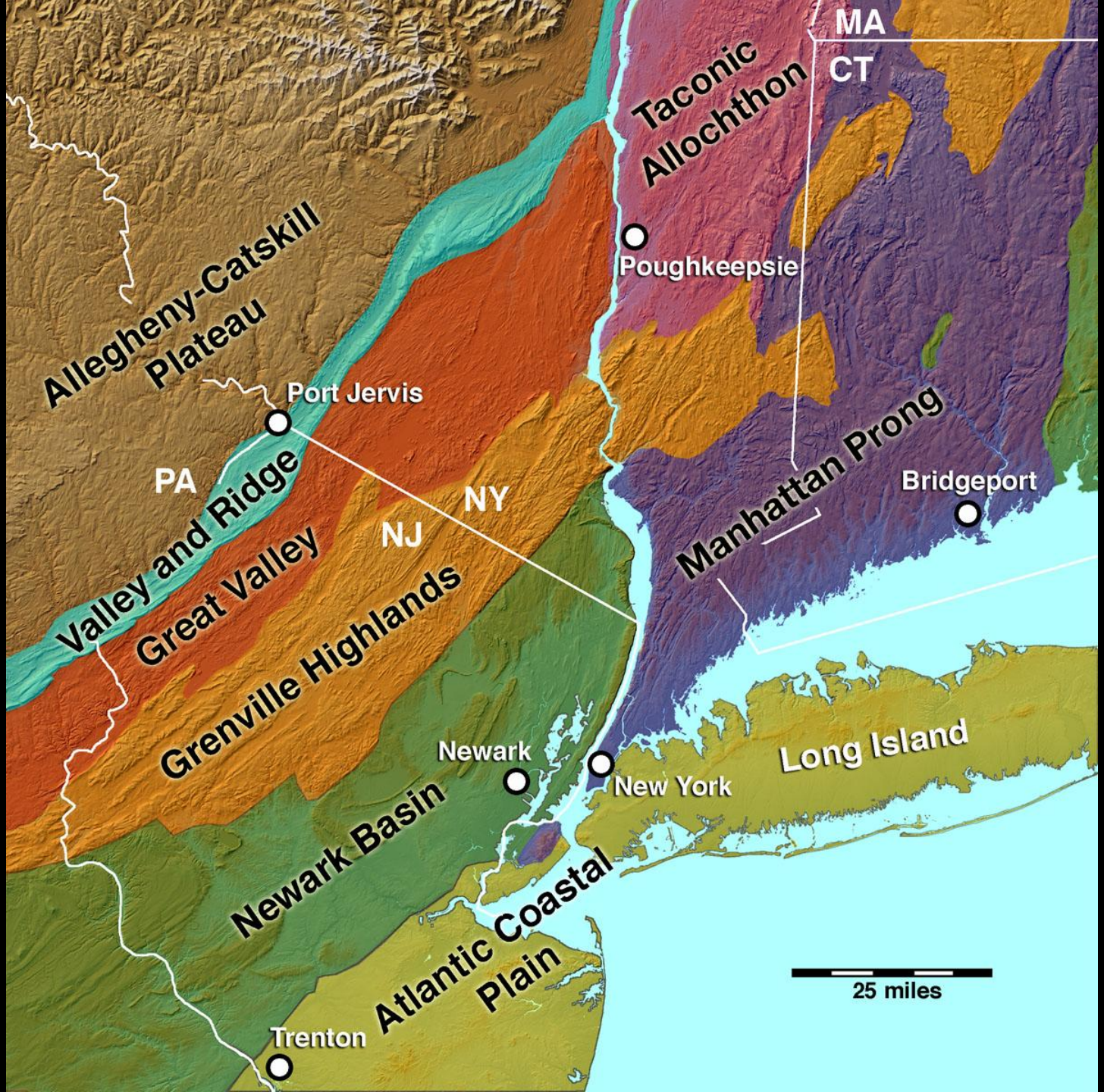
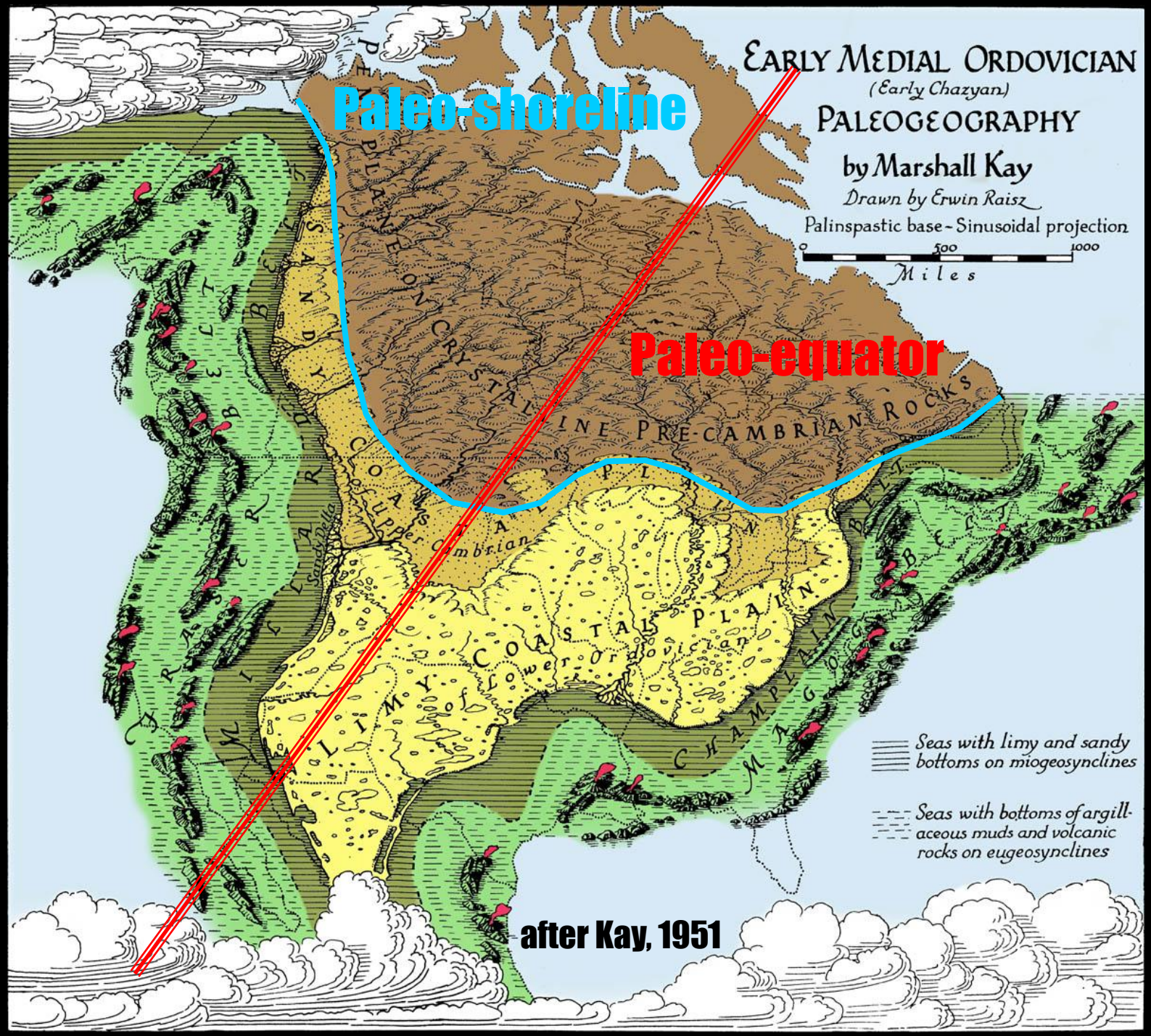
Geological Controls on Means and Methods of Hard Rock Excavation, New York City, NY

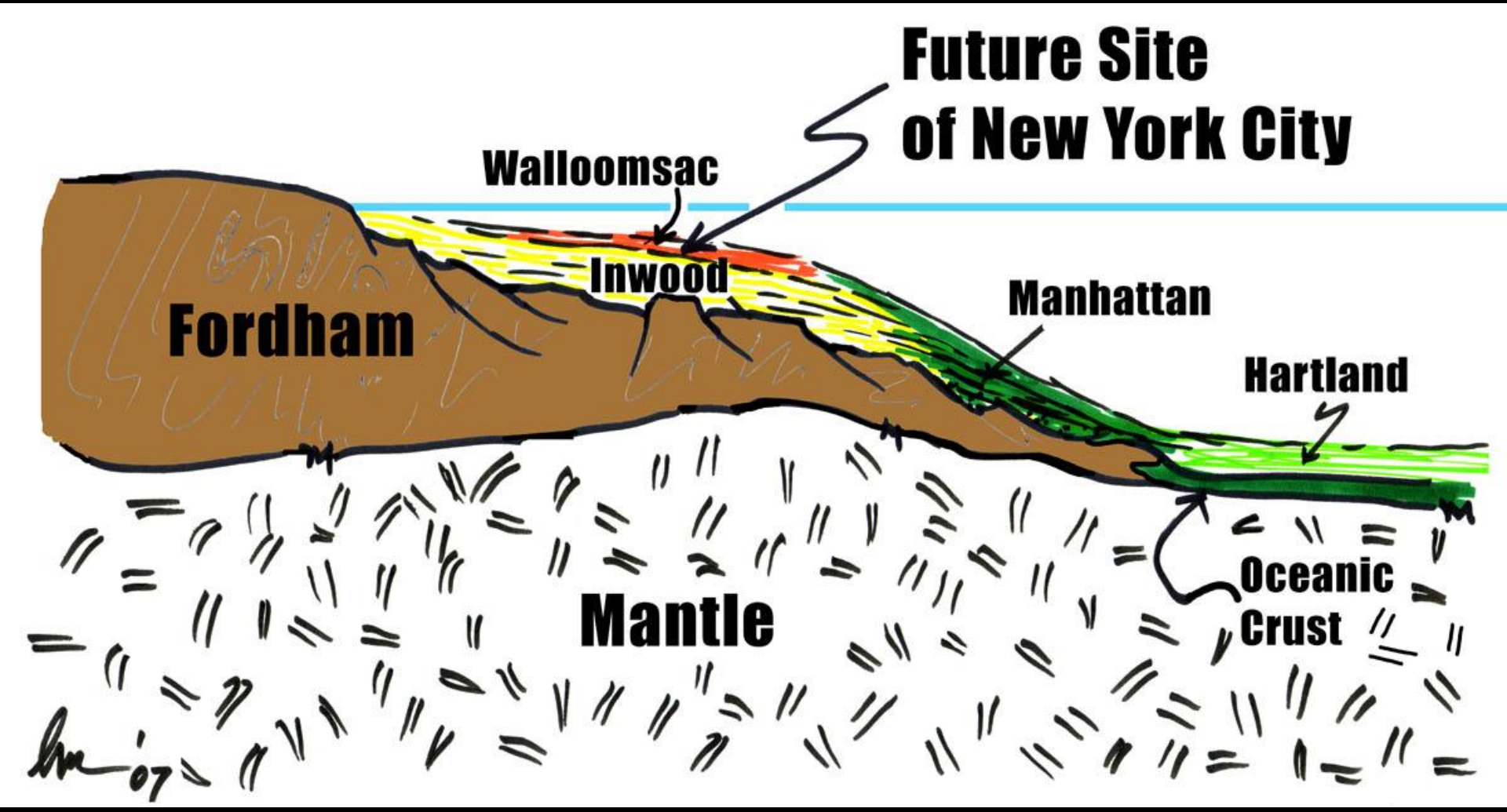
Charles Merguerian

17 October 2008

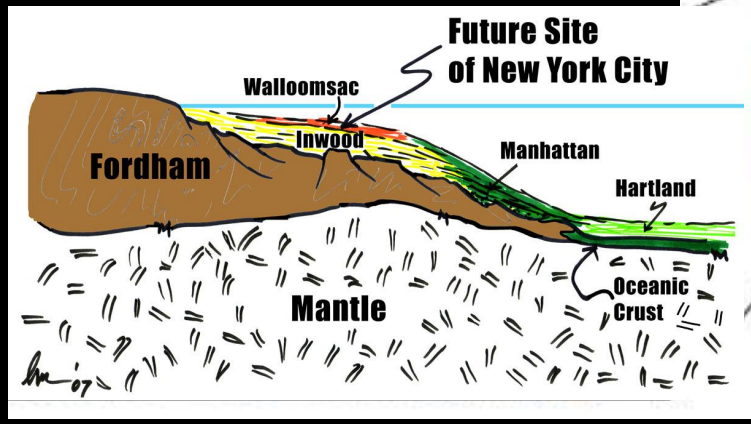

MA
CT
Taconic Allochthon
Poughkeepsie
Allegheny-Catskill Plateau
Port Jervis
PA
Valley and Ridge
NY
NJ
Great Valley
Grenville Highlands
Manhattan Prong
Bridgeport
Long Island
Newark
New York
Newark Basin
Atlantic Coastal Plain
Trenton
25 miles

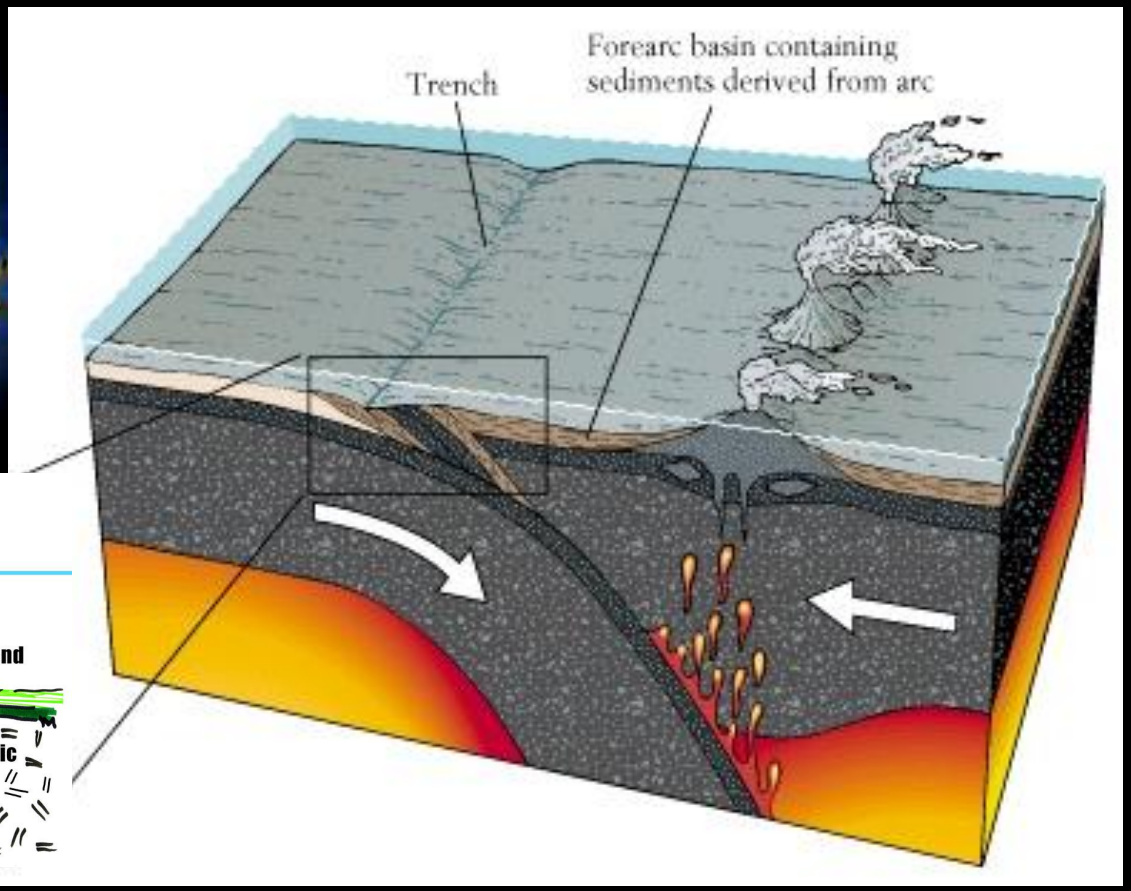
Let's Go Back In Time From Today to the Cambrian!

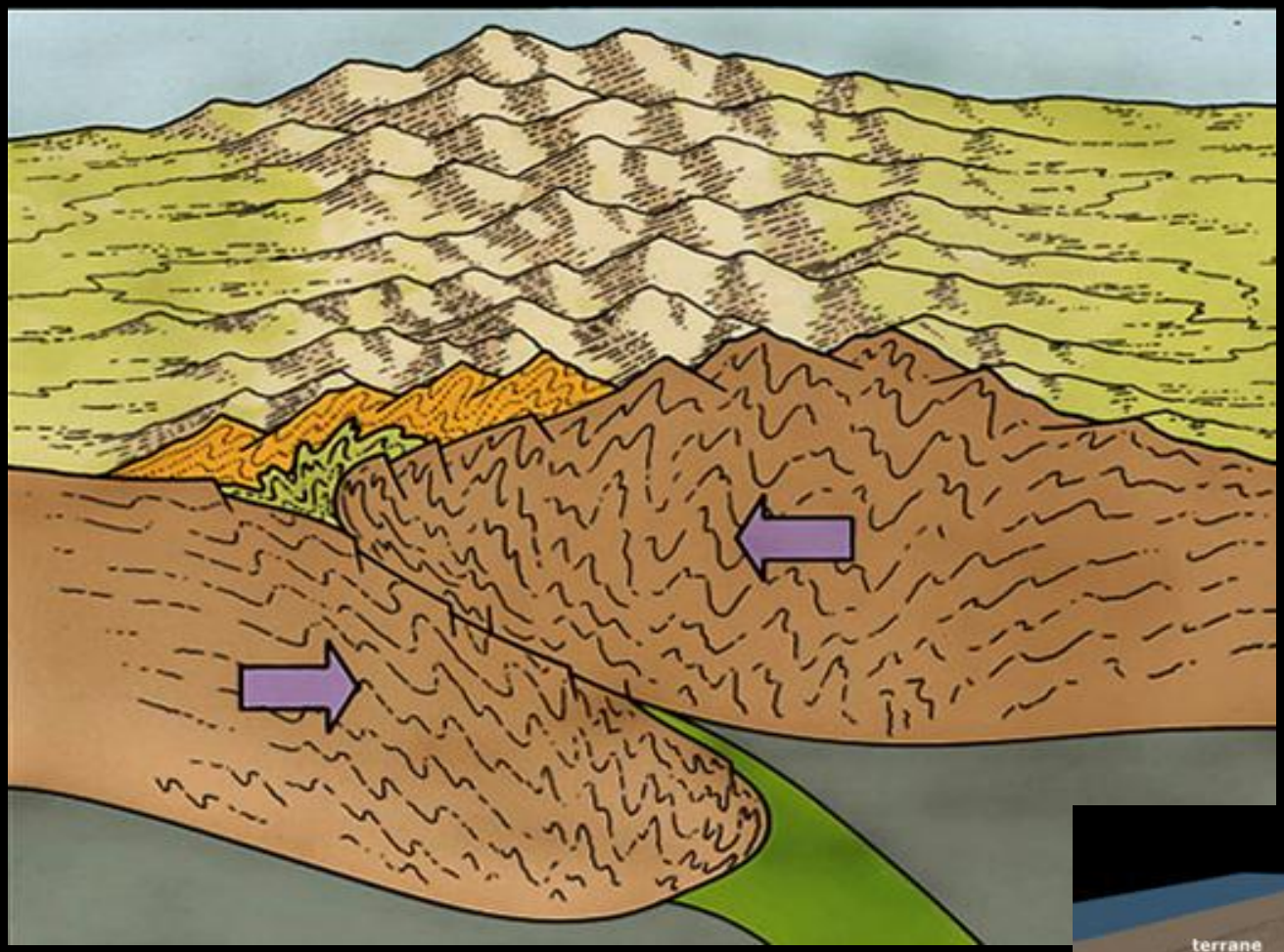

Early Medial Ordovician
(Early Chazyan)
Paleogeography
by Marshall Kay
Drawn by Erwin Raisz
Palinspastic base - Sinusoidal projection
0
500
1000
Miles
Paleo-shoreline
Paleo-equator
Peneplanation Crystalline Pre-Cambrian Rocks
Sandy Coastal Plain of Upper Cambrian
Limy Coastal Plain of Lower Ordovician
Champlain Magnesian Belt
Appalachian Belt
Seas with limy and sandy bottoms on miogeosynclines
Seas with bottoms of argillaceous muds and volcanic rocks on eugeosynclines
after Kay, 1951

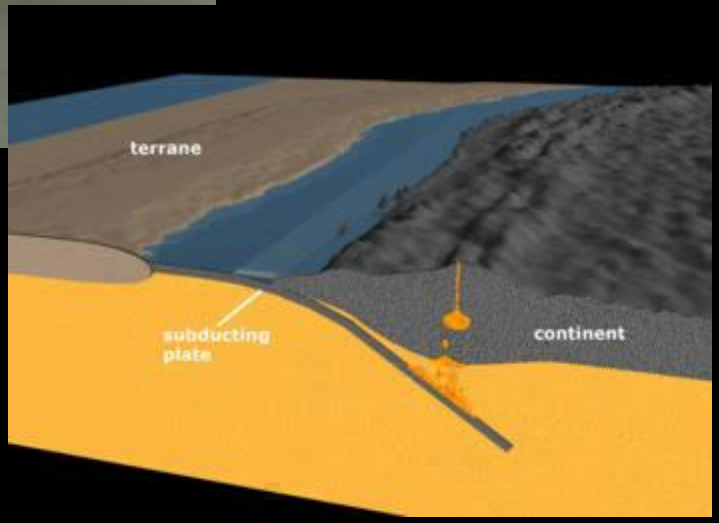

Future Site
of New York City
Walloomsac
Inwood
Fordham
Manhattan
Hartland
Oceanic
Crust
Mantle

