Dirt Talk 2012

Geology and Soils of Brooklyn, NY

Prof. Charles Merguerian

Hofstra University and Dukelabs, NY

21 February 2012

History of TBM Tunneling in NYC 1964-2012

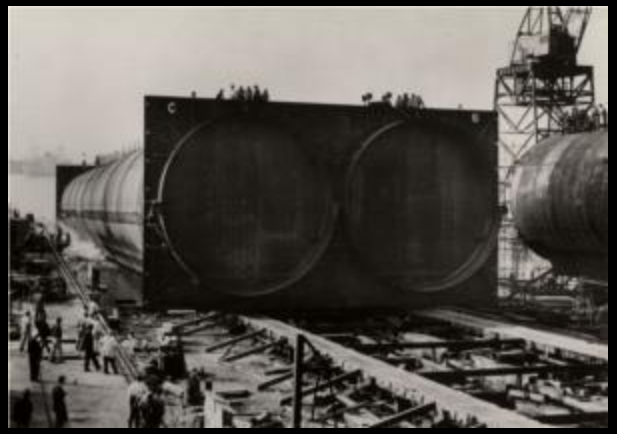
NYC TBM Projects (1964-2012)

Richmond Water Supply Tunnel
West Side Interceptor
63rd Street Tunnel
Brooklyn Water Tunnel
Queens Water Tunnel
Con Edison Steam Tunnel
Manhattan Water Tunnel
East Side Access Project
Croton Water Tunnel/Plant
No. 7 Line IRT Extension
Second Avenue Subway
East Side Access – Queens Side

NYC TBM Projects

Richmond Water Supply Tunnel

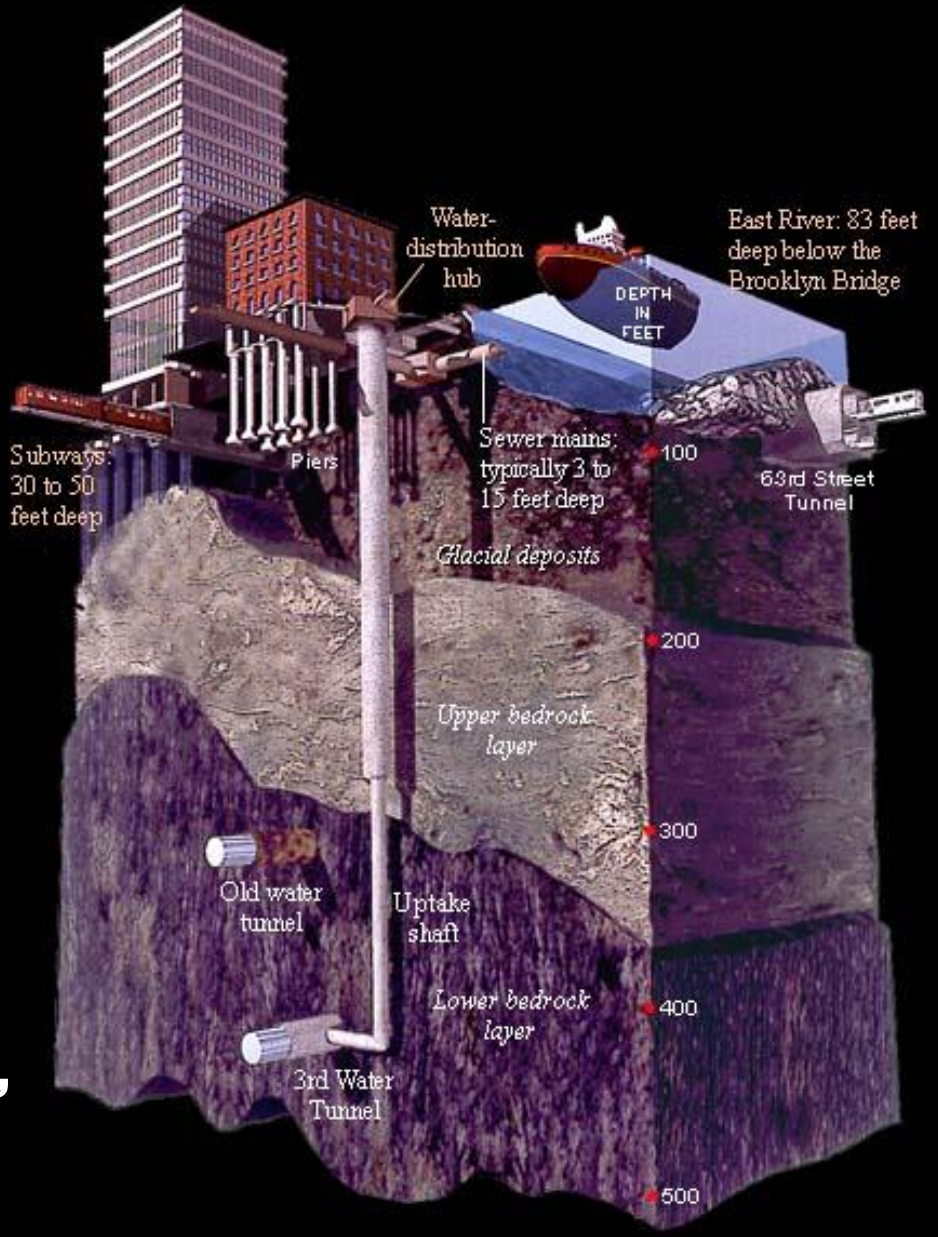
- 1964 - First TBM Job NYC (Perini-Morrison-Knudsen JV)
- Tunnel planned from Staten Island to Brooklyn
- German TBM - Failure After Only 400'
- Indurated Pegmatitic Schist Too Hard For TBM
- Cutters (Diamond Grinding Heads) and Bearings Failed
- Granite, Serpentinite, Schist = Hartland Formation
- Main Shaft in Tompkinsville, Staten Island



NYC TBM Projects

West Side Interceptor

- ~Jul 1971 - Jul 1973
- Second TBM Tunnel in NYC
- Jarva Mark 12-1200
- Two 9,000' Tunnels
- S=11' / N=8.5' Diameter
- Last 1,100' D&B Mined in Inwood Marble
- Hartland Formation (S) and Manhattan Schist (N)
- 488 Button Cutters in 8955'
- Penetration = 4.5'/Hr in 11'



NYC TBM Projects

63rd Street Tunnels

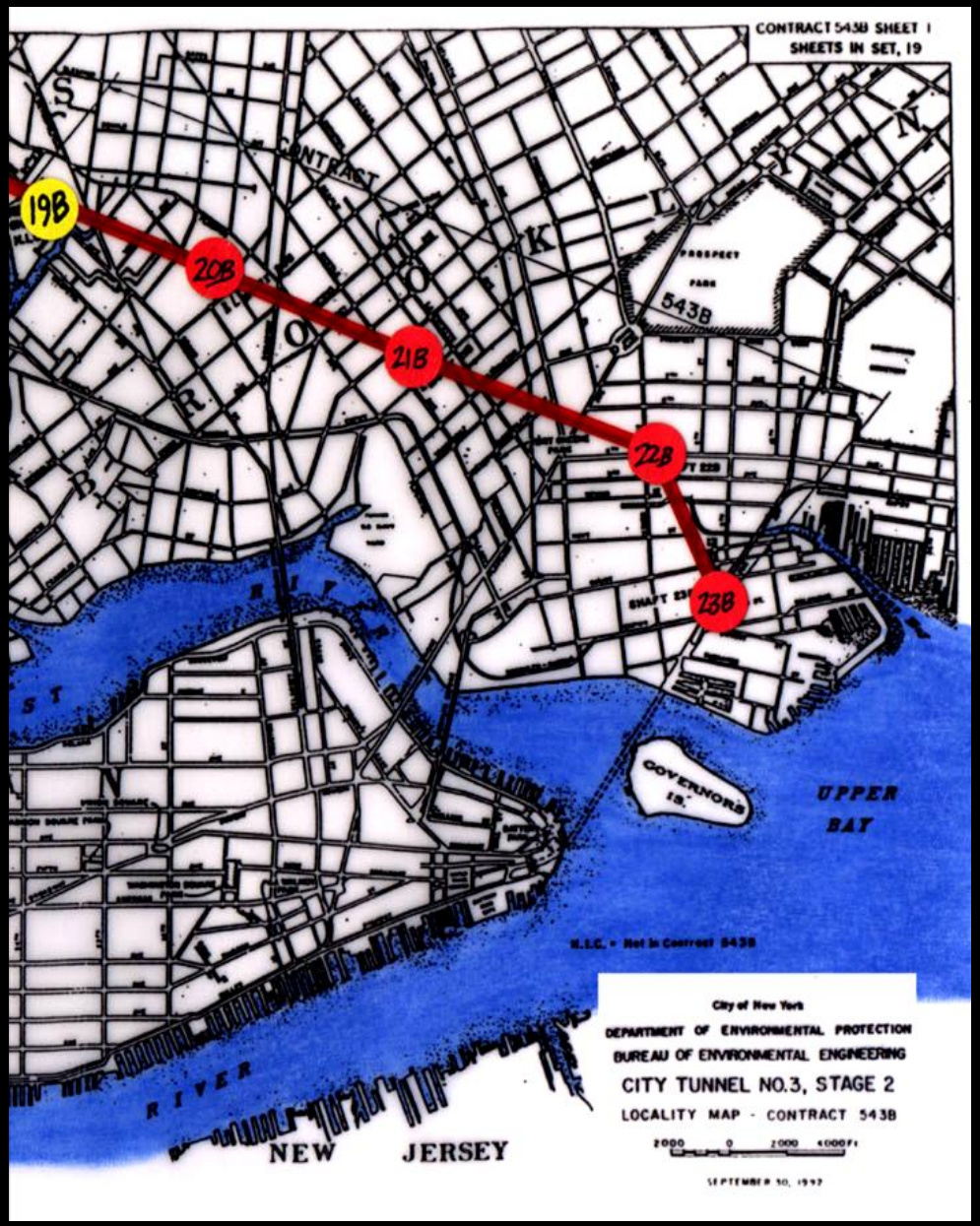
- Feb 1980 - May 1980
- Twin Tunnels - 4 Tracks
- Robbins 203-205 TBM
- Diameters 20.17'/22'
- Immersed Tube First
- Lower Level for LIRR
- Fordham Gneiss and Hartland Formation
- Penetration = 4.31'/Hr

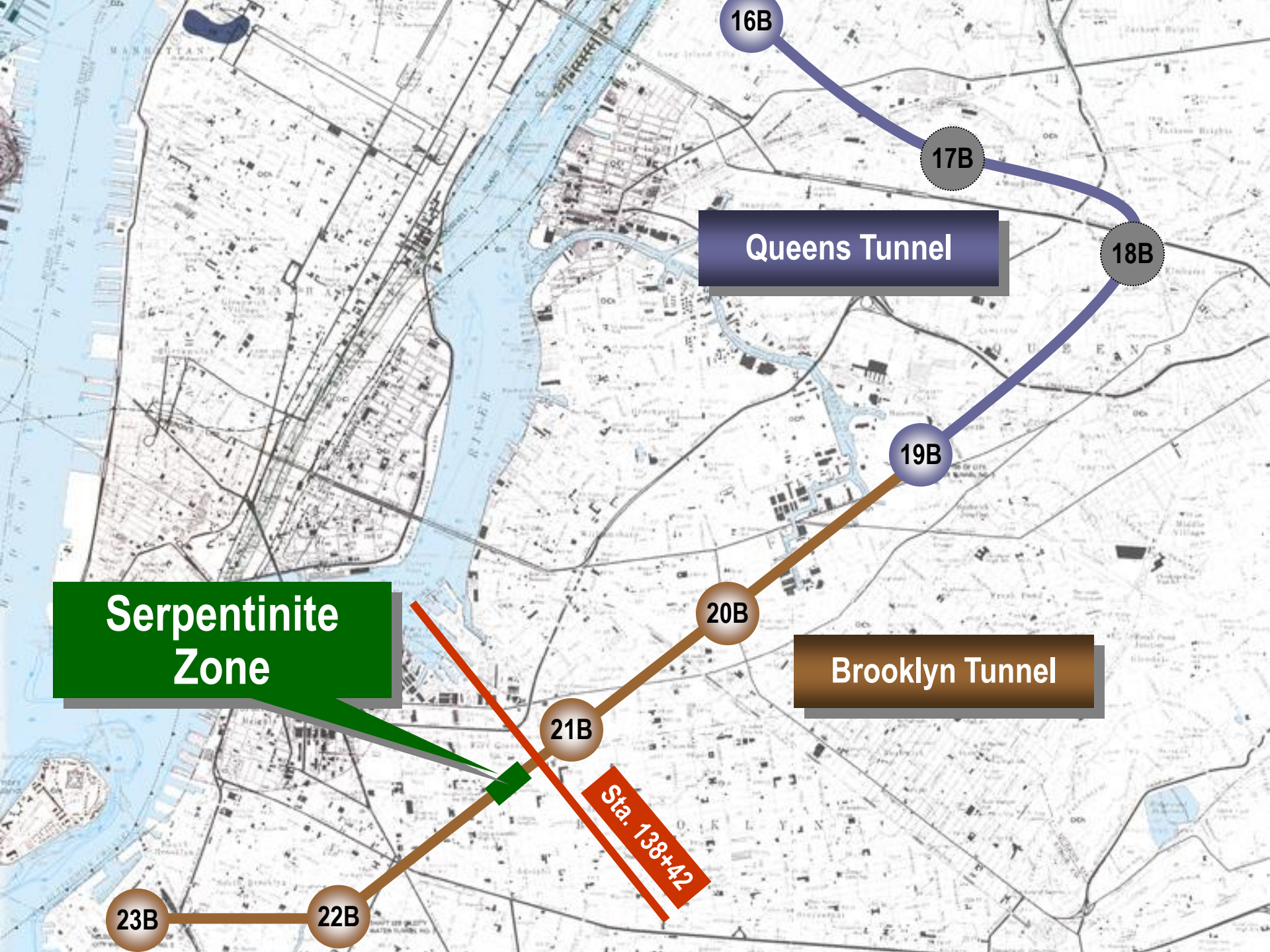
May 1980

NYC TBM Projects

Brooklyn Water Tunnel

- July 1994 – Jan 1997
- Open Beam TBM from 63rd Street Tunnel Job
- 19' Diameter; 5.5 Mi
- Variable Penetration Through Zones A, B, C
- Fordham Gneiss and Walloomsac Schist
- Penetration = ~10'/Hour

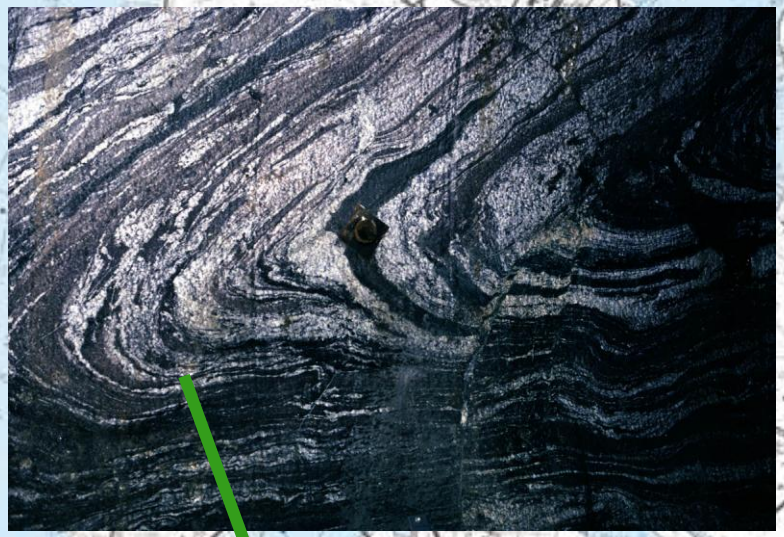



16B
17B
Queens Tunnel
18B
19B
Serpentinite Zone
20B
Brooklyn Tunnel
21B
Sta. 138+42
23B
22B

Major Serpentinite Zone

Brooklyn Tunnel – Sta. 128+30

Schistose Rock



16B

17B

Queens Tunnel

18B

19B

Zone C

20B

21B

Zone B

Brooklyn Tunnel

Zone A

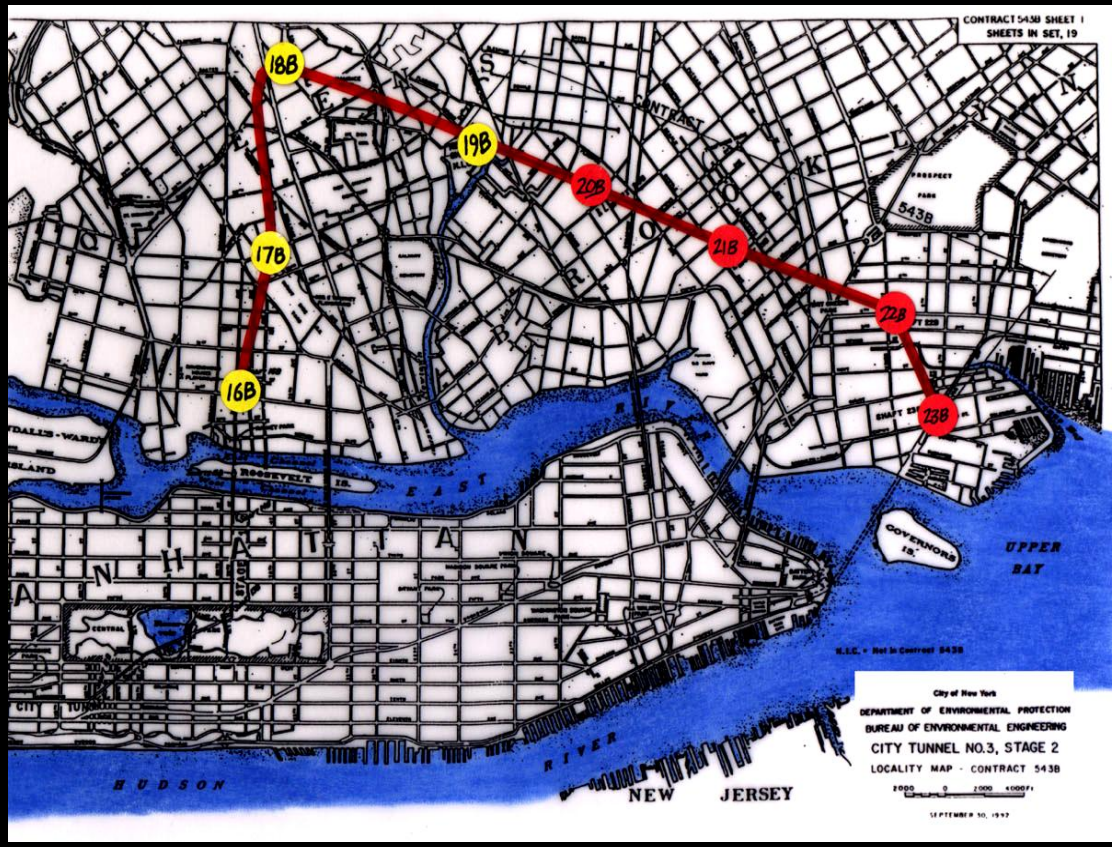
23B

22B

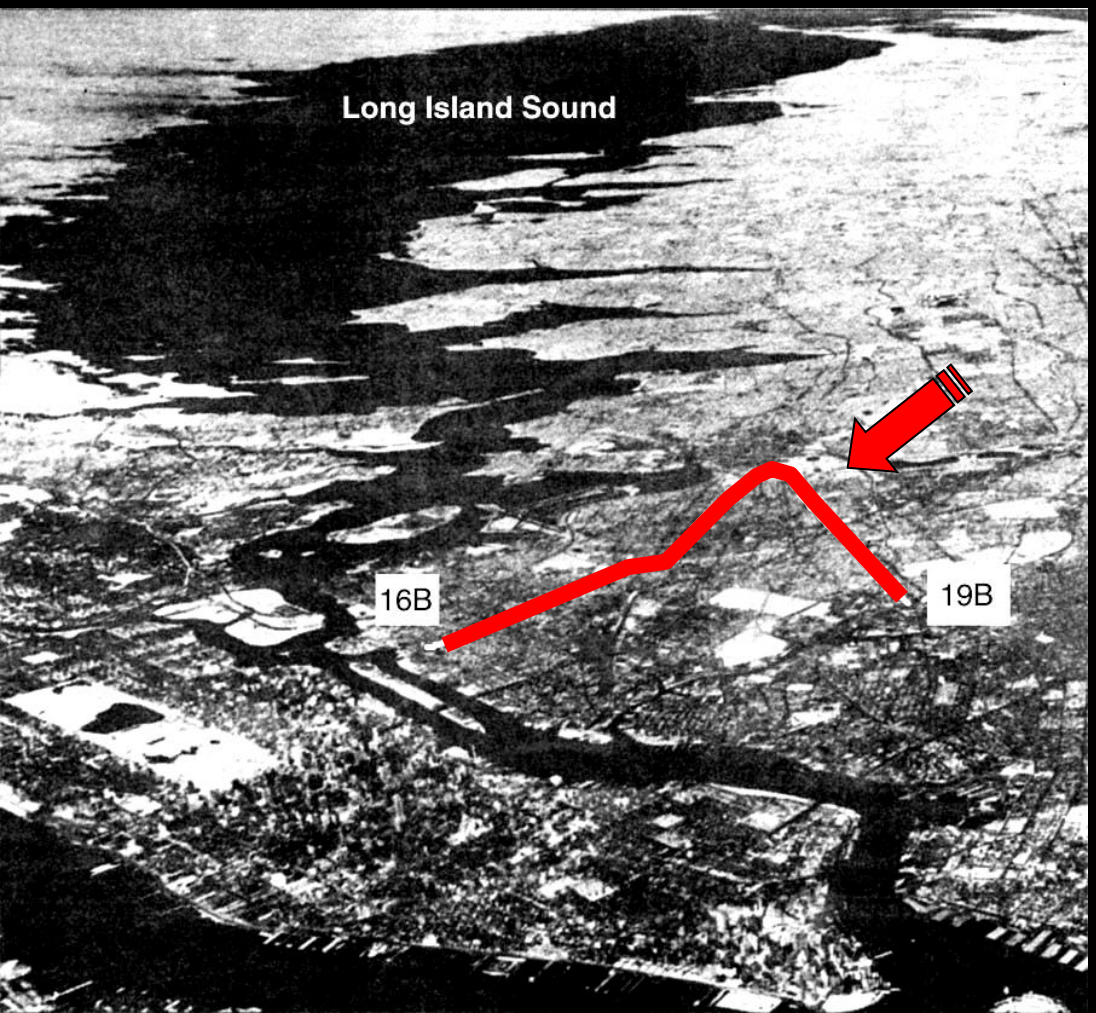
NYC TBM Projects

Queens Water Tunnel

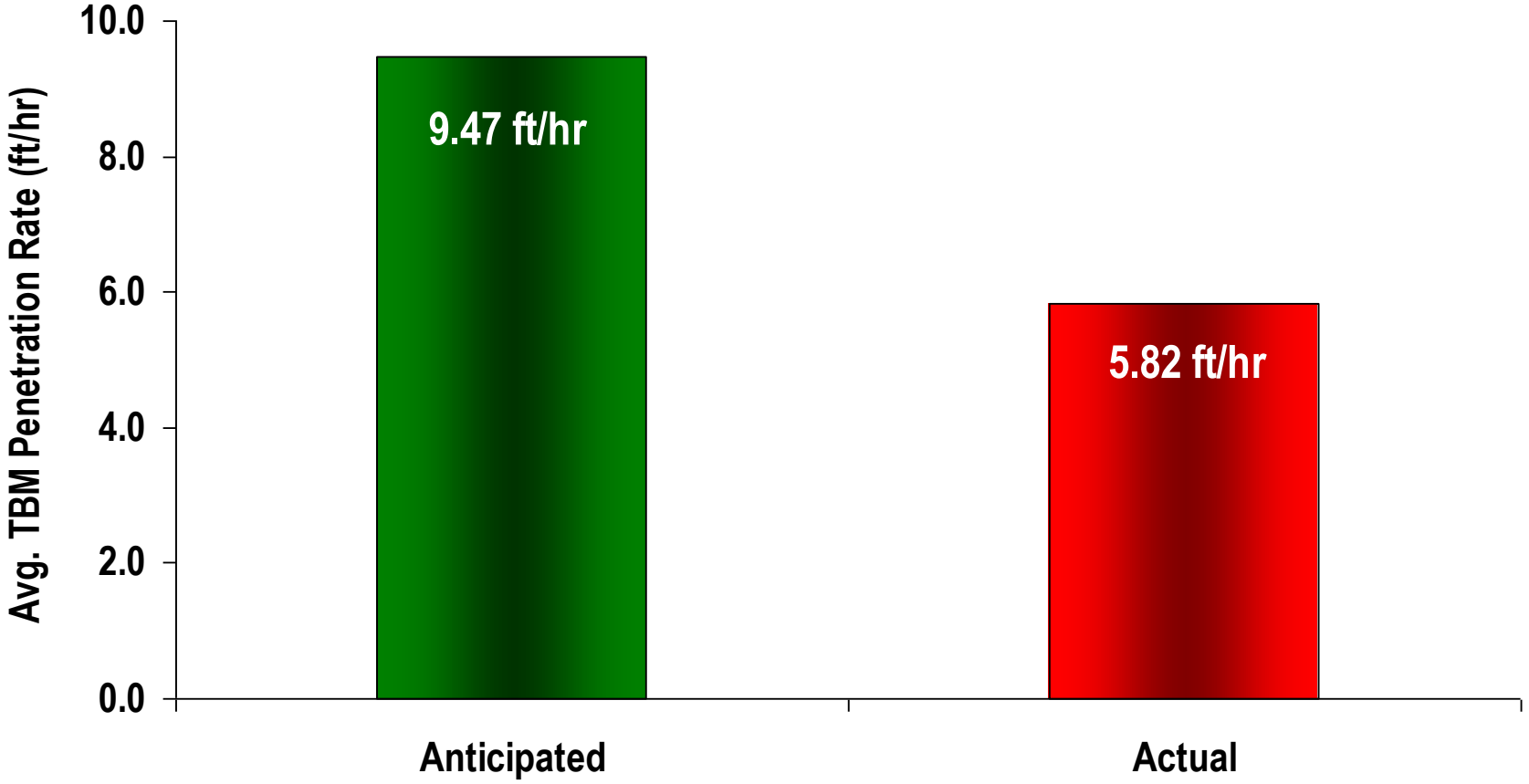
- Oct 1996 - Oct 1999
- Open Beam HP TBM
- 19” Cutters; 4.76 Mi
- Garnet Zones (10%)
- Dike Swarm
- NNE Fault System
- Intersecting Faults
- Subhorizontal Fabrics
- QTC = Fordham Gneiss
- Penetration = 5.82’/Hr



Construction of the Queens Tunnel
NYC Water Tunnel #3
Oct 1996 – Oct 1999



Anticipated vs. Actual Penetration Rate



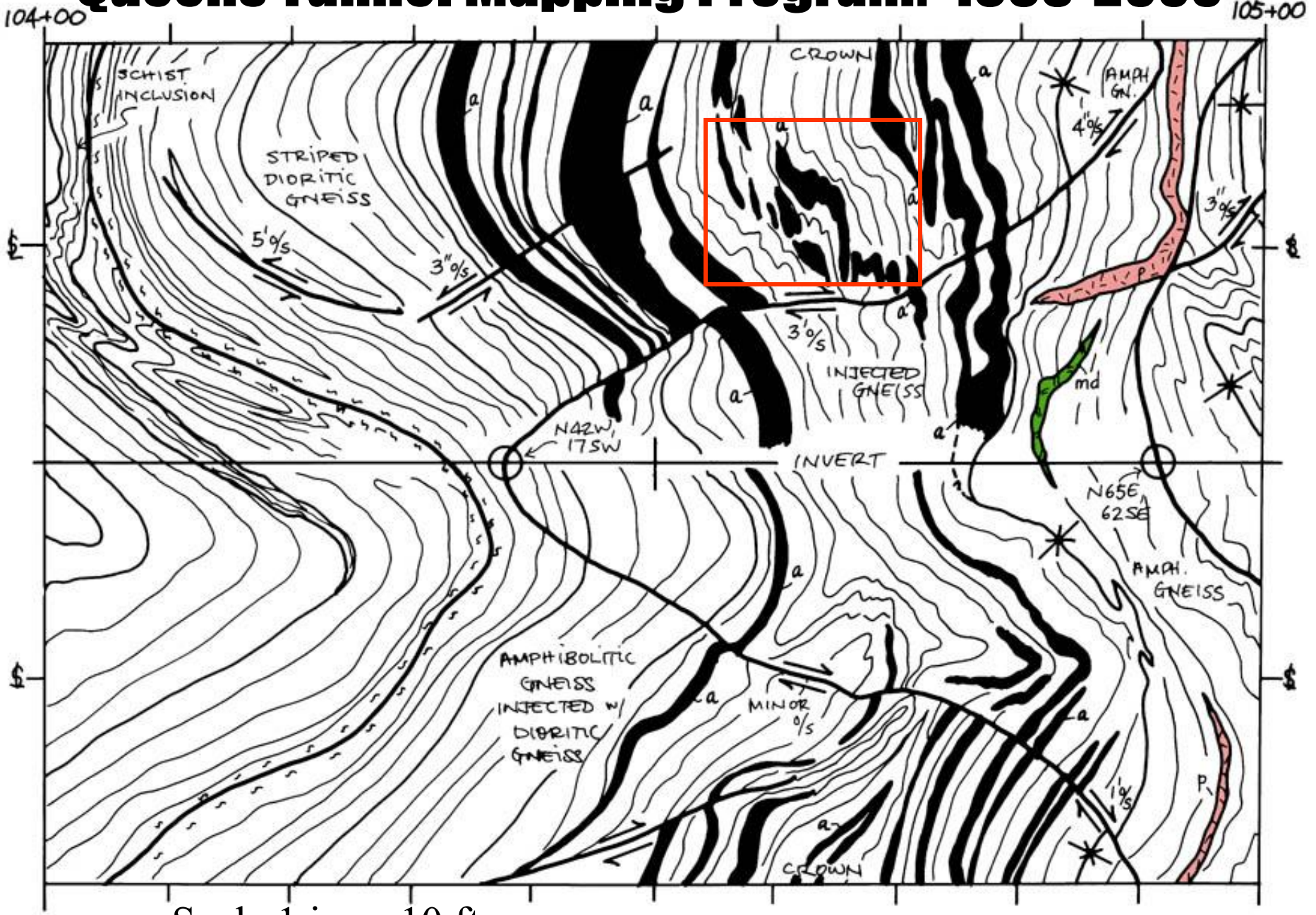
Unexpected High Garnet Content

- 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
- Queens Tunnel Garnet Zones would be called "ore deposits" in many parts of the world
- Results in abrasivity to cutters and production of excessive fines

