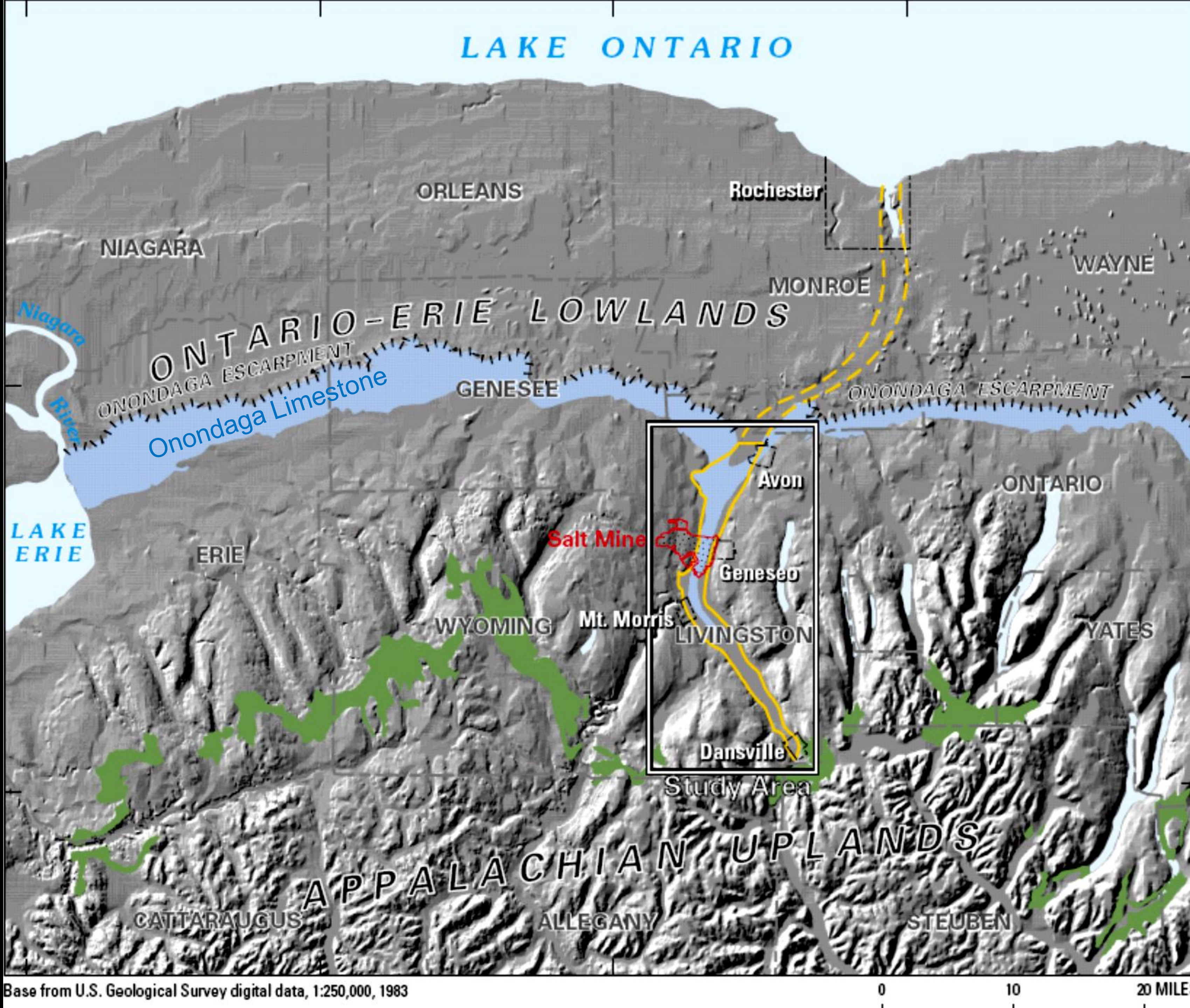
SELECTED ASPECTS of FINGER LAKES GEOLOGY

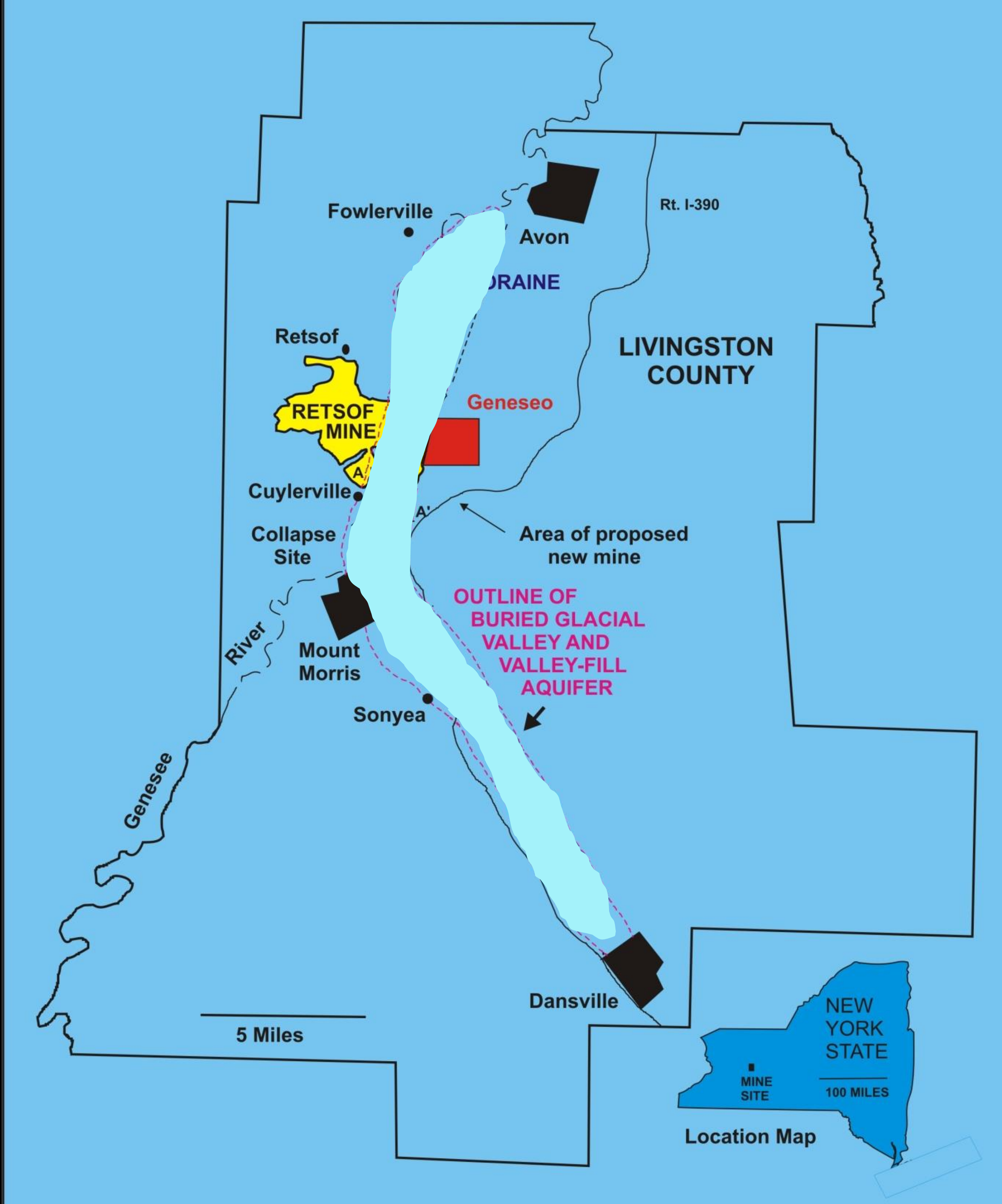
The Unappreciated Horizontal Stress Field and Topographic (Valley) Issues

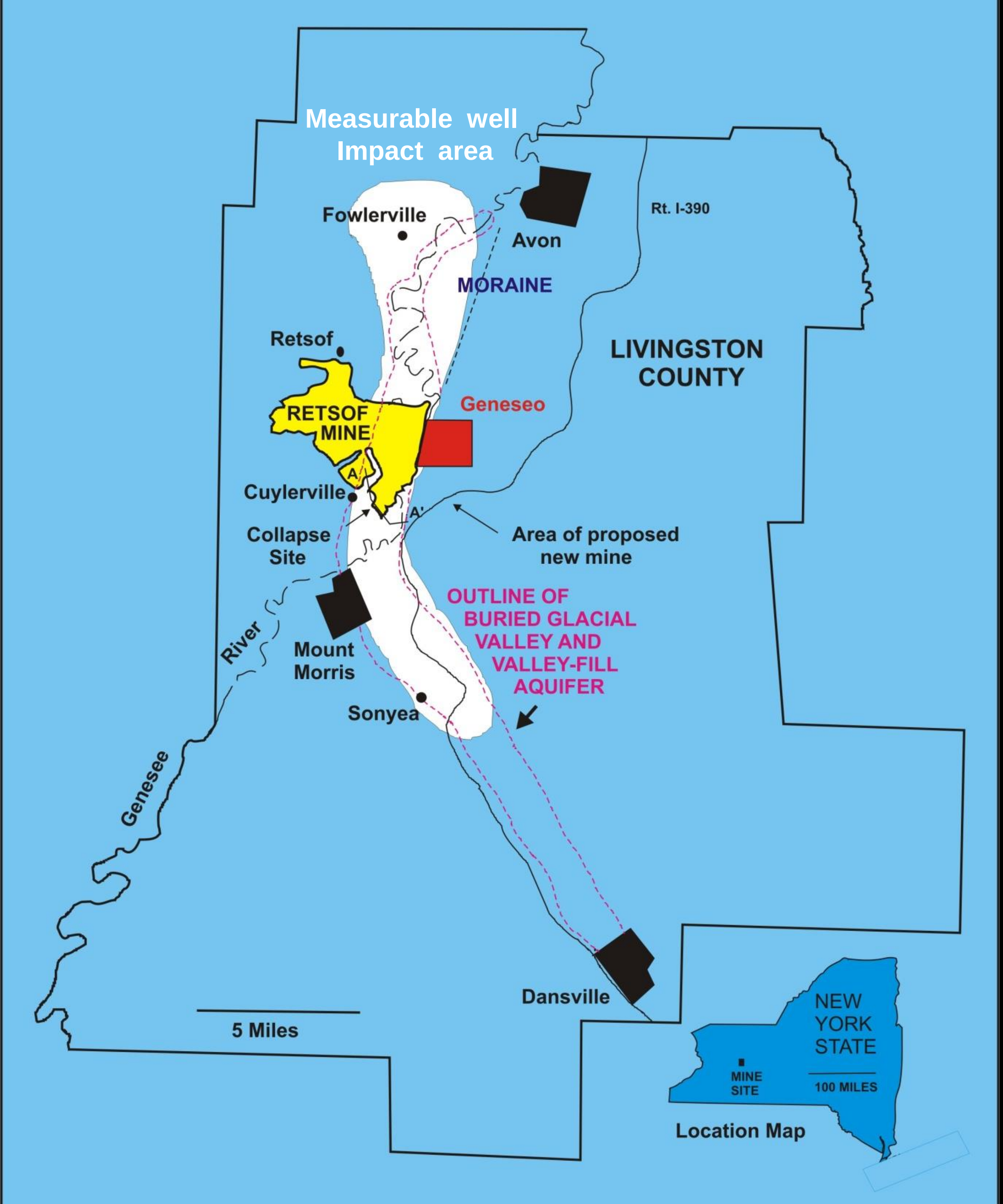
R.A. YOUNG
GEOLOGICAL SCIENCES
SUNY, GENESEO
June 2017



Base from U.S. Geological Survey digital data, 1:250,000, 1983

Glacial Lake
Geneseo
Mine
Cayuga
Lake
Tully
10 miles


Fowlerville
Avon
Rt. I-390
ORAINE
Retsof
LIVINGSTON
COUNTY
Geneseo
RETSOF
MINE
A
Cuylerville
A'
Collapse
Site
Area of proposed
new mine
OUTLINE OF
BURIED GLACIAL
VALLEY AND
VALLEY-FILL
AQUIFER
River
Mount
Morris
Sonyea
Genesee
5 Miles
Dansville
NEW
YORK
STATE
MINE
SITE
100 MILES
Location Map


Measurable well
Impact area
Fowlerville
Avon
Rt. I-390
MORAINE
Retsof
LIVINGSTON
COUNTY
Geneseo
RETSOF
MINE
A
Cuylerville
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Site
Area of proposed
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OUTLINE OF
BURIED GLACIAL
VALLEY AND
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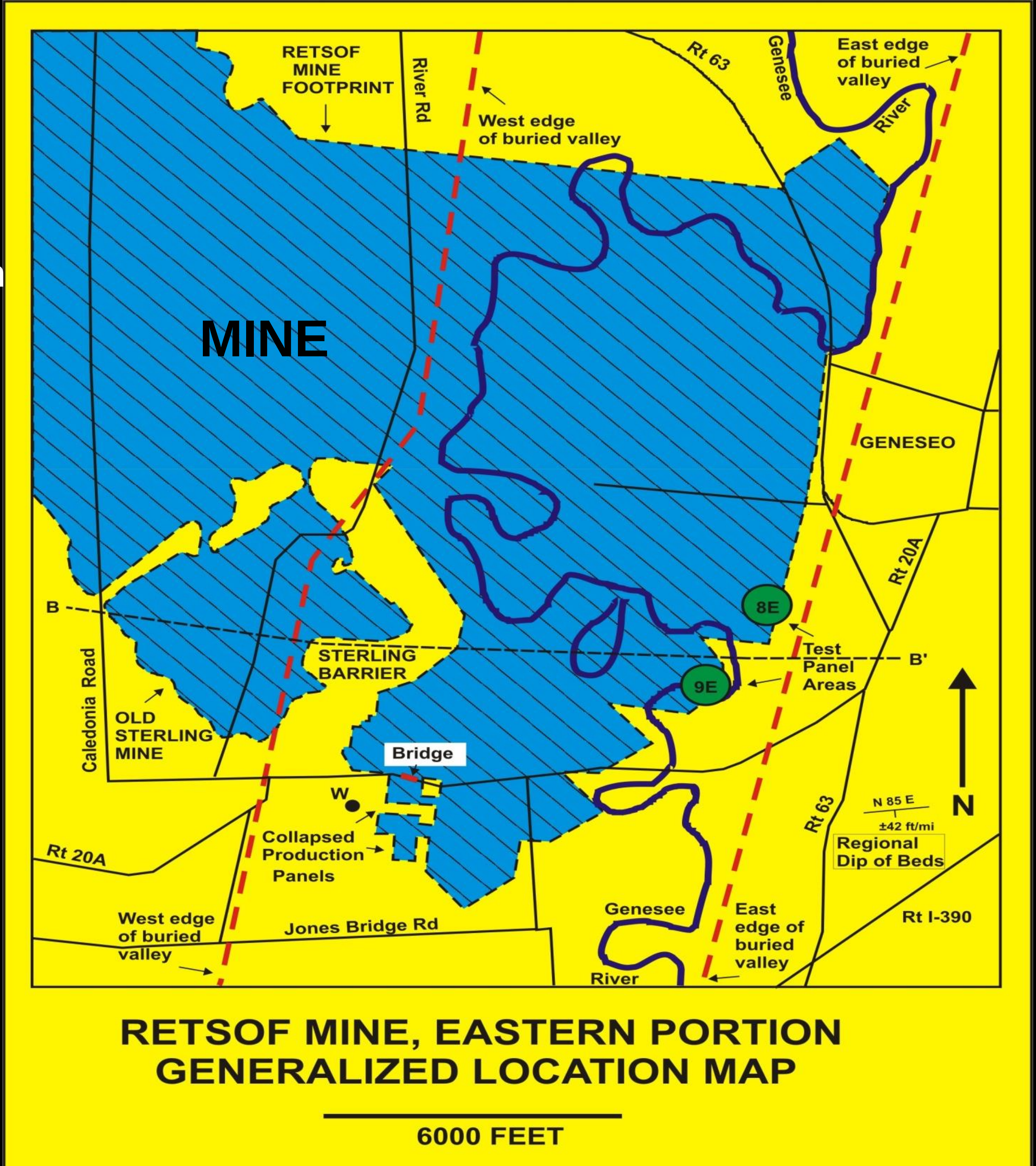
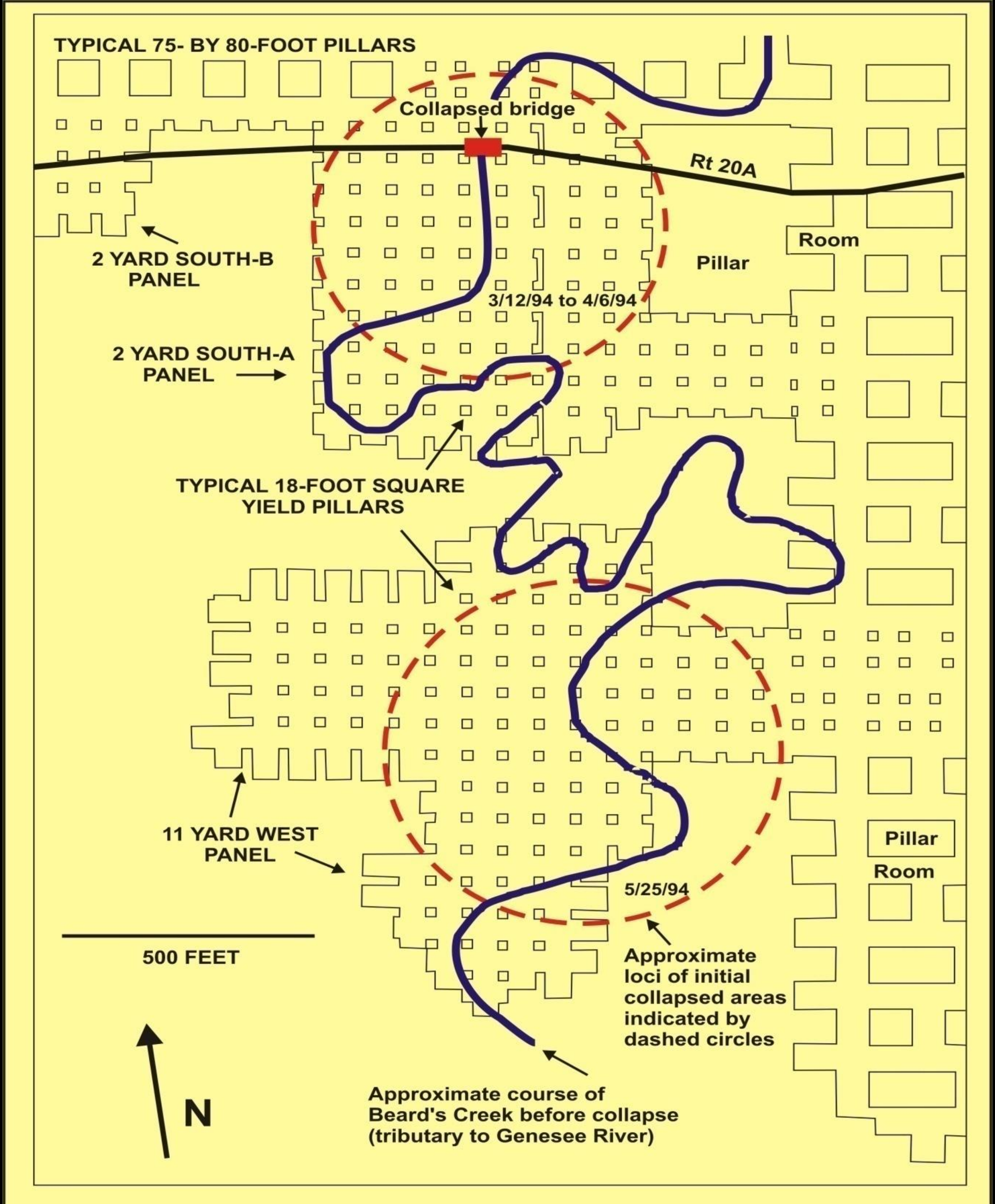
AQUIFER
River
Mount
Morris
Sonyea
Genesee
Dansville
5 Miles
NEW
YORK
STATE
MINE
SITE
100 MILES
Location Map

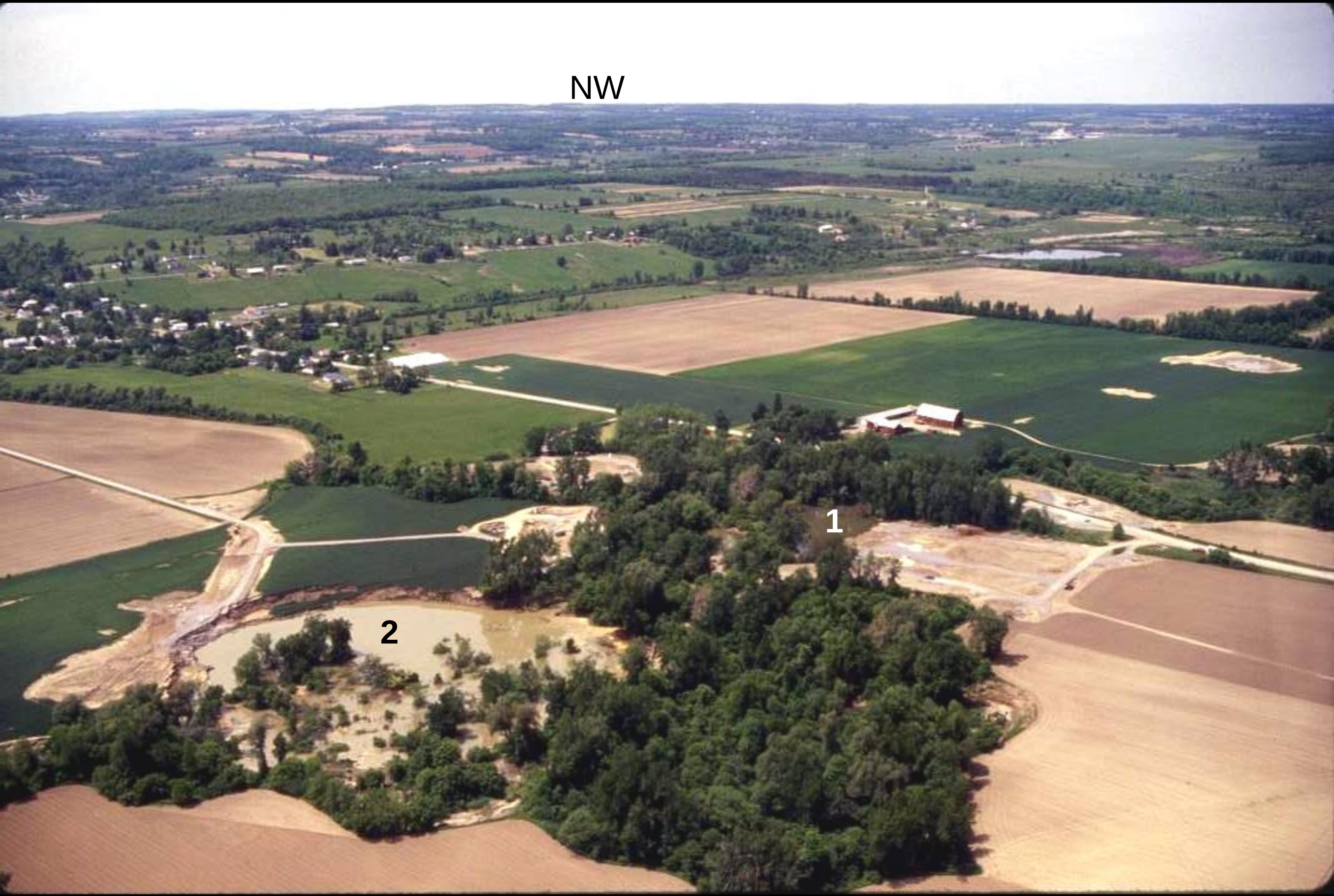
Buried valley edges shown by red lines





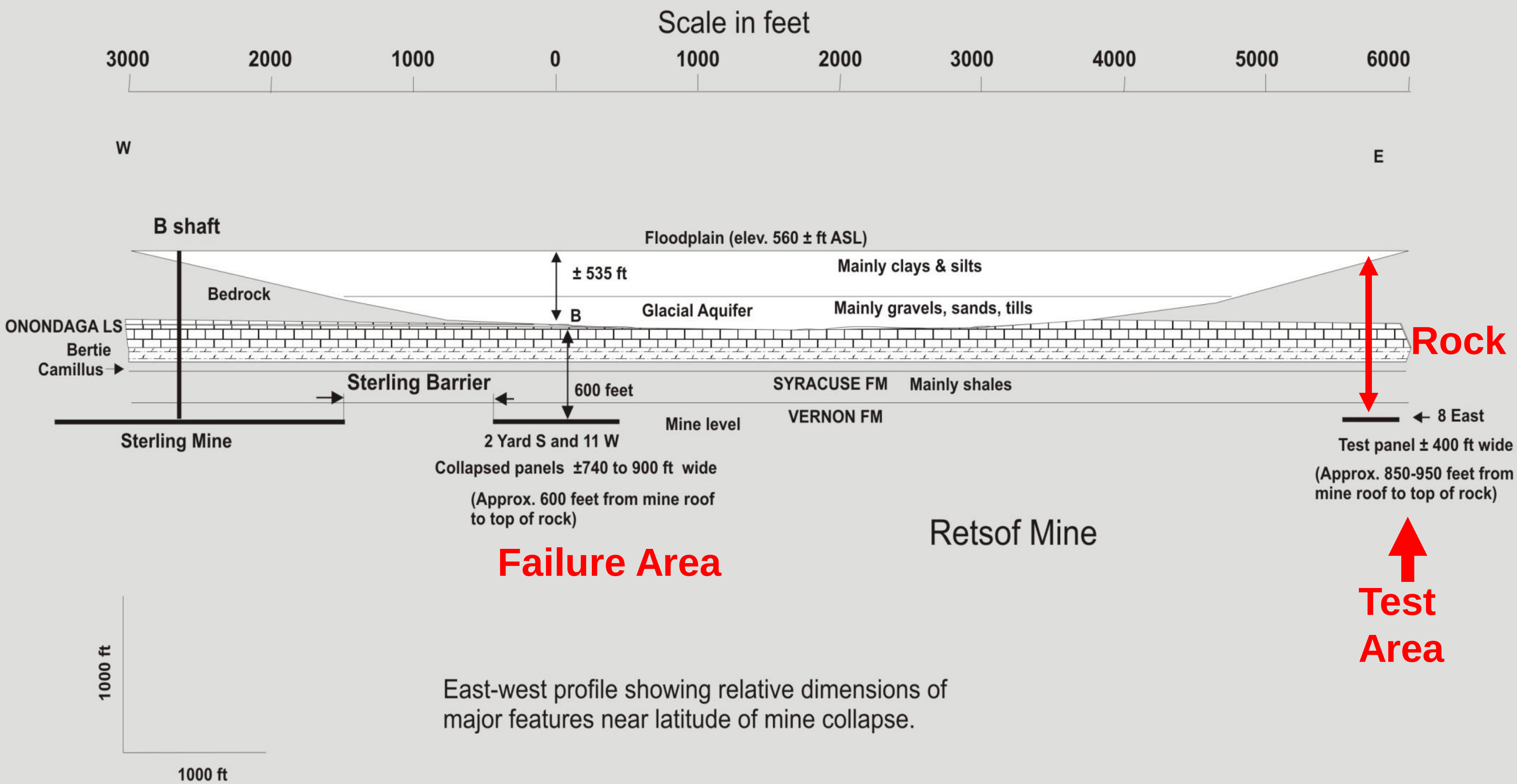
TYPICAL 75- BY 80-FOOT PILLARS
Collapsed bridge
Rt 20A
Room
Pillar
2 YARD SOUTH-B PANEL
3/12/94 to 4/6/94
2 YARD SOUTH-A PANEL
TYPICAL 18-FOOT SQUARE YIELD PILLARS
11 YARD WEST PANEL
Pillar
Room
5/25/94
500 FEET
Approximate loci of initial collapsed areas indicated by dashed circles
Approximate course of Beard's Creek before collapse (tributary to Genesee River)
N

Collapse: March 1994


NW
1
2

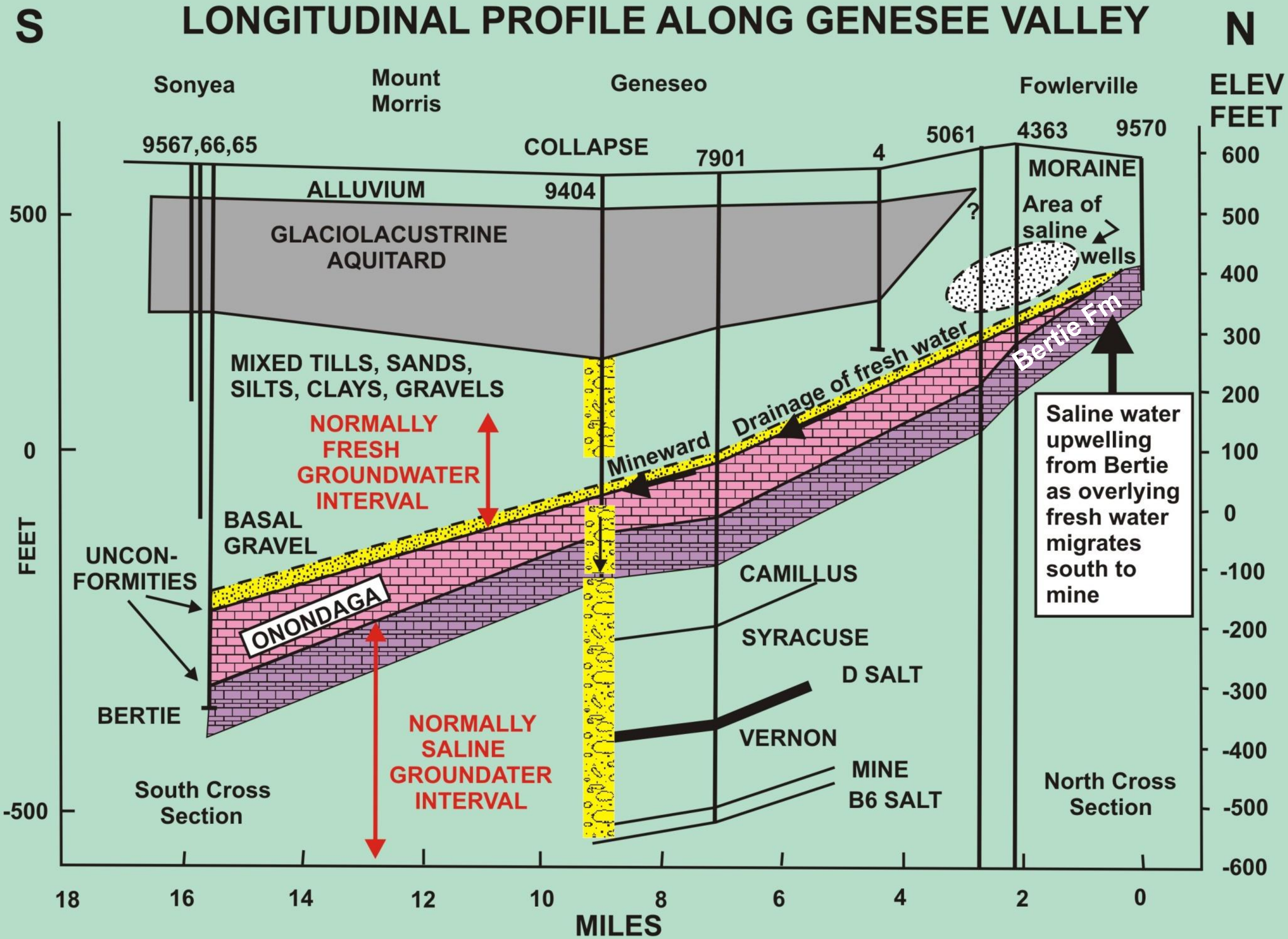

5/9/2011
1
Desalinization
Plant in 2011
2
517 ft
Google earth

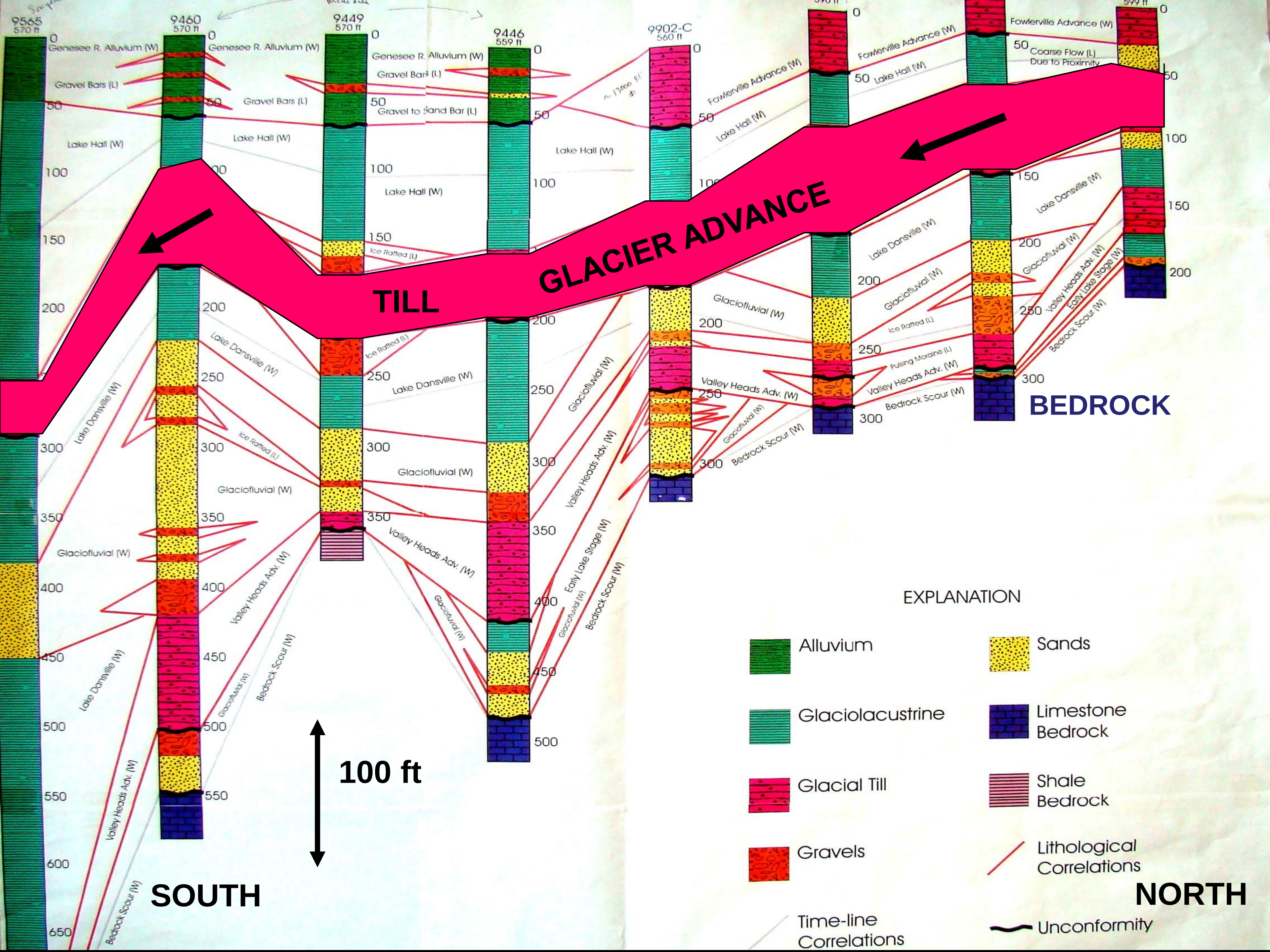
APPROXIMATE TRUE SCALE CROSS SECTION DIAGRAM OF GENESEE VALLEY



East-west profile showing relative dimensions of
major features near latitude of mine collapse.