~ 450 Ma Taconic Arc – Passive Margin Collision







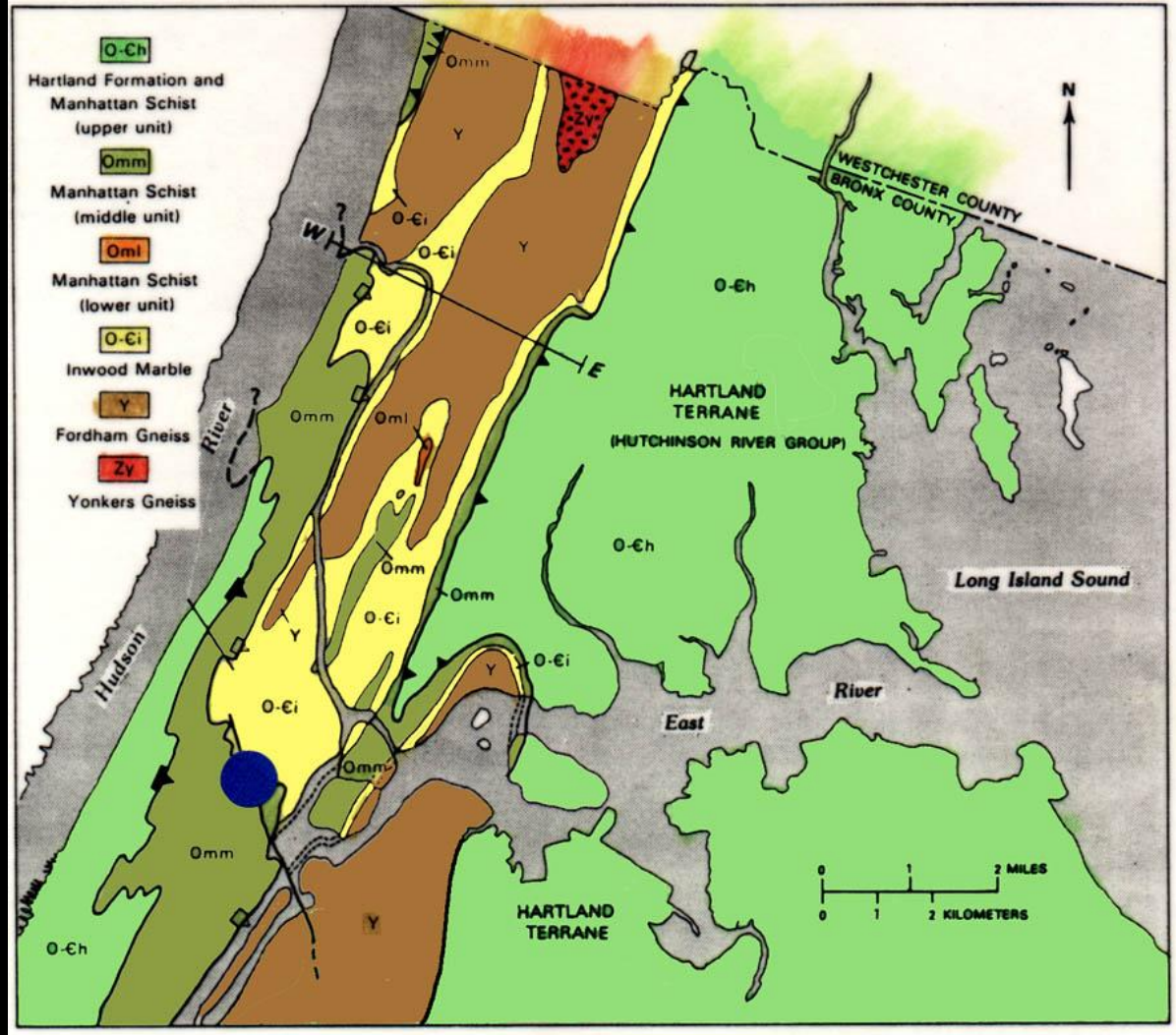


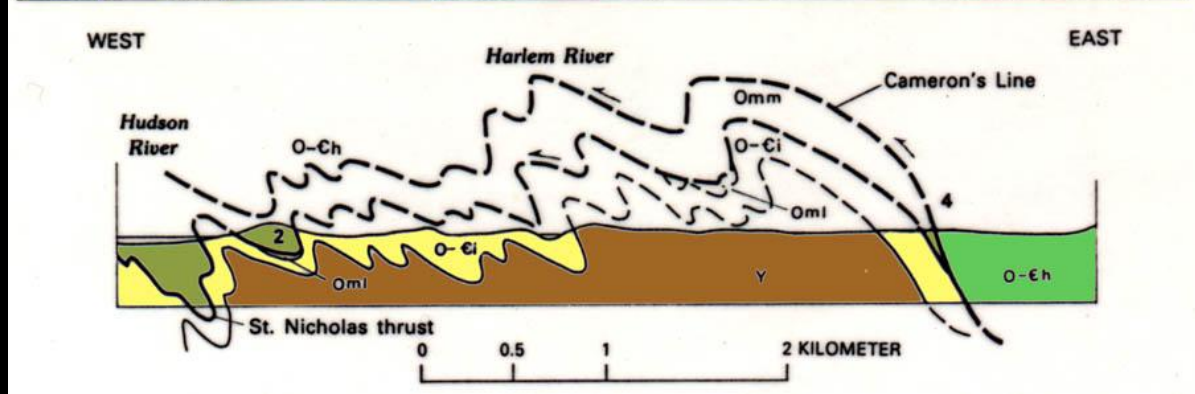
450 Ma to 250 Ma Protracted Plate Collisions Form the Appalachians

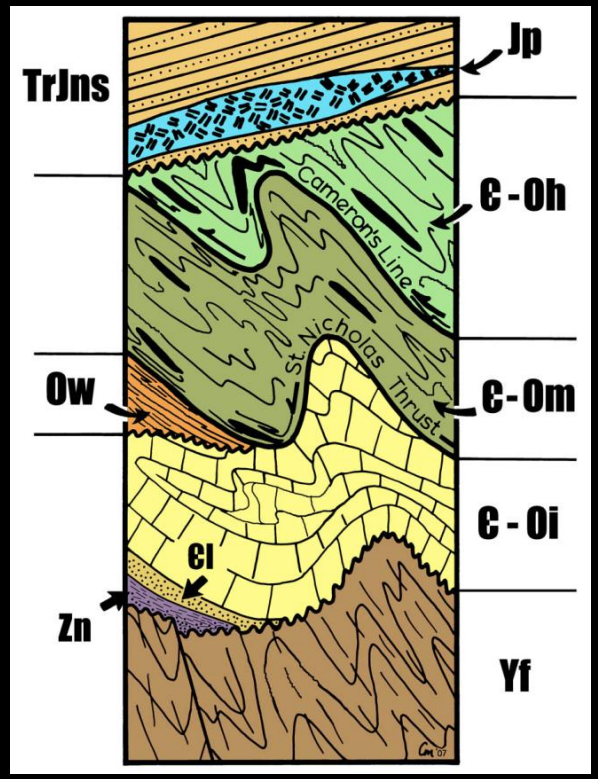
Merguerian Has Spent Most of his Career Mapping the Surface and Subsurface Geology of NYC

Proper Field Attire For NYC

New York City

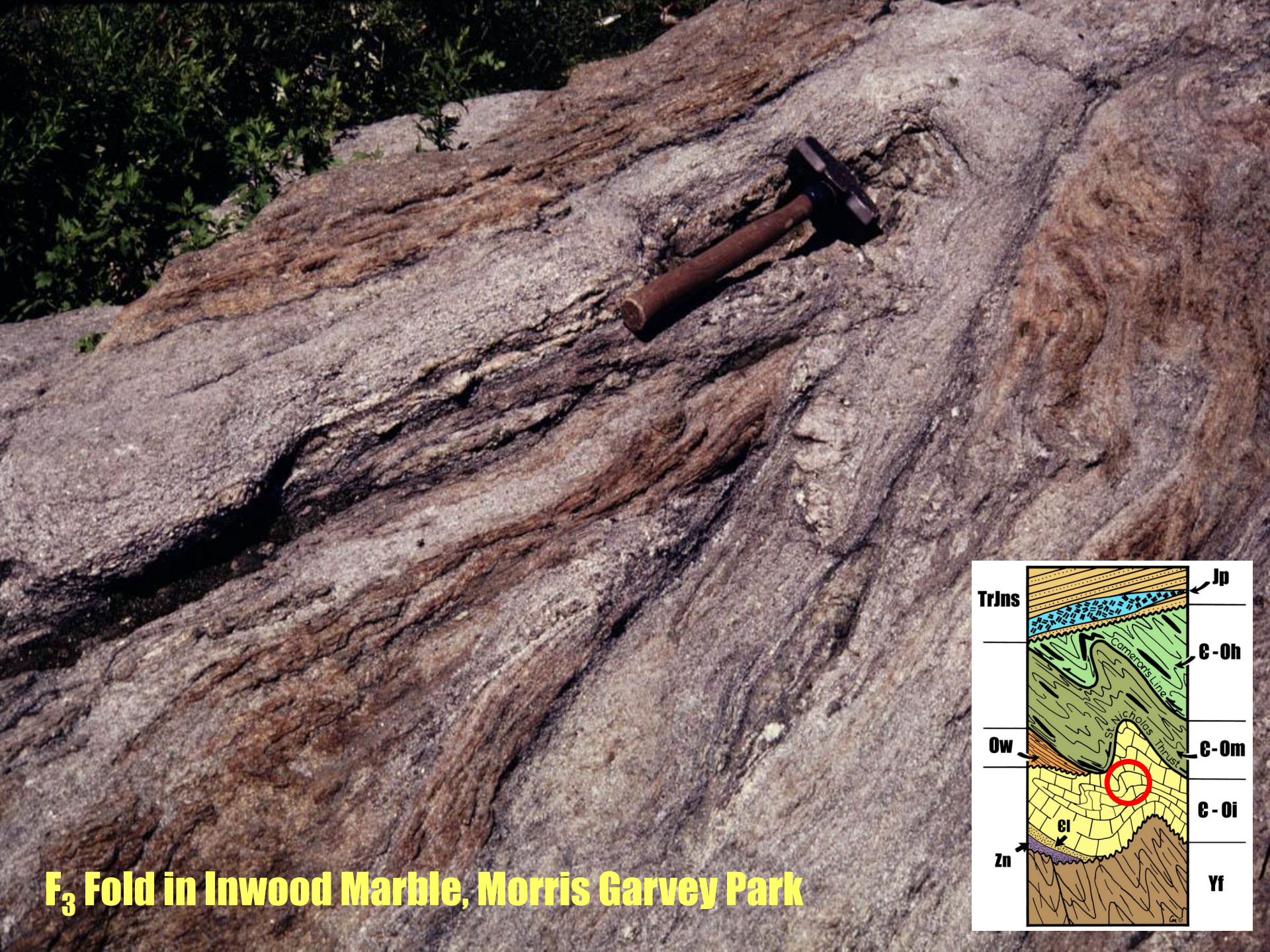






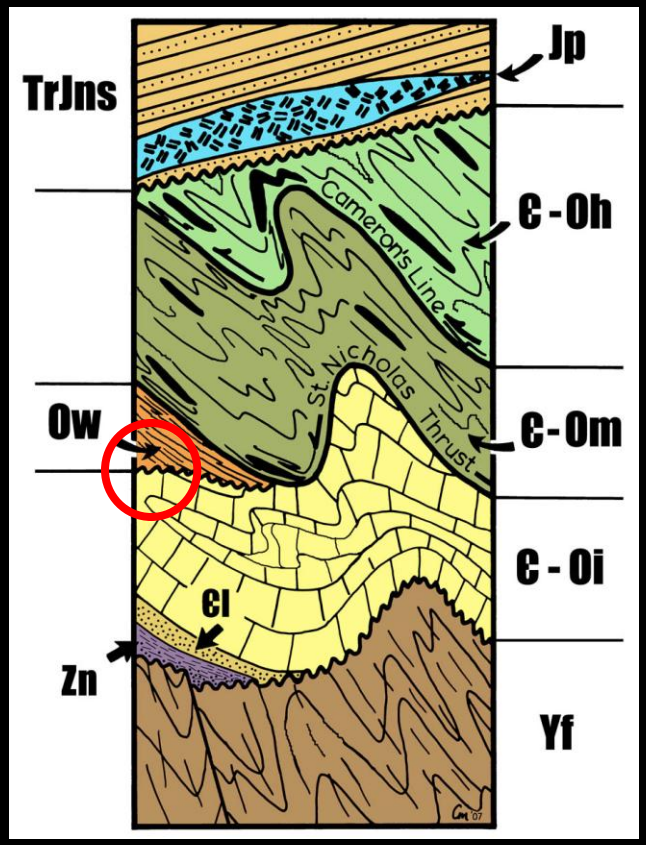
Merguerian, 2001

Fordham Gneiss, Echo Park
TrJns
Jp
Є - Oh
Cameron's Line
St. Nicholas Thrust
Ow
Є - Om
Є - Oi
Єl
Zn
Yf

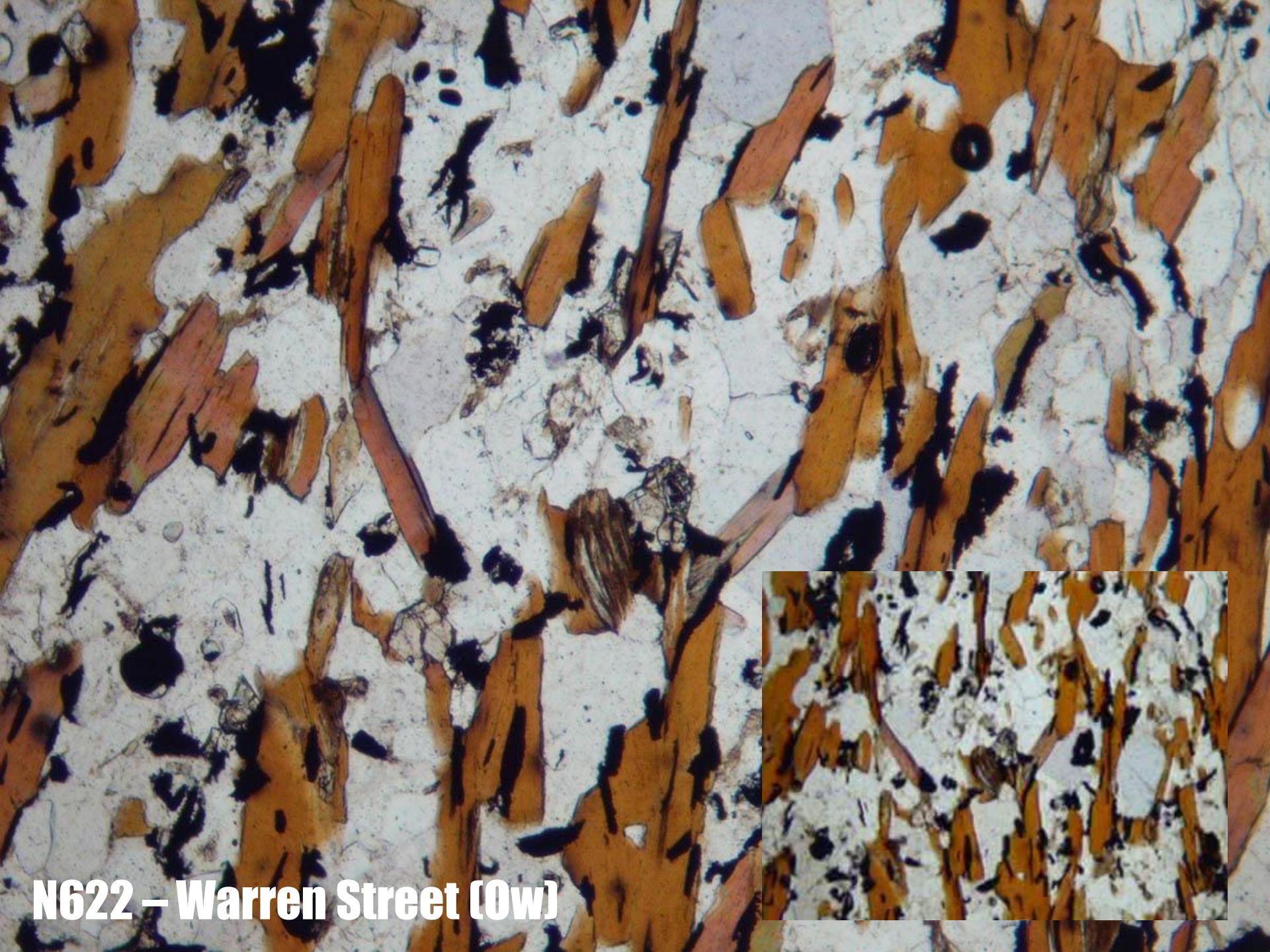


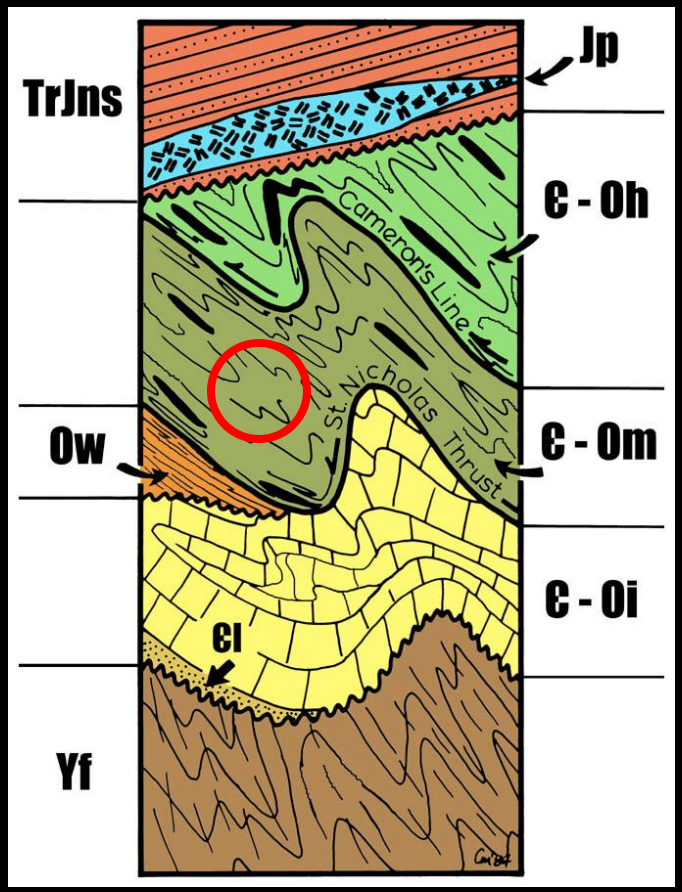
F_3 Fold in Inwood Marble, Morris Garvey Park

N631 – Warren Street (Ow)

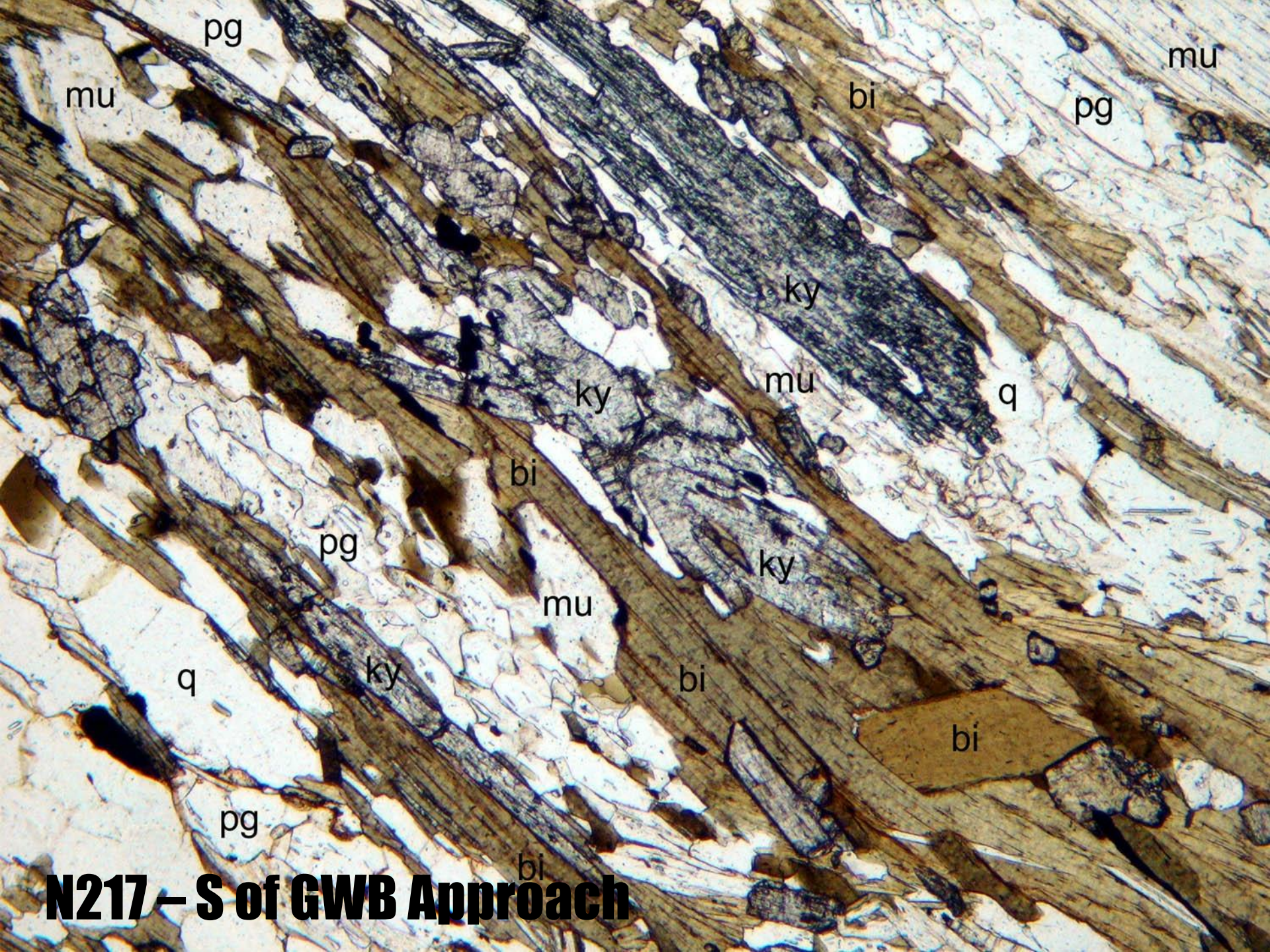


Walloomsac "Balmville" Contact, Grand Concourse, Bronx, NY


N622 – Warren Street (Ow)

