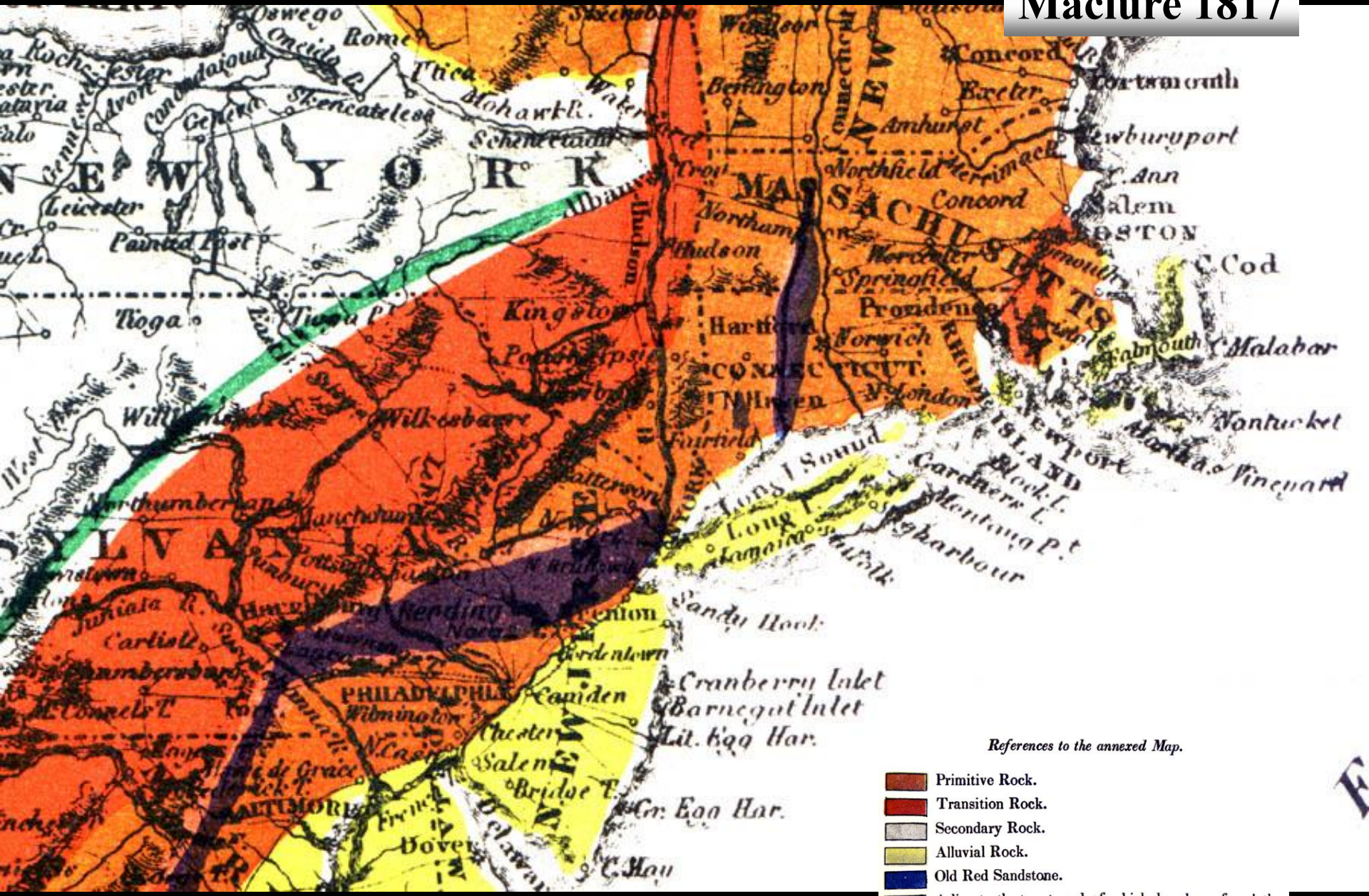
Geology of the New York City Water Tunnel System

Charles Merguerian

HOFSTRA UNIVERSITY


THE AMERICAN MVSEVM OF NATVRAL HISTORY
FOVNDED 1869

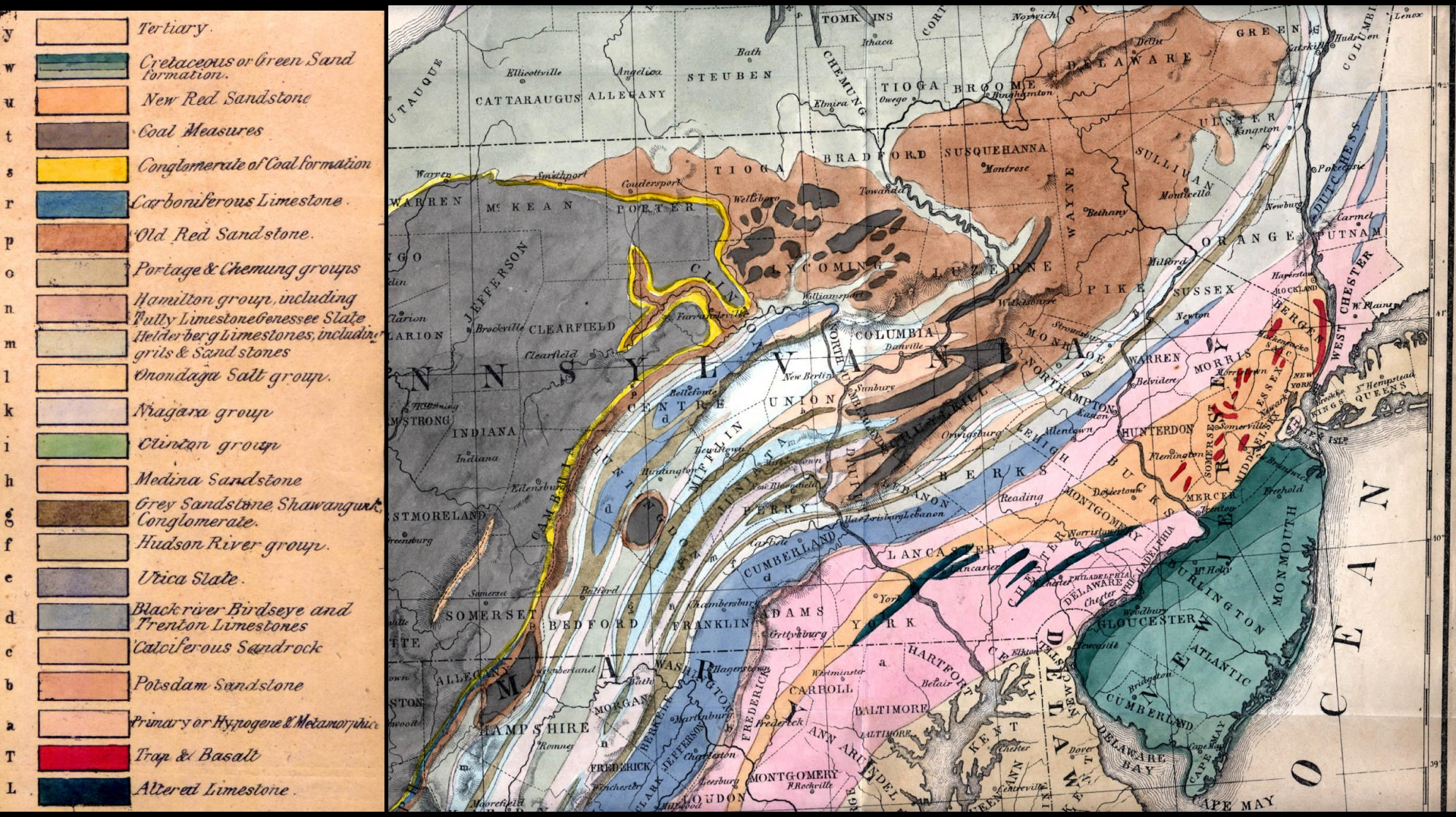
Maclure 1817



References to the annexed Map.

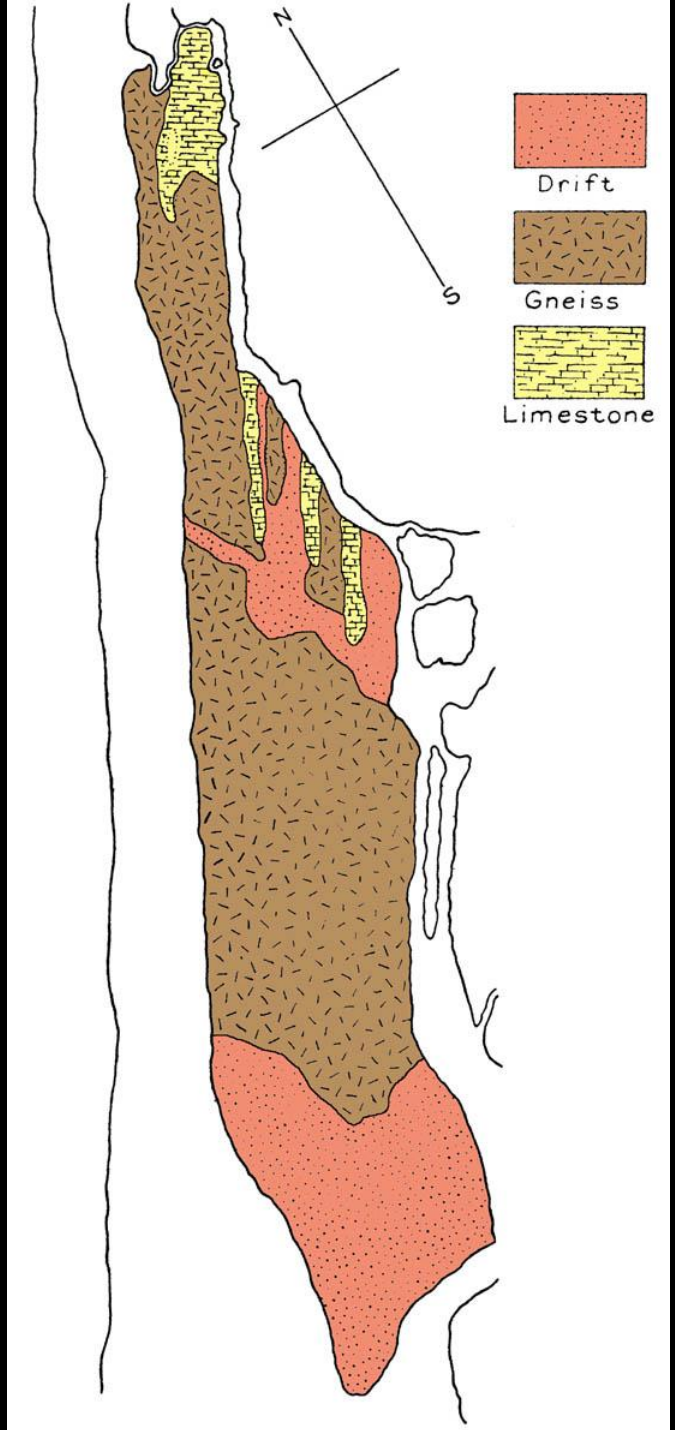
- Primitive Rock.
- Transition Rock.
- Secondary Rock.
- Alluvial Rock.
- Old Red Sandstone.
- A line to the westward of which has been found the greatest part of the Salt and Gypsum.

