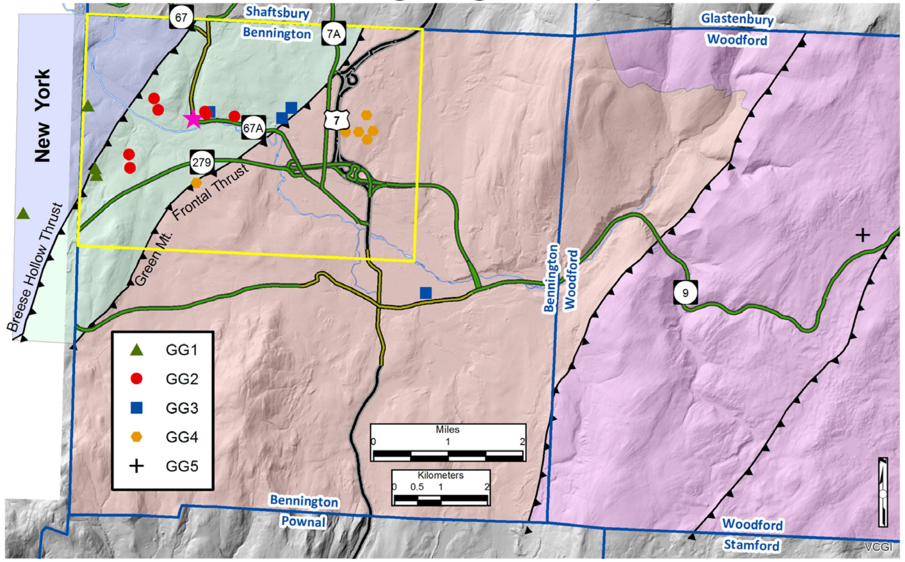

Figure 9D

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Geochemical Fingerprinting

Water – Rock Interaction + Anthropogenic Contaminants

Water – Rock Interaction

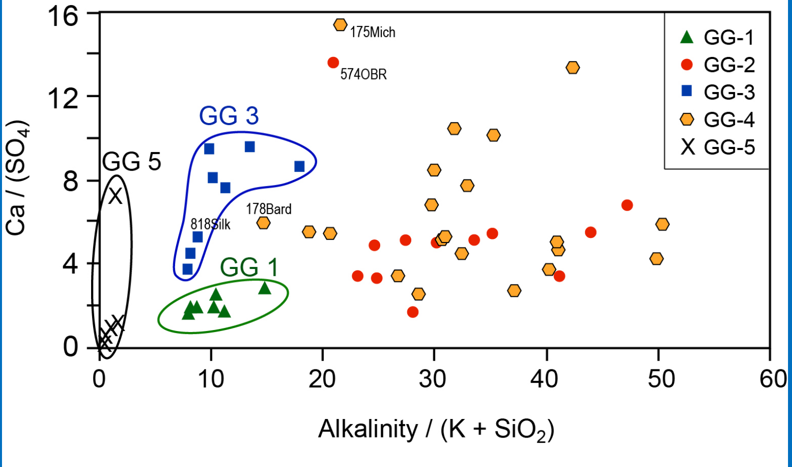
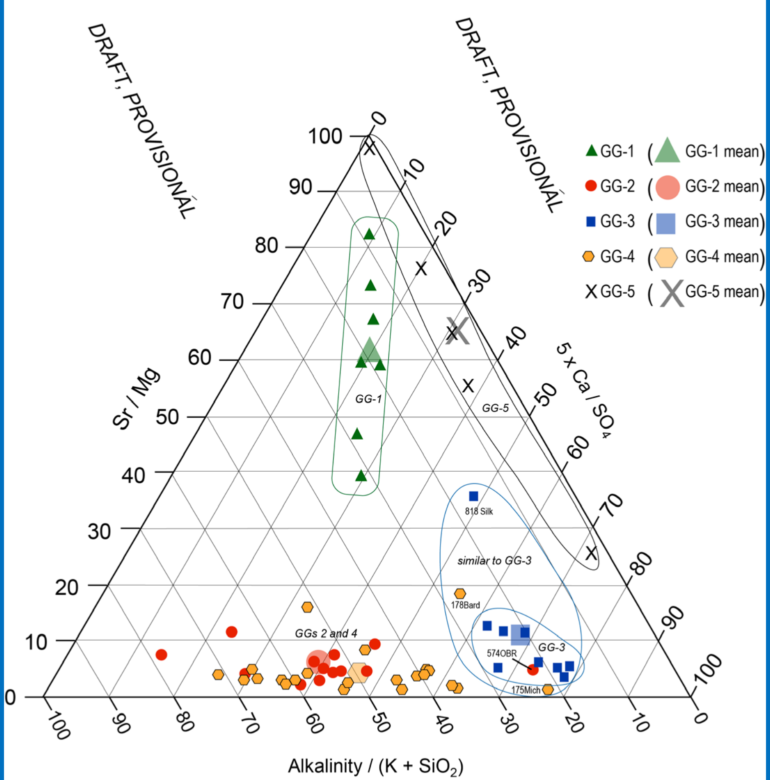