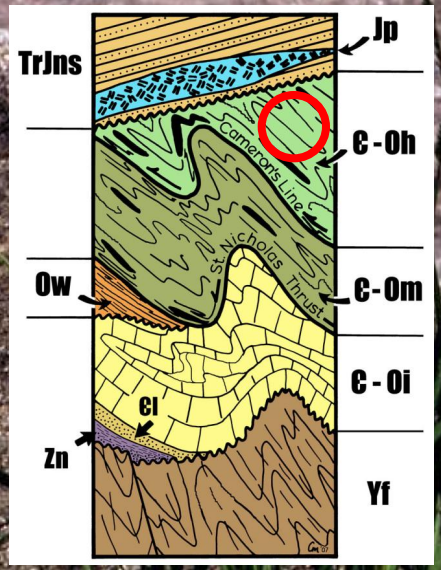


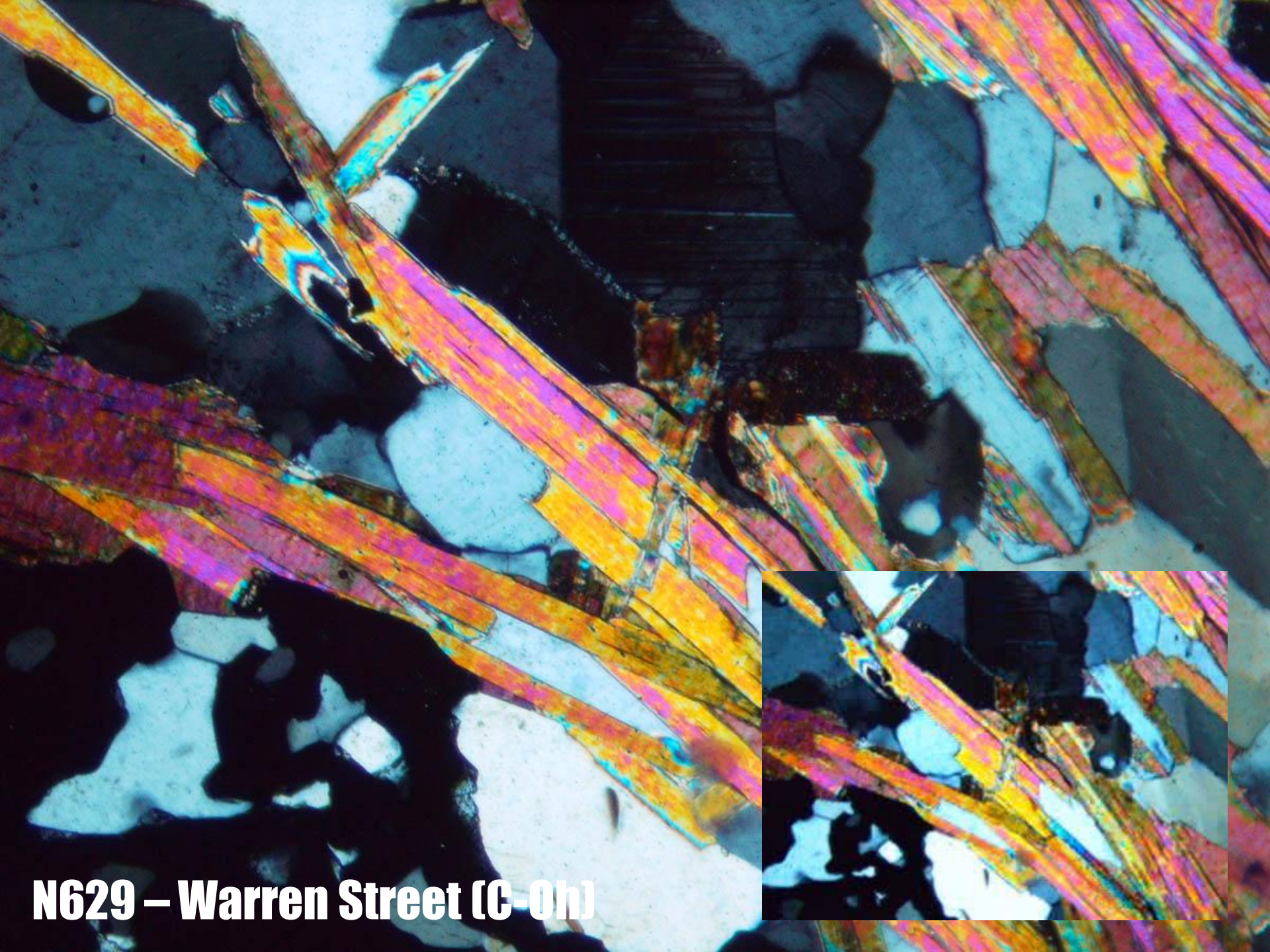
Manhattan Schist
F_3 Folds of S_2
Central Park, NYC

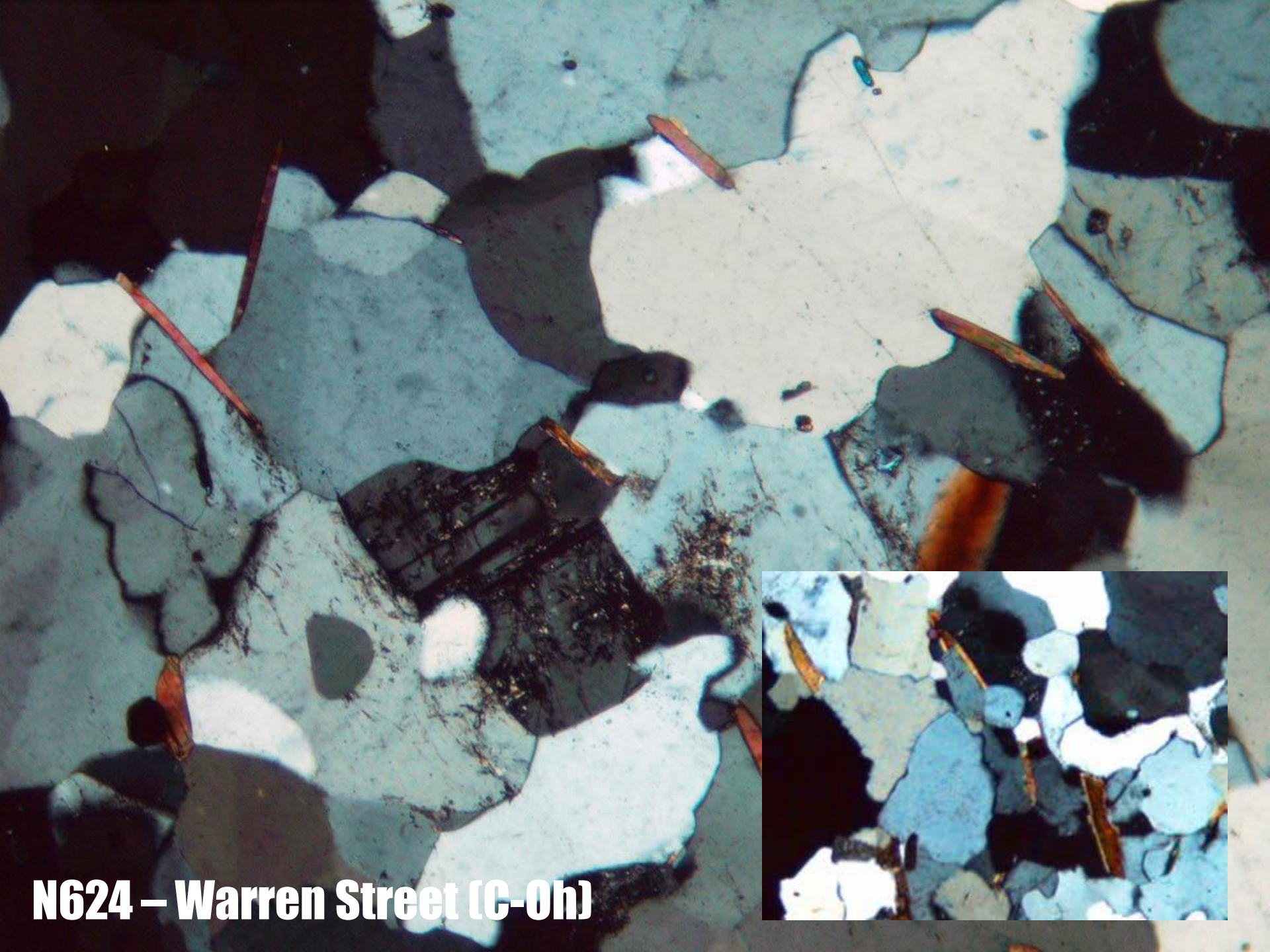


N217 – S of GWB Approach

Hartland Schist, Riverside Park

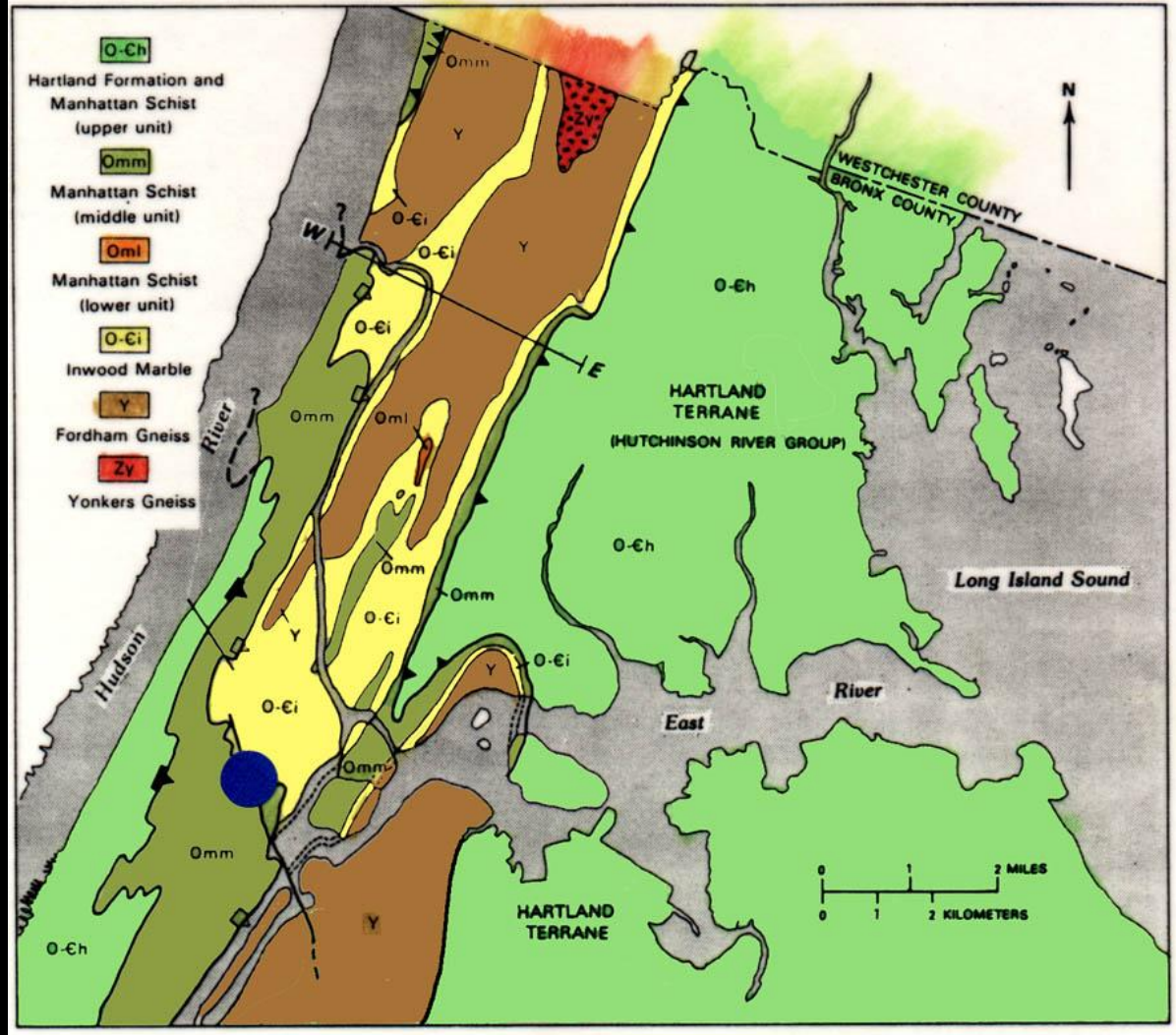


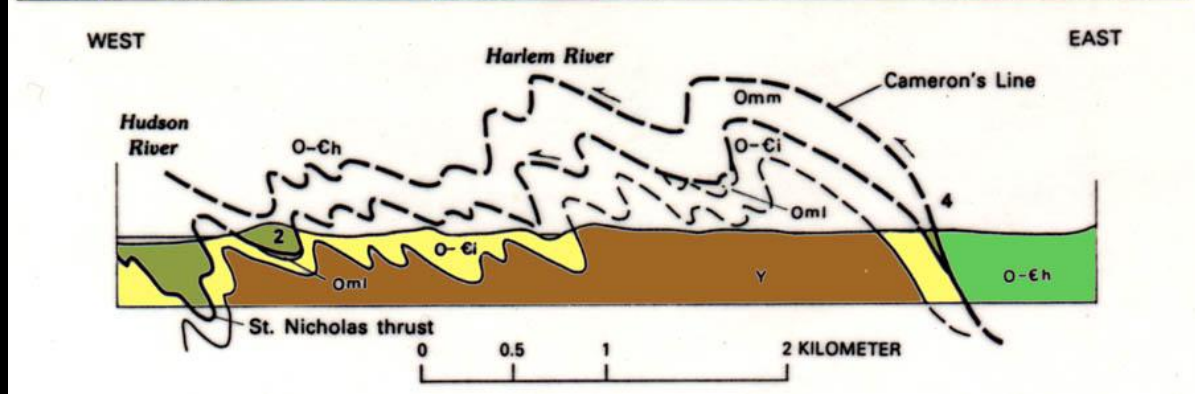

N629 – Warren Street (C-Oh)

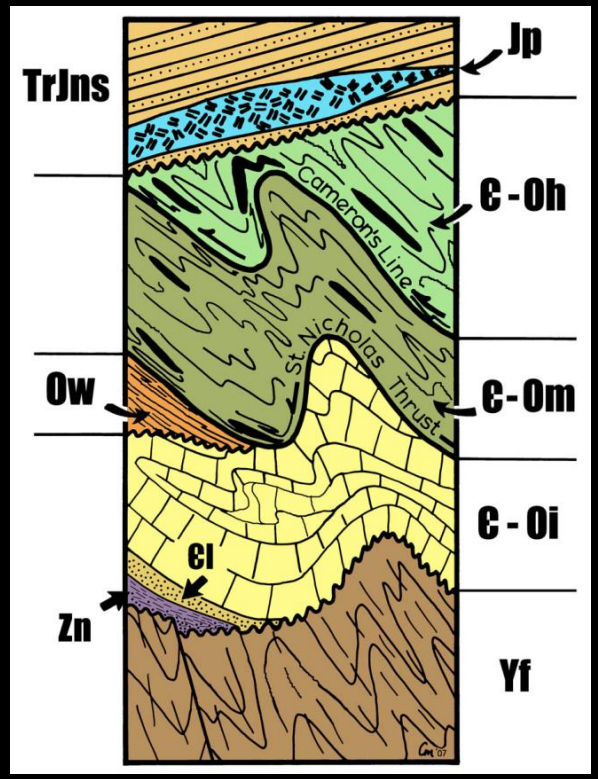

N624 – Warren Street (C-Oh)

Hartland Amphibolite N567

New York City



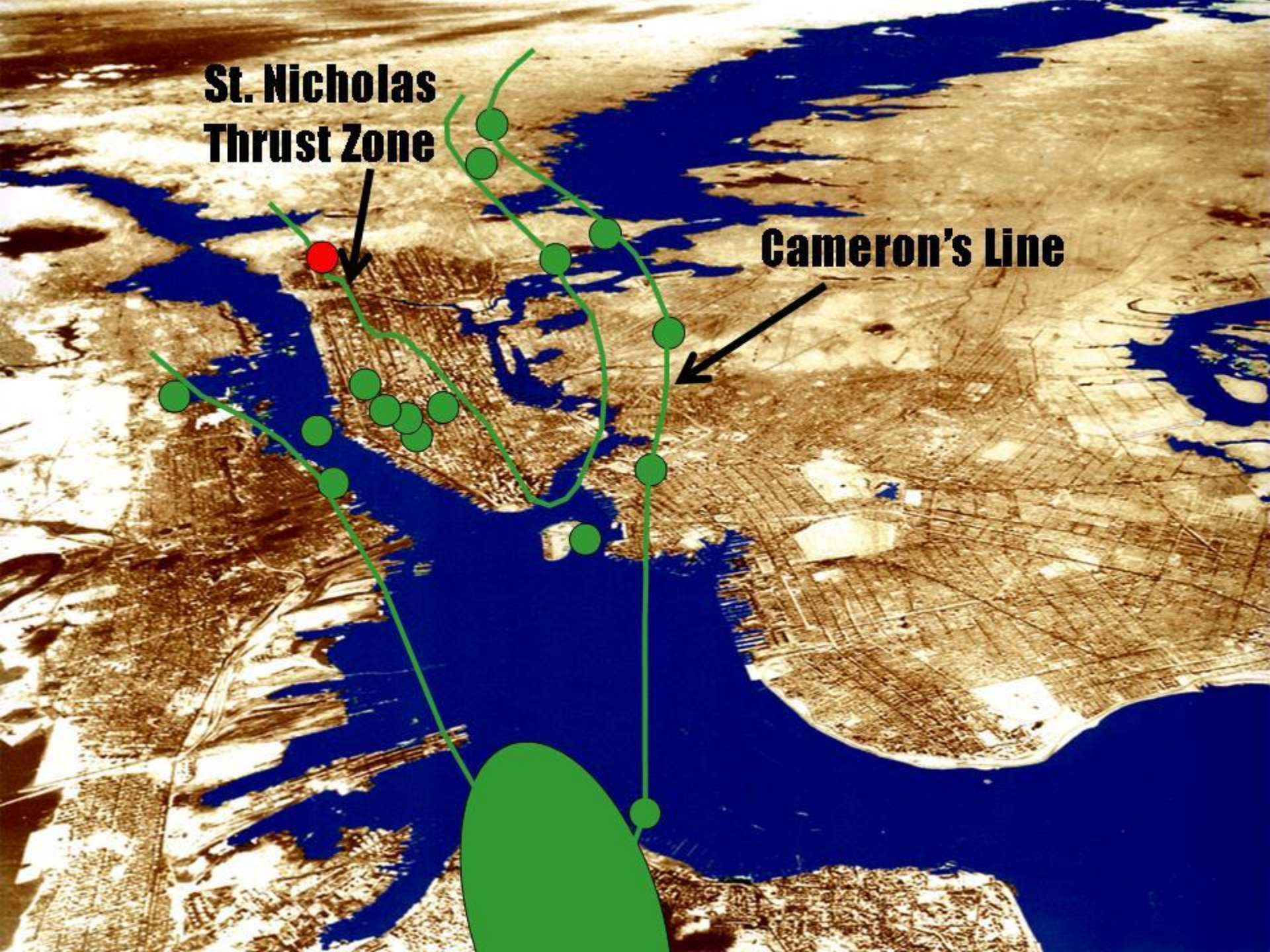




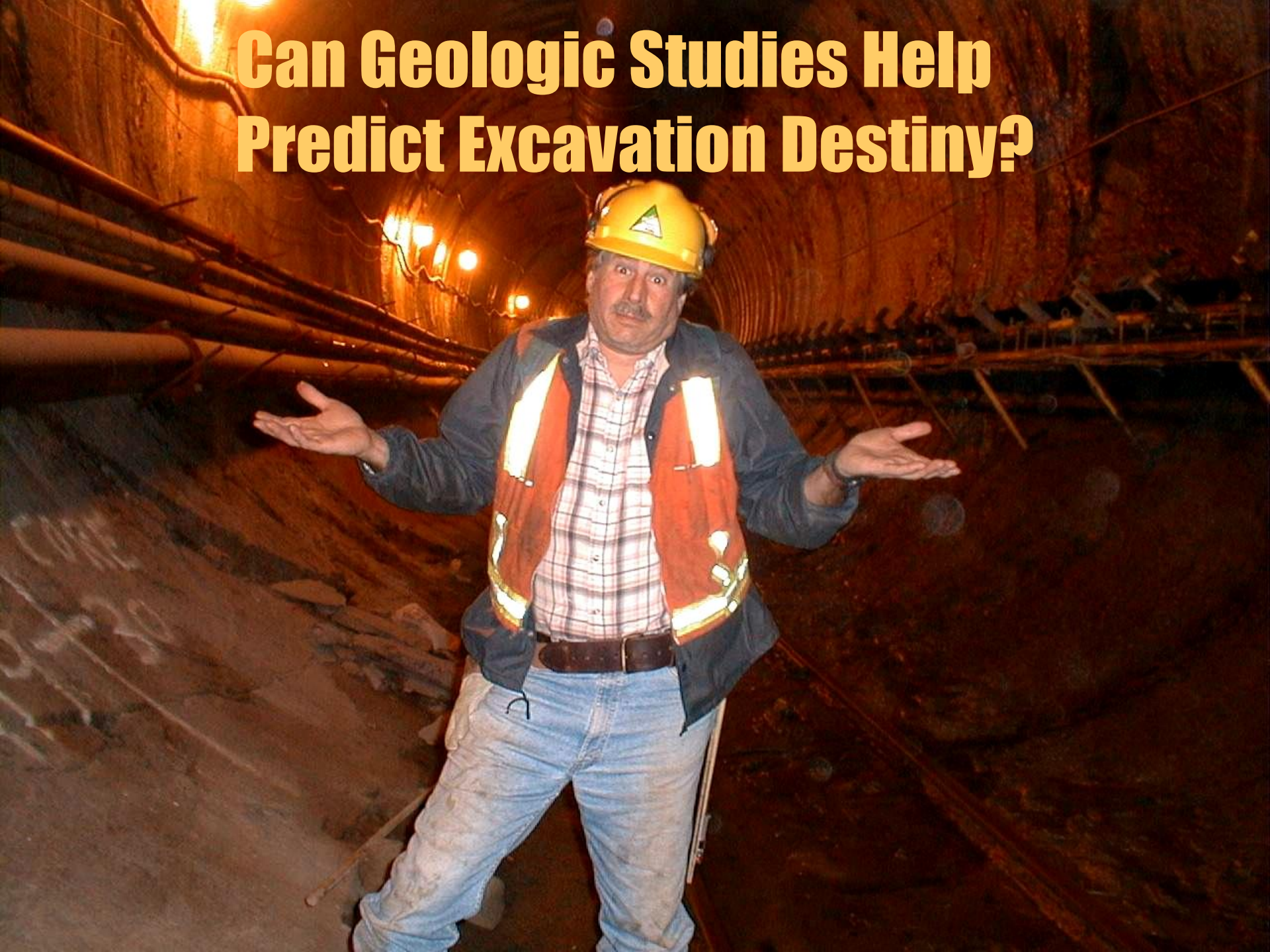
Merguerian, 2001

One Bryant Park Serpentinite
Talc-Chlorite-Biotite Shear Envelope

Cigar-Shaped Mass with Steep Plunge Southward
Base Not Exposed
>10 m Long Dimension
70º


St. Nicholas
Thrust Zone
Cameron's Line

Can Geologic Studies Help Predict Excavation Destiny?