LONGITUDINAL PROFILE ALONG GENESEE VALLEY



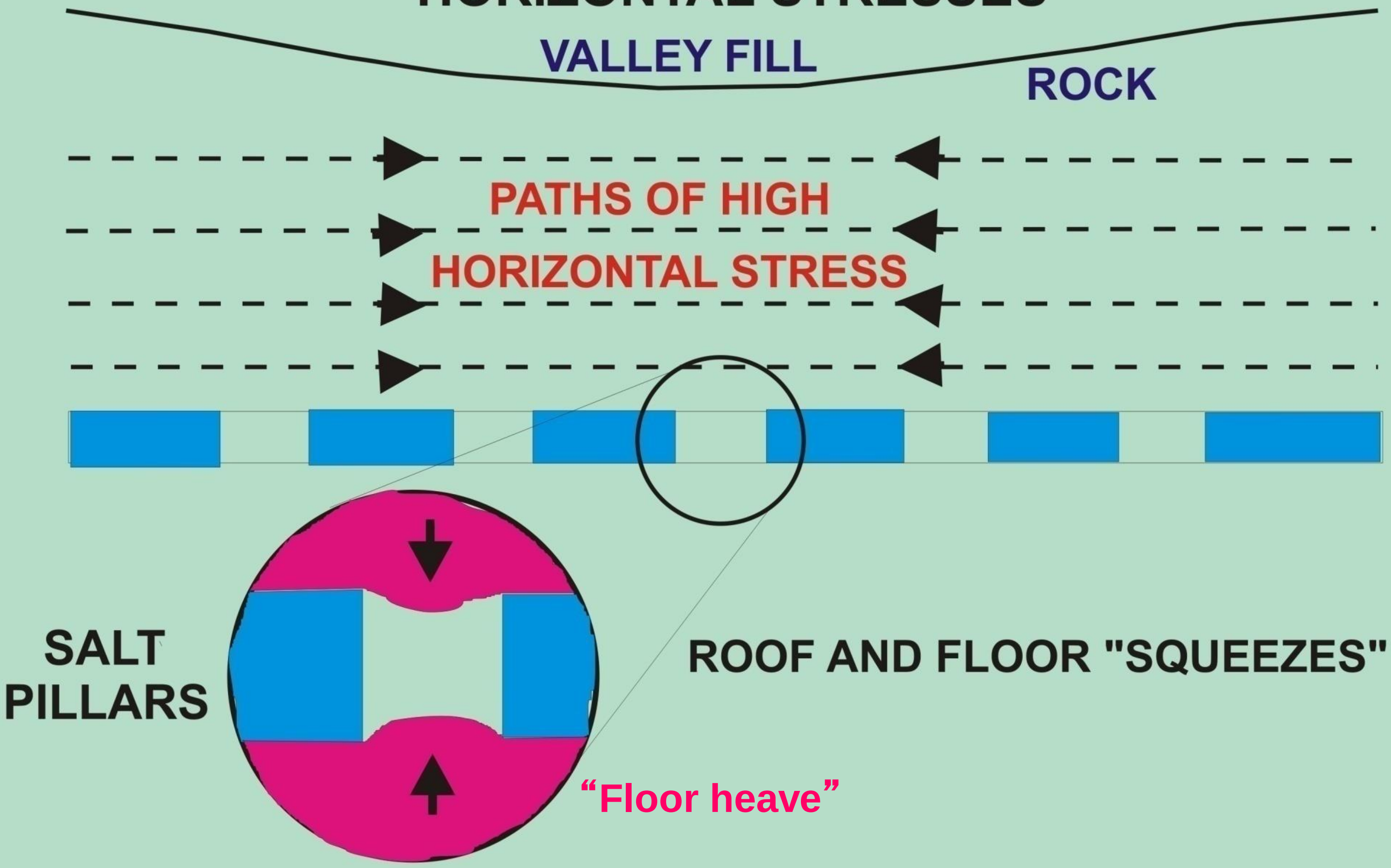


9565
570 ft
9460
570 ft
9449
570 ft
9446
559 ft
9902-C
560 ft
Genesee R. Alluvium (W)
Gravel Bars (L)
Gravel to Sand Bar (L)
Lake Hall (W)
Fowlerville Advance (W)
Coarse Flow (L)
Due to Proximity
Lake Dansville (W)
Ice Rafted (L)
Glaciofluvial (W)
Valley Heads Adv. (W)
Bedrock Scour (W)
Early Lake Stage (W)
Pulsing Moraine (L)
GLACIER ADVANCE
TILL
BEDROCK
100 ft
SOUTH
NORTH
EXPLANATION
Alluvium
Sands
Glaciolacustrine
Limestone Bedrock
Glacial Till
Shale Bedrock
Gravels
Lithological Correlations
Time-line Correlations
Unconformity

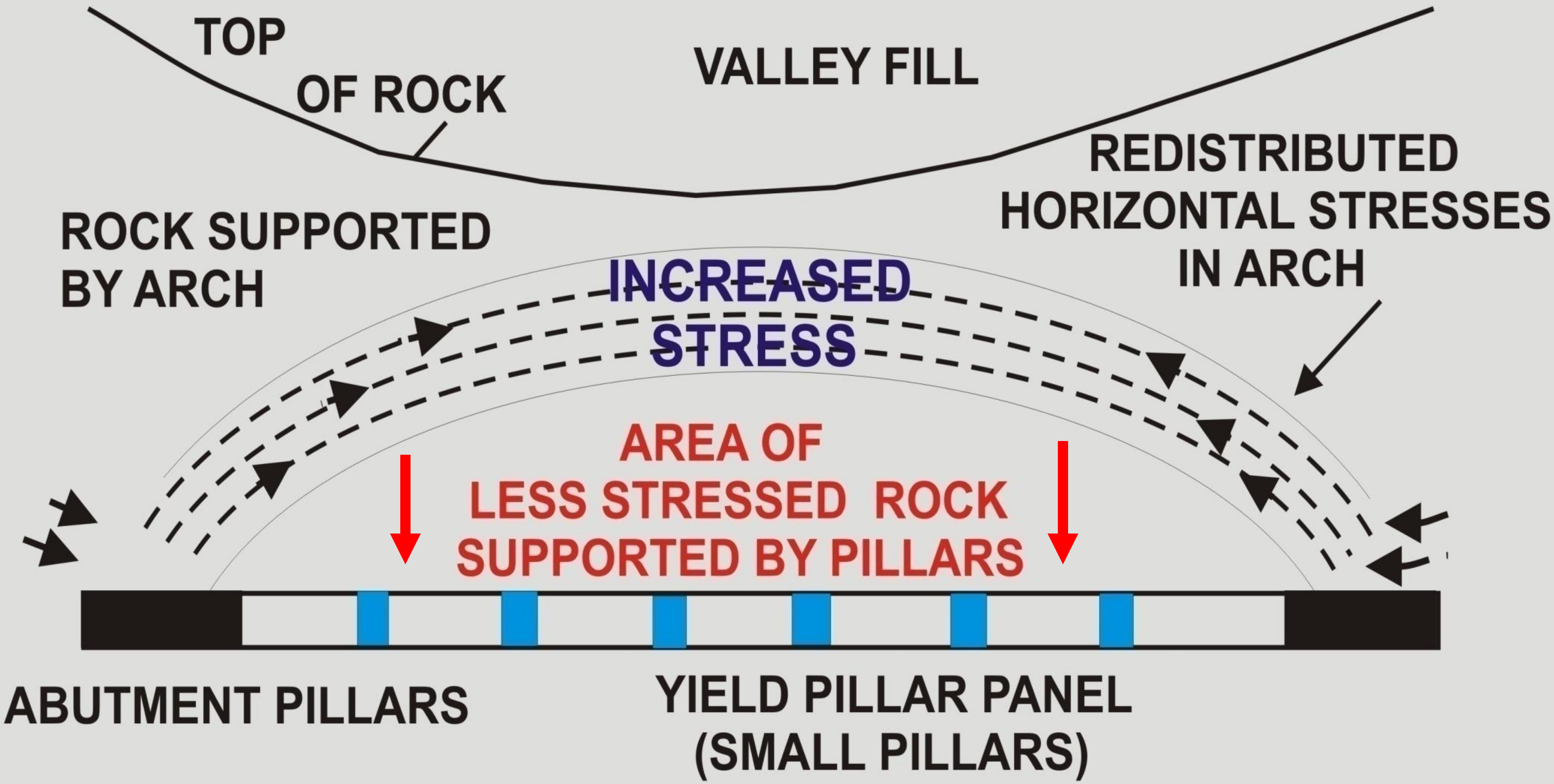
Small (Yielding) Pillar Concept

To Avoid Roof "Collapse" Issues

DIAGRAMMATIC VIEW OF LARGE PILLARS WITH ROOF AND FLOOR PROBLEMS CAUSED BY HIGH HORIZONTAL STRESSES



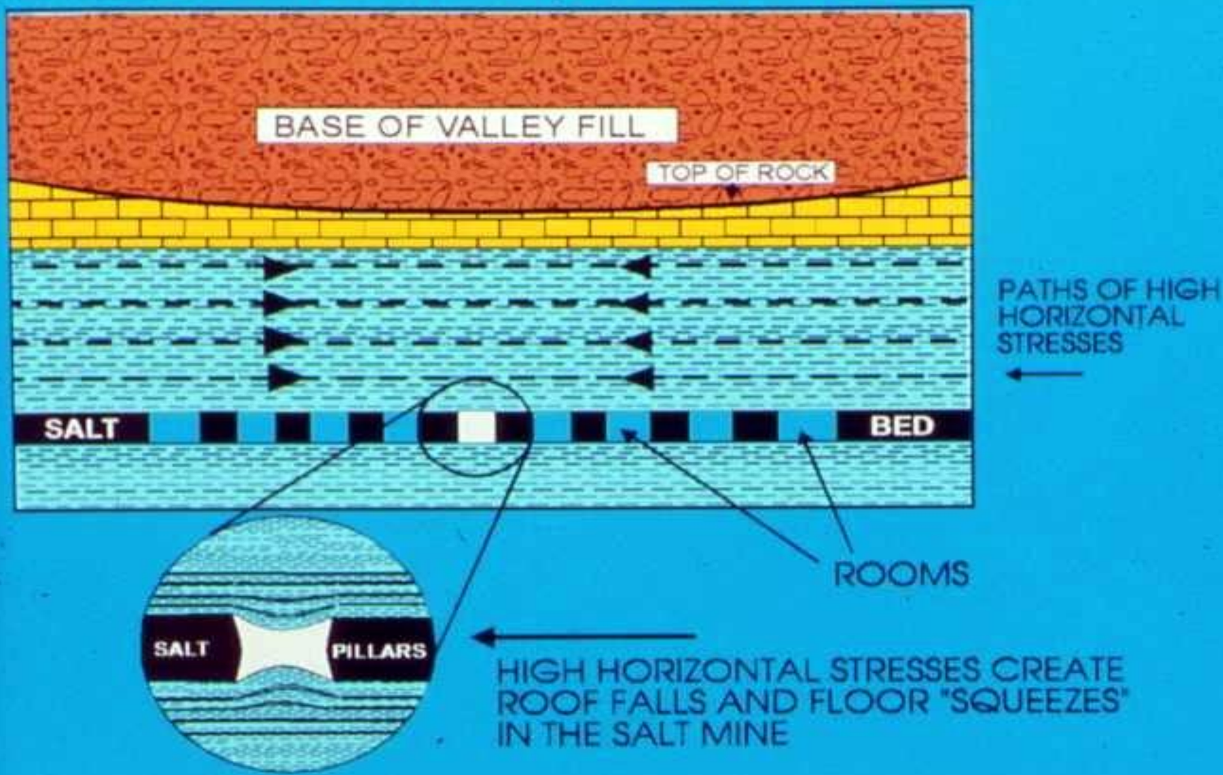
REDISTRIBUTION OF HORIZONTAL STRESSES INTO COMPRESSIVE ARCH ABOVE YIELD PILLARS



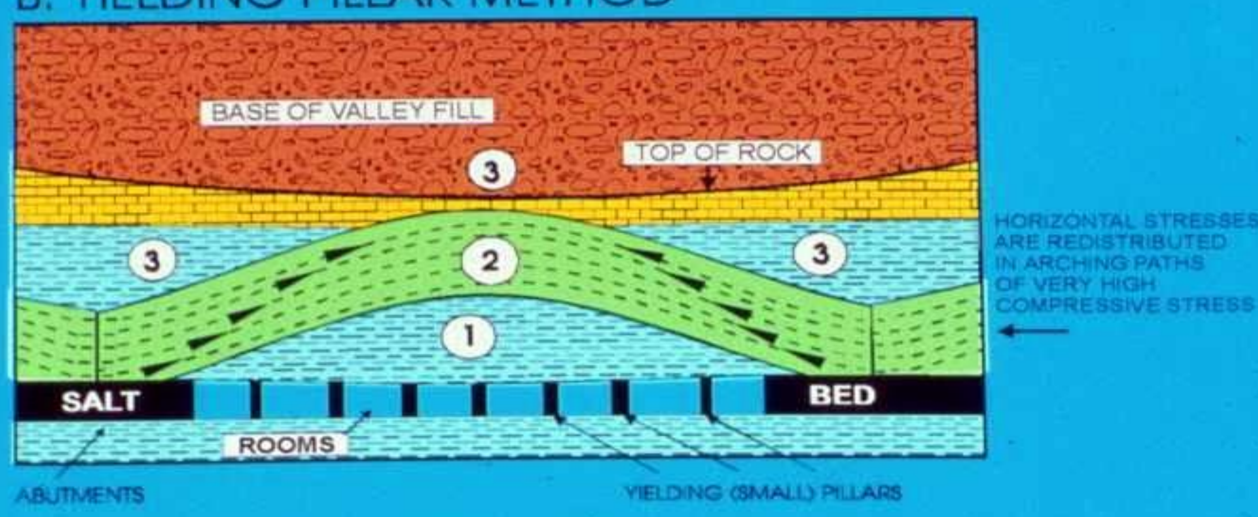
YIELD PILLAR LOAD REDUCED BY LOAD TRANSFERRED TO ARCH

ARCH SHAPE AND STRESS PATHS DETERMINED BY STRATIGRAPHY

A. REGULAR ROOM-AND-PILLAR METHOD



B. YIELDING PILLAR METHOD



Mr. Kurt Kiser. Supt.
AKZO Salt
Retsof Mine
3846 Retsof Road
Retsof. New York 14539

MEMO: November 22, 1993

(from ROCK MECHANICS ASSIST)

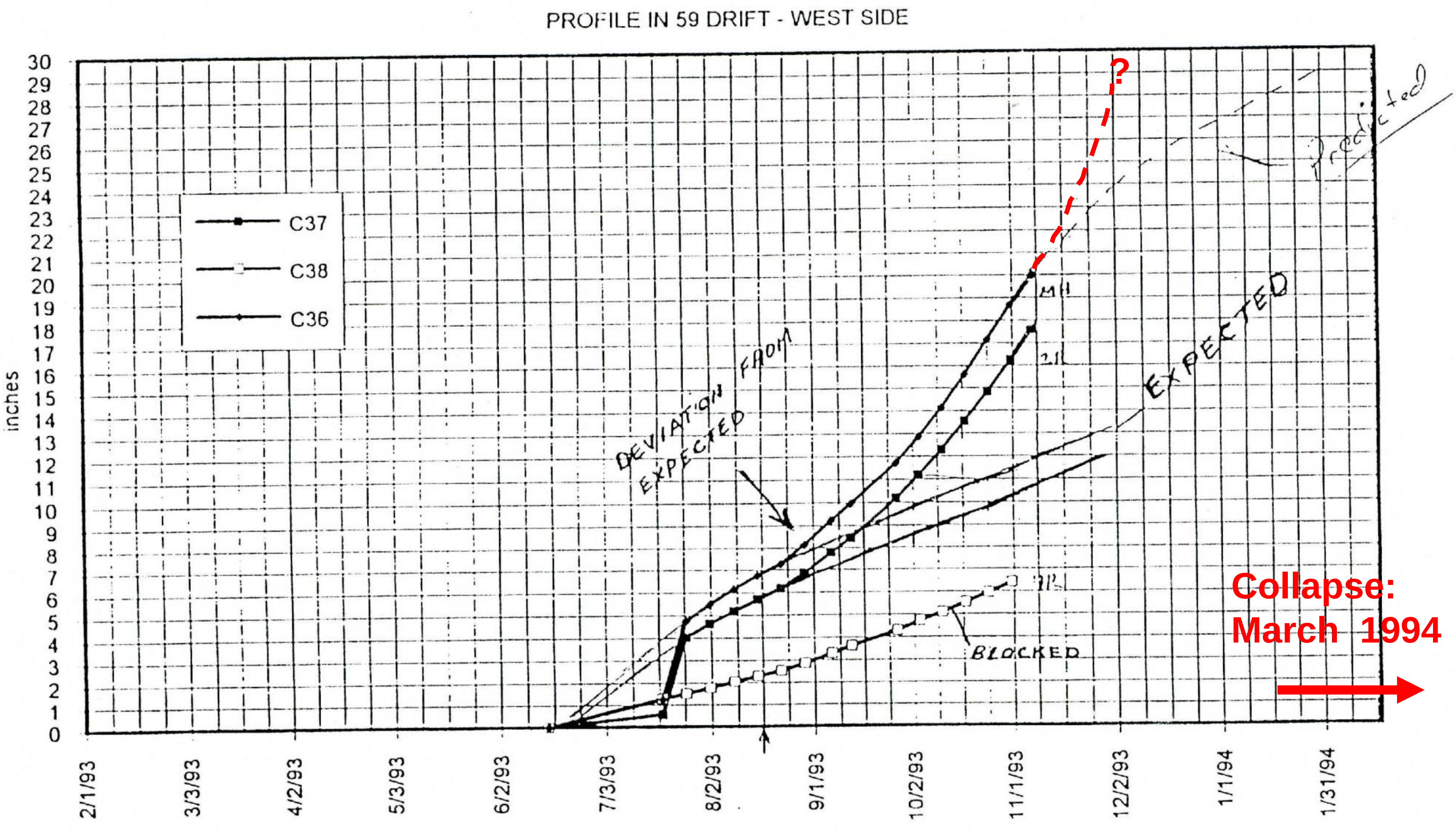
Signed by: Gary Petersen

Dear Kurt.

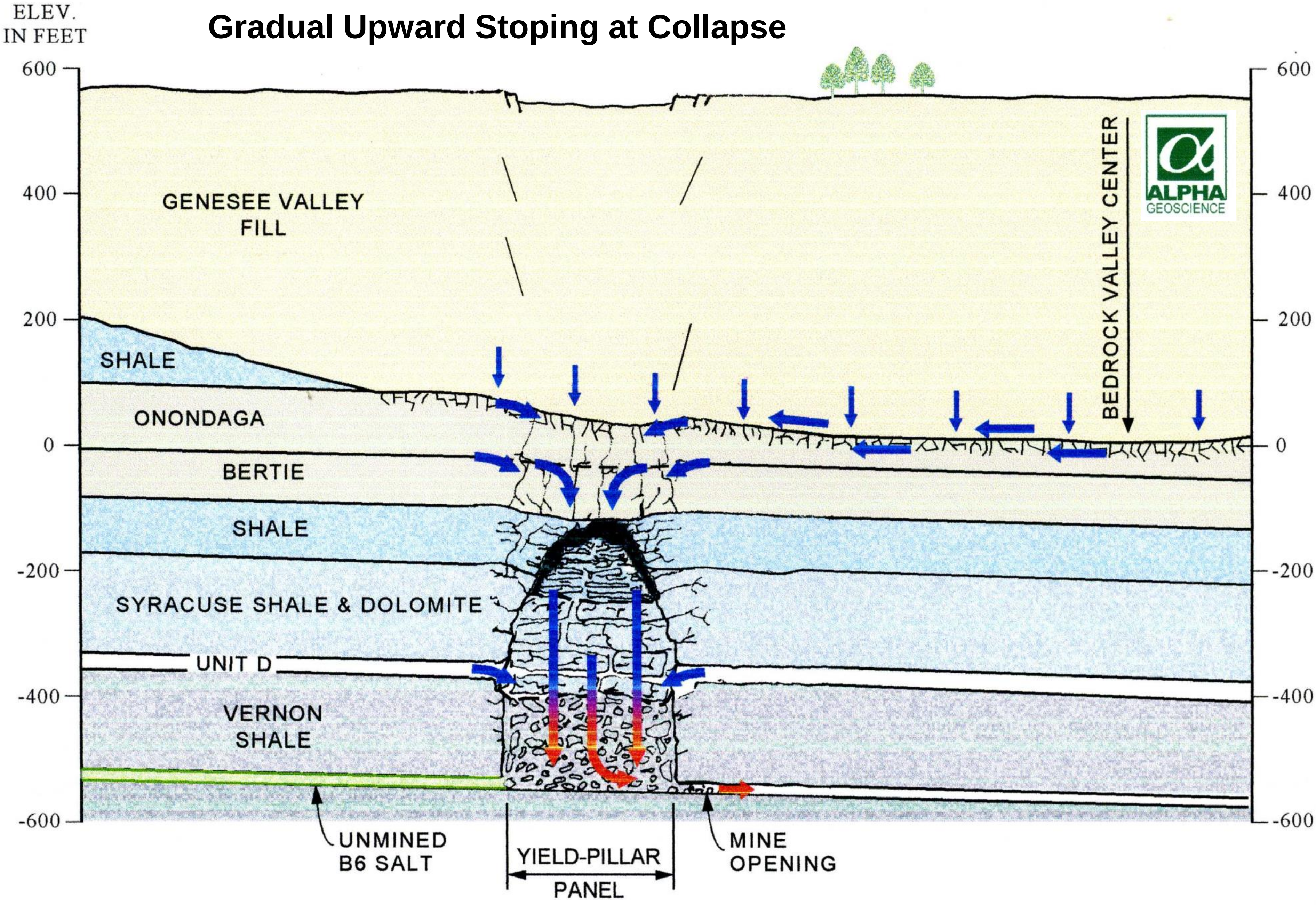
This is a recap of my last visit. which primarily addressed the performance of the 2 Yard South experiment. Mining was discontinued in the experiment the latter part of October due to excessive closure. Total closure rates were approaching 30" in some parts of the experiment. But more important than total closure was that the rate of closure was increasing instead of decreasing as was expected. Figure 1 shows a typical closure graph. Notice the deviation from the expected during the latter part of August. Continuing the experiment would have probably resulted in increasing closure rates for some time to come. During the early part of November it was decided to prohibit entry into the experimental area until closure rates began to decrease and a thorough evaluation of ground conditions could be made.

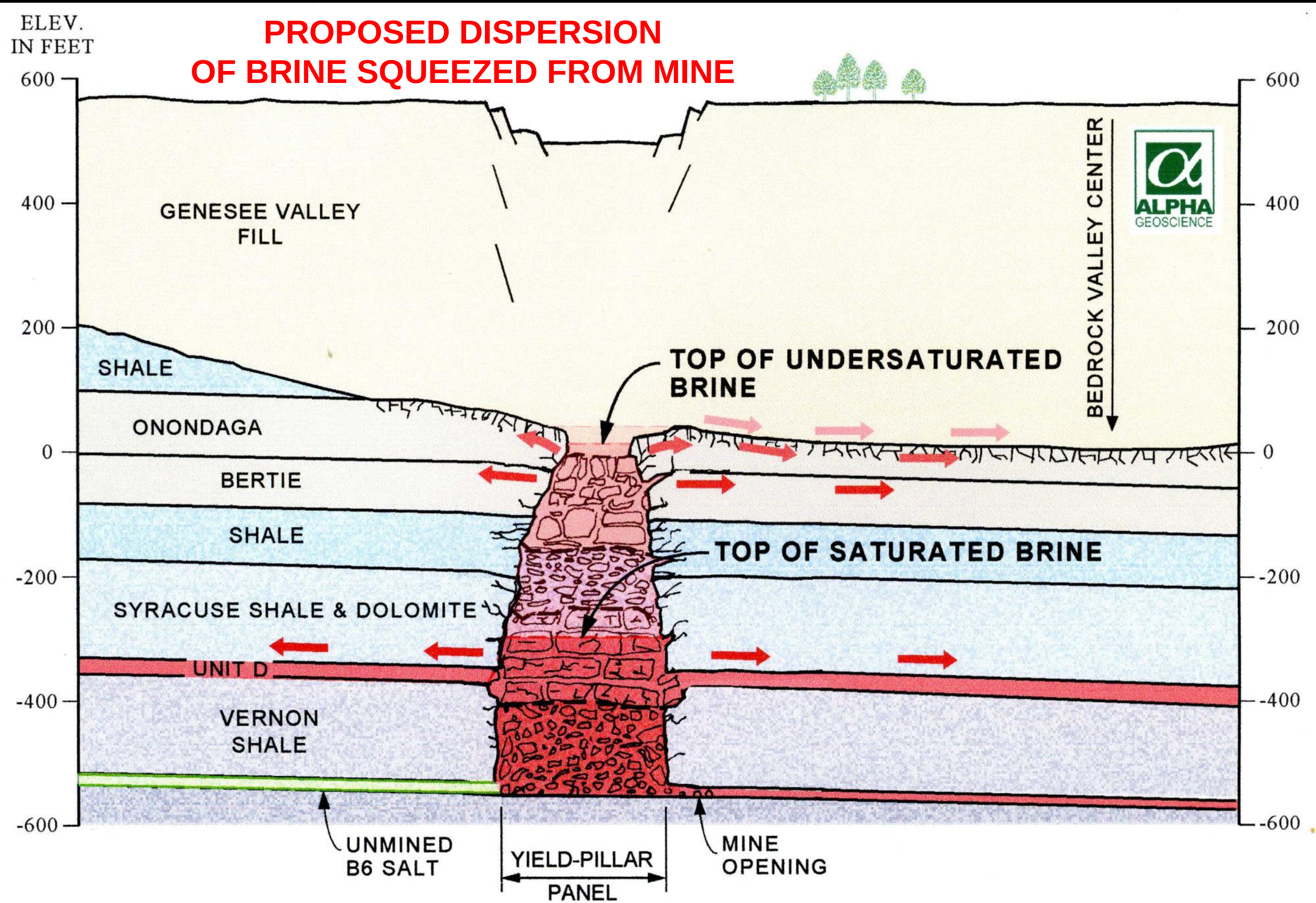
At first glance it appears that the experiment was too wide thus exceeding the critical width. After a preliminary assessment, there appears to be other factors that had a significant impact on the performance