- As-Built Mapping Program

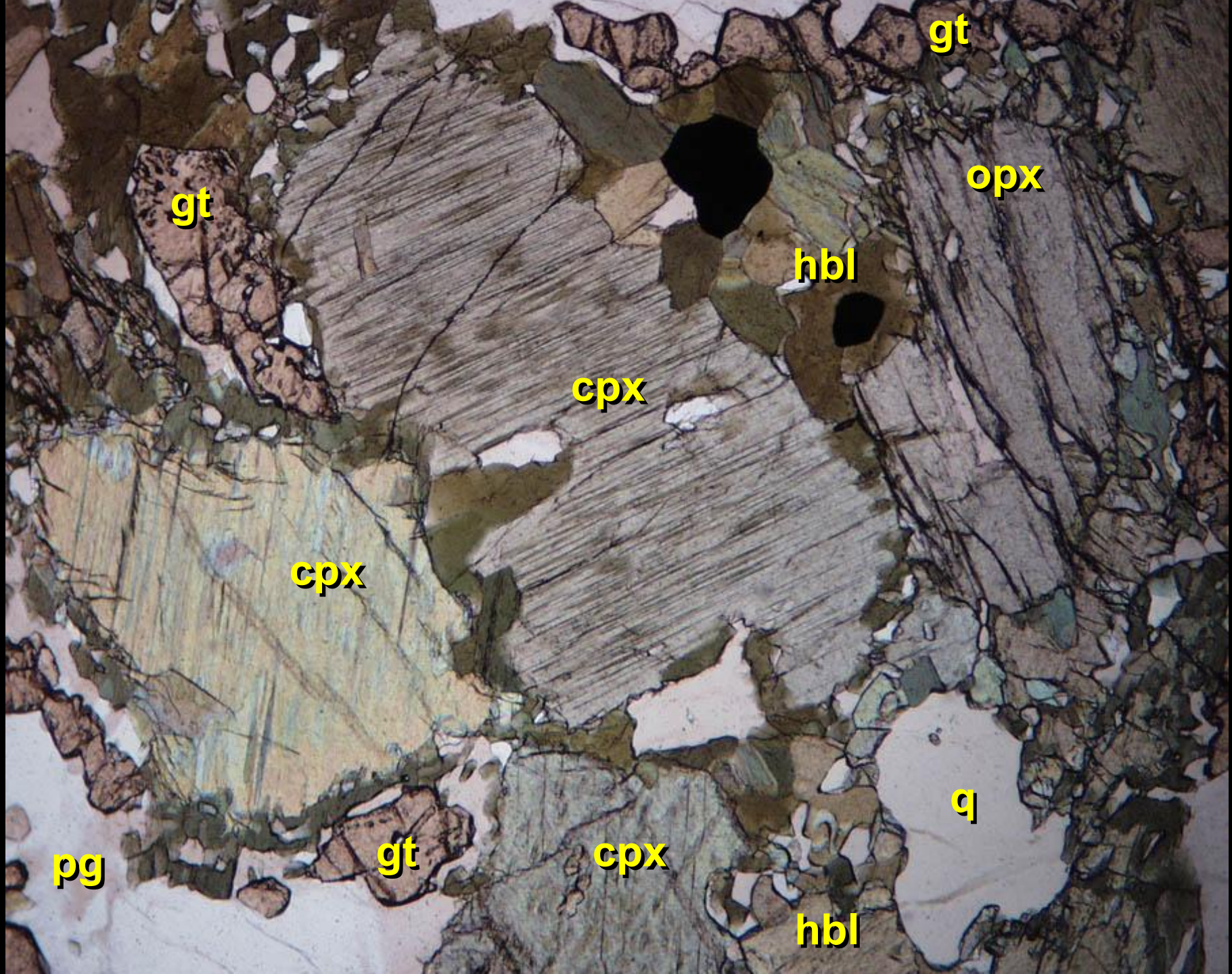
Merguerian's Queens Tunnel Field Office

Queens Tunnel Mapping Program: 1998-2000

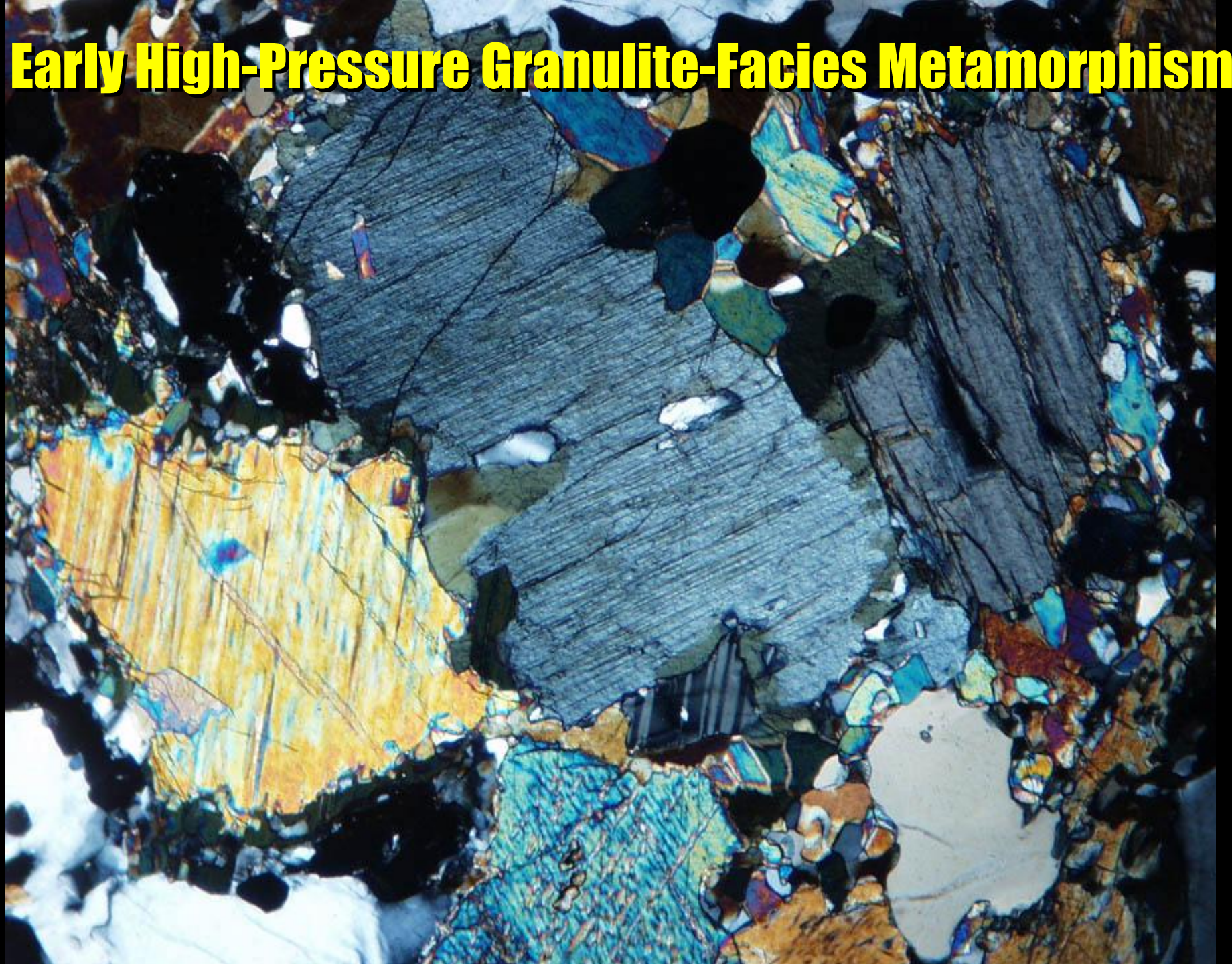


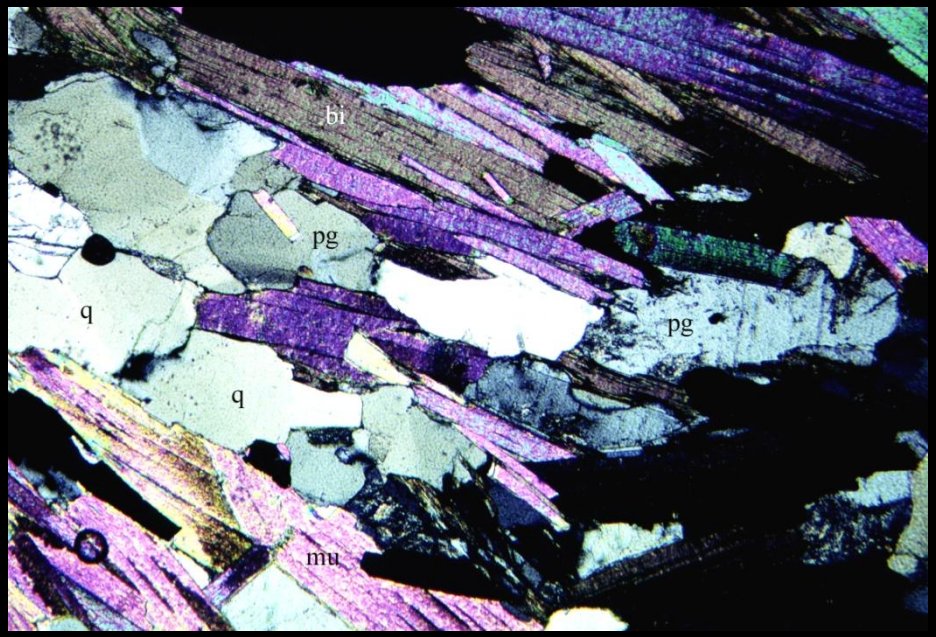
- Scale 1 in. = 10 ft


104 +60
104 +65

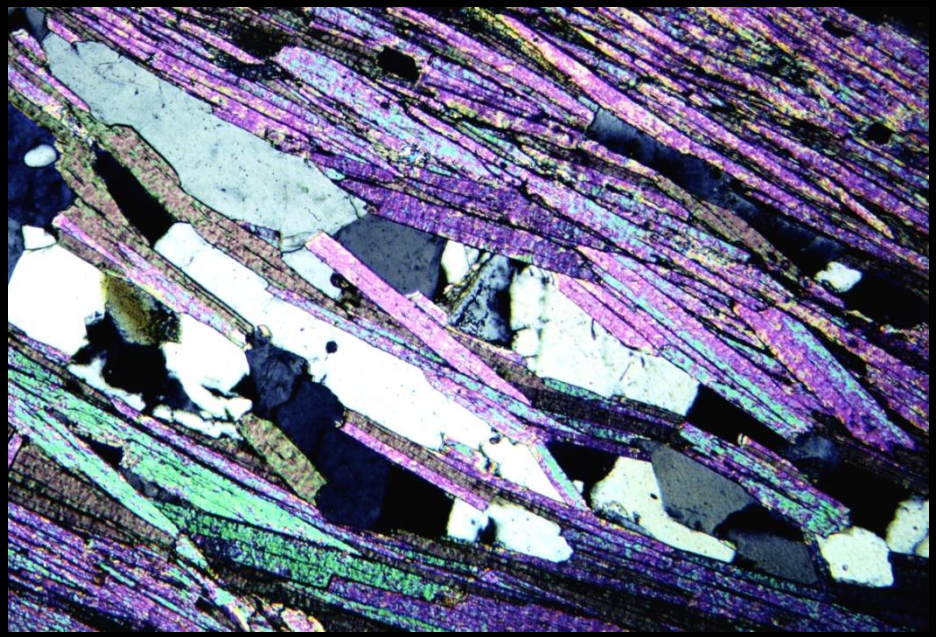

gt
opx
gt
hbl
cpx
cpx
q
pg
gt
cpx
hbl

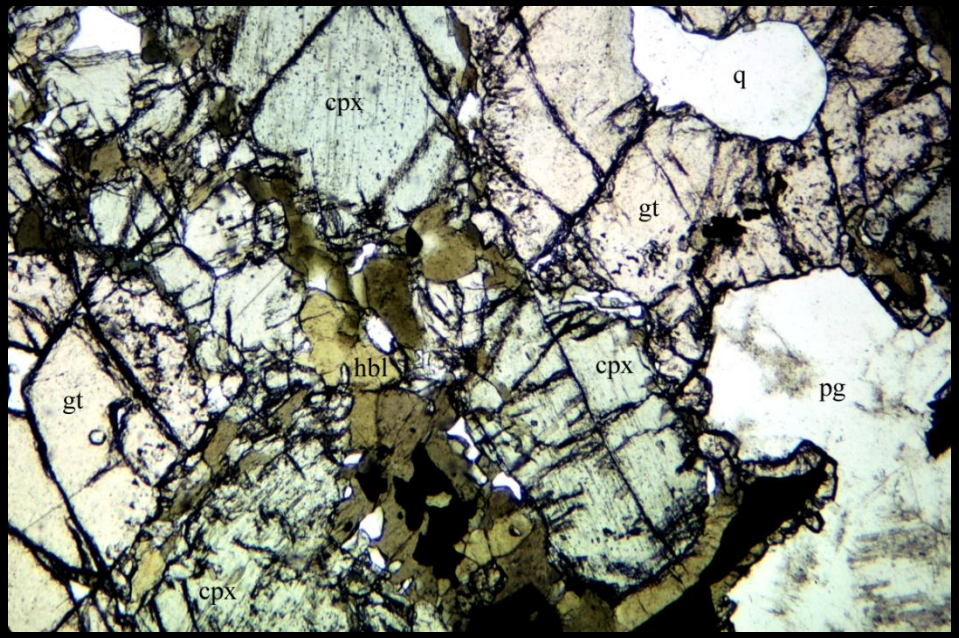
Early High-Pressure Granulite-Facies Metamorphism





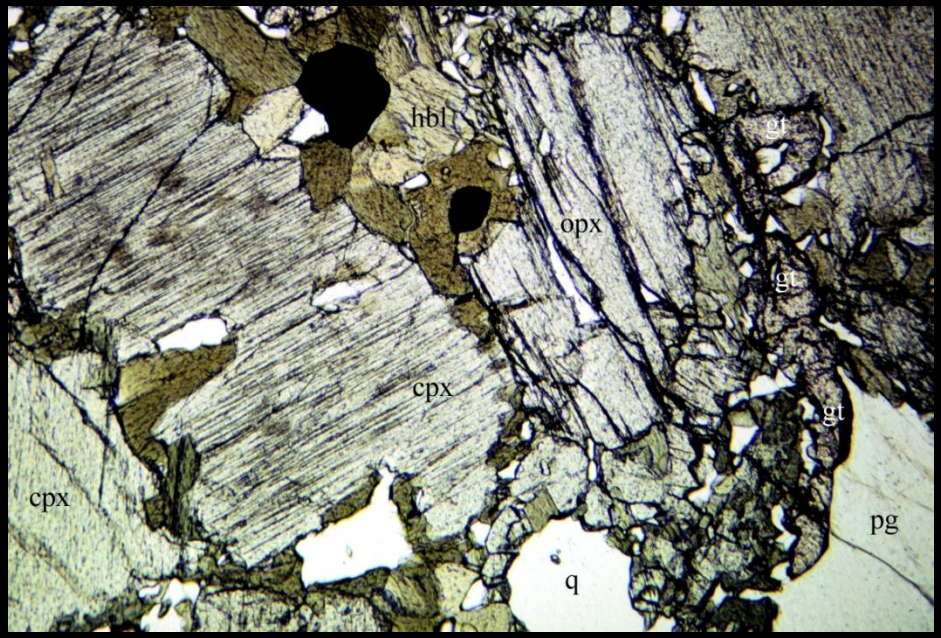
In Western and Central Manhattan:
Amphibolite Facies Schists
Well-layered Hartland Fm.
Penetrative Foliated Textures
Great Rocks for Tunneling and Excavation!

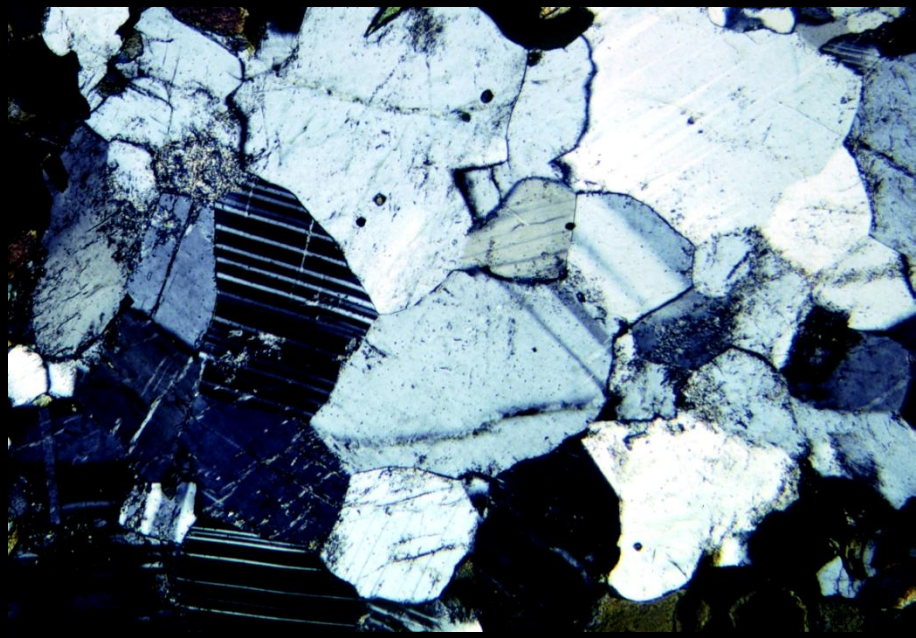




Granulite Facies Gneisses Found in the Queens Tunnel and Elsewhere = Granoblastic Textures

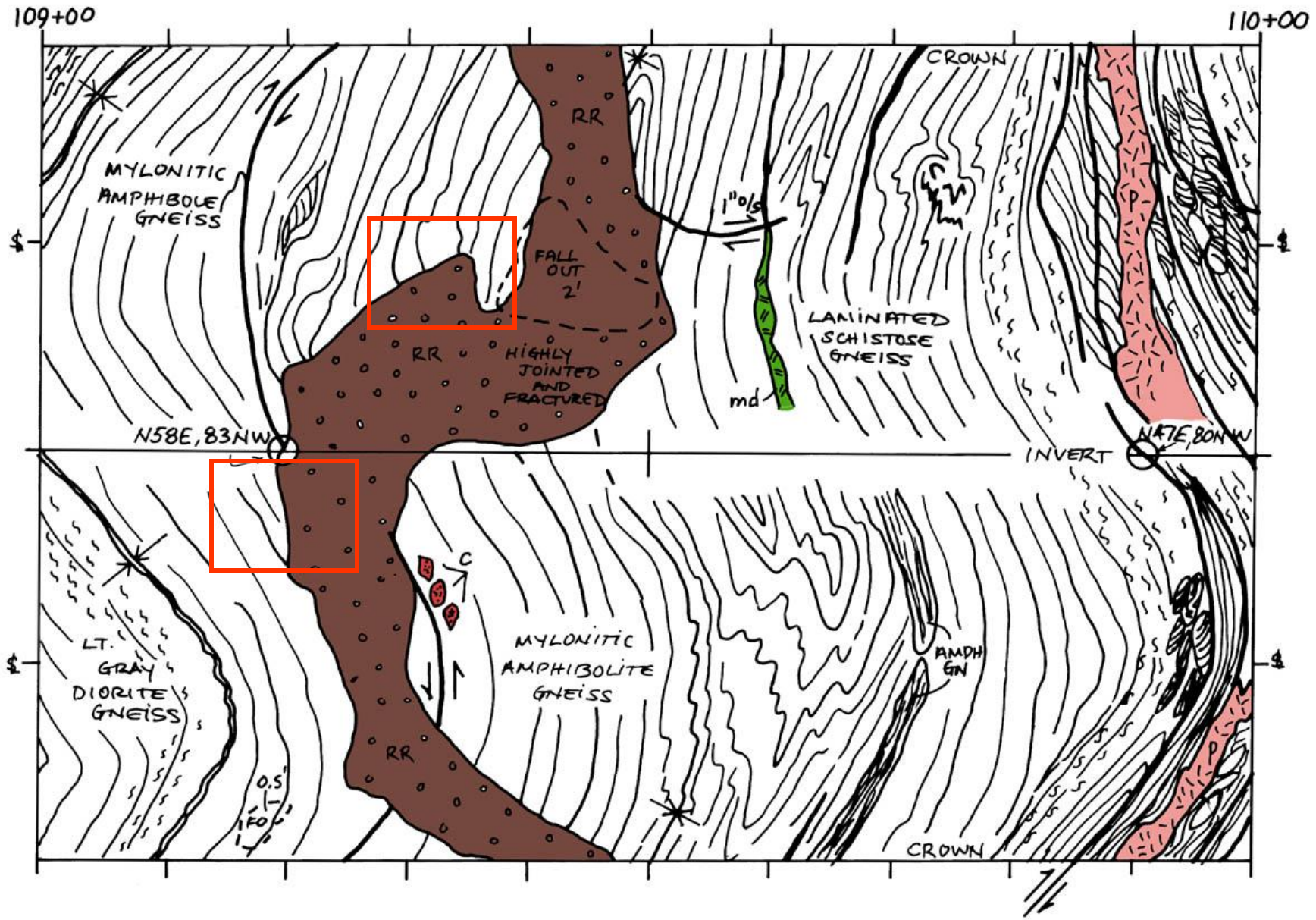
Tough Rocks for Excavation





Stage 2, City Tunnel 3

Dike 1


109+00
110+00
CROWN
MYLONITIC AMPHIBOLE GNEISS
RR
FALL OUT 2'
RR
HIGHLY JOINTED AND FRACTURED
1"o/s
md
LAMINATED SCHISTOSE GNEISS
P
N58E, 83NW
INVERT
N47E, 80NW
C
LT. GRAY DIORITE GNEISS
MYLONITIC AMPHIBOLITE GNEISS
AMDH GN
RR
0.5'
FO
P
CROWN


Station 130+40, Right Wall
Multidirectional cooling joints in rhyodacite


12:05PM
5/15/1998

Tunneling Difficulties

Major Lithologic Contrast

NYC TBM Projects (1964-2012)

Richmond Water Supply Tunnel
West Side Interceptor
63rd Street Tunnel
Brooklyn Water Tunnel
Queens Water Tunnel
Con Edison Steam Tunnel
Manhattan Water Tunnel
East Side Access Project
Croton Water Tunnel/Plant
No. 7 Line IRT Extension
Second Avenue Subway
East Side Access – Queens Side

Factors: TBM Penetration Destiny

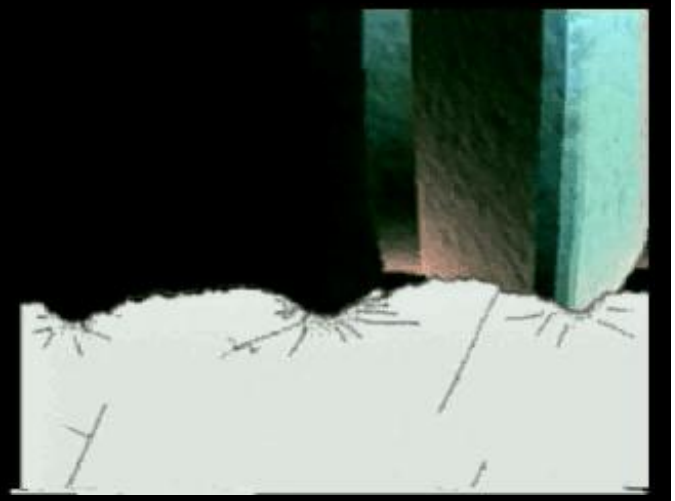
Intrinsic Factors (Penetration Rate)

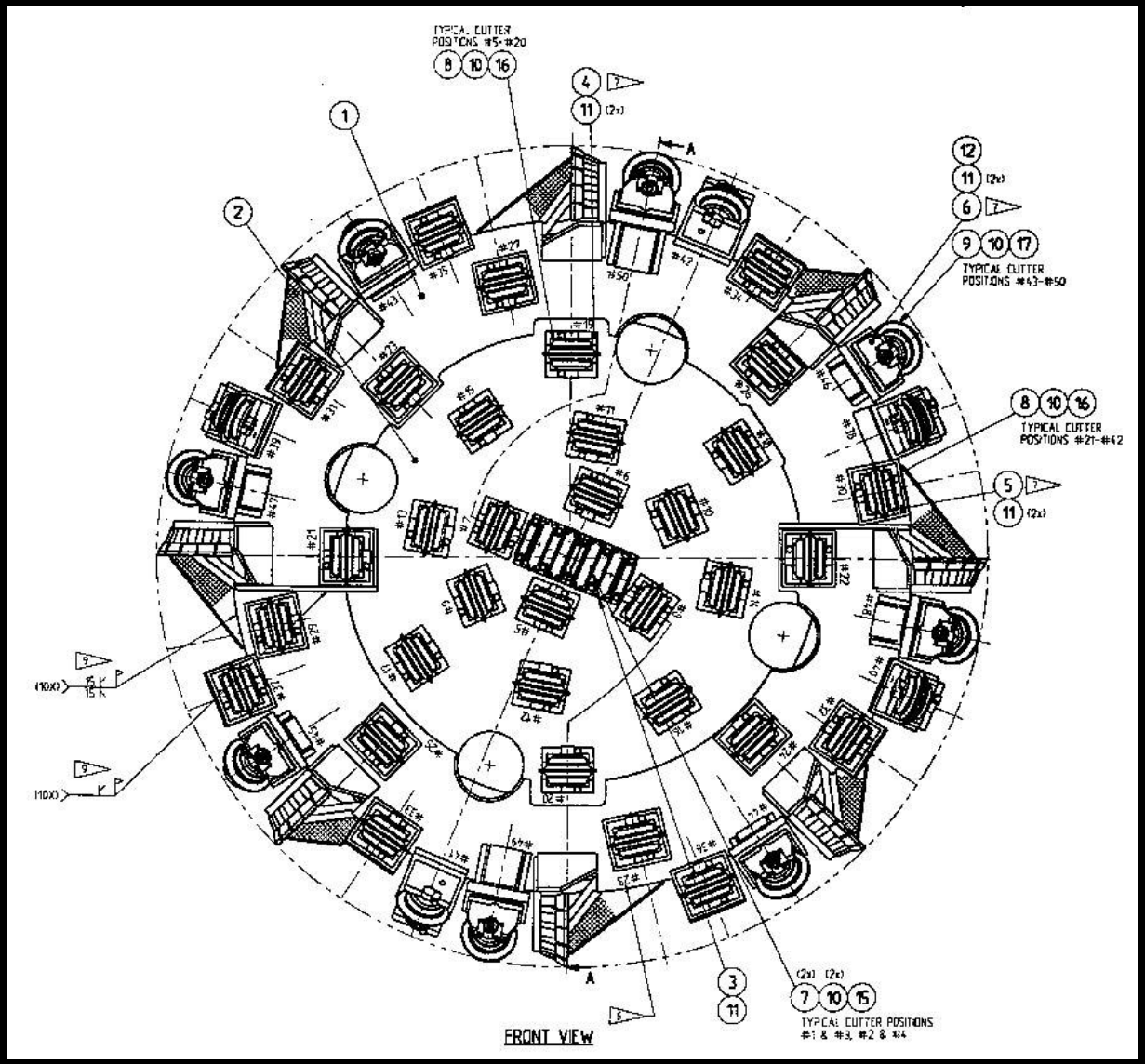
- UCS
- Fracture Density – RQD/Recovery
- Faults/Joints
- Mineralogy
- Hardness/Density
- Rock Type
- Texture/Metamorphic Grade
- Fabric Orientation/Development

Episodic Factors (Utilization)

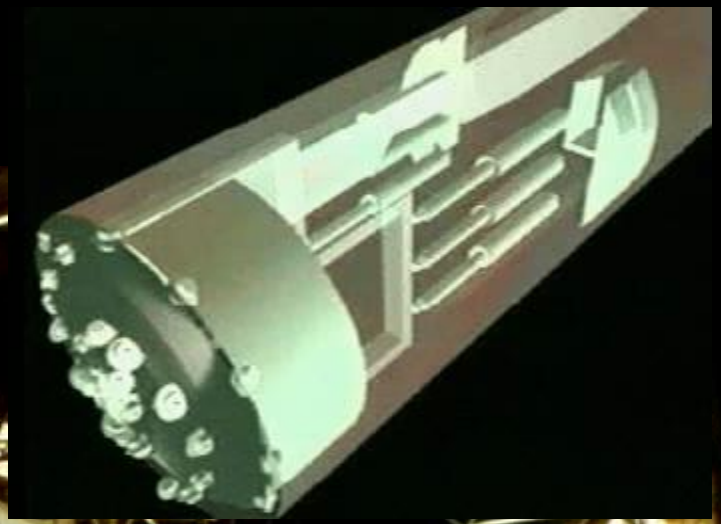
- Convergent Fault Zones
- Unusual Rock Types/Structures
- Stress Popping/Heave
- Unusual Water Inflows