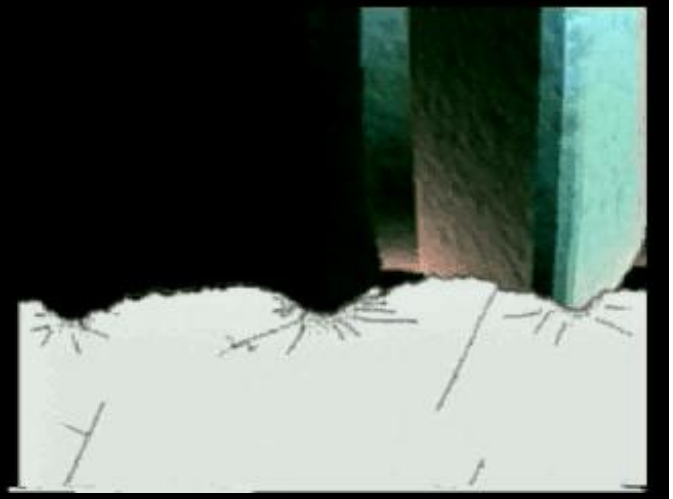
Pre-Bid Analysis Should Include:

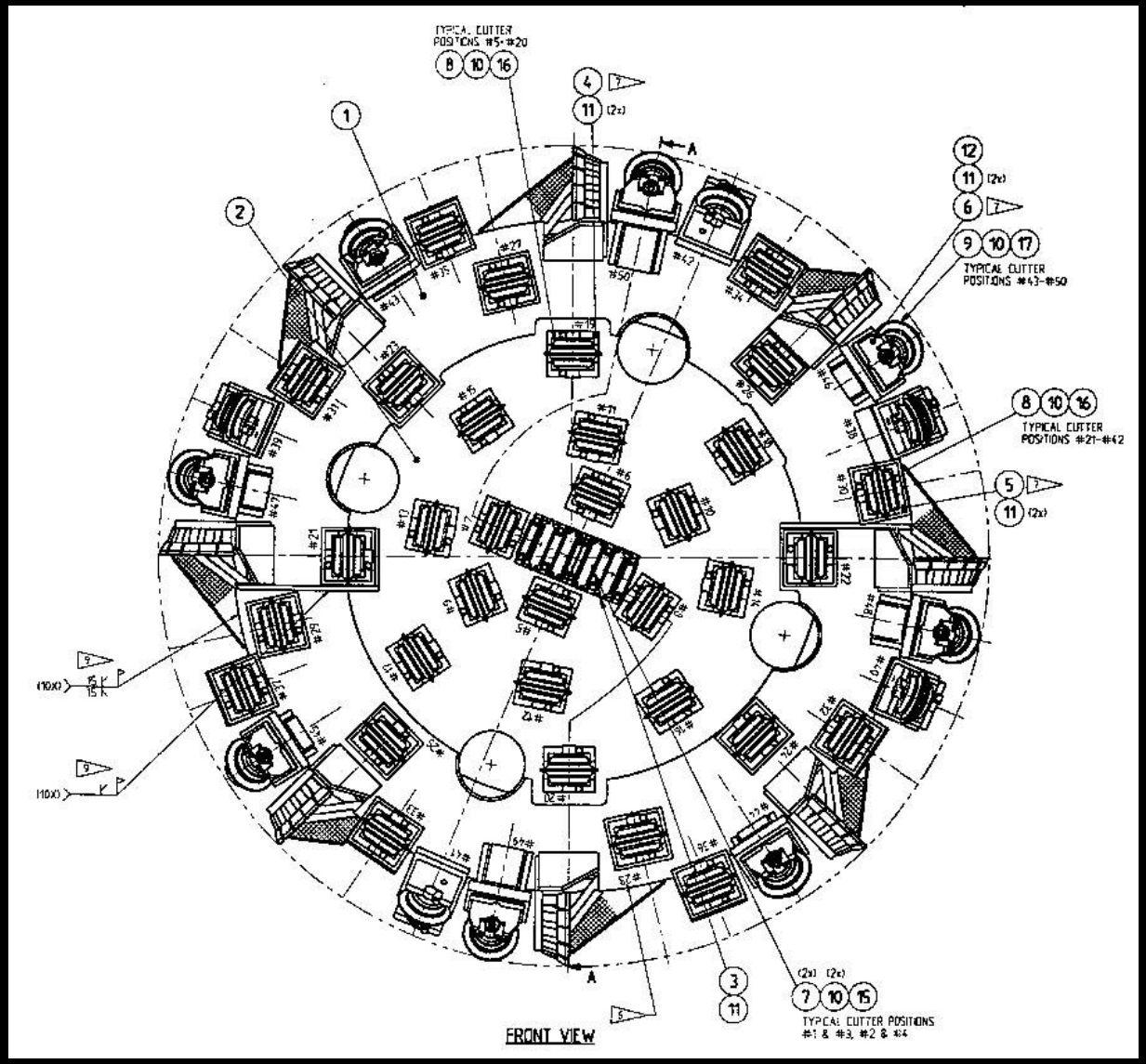
- Published Maps and Reports
- Boring Analysis
  - Fractures
  - Rock Types
  - Rock Fabrics
  - Density Studies
  - Petrographic Studies
- Rock Fabric Studies
  - Mineralogy and Texture
  - Structure
  - Orientation
  - Metamorphism

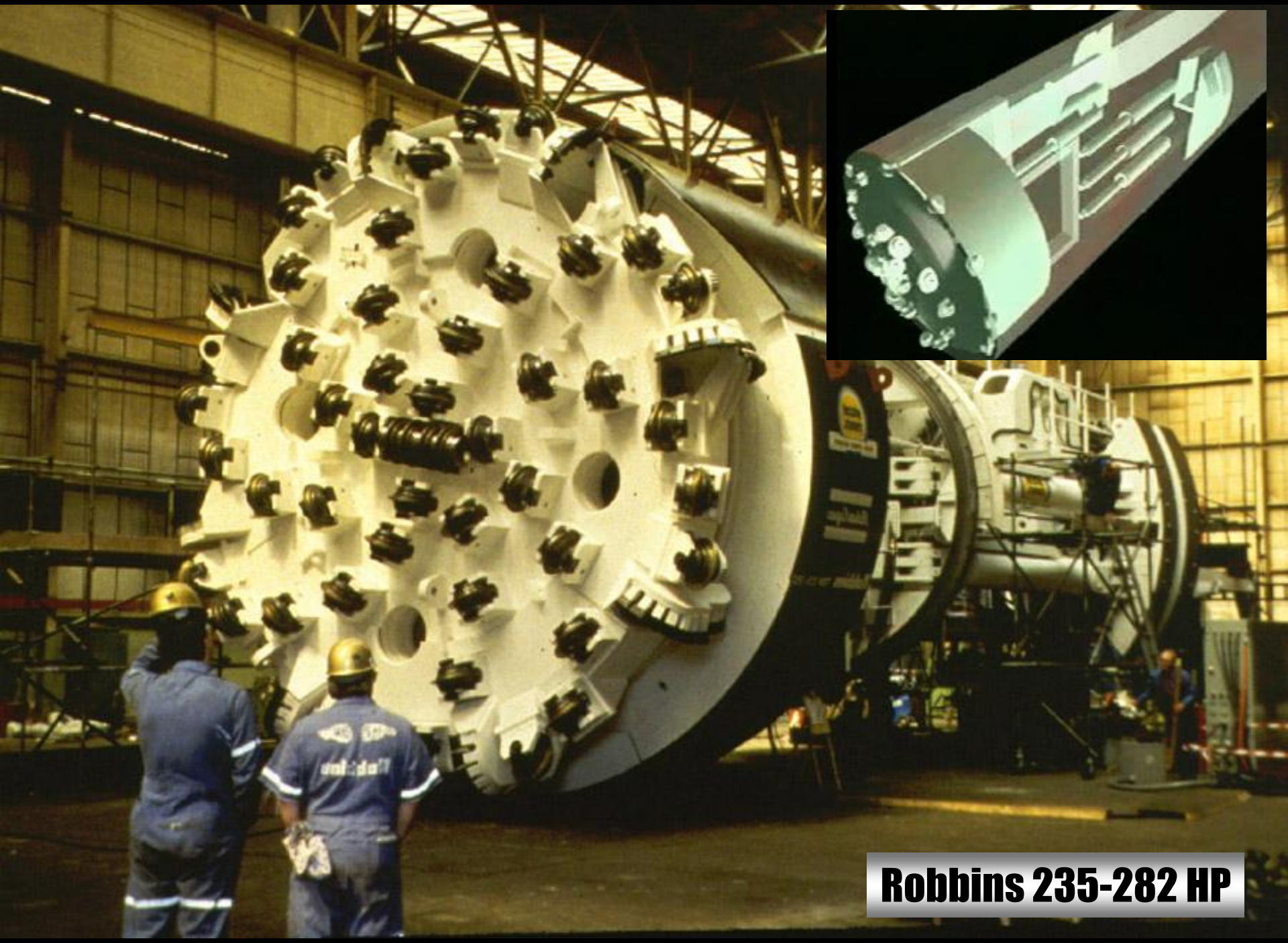
What Are the Geological Controls on Effective Hard Rock TBM Tunneling in Crystalline Terrains?

Excessive Fines
Blocky Ground
Unstable Headings and Sidewalls
Low Penetration Rates