ROOM CLOSURE - 2 YARD SOUTH

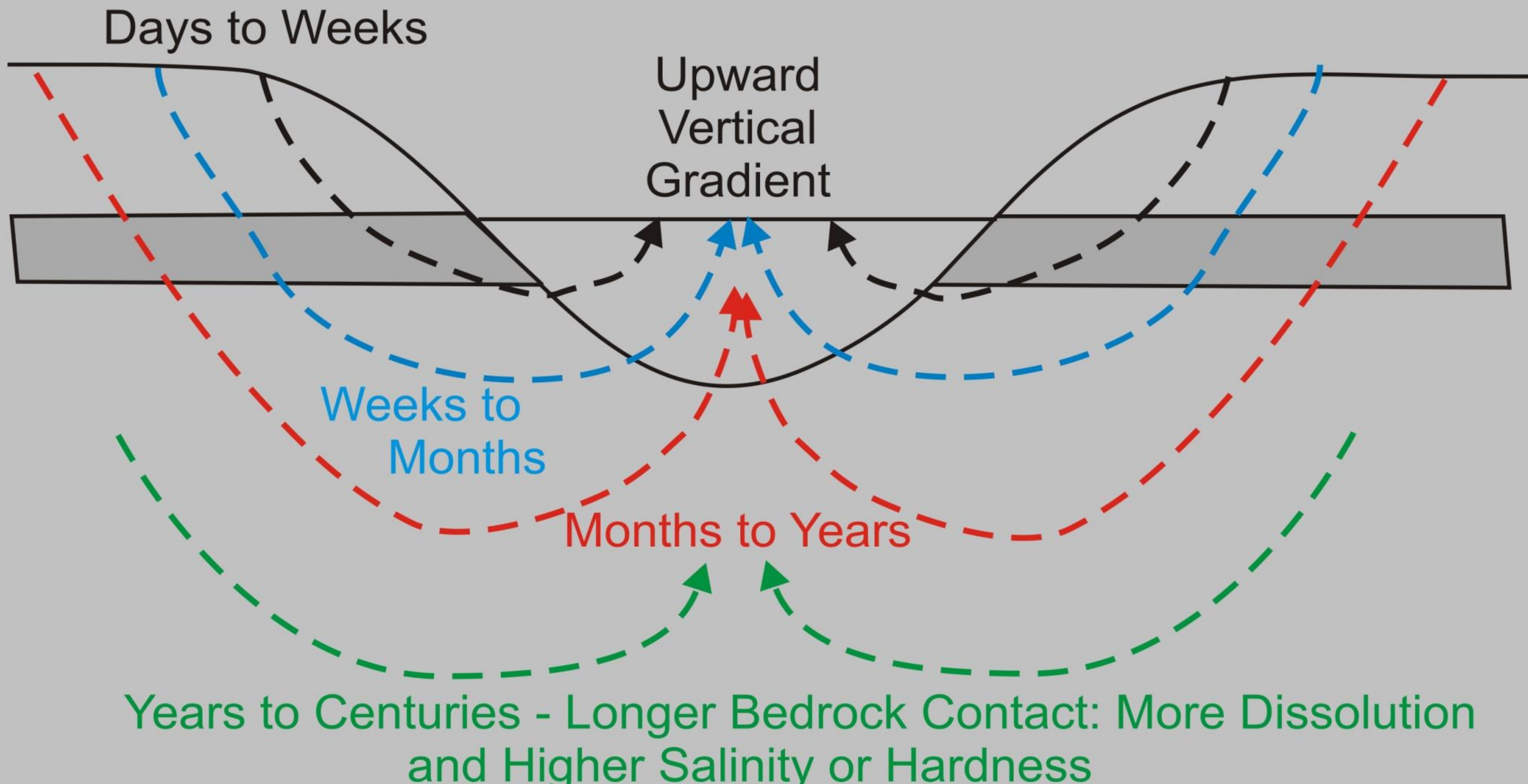


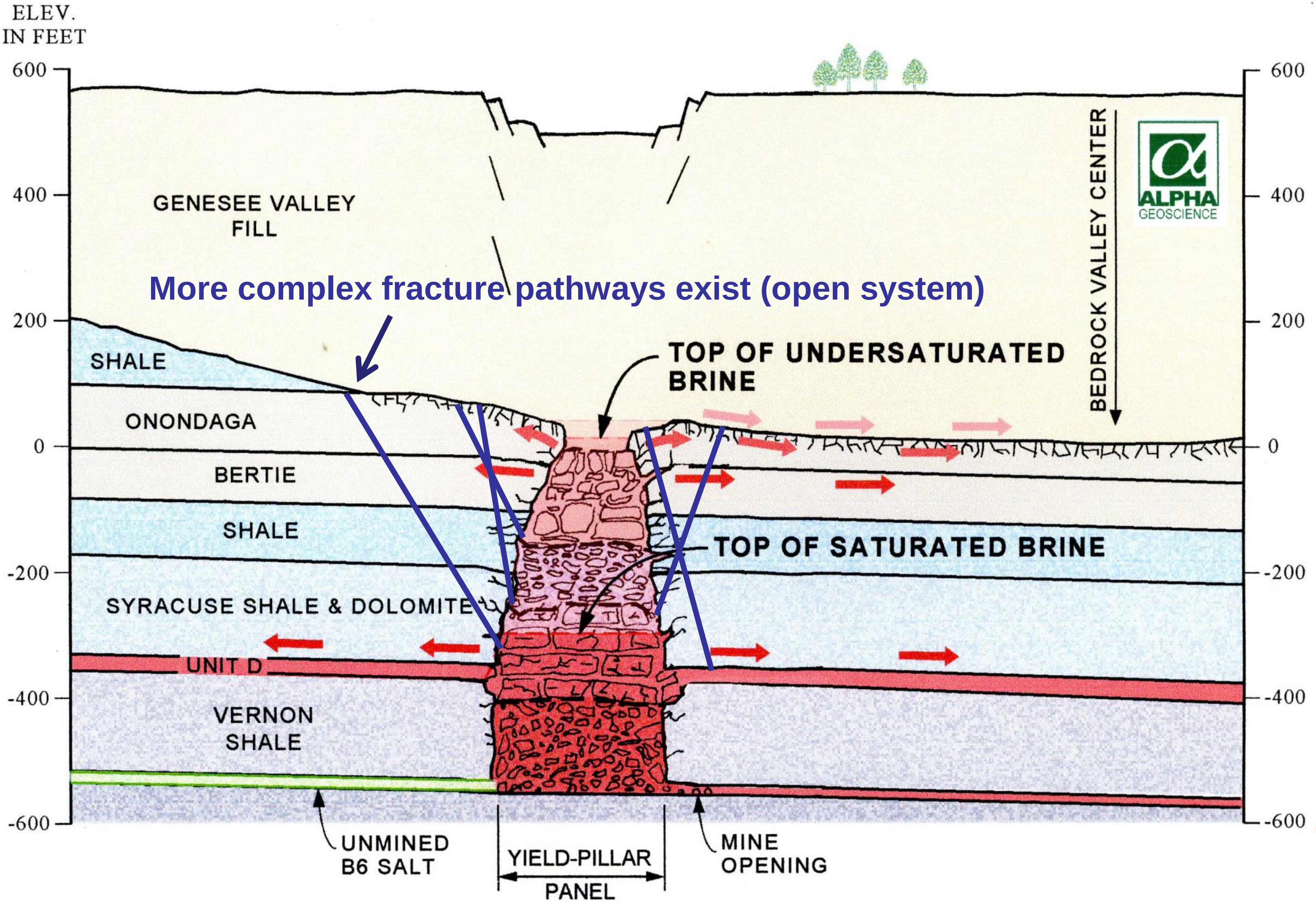
Gradual Upward Stoping at Collapse

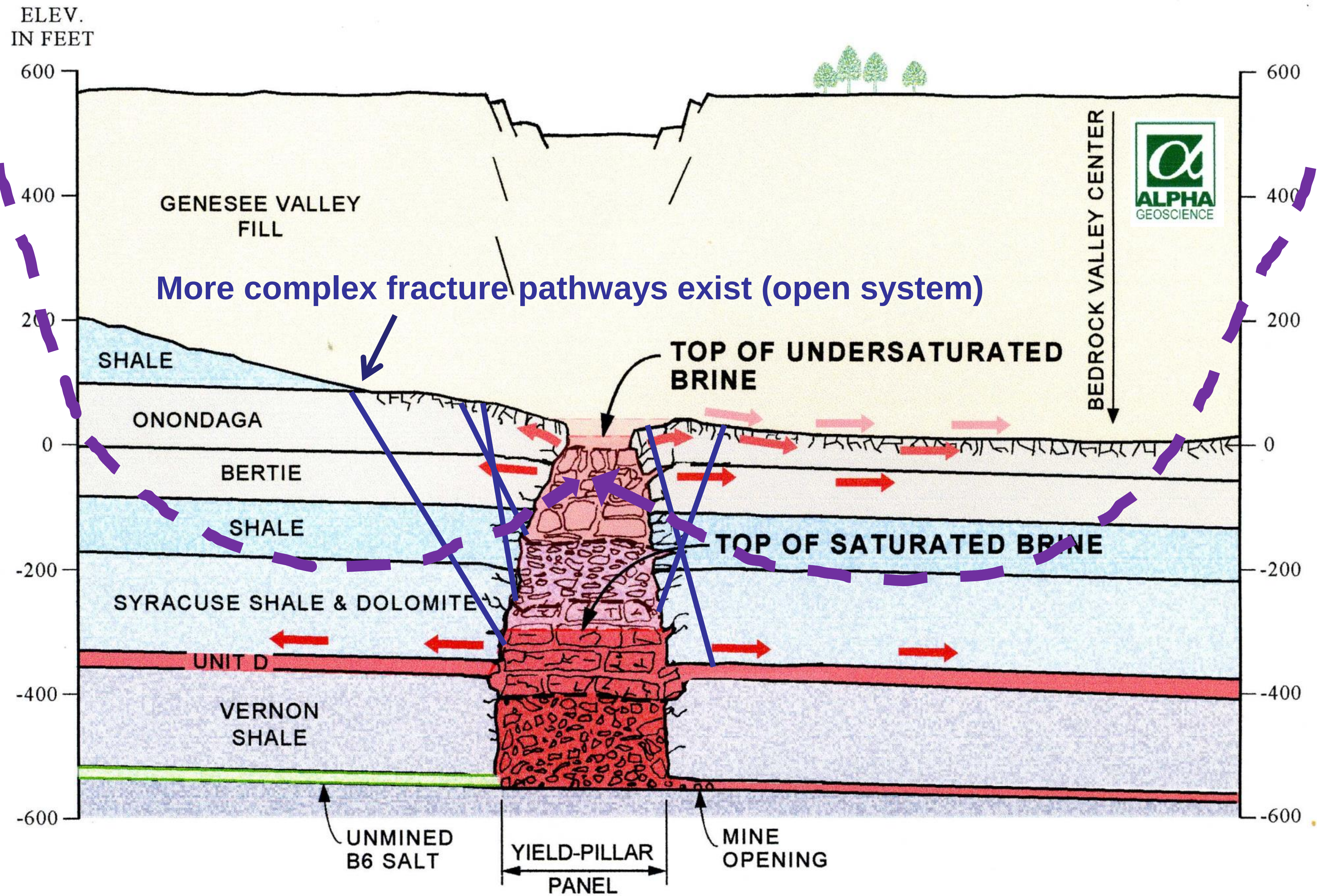



PROPOSED DISPERSION
OF BRINE SQUEEZED FROM MINE
ELEV.
IN FEET
600
400
200
0
-200
-400
-600
GENESEE VALLEY
FILL
SHALE
ONONDAGA
BERTIE
SHALE
SYRACUSE SHALE & DOLOMITE
UNIT D
VERNON
SHALE
TOP OF UNDERSATURATED
BRINE
TOP OF SATURATED BRINE
BEDROCK VALLEY CENTER
ALPHA
GEOSCIENCE
UNMINED
B6 SALT
YIELD-PILLAR
PANEL
MINE
OPENING

GROUNDWATER FLOW INTO VALLEYS




ELEV.
IN FEET
600
400
200
0
-200
-400
-600
GENESEE VALLEY
FILL
More complex fracture pathways exist (open system)
SHALE
ONONDAGA
BERTIE
SHALE
SYRACUSE SHALE & DOLOMITE
UNIT D
VERNON
SHALE
TOP OF UNDERSATURATED
BRINE
TOP OF SATURATED BRINE
BEDROCK VALLEY CENTER
ALPHA
GEOSCIENCE
UNMINED
B6 SALT
YIELD-PILLAR
PANEL
MINE
OPENING



ELEV. IN FEET
600
400
200
0
-200
-400
-600
GENESEE VALLEY FILL
More complex fracture pathways exist (open system)
SHALE
ONONDAGA
BERTIE
SHALE
SYRACUSE SHALE & DOLOMITE
UNIT D
VERNON SHALE
TOP OF UNDERSATURATED BRINE
TOP OF SATURATED BRINE
BEDROCK VALLEY CENTER
ALPHA GEOSCIENCE
UNMINED B6 SALT
YIELD-PILLAR PANEL
MINE OPENING

Additional Geologic Issues:

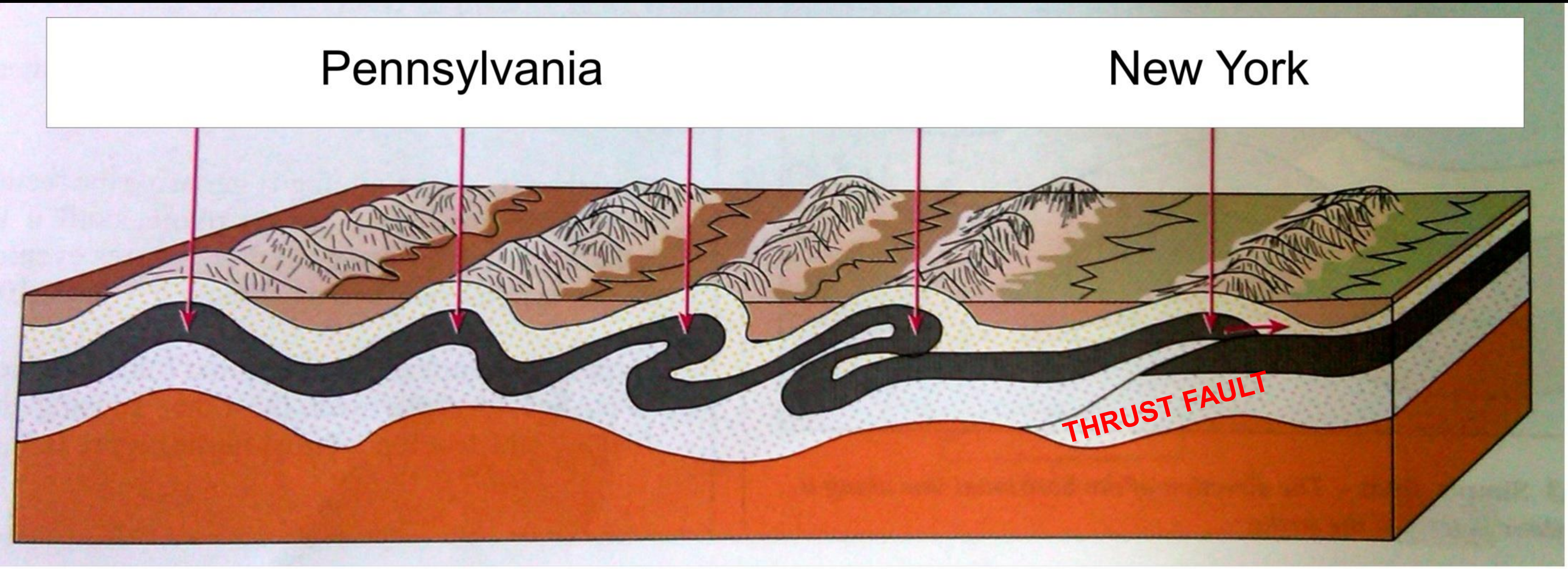
- Plate Tectonic Stresses in the Earth's Crust.

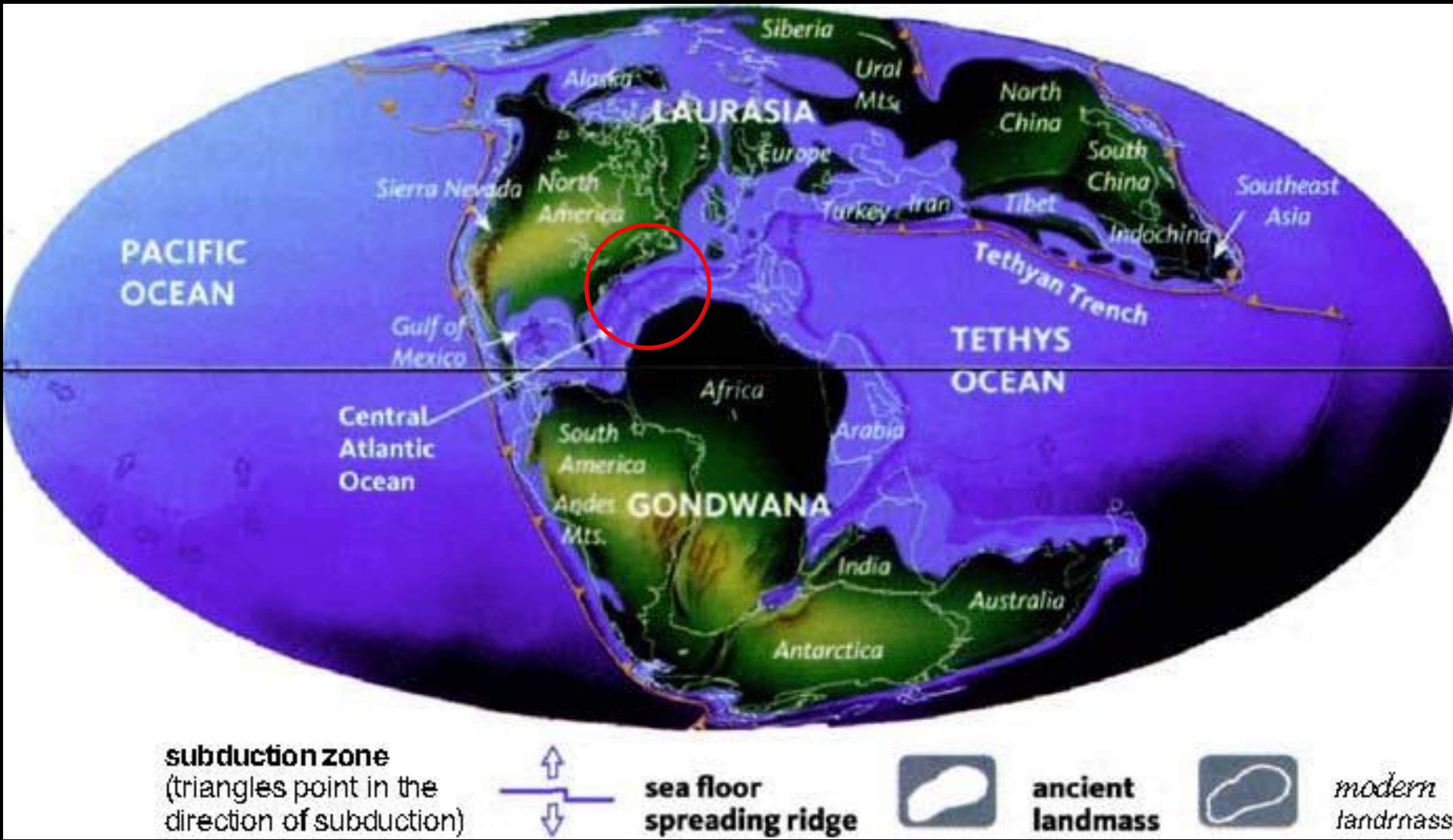
- Local Rock Structures: Faults & Fractures.

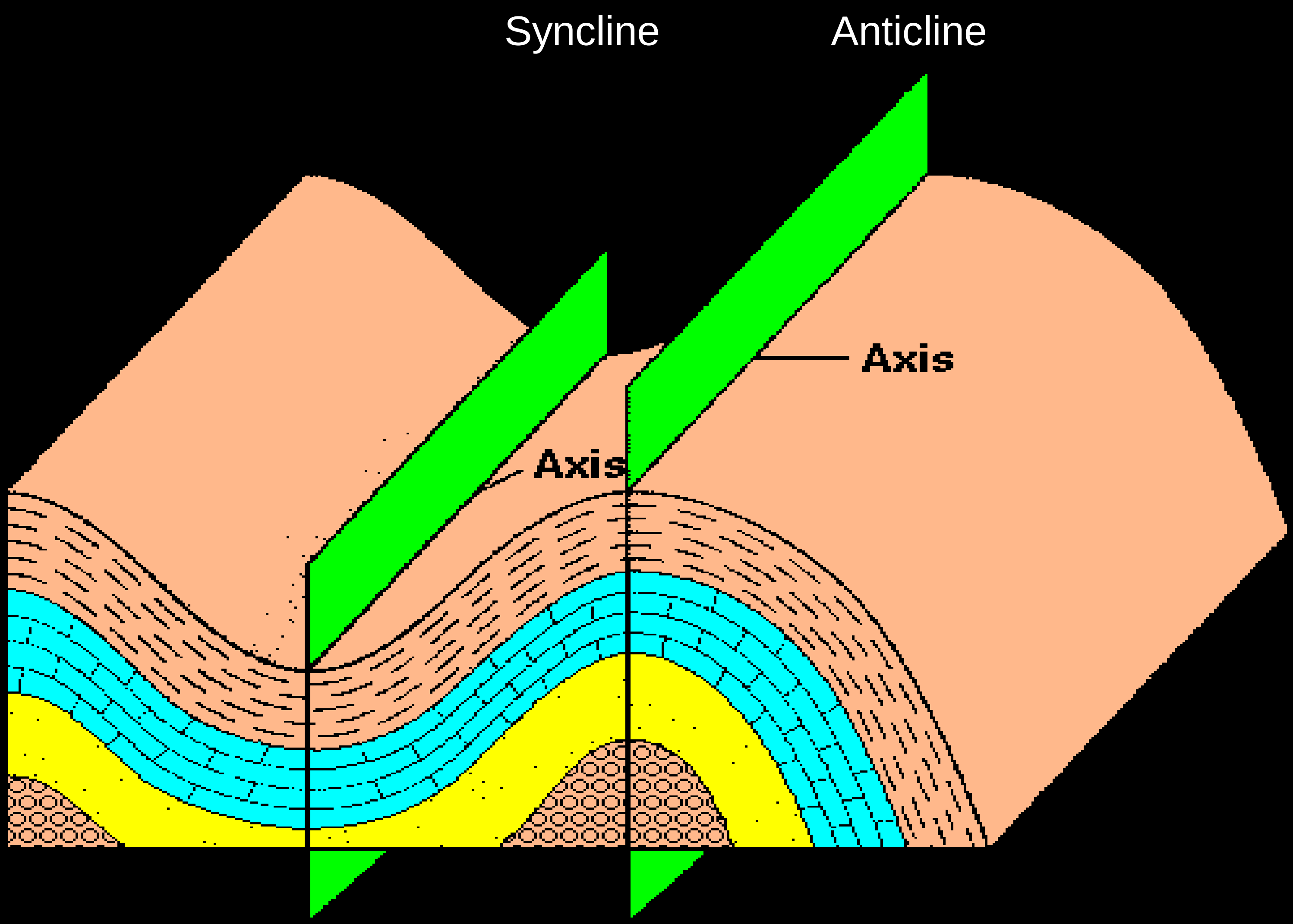
  Fluid Migration; Contamination

- Stresses Resulting From Valley Topography.

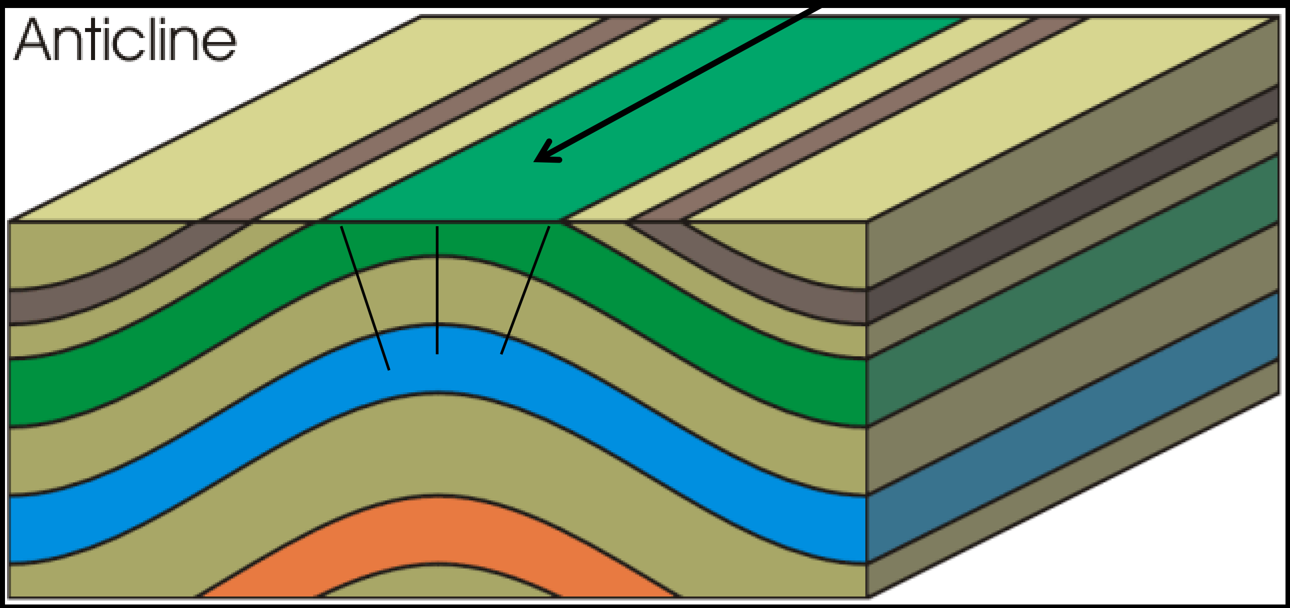
REGIONAL GEOLOGY



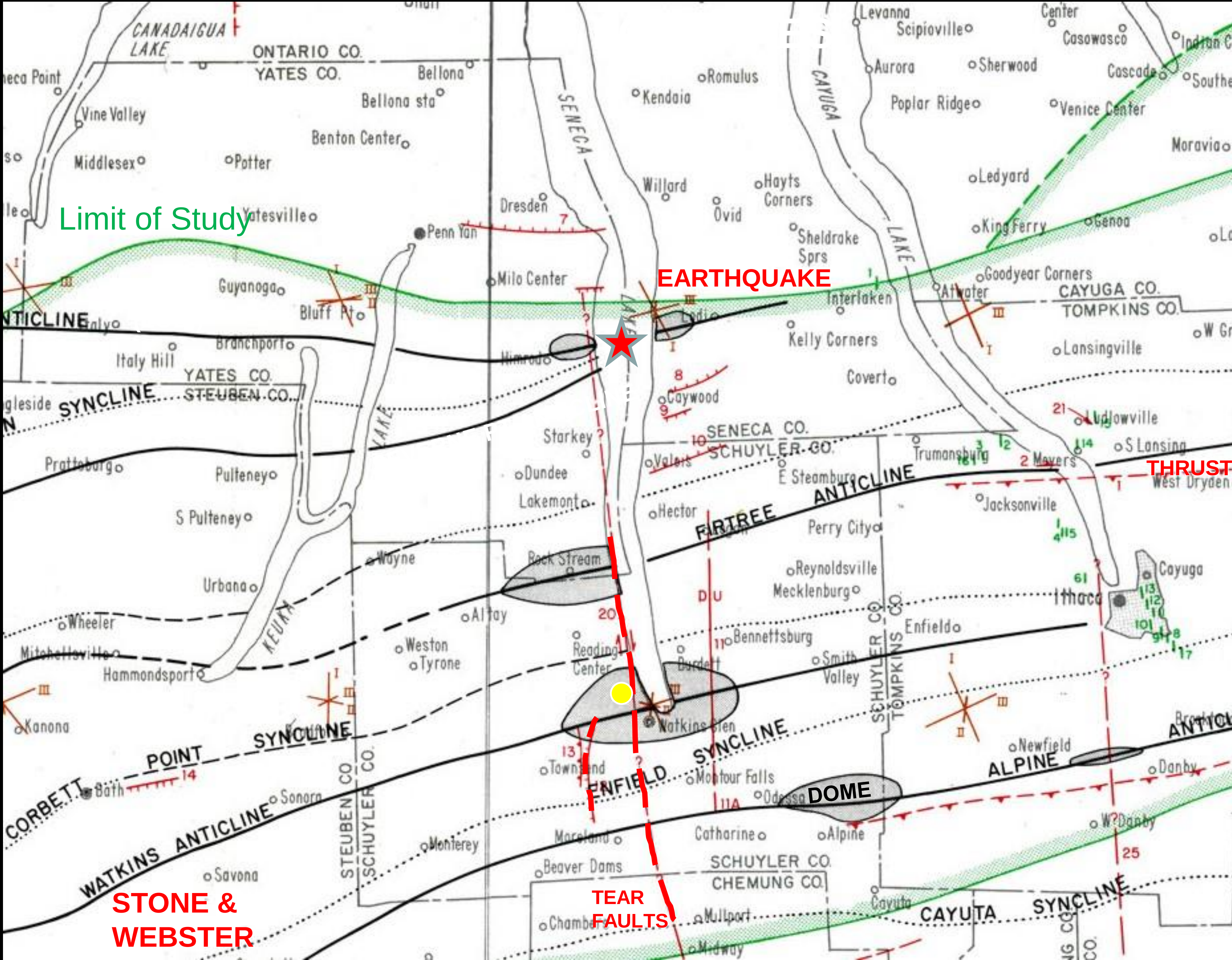

Siberia
Ural Mts.
Alaska
LAURASIA
North China
Europe
South China
Sierra Nevada
North America
Turkey
Iran
Tibet
Southeast Asia
Indochina
PACIFIC OCEAN
Tethyan Trench
Gulf of Mexico
TETHYS OCEAN
Africa
Central Atlantic Ocean
South America
Arabia
Andes Mts.
GONDWANA
India
Australia
Antarctica
subduction zone
(triangles point in the direction of subduction)
sea floor spreading ridge
ancient landmass
modern landmass


Syncline
Anticline
Axis
Axis

Joints form by Stretching (extension) on Anticlin

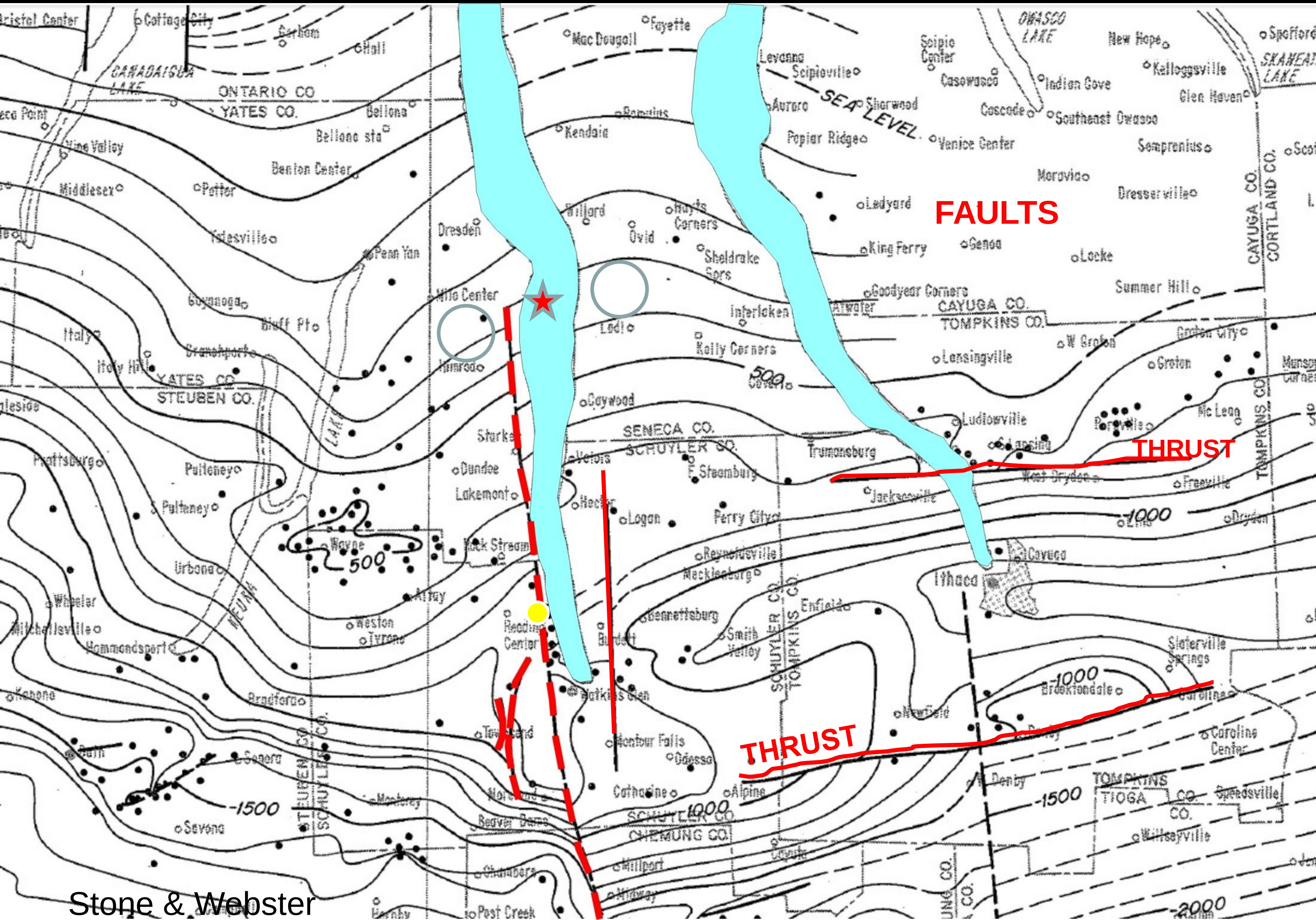


Fractures At Crest of Anticline



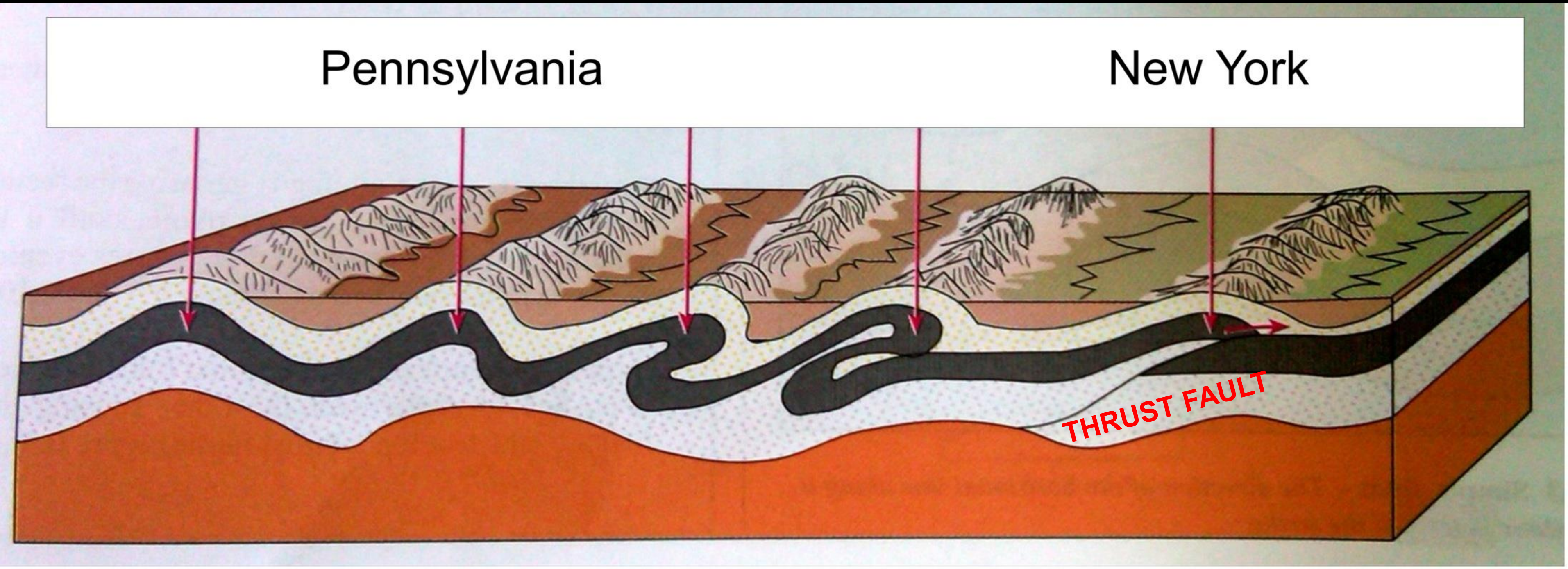
Limit of Study
EARTHQUAKE
THRUST
TEAR FAULTS
STONE & WEBSTER
DOME
CANADAIGUA LAKE
SENECA LAKE
CAYUGA LAKE
KEUKA LAKE
ONTARIO CO.
YATES CO.
SENECA CO.
SCHUYLER CO.
CAYUGA CO.
TOMPKINS CO.
STEUBEN CO.
CHEMUNG CO.
SYNCLINE
FIRTREE ANTICLINE
ENFIELD SYNCLINE
WATKINS ANTICLINE
CORBETT POINT SYNCLINE
ALPINE
CAYUTA SYNCLINE
Penn Yan
Ithaca
Watkins Glen
Dresden
Ovid
Interlaken
Trumansburg
Hammondsport
Bath