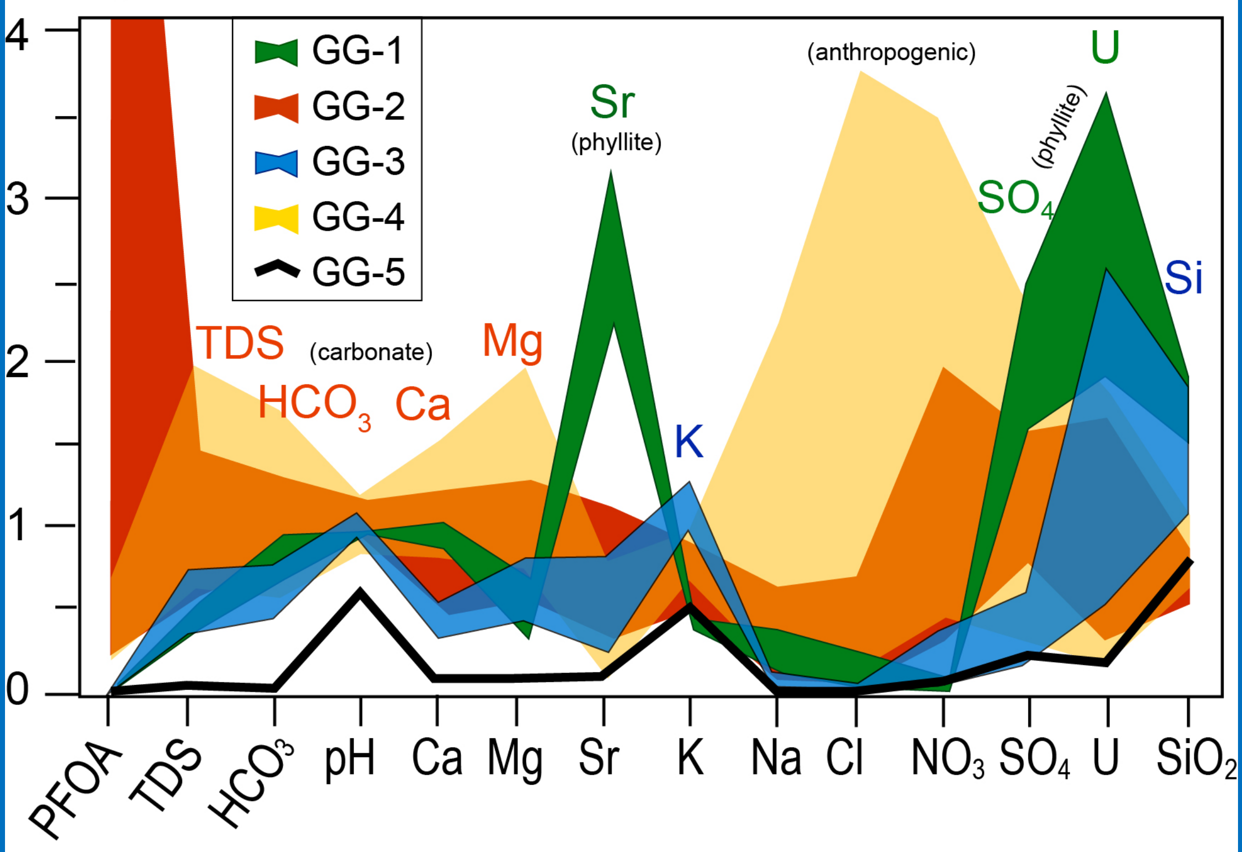
Figure11A

Figure 11C



Plotted values are ratios of concentrations in mg/L (ppm) except for Sr (ppb). SO_4 value is for SO_4 or S?

Figure11B



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Geochemical Group Locations

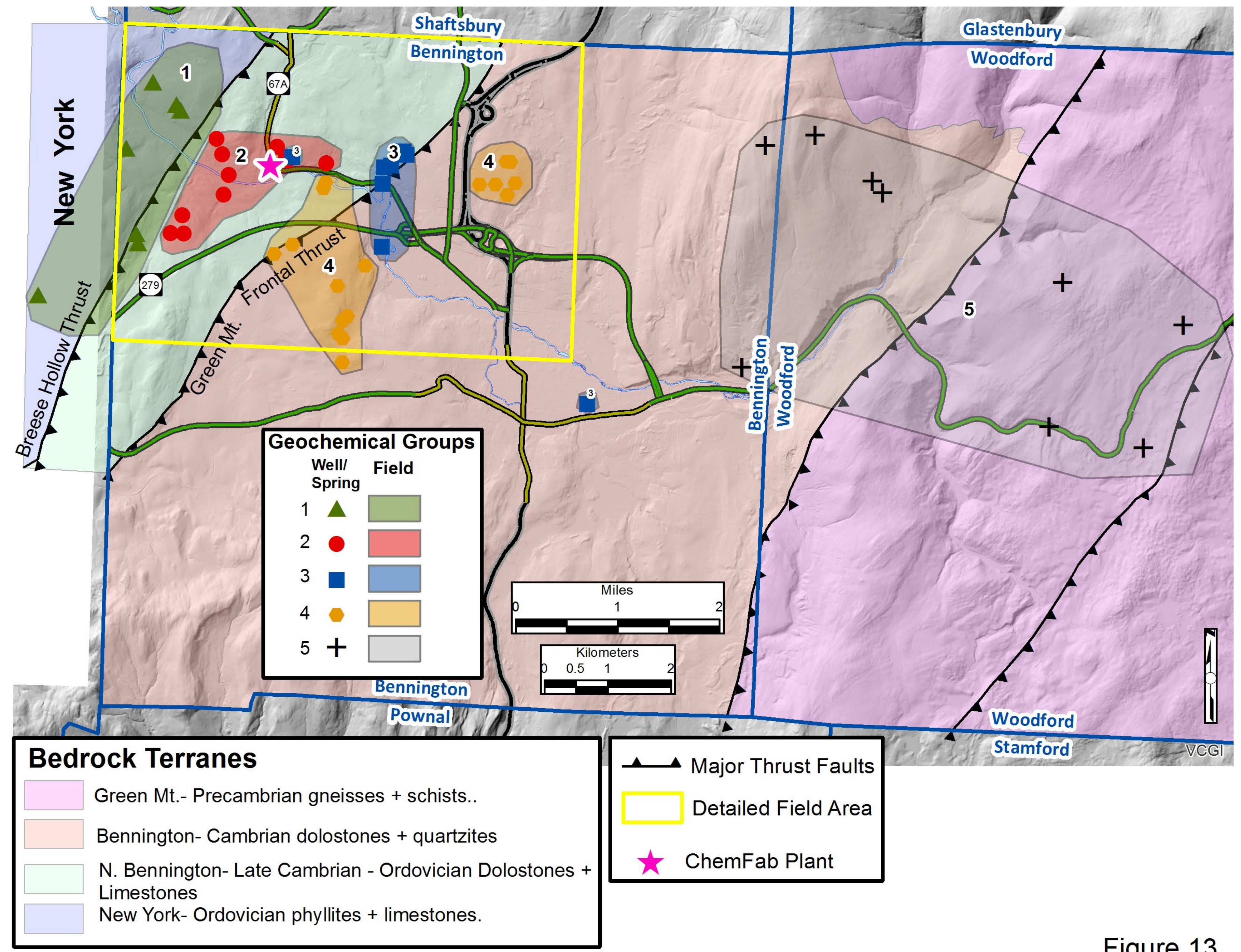

Figure 13

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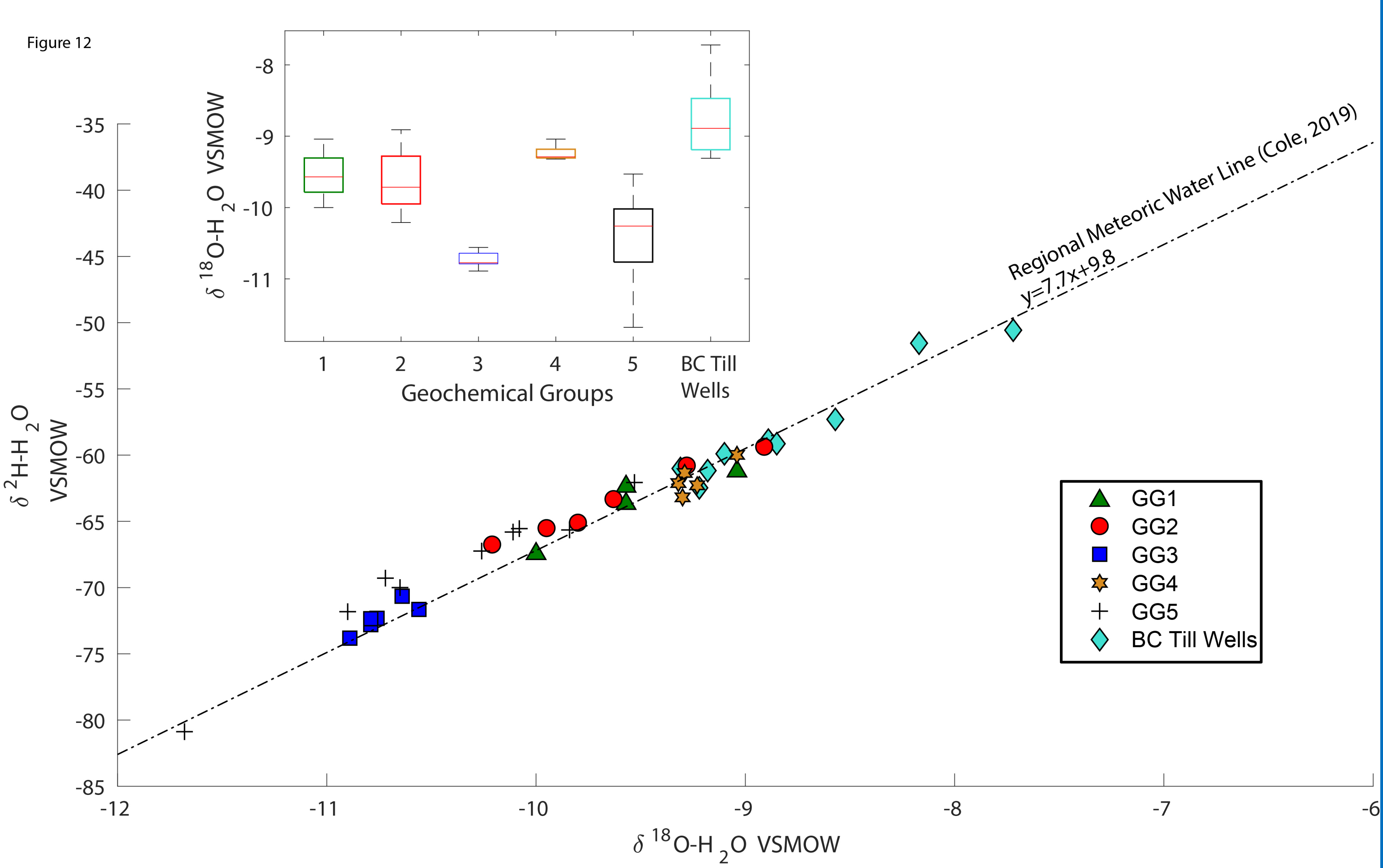
Stable Isotopic Signatures of Groundwater