TBM Chip Production





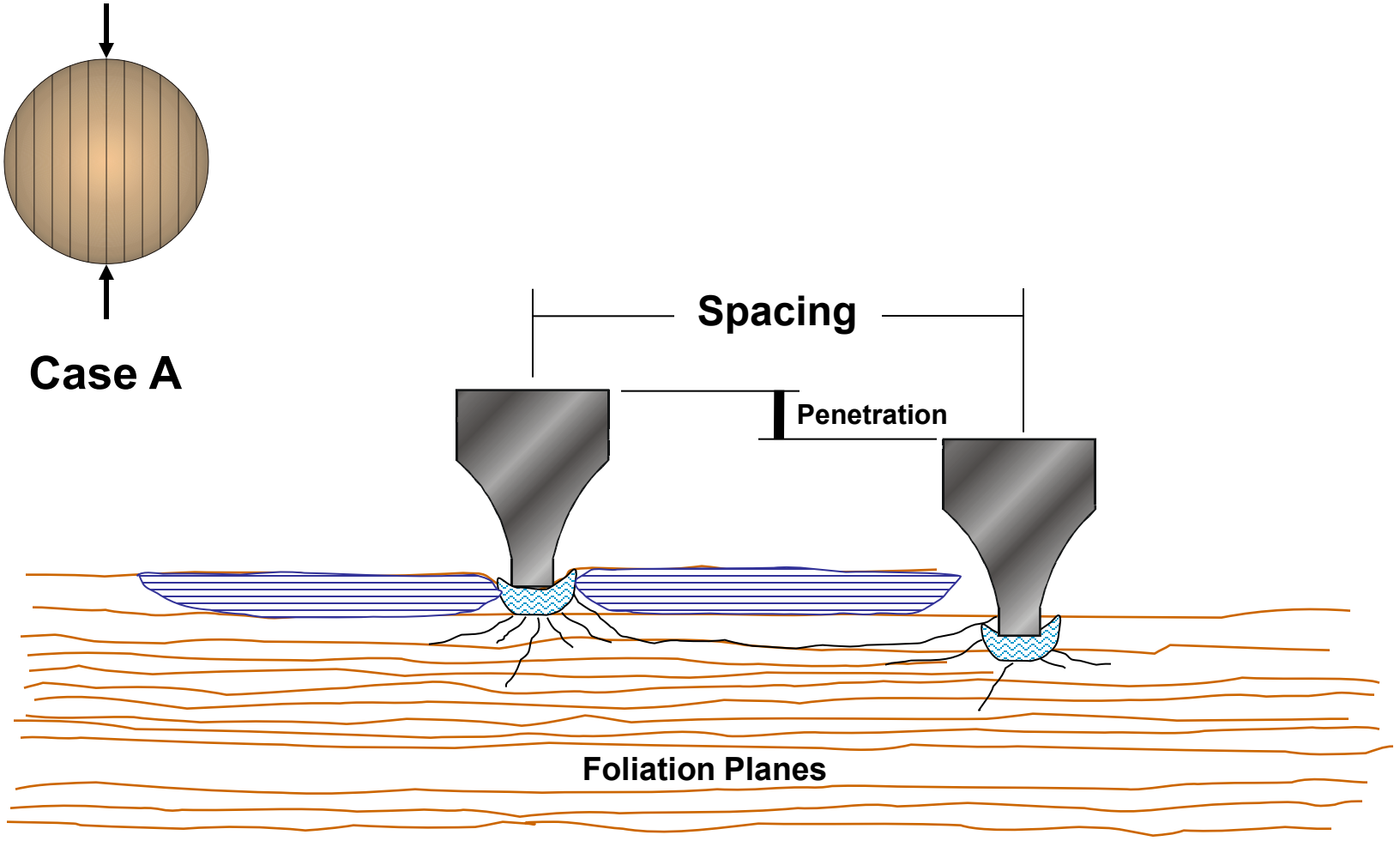
Robbins 235-282 HP Main Beam TBM



Chesterfield, England - 1996

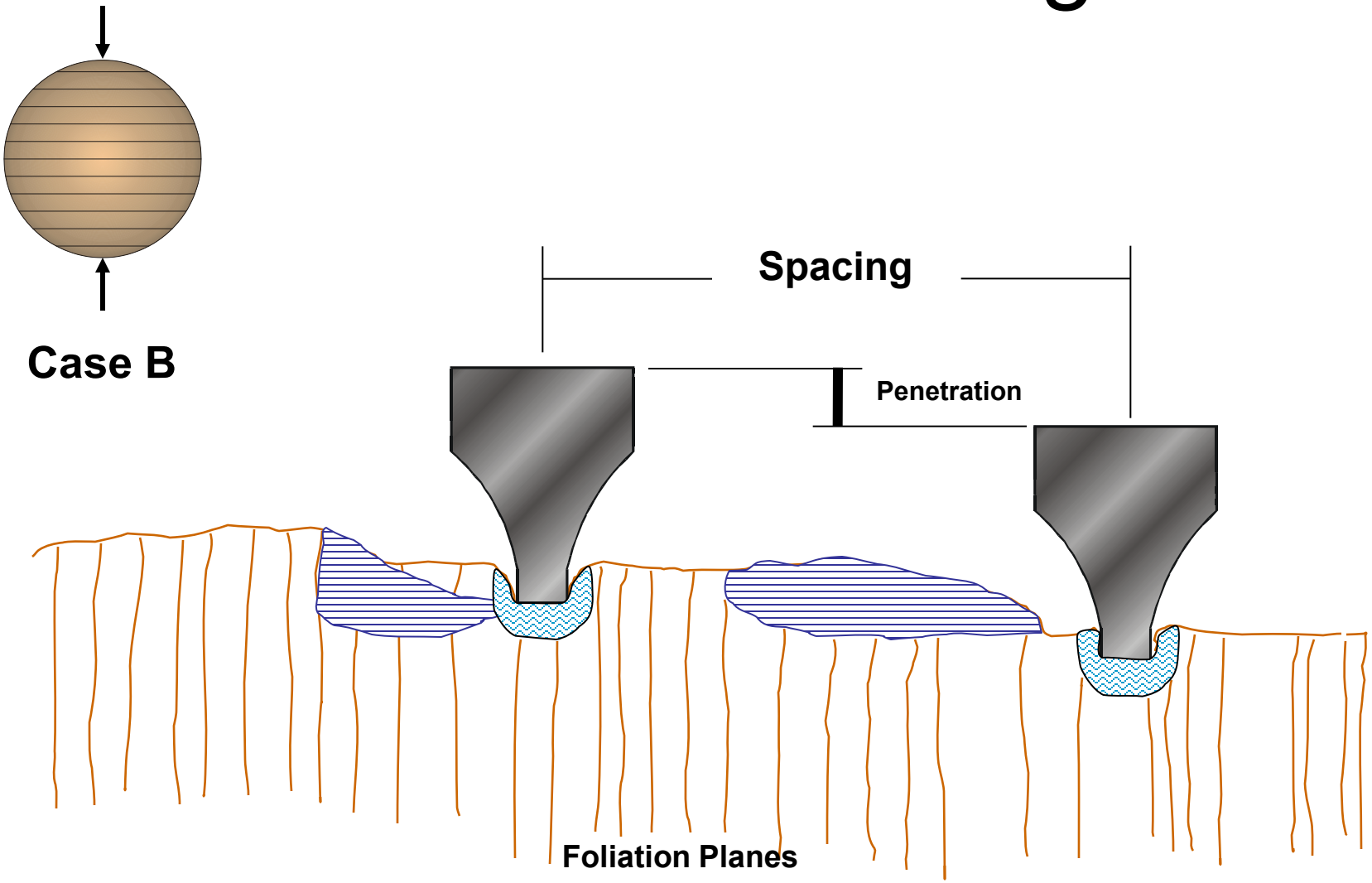
Desirable Kerf Pattern in Hard Rocks

Foliation Planes Parallel

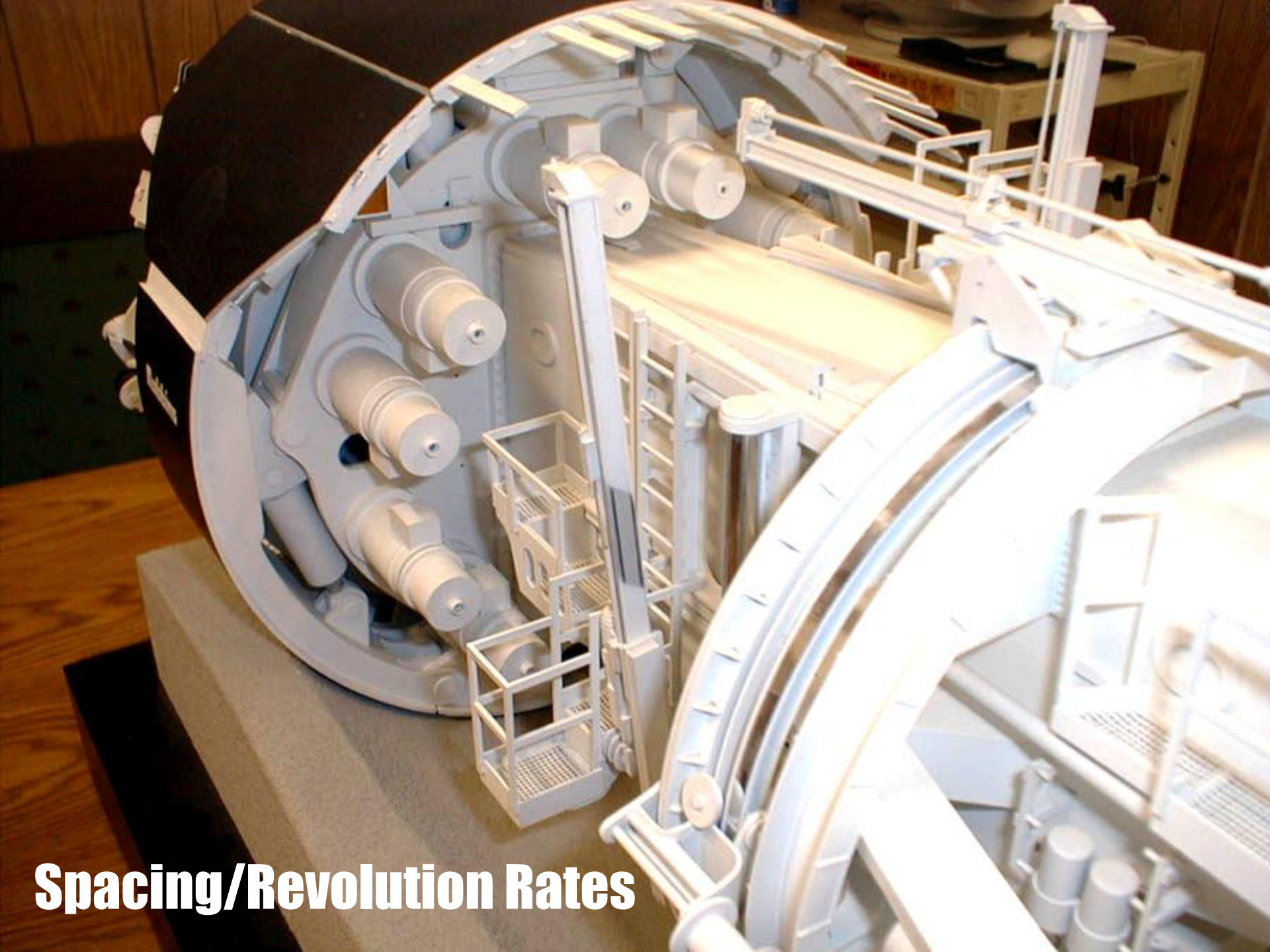


Chipping mechanism when TBM advancing perpendicular to foliation (Case A)

Foliation Planes Orthogonal



Chipping mechanism when TBM advancing parallel to foliation (Case B)


Spacing/Revolution Rates

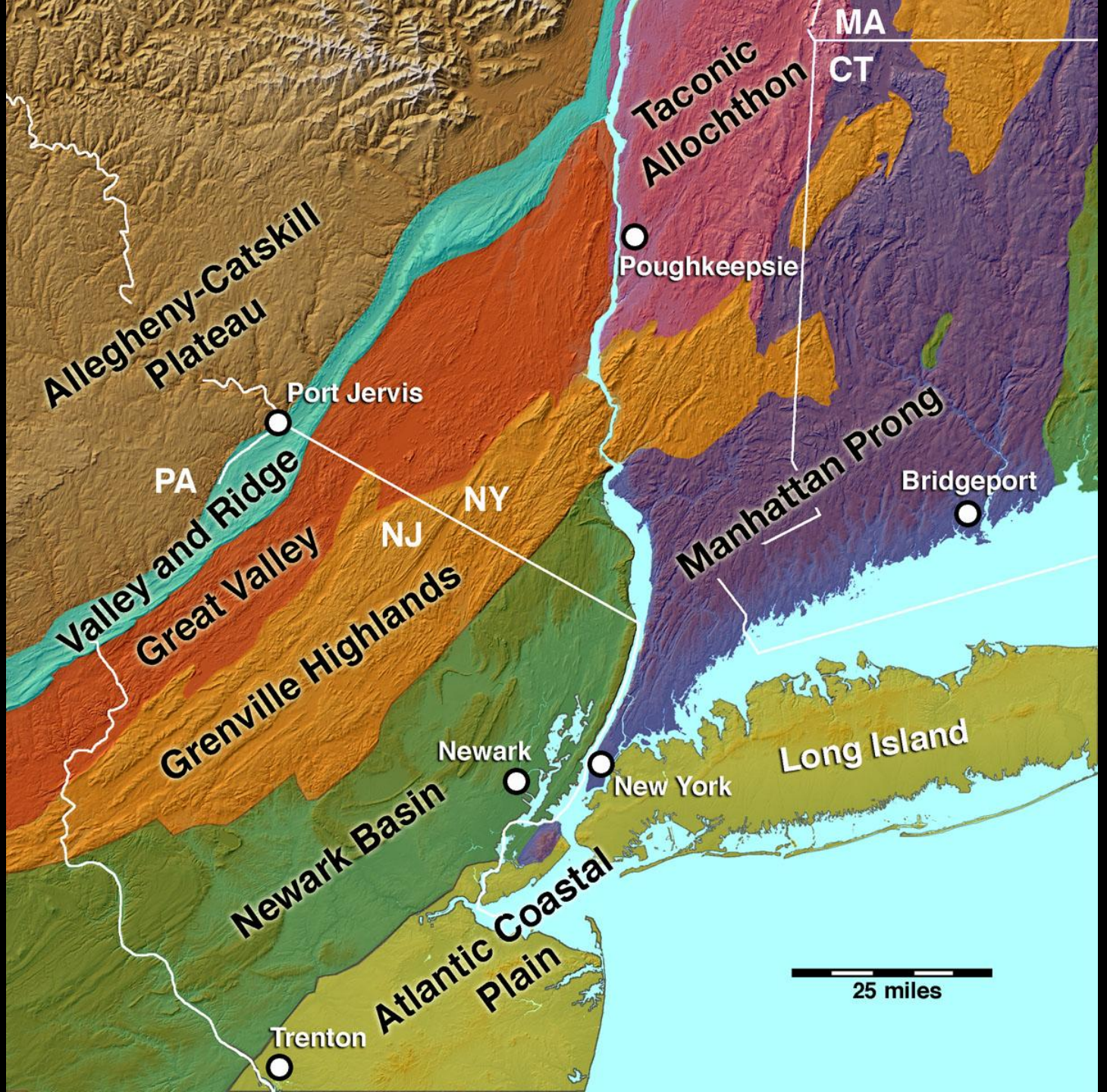
Queens Tunnel TBM
422 HP Electric
Water Cooled,
Three Phase Motors

10 Motors Total
Usually 8 Online
Rotated Cutterhead
at 8.3 Rev/Min

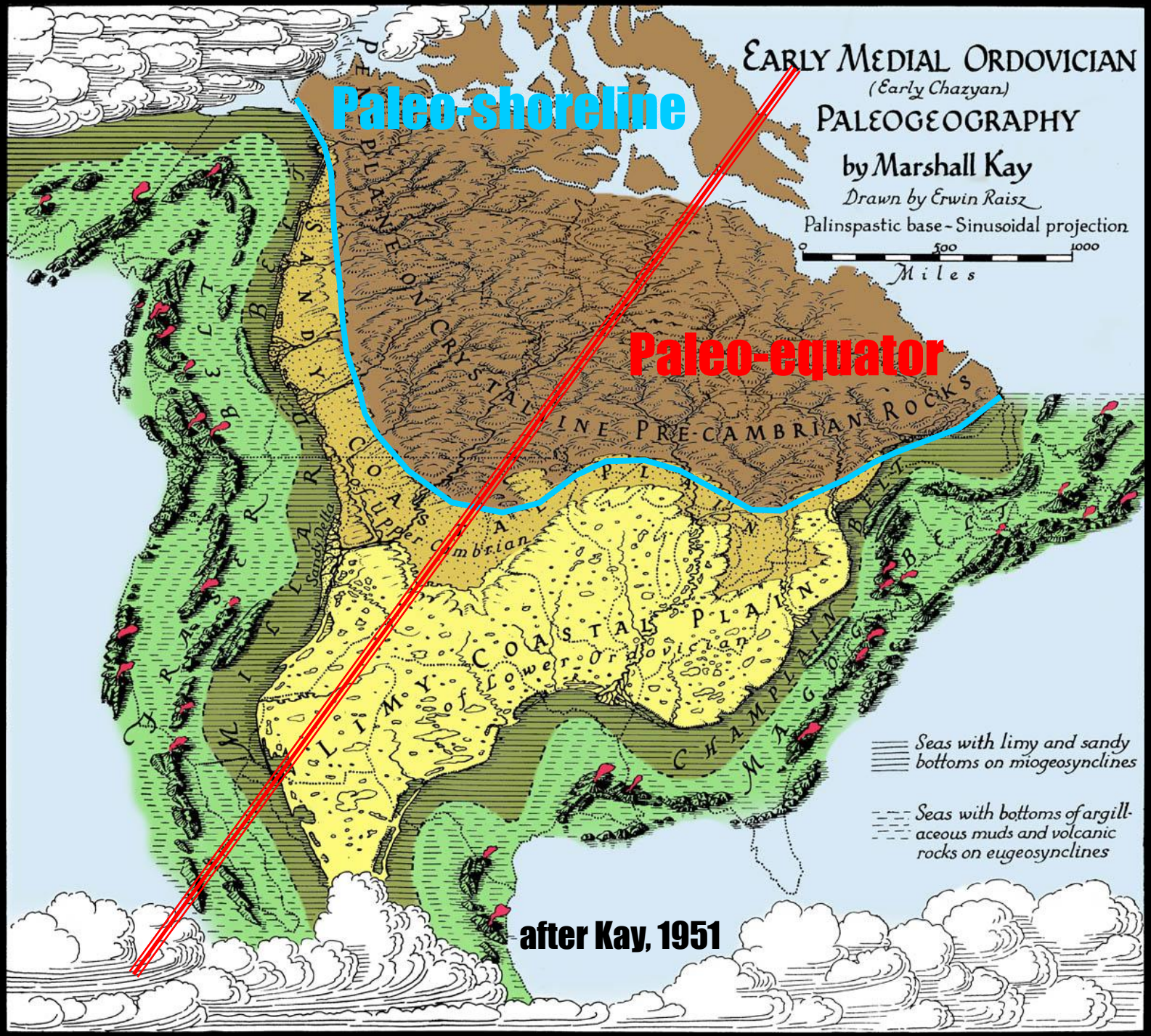
New Dukelabs Research TBM Cutter Head Torque Dynamics

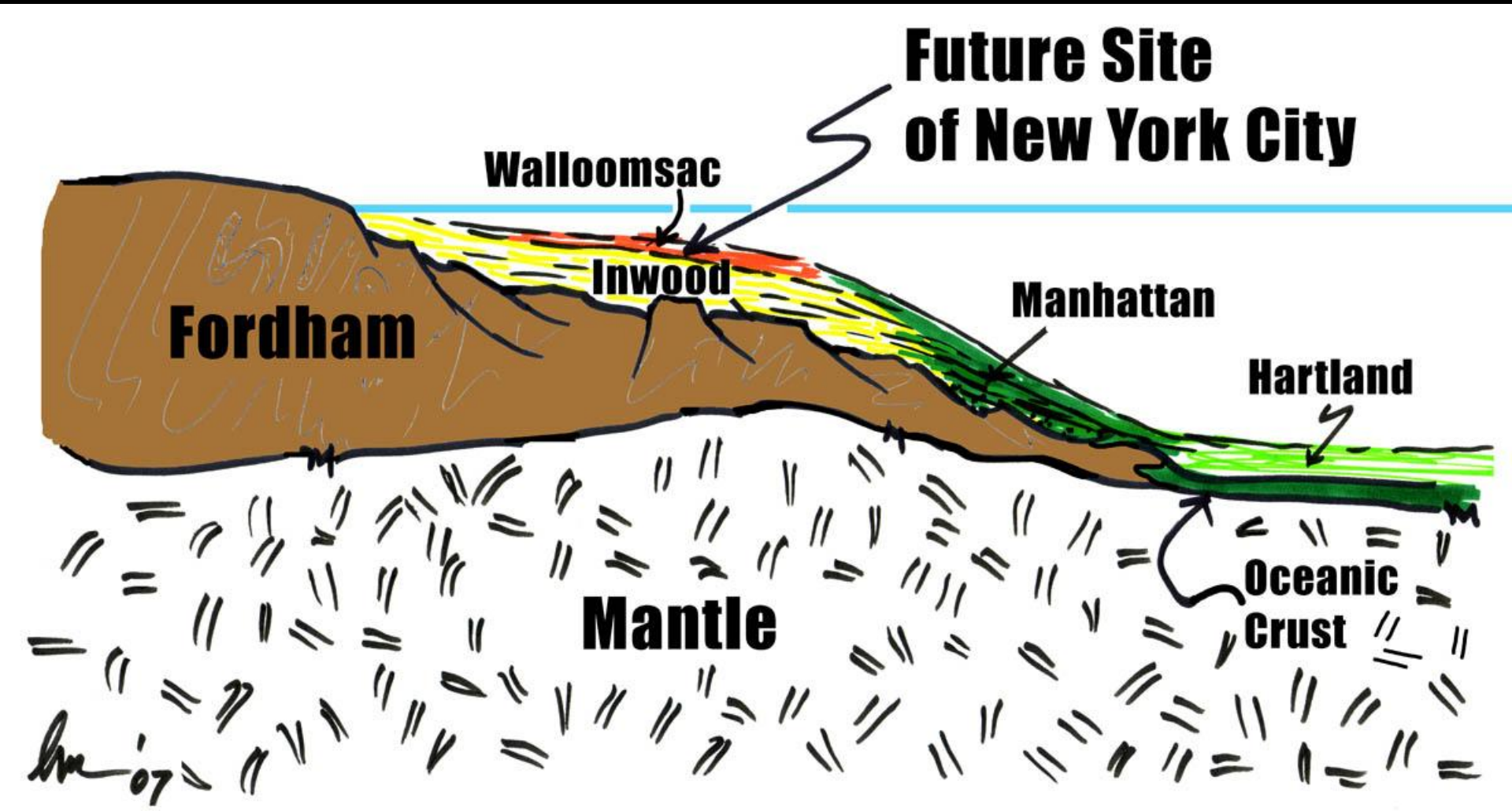
The History Channel: Super City – New York
22 September 2008

Hollywood Fat Cat Merguerian and Director of Operations Genevieve Glasson at Geology "Hammy" Awards Presentation (2008)

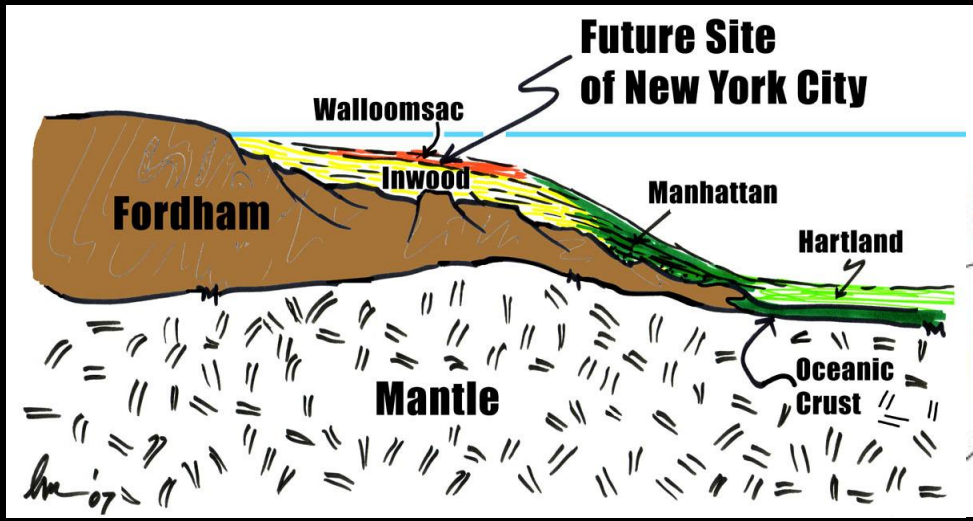

MA
CT
Taconic Allochthon
Poughkeepsie
Allegheny-Catskill Plateau
Port Jervis
PA
NY
NJ
Valley and Ridge
Great Valley
Grenville Highlands
Manhattan Prong
Bridgeport
Newark
New York
Long Island
Newark Basin
Atlantic Coastal Plain
Trenton
25 miles

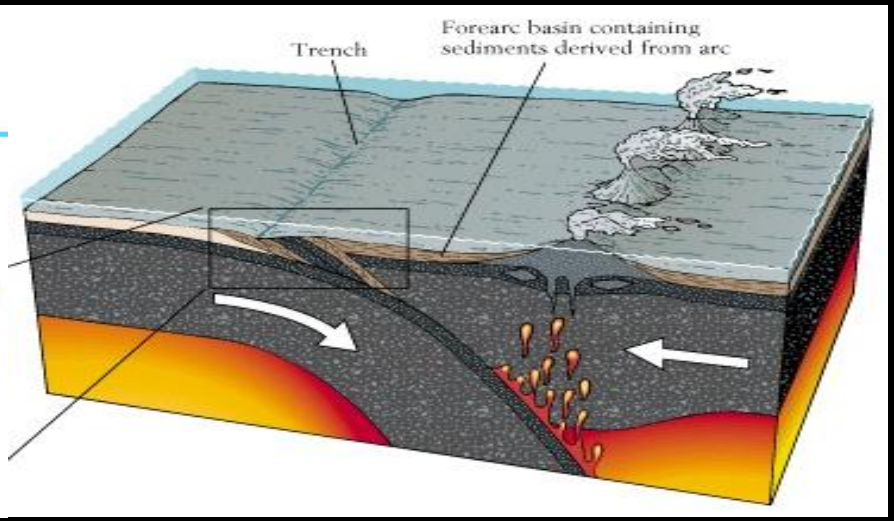
Let's Go Back In Time From Today to the Cambrian!

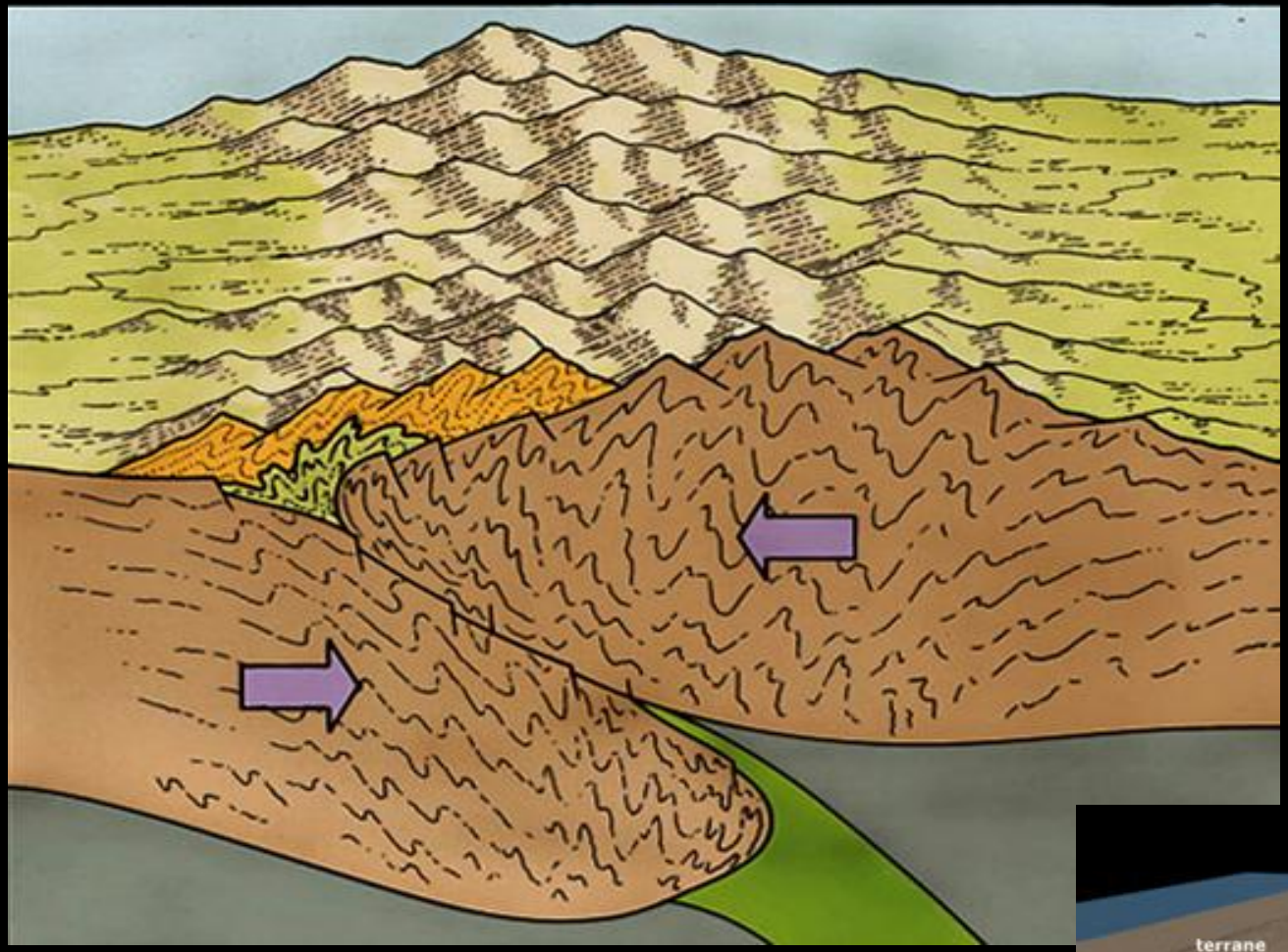

Paleo-shoreline
Paleo-equator
EARLY MEDIAL ORDOVICIAN
(Early Chazyan)
PALEOGEOGRAPHY
by Marshall Kay
Drawn by Erwin Raisz
Palinspastic base - Sinusoidal projection
500
1000
Miles
PENEPLANED CRYSTALLINE PRE-CAMBRIAN ROCKS
SANDY COASTAL PLAIN of Upper Cambrian
LIMY COASTAL PLAIN of Lower Ordovician
CHAMPLAIN MAGEOGEOSYNCLINE
APPALACHIAN GEOSYNCLINE
Seas with limy and sandy bottoms on miogeosynclines
Seas with bottoms of argillaceous muds and volcanic rocks on eugeosynclines
after Kay, 1951

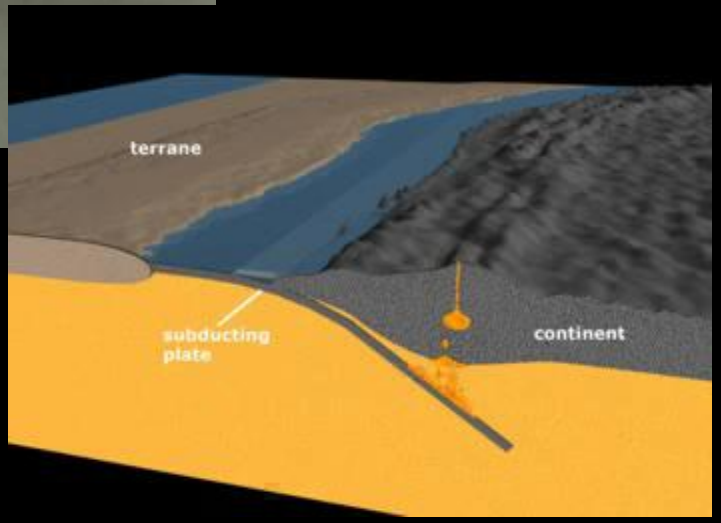

Future Site
of New York City
Walloomsac
Inwood
Fordham
Manhattan
Hartland
Oceanic
Crust
Mantle
'07