Onondaga Limestone Surface

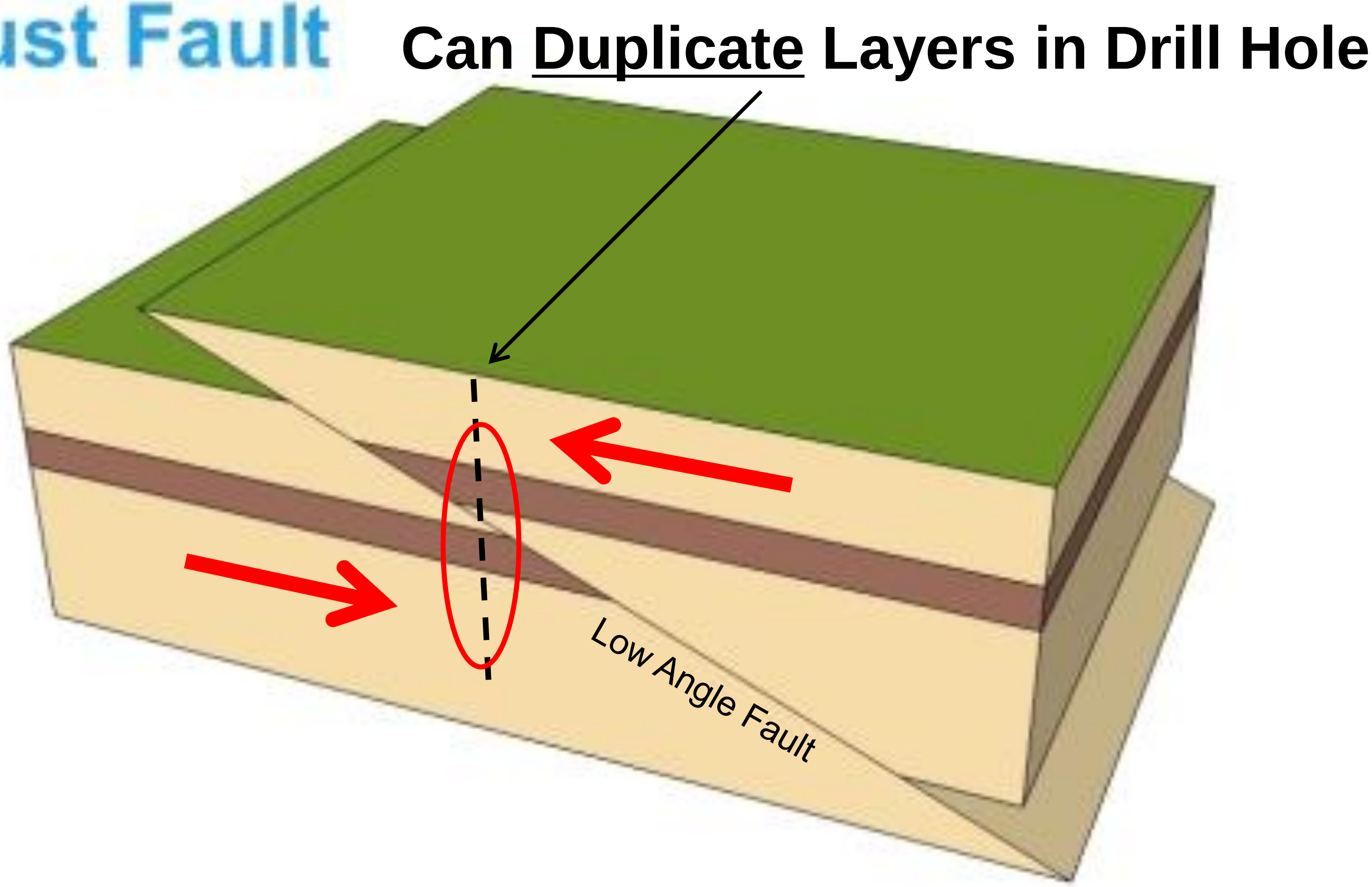


Stone & Webster

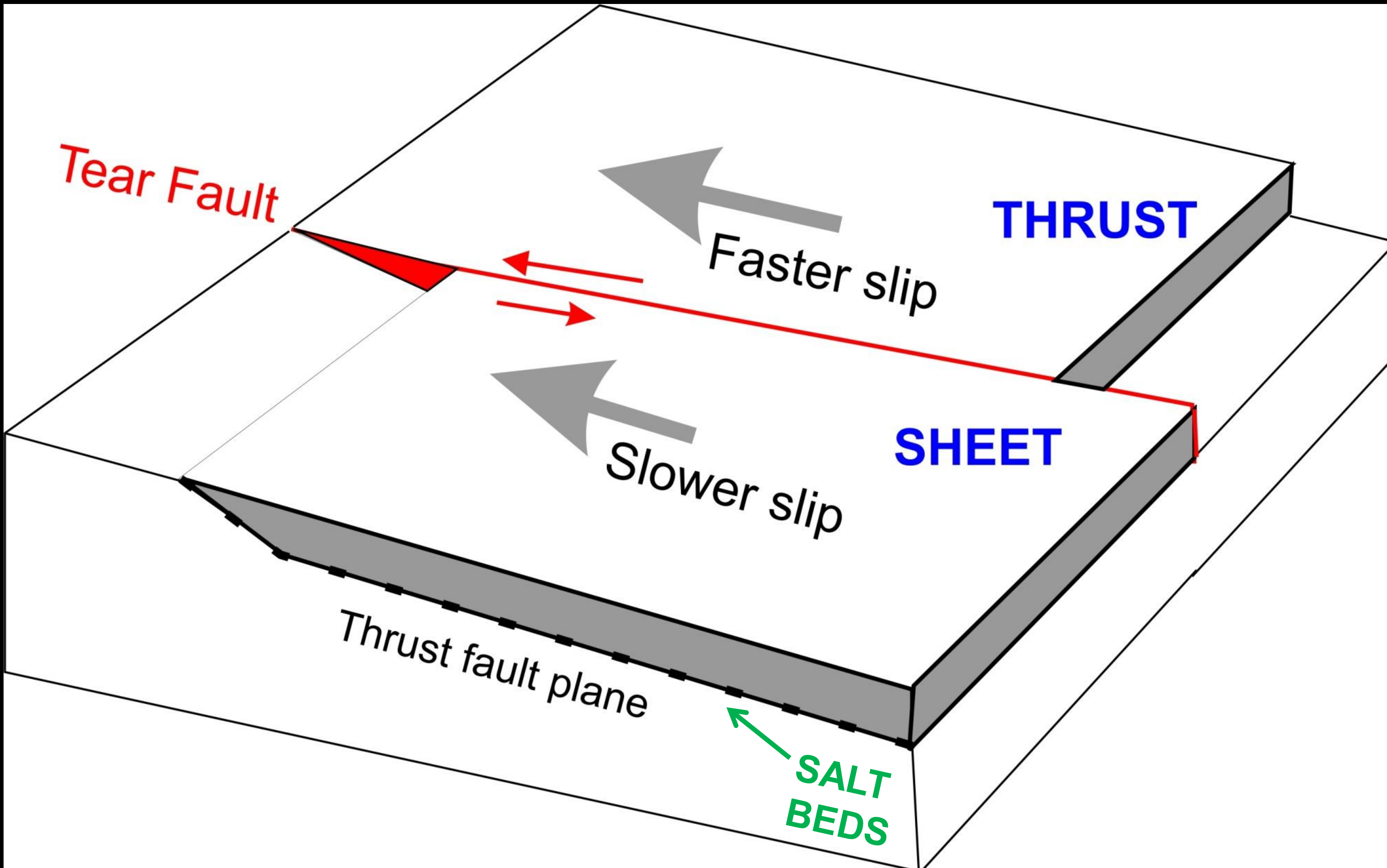
REGIONAL GEOLOGY

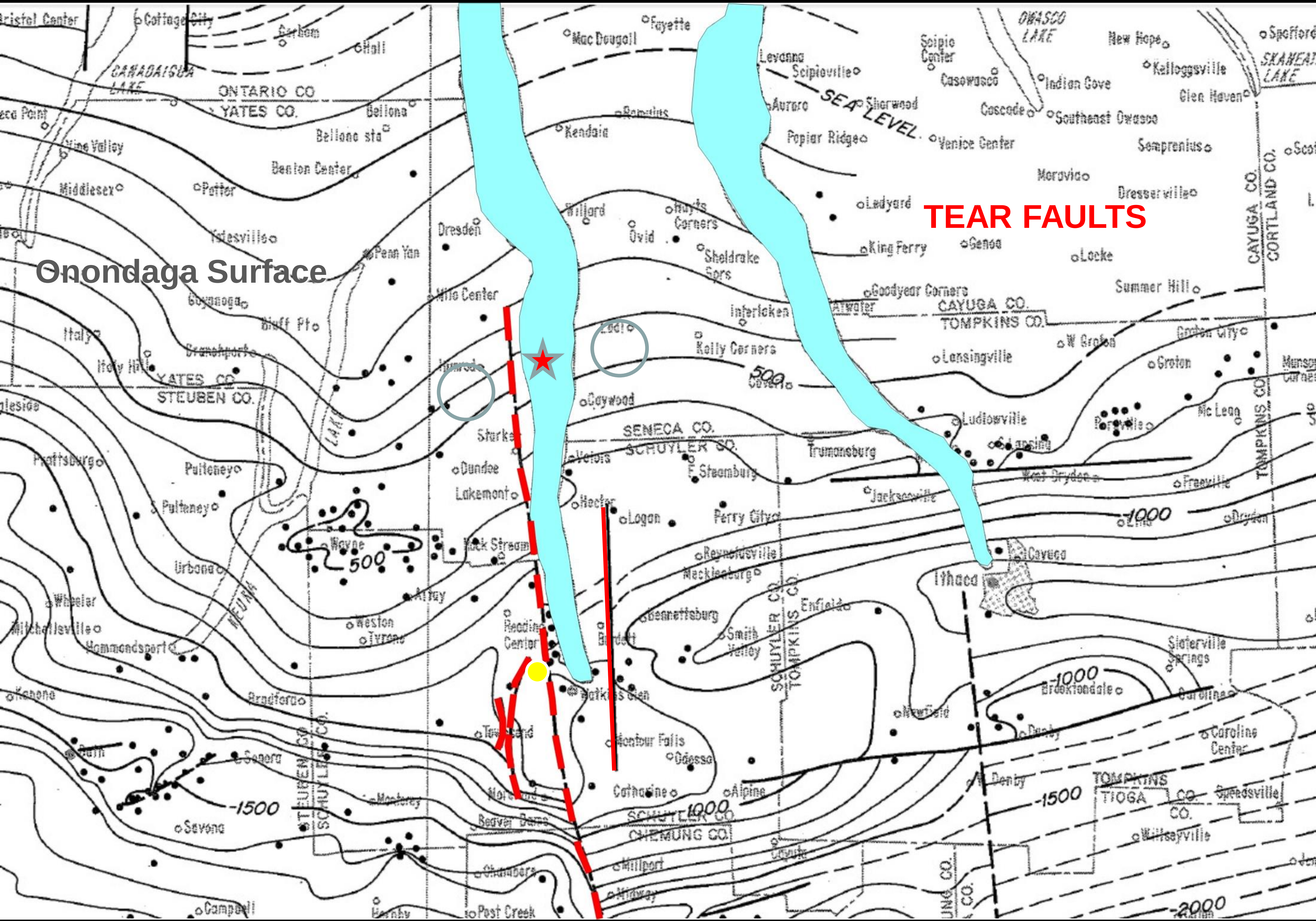


Thrust Fault




Thrust
Fault


Tear Fault
THRUST
Faster slip
SHEET
Slower slip
Thrust fault plane
SALT
BEDS



100 foot contours on top of Onondaga Limestone

Such Generalized Cross Sections Ignore Details

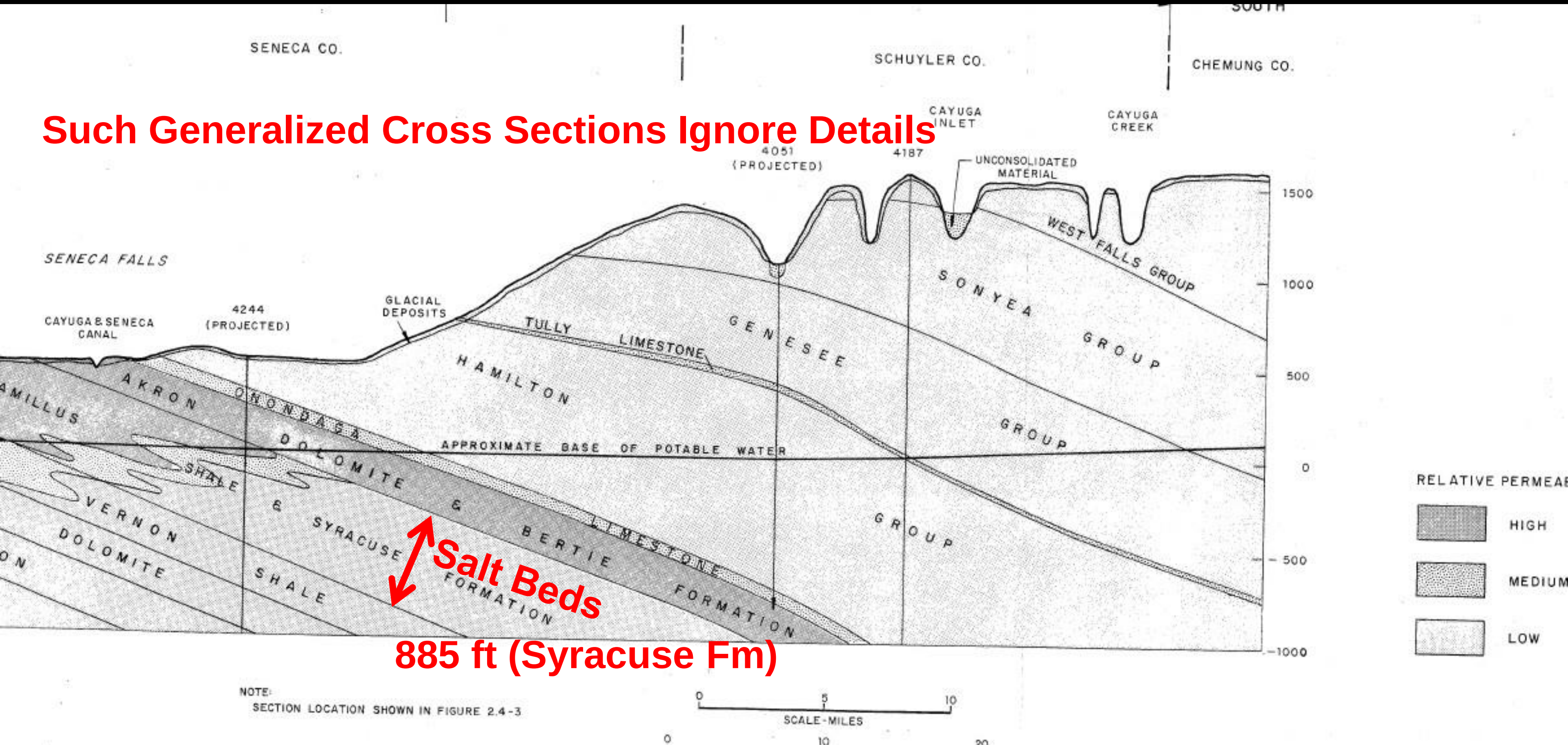
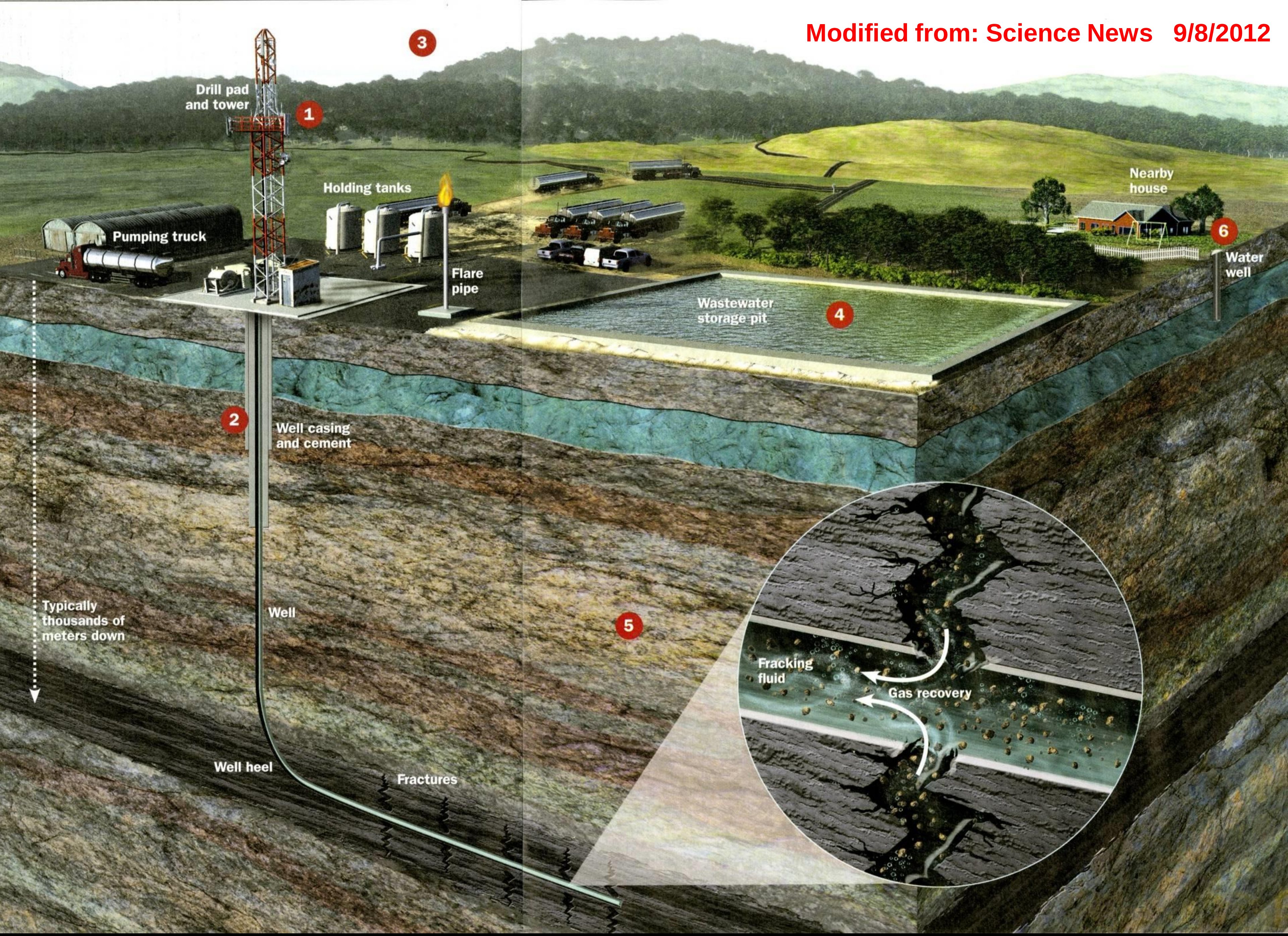


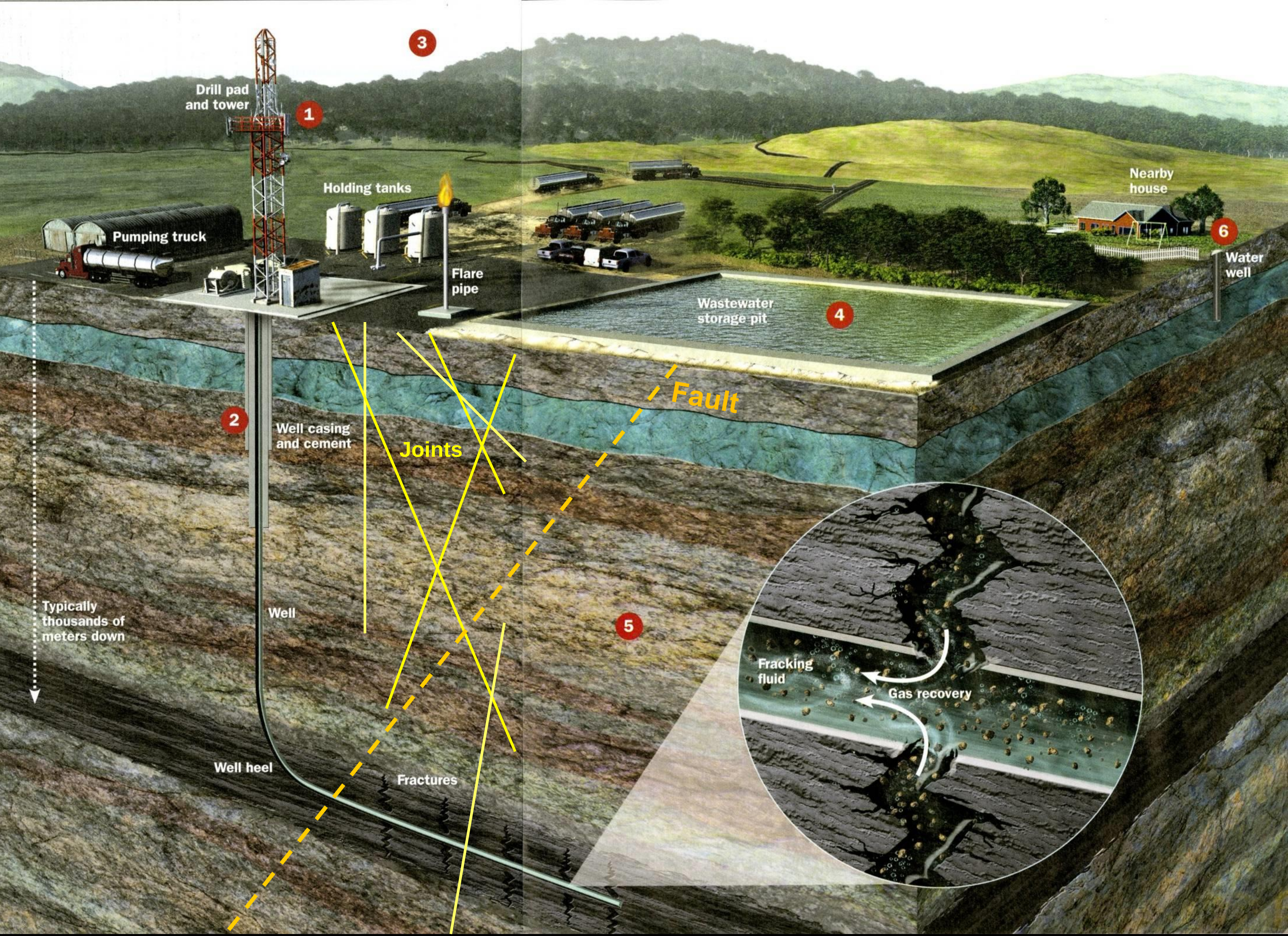
FIGURE 2.4 – 2
HYDROGEOLOGIC SECTION THROUG

Geologic Details Ignored

Widespread Jointing, Faulting

Modified from: Science News 9/8/2012





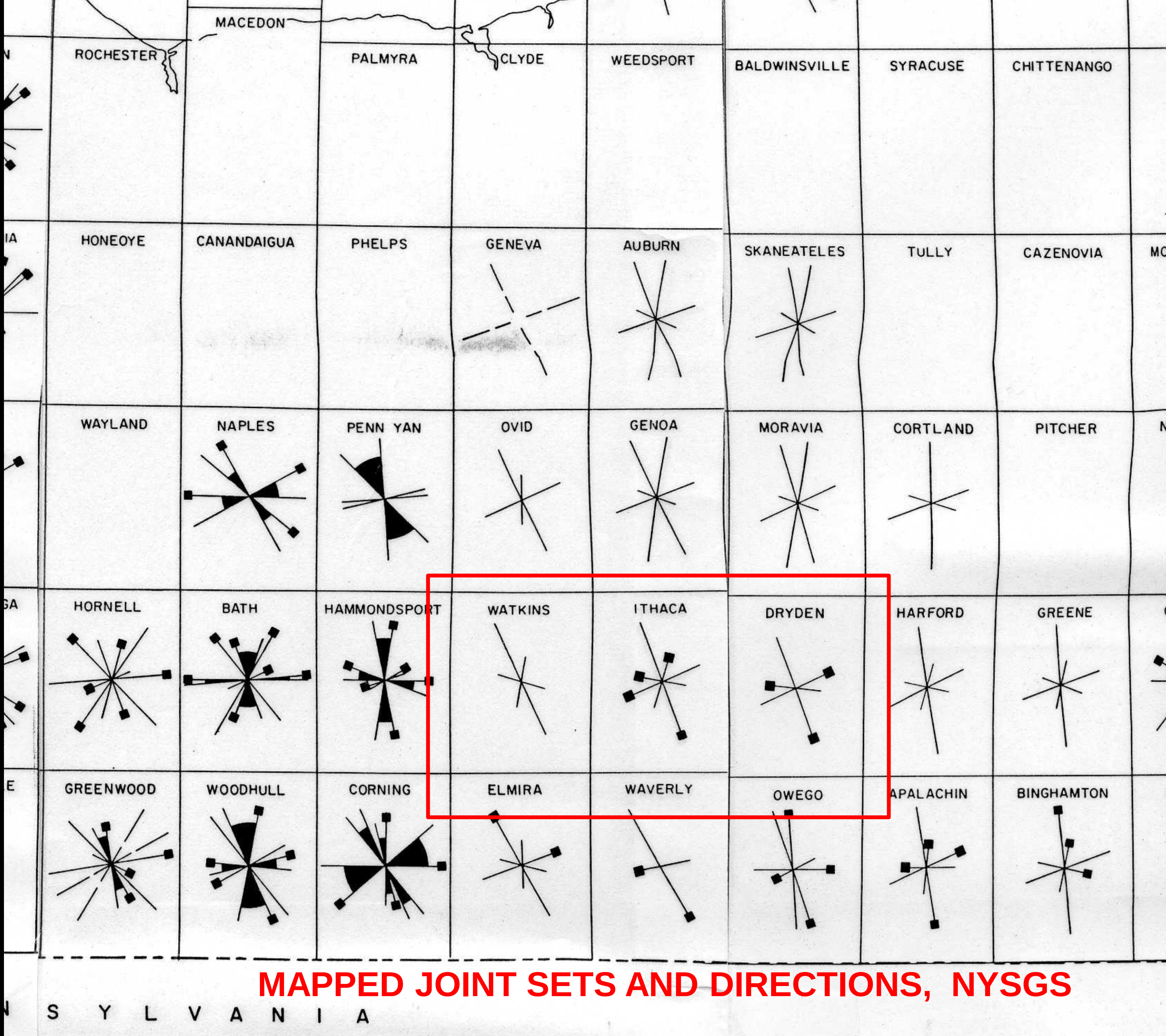
Modified from: Science News 9/8/2012

Rock Jointing

Joints (fractures) are Pervasive in <u>all</u> Sedimentary Rocks.

Water Wells in western NY commonly derive water supplies from fractured (jointed) rock aquifers


Seneca Stone Quarry

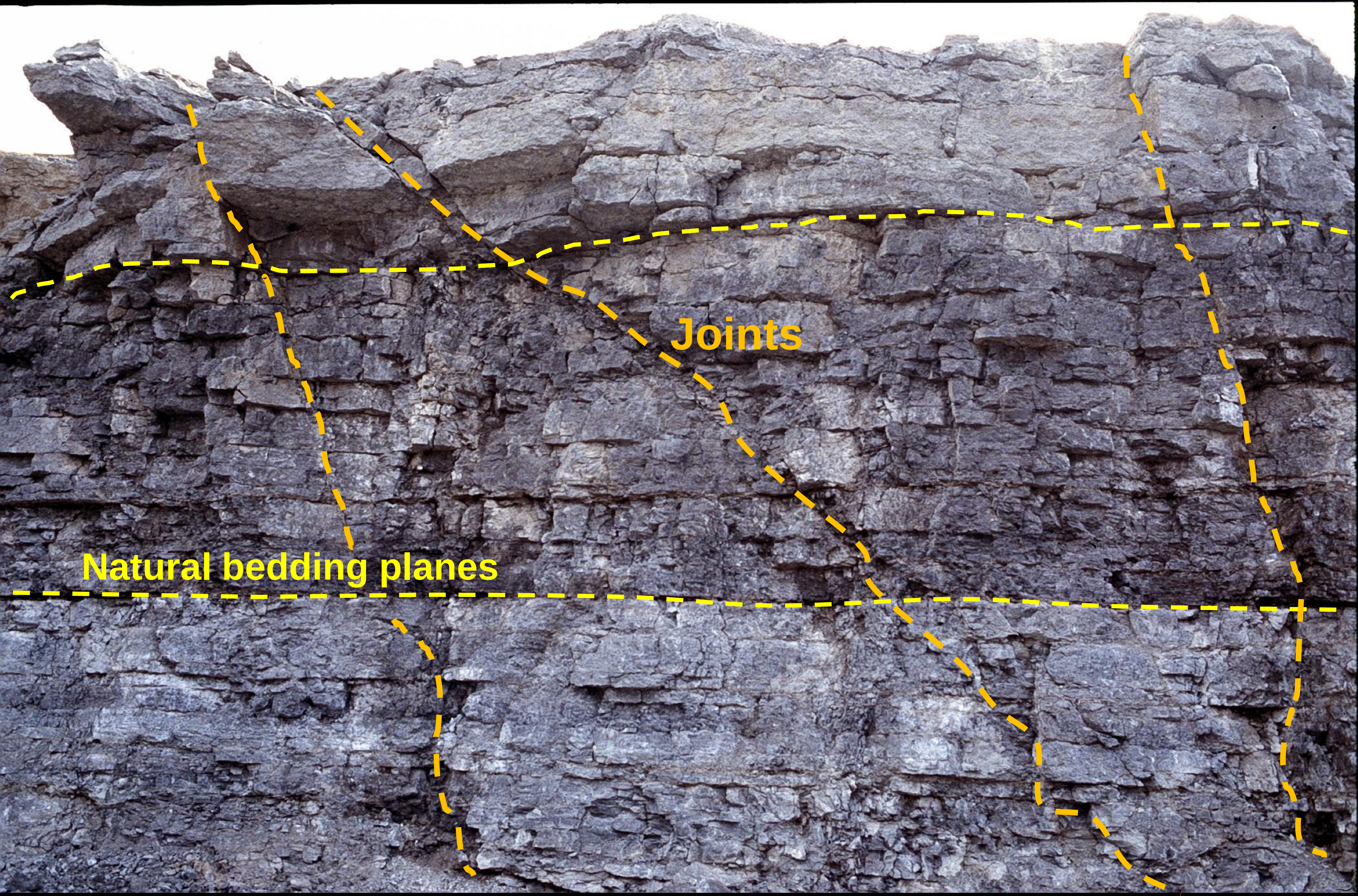


MAPPED JOINT SETS AND DIRECTIONS, NYSGS


Joints are often best exposed in local
streams, eroded into bedrock:
Taughannock Falls

Not all master joints or joint sets are vertical

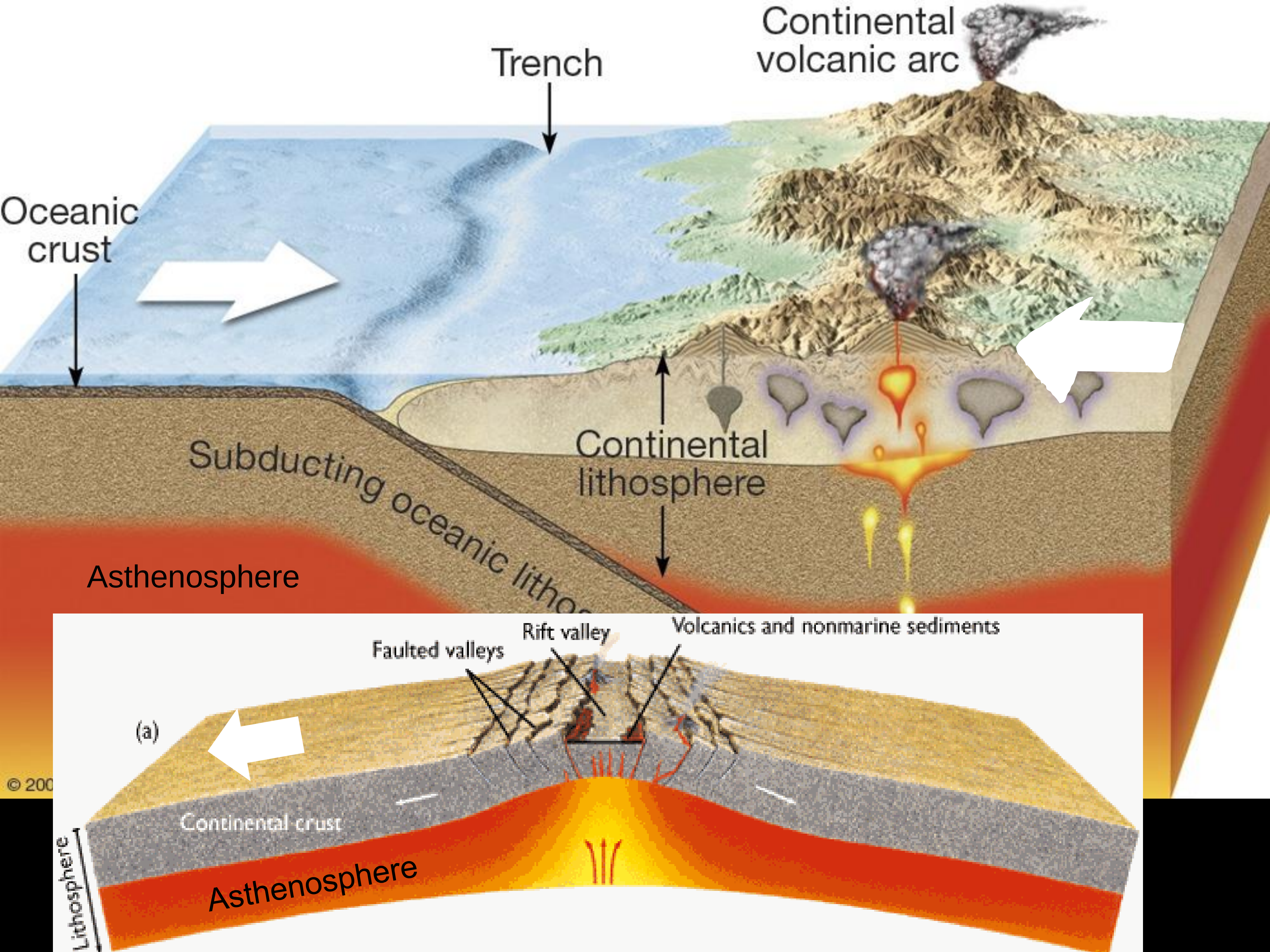
Not all master joints or joint sets are vertical