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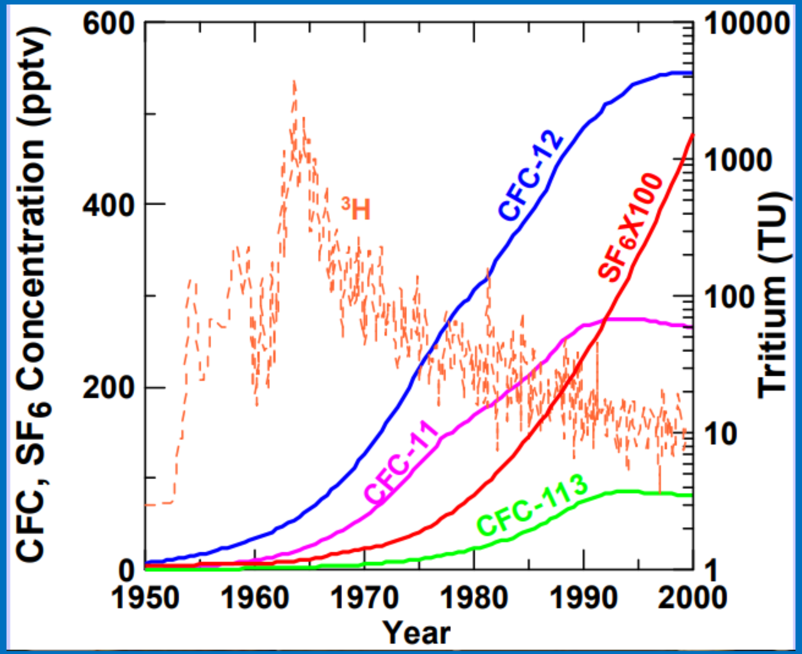
Groundwater Recharge-Ages



Some data from Shanley et al. (2018)

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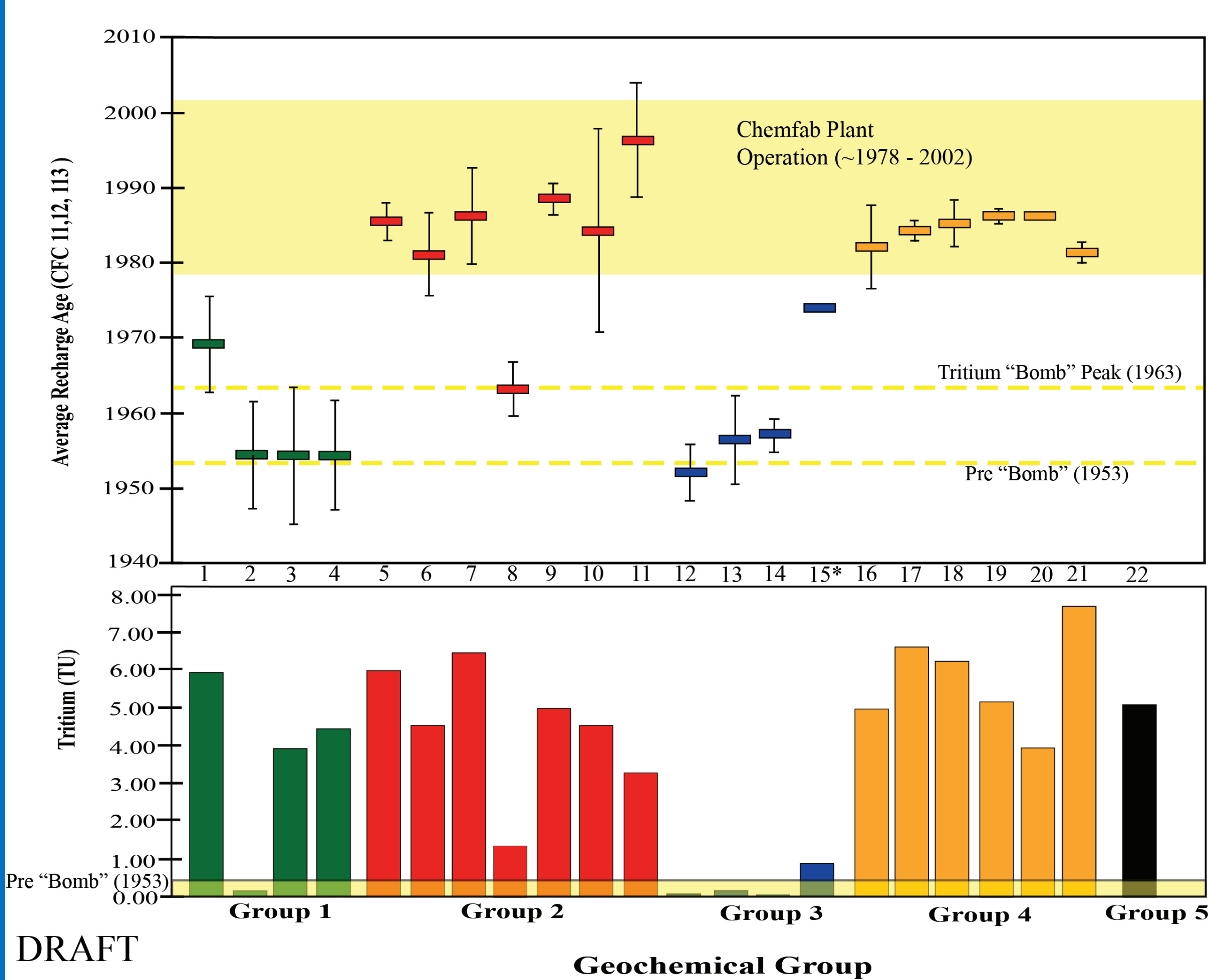
Figure 13