James Hall [1811-1898]

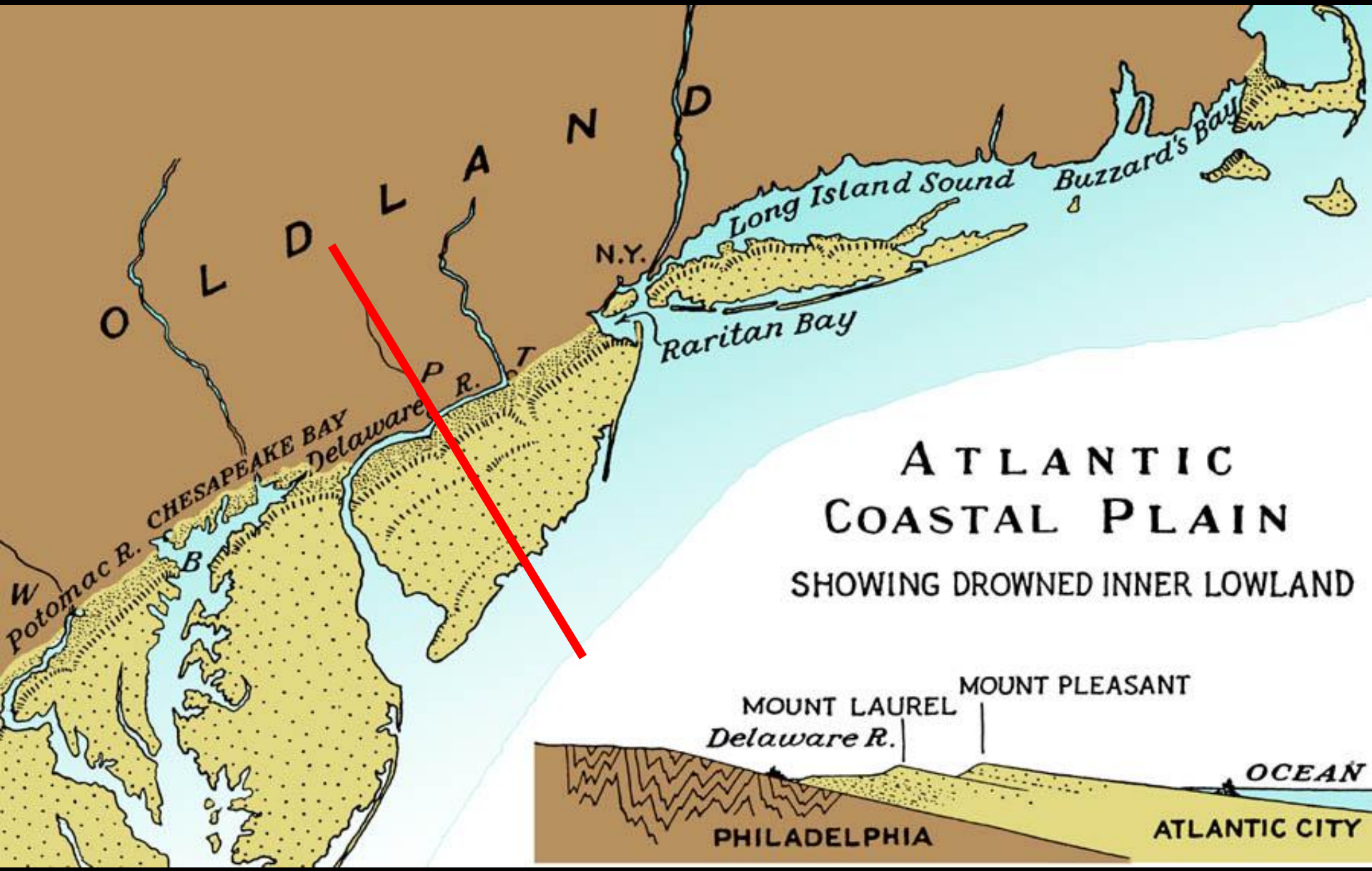


Hall 1843

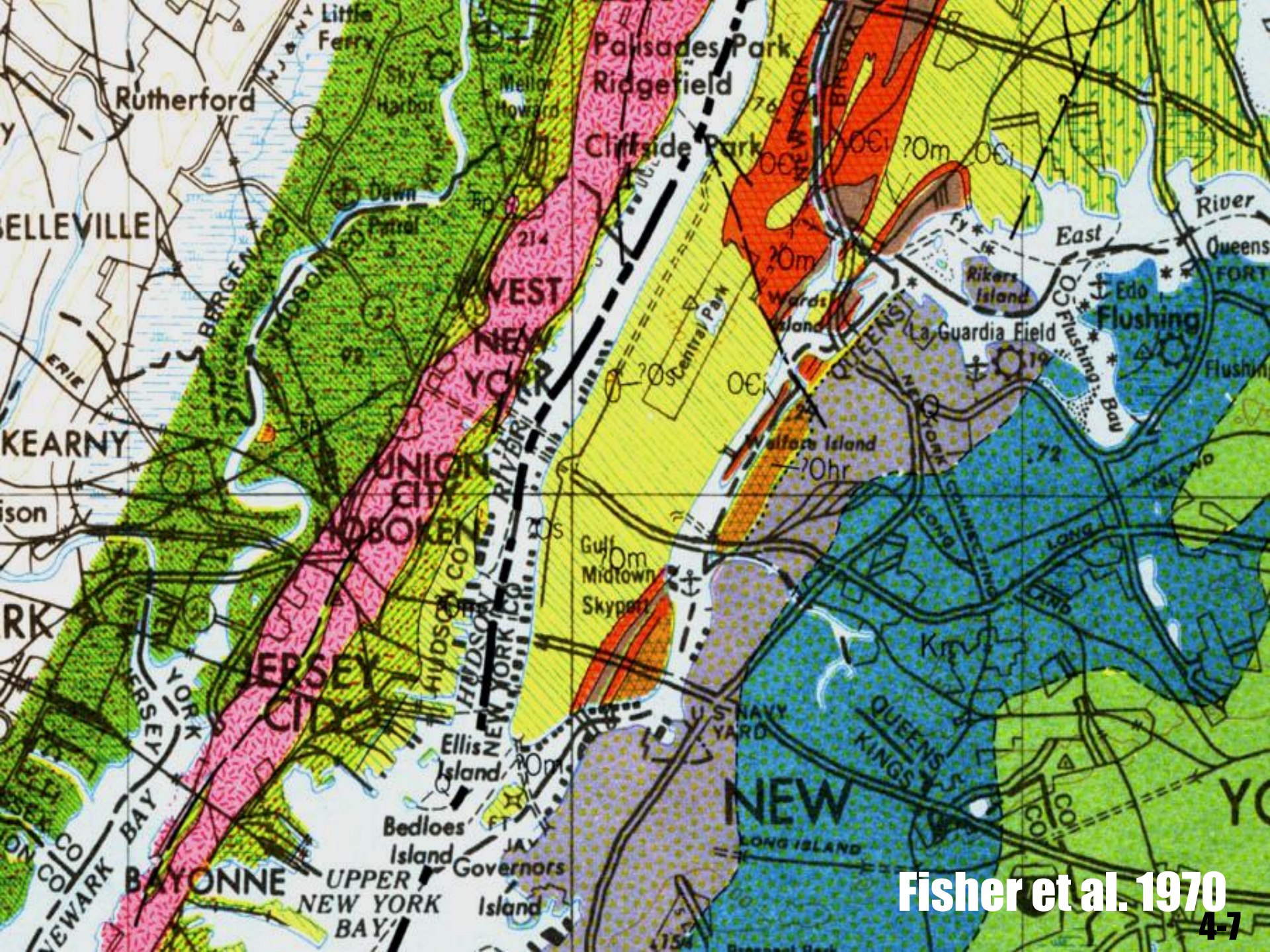
Geologic Map Manhattan *(after Kemp)*

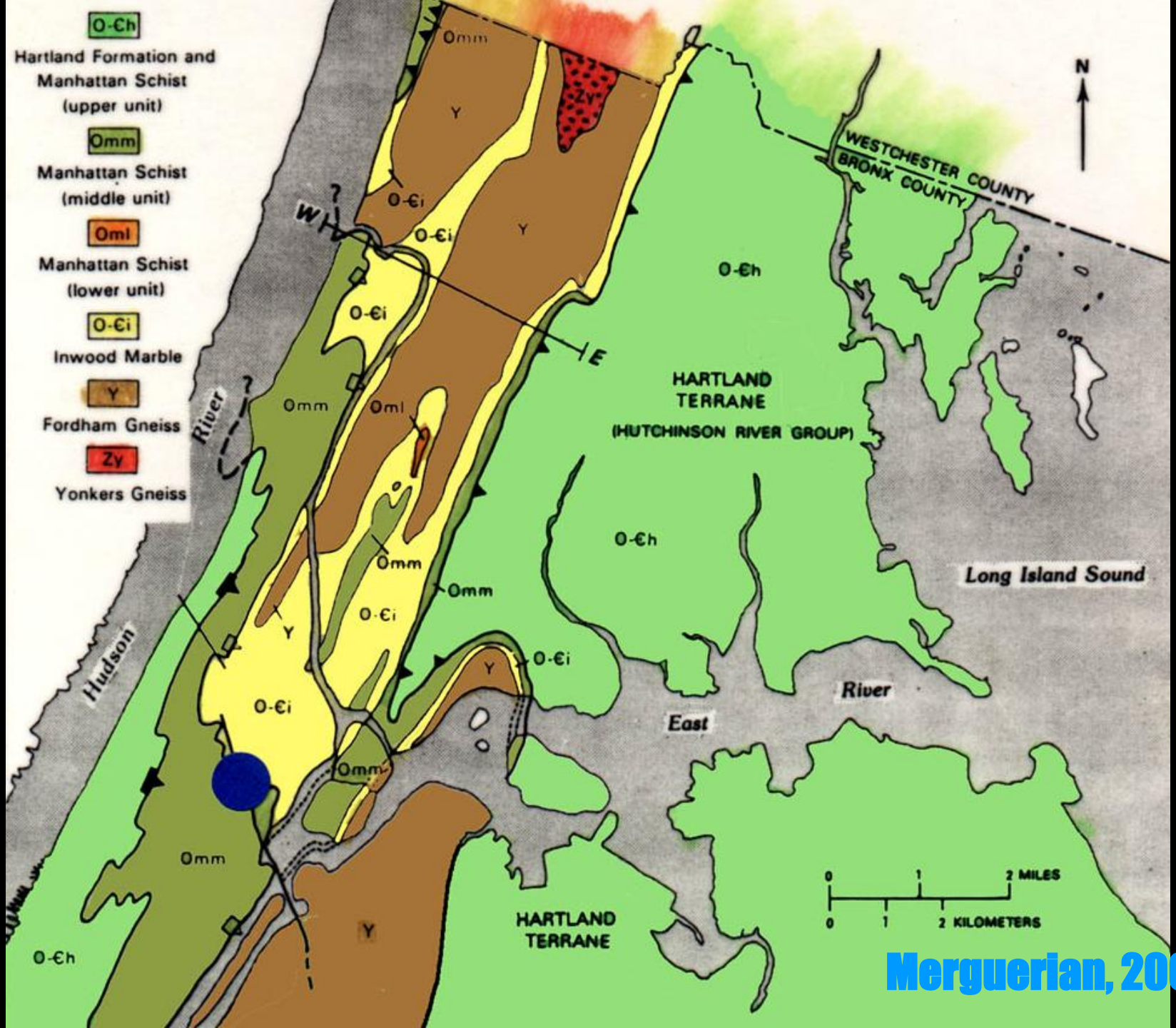


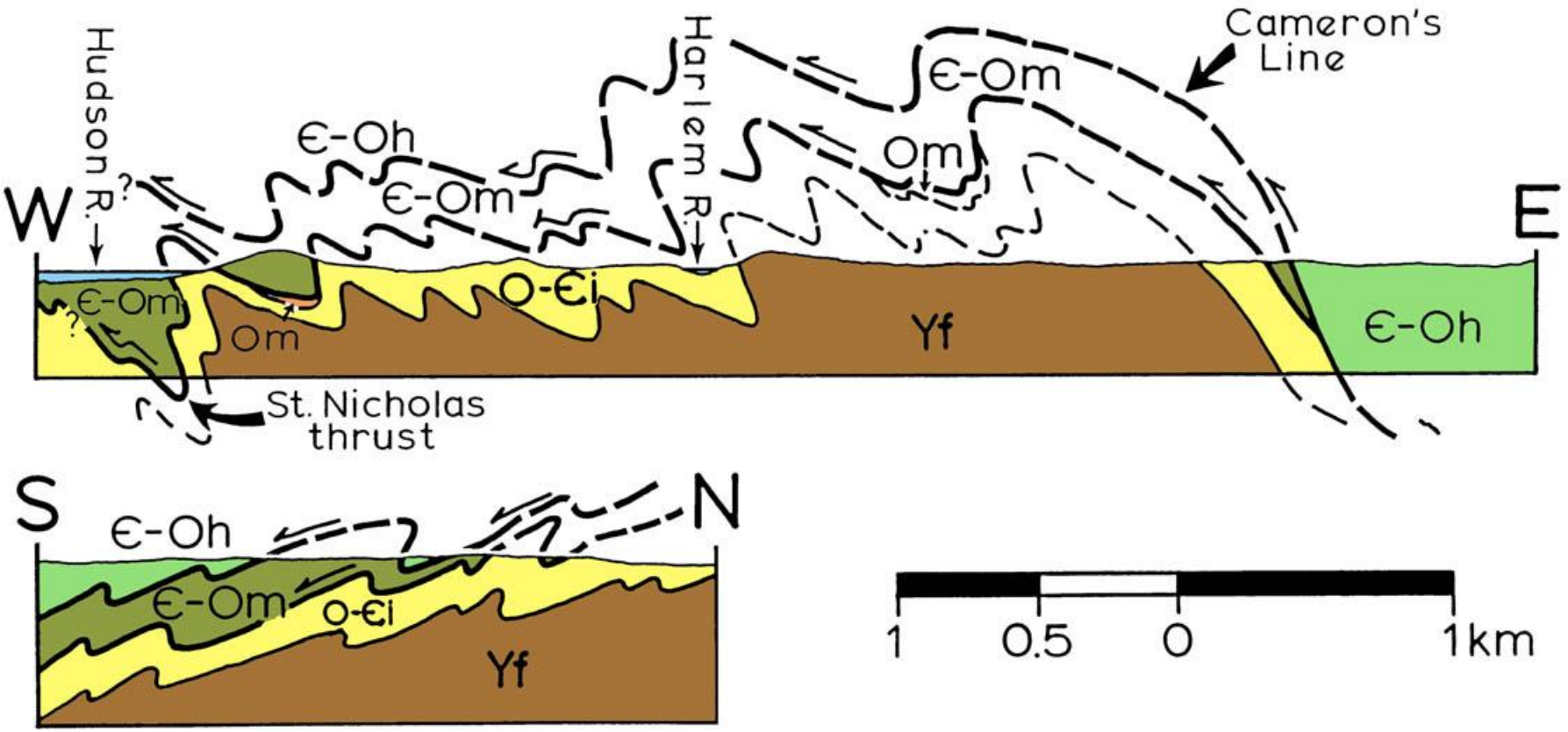
After Berkey 1910

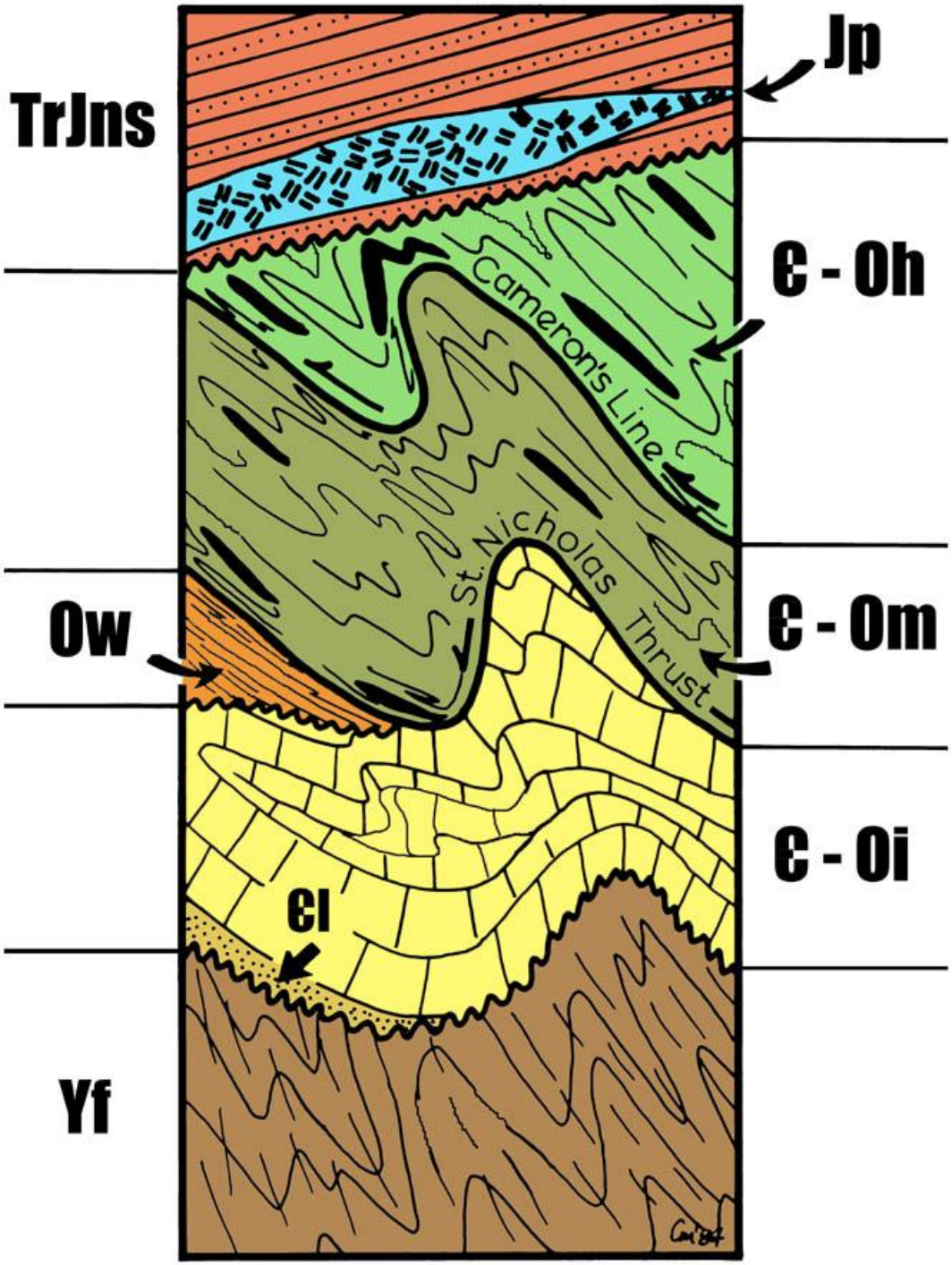


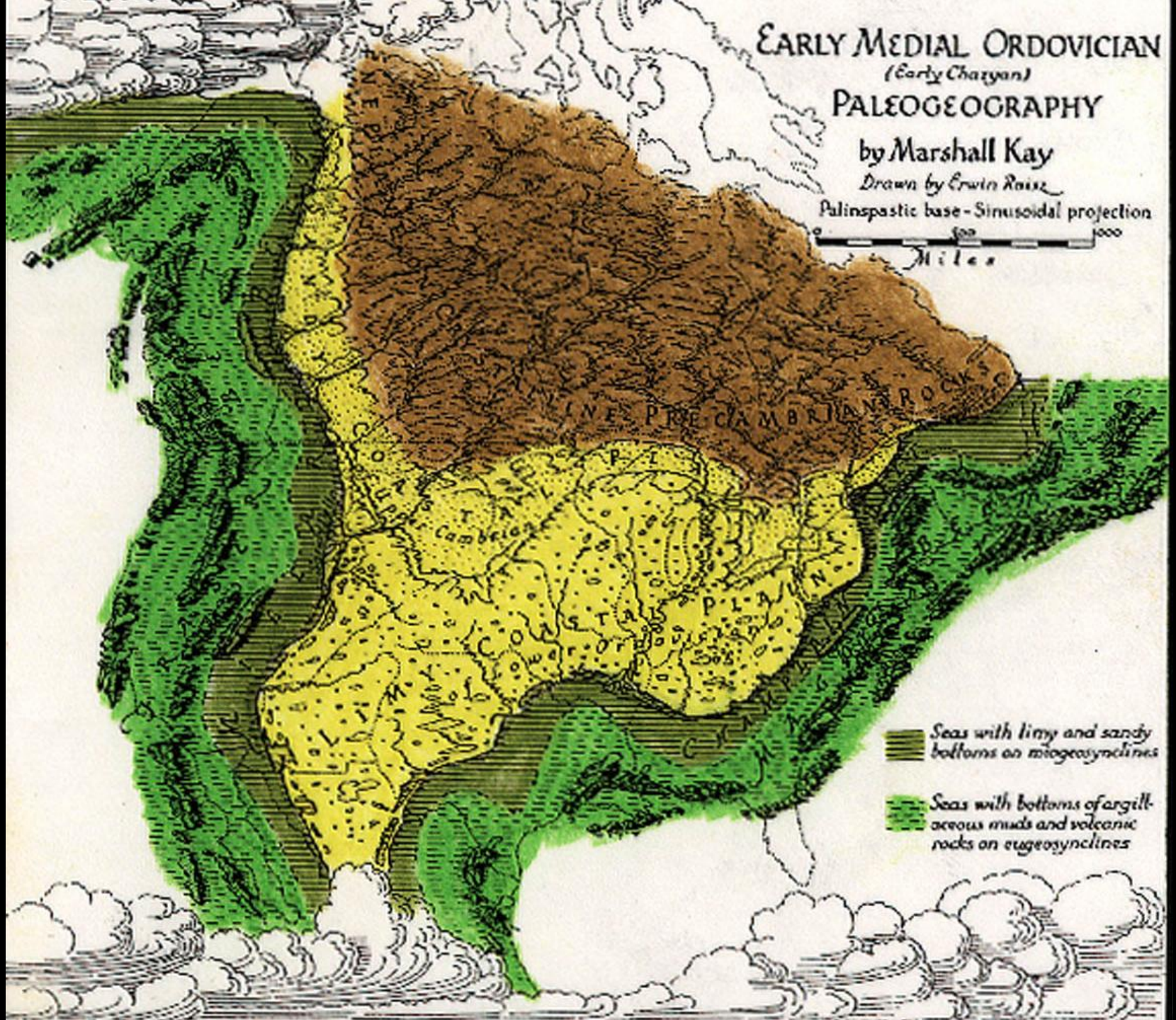
After Lobeck 1939


Rutherford
Little Ferry
Palisades Park
Ridgefield
Cliffside Park