~ 480 Ma Taconian Arc – Passive Margin Collision



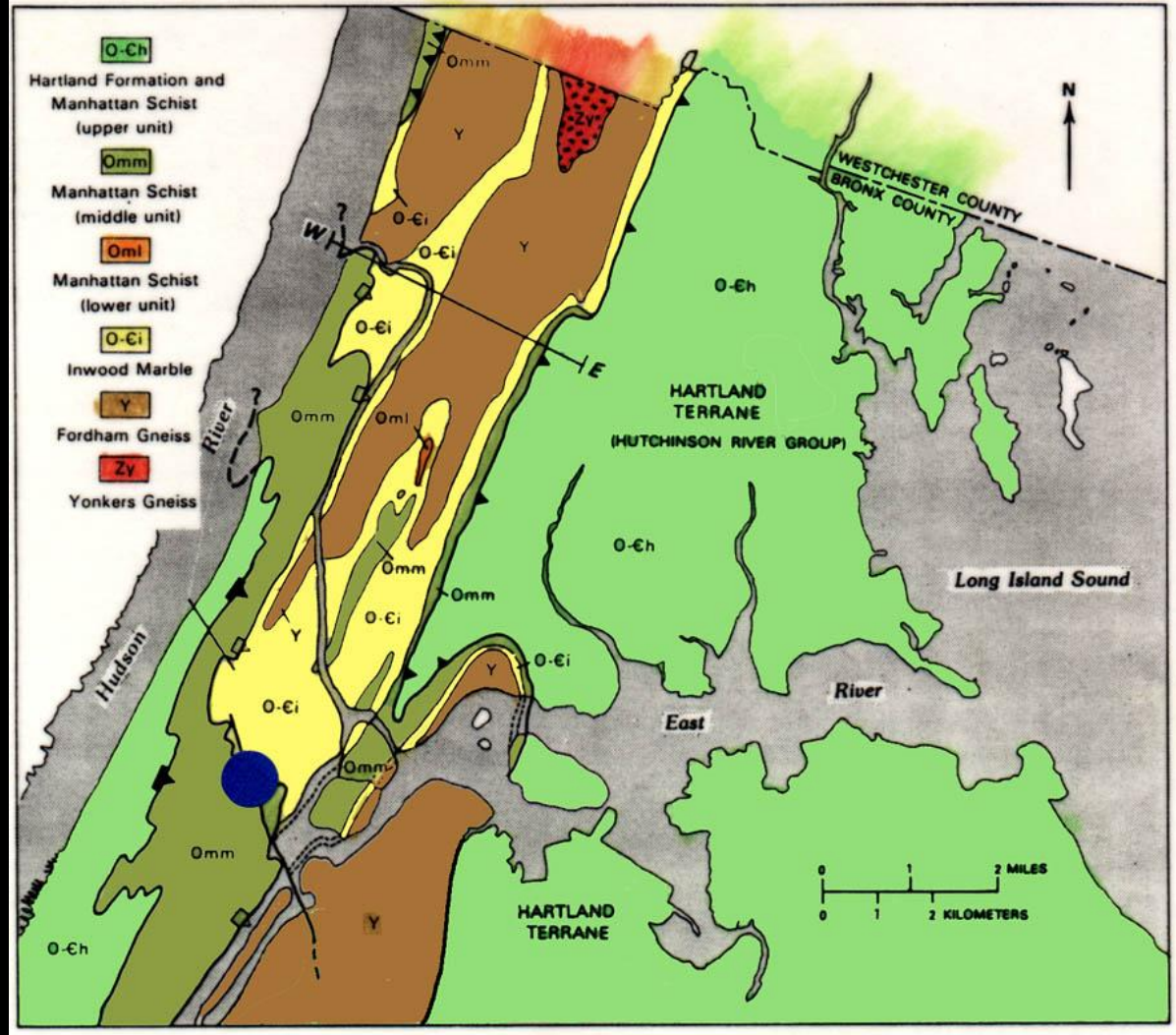


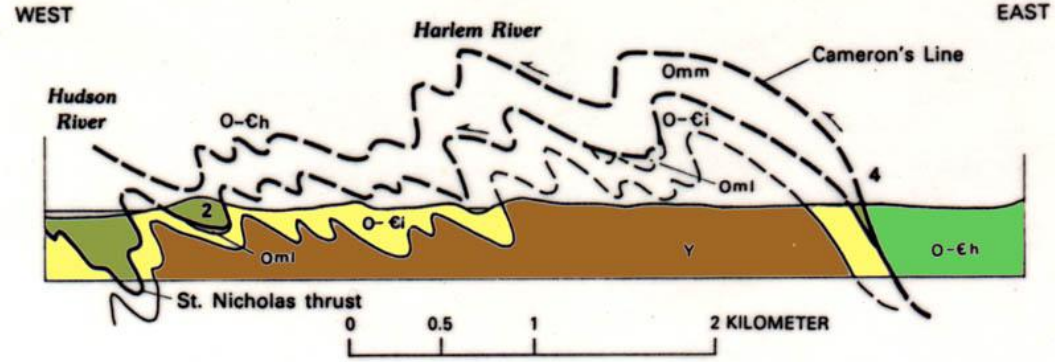


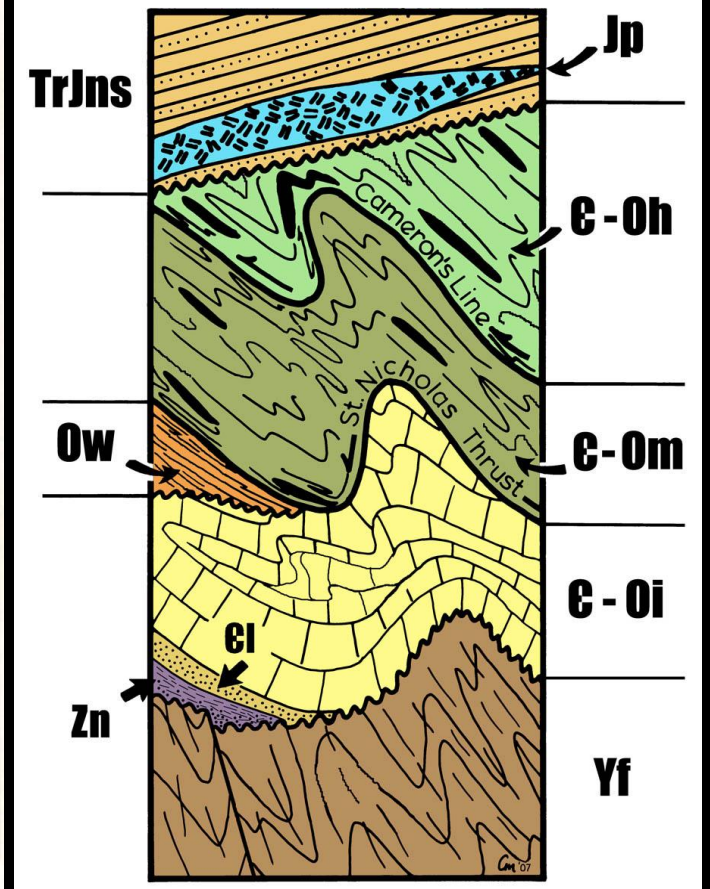


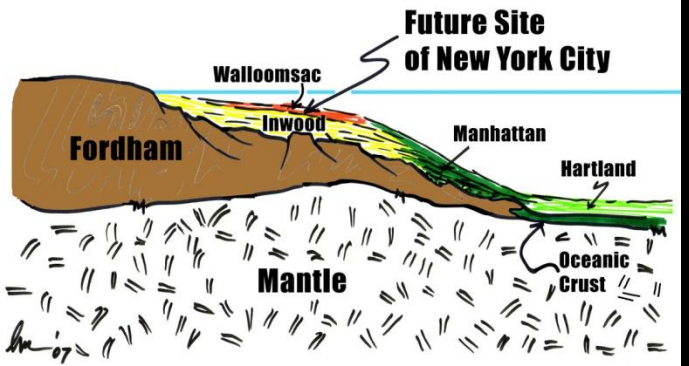
450 Ma to 250 Ma Protracted Plate Collisions Produce the Appalachians

New York City

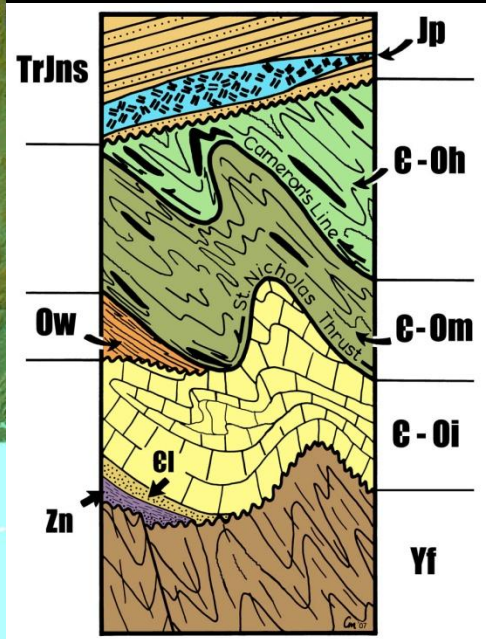








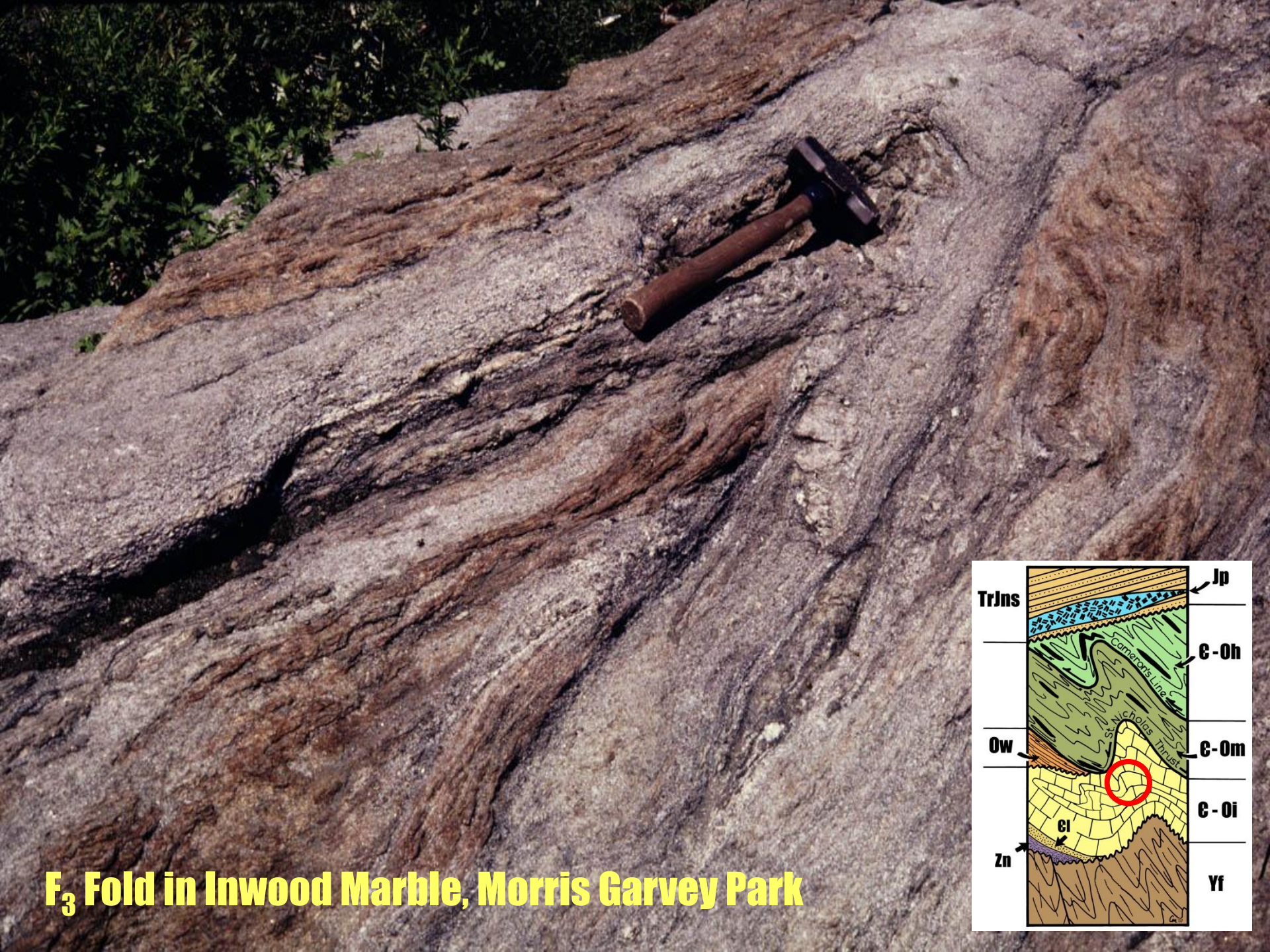
NYC Rocks



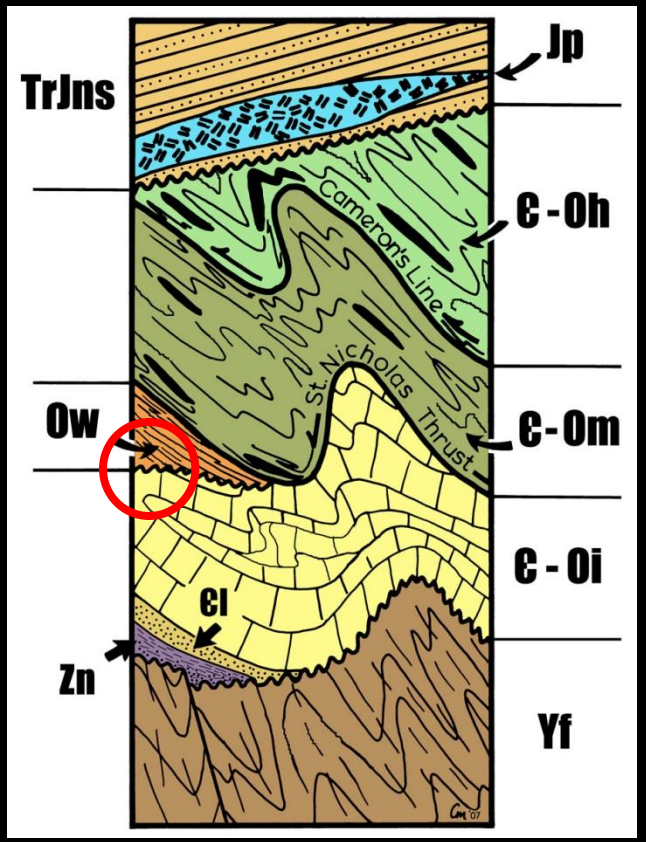
MA
CT
Taconic Allochthon
Poughkeepsie
Allegheny-Catskill Plateau
Port Jervis
PA
NY
NJ
Valley and Ridge
Great Valley
Grenville Highlands
Manhattan Prong
Bridgeport
Newark
New York
Long Island
Newark Basin
Atlantic Coastal Plain
Trenton
25 miles


Fordham Gneiss, Echo Park

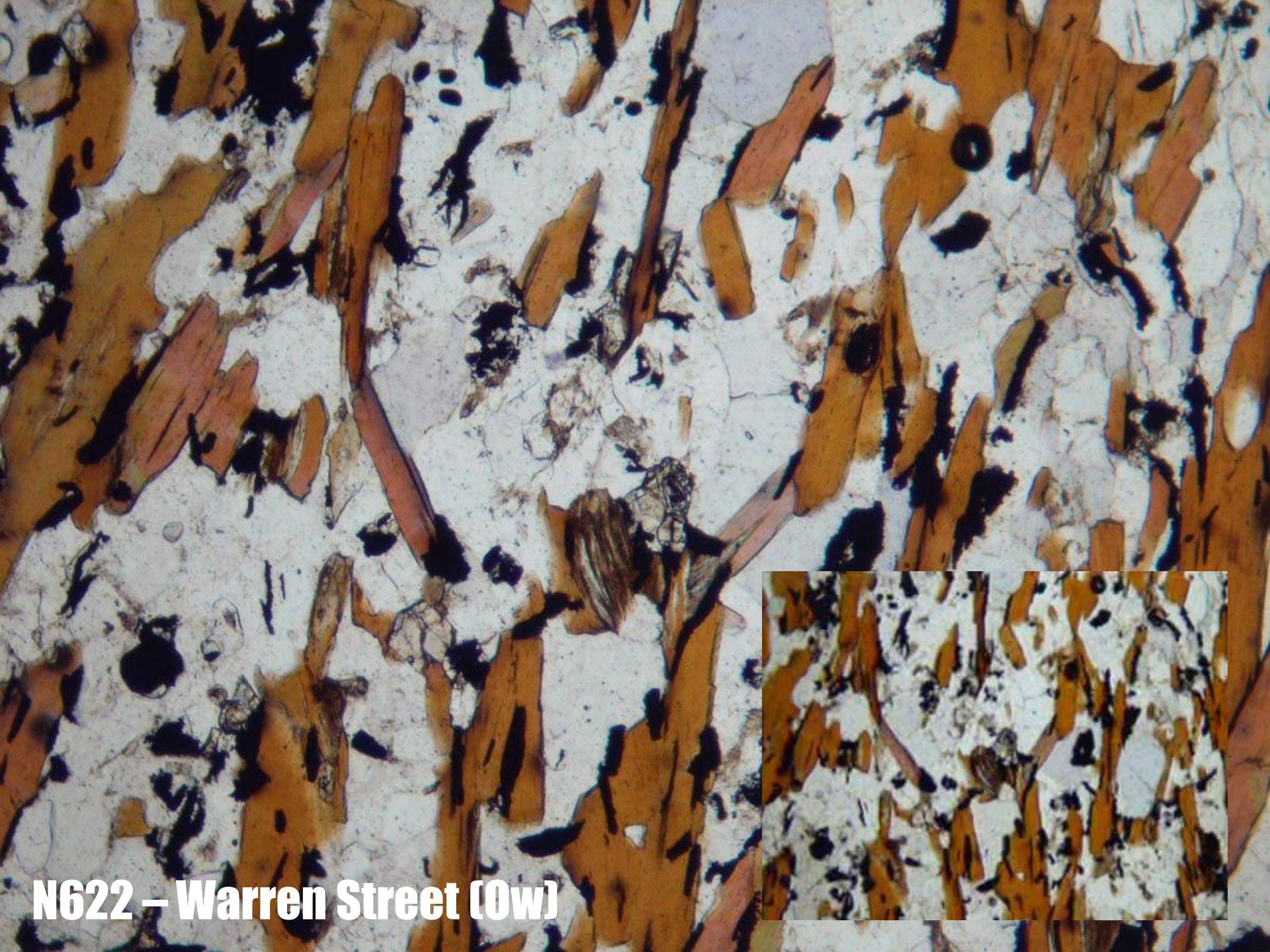
TrJns
Jp
Cameron's Line
St. Nicholas Thrust
Ow
Zn
Yf



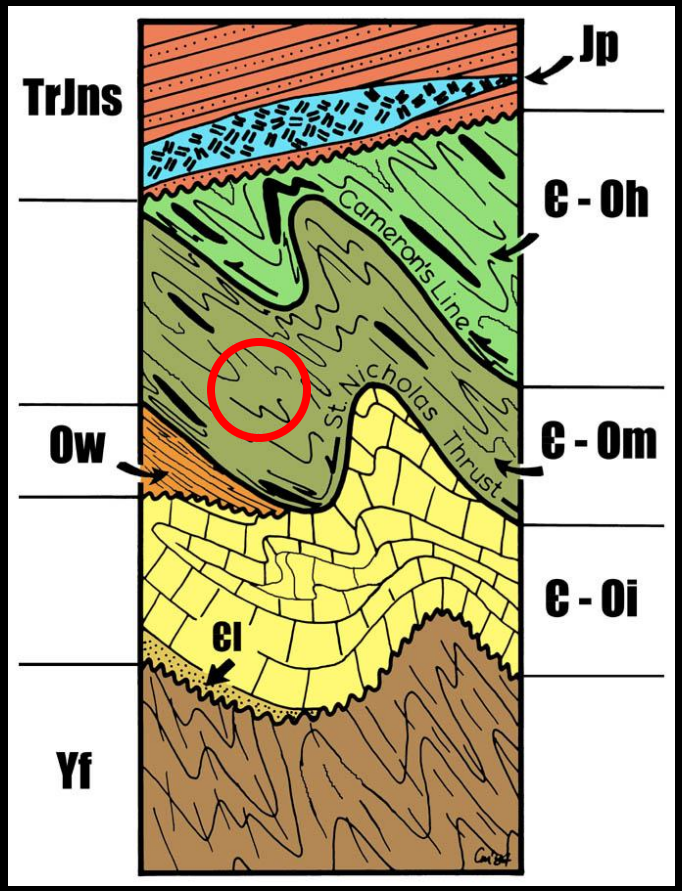
F_3 Fold in Inwood Marble, Morris Garvey Park



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

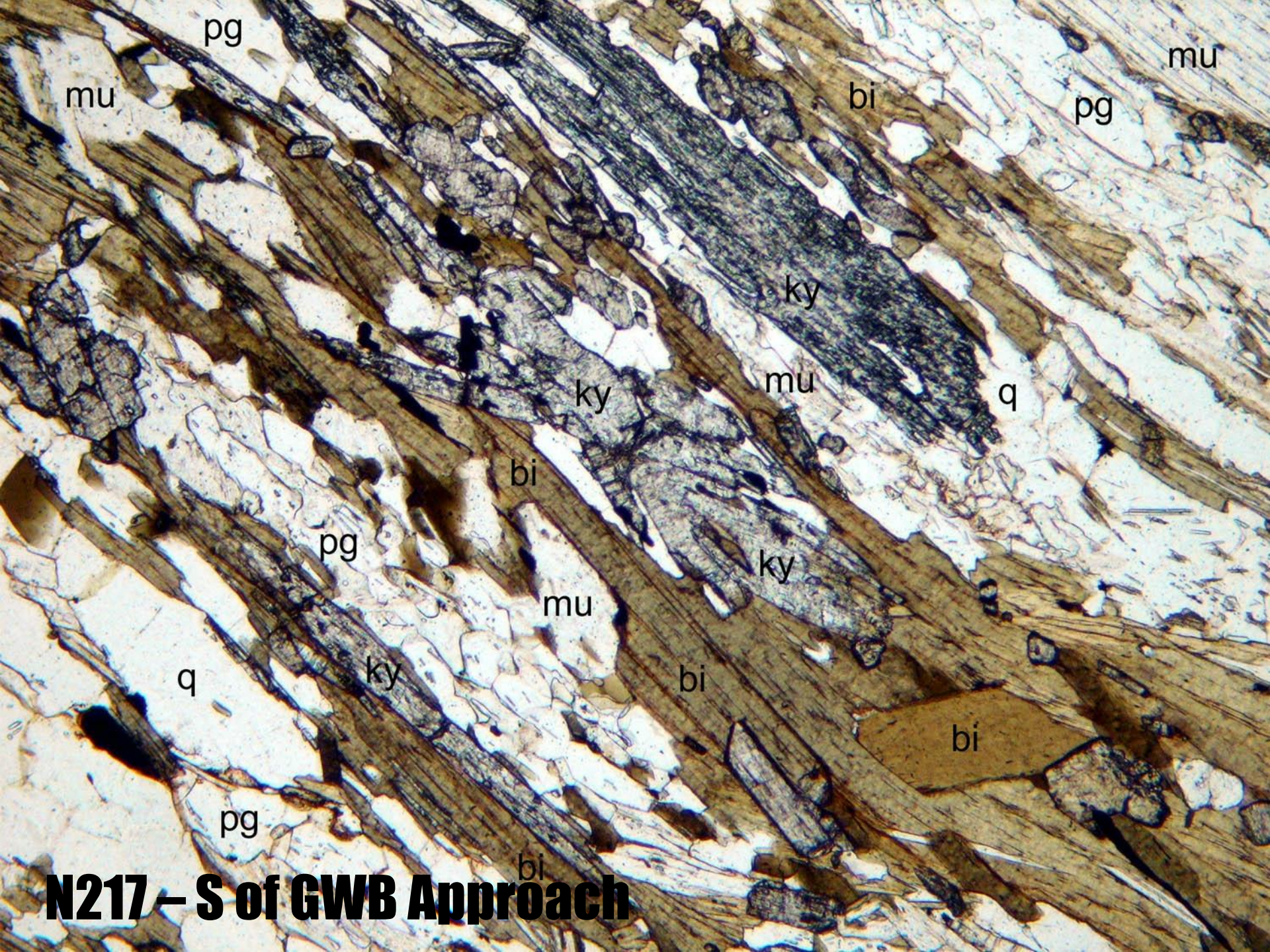


N622 – Warren Street (Ow)



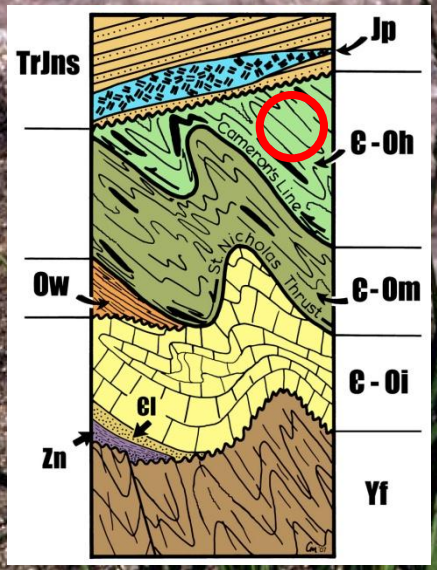
Manhattan Schist
F_3 Folds of S_2
Central Park, NYC

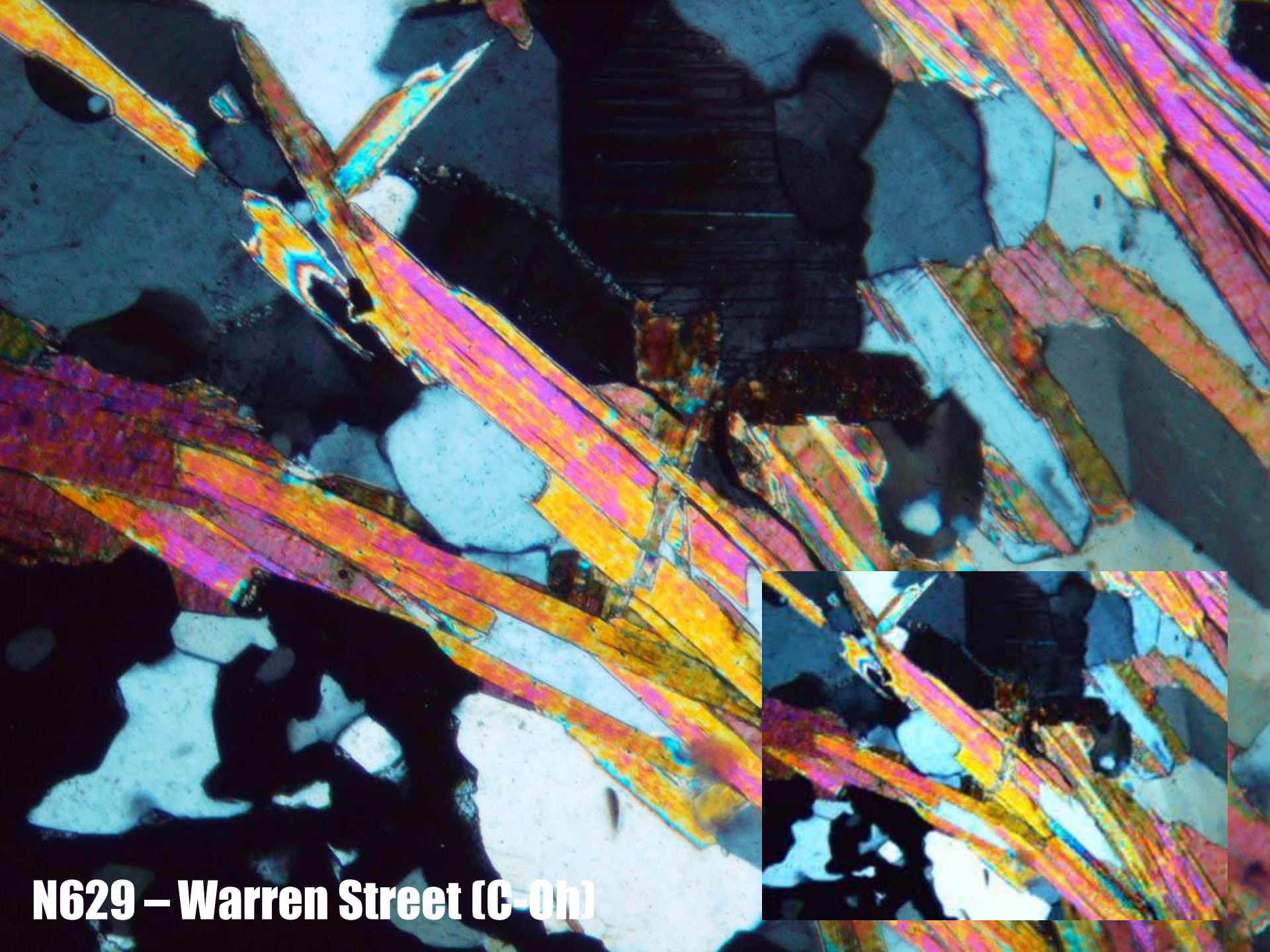

Manhattan Schist, Central Park
TrJns
Jp
Cameron's Line
St. Nicholas Thrust
Ow
Zn
Yf

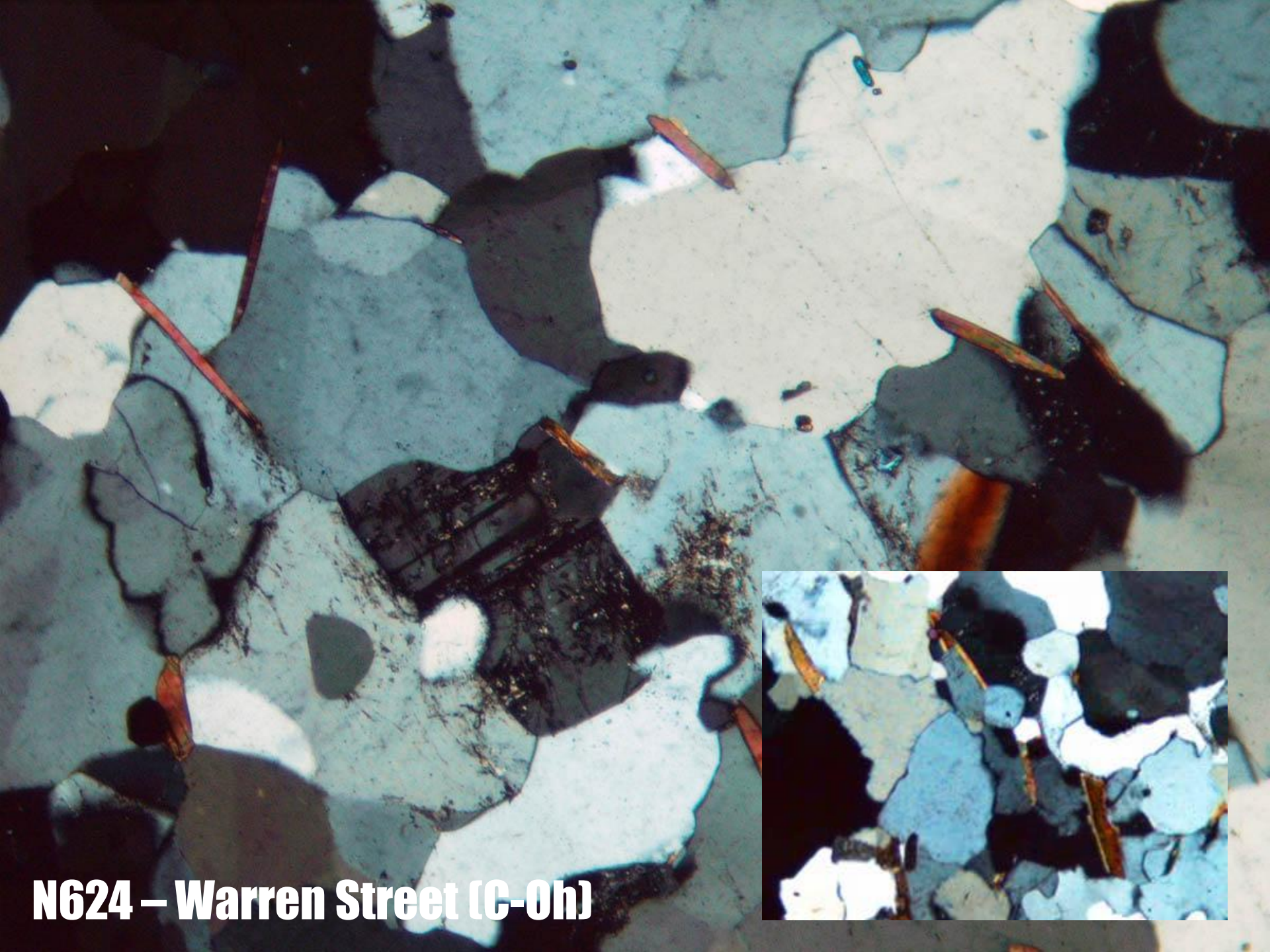


N217 – S of GWB Approach

Hartland Schist, Riverside Park




N629 – Warren Street (C-Oh)



N624 – Warren Street (C-Oh)

HERRENKNECHT TBM ADVERTISEMENT

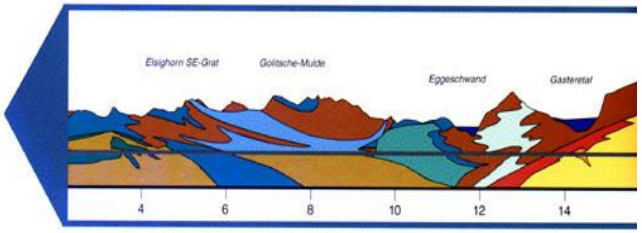
Rock Does Not Equal Rock

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".