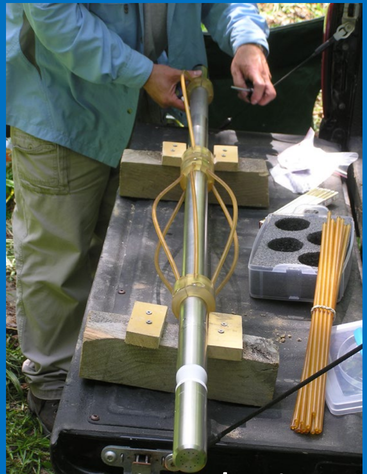
Geophysical Logging

Borehole Camera

Temp.- Conductivity

Gamma

Caliper



Acoustic Televiewer

Heat-Pulse Flow-meter

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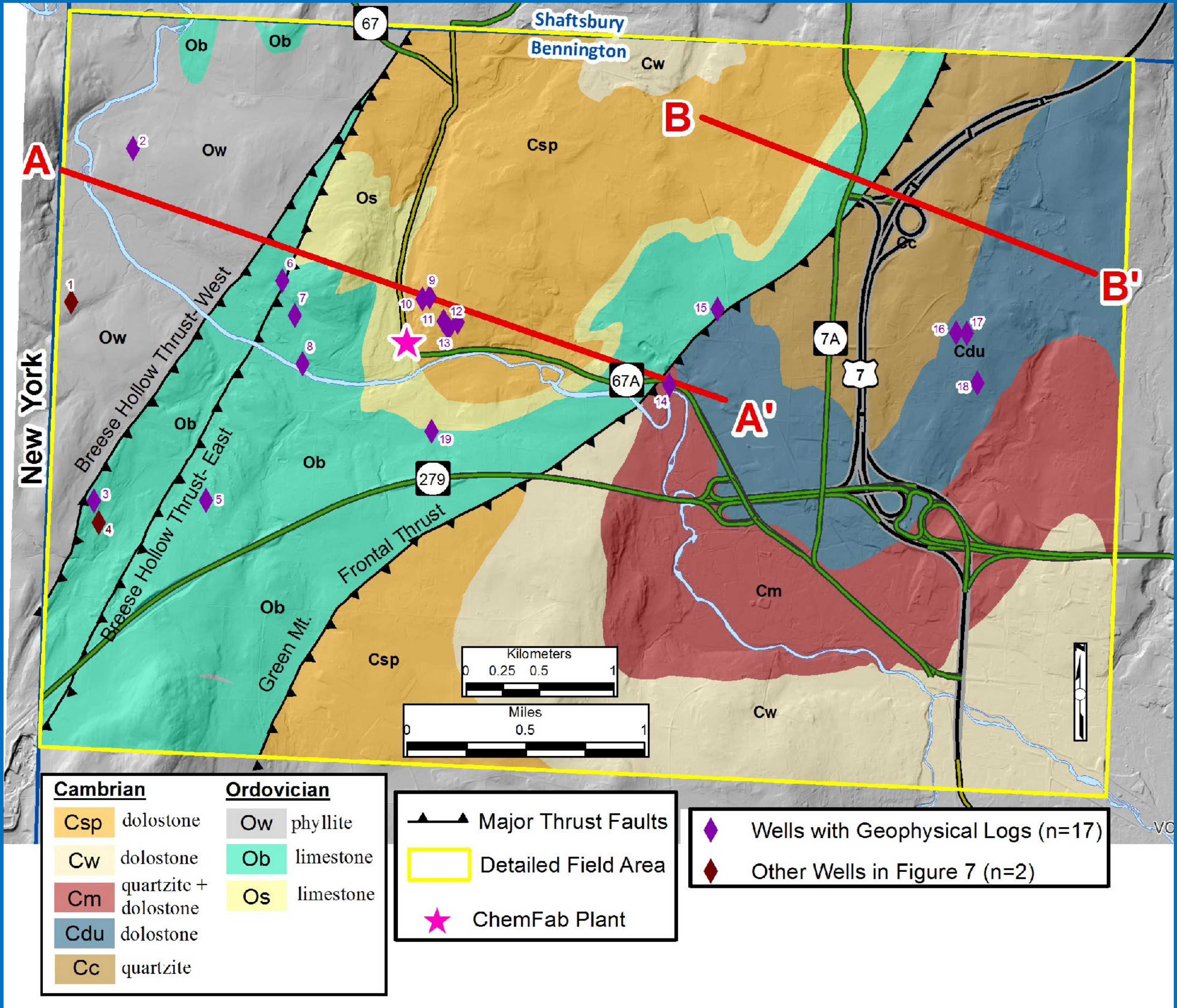
Geophysical Logging

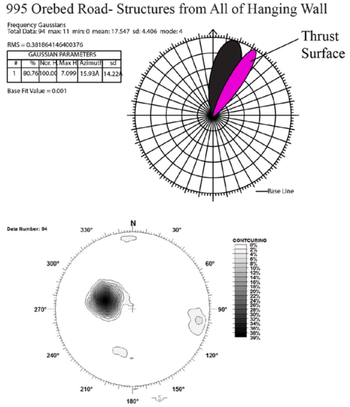


Draft

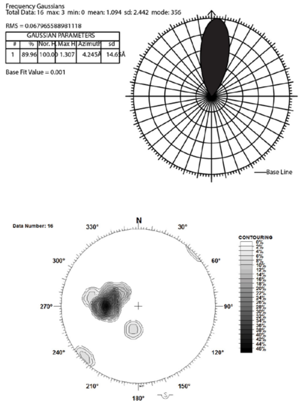
Breese Hollow Thrust Well (995 Ore Bed Rd)