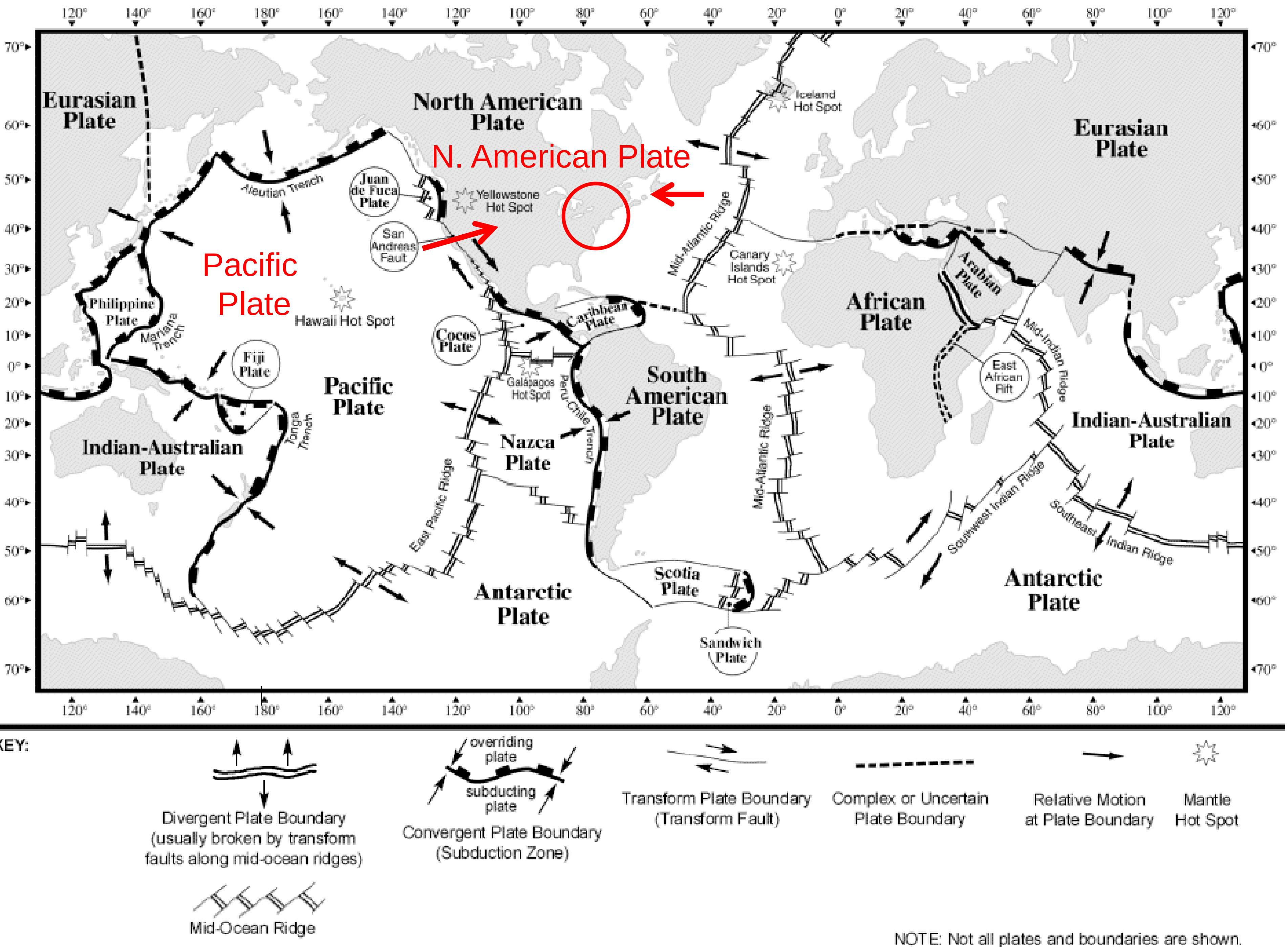


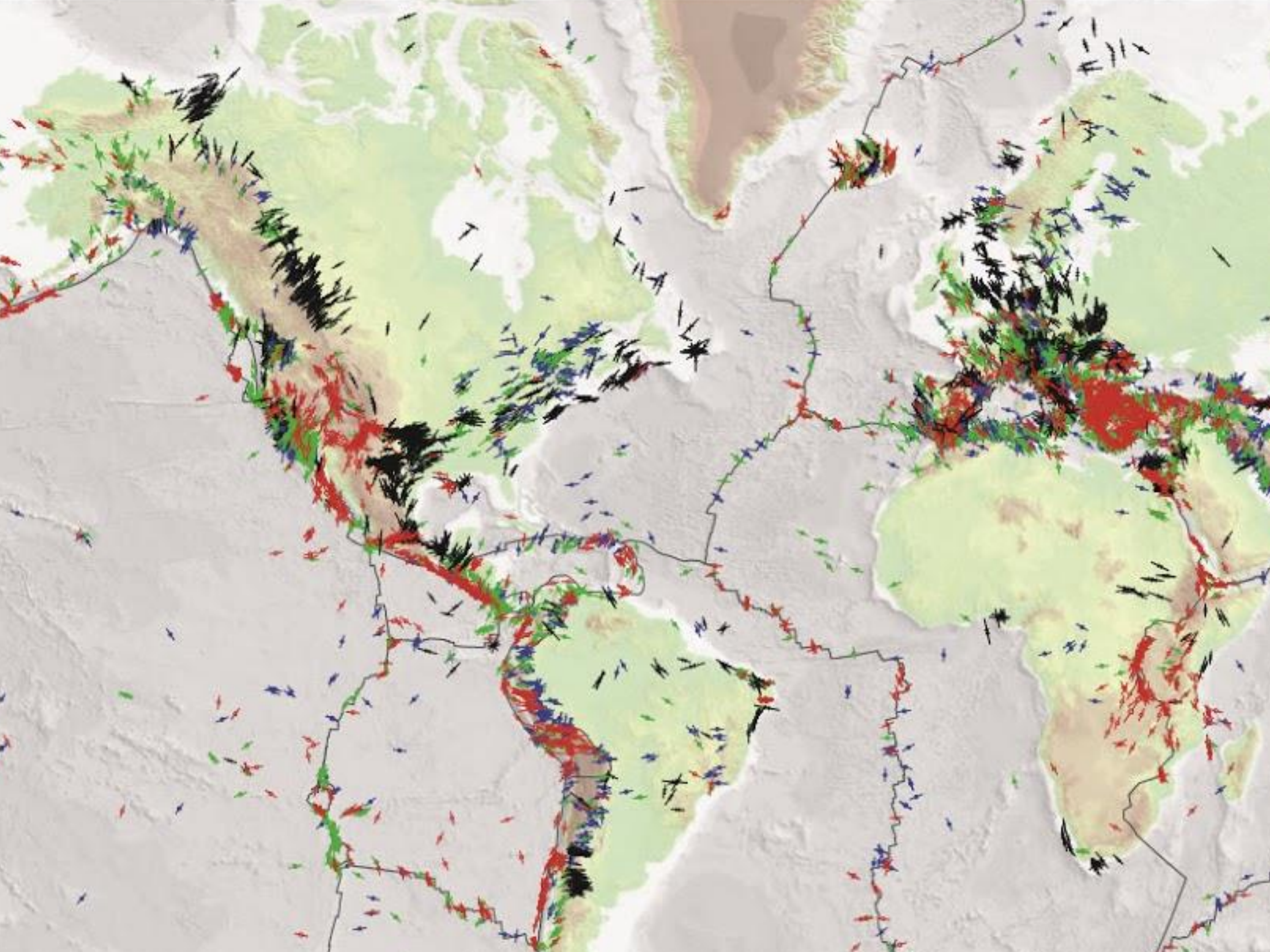
Evidence of Horizontal Stress Field: Quarry "Pop up" Structures

Horizontal stress (pressure) is often greater than vertical rock load to depths of 3000 feet (Zoback, 1980)

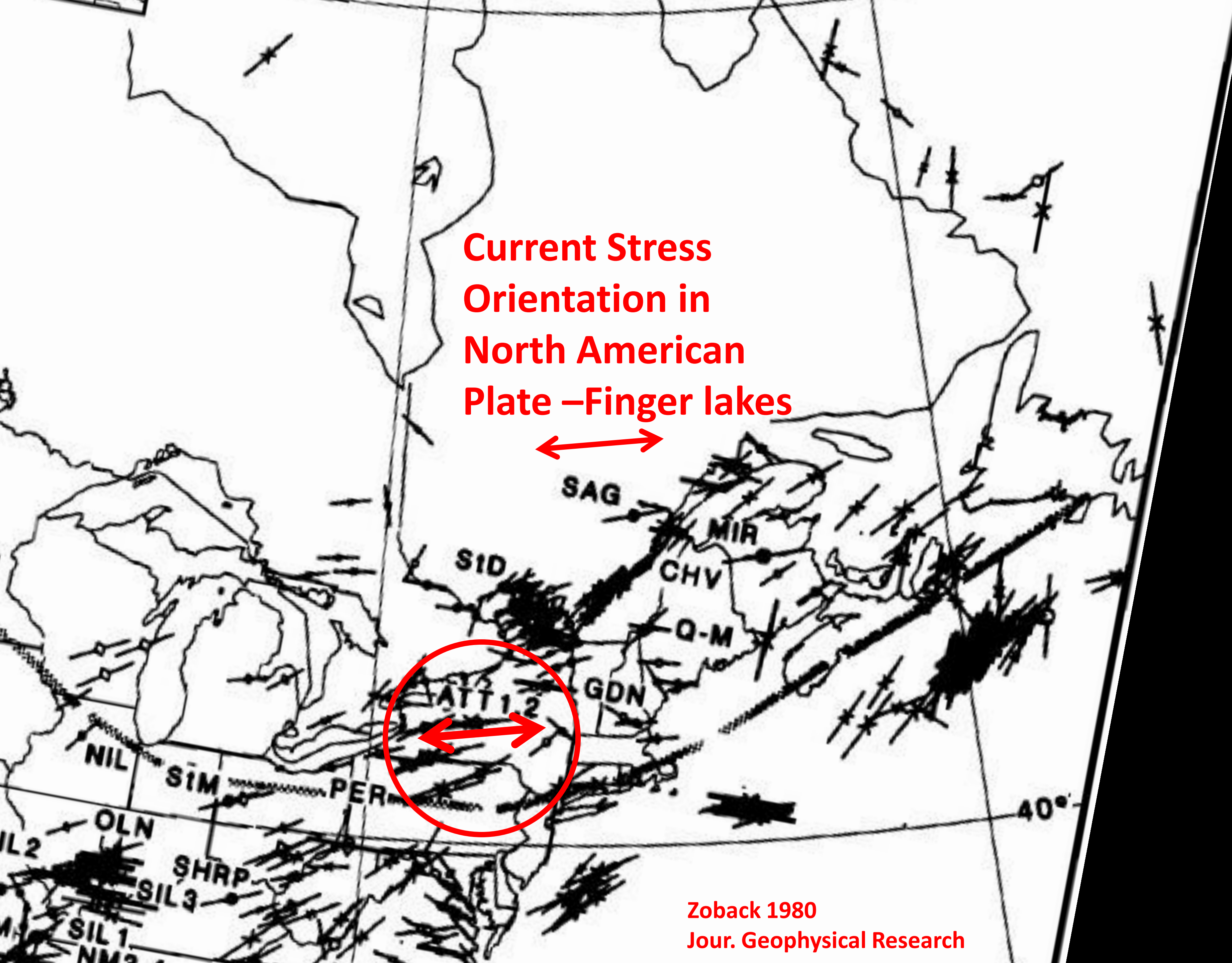
Genesee Valley Margin: Horizontal / Vertical stress is **>2** at 672 ft depth


Continental volcanic arc
Trench
Oceanic crust
Subducting oceanic litho
Continental lithosphere
Asthenosphere
© 200
Rift valley
Volcanics and nonmarine sediments
Faulted valleys
(a)
Continental crust
Lithosphere
Asthenosphere

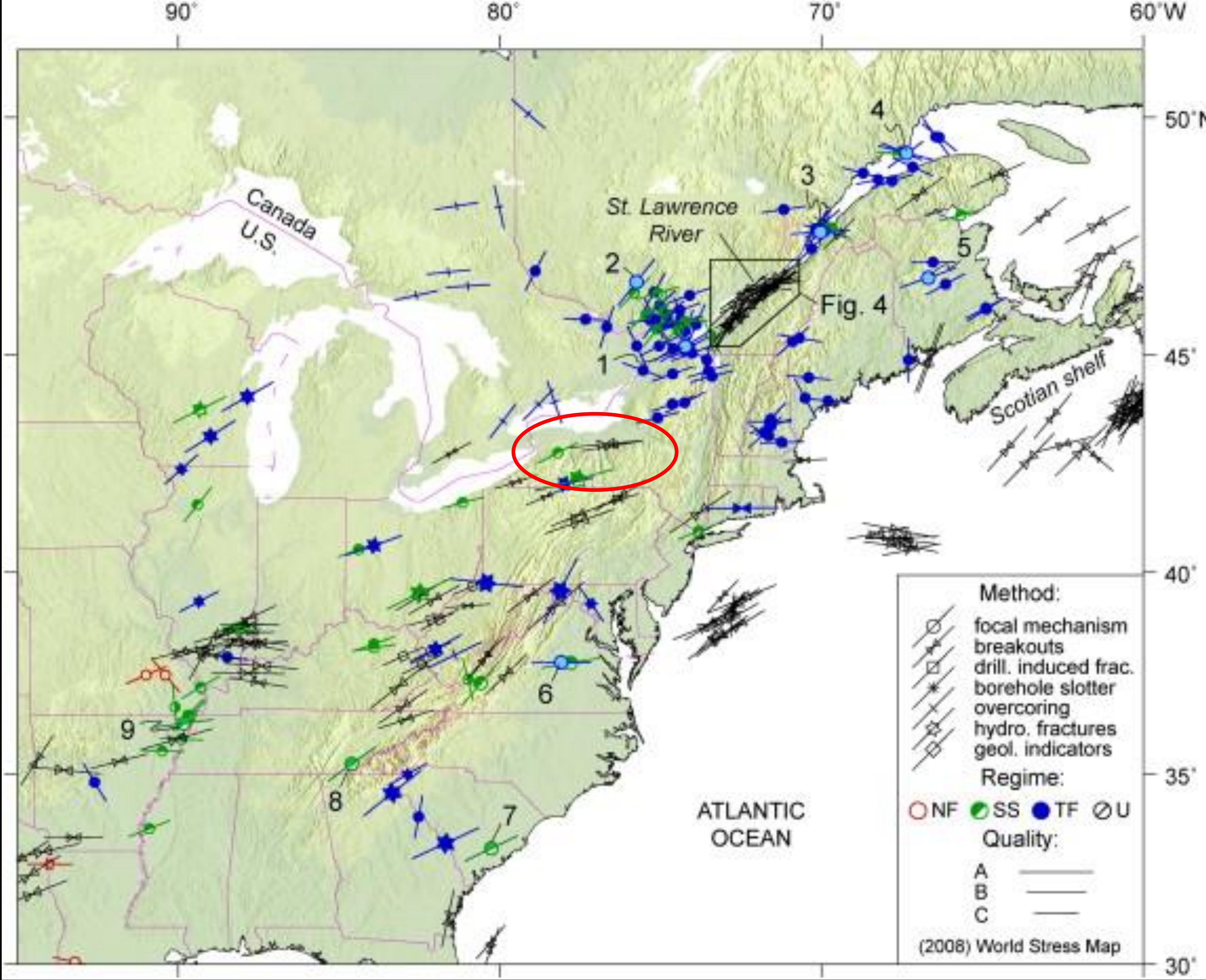

Eurasian Plate
North American Plate
N. American Plate
Pacific Plate
Juan de Fuca Plate
Yellowstone Hot Spot
San Andreas Fault
Aleutian Trench
Iceland Hot Spot
Eurasian Plate
Canary Islands Hot Spot
Mid-Atlantic Ridge
Arabian Plate
African Plate
Philippine Plate
Mariana Trench
Hawaii Hot Spot
Cocos Plate
Caribbean Plate
Fiji Plate
Pacific Plate
Galápagos Hot Spot
Peru-Chile Trench
South American Plate
Mid-Indian Ridge
East African Rift
Indian-Australian Plate
Tonga Trench
Nazca Plate
Indian-Australian Plate
East Pacific Ridge
Mid-Atlantic Ridge
Southwest Indian Ridge
Southeast Indian Ridge
Scotia Plate
Antarctic Plate
Antarctic Plate
Sandwich Plate
KEY:
Divergent Plate Boundary (usually broken by transform faults along mid-ocean ridges)
overriding plate
subducting plate
Convergent Plate Boundary (Subduction Zone)
Transform Plate Boundary (Transform Fault)
Complex or Uncertain Plate Boundary
Relative Motion at Plate Boundary
Mantle Hot Spot
Mid-Ocean Ridge
NOTE: Not all plates and boundaries are shown.



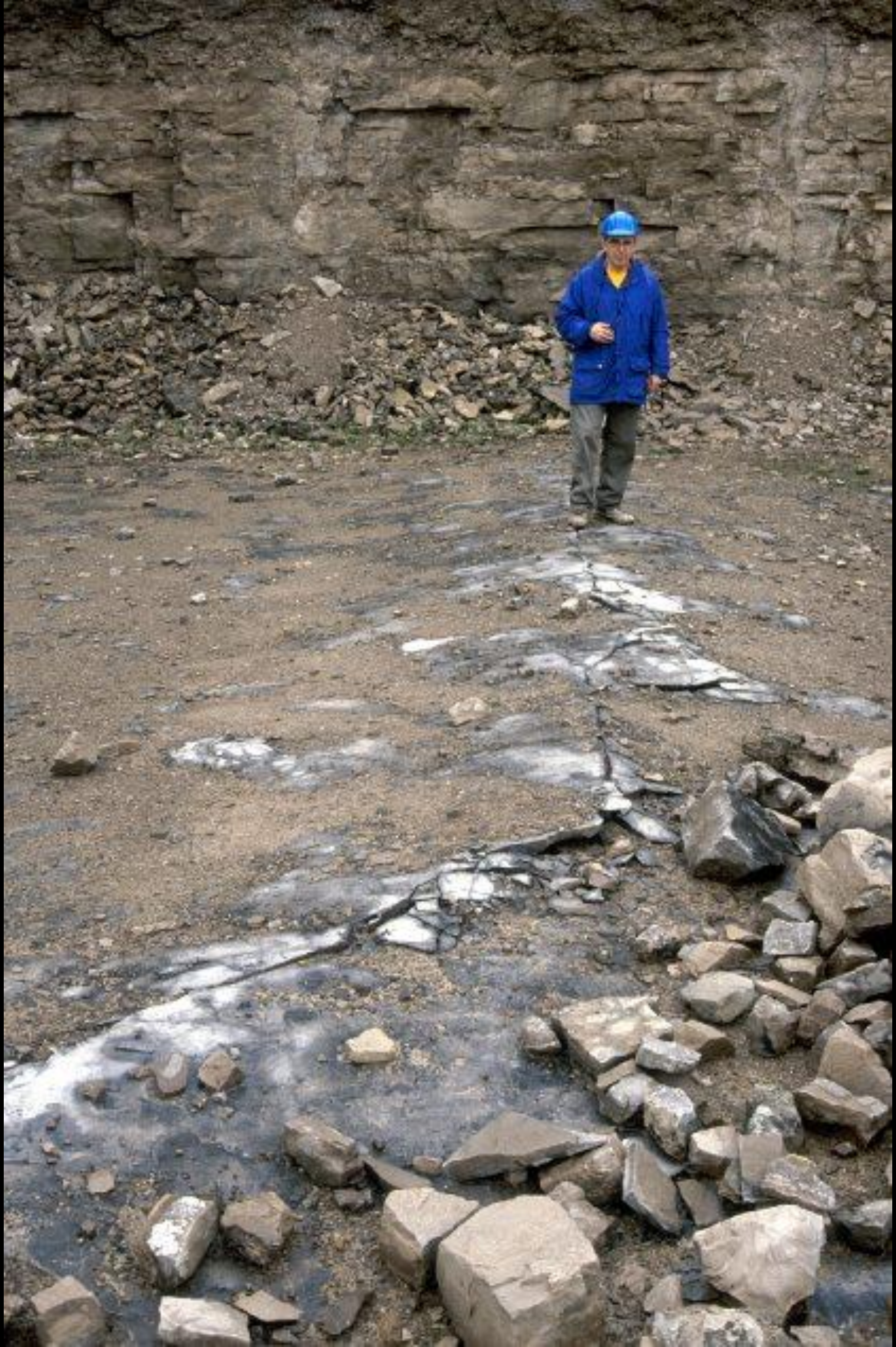
Current Stress Orientation in North American Plate –Finger lakes



Zoback 1980
Jour. Geophysical Research


90°
80°
70°
60°W
50°N
45°
40°
35°
30°
Canada
U.S.
St. Lawrence River
Fig. 4
Scotian shelf
ATLANTIC OCEAN
1
2
3
4
5
6
7
8
9
Method:
focal mechanism
breakouts
drill. induced frac.
borehole slotter
overcoring
hydro. fractures
geol. indicators
Regime:
NF
SS
TF
U
Quality:
A
B
C
(2008) World Stress Map

Quarry floor “Pop-Ups”



MICHIGAN 2010

Horizontal Stress Release


Pop-Up

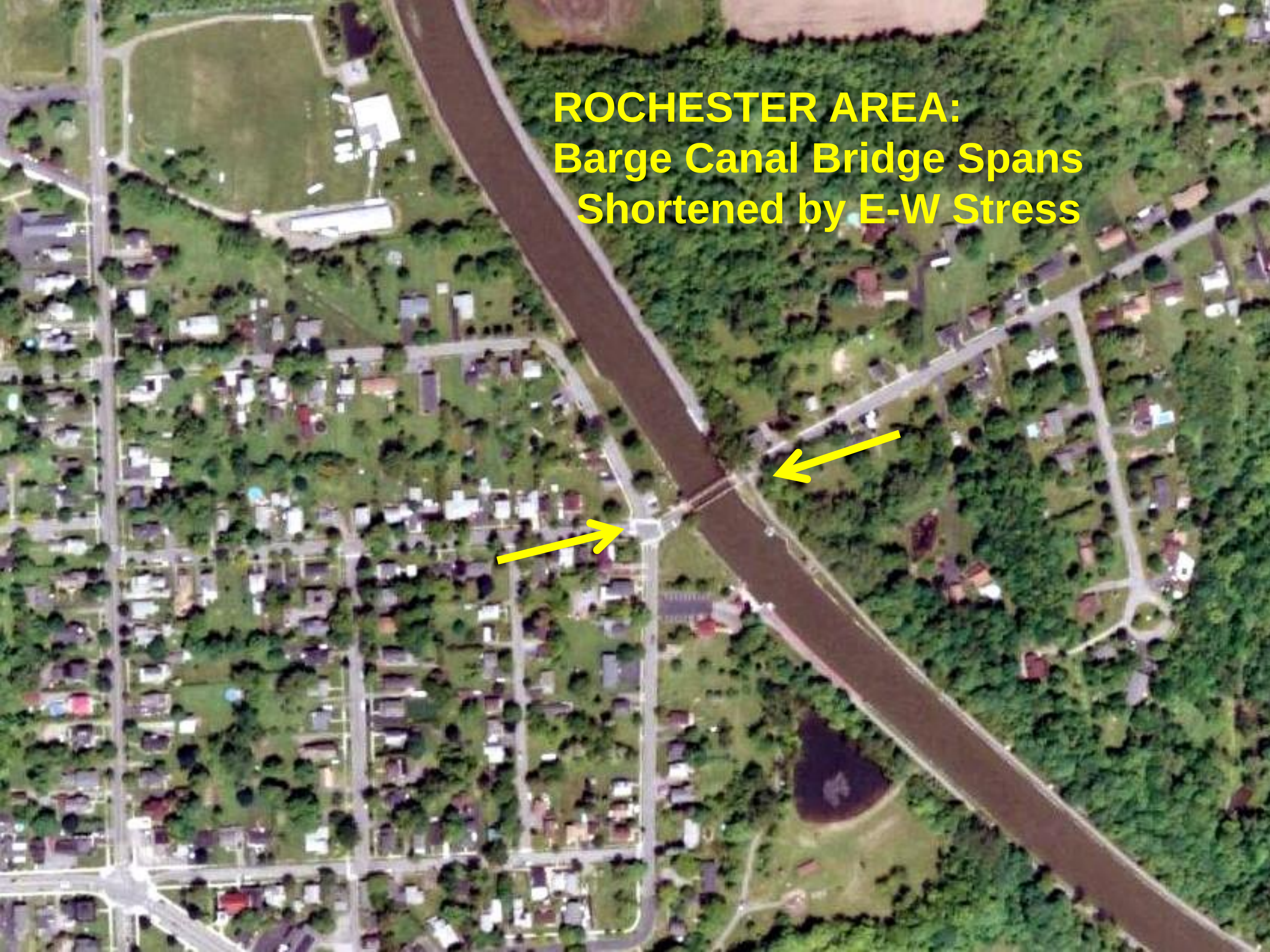
Horizontal Compressive Stresses in Rocks

Utah

Arizona


Gasport, NY

NY “Pop-ups” originally looked like this


ROCHESTER AREA:
Barge Canal Bridge Spans
Shortened by E-W Stress

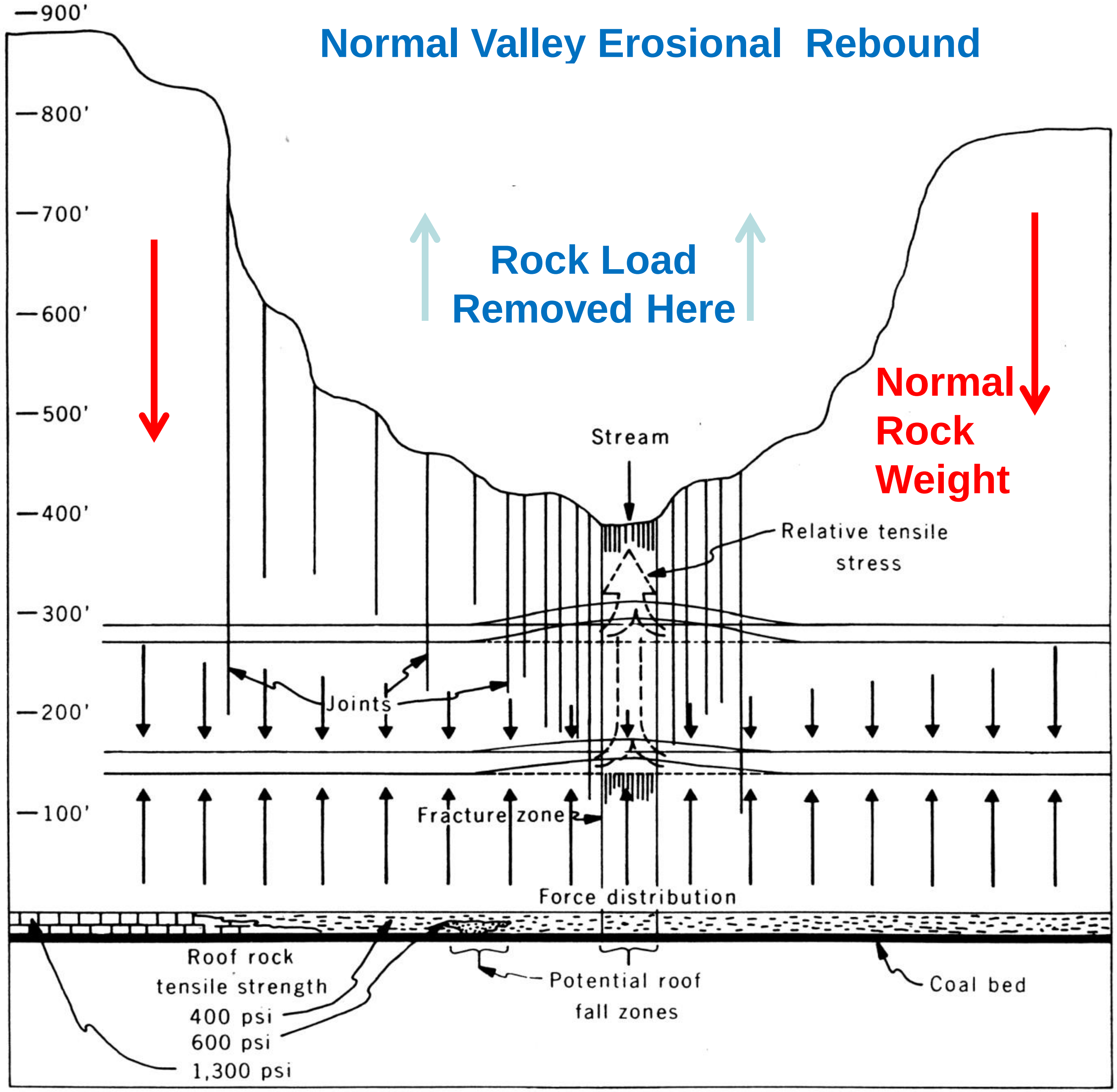


FIGURE 5. - Schematic diagram of postulated mechanism of creation of fracture zones and potential roof fall zones by erosion of overburden.

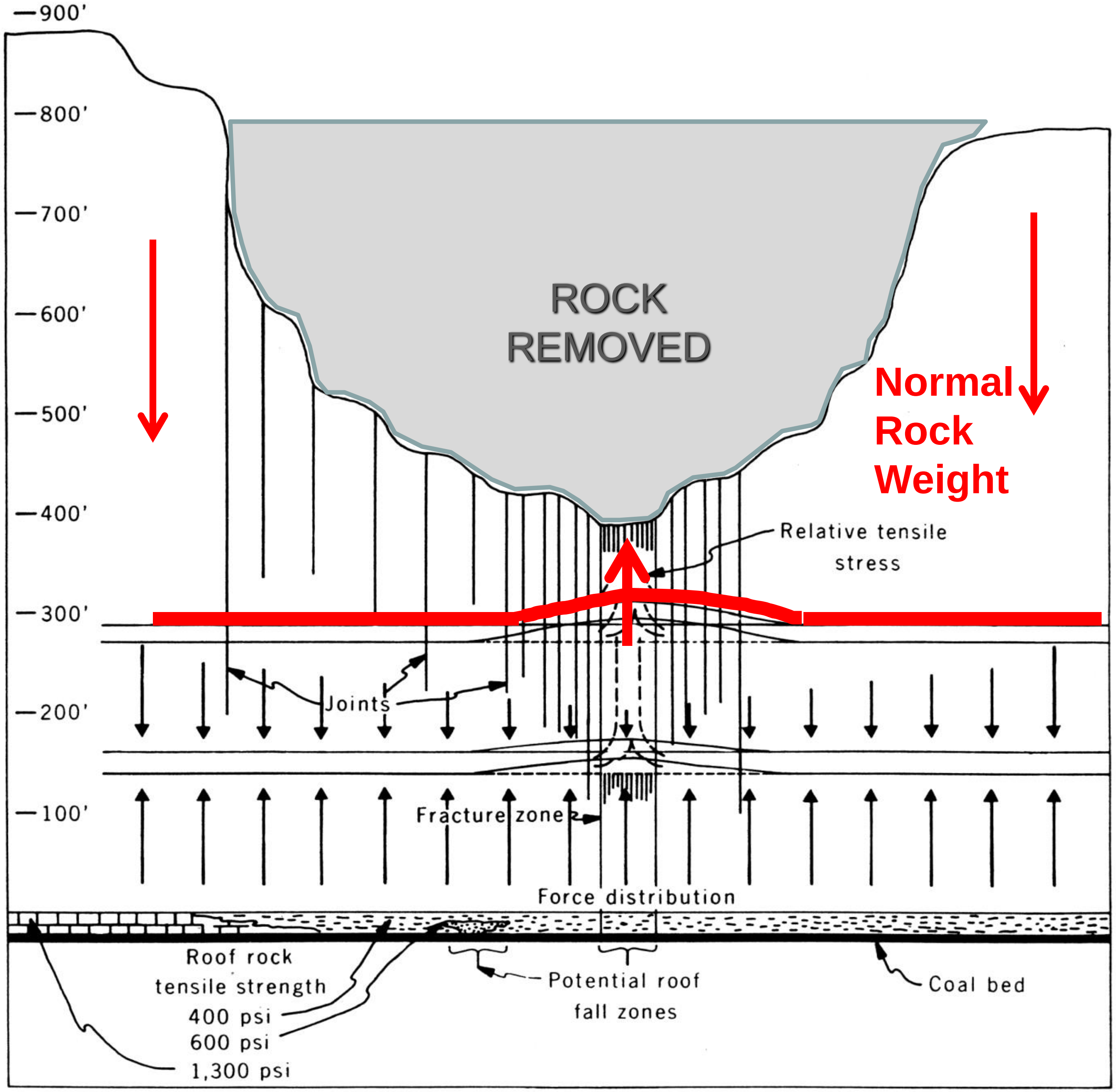


FIGURE 5. - Schematic diagram of postulated mechanism of creation of fracture zones and potential roof fall zones by erosion of overburden.