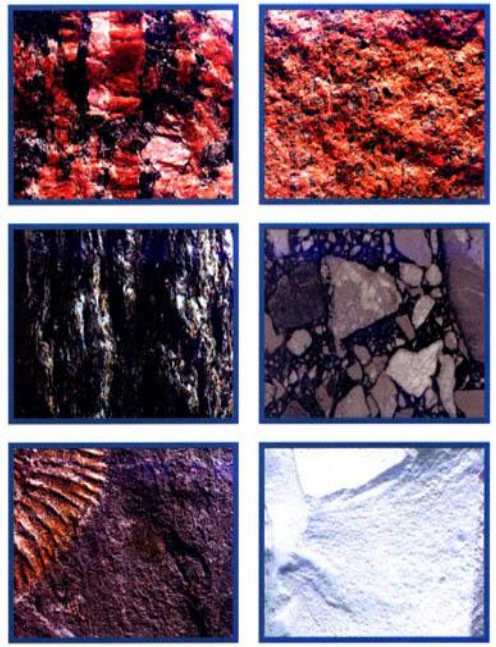
Whether it is solid rock, abrasive rock or rock under high pressure, weathered transition zones with high ground water pressure or caverns, the variety of the geological conditions in a planned tunnel route is virtually unlimited. At Herrenknecht, the geological analysis of the ground conditions is always 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

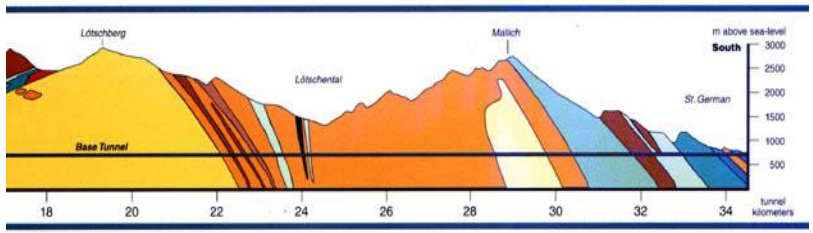
The excavation process in hard rock takes place in the peak state of the shear and compression resistance as well as tensile strengths of the rock. At the same time, the best possible tunnelling performance has to be achieved. At Herrenknecht, a team of internal specialists from the disciplines of rock mechanics, mechanical engineering and process technology find the optimum project solution for developing the machine design.

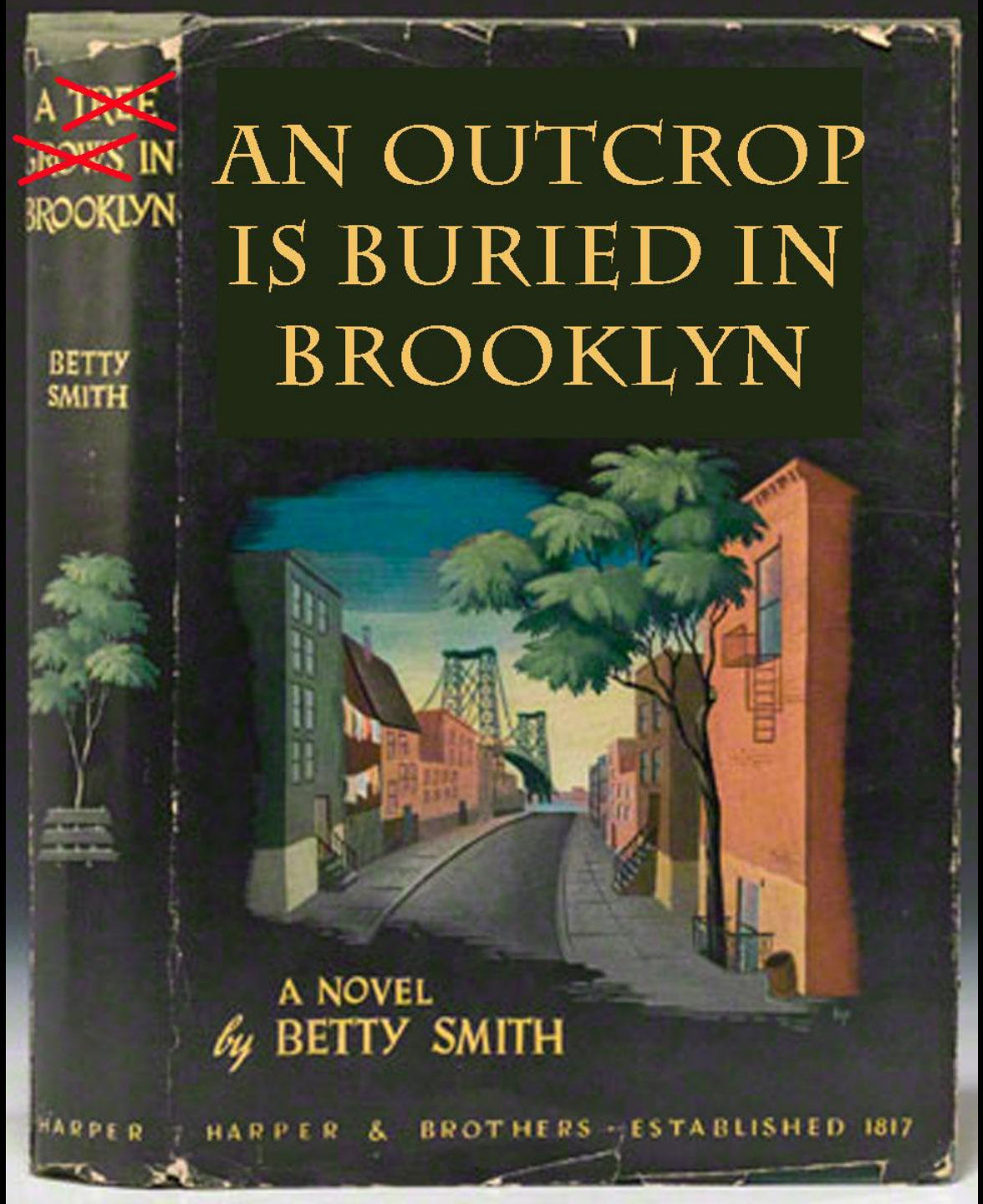


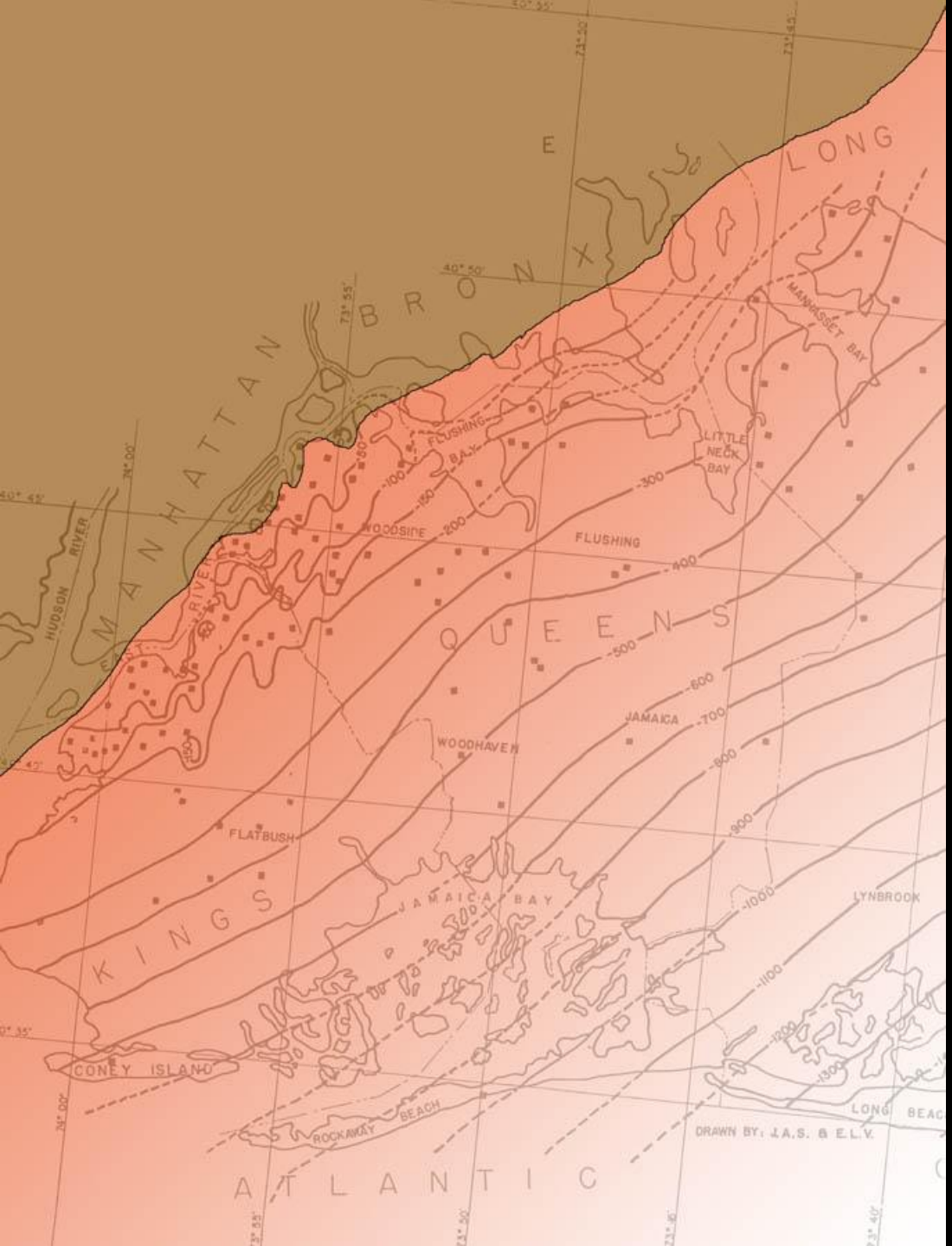
Mechanical rock excavation is confronted by rock with varying degrees of hardness, e.g. with extremely hard gneiss (top left) and granite (top right), medium hard mica schist (center left), breccia (center right) and claystone (bottom left) as well as limestone (bottom right).



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.



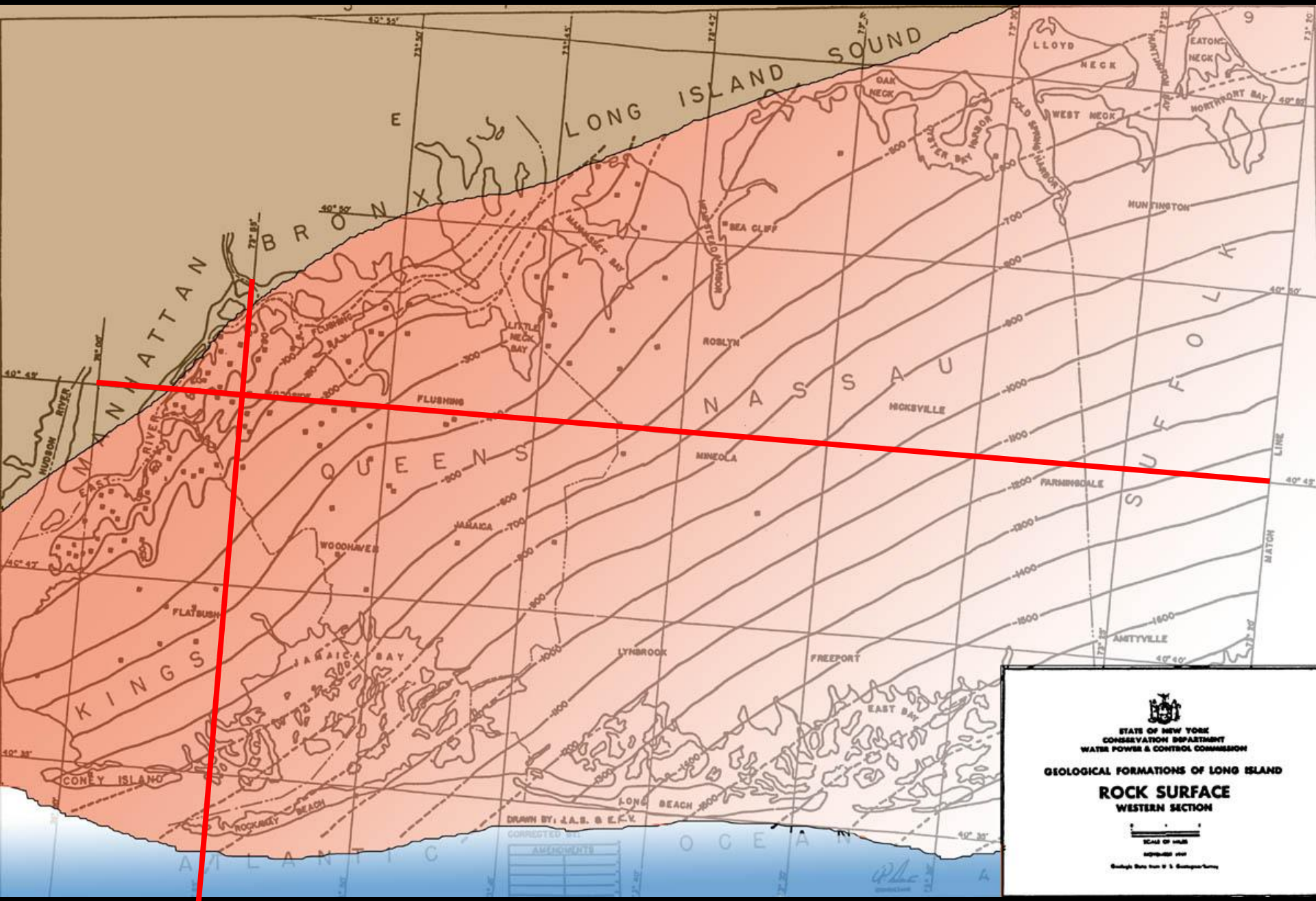

A TREE GROWS IN BROOKLYN
BETTY SMITH
AN OUTCROP IS BURIED IN BROOKLYN
A NOVEL
by BETTY SMITH
HARPER
HARPER & BROTHERS · ESTABLISHED 1817

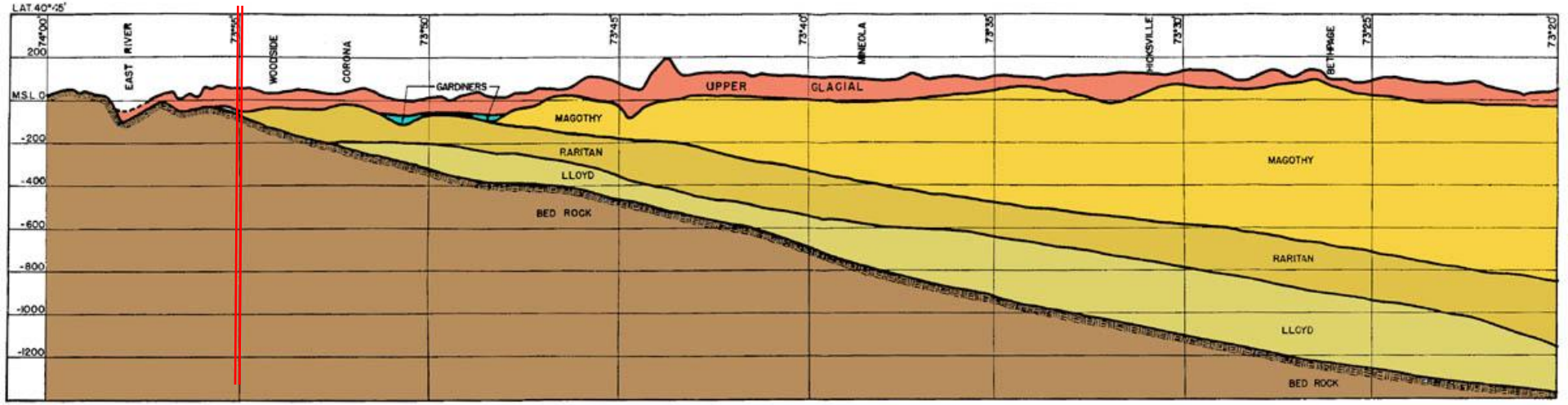


Depth to Basement

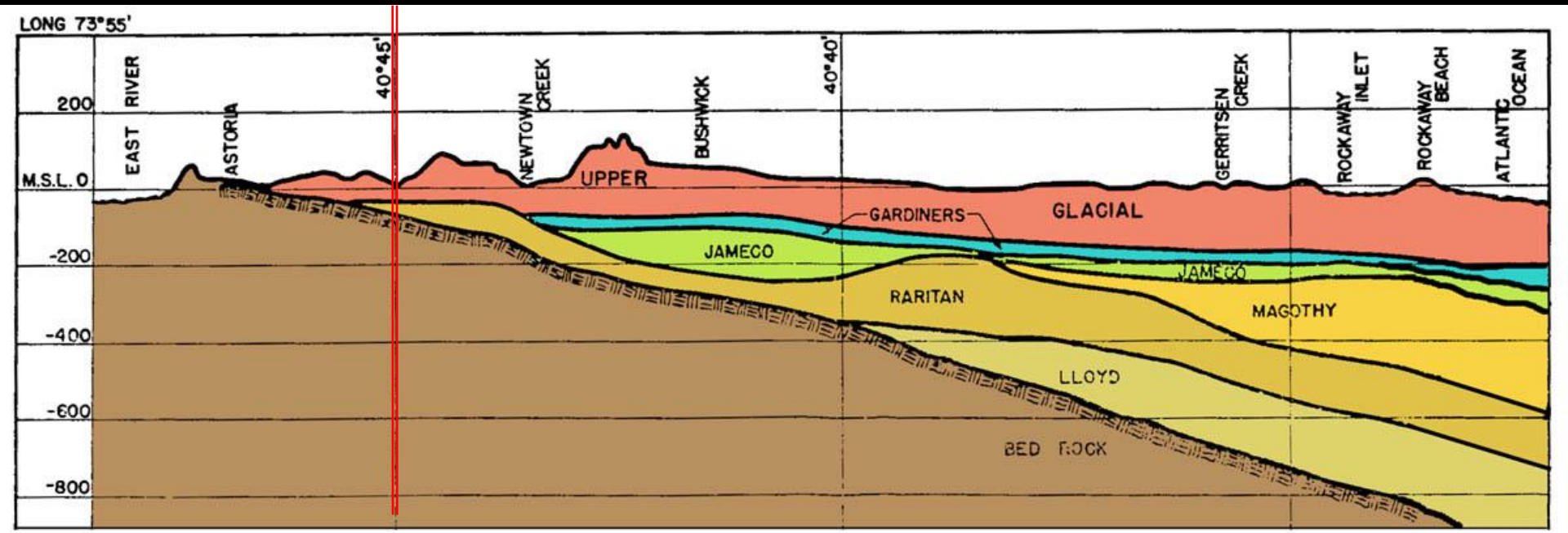
SE Slope

after Suter et al, 1949


LONG ISLAND SOUND
MANHATTAN
BRONX
QUEENS
NASSAU
SUFFOLK
KINGS
ATLANTIC OCEAN
LLOYD NECK
EATONS NECK
OAK NECK
WEST NECK
HUNTINGTON
BEA CLIFF
ROSLYN
FLUSHING
HICKSVILLE
MINEOLA
FARMINGDALE
JAMAICA
WOODHAVEN
FLATBUSH
JAMAICA BAY
LYNBROOK
FREEPORT
EAST BAY
AMITYVILLE
CONEY ISLAND
ROCKAWAY BEACH
LONG BEACH
HUDSON RIVER
EAST RIVER
MATCH LINE
STATE OF NEW YORK
CONSERVATION DEPARTMENT
WATER POWER & CONTROL COMMISSION
GEOLOGICAL FORMATIONS OF LONG ISLAND
ROCK SURFACE
WESTERN SECTION
DRAWN BY: J.A.B. & E.C.V.



LAT. 40°=45' N



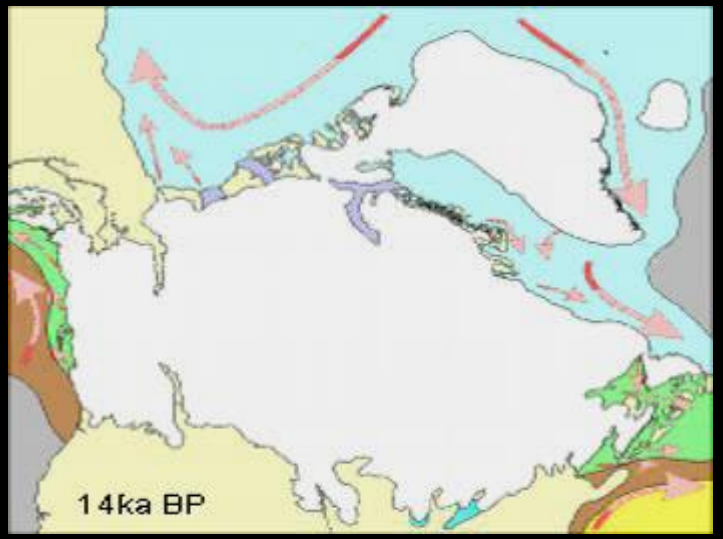
LONG. 73°=55' W

Suter et al, 1949

Glaciers of New York City

Pleistocene Glaciation

Glacial Meltback
14 Ka

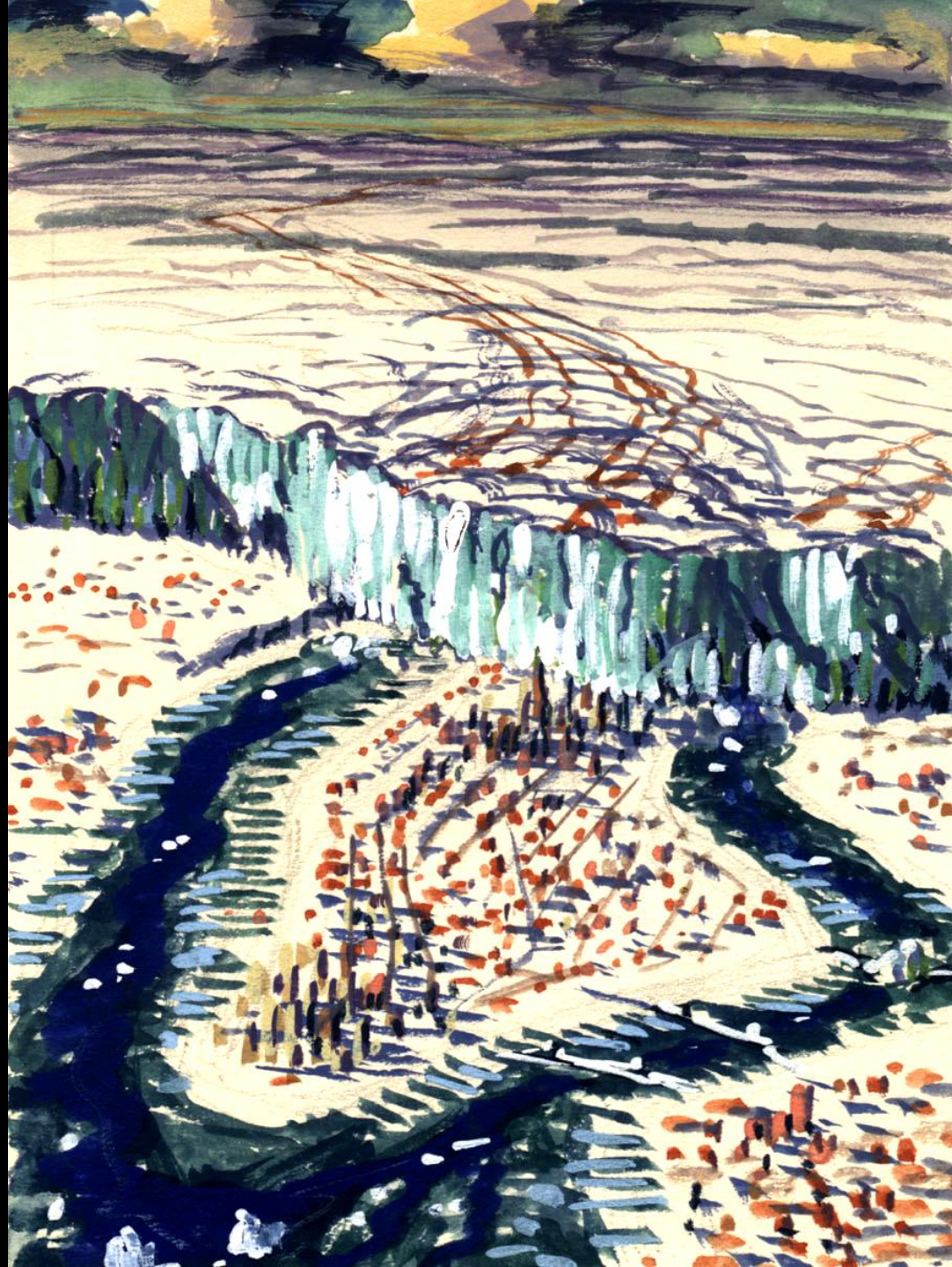


Rock - Paper - Scissors

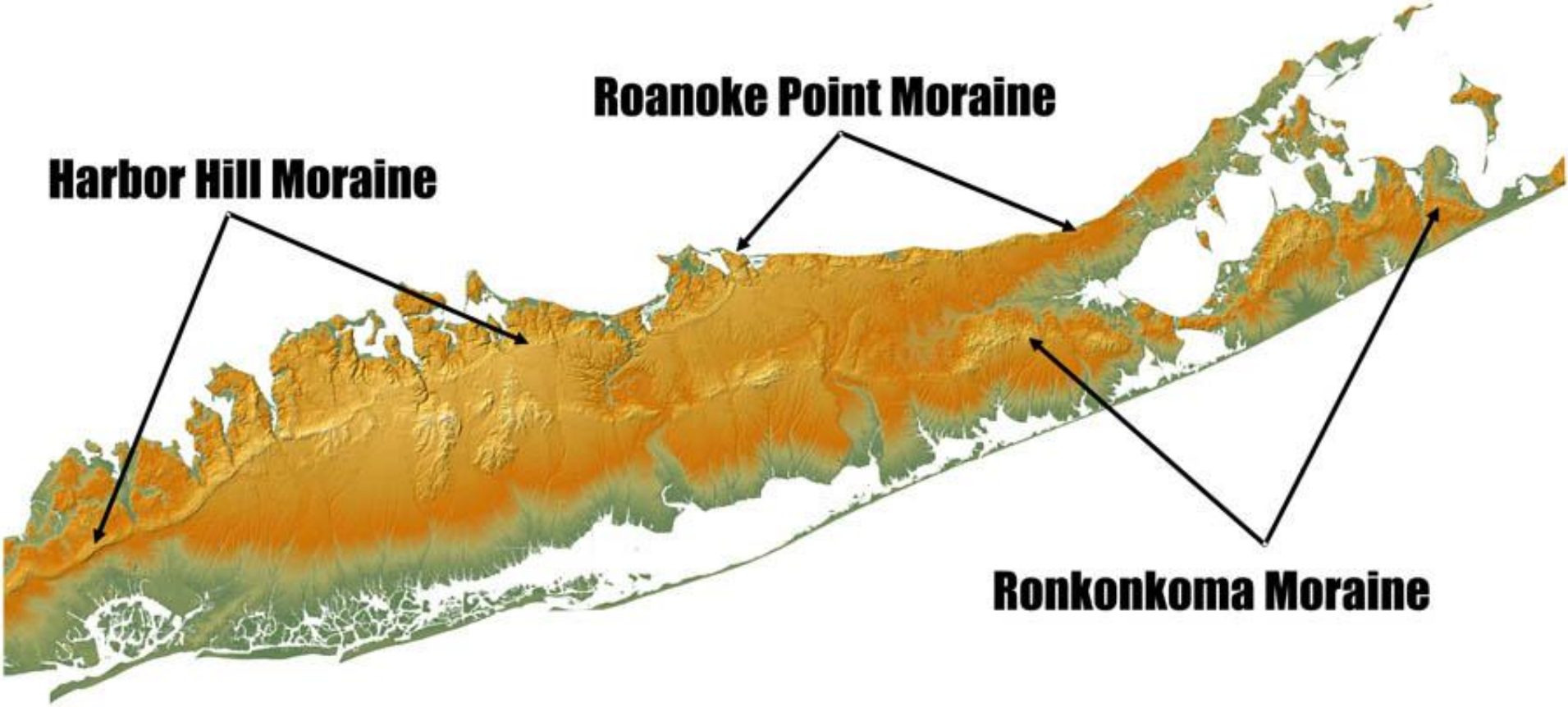
Paper Covers Rock

Glacier Covers NYC

Not a One-Shot Deal!
Multiple Glaciers
Sculpted and Supplied
Sediment to the
NYC and LI Region