TBM Chip Production







Robbins 235-282 HP

Excessive Fines

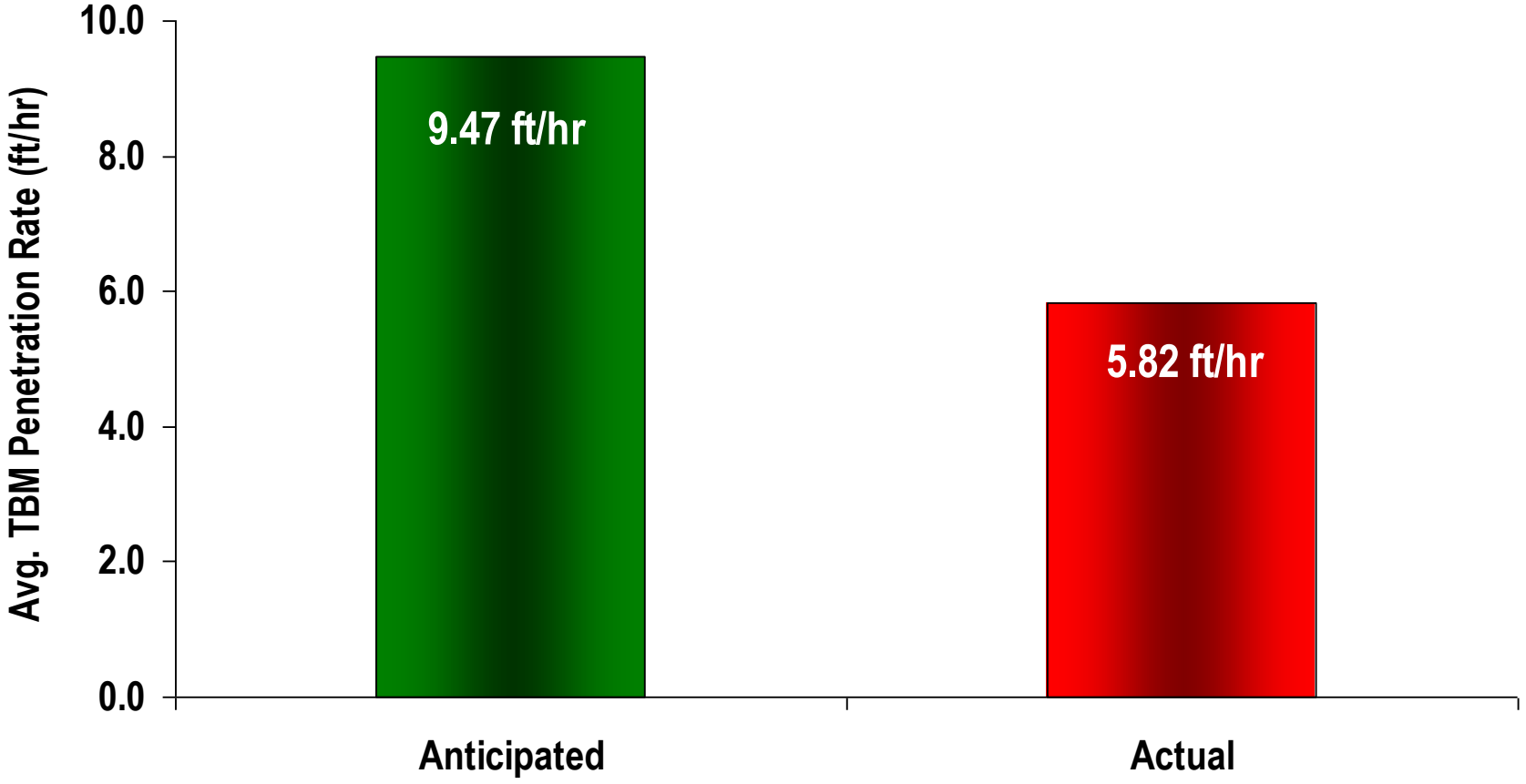
Blocky Ground

Desirable Kerf Pattern in Hard Rocks

Collapsed Crown and Sidewalls
Short Stand-up Times
Station 153+30

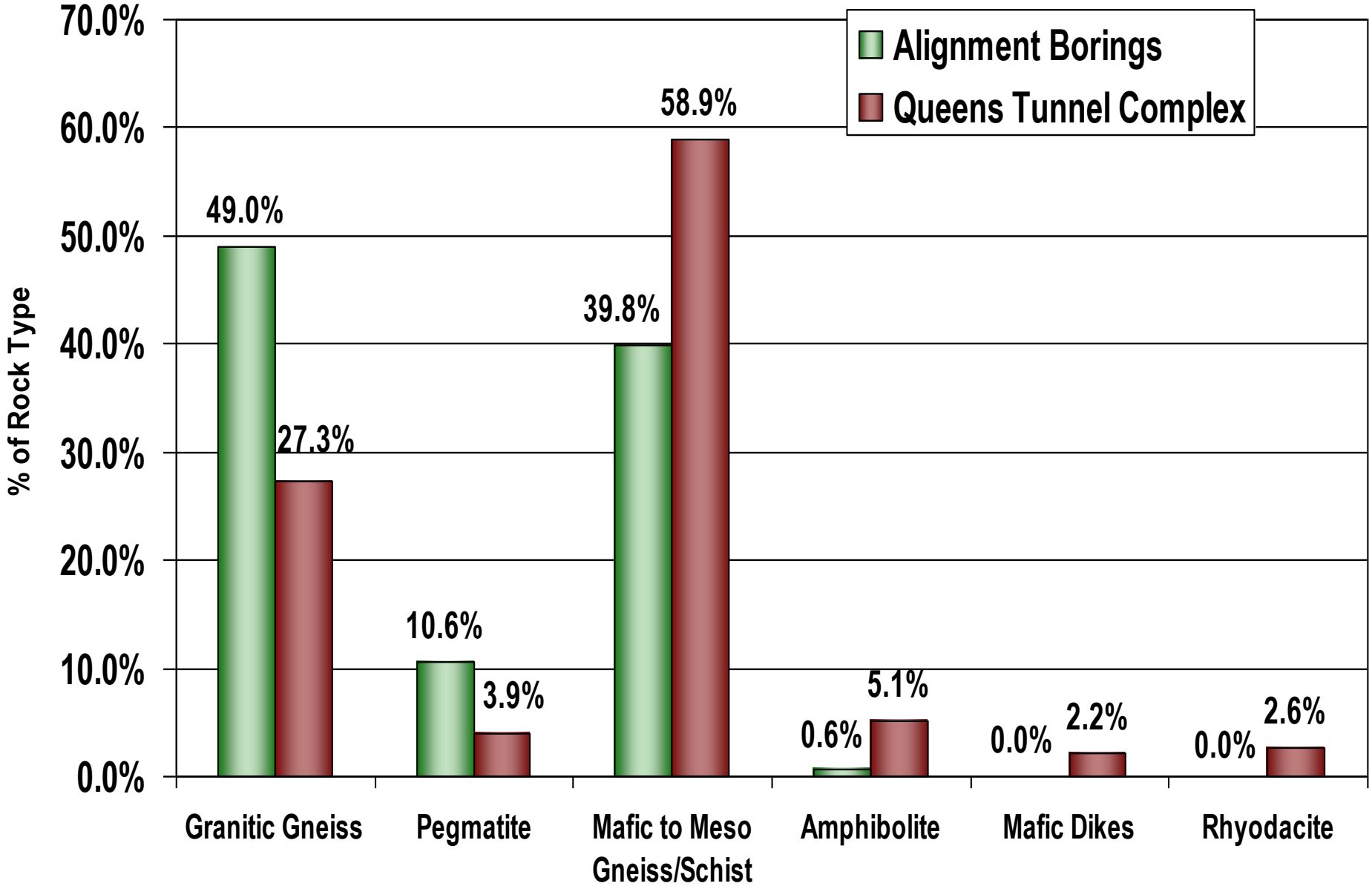
Unforseen Tunneling Problems

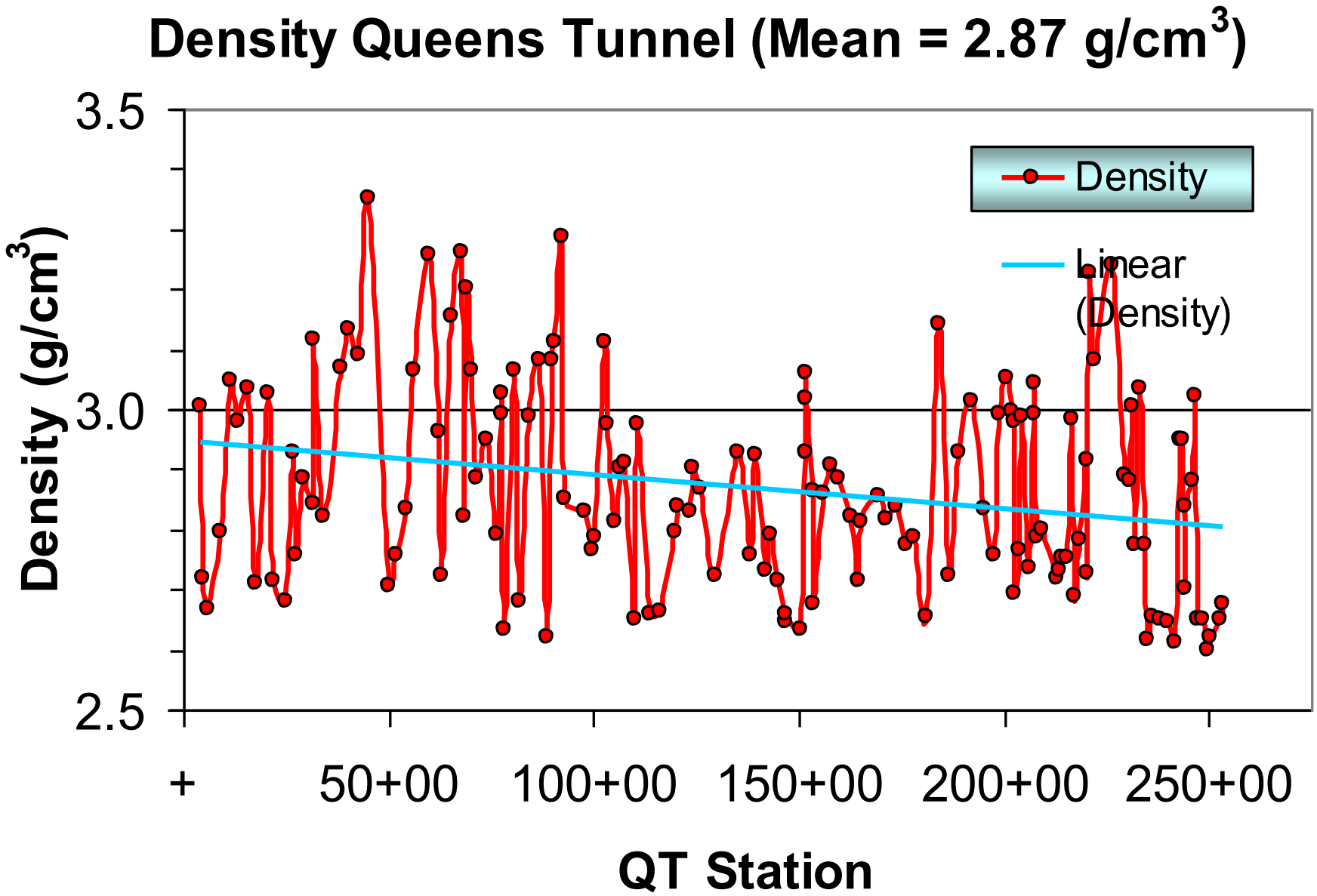
Anticipated vs. Actual Penetration Rate

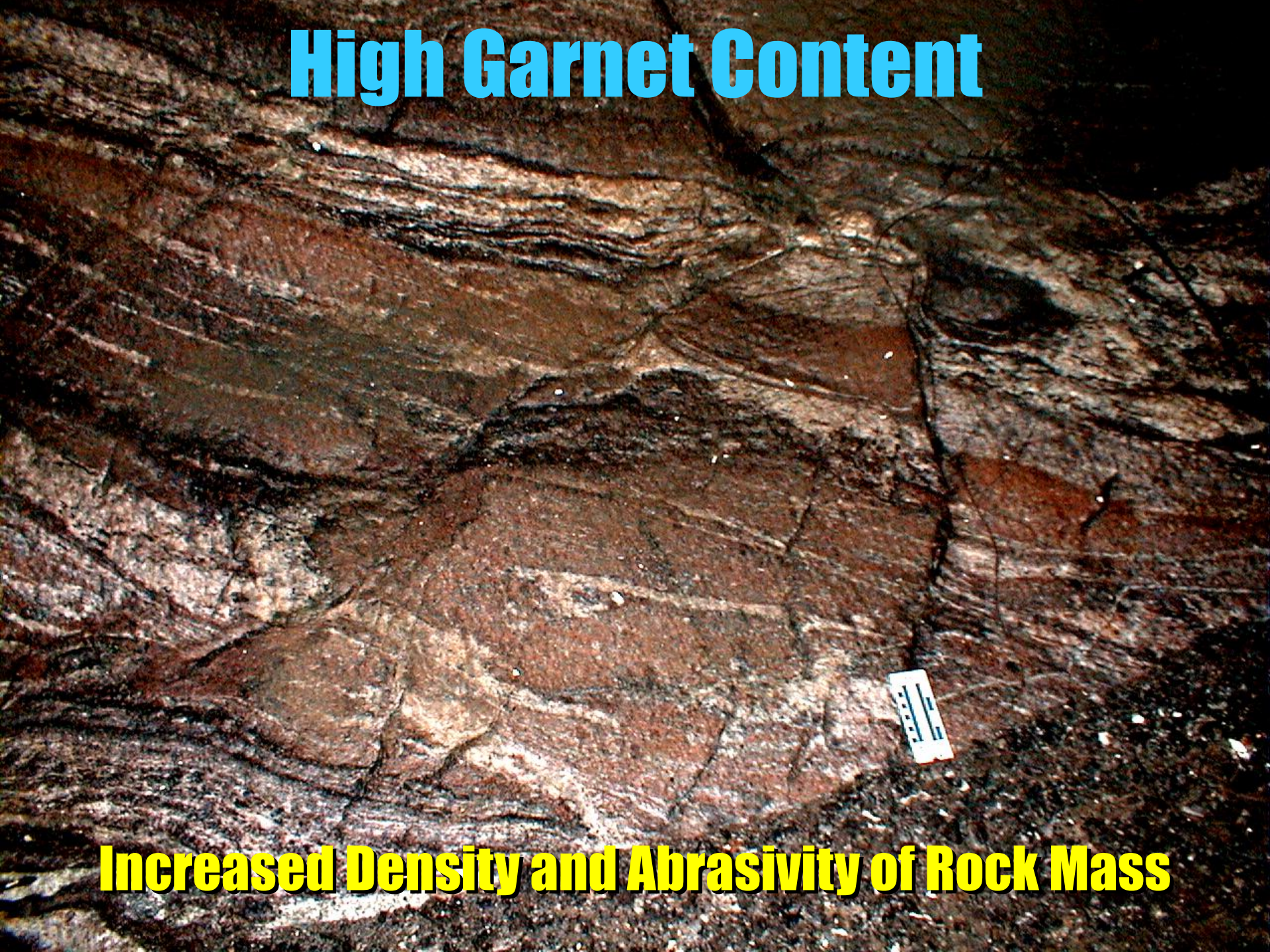


Merguerian's Queens Tunnel Field Office

Comparative Lithologic Analysis



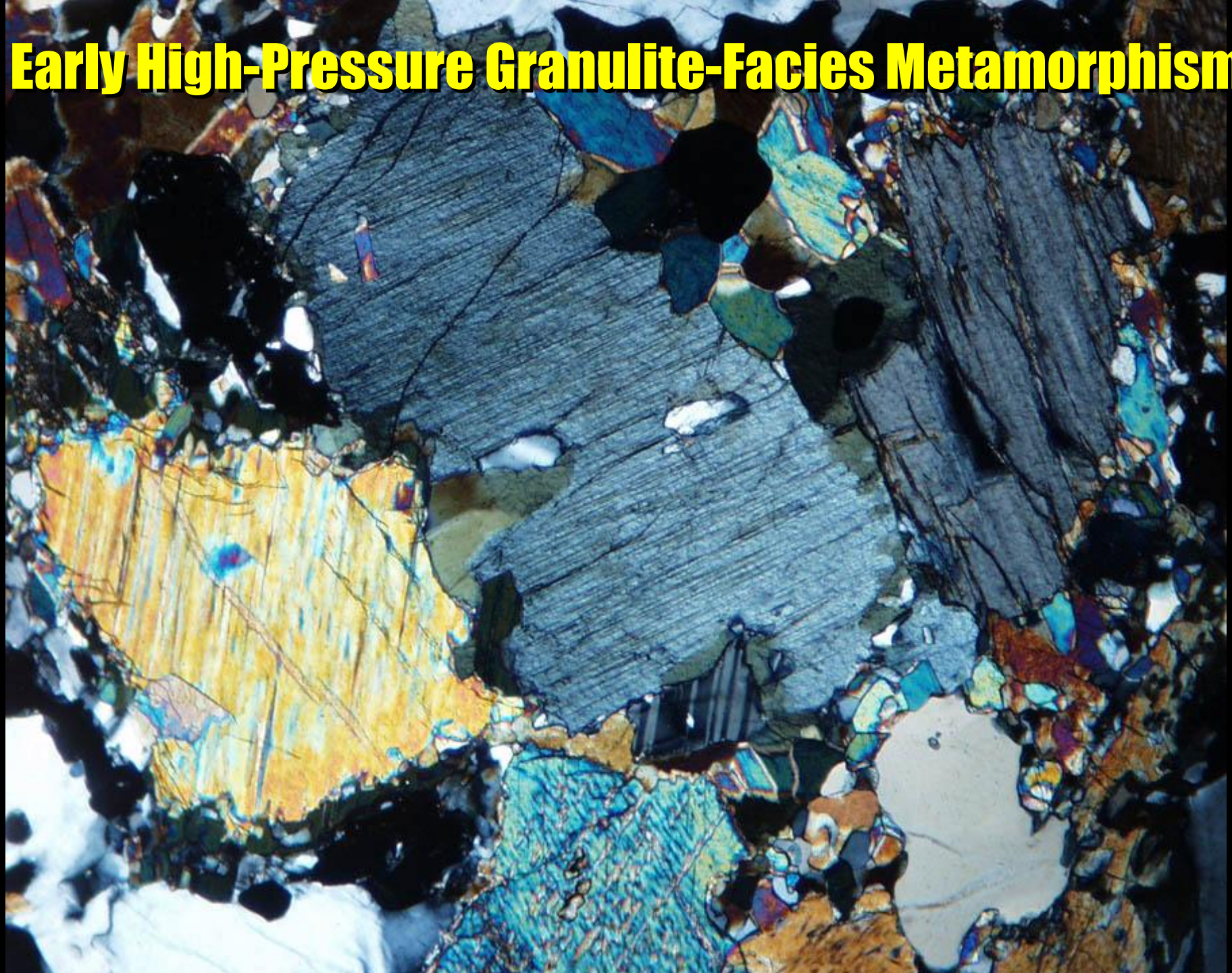

Density Queens Tunnel (Mean = 2.87 g/cm3)
3.5
3.0
2.5
Density (g/cm3)
Density
Linear (Density)
+
50+00
100+00
150+00
200+00
250+00
QT Station

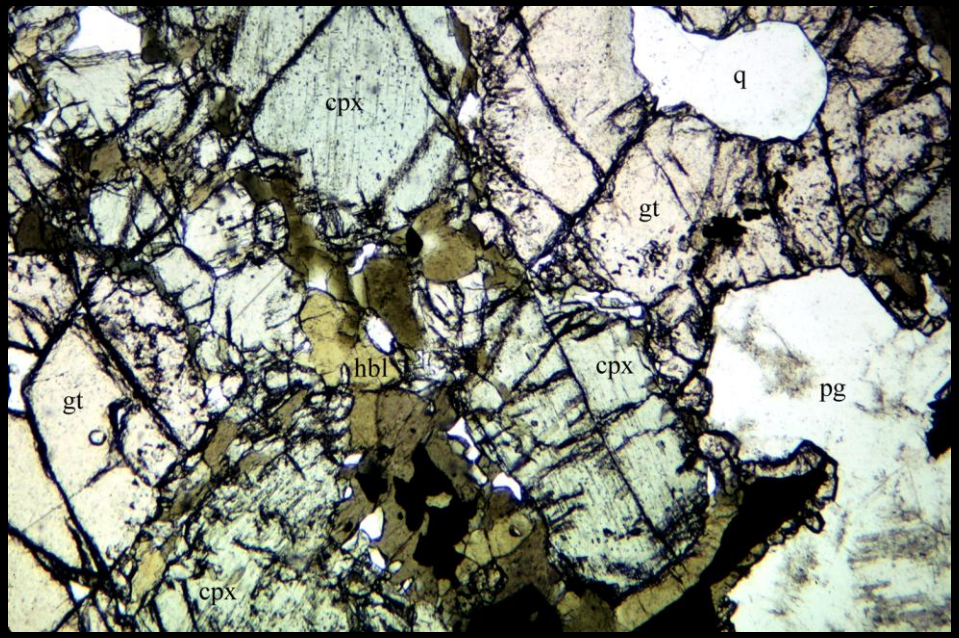

High Garnet Content
Increased Density and Abrasivity of Rock Mass

Unexpected High Garnet Content

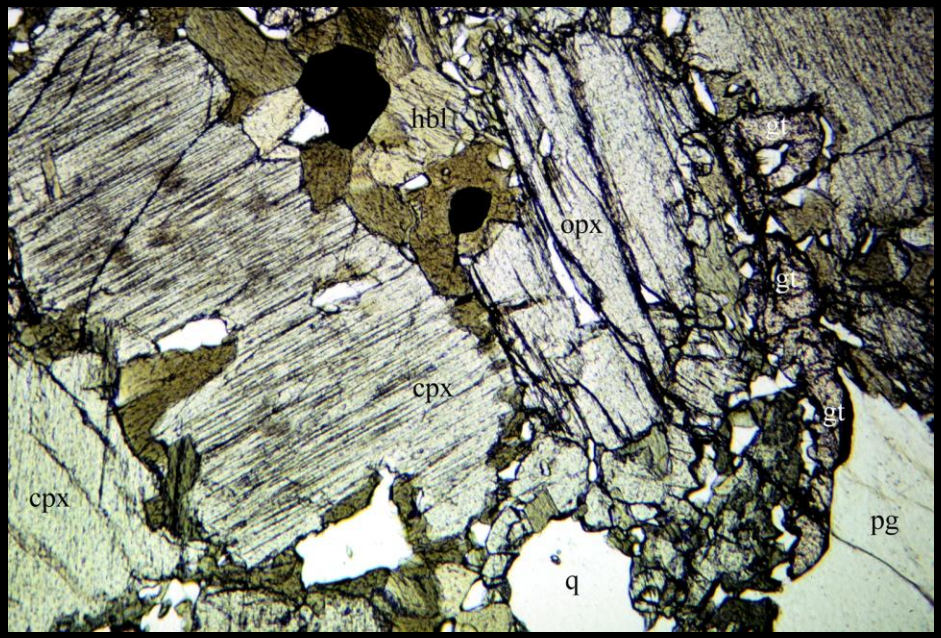
- The boring logs cite the term garnetiferous throughout. To most geologists, “garnetiferous” rocks contain a few % garnet
- Thirty two Queens Tunnel Garnet Zones mapped. They underlie 2,663’ or 10.64% of as-built tunnel
- The Queens Tunnel rocks contain up to 50% garnet
- The Queens Tunnel Garnet Concentrations would be called “ore deposits” in many parts of the world
- Results in abrasivity to cutters and production of excessive fines

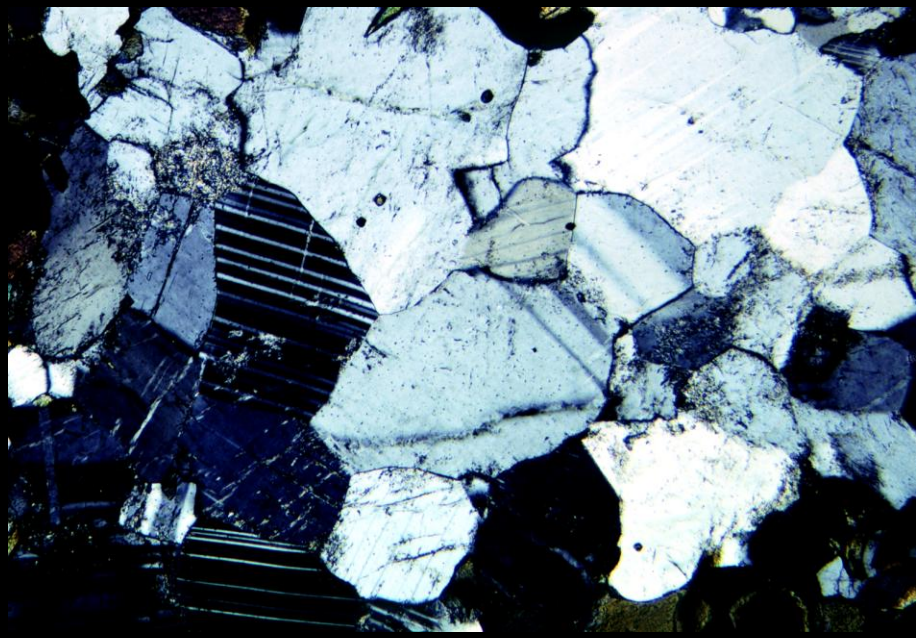
Early High-Pressure Granulite-Facies Metamorphism



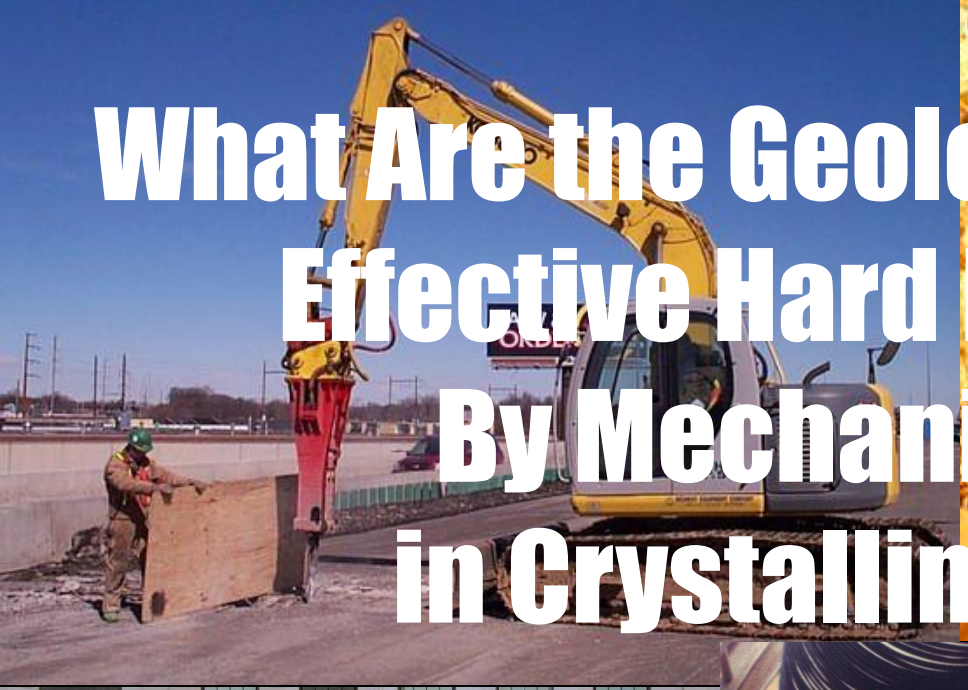


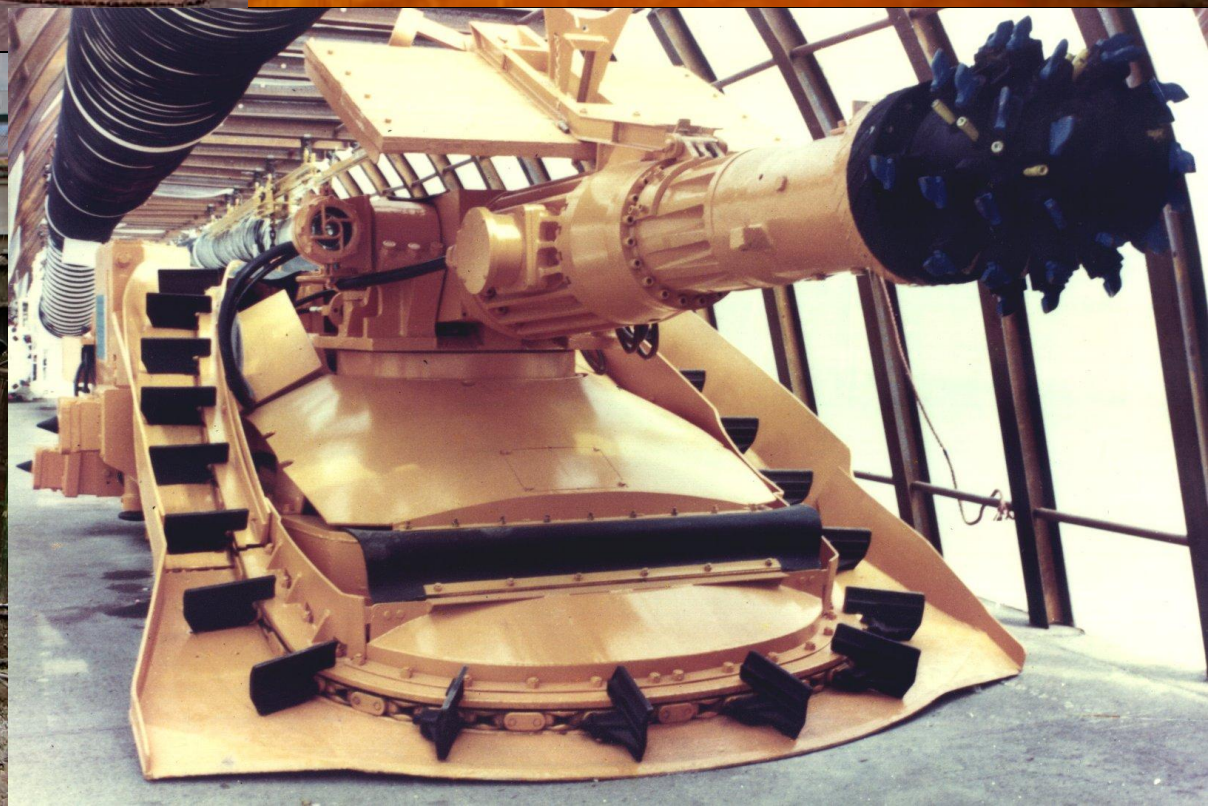
Granulite Facies Gneisses Found in the Queens Tunnel and Elsewhere With Granoblastic Textures = Tough Rocks for Excavation!

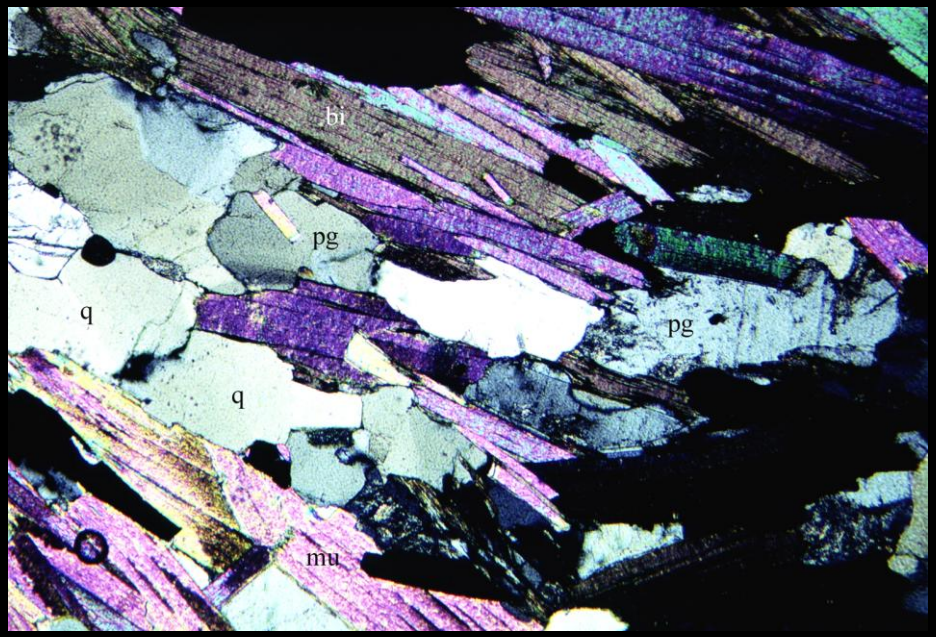




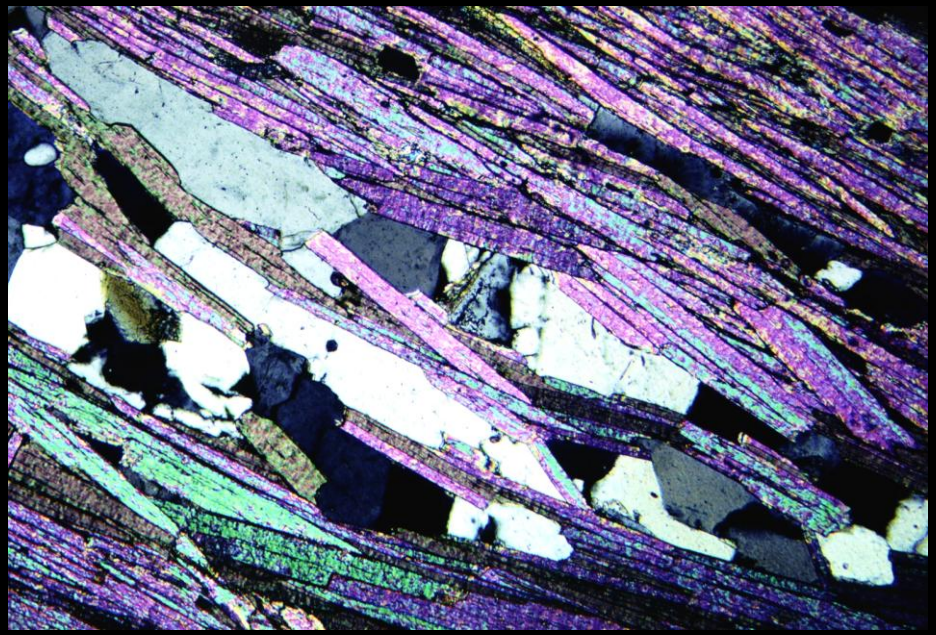
What Are the Geological Controls on Effective Hard Rock Removal By Mechanical Means in Crystalline Terrains?