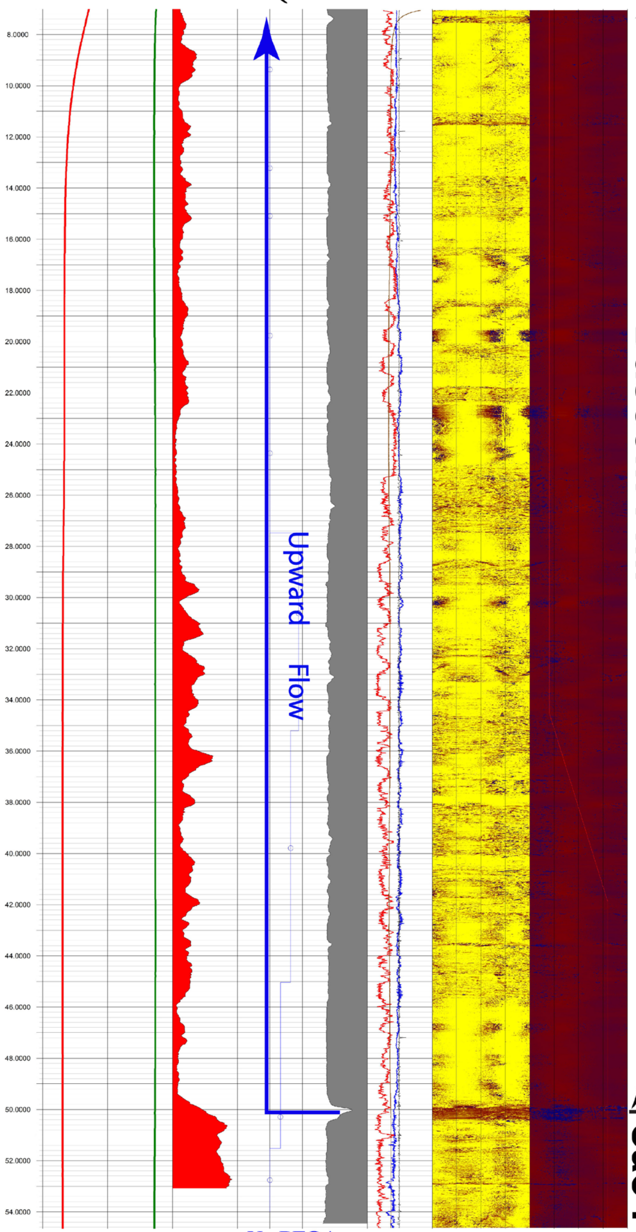
Hanging Wall Structures

995 Orebed Road- Structures from All of Hanging Wall



Foot Wall Structures





-No PFOA
-Intermediate Stable Isotopes
-Major- Trace Chemical Signature of New York Slice
-50 - 70 Year Recharge Age

Bascom Formation Outcrop

Walloomsac Formation Well-Cuttings

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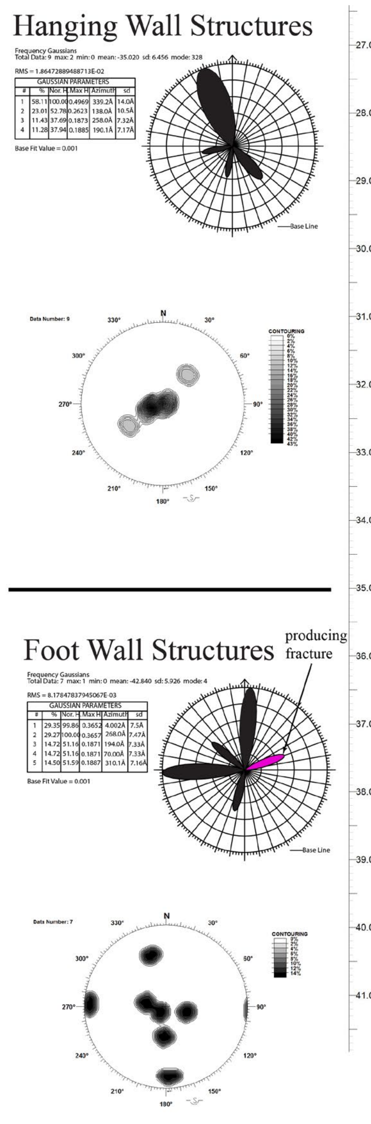
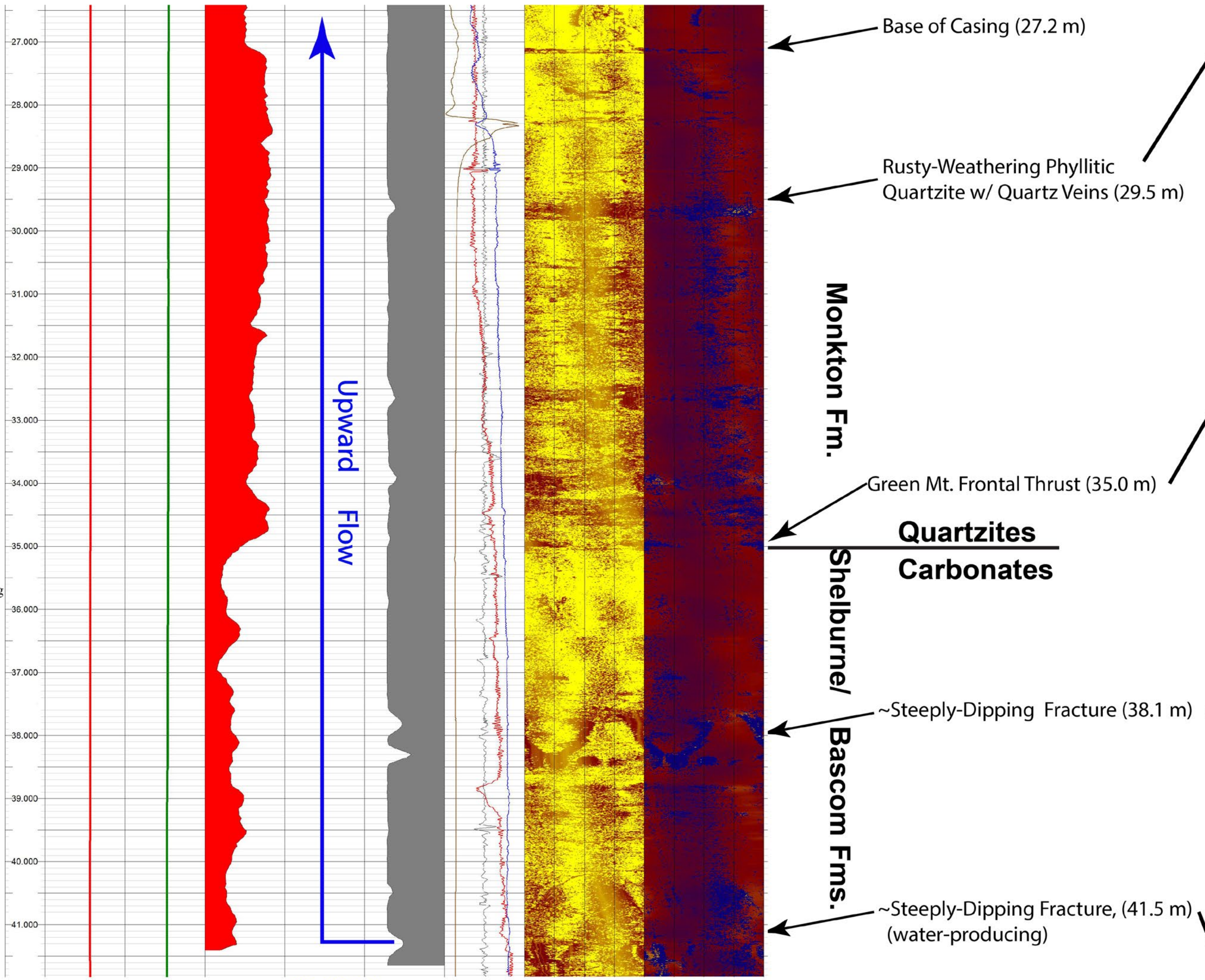
Rice Lane Low Well (1429 Silk Road)





- No PFOA
- Depleted Stable Isotopes
- RLL Major- Trace Chemical Signature
- Tritium "Dead"

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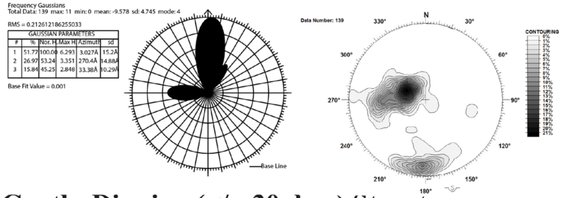
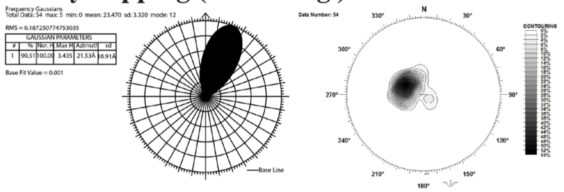
26 Susan Taylor Lane Well