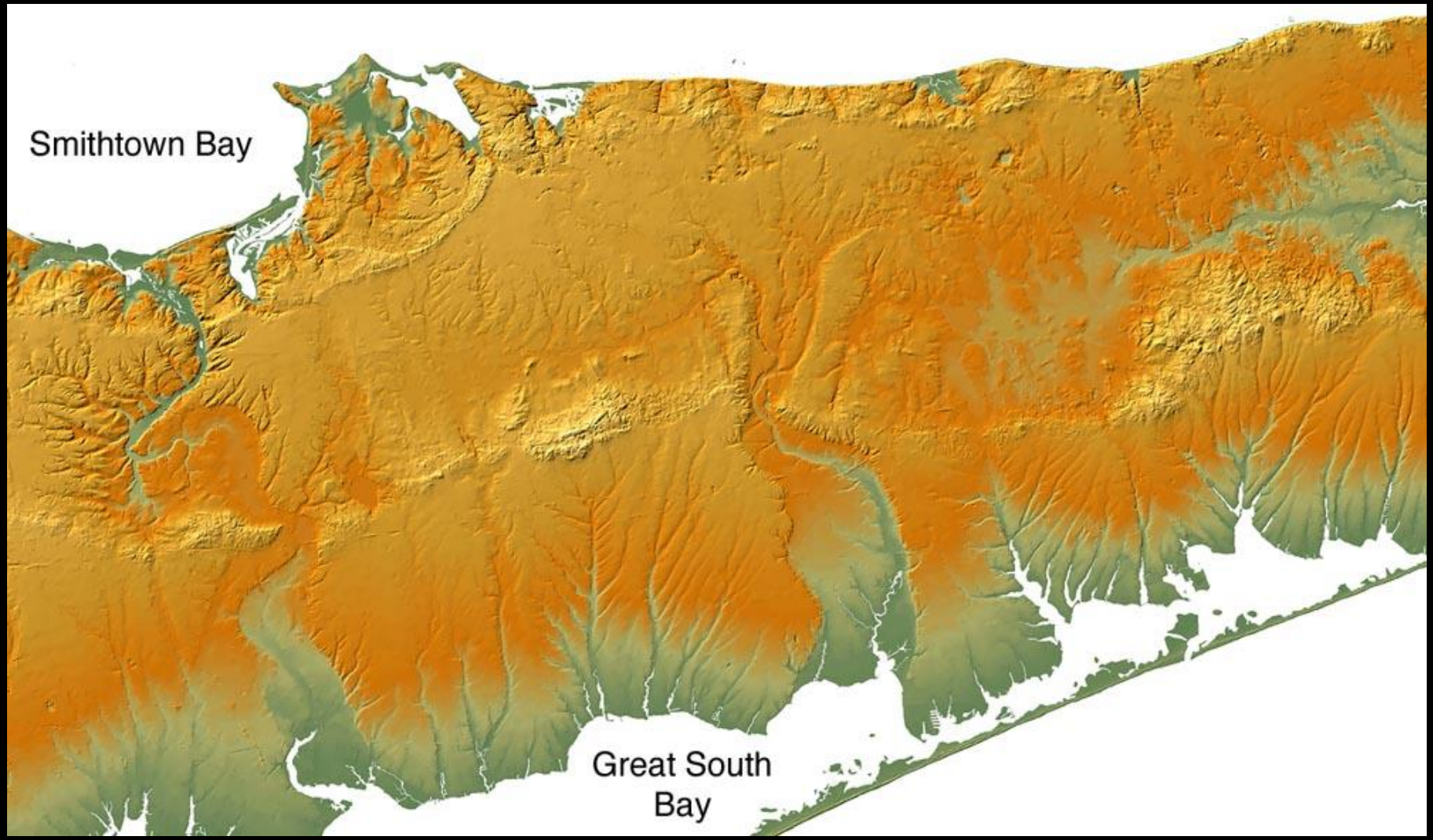


Long Island's Moraines



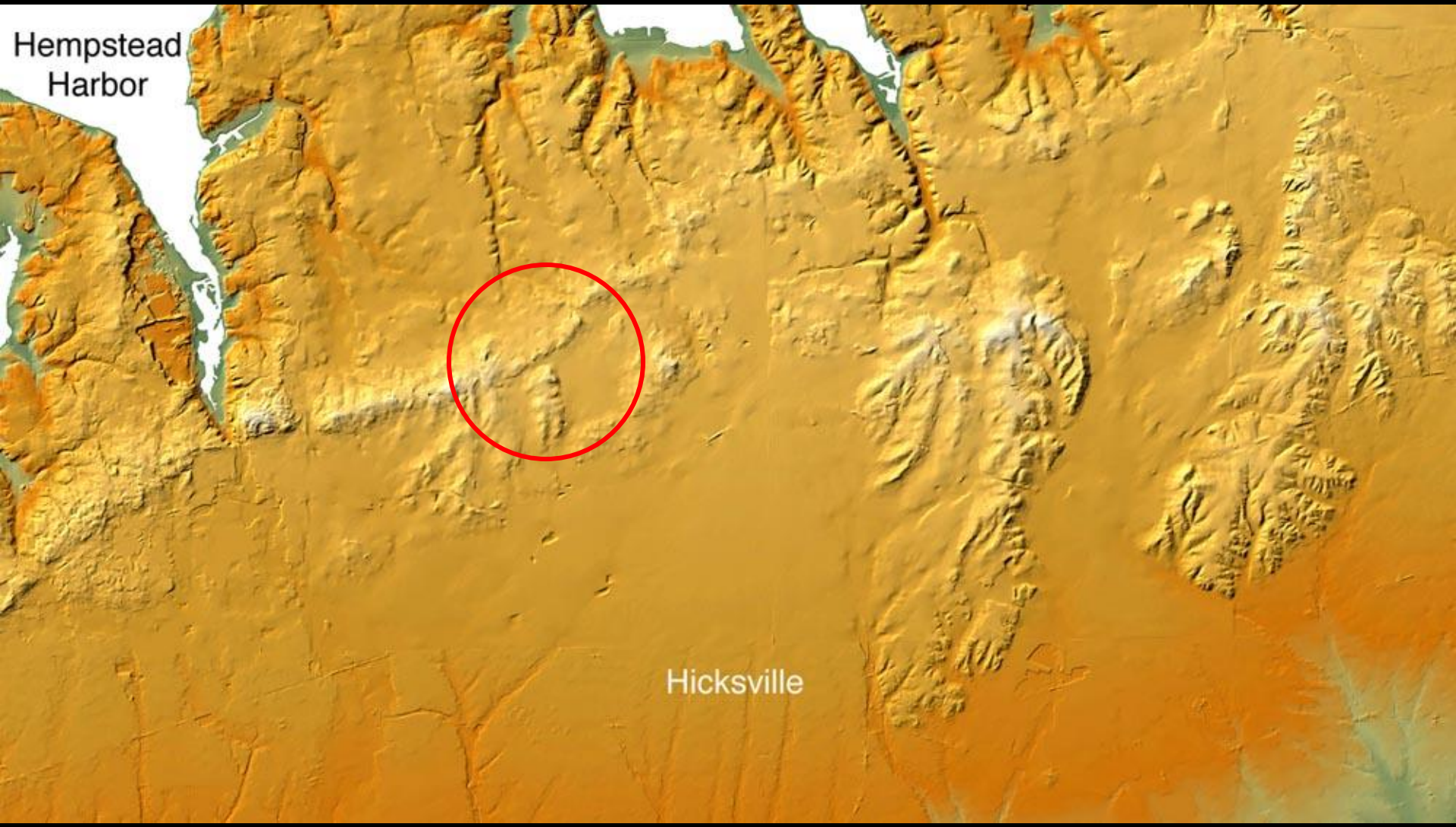
after Bennington, 2003

Ronkonkoma and Harbor Hill Moraines

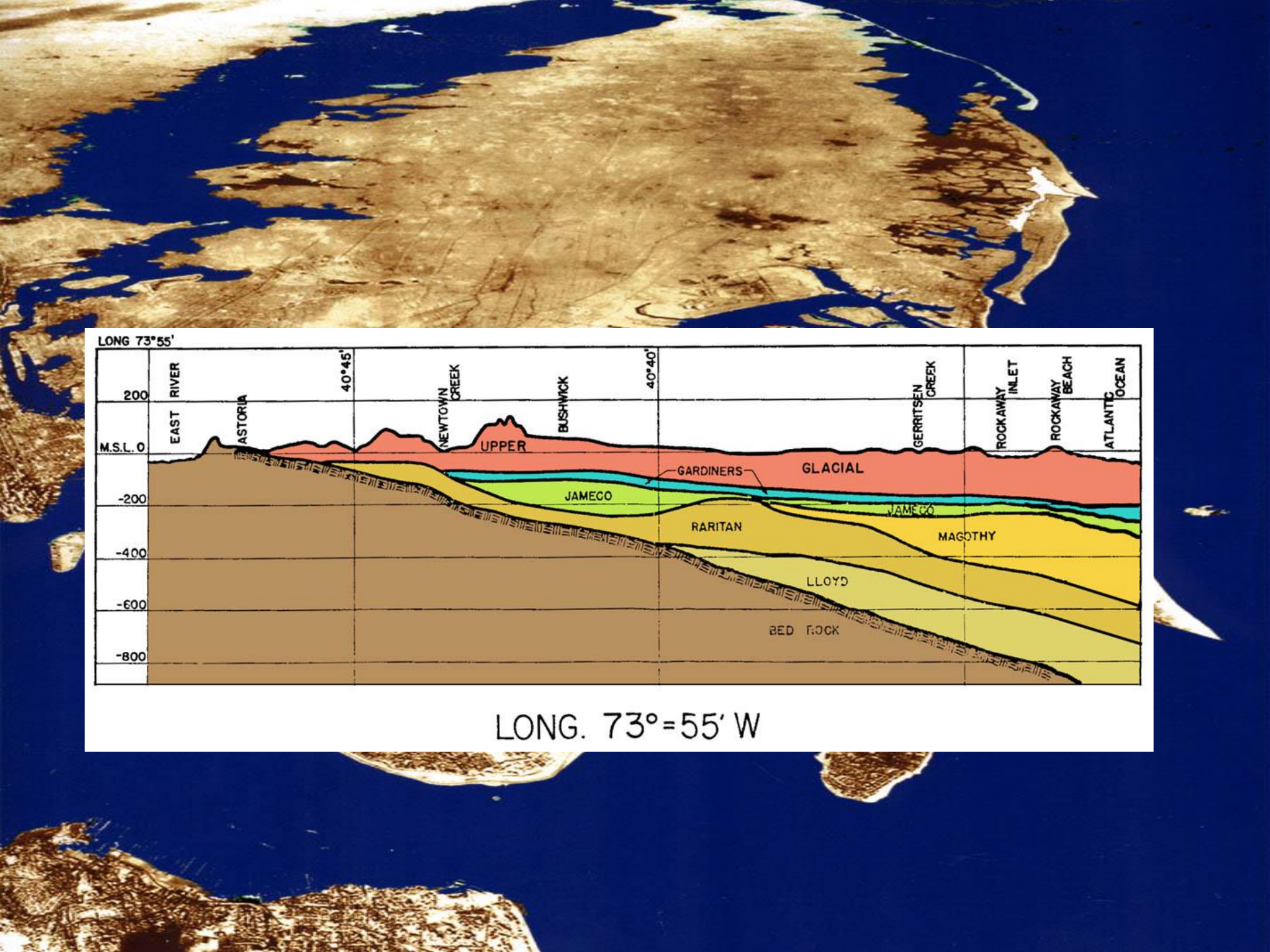


after Bennington, 2003

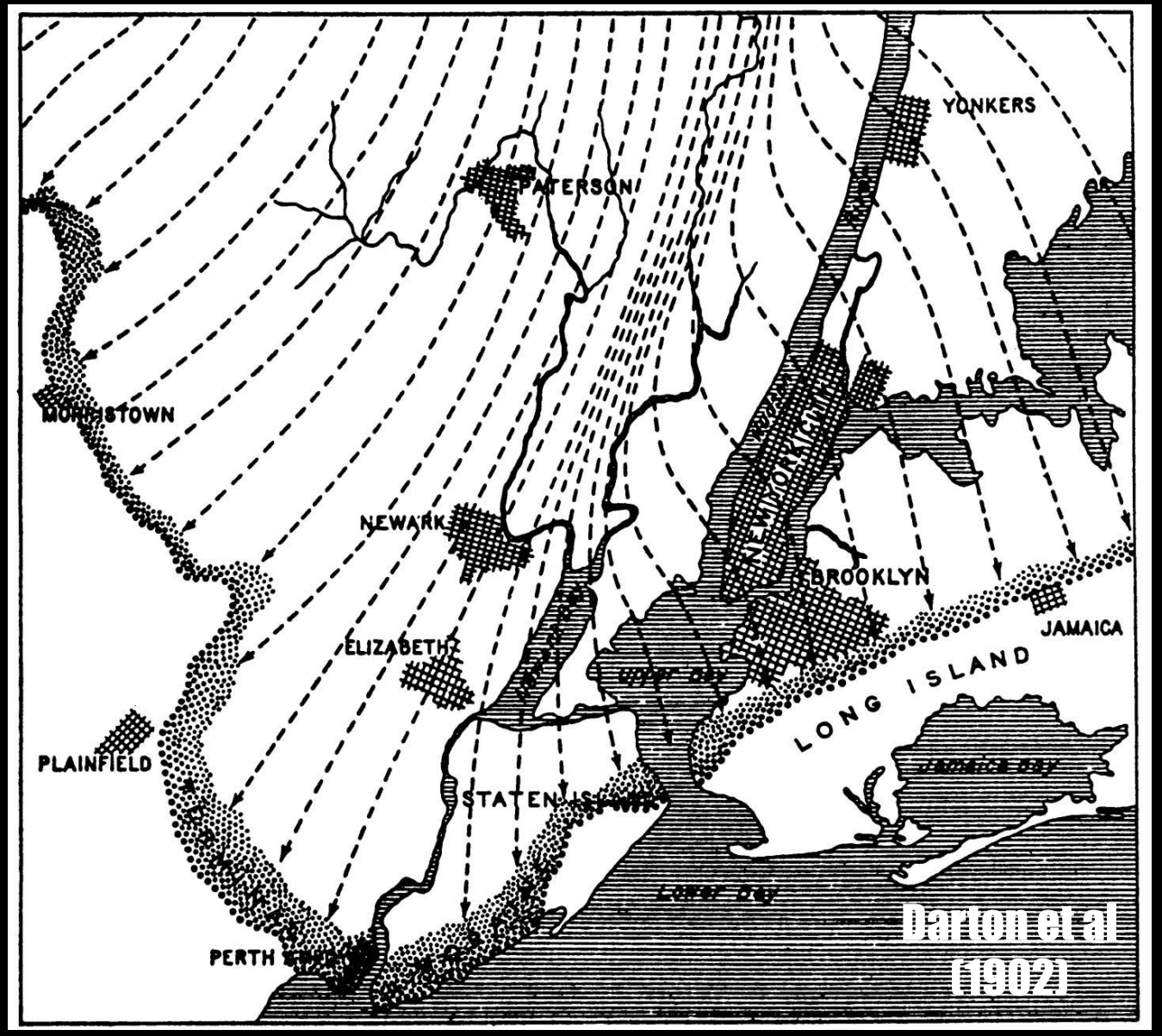
Truncation of Ronkonkoma by Harbor Hill Moraine



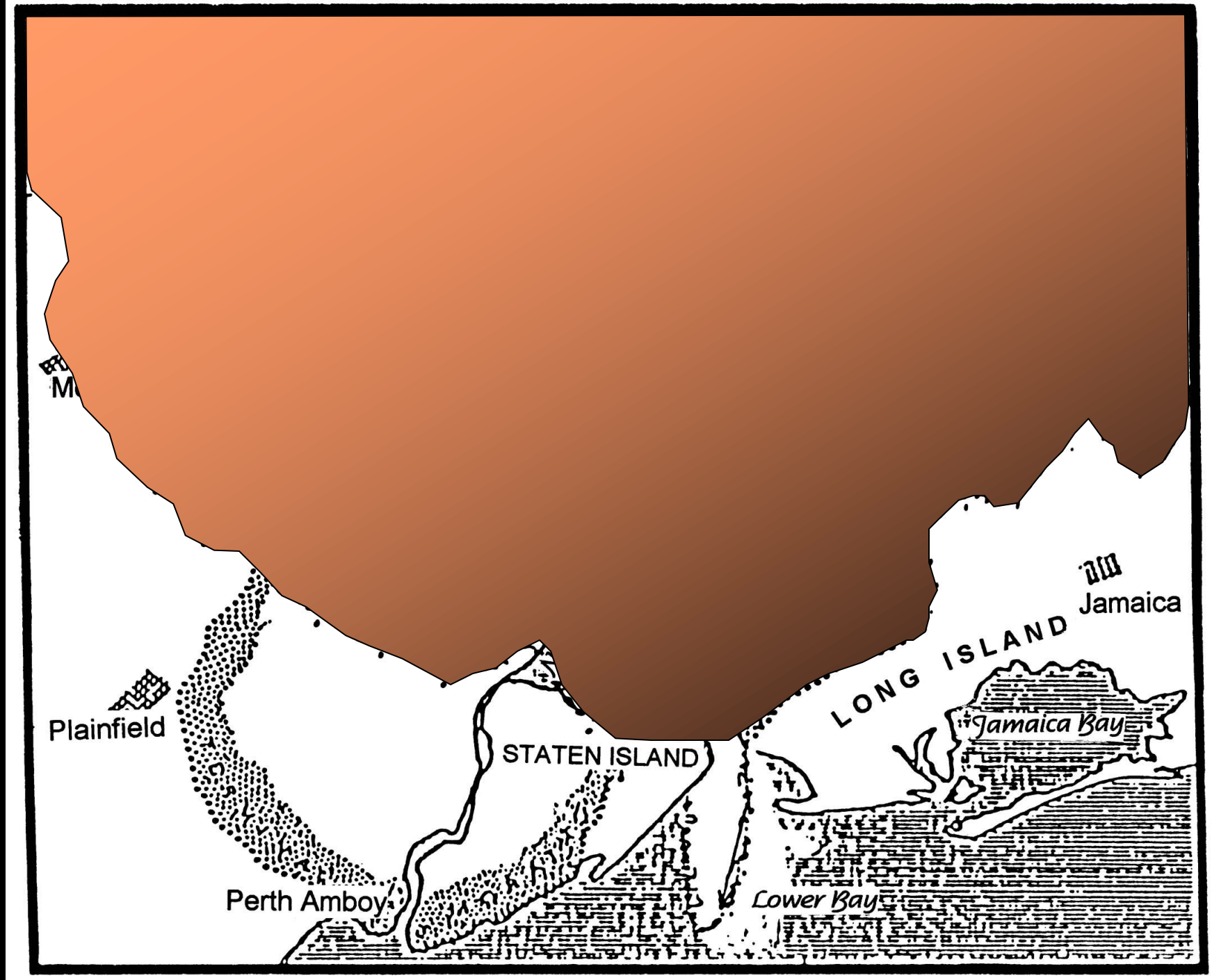
after Bennington, 2003

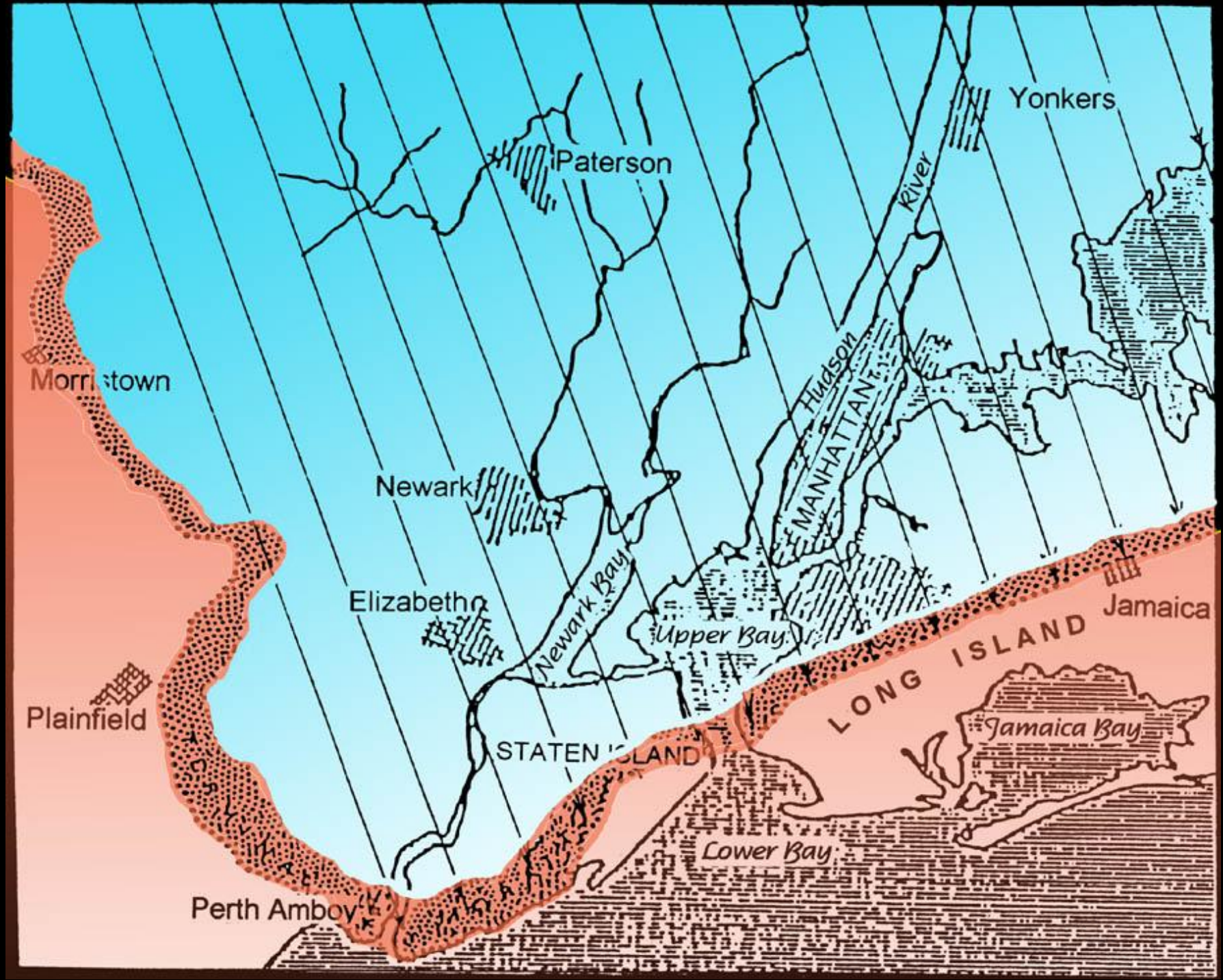

LONG 73°55'
200
M.S.L. 0
-200
-400
-600
-800
EAST RIVER
ASTORIA
40°45'
NEWTOWN CREEK
BUSHWICK
40°40'
GERRITSEN CREEK
ROCKAWAY INLET
ROCKAWAY BEACH
ATLANTIC OCEAN
UPPER
GLACIAL
GARDINERS
JAMECO
RARITAN
JAMECO
MAGOTHY
LLOYD
BED ROCK
LONG. 73°=55' W