BELLEVILLE
KEARNY
WEST NEW YORK
UNION CITY
HOBOKEN
JERSEY CITY
Central Park
Rikers Island
La Guardia Field
Flushing
Flushing Bay
East River
Queens
Welfare Island
Gulf
Midtown Skyport
Ellis Island
Bedloes Island
Governors Island
BAYONNE
UPPER NEW YORK BAY
U.S. NAVY YARD
QUEENS
KINGS
LONG ISLAND
NEW
?Om
?Ohr
?Os
OCi
Fisher et al. 1970

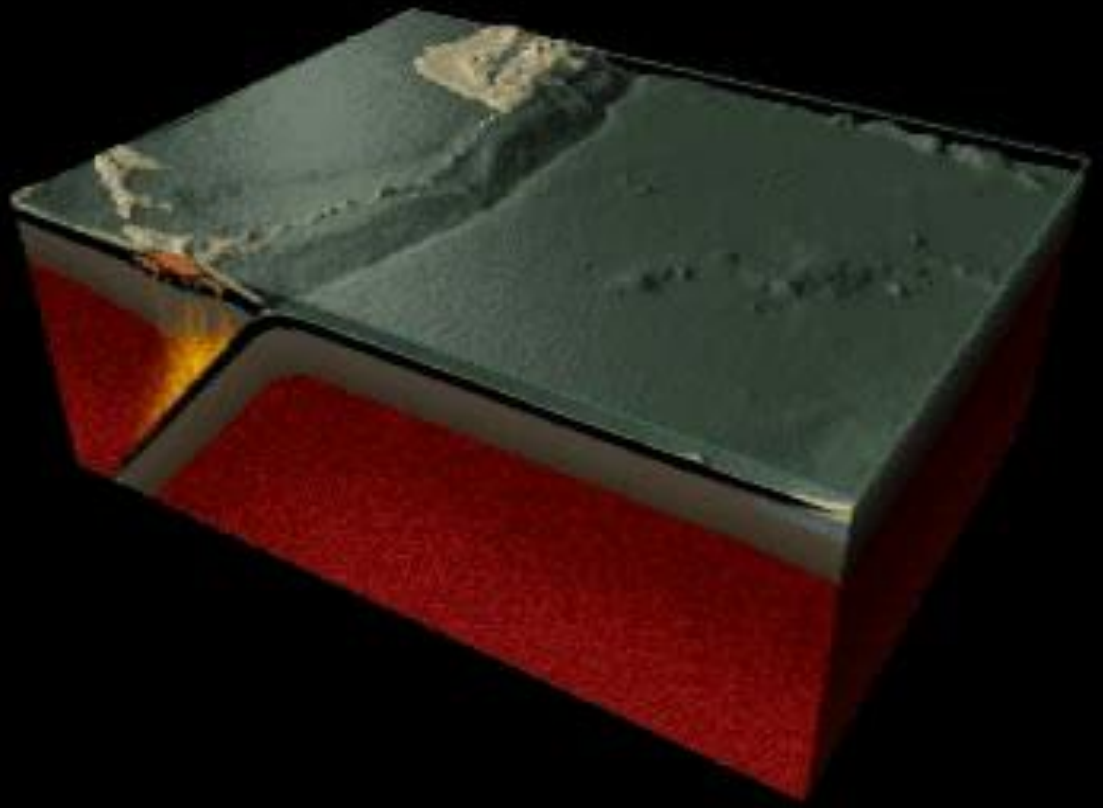

O-Ch
Hartland Formation and Manhattan Schist (upper unit)
Omm
Manhattan Schist (middle unit)
Oml
Manhattan Schist (lower unit)
O-Ci
Inwood Marble
Y
Fordham Gneiss
Zy
Yonkers Gneiss
N
WESTCHESTER COUNTY
BRONX COUNTY
HARTLAND TERRANE
(HUTCHINSON RIVER GROUP)
HARTLAND TERRANE
Long Island Sound
Hudson River
East River
W
E
0 1 2 MILES
0 1 2 KILOMETERS
Merguerian, 2002


Hudson R.
Harlem R.
Cameron's Line
W
E
S
N
Є-Oh
Є-Om
Om
O-Єi
Yf
St. Nicholas thrust
1
0.5
0
1km