Normal Valley Processes

US Bureau of Mines – TPR 70 (1992)

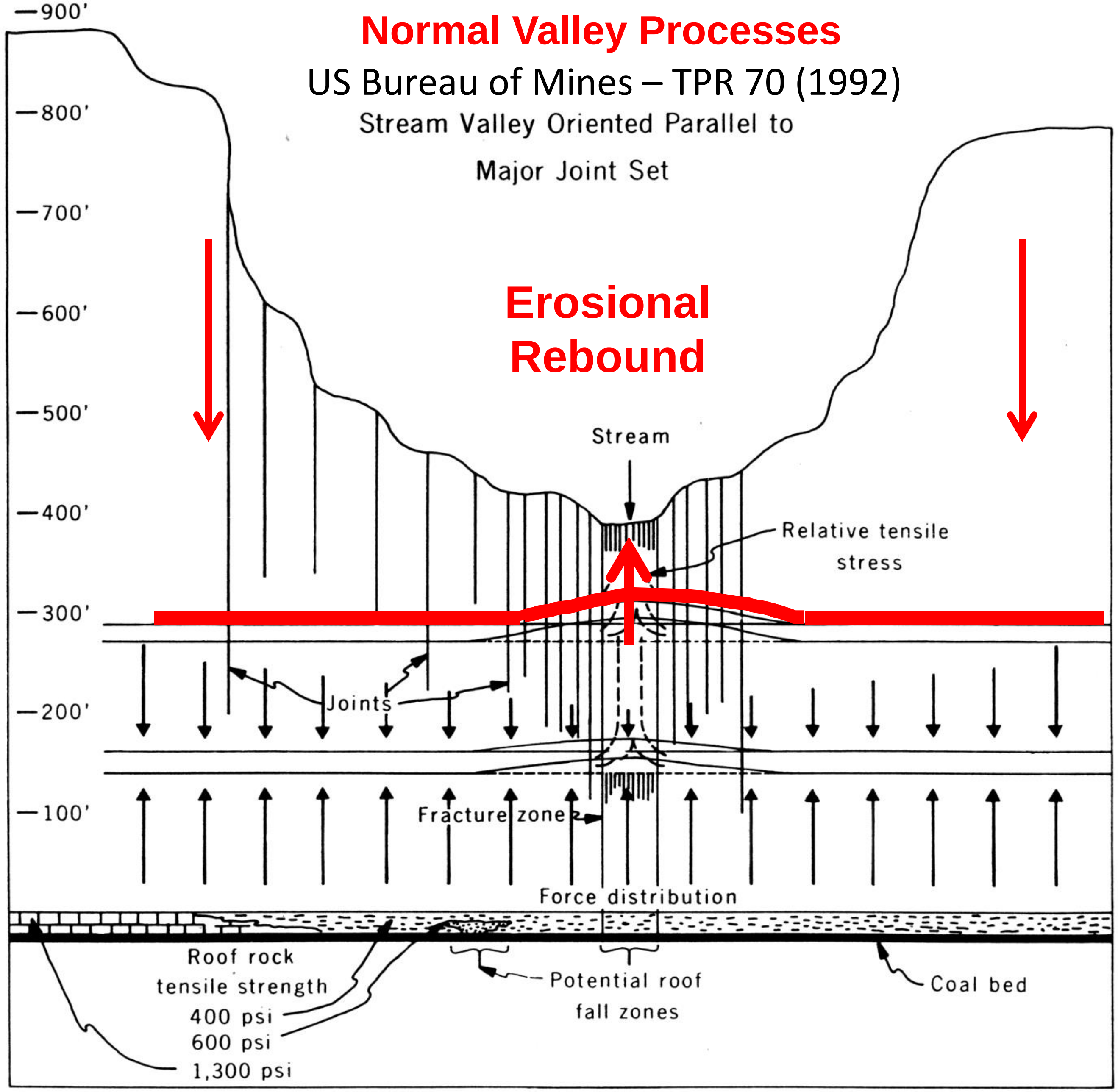
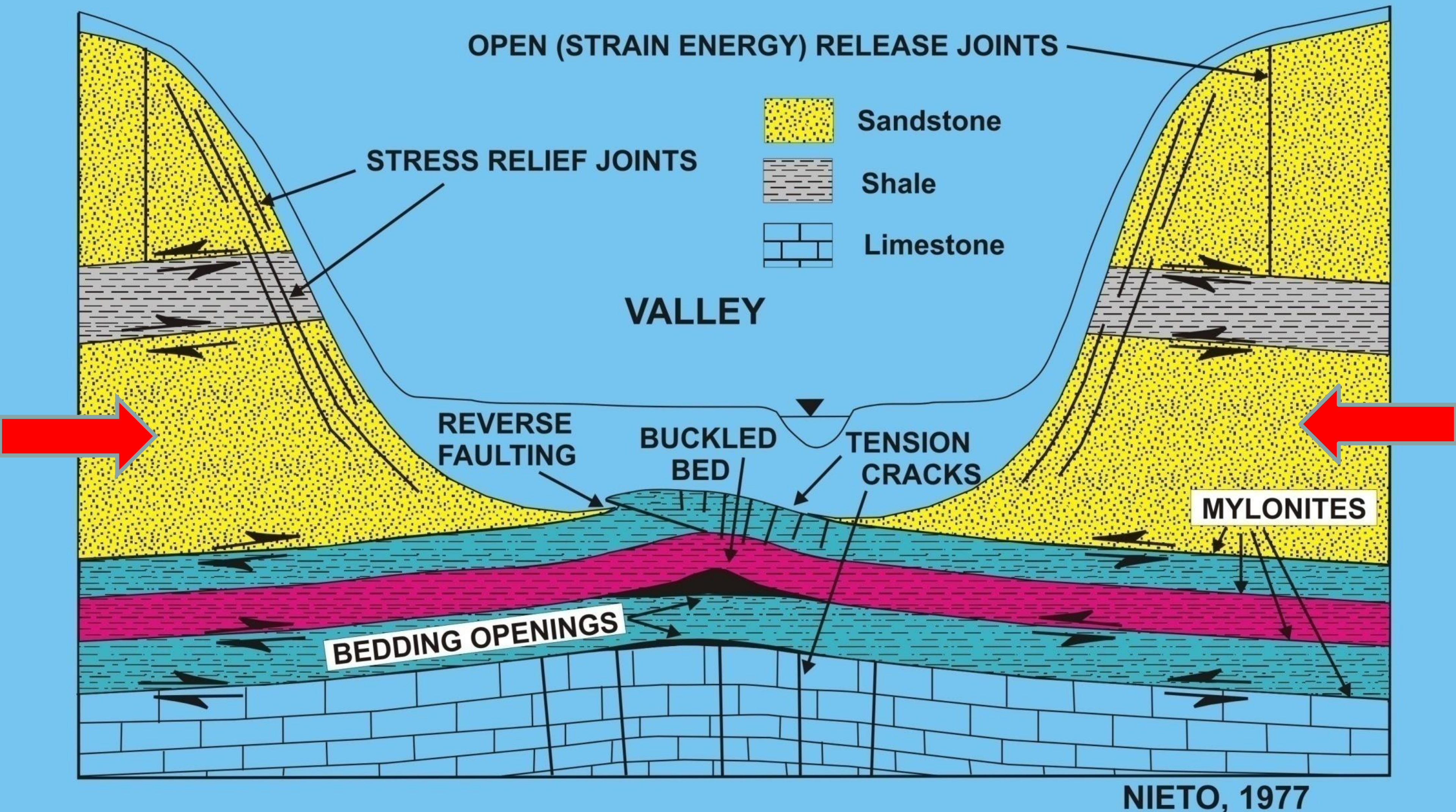


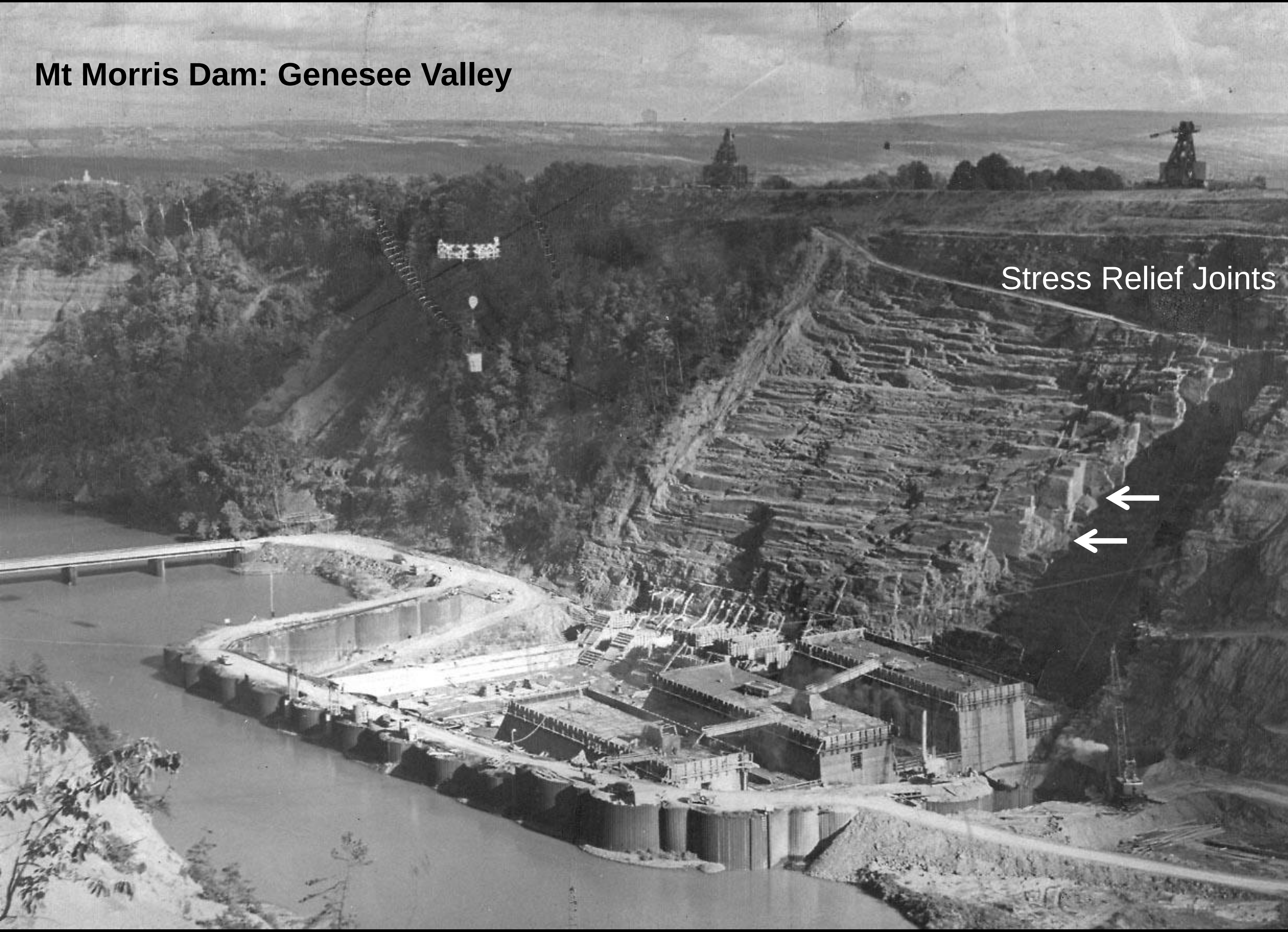
FIGURE 5. - Schematic diagram of postulated mechanism of creation of fracture zones and potential roof fall zones by erosion of overburden.

VALLEY ANTICLINE FEATURES

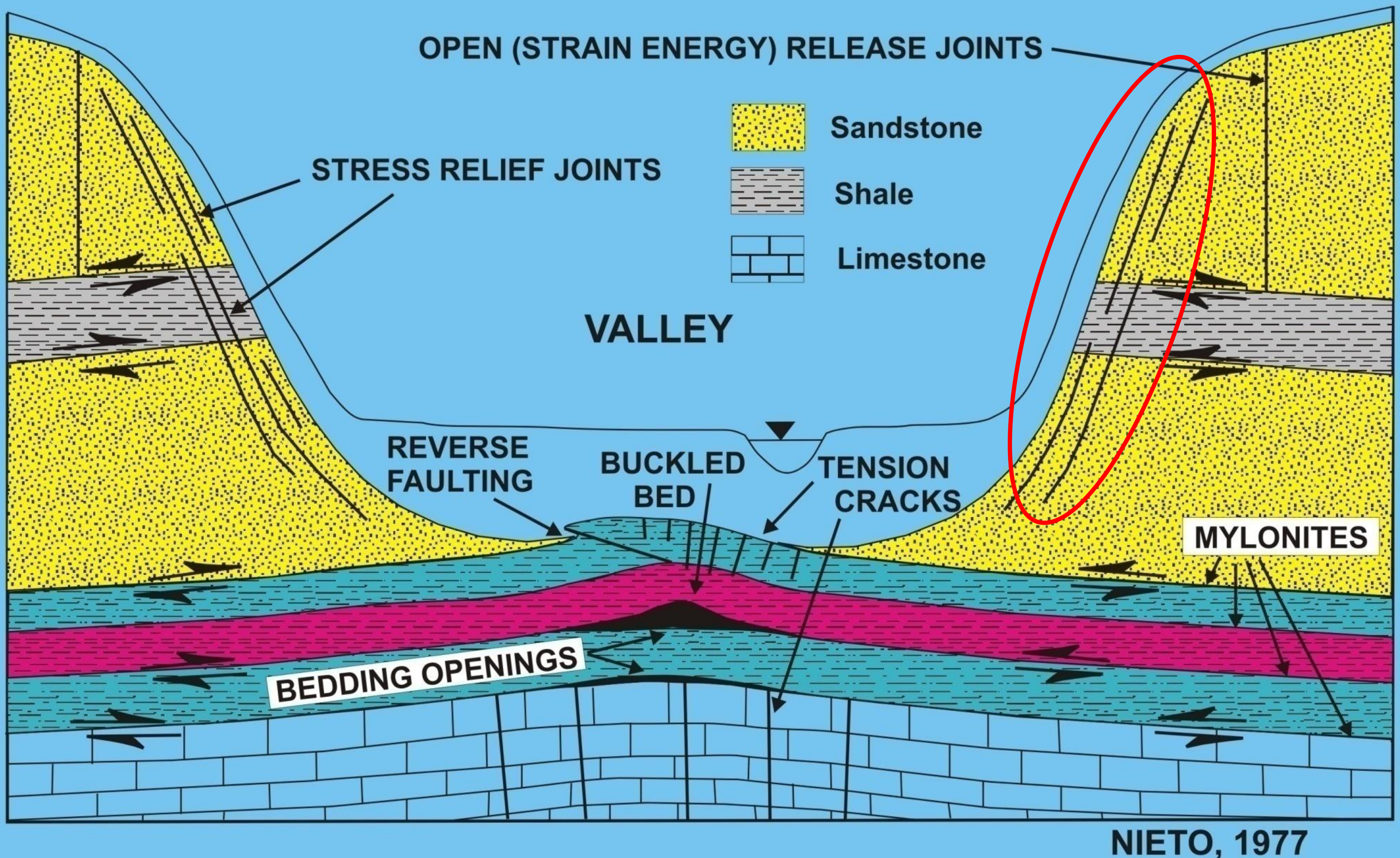


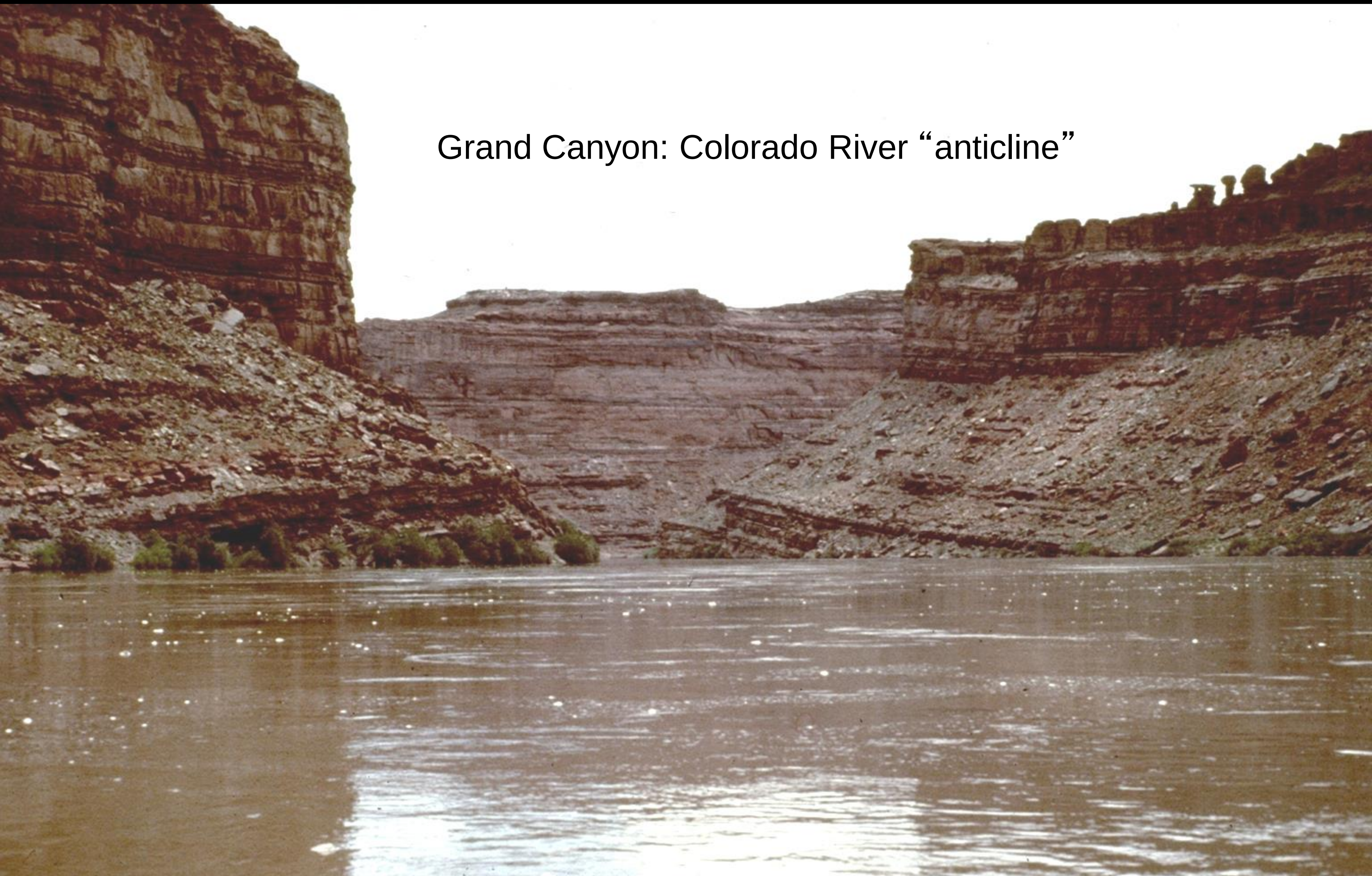
Erosional unloading and horizontal stress field combined

Mt Morris Dam: Genesee Valley



VALLEY ANTICLINE FEATURES




Grand Canyon: Colorado River “anticline”

Observed deformation in bedrock layers above coal mines under valleys (PA, WV)

Molinda et al. US Bureau of Mines, 1992

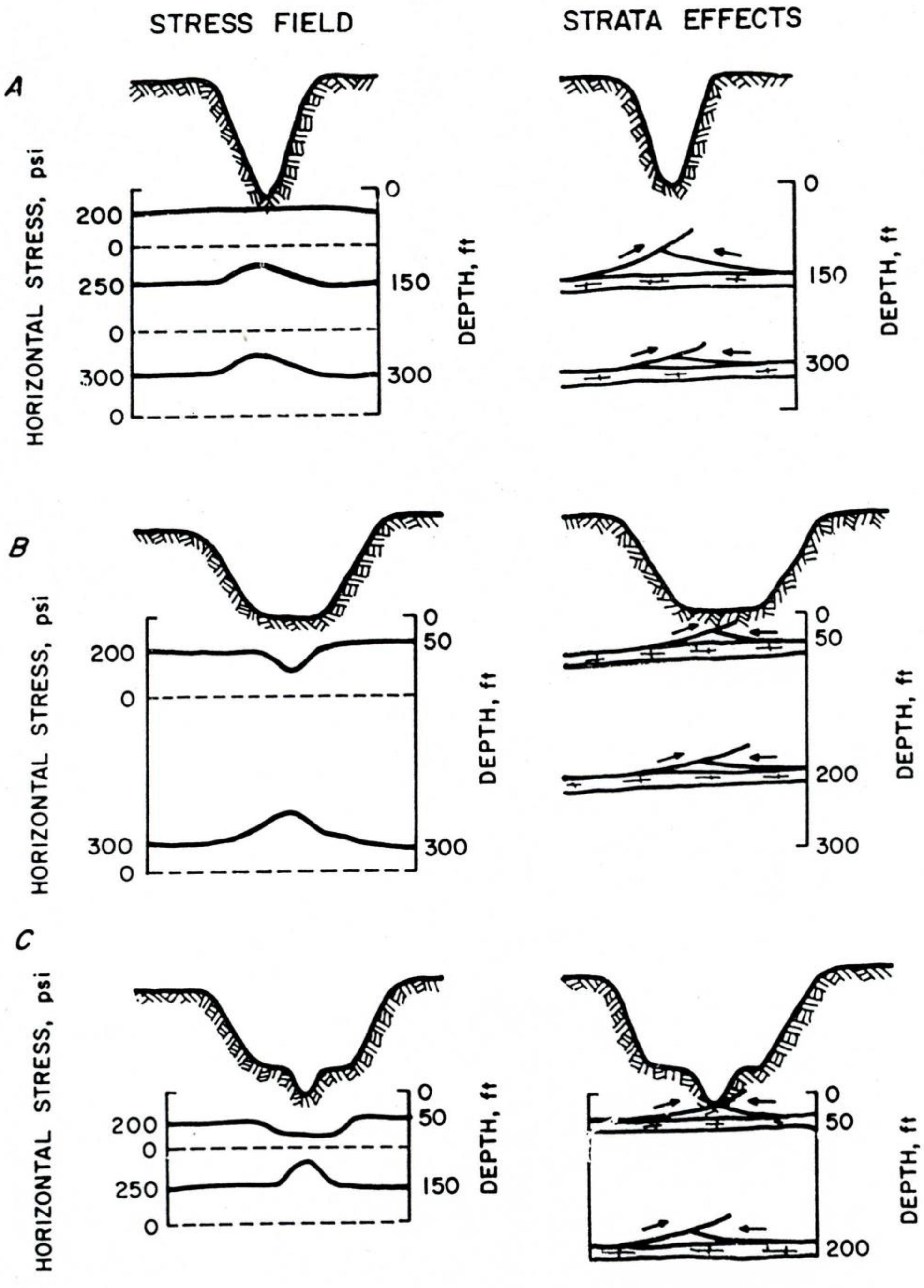


Figure 26.—Representation of modeled stress field and roof effects beneath Valleys No. 9 and No. 12. A, Valley No. 9; B, Valley No. 12; C, rejuvenated Valley No. 12.

PATHWAYS FOR POLLUTION

STRESS COMPLICATIONS

Rock loads: Weight Only

Density = 2.4 - 2.6, or weight = 150 -162 lbs. per cubic foot

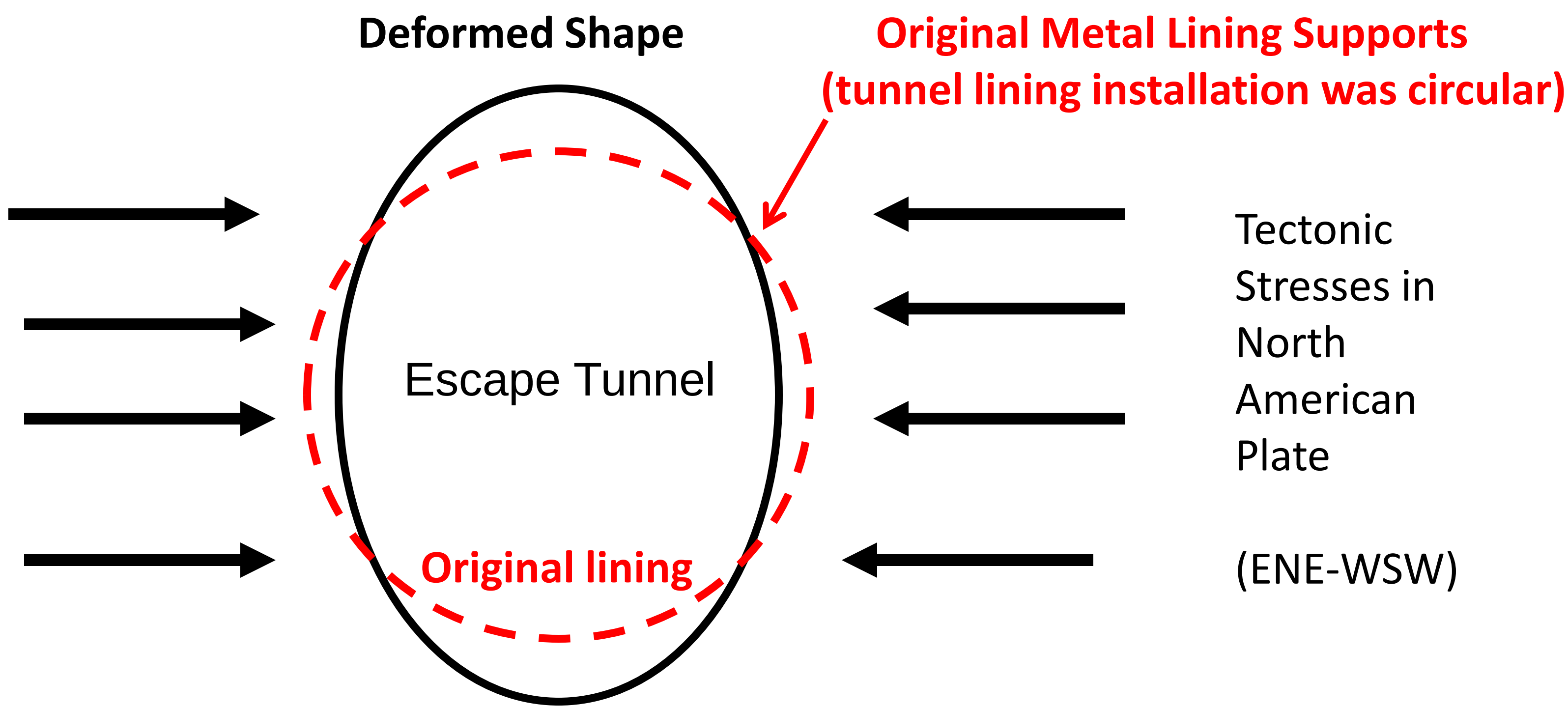
Vertical Loads: Approx. 1 psi (per foot of depth)

HOWEVER……….

Horizontal Stresses may be 3 times vertical rock loads (weight) at depths of several thousand feet

Old Sterling Mine Shaft

Observed Style of Horizontal Deformation in Old Sterling Mine, Genesee Valley, NY

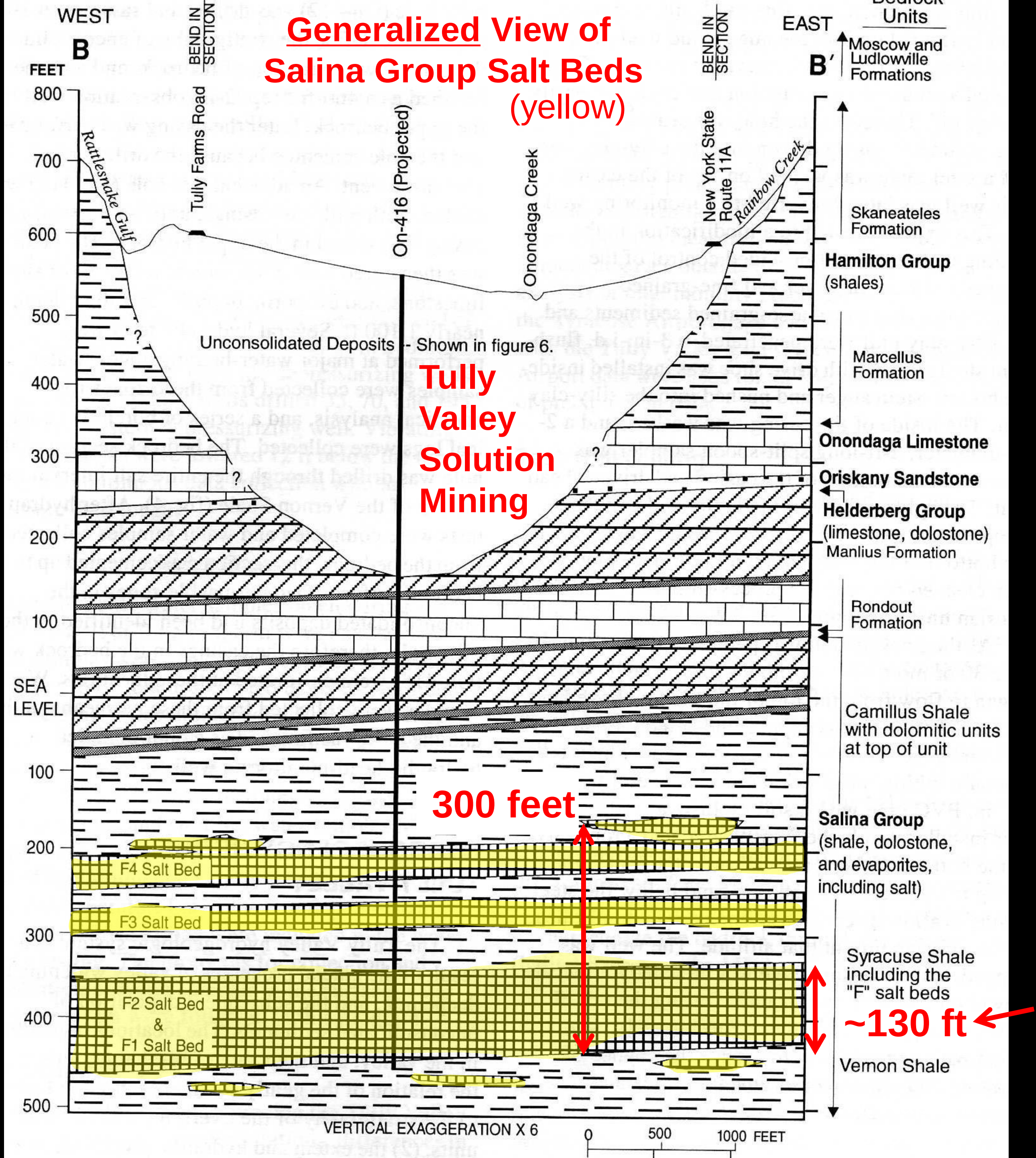


At depths of 600-800 feet horizontal stresses are 2X to 3X vertical loads.
(From "overcoring" measurements in borings for new American Rock Salt mine.)

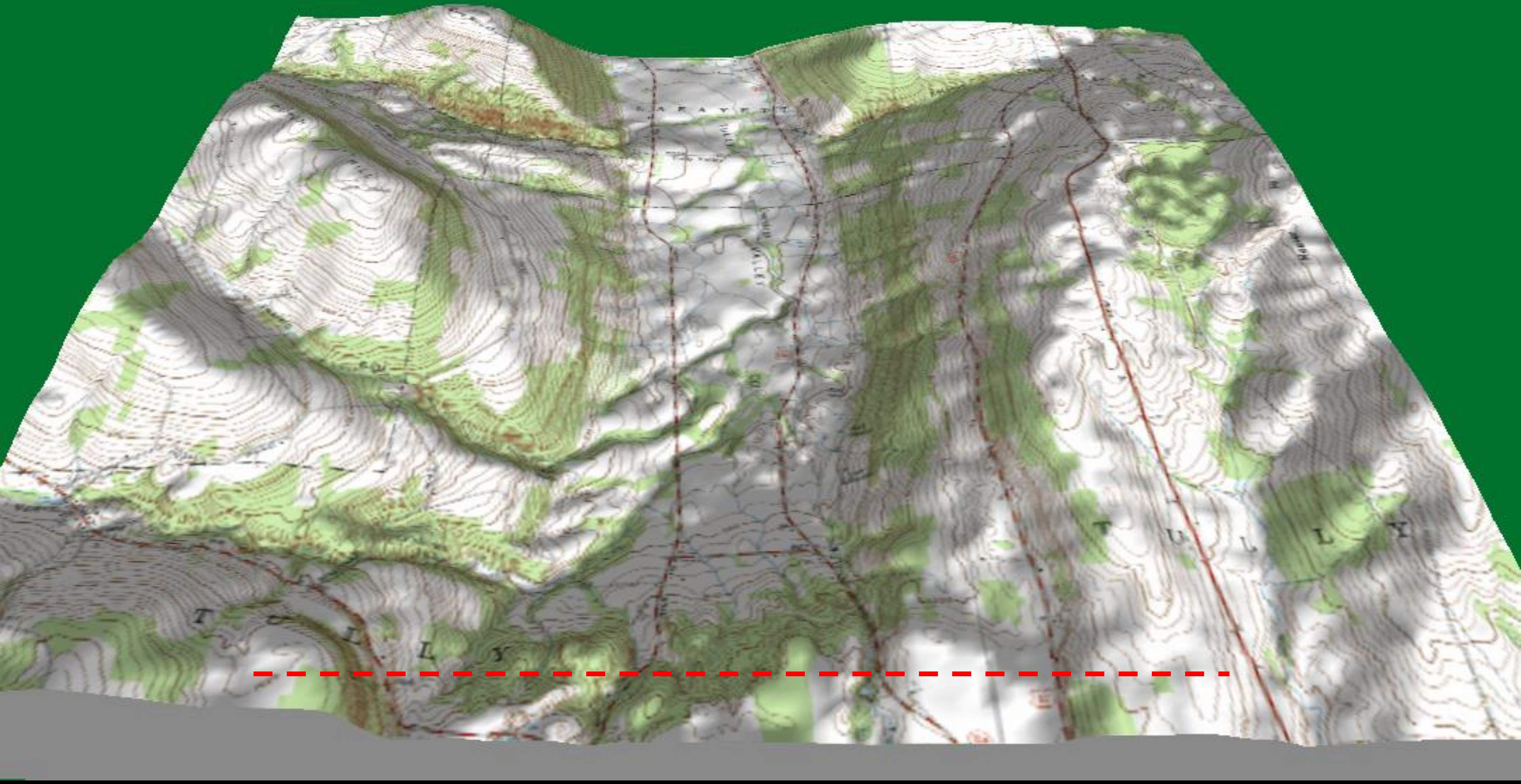
Tully Valley Mining Data

Evidence for Horizontal Compression

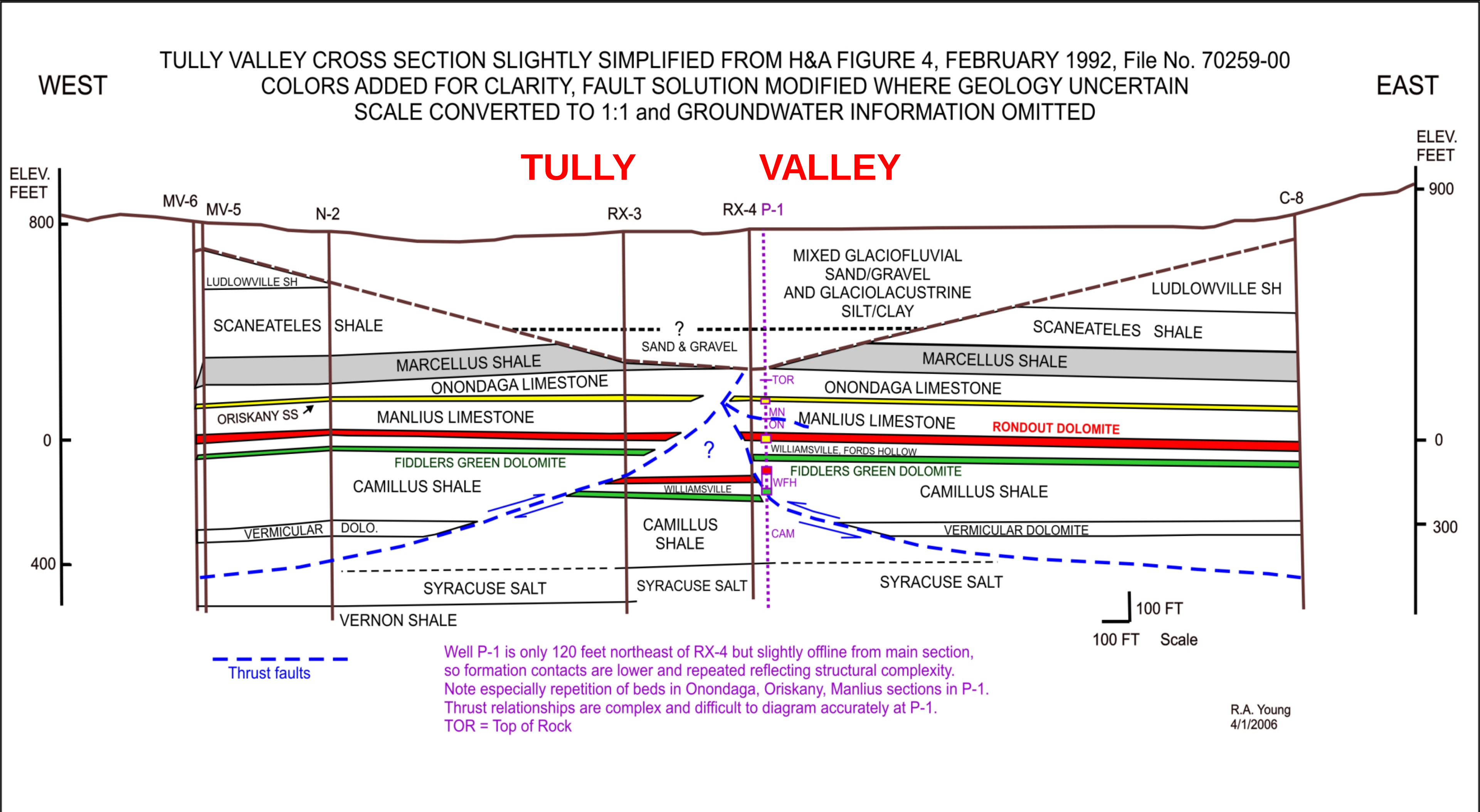
Generalized View of Salina Group Salt Beds (yellow)