A Tale of Two Tills

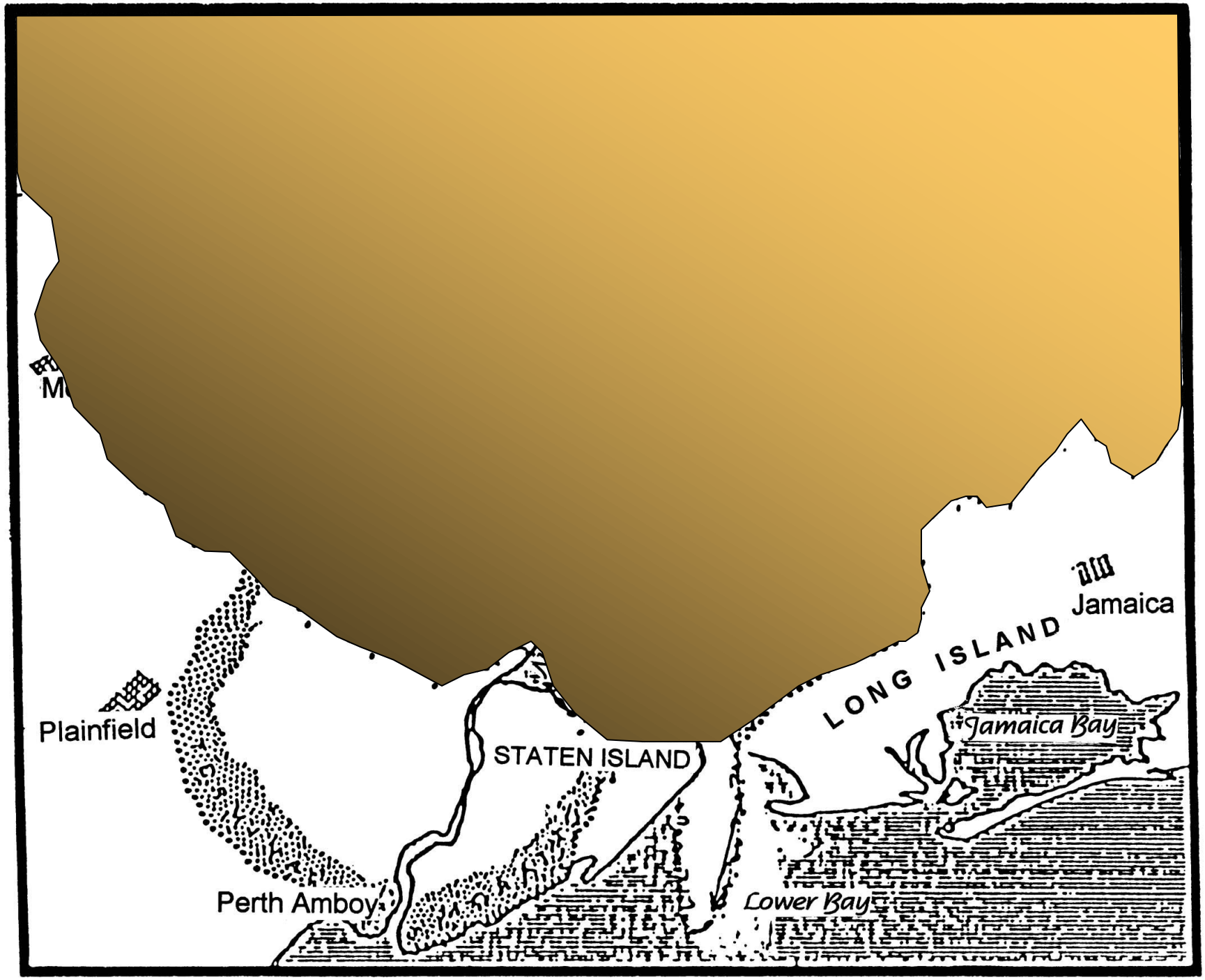


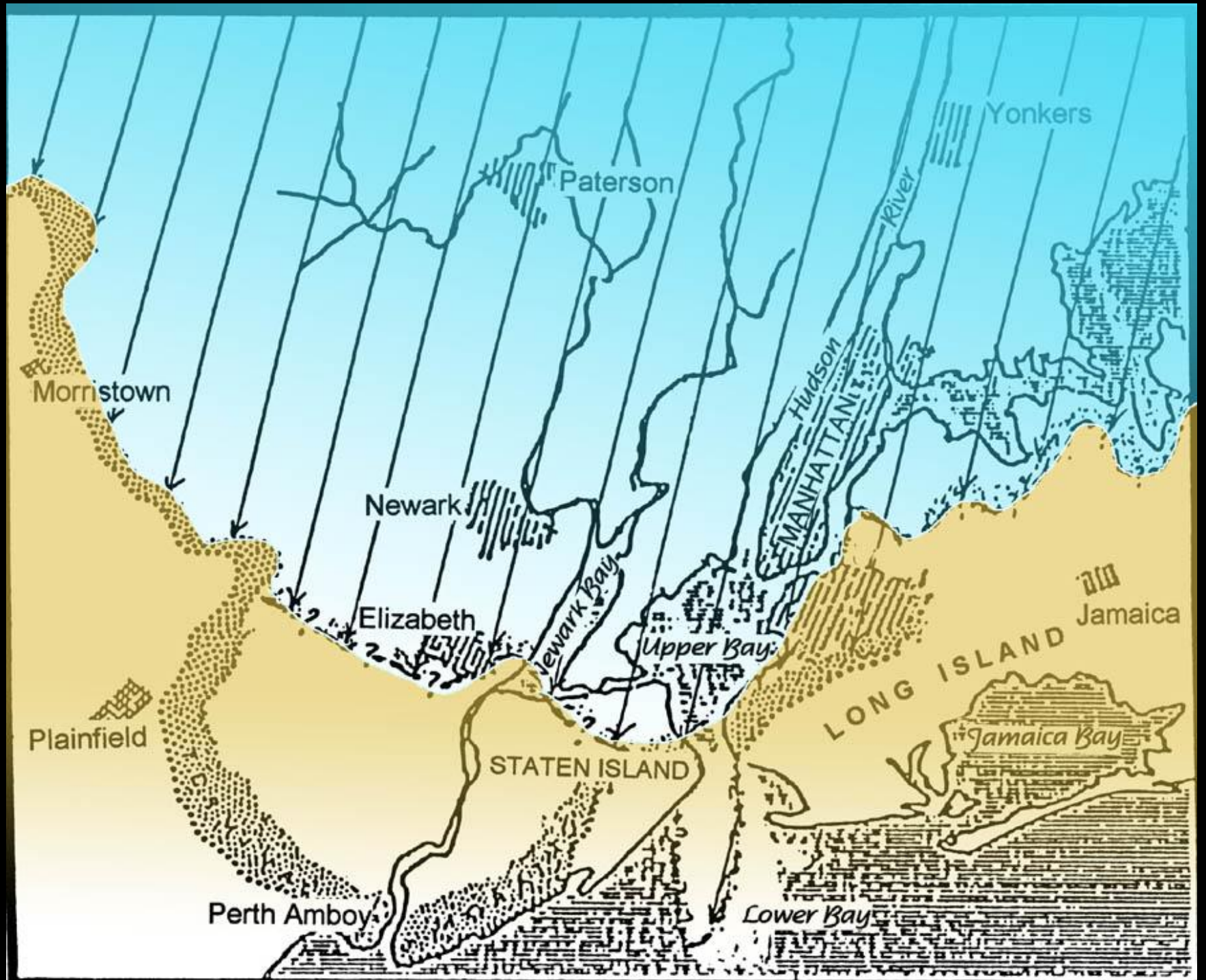
Bear Mtn Peak

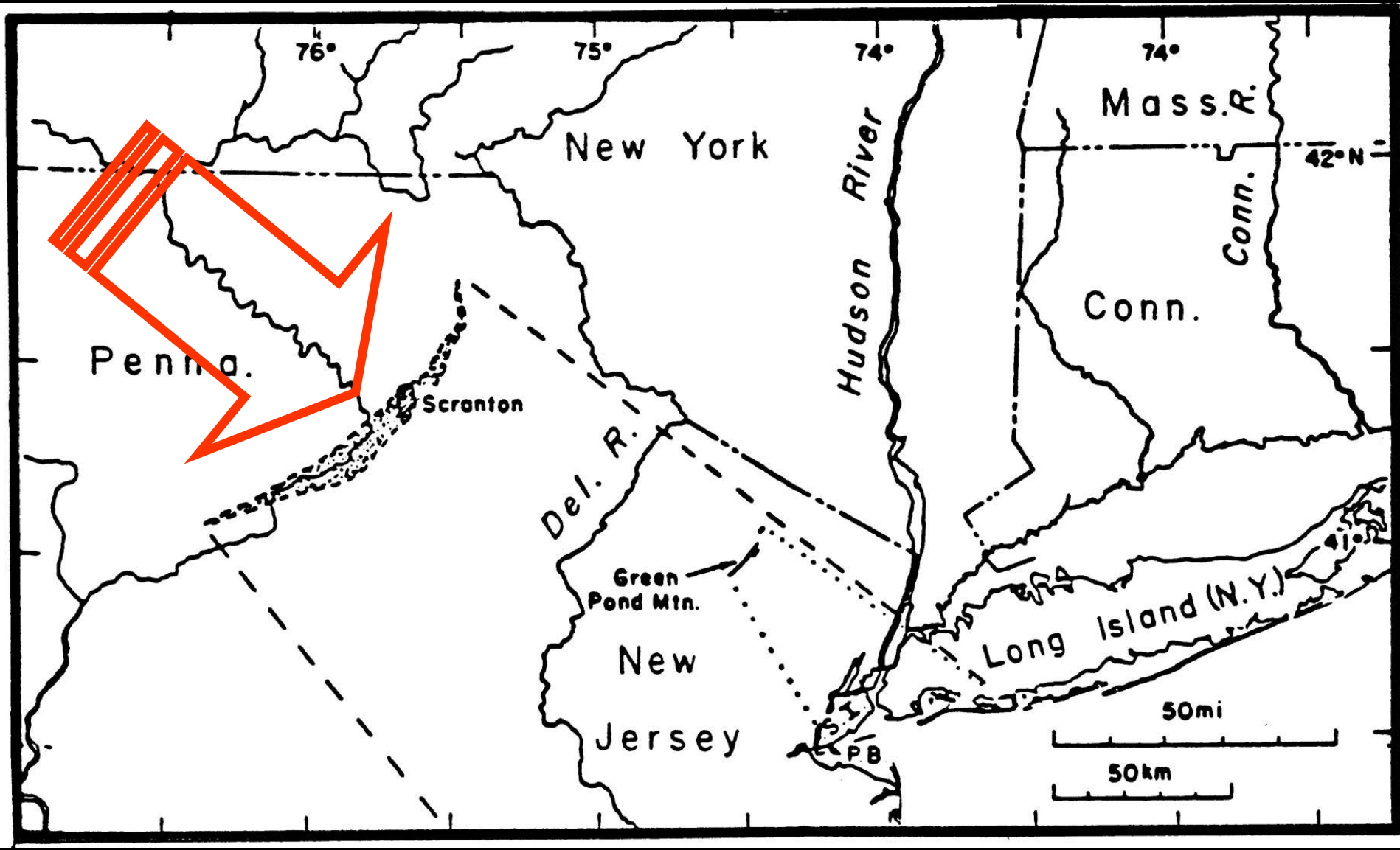

Plainfield
Perth Amboy
STATEN ISLAND
LONG ISLAND
Jamaica
Jamaica Bay
Lower Bay


Yonkers
Paterson
Hudson River
MANHATTAN
Morristown
Newark
Elizabeth
Newark Bay
Upper Bay
Jamaica
LONG ISLAND
Plainfield
Jamaica Bay
STATEN ISLAND
Lower Bay
Perth Amboy

SE-Directed Glacial Striae, Central Park, NYC

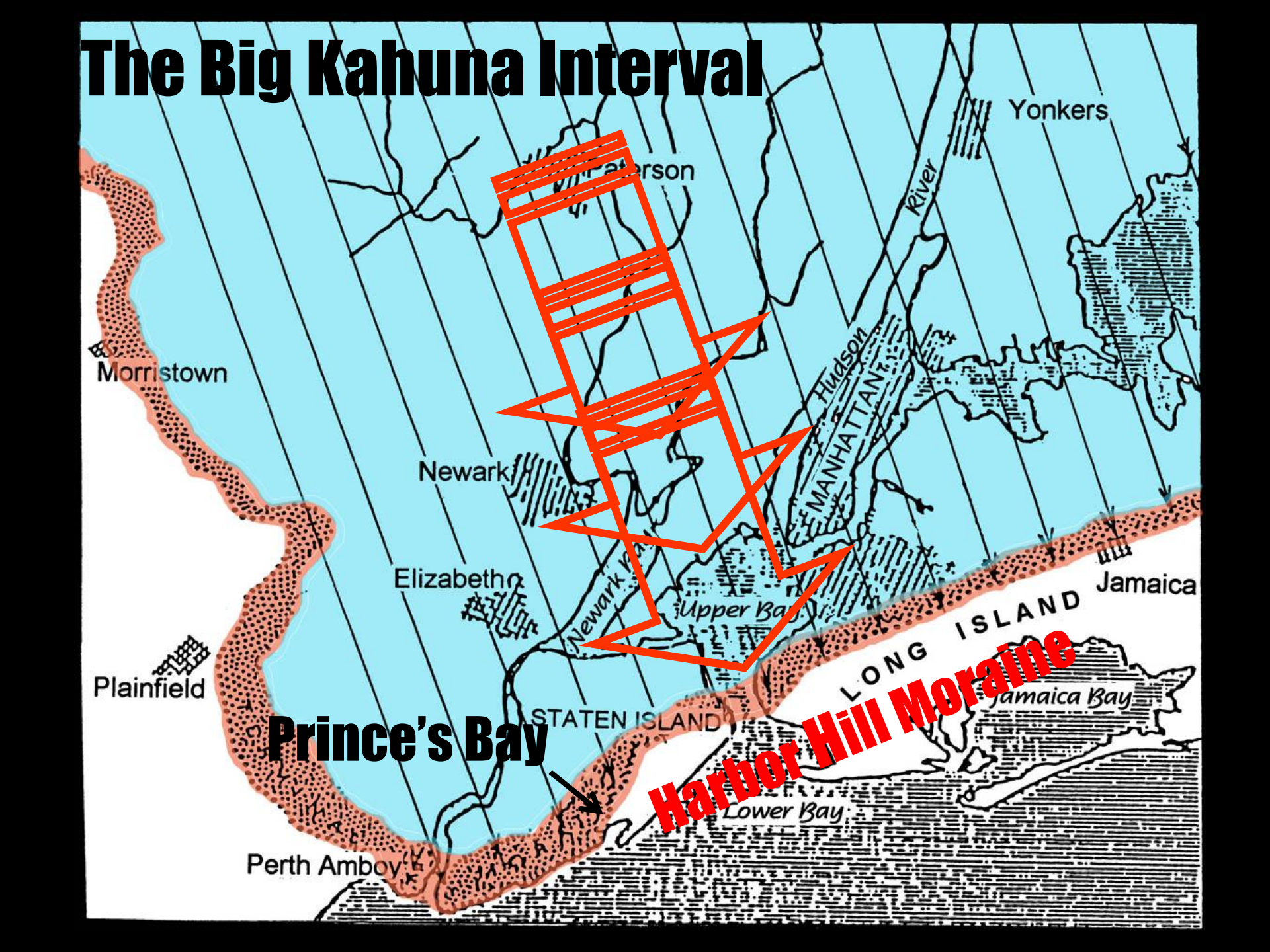

Plainfield
Perth Amboy
STATEN ISLAND
LONG ISLAND
Jamaica
Jamaica Bay
Lower Bay


Yonkers
Paterson
Hudson River
Morristown
MANHATTAN
Newark
Newark Bay
Elizabeth
Upper Bay
Jamaica
LONG ISLAND
Plainfield
Jamaica Bay
STATEN ISLAND
Perth Amboy
Lower Bay



Anthracite and Green Pond Conglomerate Indicator Stones

Friedman and Sanders (1994)


The Big Kahuna Interval
Yonkers
Hudson River
MANHATTAN
Morristown
Newark
Elizabeth
Upper Bay
Jamaica
LONG ISLAND
Plainfield
Jamaica Bay
STATEN ISLAND
Prince's Bay
Harbor Hill Moraine
Lower Bay
Perth Amboy

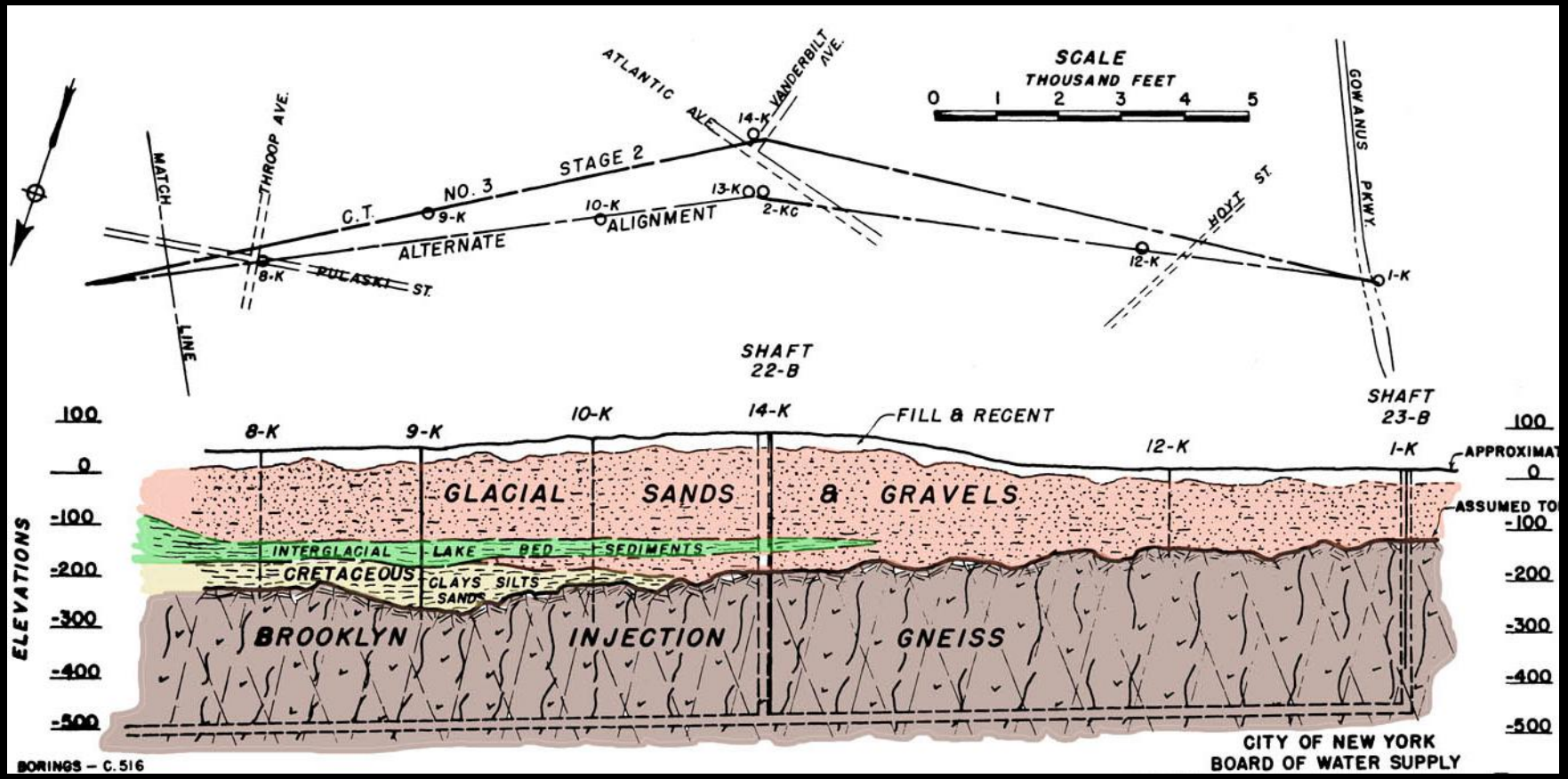
World Trade Center
100’ Deep Plunge Pools


Existing caisson
Location Where Wood Was Found
X
Silt Lens
Surrounding Till

Age	Till No.	Ice-flow Direction	Description; remarks
Late Wisconsinan ("Woodfordian"?)	I	NNE to SSW	Gray-brown till in Westchester Co., Staten Is., Brooklyn, & Queens (but not present on rest of Long Island); Hamden Till in CT with terminal moraine lying along the S coast of CT; gray lake sediments at Croton Point Park, Westchester Co.
Mid-Wisconsinan (?)			Paleosol on Till II, SW Staten Island.
Early Wisconsinan(?)	II	NW to SE	Harbor Hill Terminal Moraine and associated outwash (Bellmore Fm. in Jones Beach subsurface); Lake Chamberlain Till in southern CT.
Sangamonian(?)			Wantagh Fm. (in Jones Beach subsurface).
	IIIA	NW to SE	Ronkonkoma Terminal Moraine and associated outwash (Merrick Fm. in Jones Beach subsurface).
Illinoian(?)	IIIB		Manhasset Fm. of Fuller (with middle Montauk Till Member; in lower member, coarse delta foresets (including debris flows) deposited in Proglacial Lake Long Island dammed in on S by pre-Ronkonkoma terminal moraine.
	IIIC		
Yarmouthian			Jacob Sand, Gardiners Clay.
Kansan(?)	IV	NNE to SSW	Gray till with decayed stones at Teller's Point (Croton Point Park, Westchester Co.); gray till with green metavolcanic stones, Target Rock, LI.
Aftonian(?)			No deposits; deep chemical decay of Till V.
Nebraskan (?)	V	NW to SE	Reddish-brown decayed-stone till and -outwash at AKR Co., Staten Island, and at Garvies Point, Long Island; Jameco Gravel fills subsurface valley in SW Queens.
			Pre-glacial (?) Mannetto Gravel fills subsurface valleys.

Sanders and Merguerian, 1998

Atlantic Avenue, Brooklyn



Soils of Brooklyn

Chemical and Physical Weathering

Bedrock vs. Transported Regolith

Results Over Time in Pedalfer Soil

Soil Horizons:

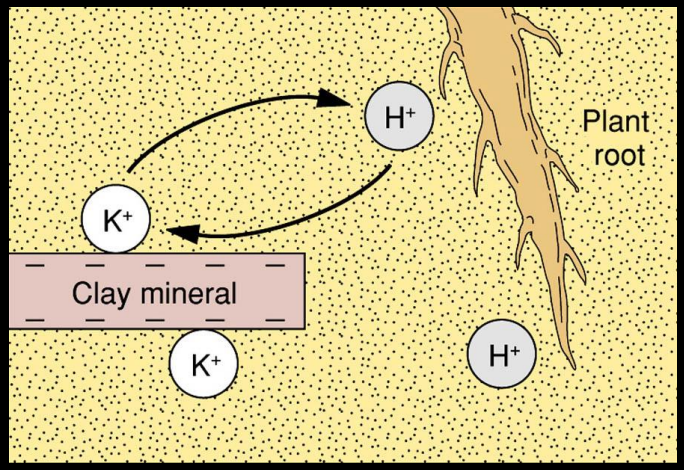
O = Thin Organic Layer

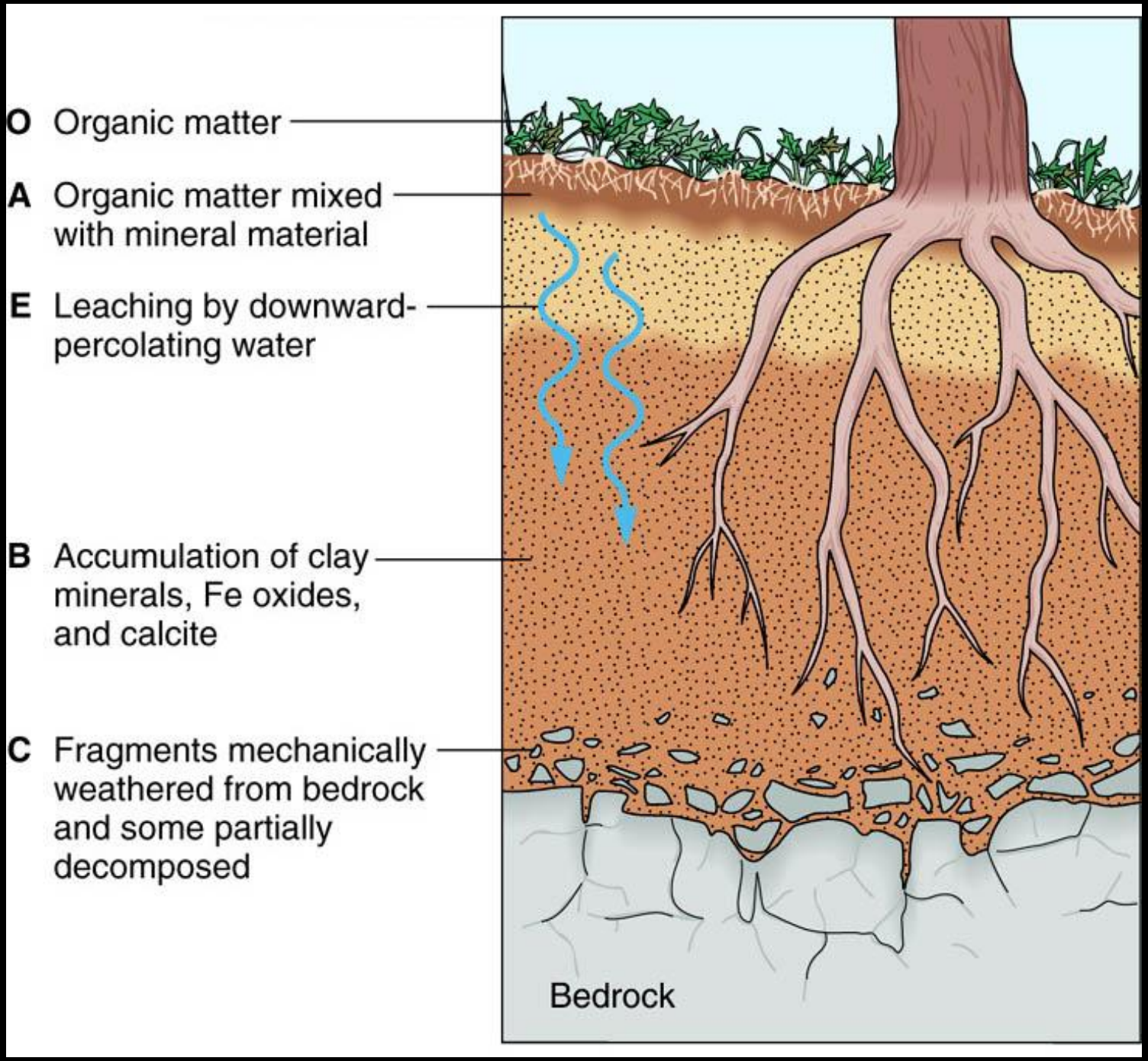
A = Mixed Organics and Minerals

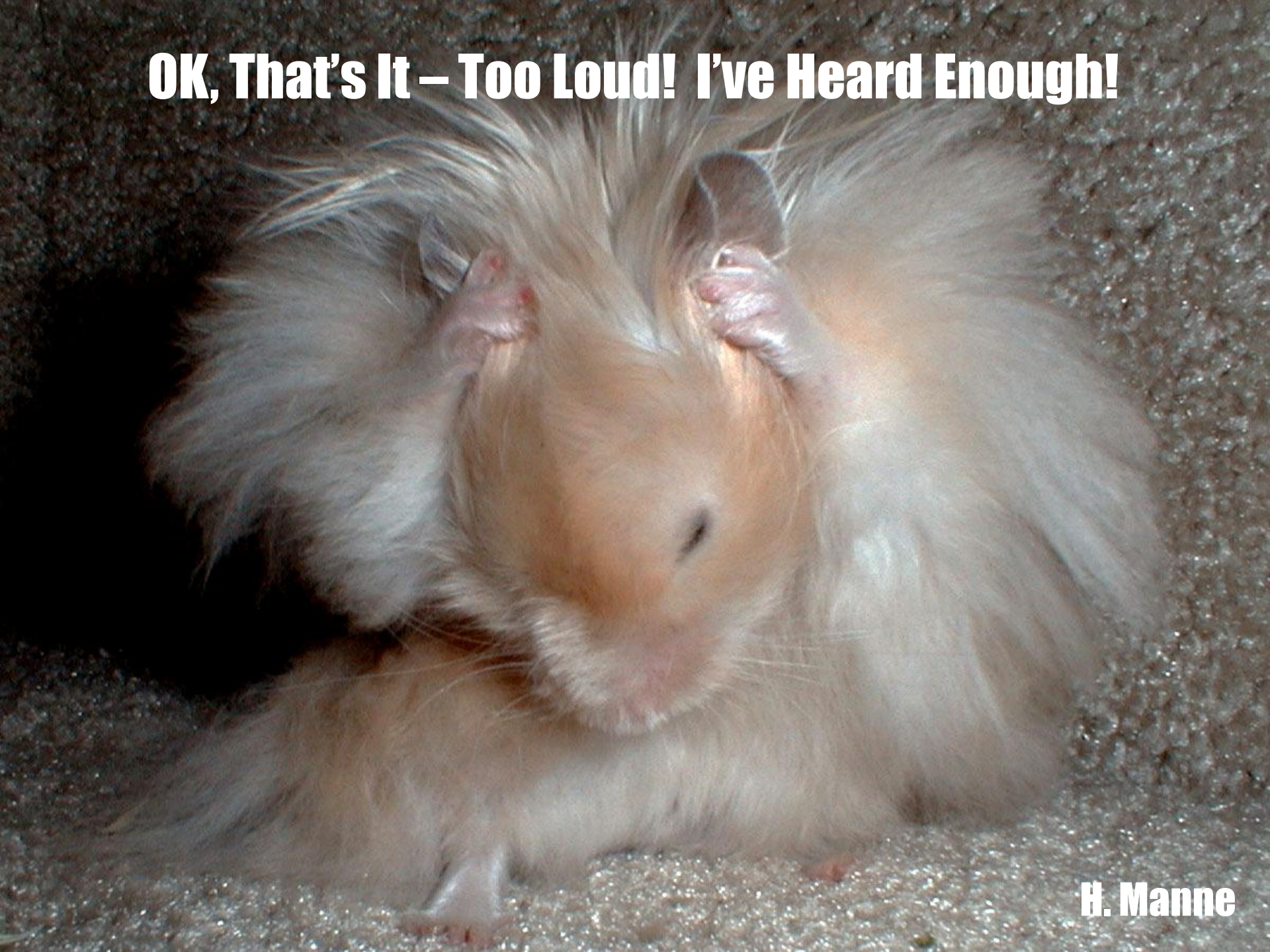
E = Zone of Leaching

B = Zone of Accumulation

C = Decomposed Bedrock/ Regolith



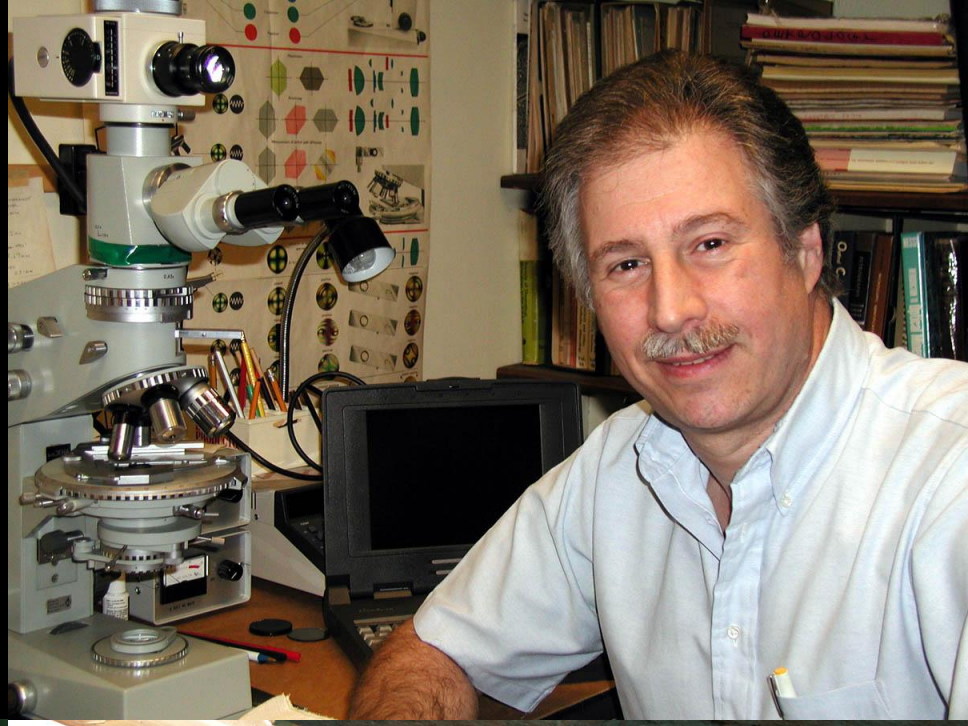

O Organic matter
A Organic matter mixed with mineral material
E Leaching by downward-percolating water
B Accumulation of clay minerals, Fe oxides, and calcite
C Fragments mechanically weathered from bedrock and some partially decomposed
Bedrock