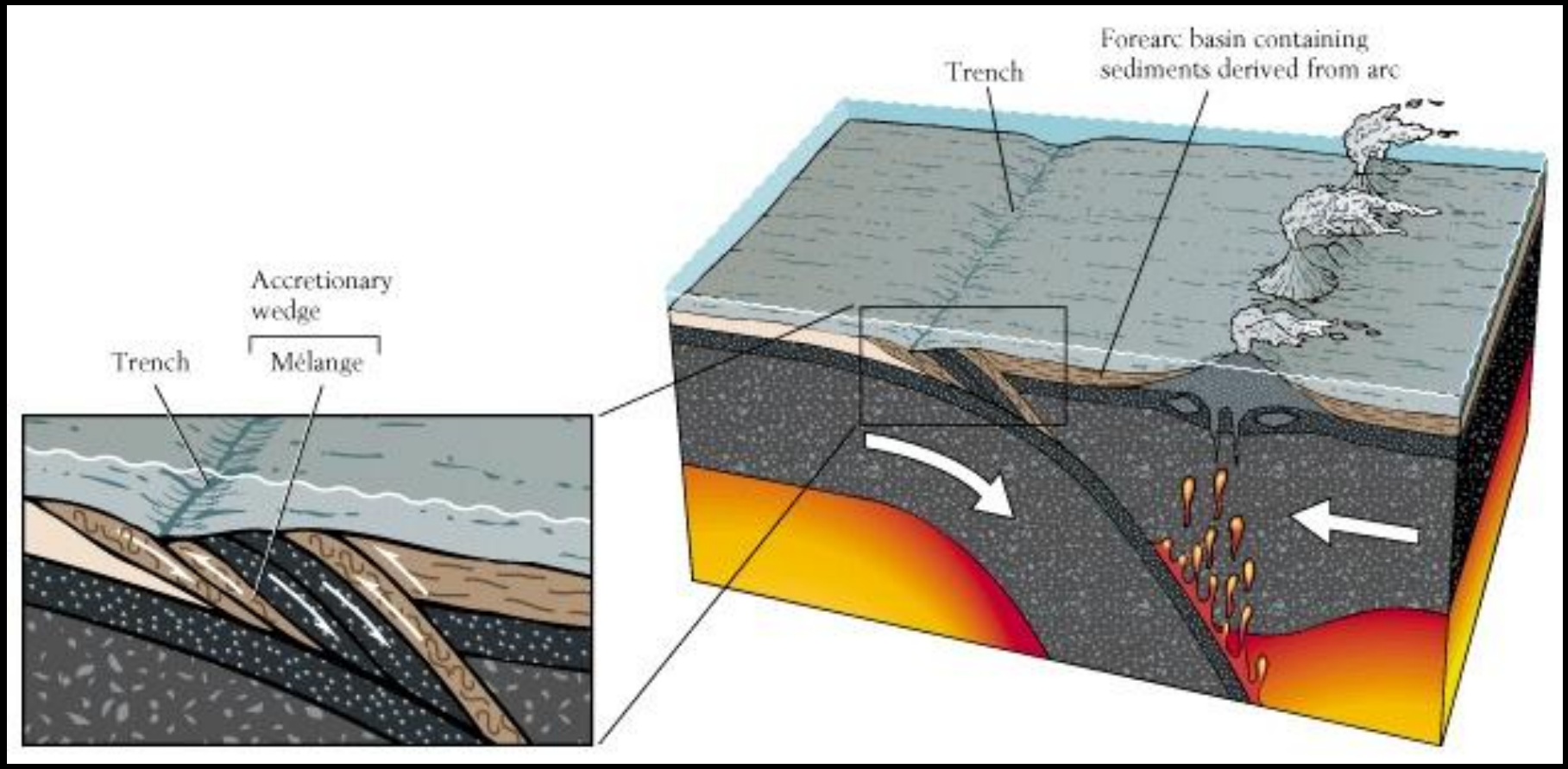

Jp
TrJns
Є - Oh
Cameron's Line
St. Nicholas Thrust
Ow
Є - Om
Є - Oi
Єl
Yf

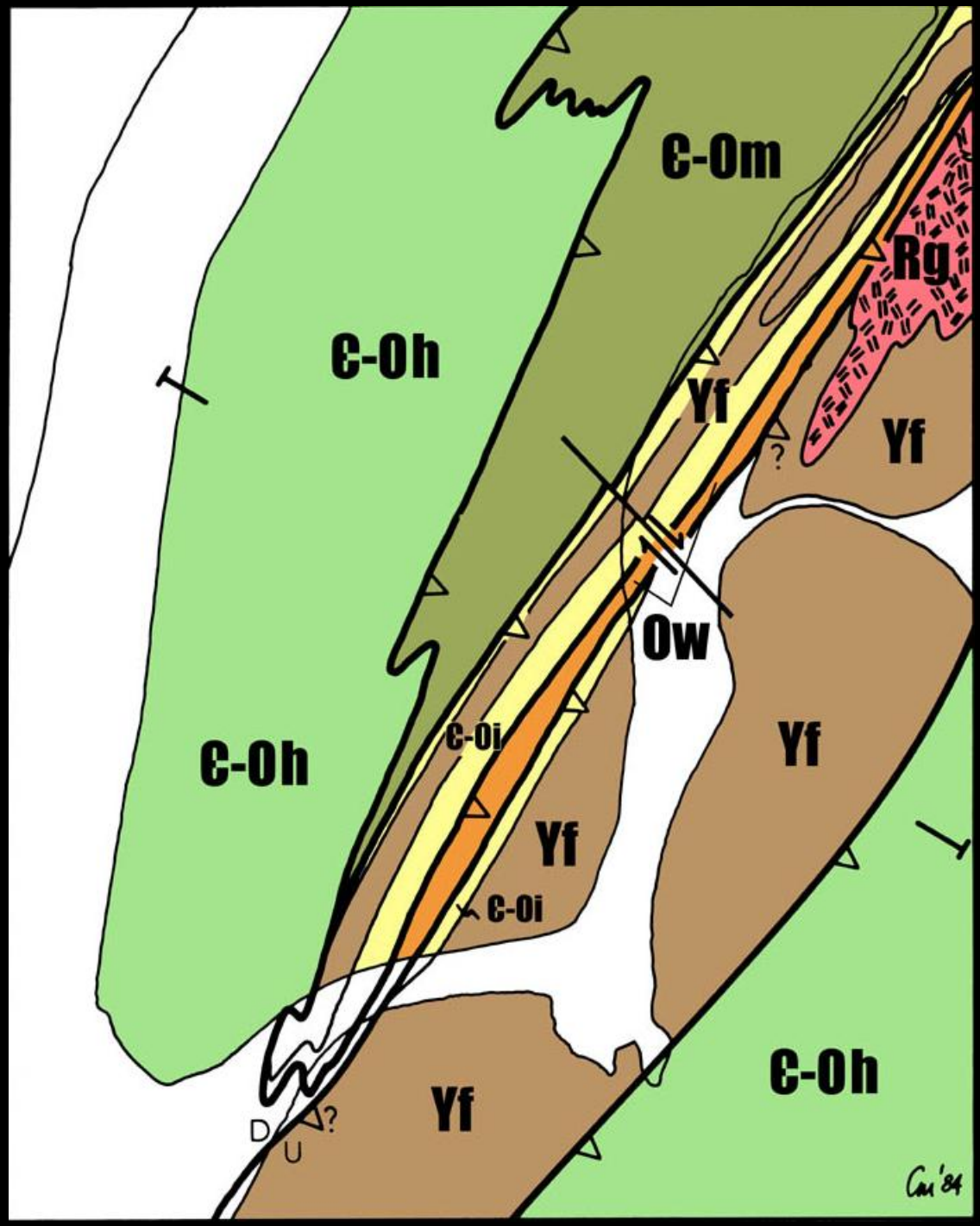

EARLY MEDIAL ORDOVICIAN
(Early Chazyan)
PALEOGEOGRAPHY
by Marshall Kay
Drawn by Erwin Raisz
Palinspastic base - Sinusoidal projection
Miles
Seas with limy and sandy bottoms on miogeosynclines
Seas with bottoms of argillaceous muds and volcanic rocks on eugeosynclines

Taconic Arc – Passive Margin Collision



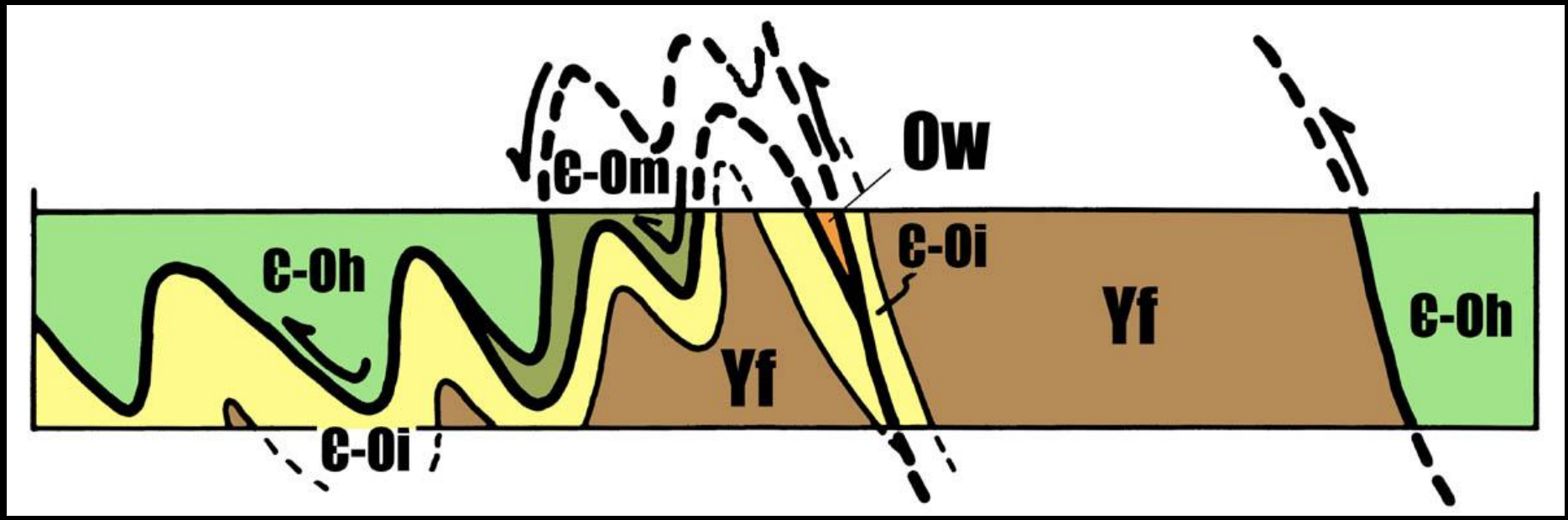
Accretionary Wedge

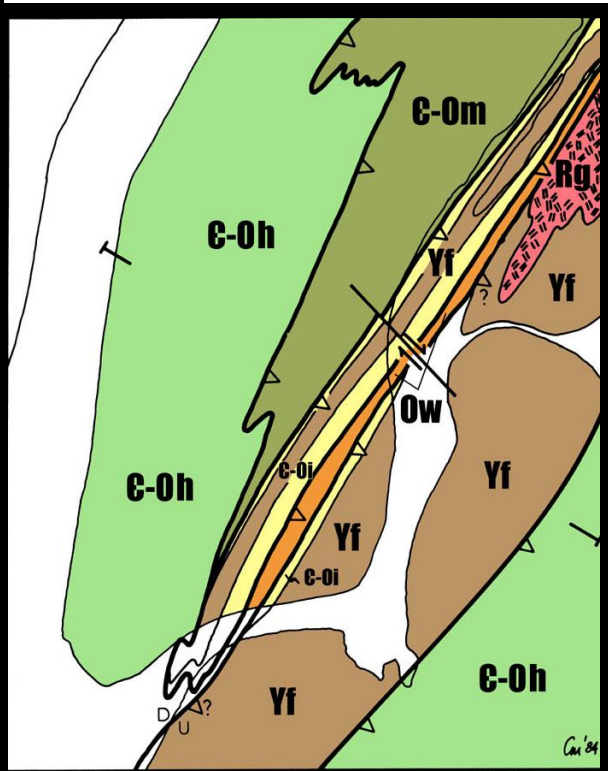




Interpretive Geologic Map of SE Manhattan and Adjacent Areas Based on Borings From Berkey 1910