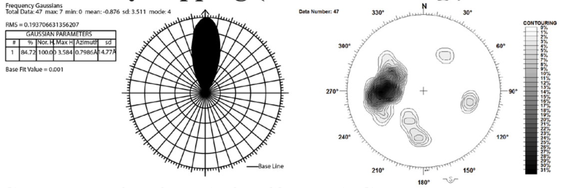
All Structures from Acoustic Televiewer (AT) Log



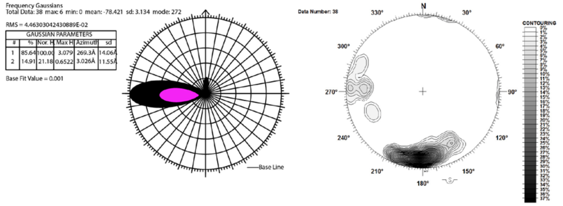
Gently-Dipping (</= 30 deg.) Structures



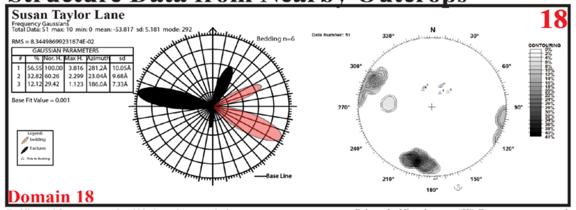
Moderately-Dipping (30 < X < 60 deg.) Structures



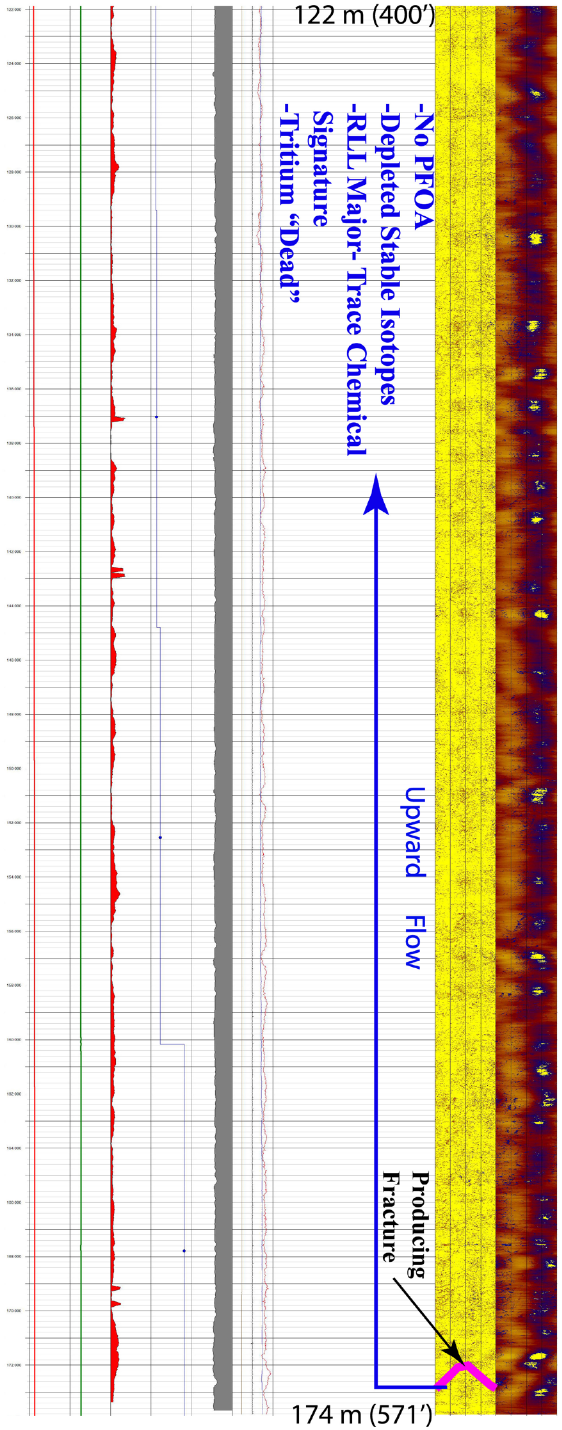
Steeply-Dipping (>/= 60 deg.) Structures



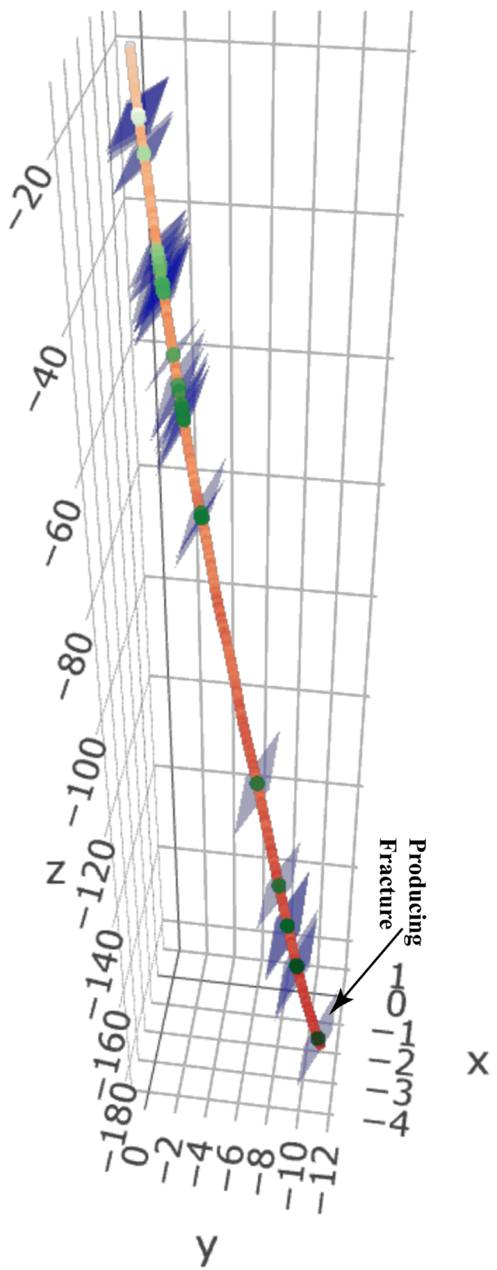
Structure Data from Nearby Outcrops



Bedding and fractures are red and black petals, respectively. Poles to bedding shown as "X". Fractures are contoured.