OK, That's It – Too Loud! I've Heard Enough!
H. Manne

Duke Geological Lab

Full Service Geotechnical Tunneling Analysis

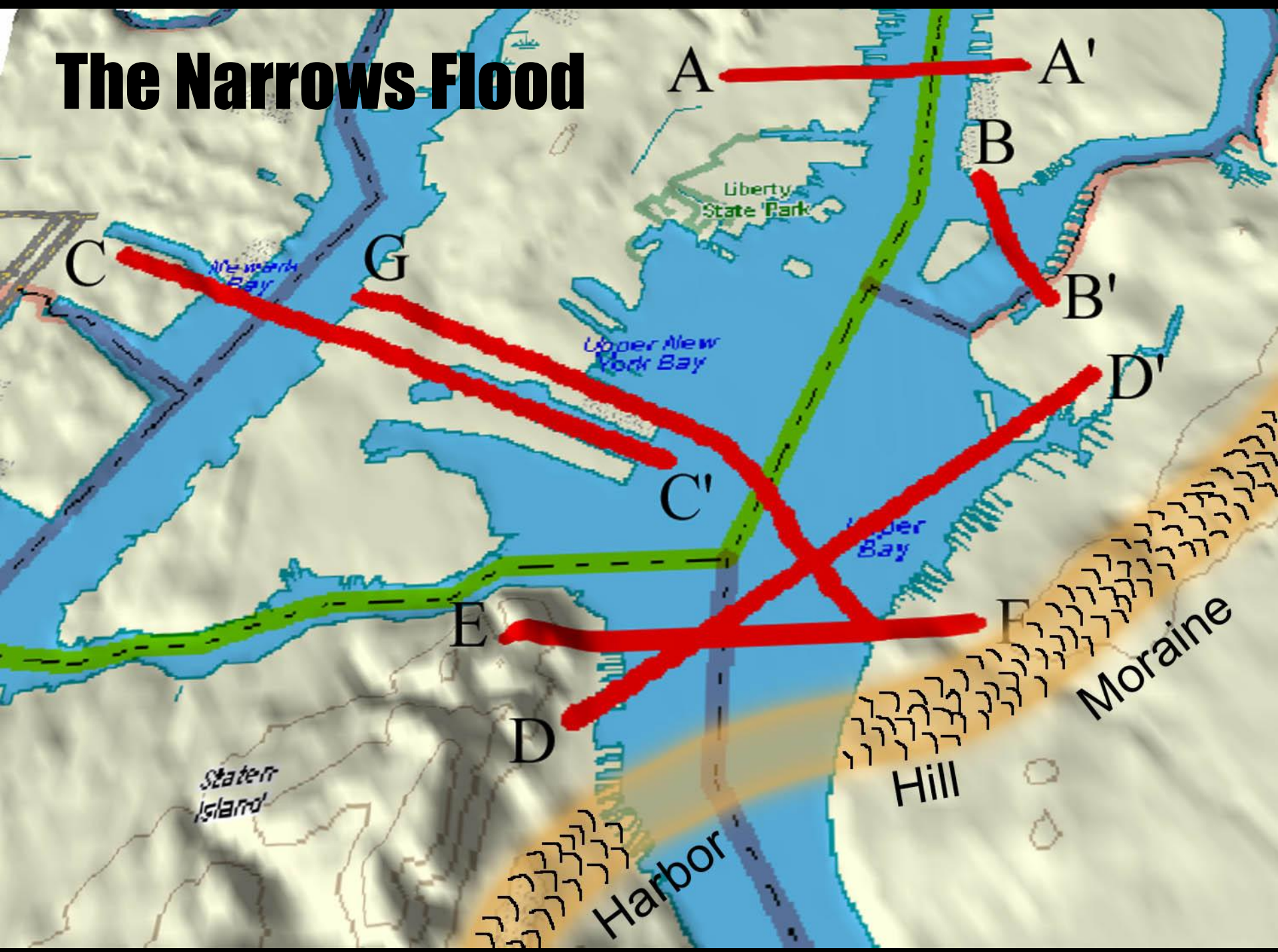
www.dukelabs.com

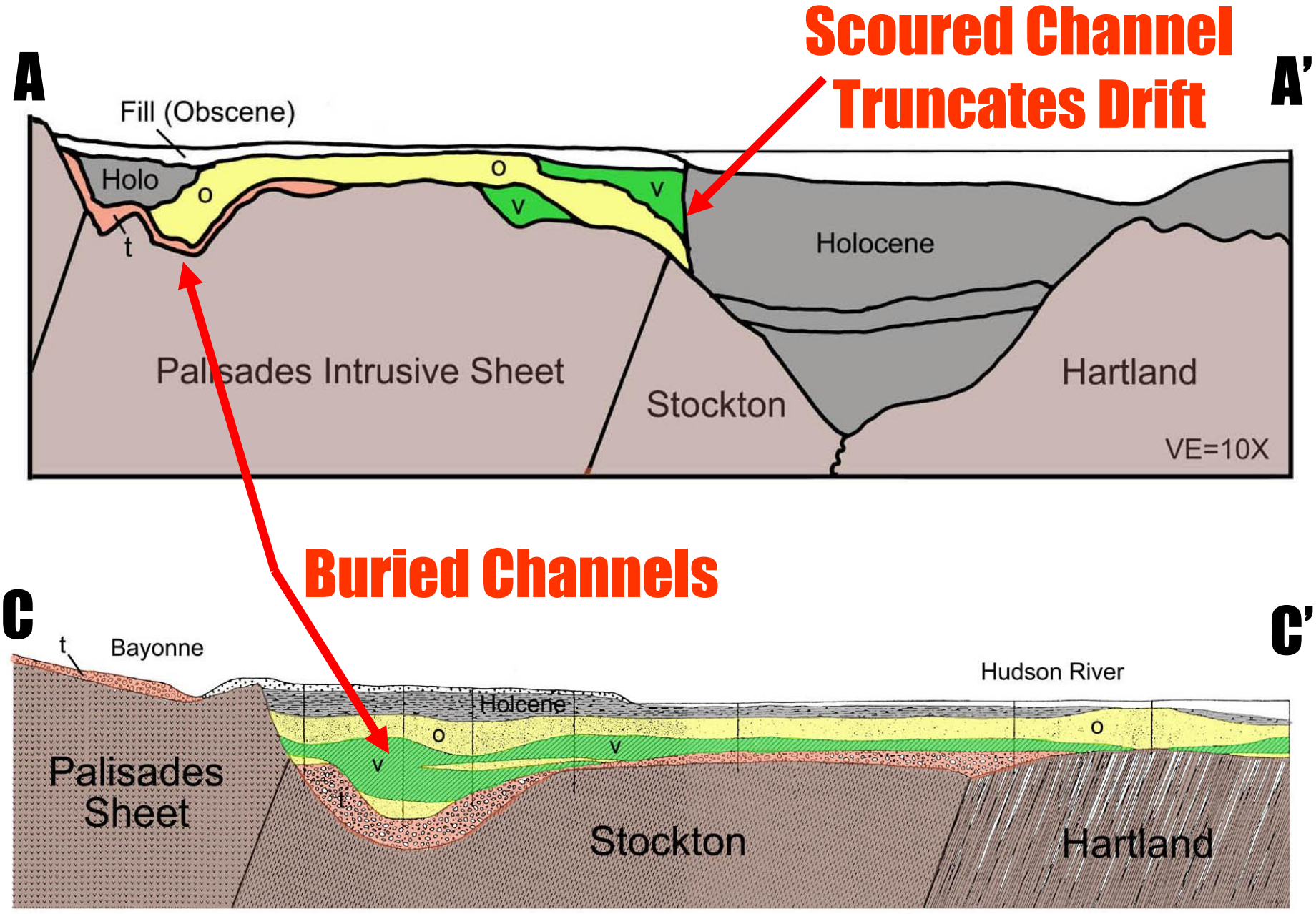


Download NYC Geology Publications @

www.hofstra.edu

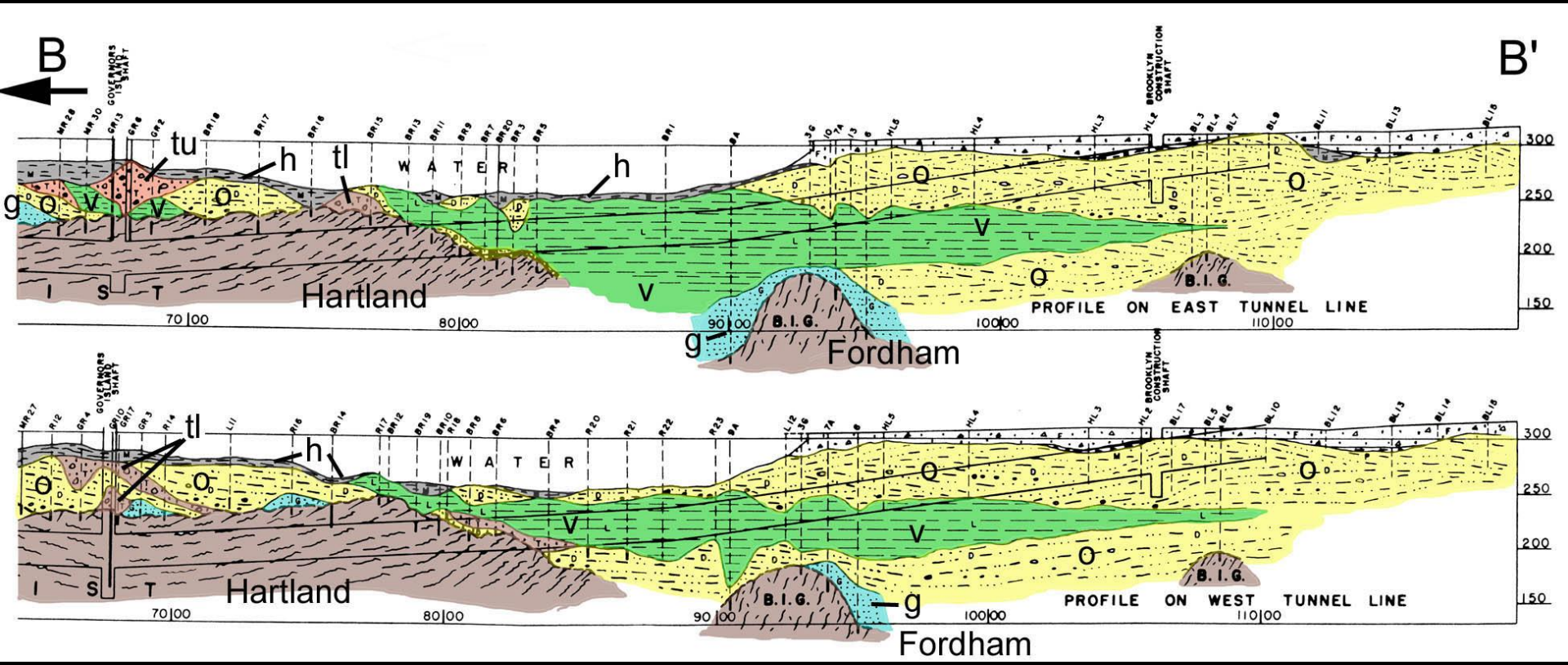
www.dukelabs.com

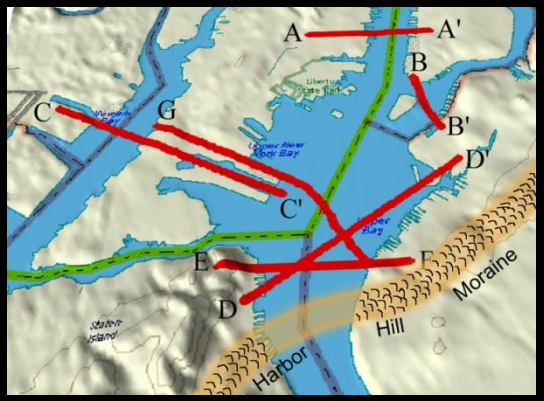

The Narrows Flood
A
A'
B
B'
C
C'
D
D'
E
F
G
Liberty State Park
Upper New York Bay
Lower Bay
Staten Island
Moraine
Hill
Harbor



Lovegreen (1974)

Brooklyn Battery Tunnel

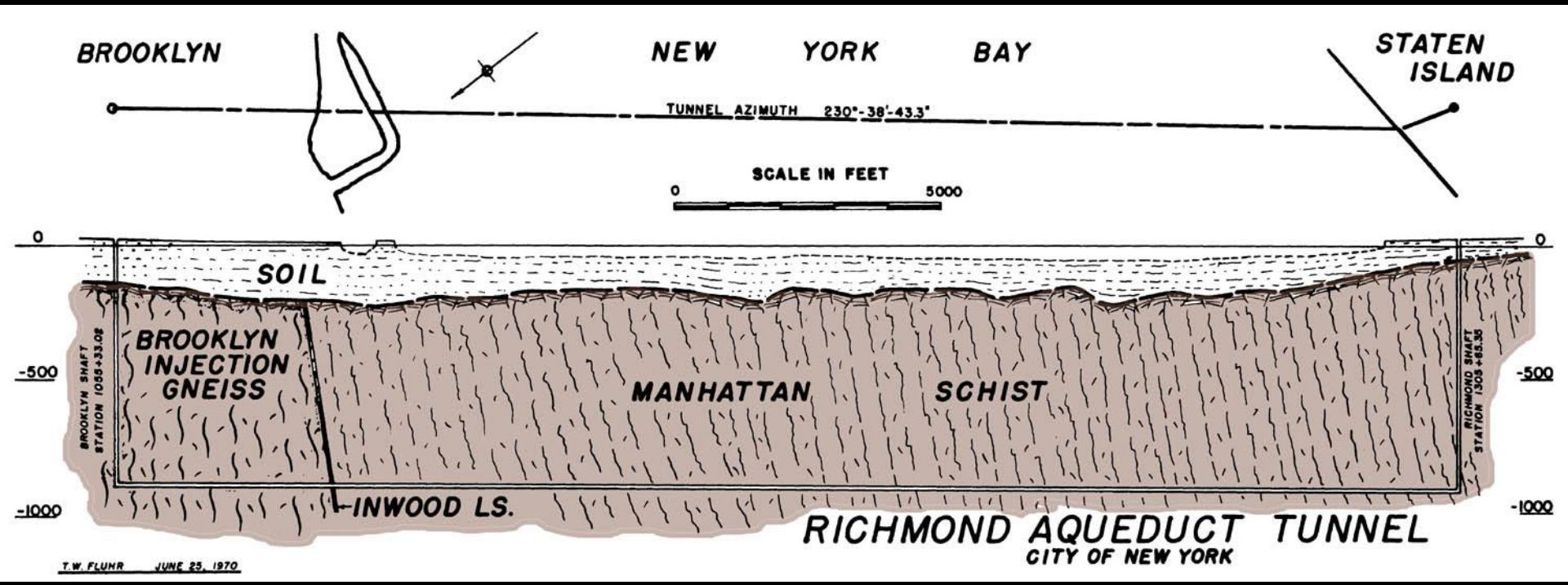


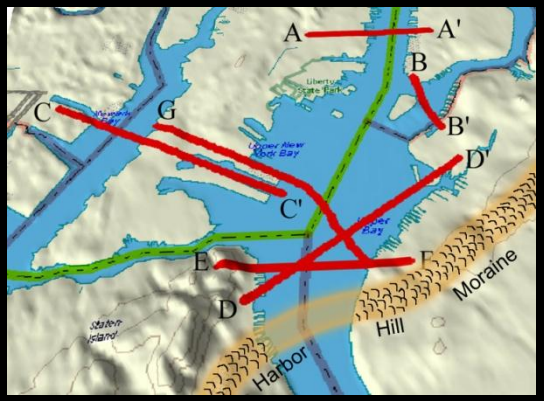


Berkey (1948)

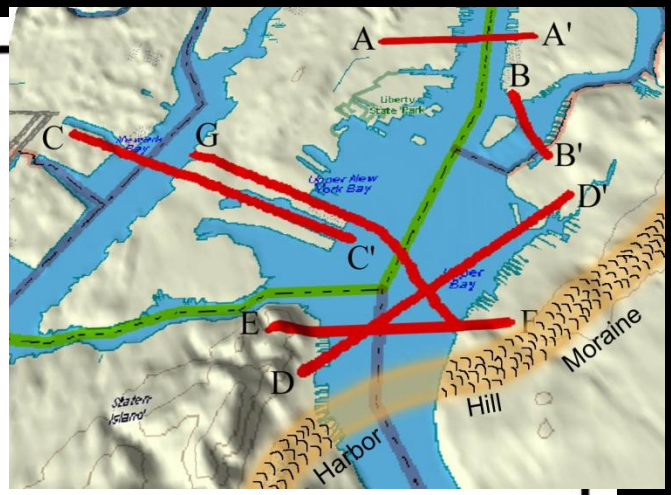
Richmond Aqueduct Tunnel

D’ D





Fluhr (1962)



G

o

tu

Stockton

v

o

tu

Walloomsac

v

o

Holocene silt

v

Hartland

o

tu

tl

F

E

o

tu

o

v

v

Holocene
Silt

o

tu

tl

o

tl

o

?

?

Serpentinite

Hartland

QT Complex

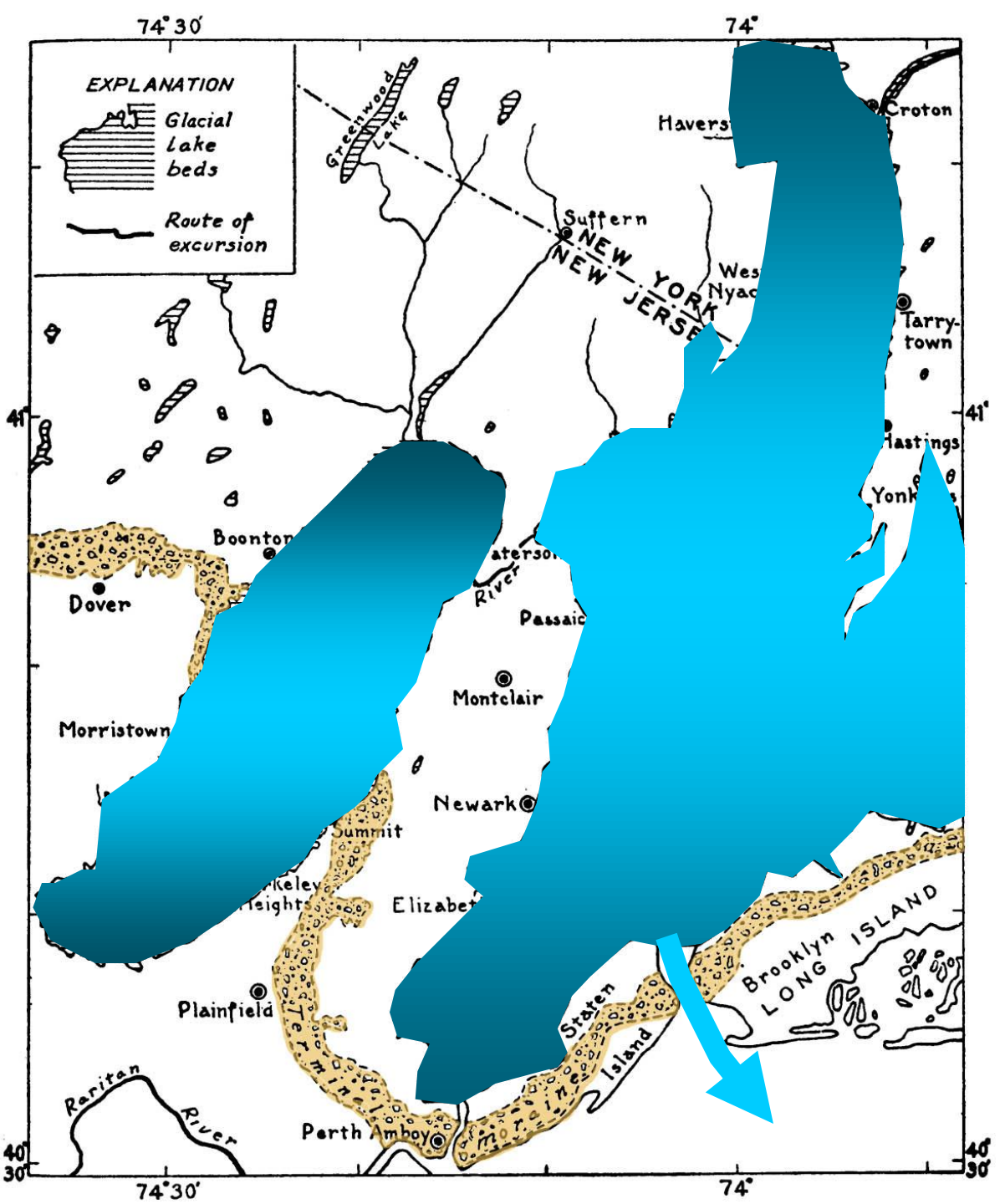
'03

Two Tills and Varved Lake Strata Cut by Channels

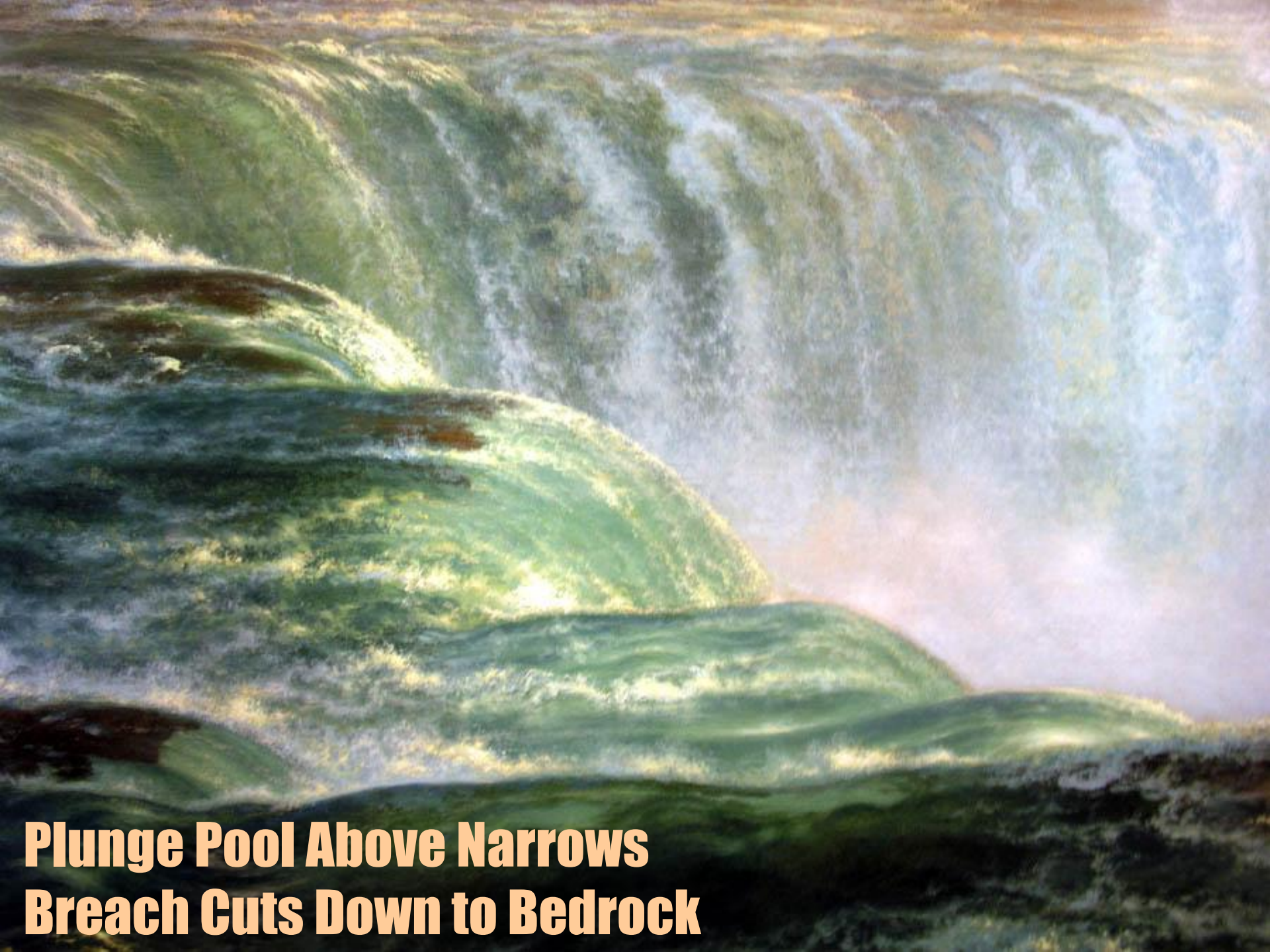
Glacial Lake Strata and the Harbor Hill Moraine

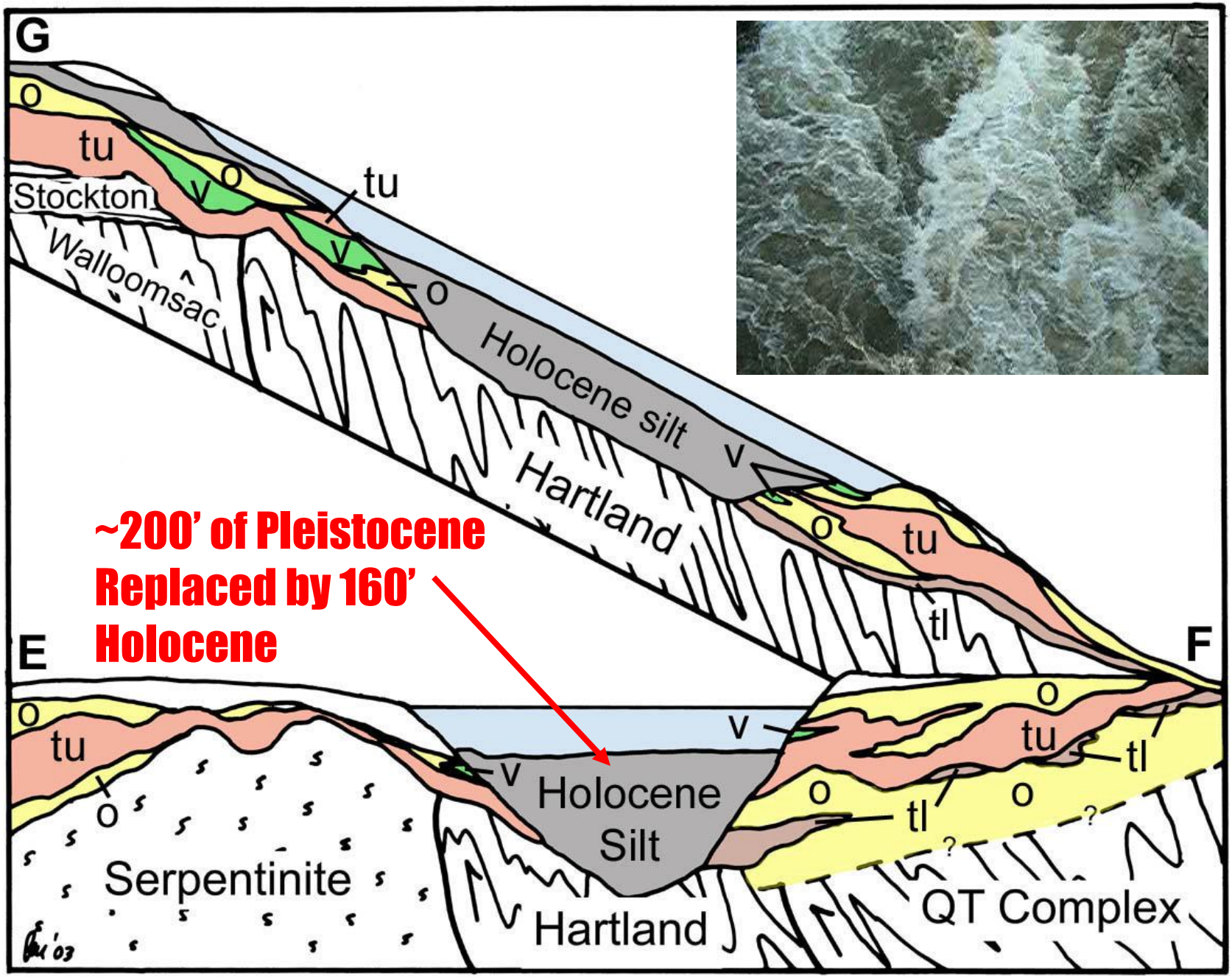
Woodfordian Drainage Through The Narrows

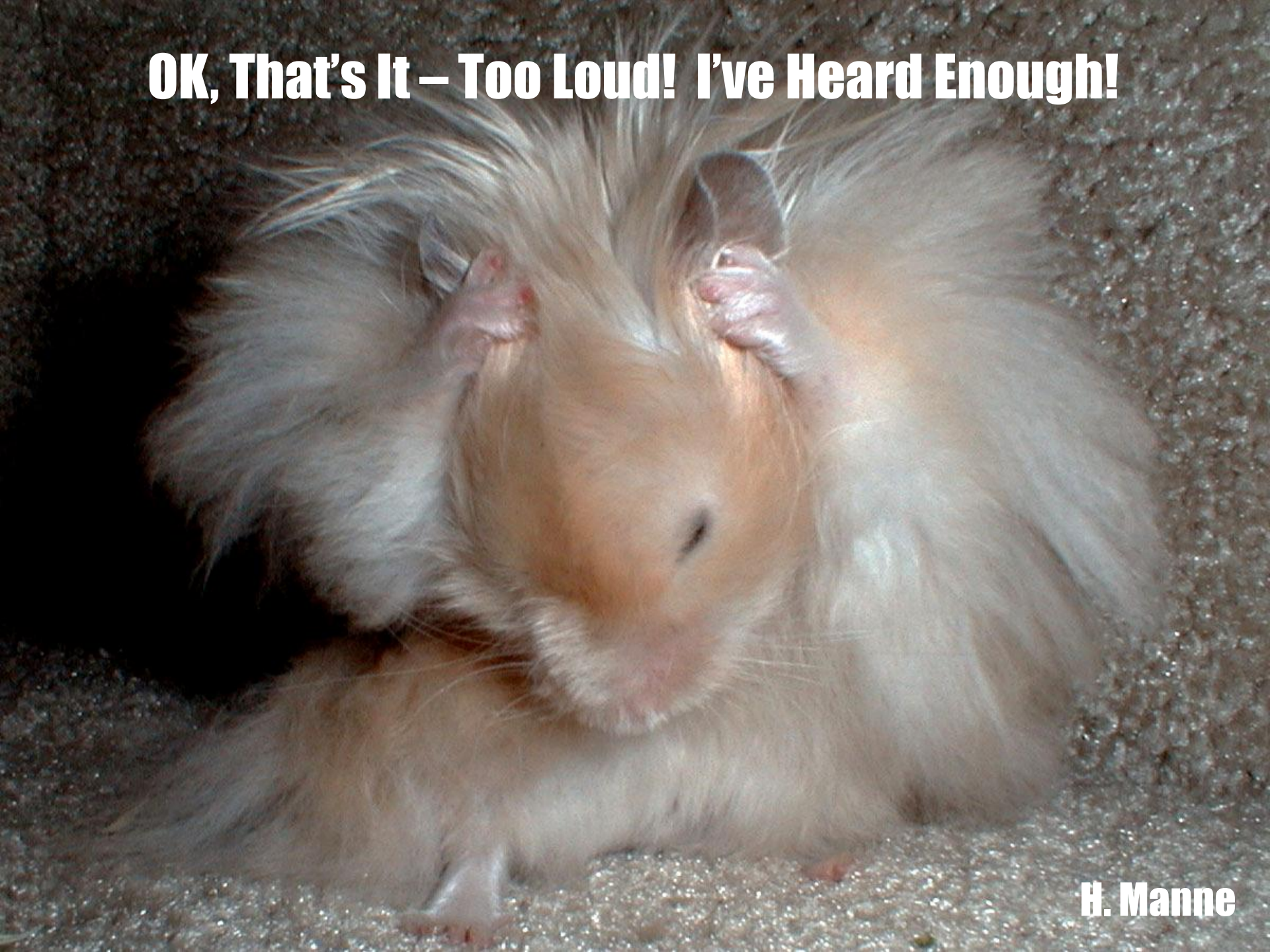
Berkey (1933)



Hudson Abandons Former Channel – Floods Through Narrows


Plunge Pool Above Narrows
Breach Cuts Down to Bedrock

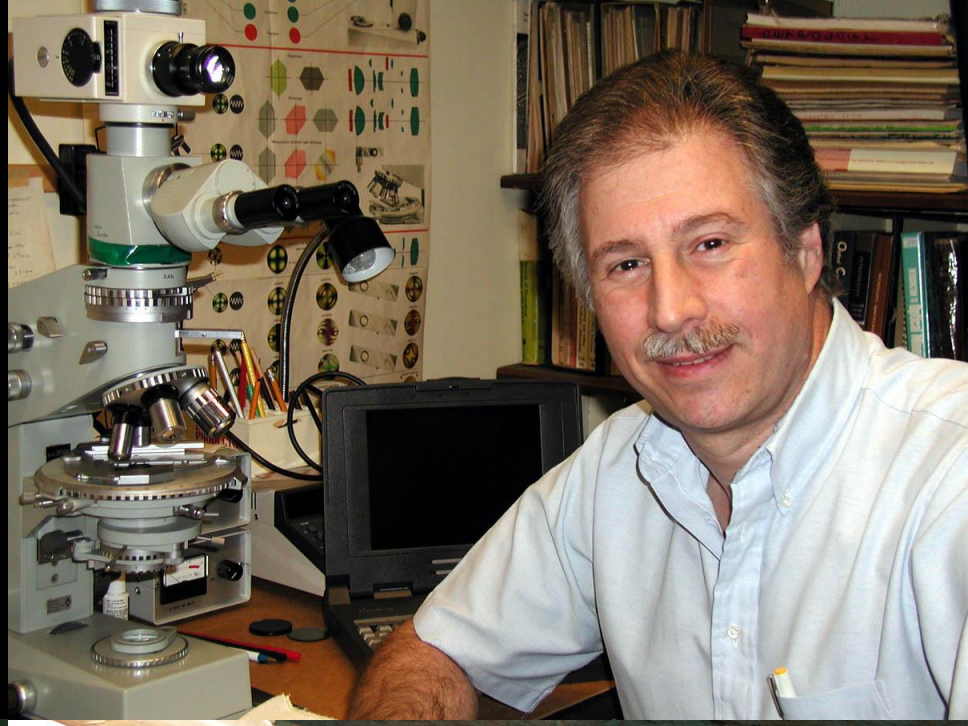

G
o
tu
Stockton
v
o
tu
v
o
Walloomsac
Holocene silt
v
Hartland
o
tu
tl
F
~200' of Pleistocene
Replaced by 160'
Holocene
E
o
tu
o
v
v
Holocene
Silt
o
tu
tl
o
tl
o
?
?
Serpentinite
Hartland
QT Complex


OK, That's It – Too Loud! I've Heard Enough!
H. Manne

Duke Geological Lab

Full Service Geotechnical Tunneling Analysis

www.dukelabs.com



Download NYC Geology Publications @

www.hofstra.edu

www.dukelabs.com