TULLY VALLEY CROSS SECTION: SOLUTION MINING WELL DATA



Tully Valley: South of Syracuse (Salt Solution Mining)



Observed deformation in bedrock layers above coal mines under valleys (PA, WV)

Molinda et al. US Bureau of Mines, 1992

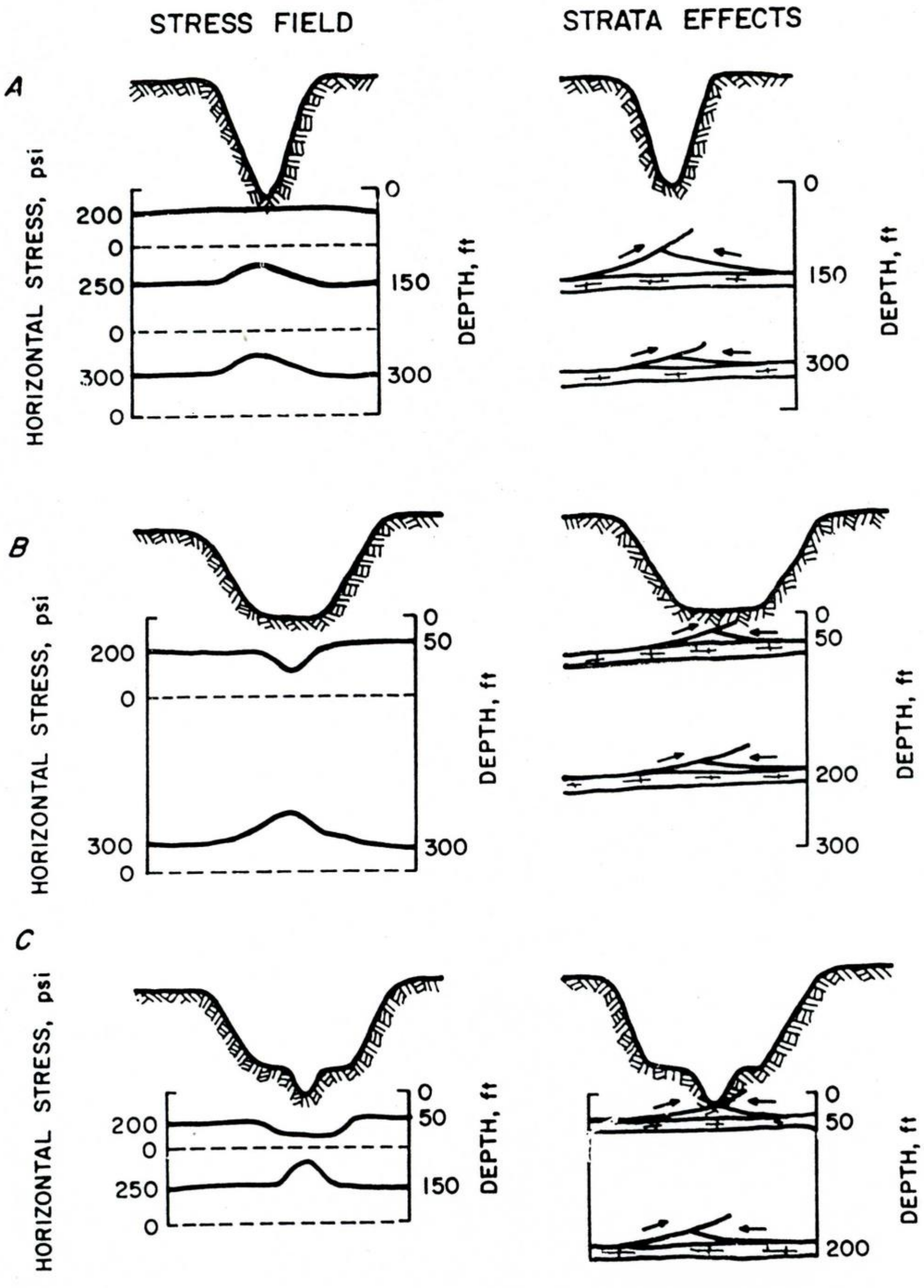
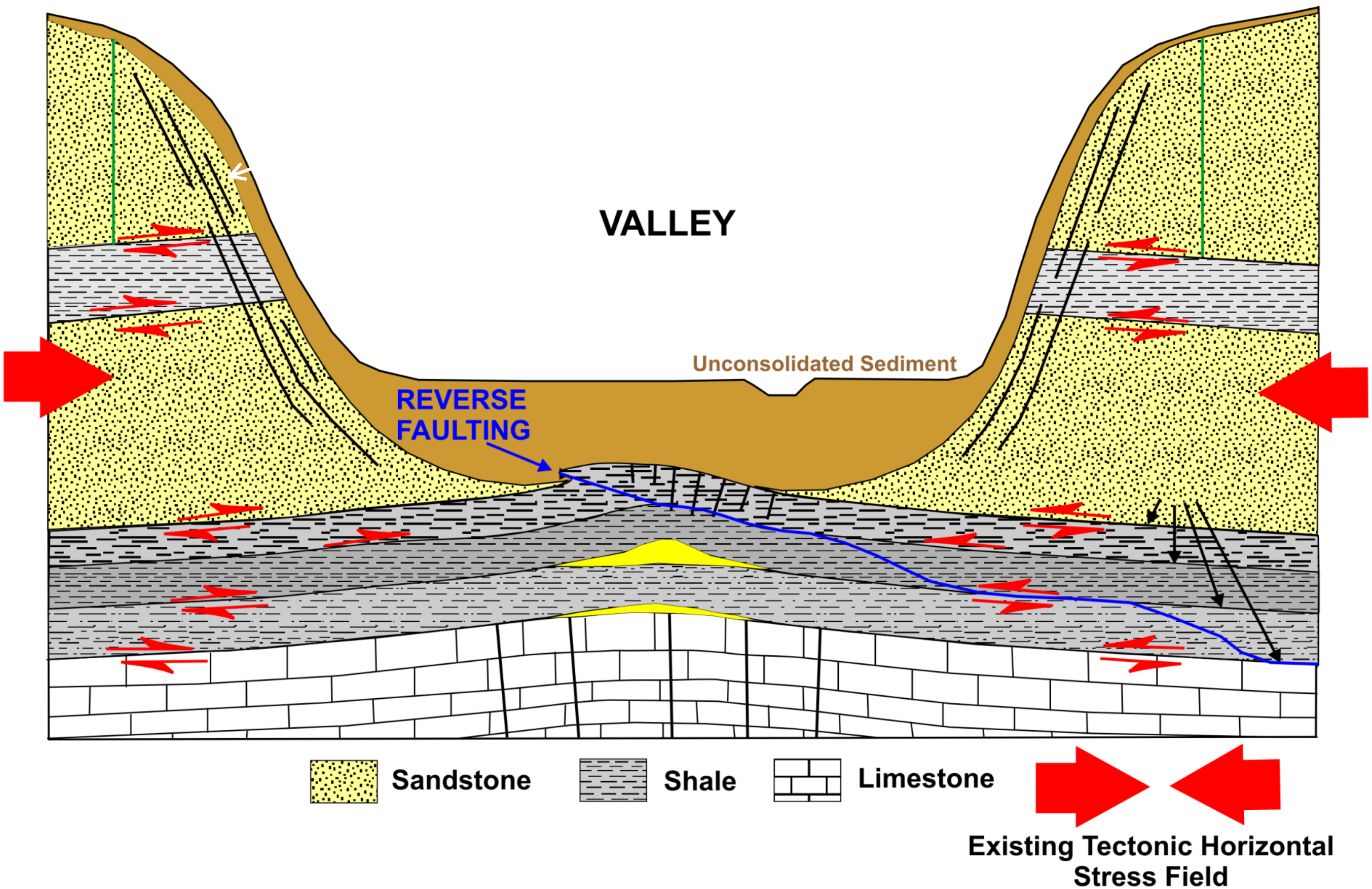


Figure 26.—Representation of modeled stress field and roof effects beneath Valleys No. 9 and No. 12. A, Valley No. 9; B, Valley No. 12; C, rejuvenated Valley No. 12.

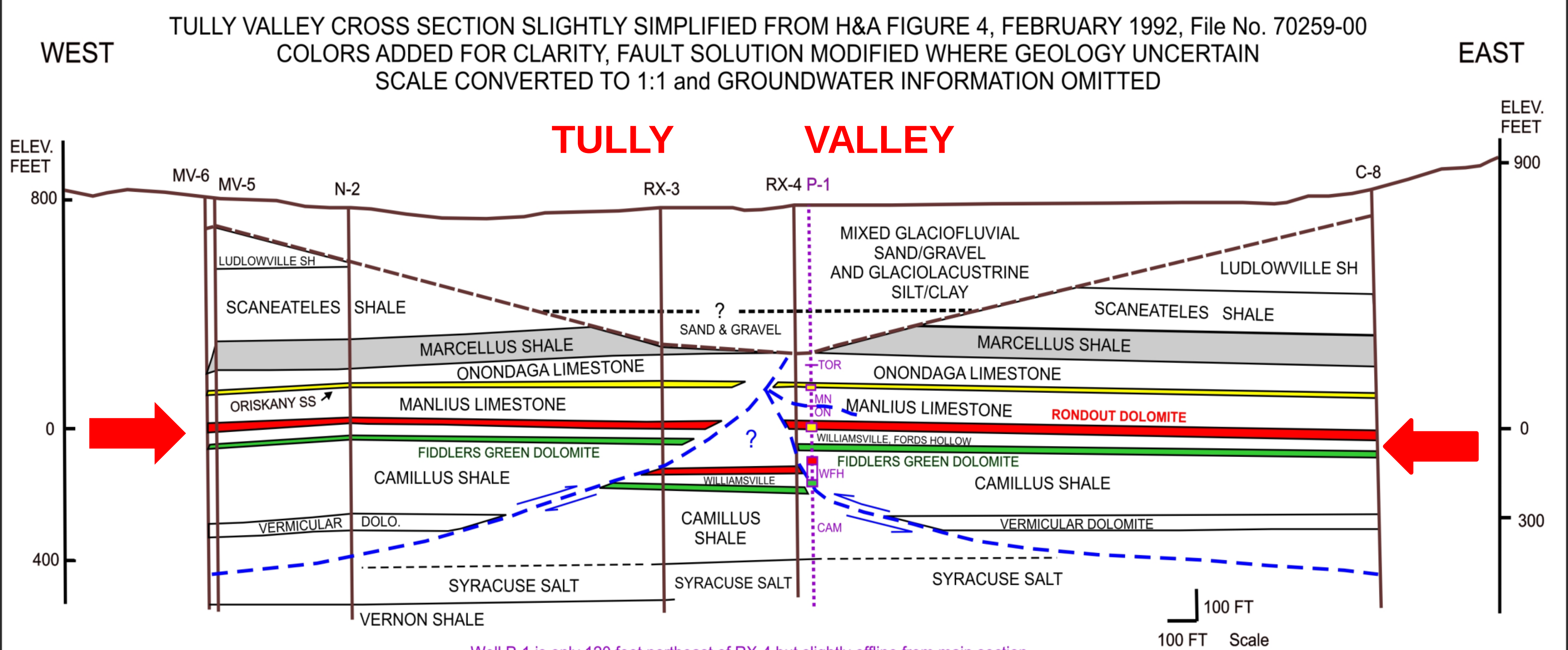
PATHWAYS FOR POLLUTION

STRESS COMPLICATIONS

VALLEY ANTICLINE AND RELATED TECTONIC FEATURES



Tully Valley: South of Syracuse (Salt Solution Mining)



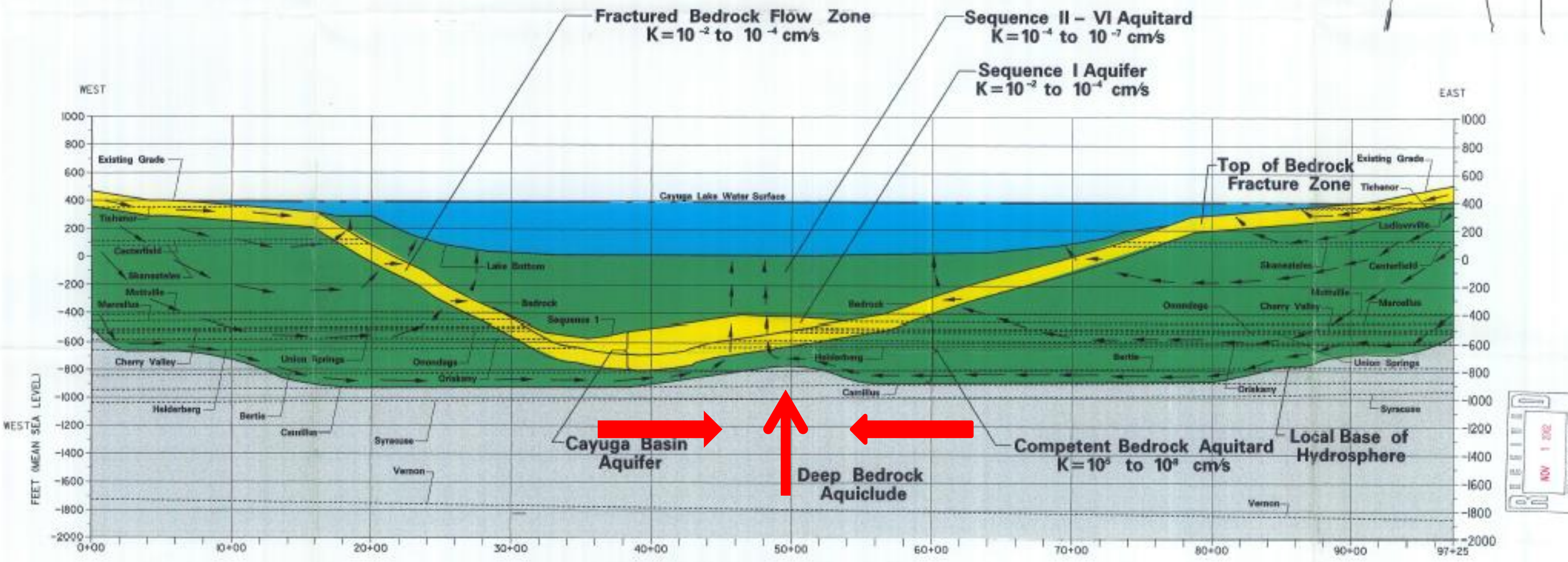
Well P-1 is only 120 feet northeast of RX-4 but slightly offline from main section, so formation contacts are lower and repeated reflecting structural complexity. Note especially repetition of beds in Onondaga, Oriskany, Manlius sections in P-1. Thrust relationships are complex and difficult to diagram accurately at P-1. TOR = Top of Rock

R.A. Young
4/1/2006

Cayuga Lake Salt Mine

SOURCE:
GEOLOGY/HYDROGEOLOGY OF
THE CAYUGA SALT MINE,
LANSING, NEW YORK
SEAR-BROWN, OCTOBER 2000.

CAYUGA LAKE VALLEY



Profile 2000 'B'

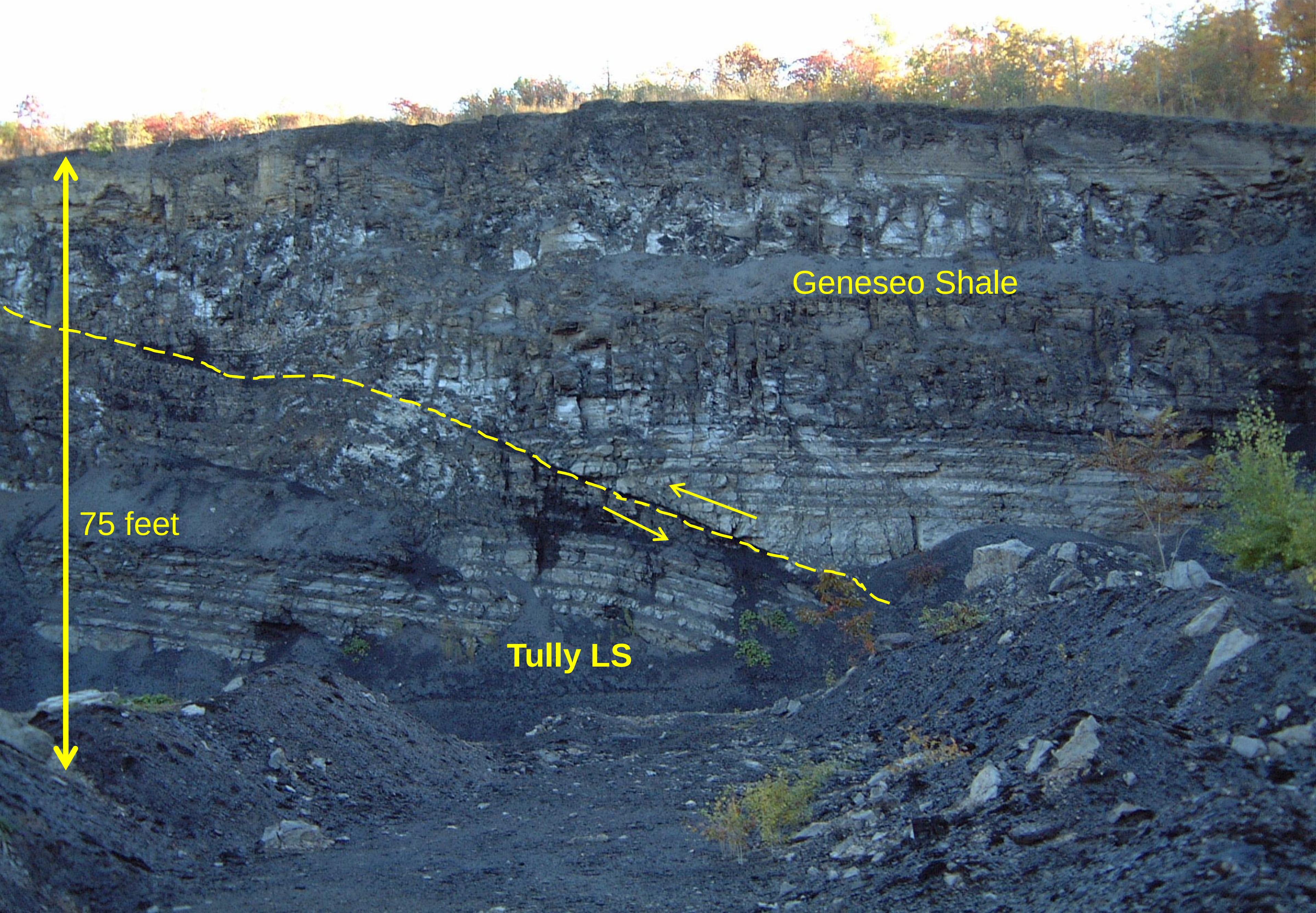
Examples of Unmapped Deformation Structures In Western NY

(Aside from Normal Rock Jointing)

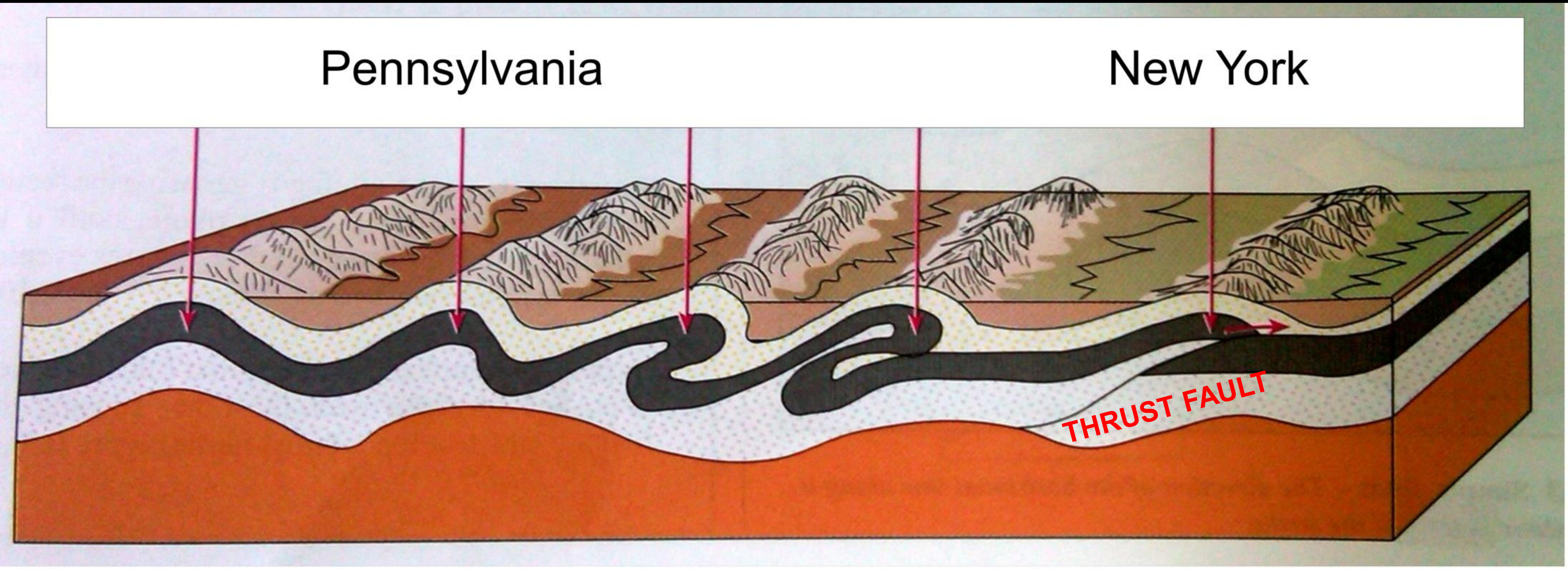
(PATHWAYS FOR FLUID MIGRATION)


Typical
Fault
Zone
(Not Always Narrow)
Highly
Fractured
Rocks

Thrust Fault: Cayuga Crushed Stone Quarry (East End of Firtree Anticline)