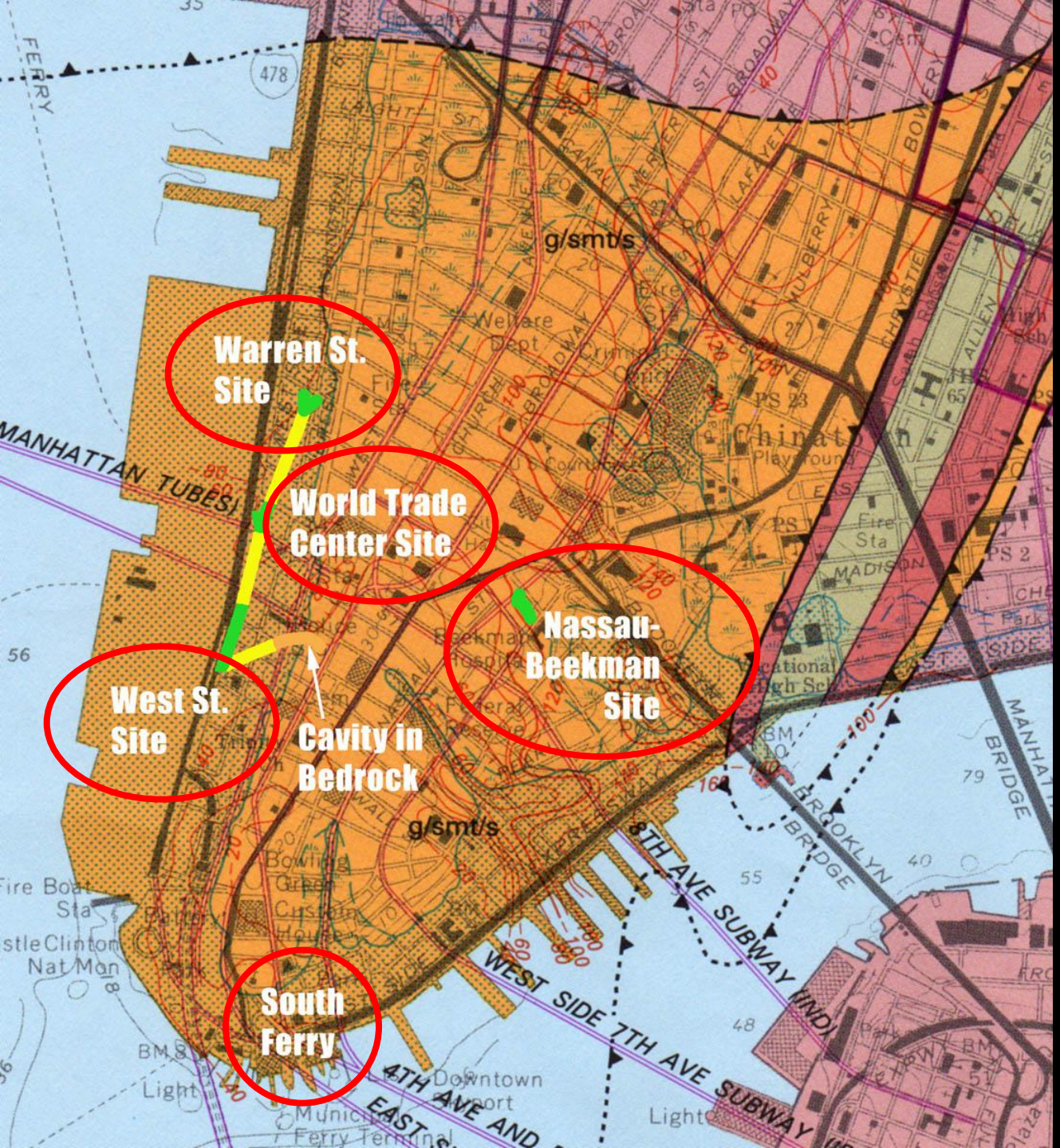






In Western and Central Manhattan:
Amphibolite Facies Schists
Well-layered Hartland Fm.
Penetrative Foliated Textures
Great Rocks for Tunneling and Excavation!



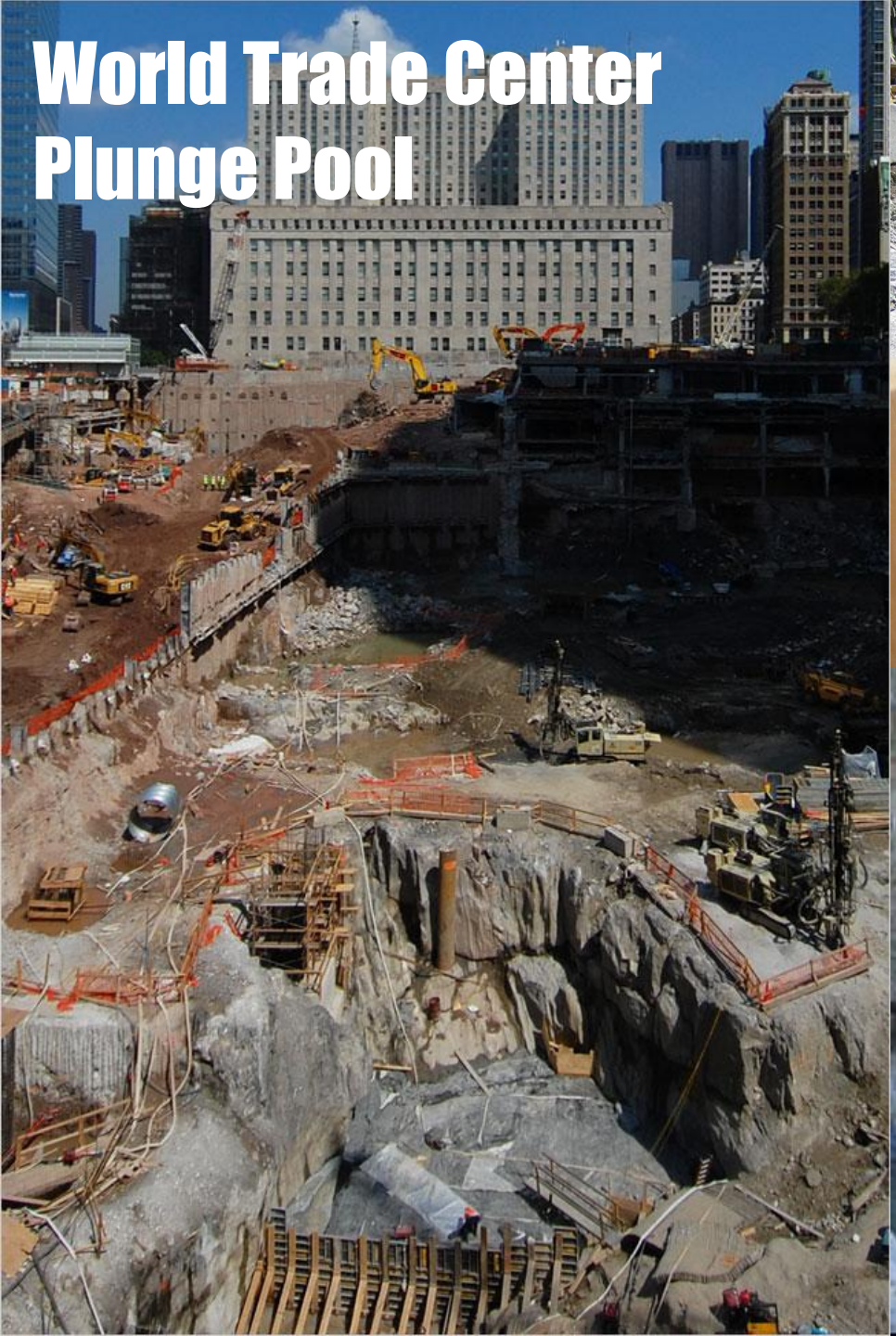


Five Localities South of Canal Street

Display Sheared Manhattan, Hartland, and Walloomsac Rocks!

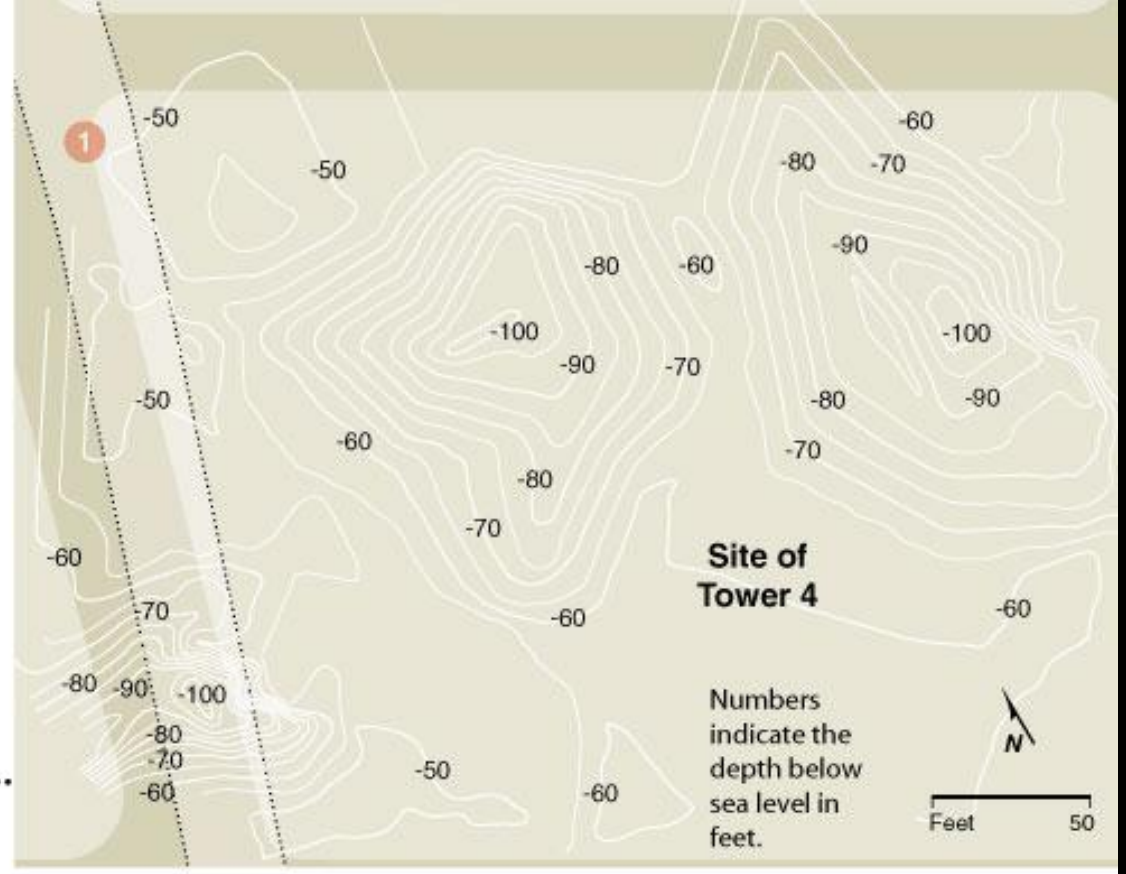
after Baskerville 1994, Merguerian and Moss 2007

World Trade Center Plunge Pool



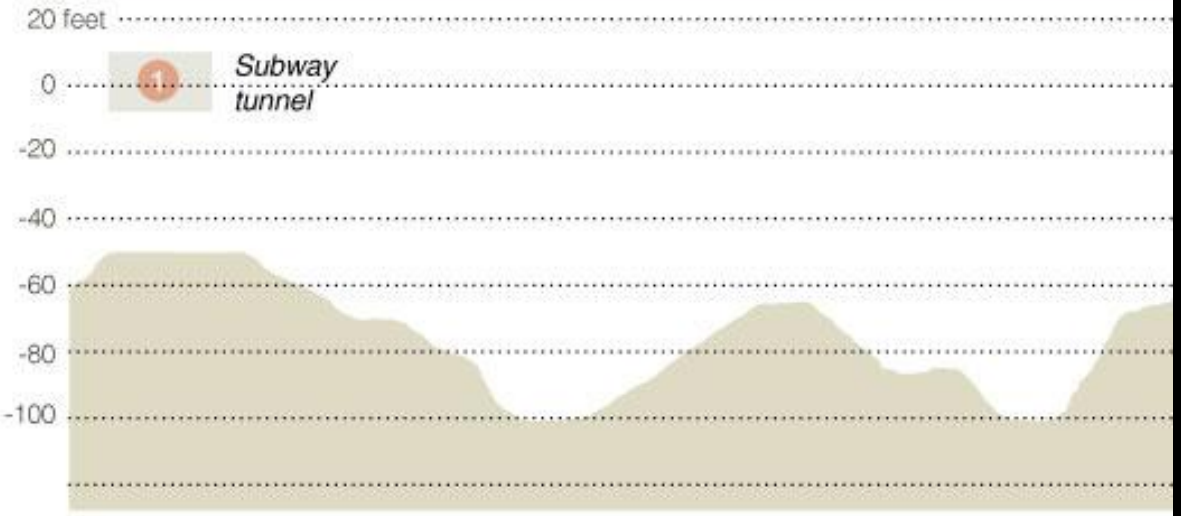
Glacial Terrain At Ground Zero

Excavations for Tower 4 at the southeast corner of the World Trade Center site uncovered a landscape carved by glaciers out of bedrock at least 20,000 years ago, with deep pools known as potholes.



BELOW CITY STREETS

Map at upper right shows bedrock contours of the Tower 4 site from above. At right is a cross section. In the measurement scale, 0 is close to sea level and is10 to 20 feet below street level. That means the bottoms of the potholes (-100) are about 110 feet to 120 feet below the street.