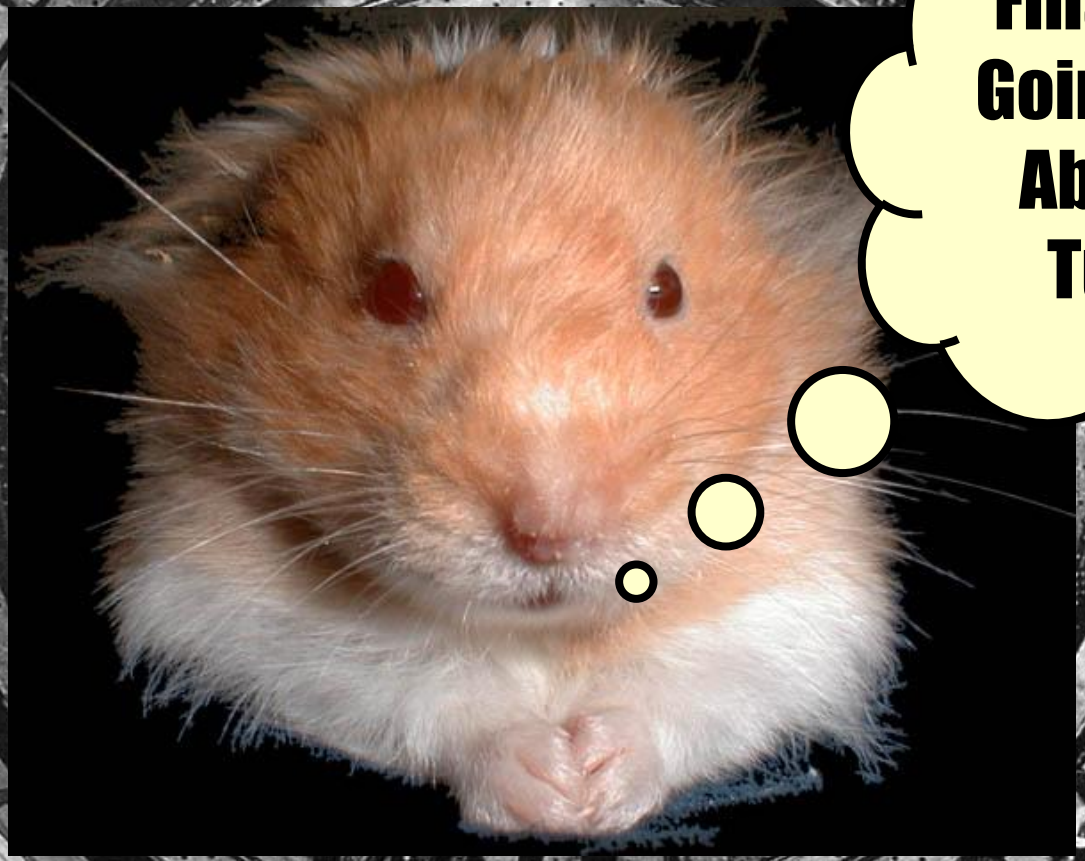
Merguerian 1984





Interpretive NW-SE Geologic Section

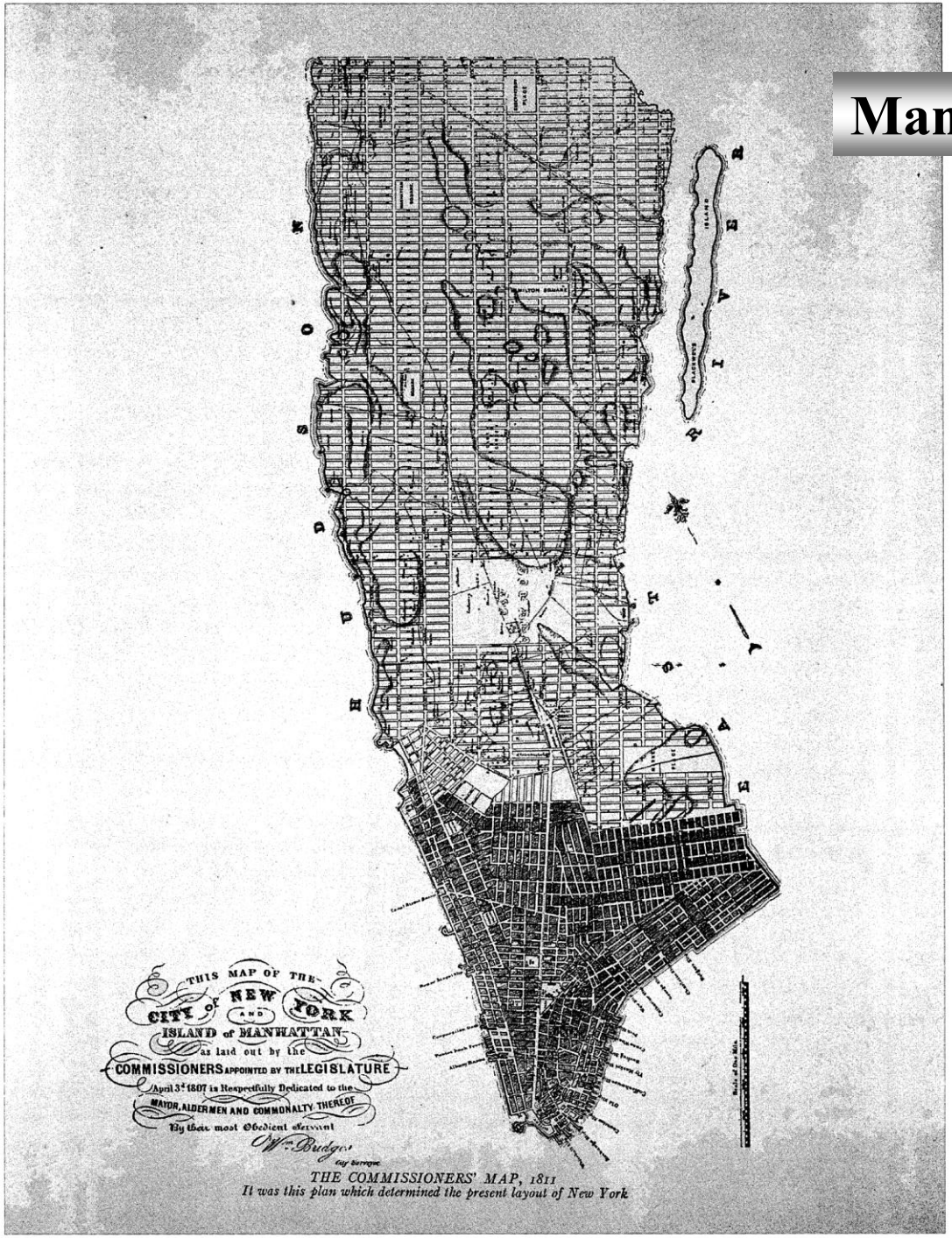
Merguerian 1984



Finally, He's Going to Talk About The Tunnels

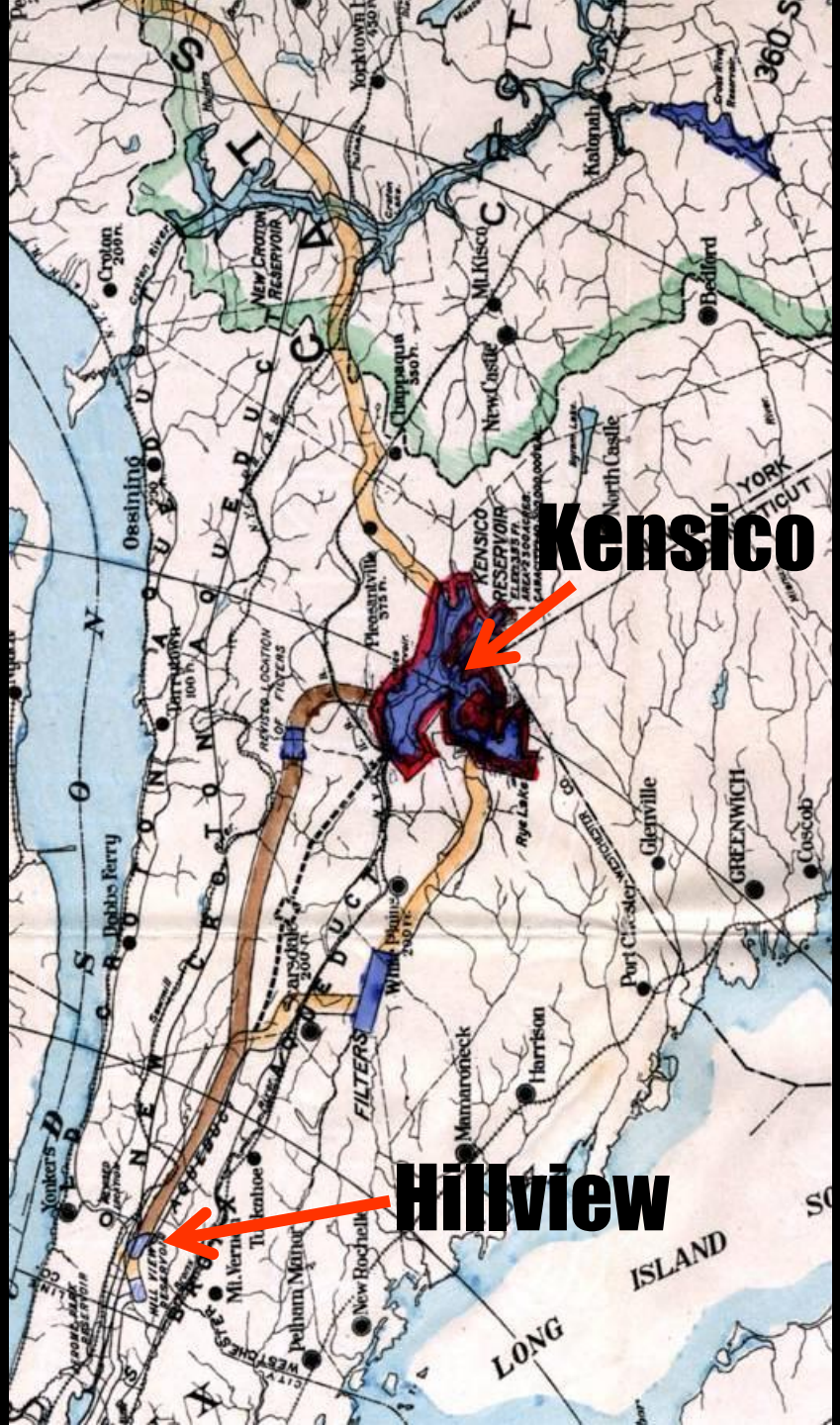