Distribution of Steeply-Dipping, ~E-W Striking Fractures Along Deviated Borehole



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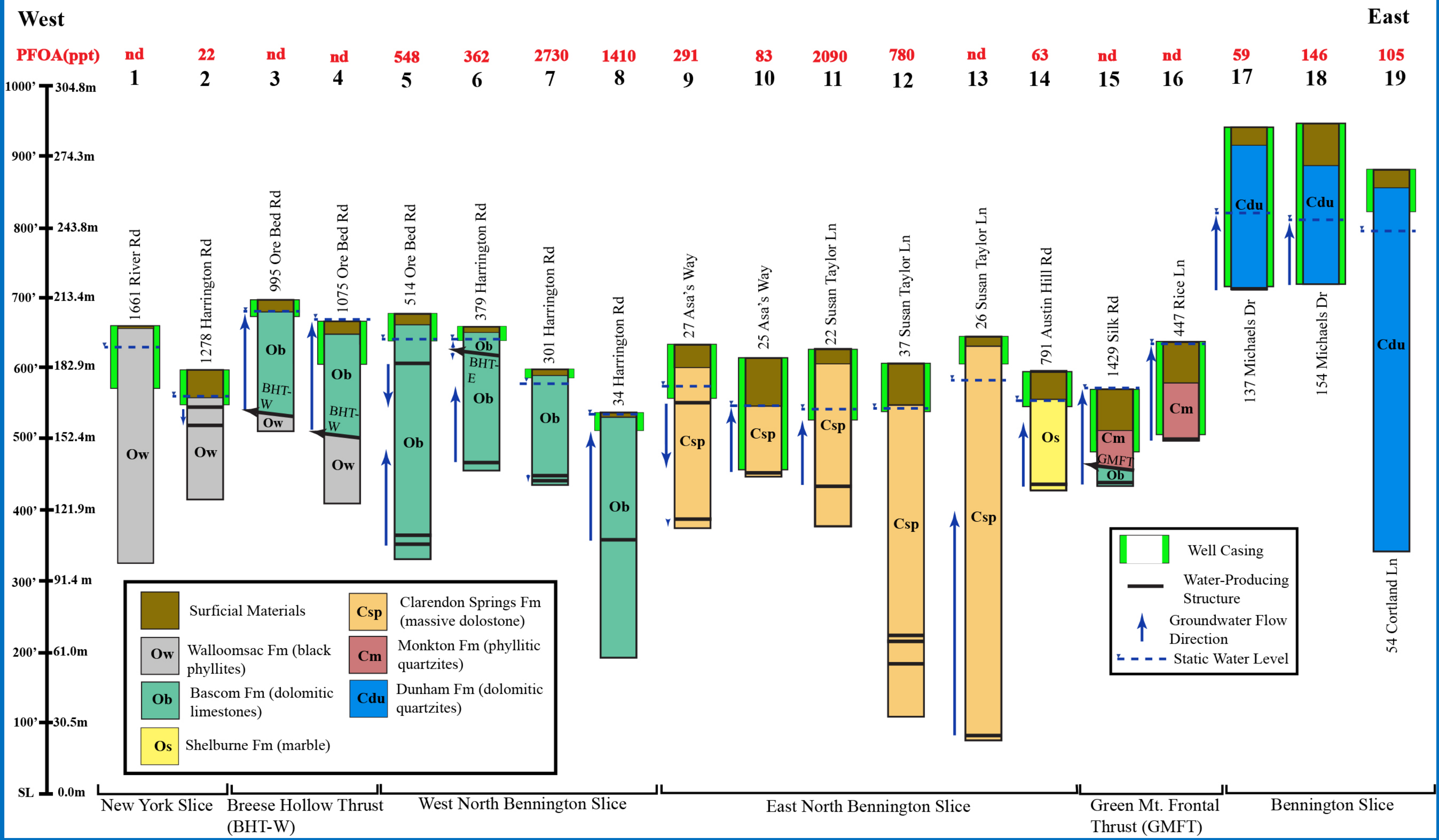
Geophysical Logging

Figure 8



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CSM Map

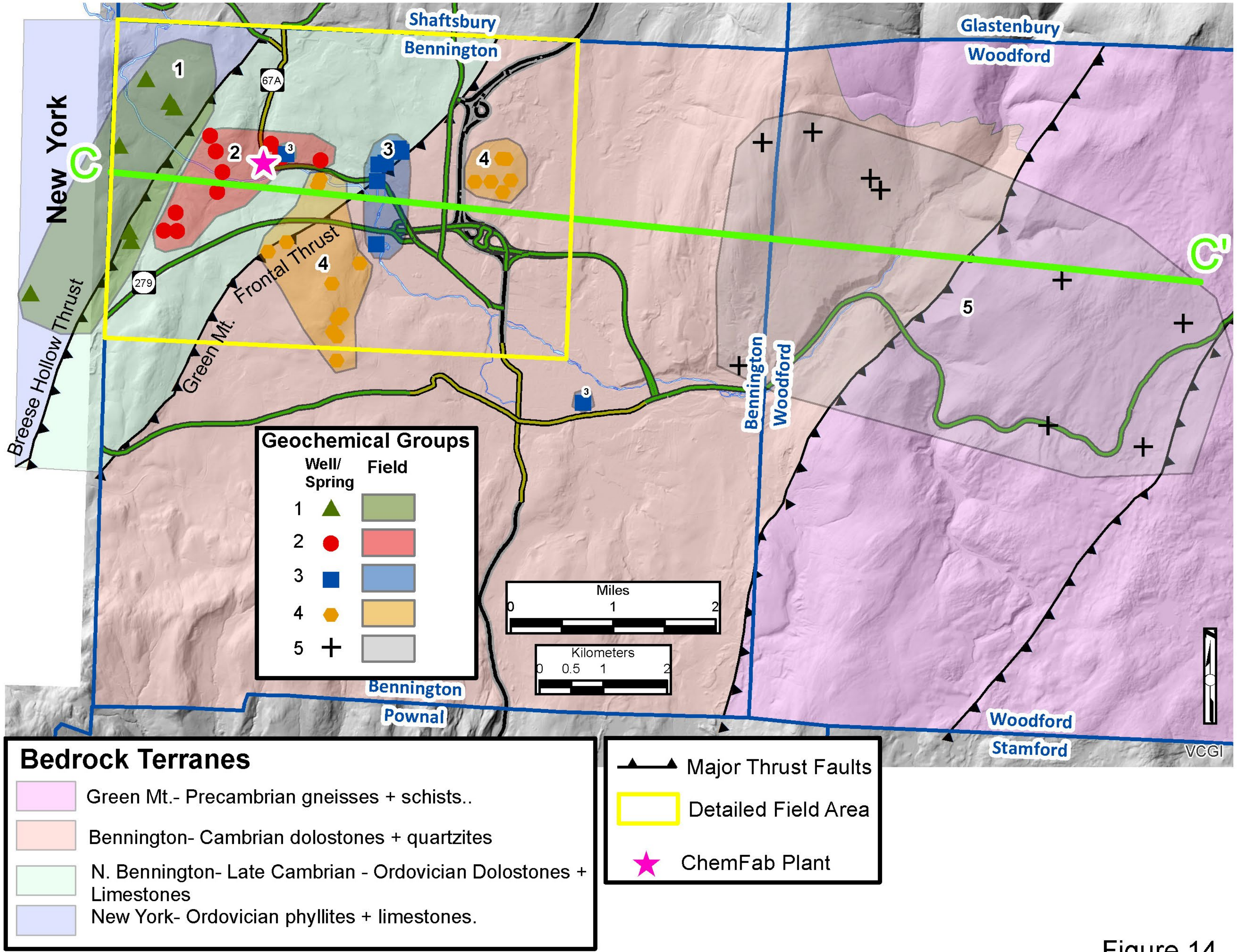

Figure 14

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CSM Cross-Section

Chemical evolution of groundwater by water-rock interaction and anthropogenic contaminants along structural and topographic flow paths