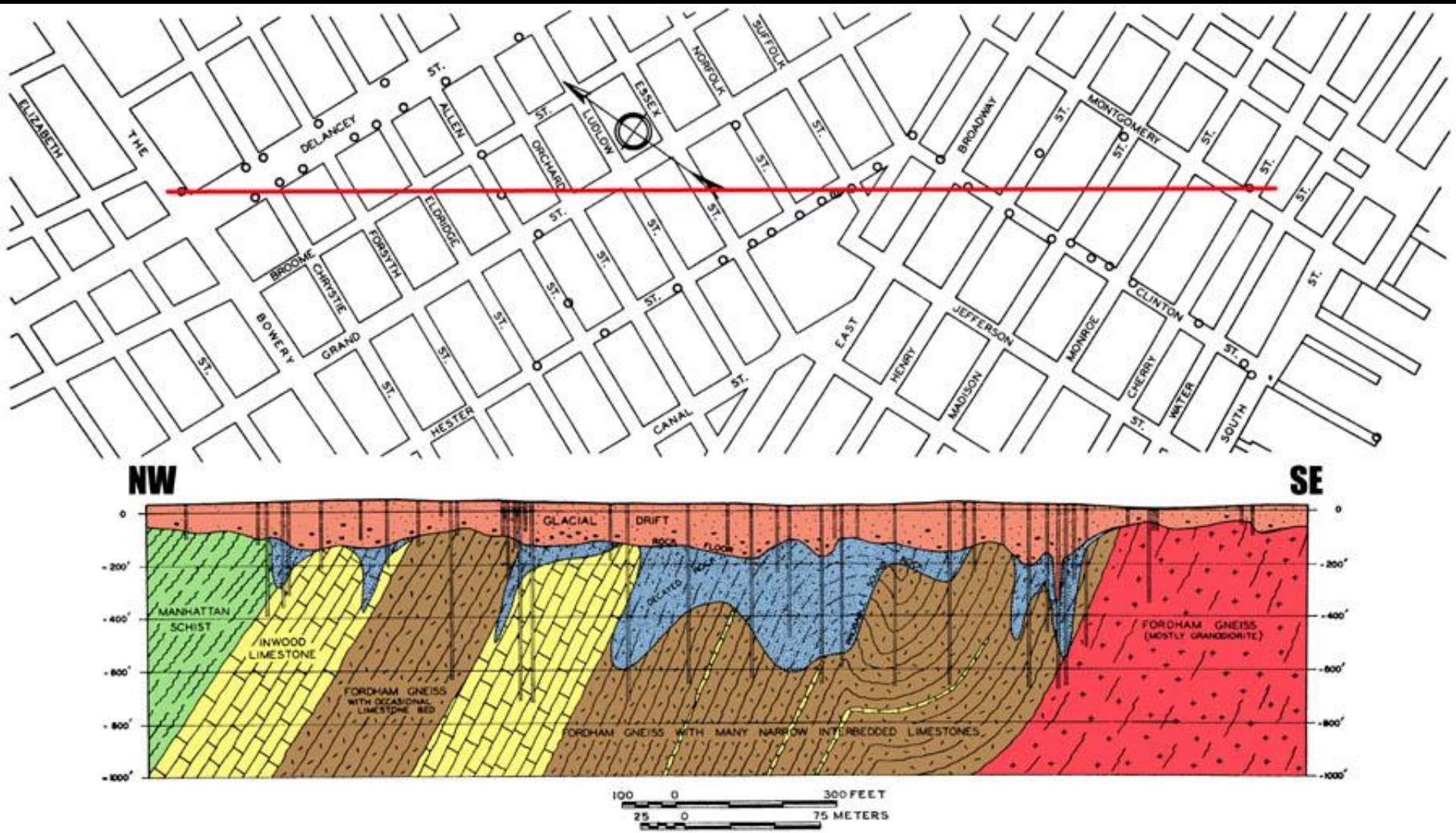


THE NEW YORK TIMES

CAT

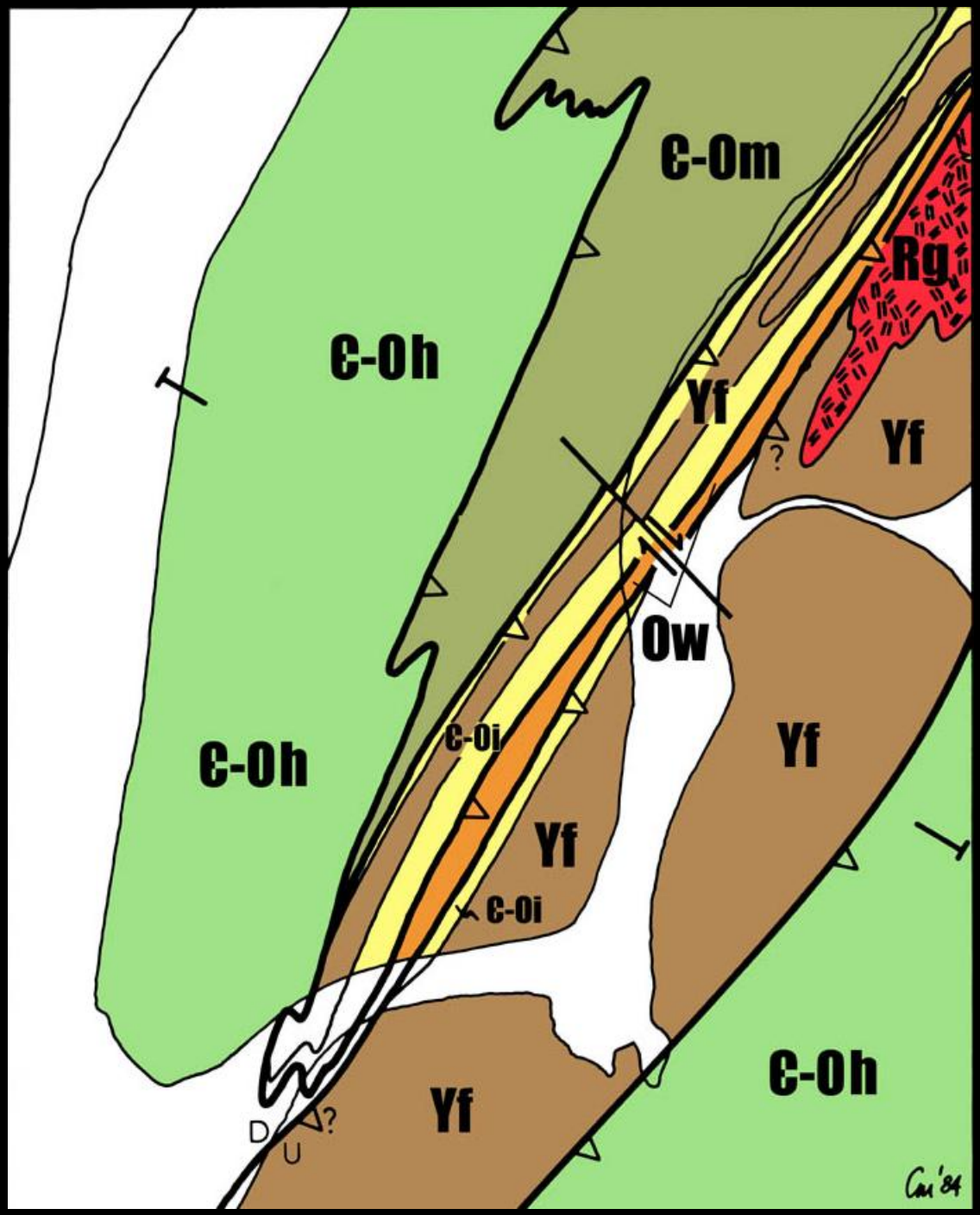
Berkey, 1911

SE Manhattan



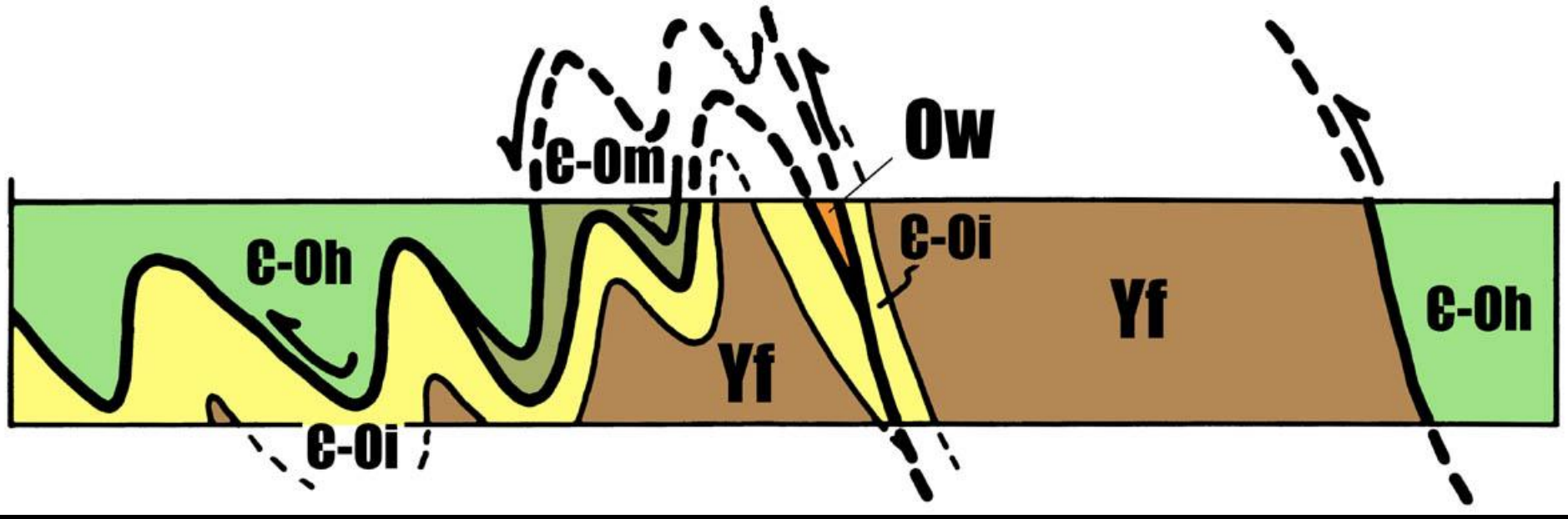
CT 1

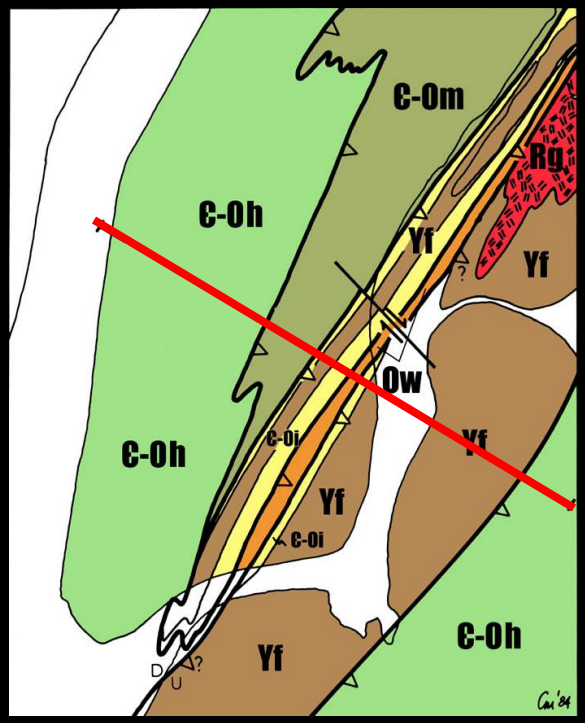
after Berkey 1911 and 1933



Interpretive Geologic Map of SE Manhattan, Brooklyn, and Queens Based on Borings of Berkey (1910)

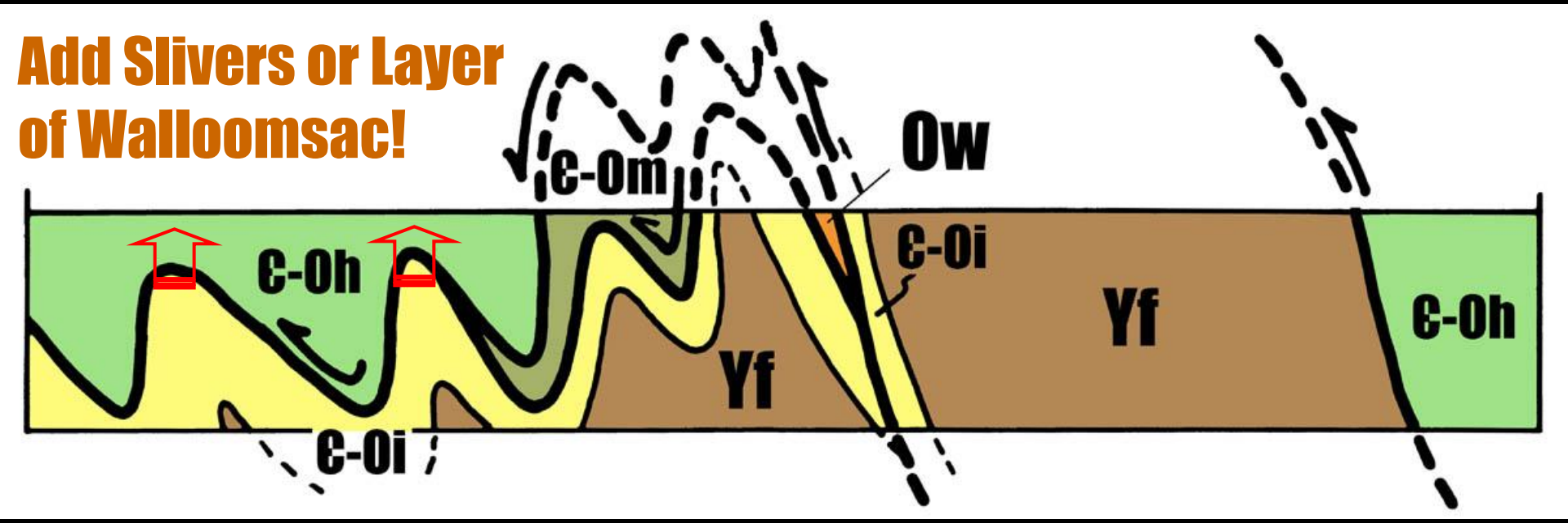
Merguerian, 1984

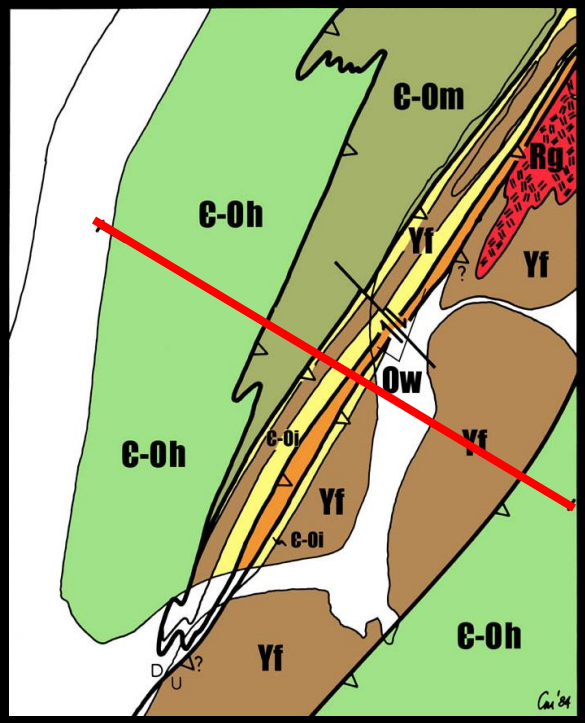




Interpretive NW-SE Geologic Section Based on Berkey 1910 Boring Data

Merguerian, 1984



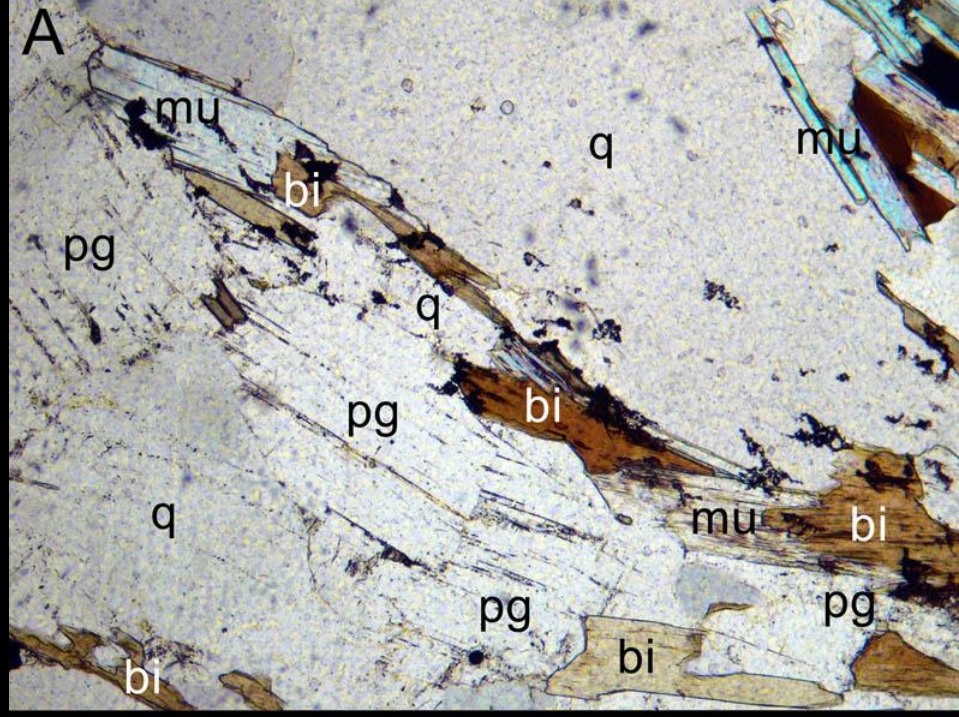


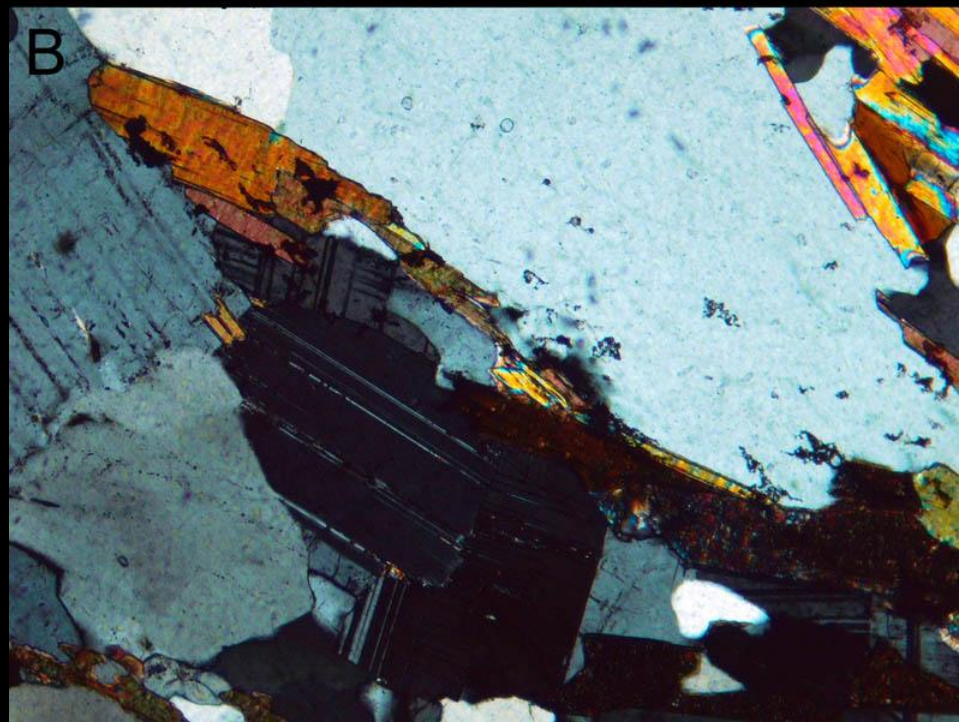
Interpretive NW-SE Geologic Section Based on Berkey 1910 Boring Data

Merguerian, ~~1984~~ (2006)

Southern Manhattan

Very Low Mica Content





N701A

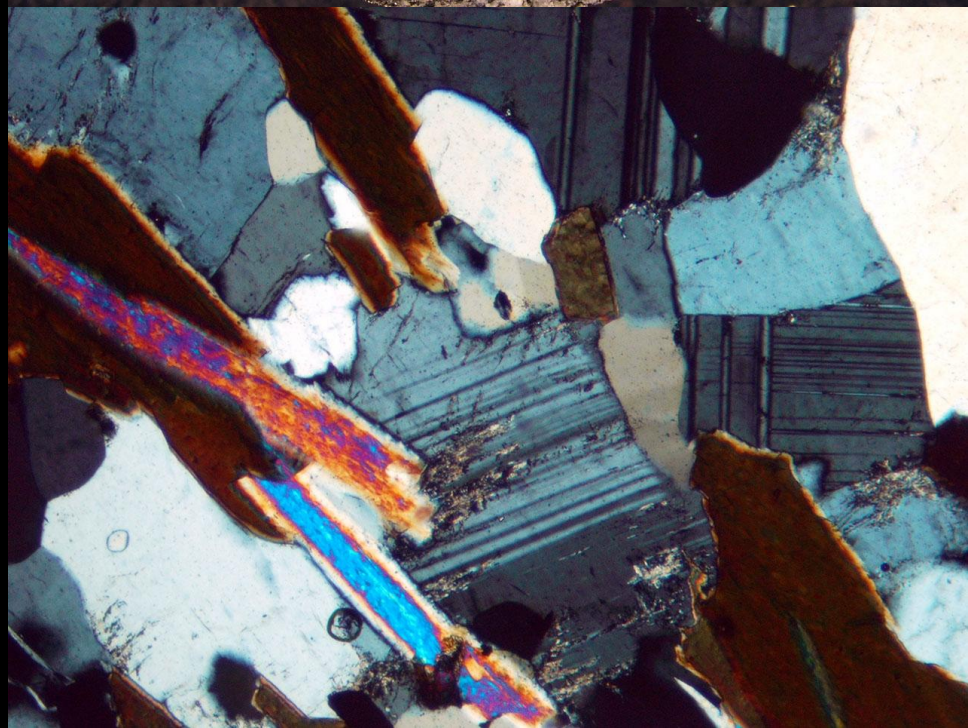
Low Mica Content
16%

Granofels

Interlocking Texture is
“Knitted” by Micas

Stretched Garnet and
Discontinuous Folia
= Polymetamorphism

N752



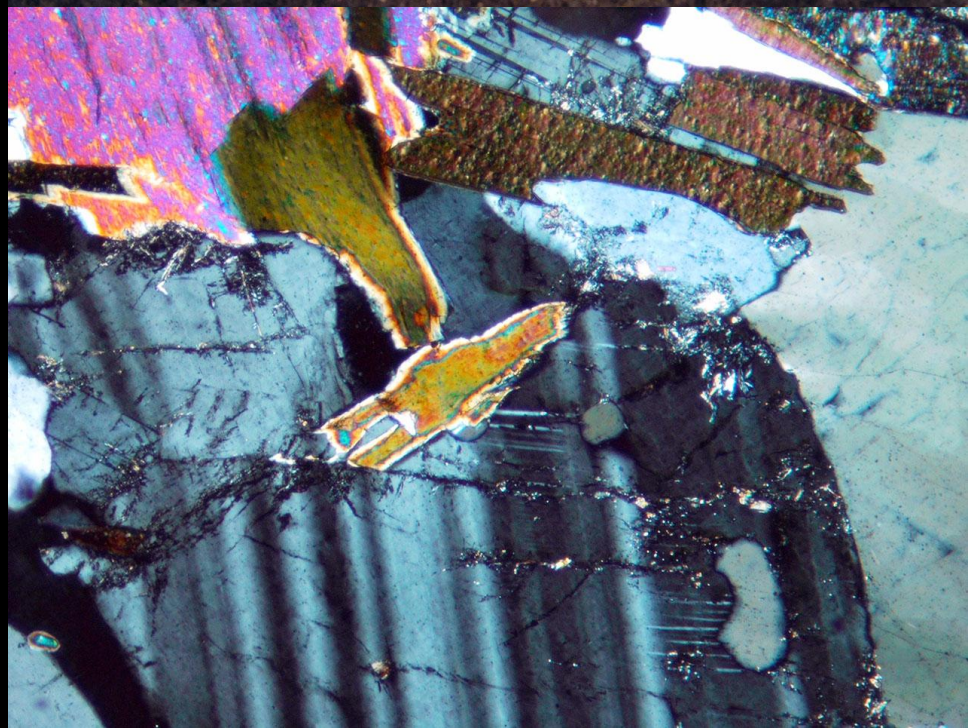
Low Mica Content
22%

Folded
Migmatite Gneiss

Interlocking Texture is "Knitted" by Micas Grown at Many Angles

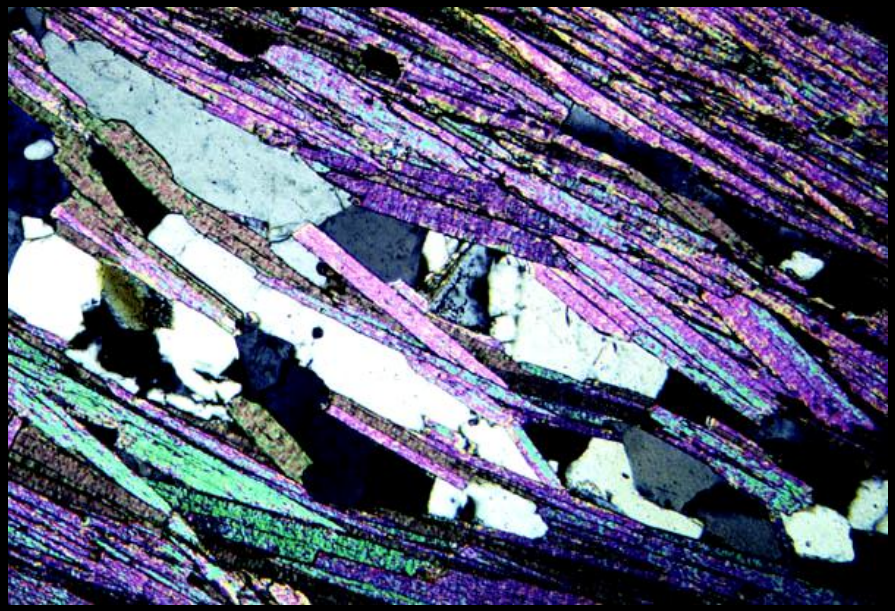
Discontinuous Foliation = Polymetamorphism

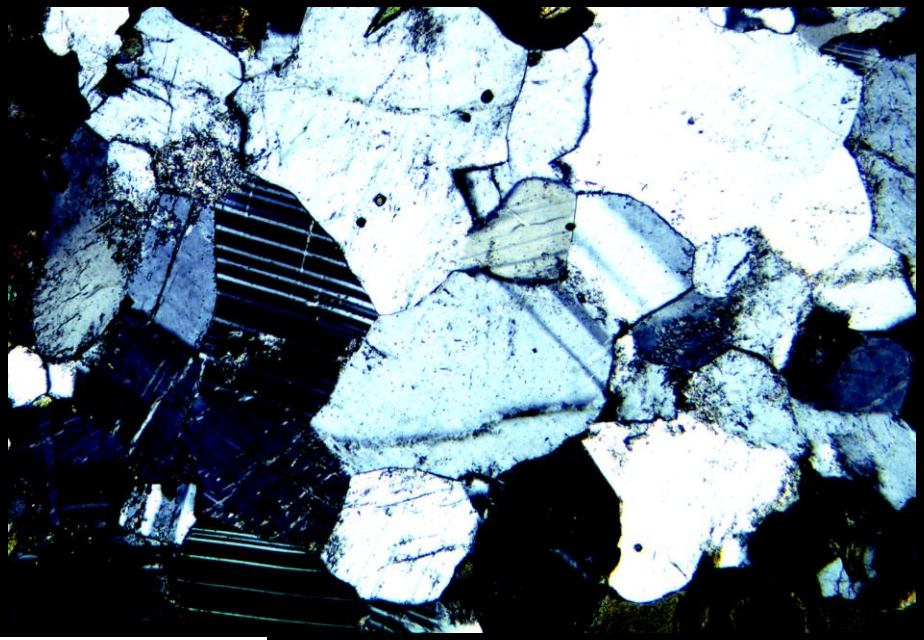
N753



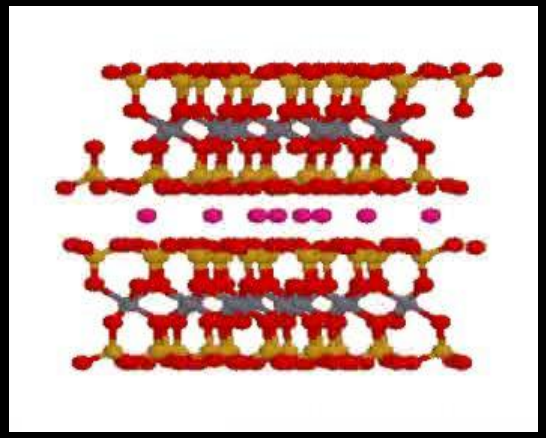
Mica Content of Rock Fabric

Micaceous (+/- hornblende) penetrative foliation vs. non-foliated "granoblastic" rock mass