Dutch Settlers, South Manhattan

Manhattan 1811

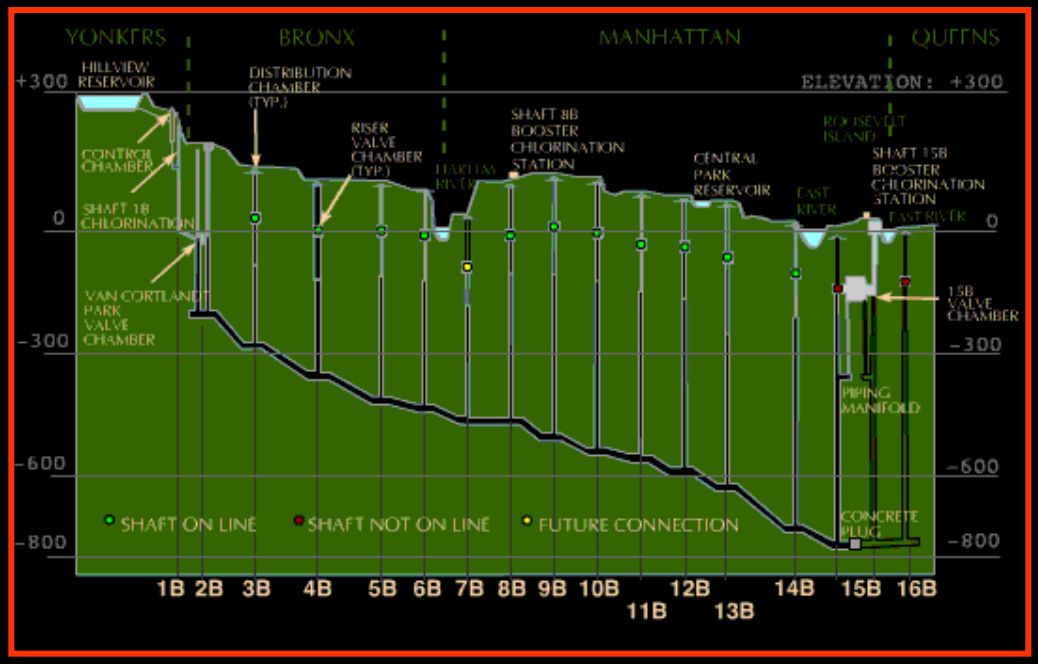


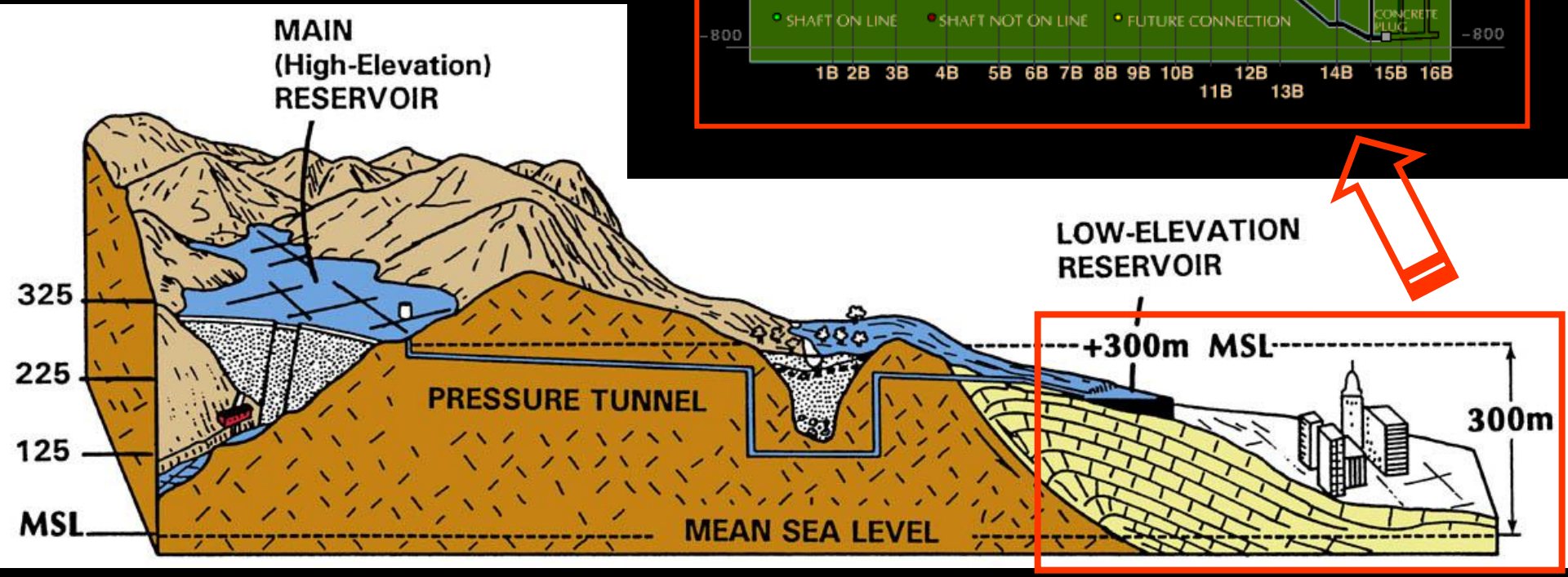
THE COMMISSIONERS' MAP, 1811
It was this plan which determined the present layout of New York