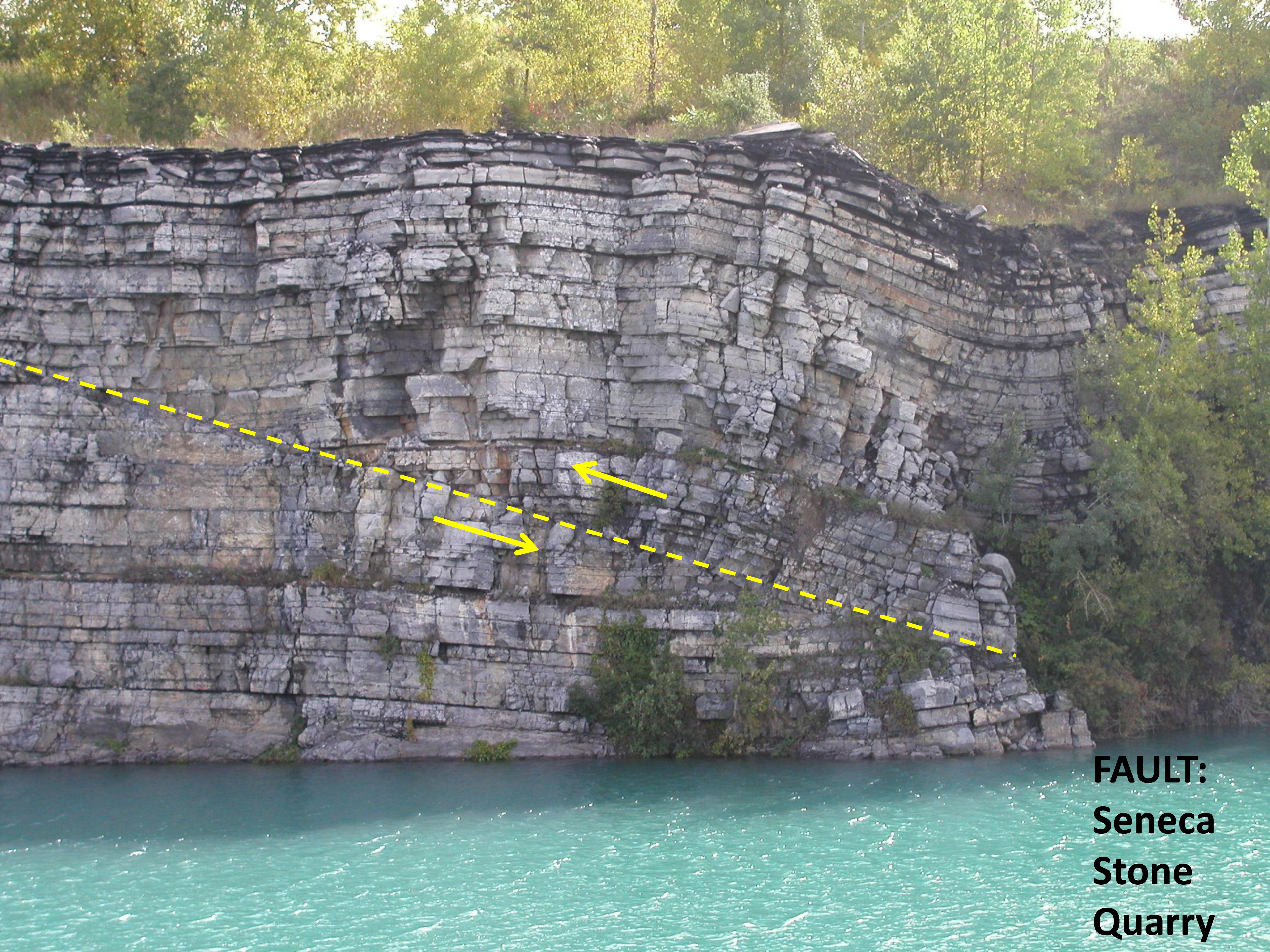


REGIONAL GEOLOGY



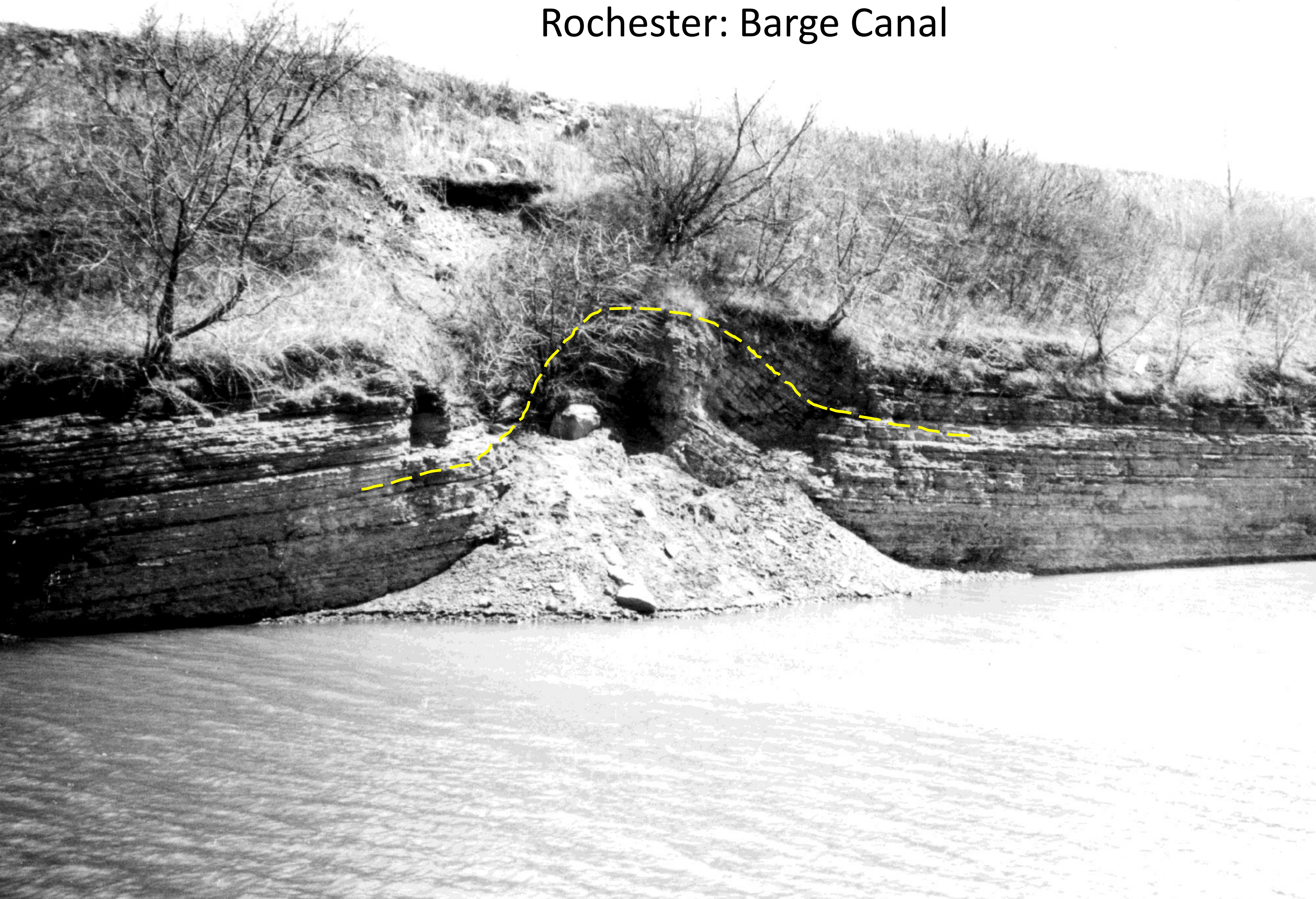

Folds & Faults: Genesee Va., NY
Glacial sediments
Hide rock structures

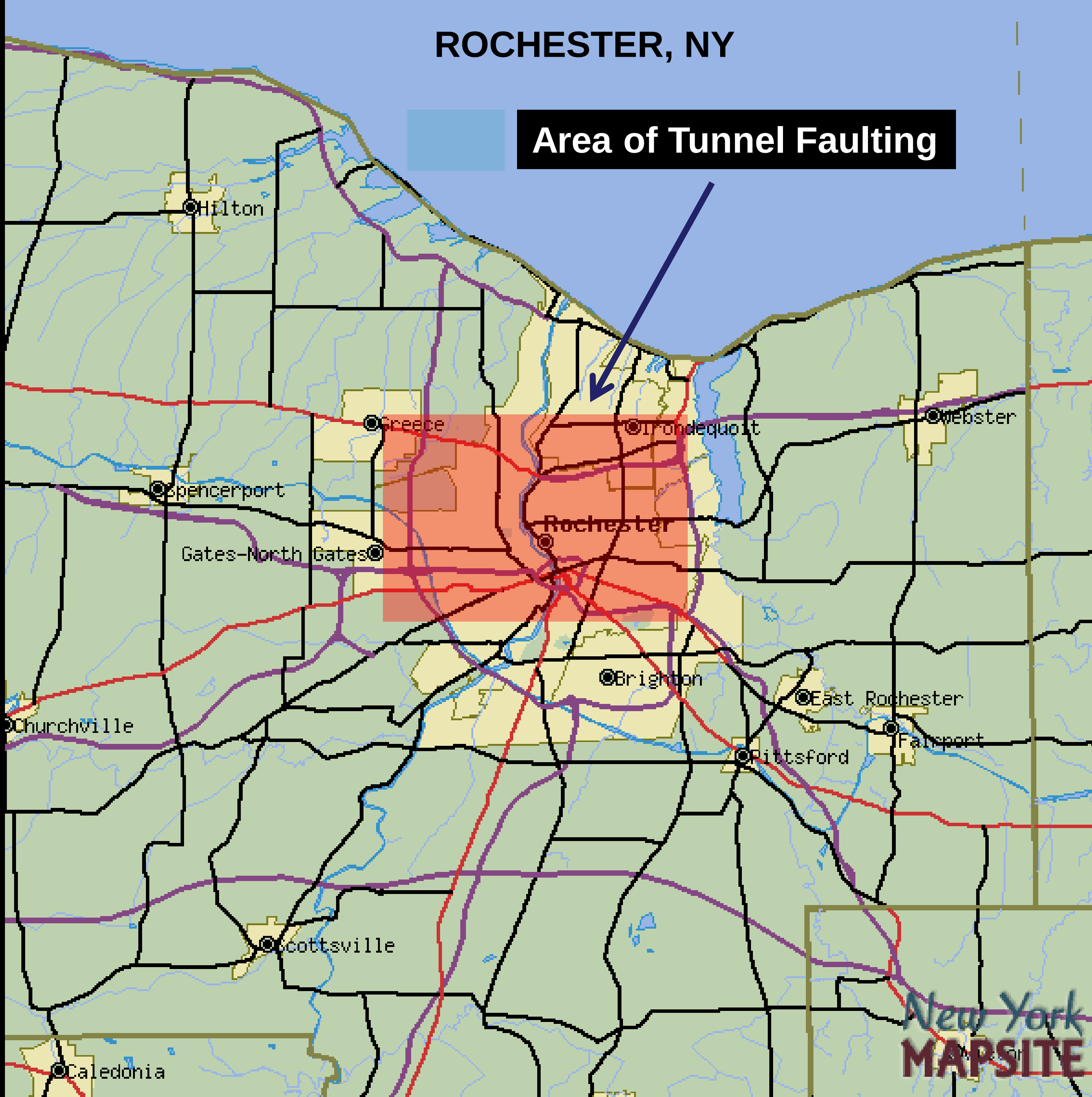

Small Fold


FAULT:
Seneca
Stone
Quarry

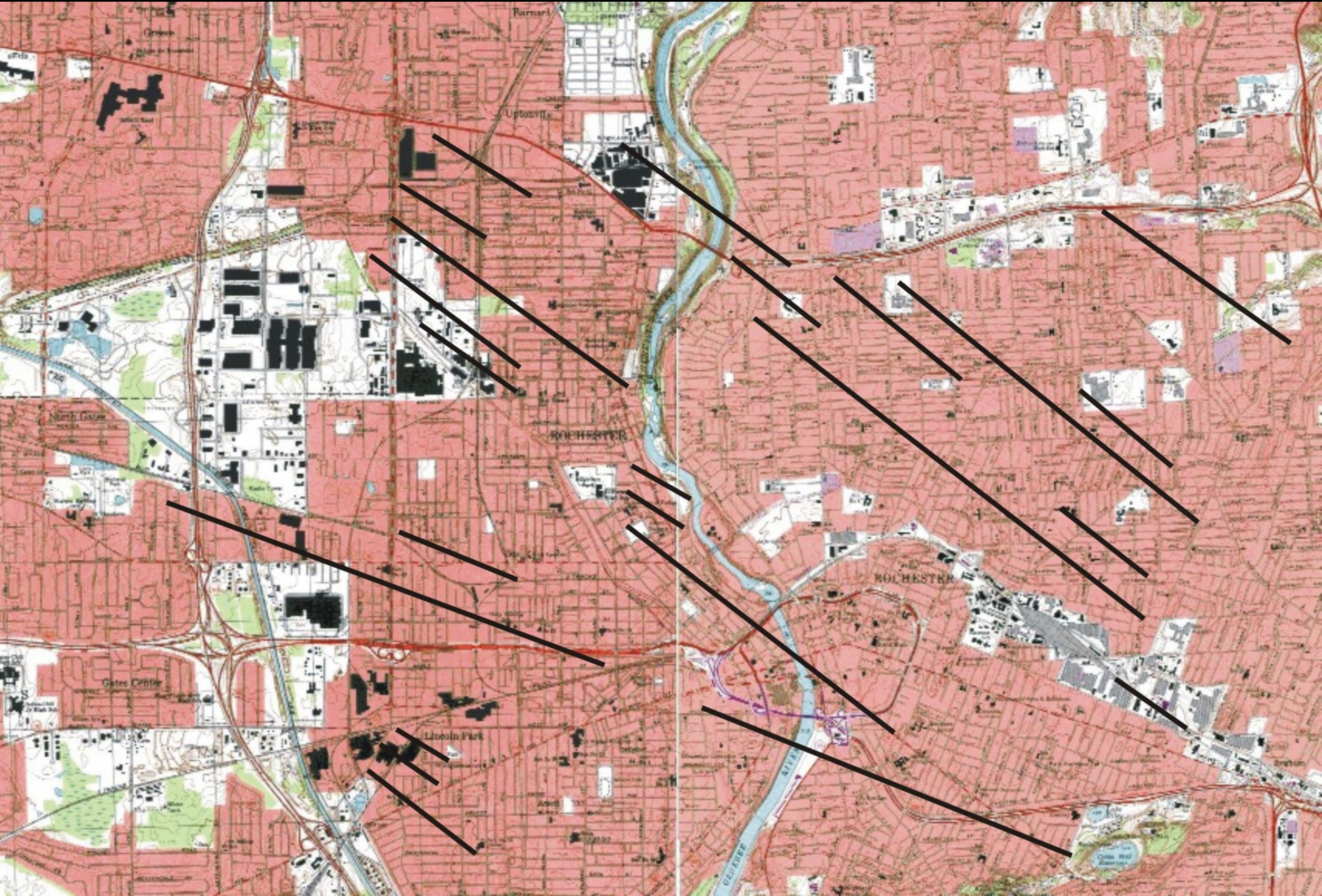

Senaca Stone
Quarry Faulting

Rochester: Barge Canal

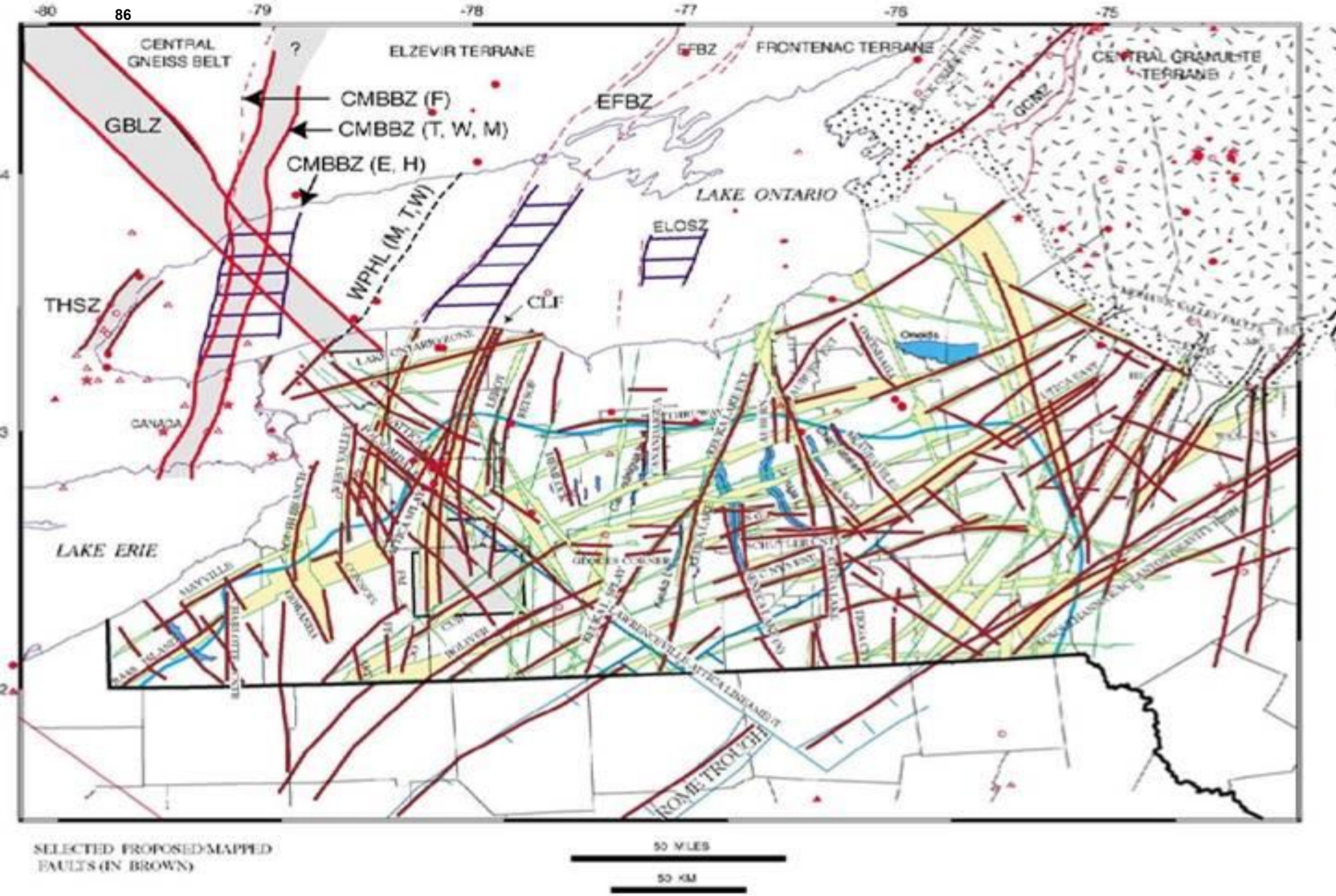



ROCHESTER, NY
Area of Tunnel Faulting
Hilton
Greece
Irondequoit
Webster
Spencerport
Rochester
Gates-North Gates
Brighton
East Rochester
Fairport
Pittsford
Churchville
Scottsville
Caledonia
New York MAPSITE

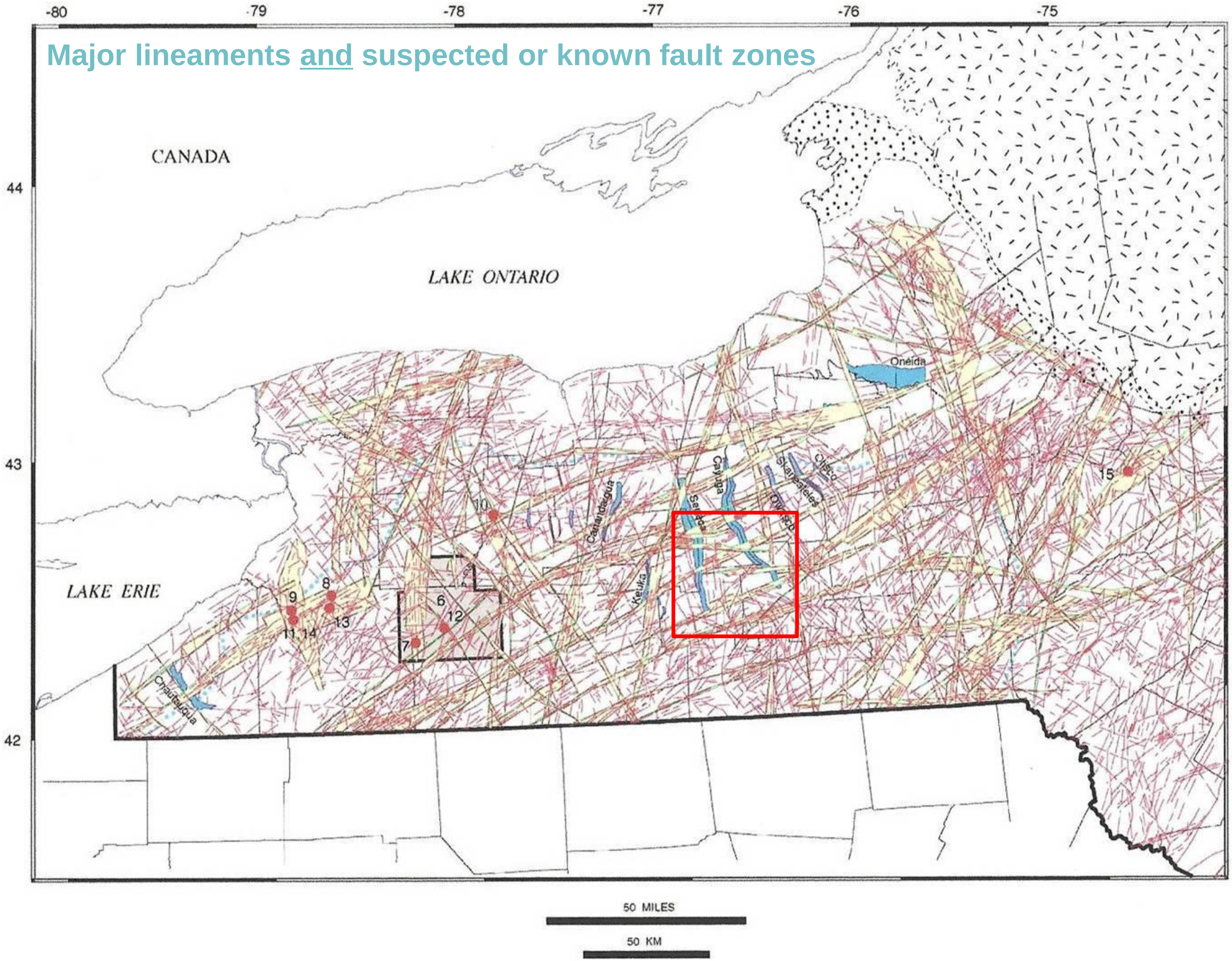
(ROCHESTER FAULTS / FOLDS: Extrapolated vertically to surface from tunnel depths)

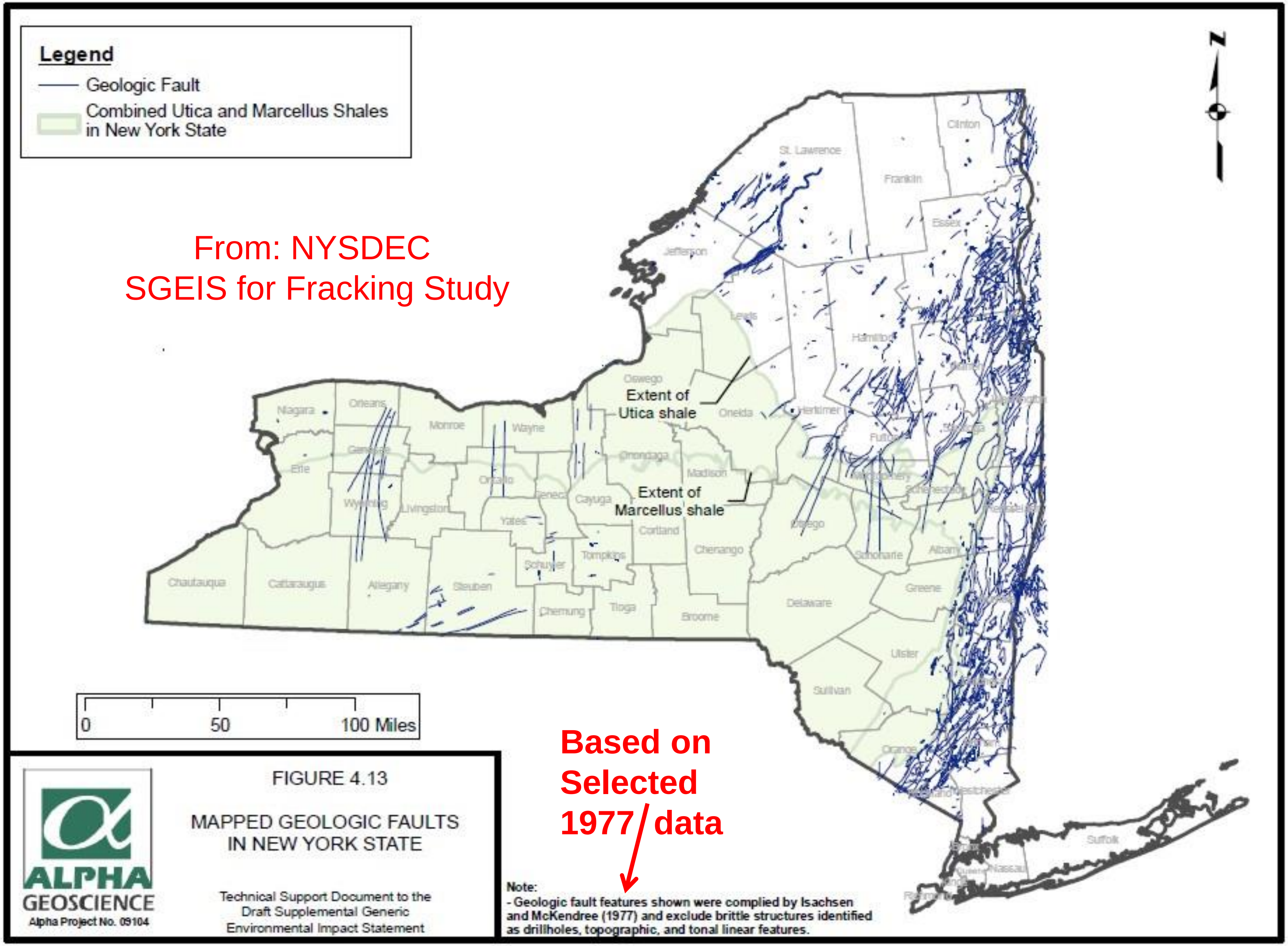


Major Fault Zones – R. Jacobi SUNY Buffalo (Tectonophysics)



Major lineaments and suspected or known fault zones




Legend
Geologic Fault
Combined Utica and Marcellus Shales in New York State
From: NYSDEC
SGEIS for Fracking Study
Extent of Utica shale
Extent of Marcellus shale
0
50
100 Miles
Based on Selected 1977 data
St. Lawrence
Clinton
Franklin
Essex
Jefferson
Lewis
Hamilton
Oswego
Oneida
Herkimer
Niagara
Orleans
Monroe
Wayne
Erie
Genesee
Onondaga
Madison
Ontario
Wyoming
Livingston
Seneca
Cayuga
Yates
Cortland
Otsego
Chenango
Schoharie
Albany
Schenectady
Tompkins
Schuyler
Chautauqua
Cattaraugus
Allegany
Steuben
Chemung
Tioga
Broome
Delaware
Greene
Ulster
Sullivan
Orange
Suffolk
Nassau
FIGURE 4.13
MAPPED GEOLOGIC FAULTS IN NEW YORK STATE
ALPHA GEOSCIENCE
Alpha Project No. 09104
Technical Support Document to the Draft Supplemental Generic Environmental Impact Statement
Note:
- Geologic fault features shown were complied by Isachsen and McKendree (1977) and exclude brittle structures identified as drillholes, topographic, and tonal linear features.

UNRESOLVED ISSUES

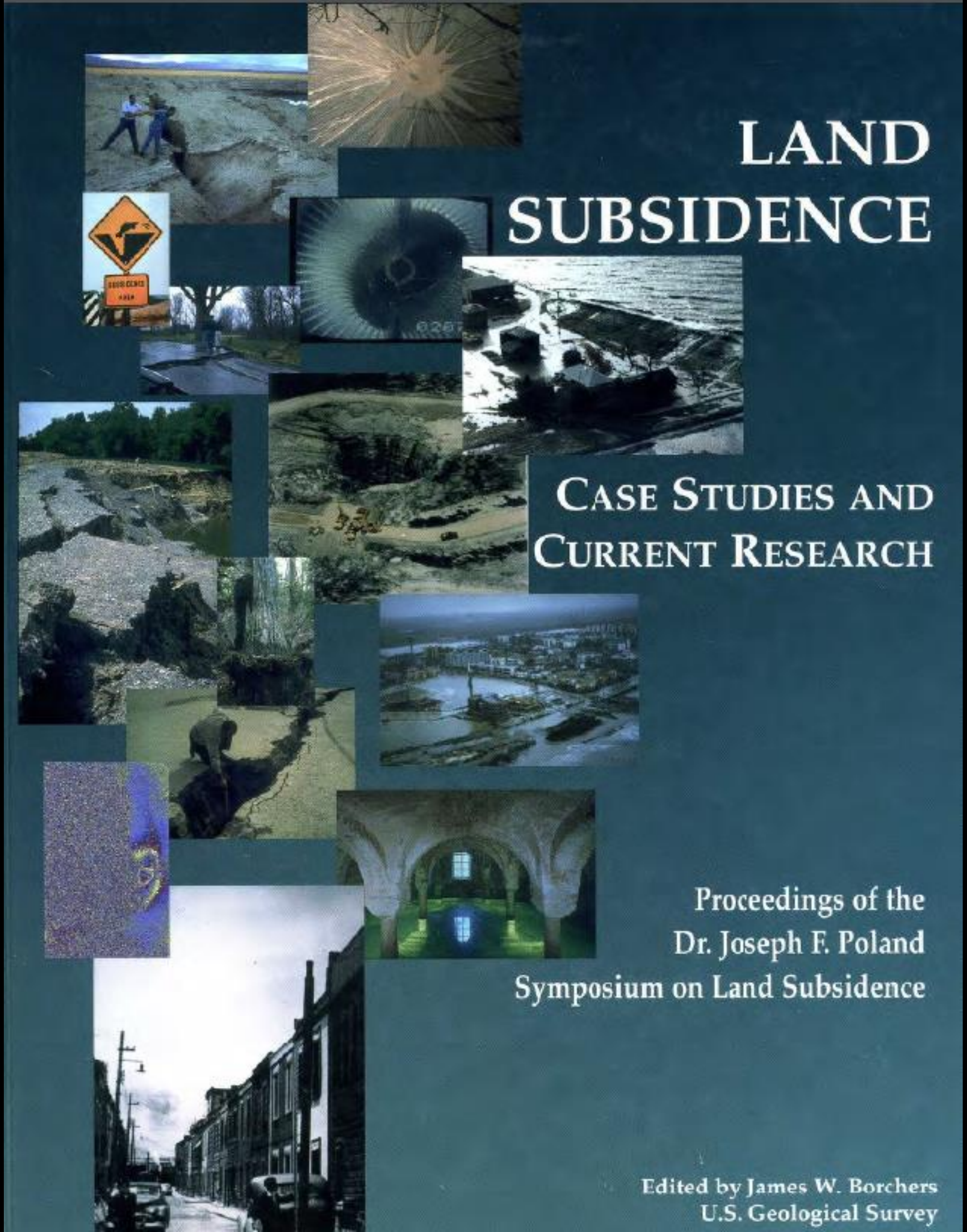
- Significance of Undefined Horizontal Stress Field (tendency for deformation of valley axis)

- Unmapped structures (faults, folds, joints)

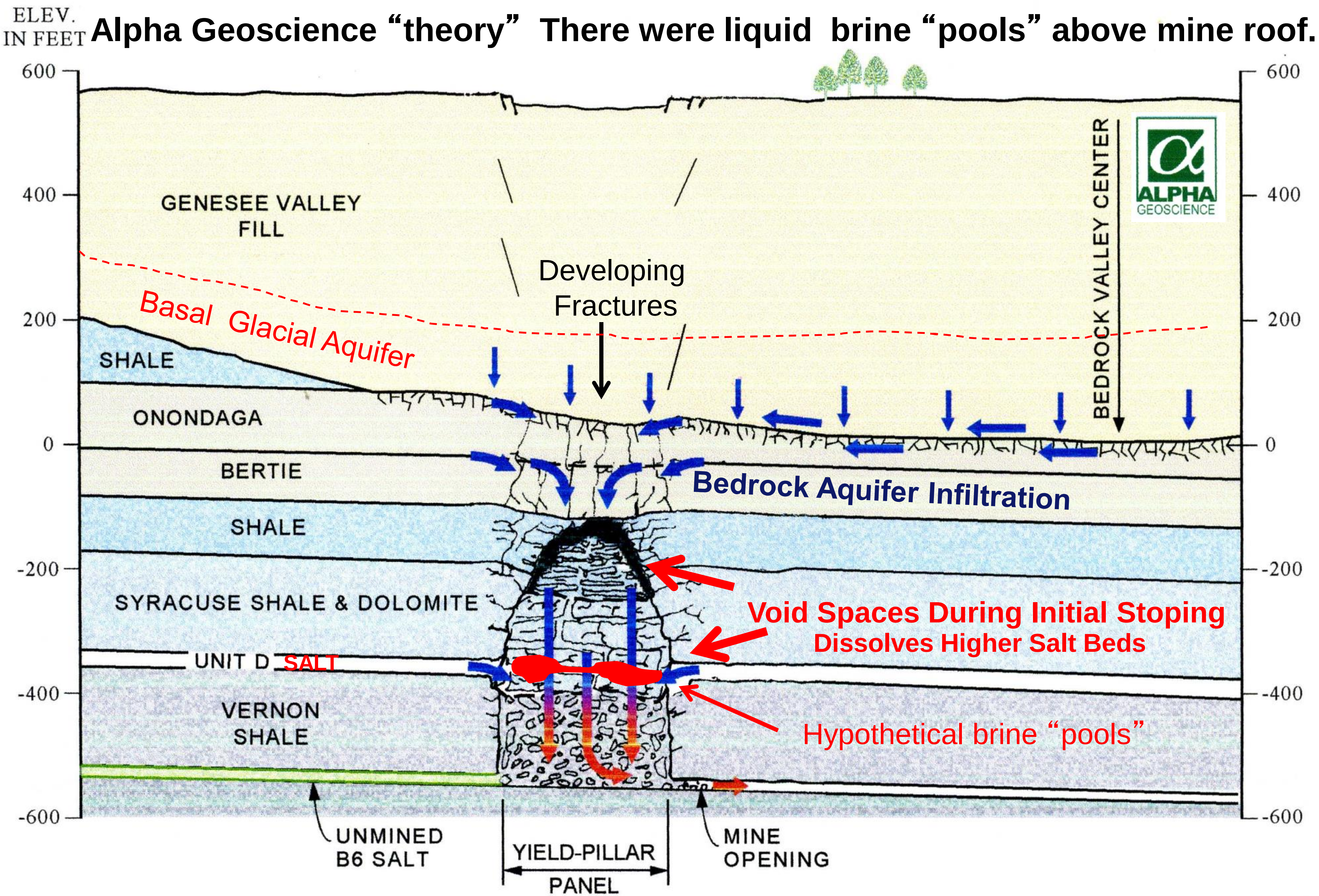
- Stress Arch Concept ? Competence to Support Roof? (Retsof Similarities?)

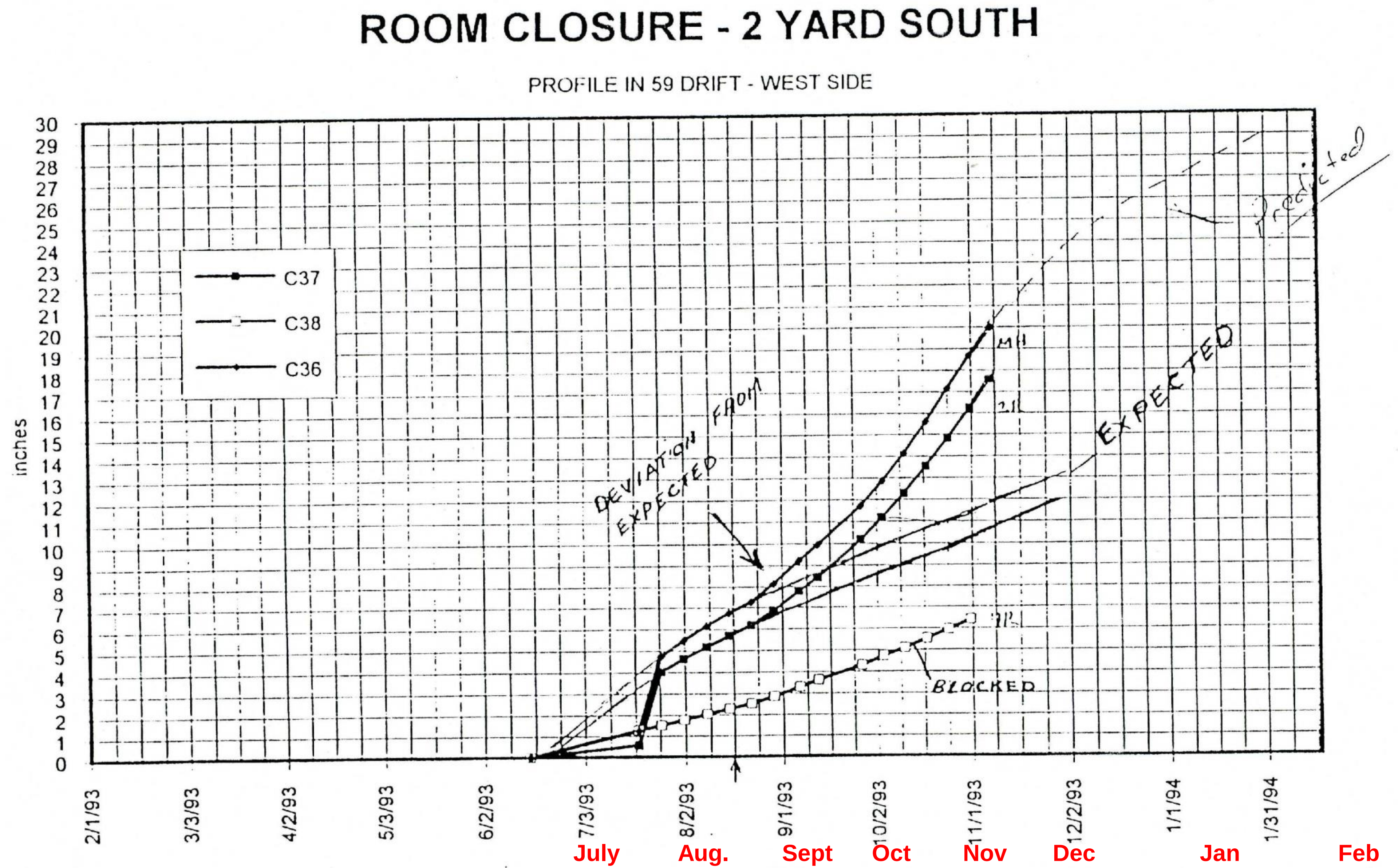
- Clear Evidence in Similar Finger Lake Valleys (and elsewhere)

Reference
List Available

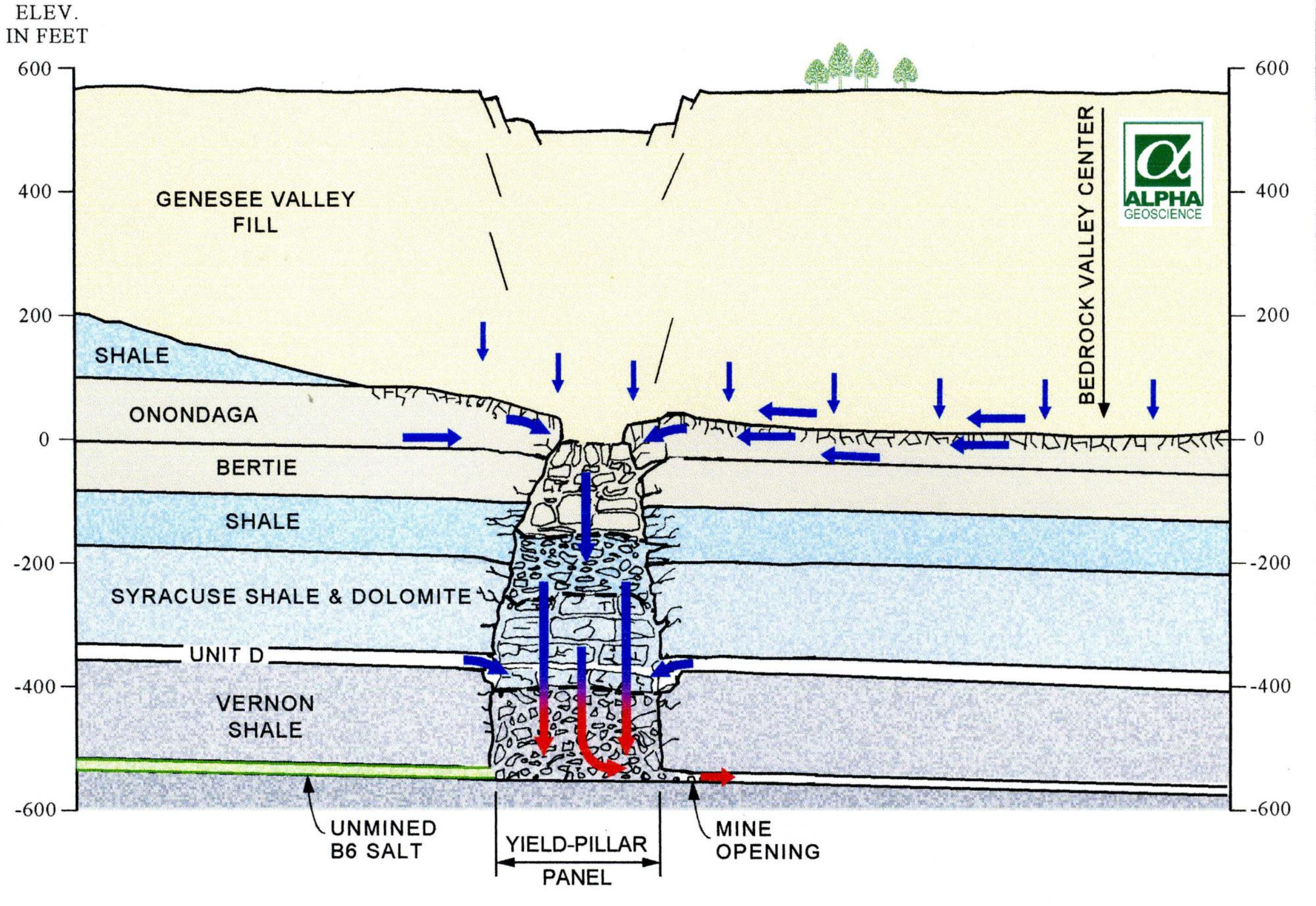


Alpha Geoscience "theory" There were liquid brine "pools" above mine roof.





Collapse occurred March 12
(9 months)


ELEV. IN FEET
600
400
200
0
-200
-400
-600
GENESEE VALLEY FILL
BEDROCK VALLEY CENTER
ALPHA GEOSCIENCE
SHALE
ONONDAGA
BERTIE
SHALE
SYRACUSE SHALE & DOLOMITE
UNIT D
VERNON SHALE
UNMINED B6 SALT
YIELD-PILLAR PANEL
MINE OPENING

USGS Study (Yeager et al., 2009) USGS Professional Paper 1767

"Borehole geophysical surveys have identified three saline-water-bearing fracture zones in the bedrock: at stratigraphic contacts between the Onondaga and Bertie Limestones (O/B-FZ) and the Bertie Limestone and the Camillus Shale (B/C-FZ), and in the Syracuse Formation (Syr-FZ)."

"In model A, the salinity of water in the upper part of the rubble chimneys is derived mainly from the inflow of bedrock water from the O/B-FZ, (Onondaga and Bertie Fracture Zone) as indicated by geochemical models."