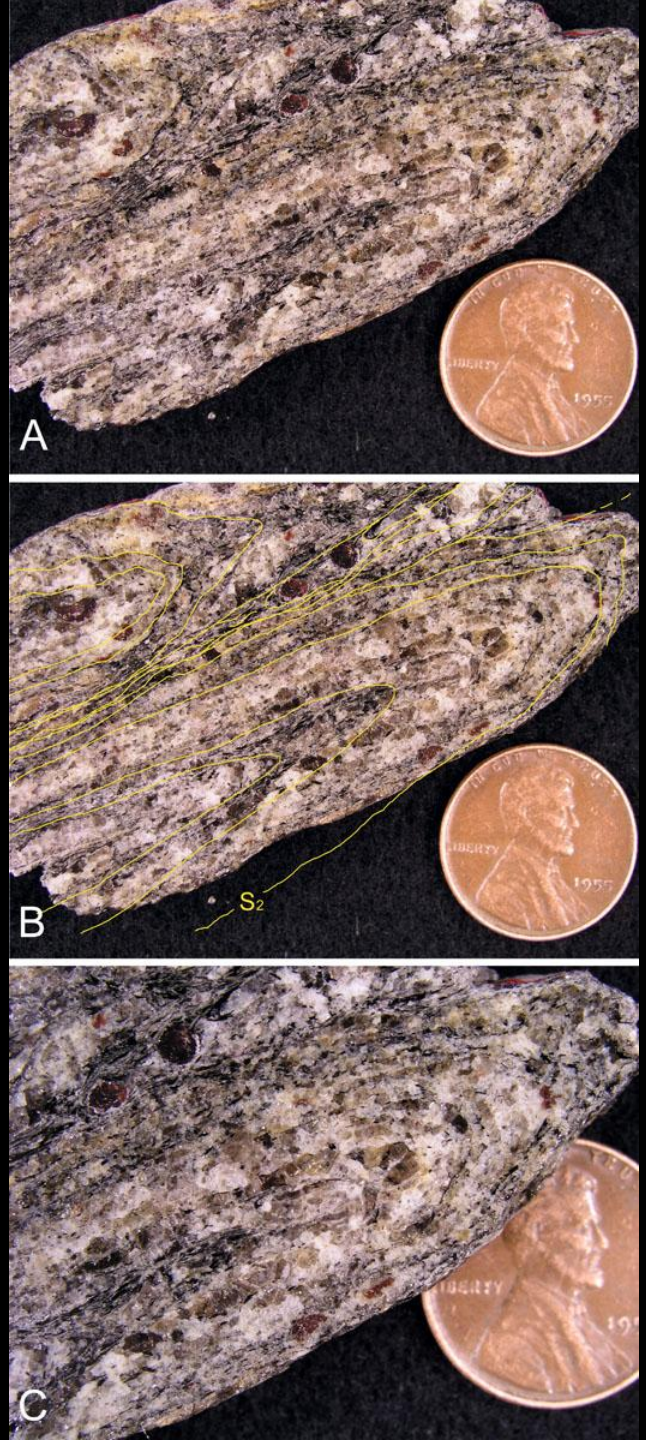


Foliated = Schist



Non-Foliated = Gneiss

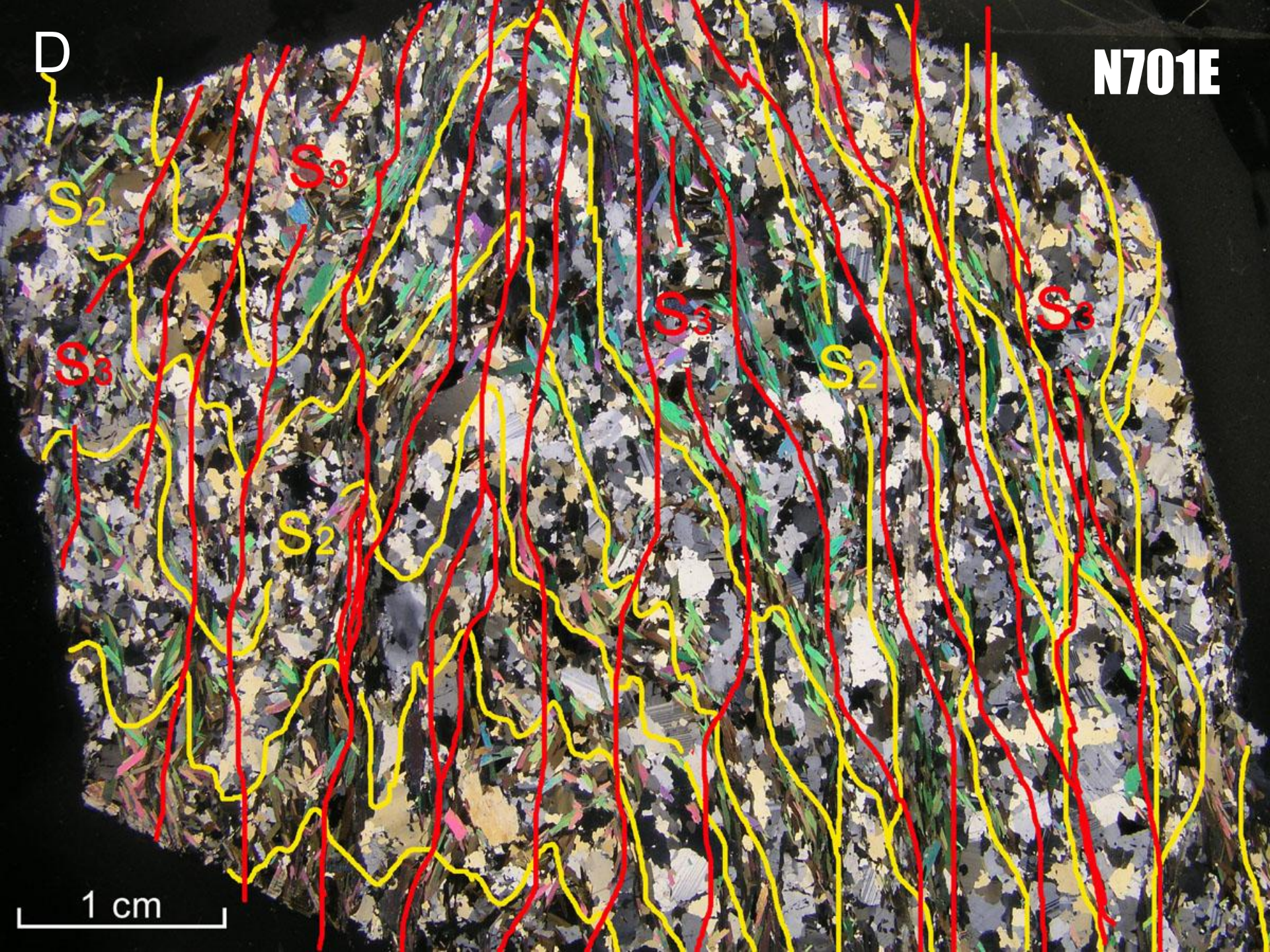
Southern Manhattan
N701C


A
B
S_2
C

N701C

S2
N701C
IN GOD WE TRUST
LIBERTY
1955

B
N701E


D
N701E
S2
S3
S3
S2
S3
S2
S3
1 cm

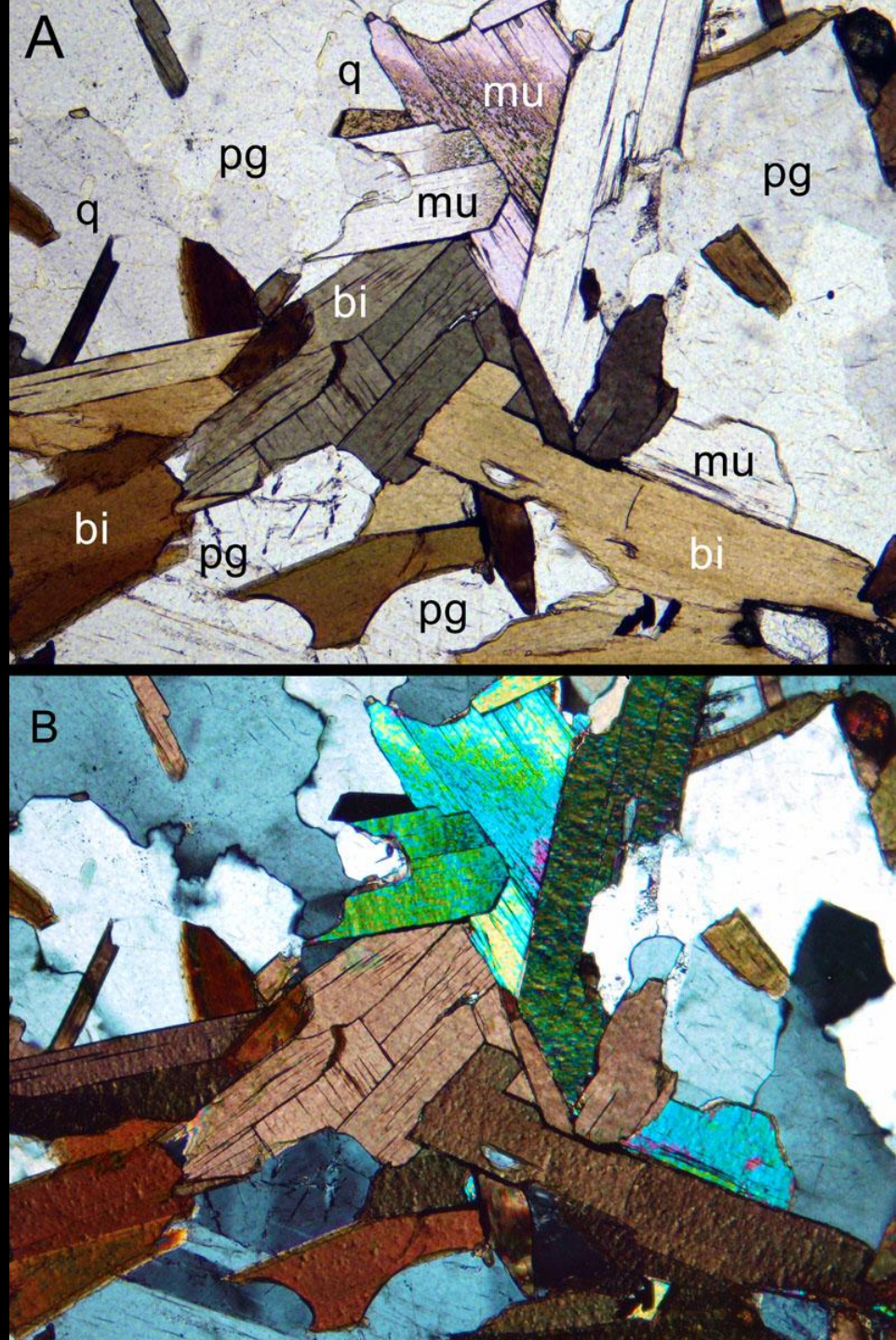
Structurally Folded Multi-directional Fabric

Interlocking Texture is "Knitted" by Soft Micas

Polymetamorphism

Straw in Bricks

N701E



Southern Manhattan Hartland Gneiss and Granofels Unit

Low Mica Content (26%) +

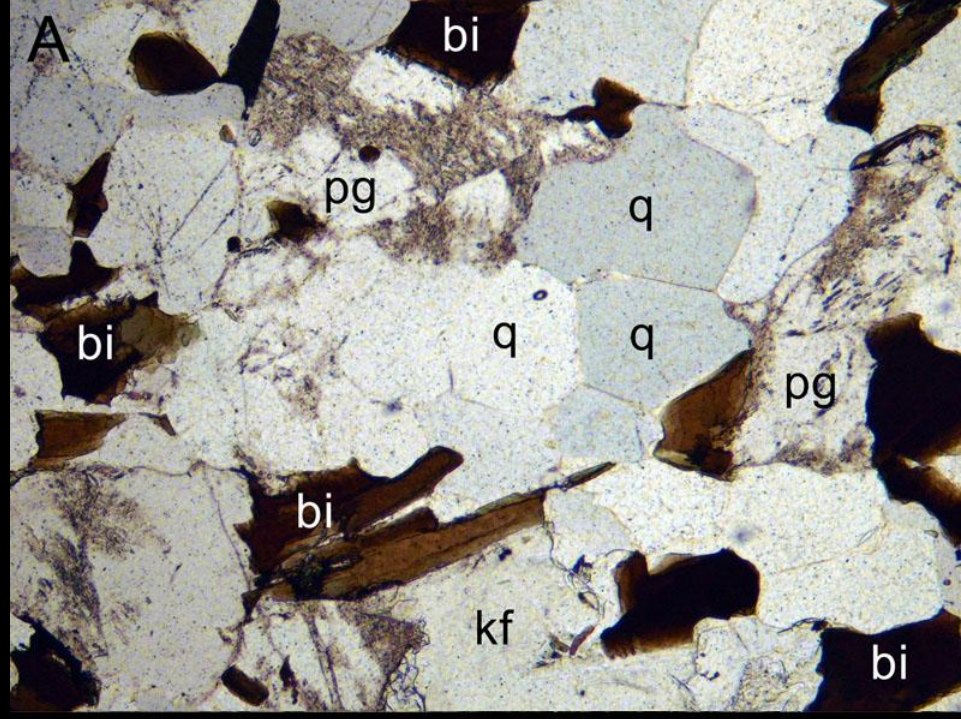
Granoblastic Textures +

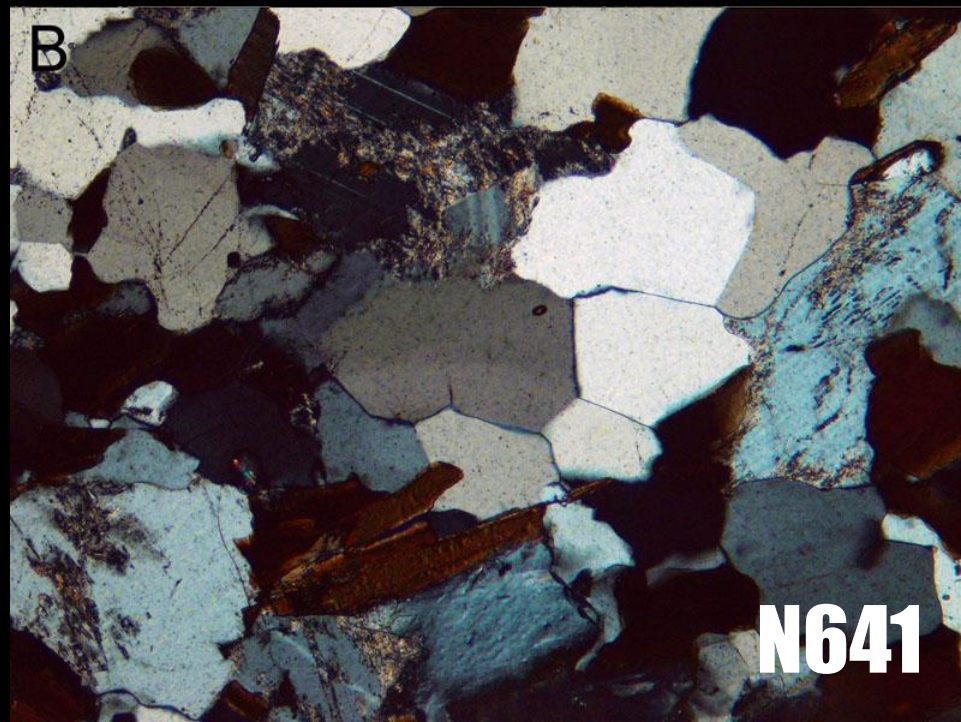
Interlocking Minerals +

Discontinuous Fabric +

Variable Orientation =

Poor Excavation Rates





HERRENKNECHT TBM ADVERTISEMENT

Rock Does Not Equal Rock

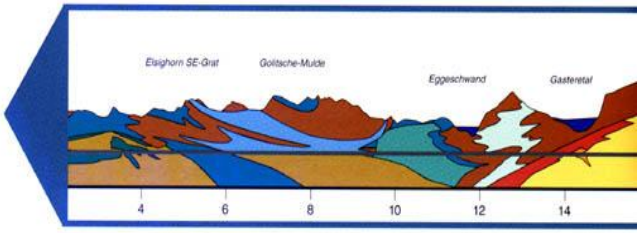
At Herrenknecht, maximum tunnelling performance and the greatest possible safety are the ultimate goals for the development of tunnelling machines. Expert analysis of the geological conditions result in a "tailored hard rock machine".

Whether it is solid rock, abrasive rock or rock under high pressure, weathered transition zones with high ground water pressure or caverns, the variety of the geological conditions in a planned tunnel route is virtually unlimited. At Herrenknecht, the geological analysis of the ground conditions is always taken into consideration in the machine design. Cutters and cutterhead are ideally adapted to the varying degrees of hardness and abrasion in sedimentary, metamorphic or igneous rock.

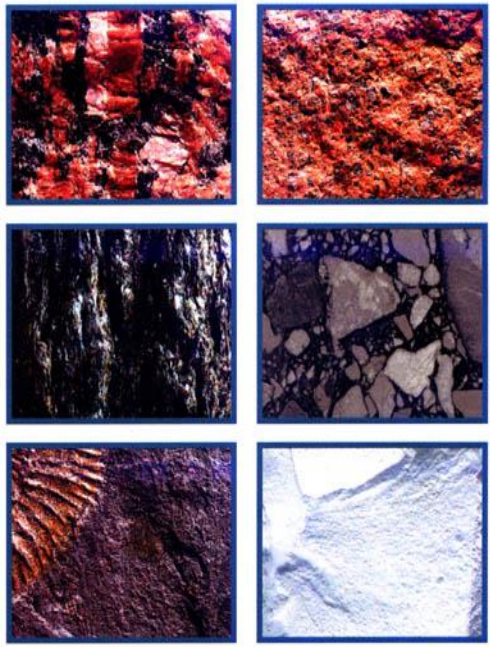
All Experts On One Team

The excavation process in hard rock takes place in the peak state of the shear and compression resistance as well as tensile strengths of the rock. At the same time, the best possible tunnelling performance has to be achieved.

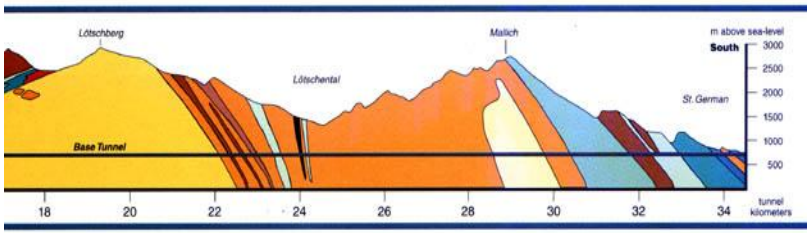
At Herrenknecht, a team of internal specialists from the disciplines of rock mechanics, mechanical engineering and process technology find the optimum project solution for developing the machine design.



Mechanical rock excavation is confronted by rock with varying degrees of hardness, e.g. with extremely hard gneiss (top left) and granite (top right), medium hard mica schist (center left), breccia (center right) and claystone (bottom left) as well as limestone (bottom right).



The formation of each mountain range is unique. Lötschberg in Switzerland consists of a wide variety of rock formations along the tunnel route. Herrenknecht supplied two single gripper machines (Ø 9.43 m), which enable mechanical rock stabilization as close as 4.2 m behind the cutterhead.



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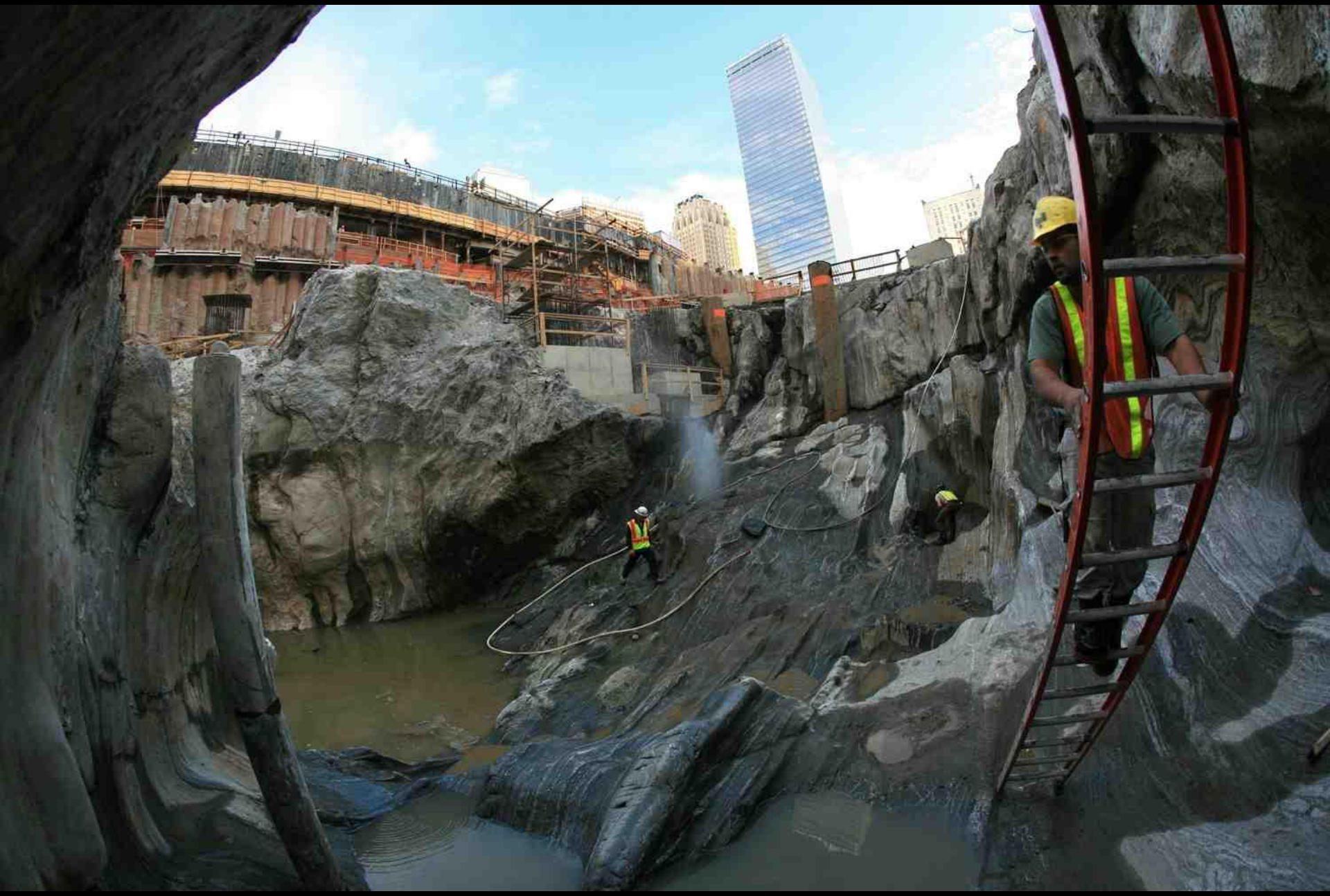
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