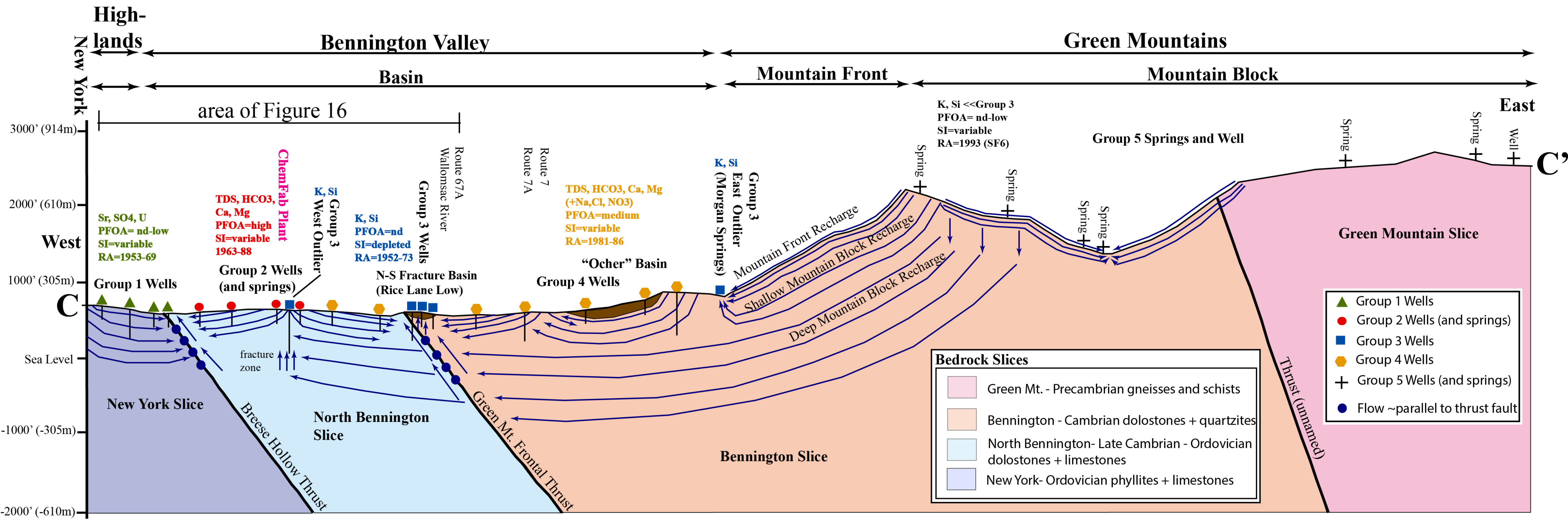

Figure 15

Mountain Front and Mountain Block Recharge (e.g. Wilson and Guan, 2004)

Acknowledgement:
Waste Management Division
VT Dept. of Environmental Conservation

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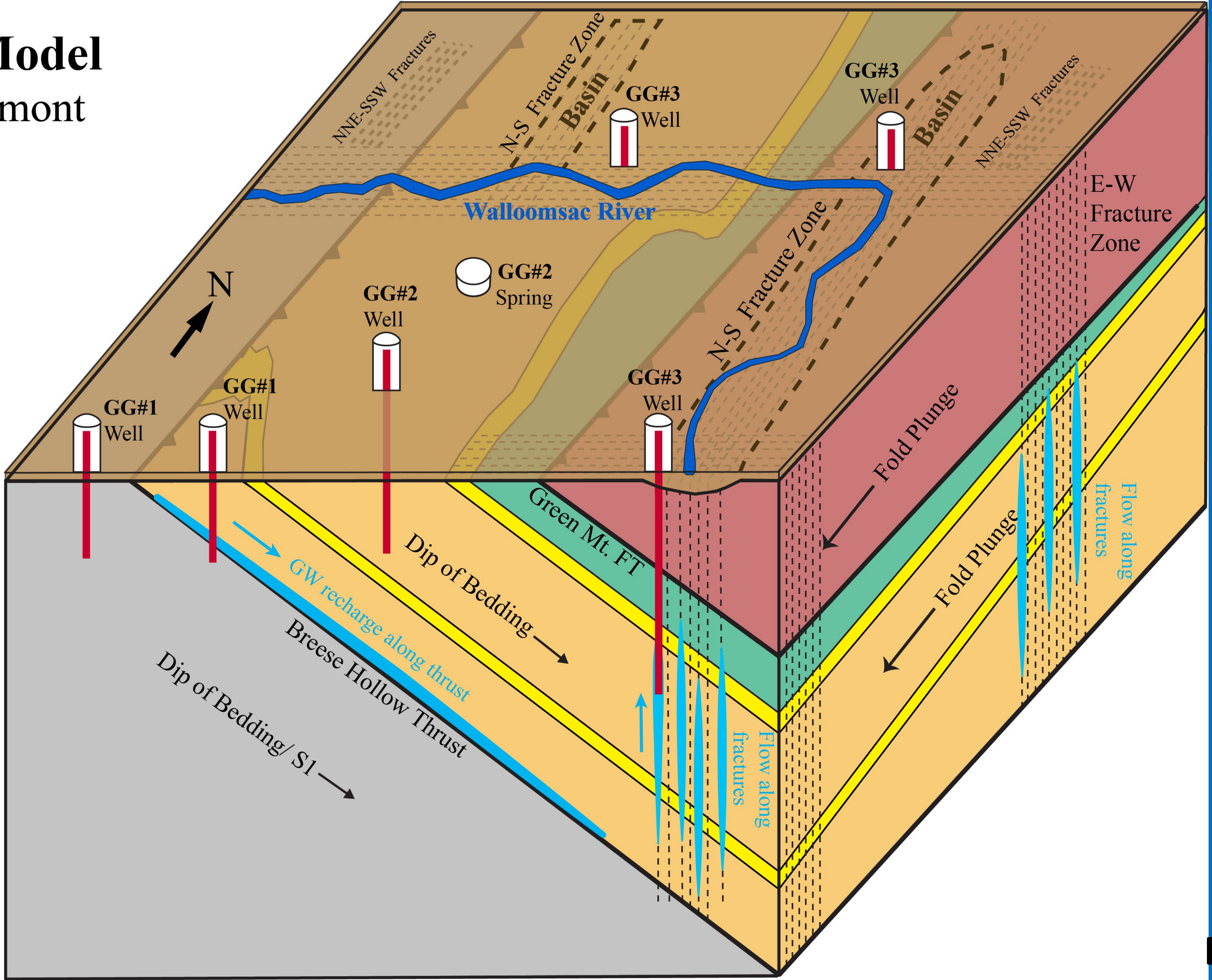
Conceptual Model

Bennington, Vermont



LEGEND

- Ground Water
- Surface Water
- Surficial Material
- Red Dolomitic Quartzite
- Gray Dolomitic Limestone
- White Limestone
- Massive Dolostone
- Gray Phyllites

Slice 3 ↑ Slice 2 ↓ Slice 1

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Outline

- Bennington PFOA Timeline
- Vermont Geological Survey Involvement Timeline
- Aquifer Characterization Retrospective
  - Where PFOA <u>was not</u> in groundwater
- Conceptual Site Model

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