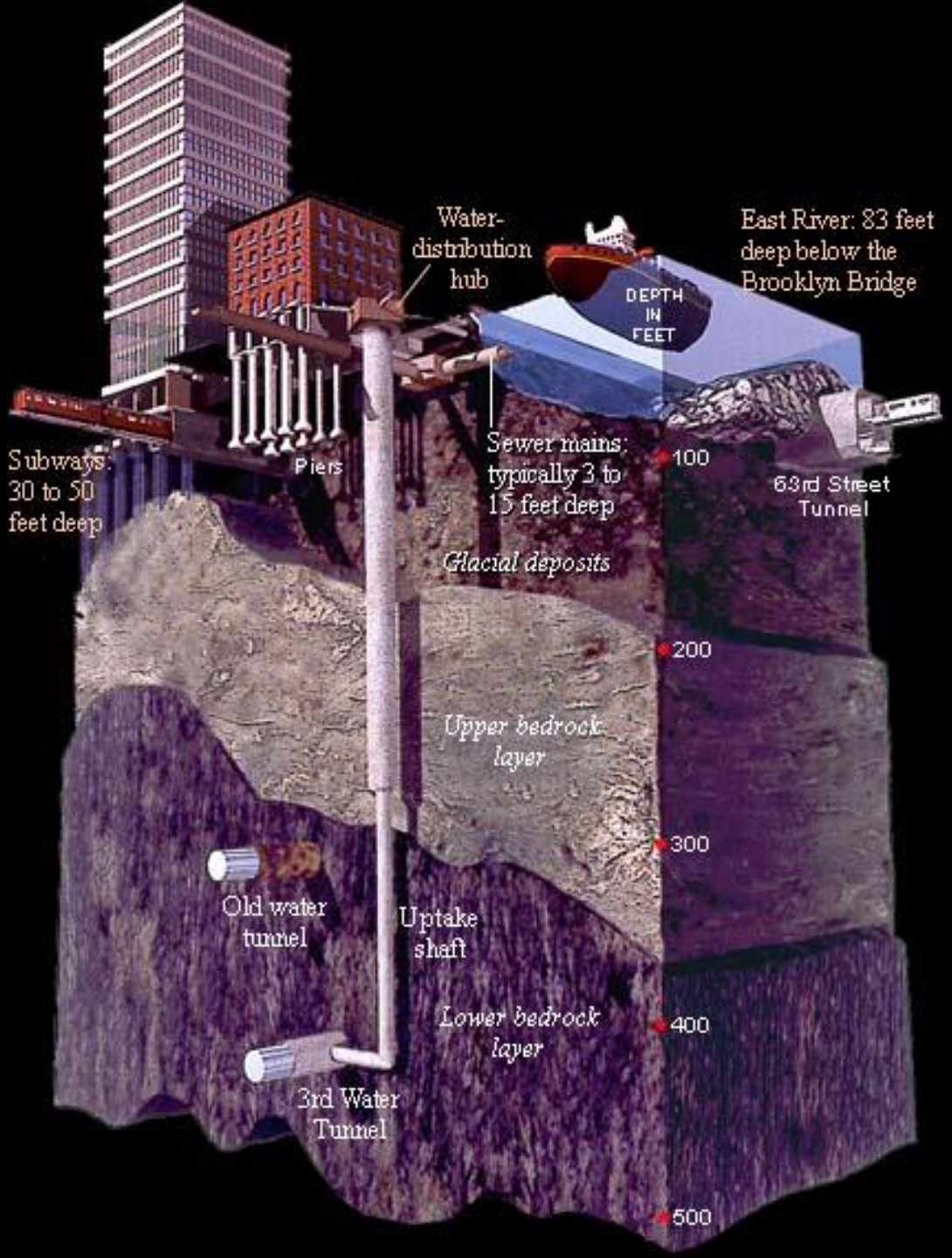
NYC Aqueduct System



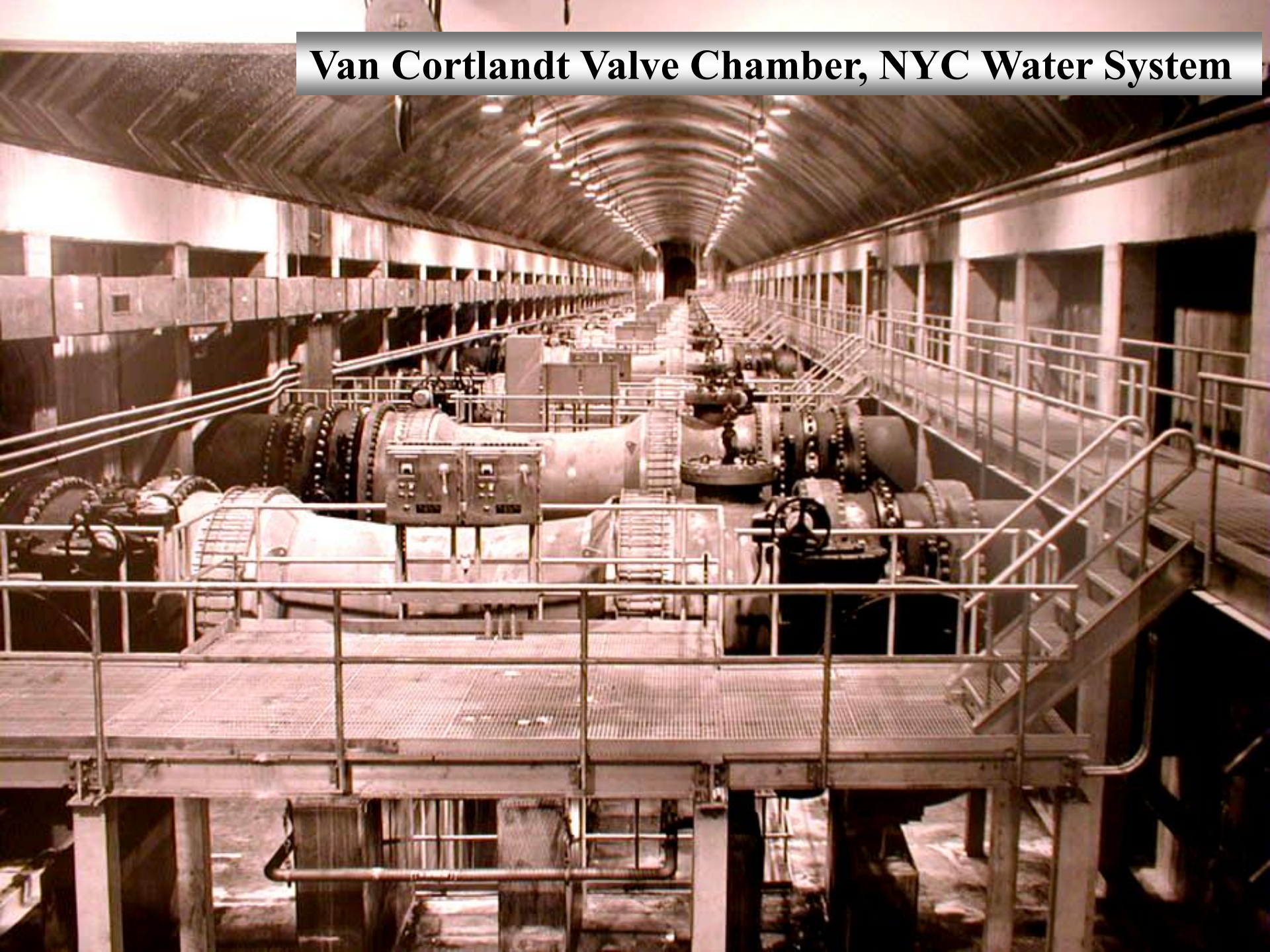
Gravity Feed System

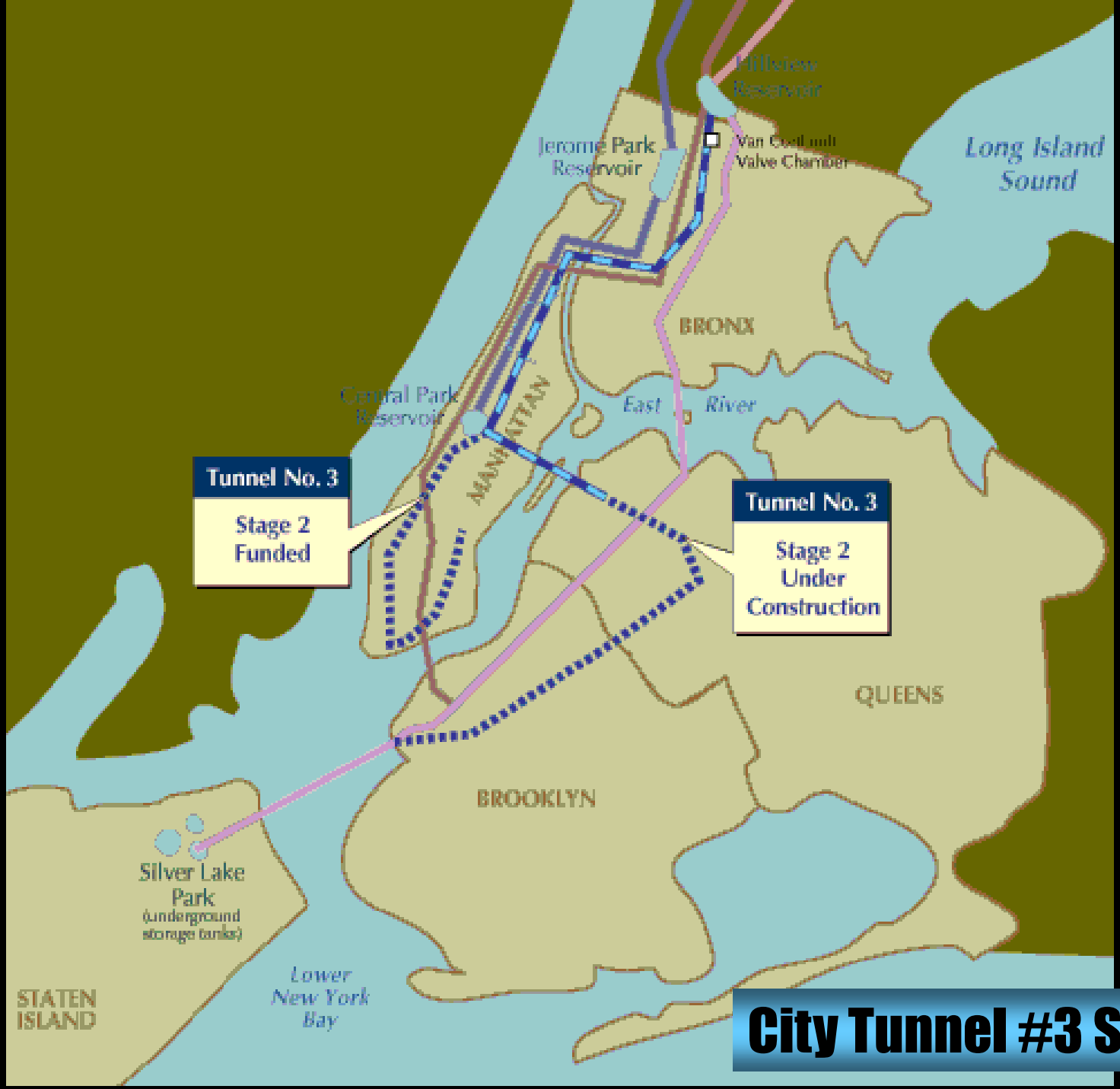





Water-distribution hub
East River: 83 feet deep below the Brooklyn Bridge
DEPTH IN FEET
Subways: 30 to 50 feet deep
Piers
Sewer mains: typically 3 to 15 feet deep
100
63rd Street Tunnel
Glacial deposits
200
Upper bedrock layer
300
Old water tunnel
Uptake shaft
Lower bedrock layer
400
3rd Water Tunnel
500

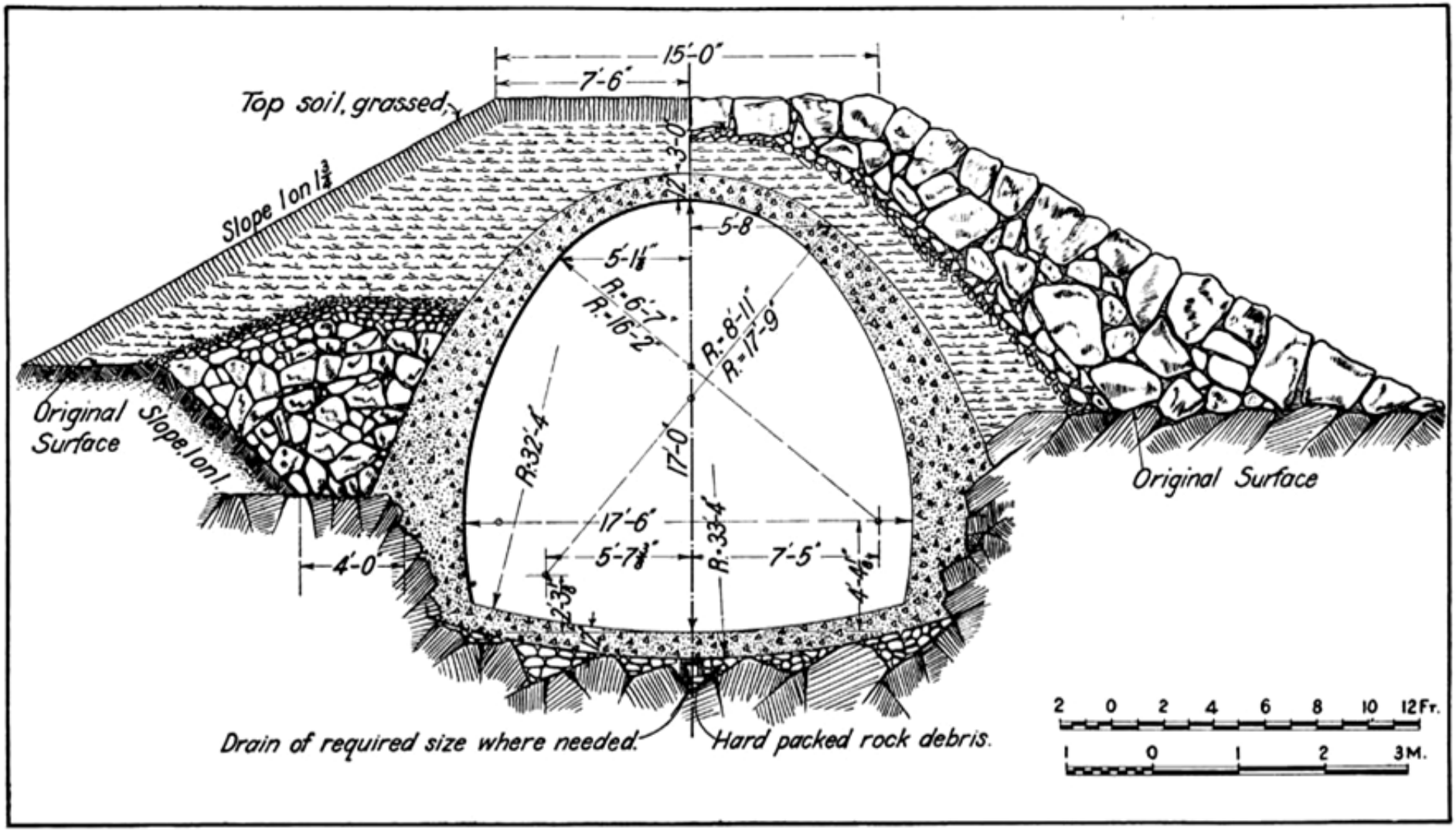
City Tunnel #3 Stage 1


Van Cortlandt Valve Chamber, NYC Water System

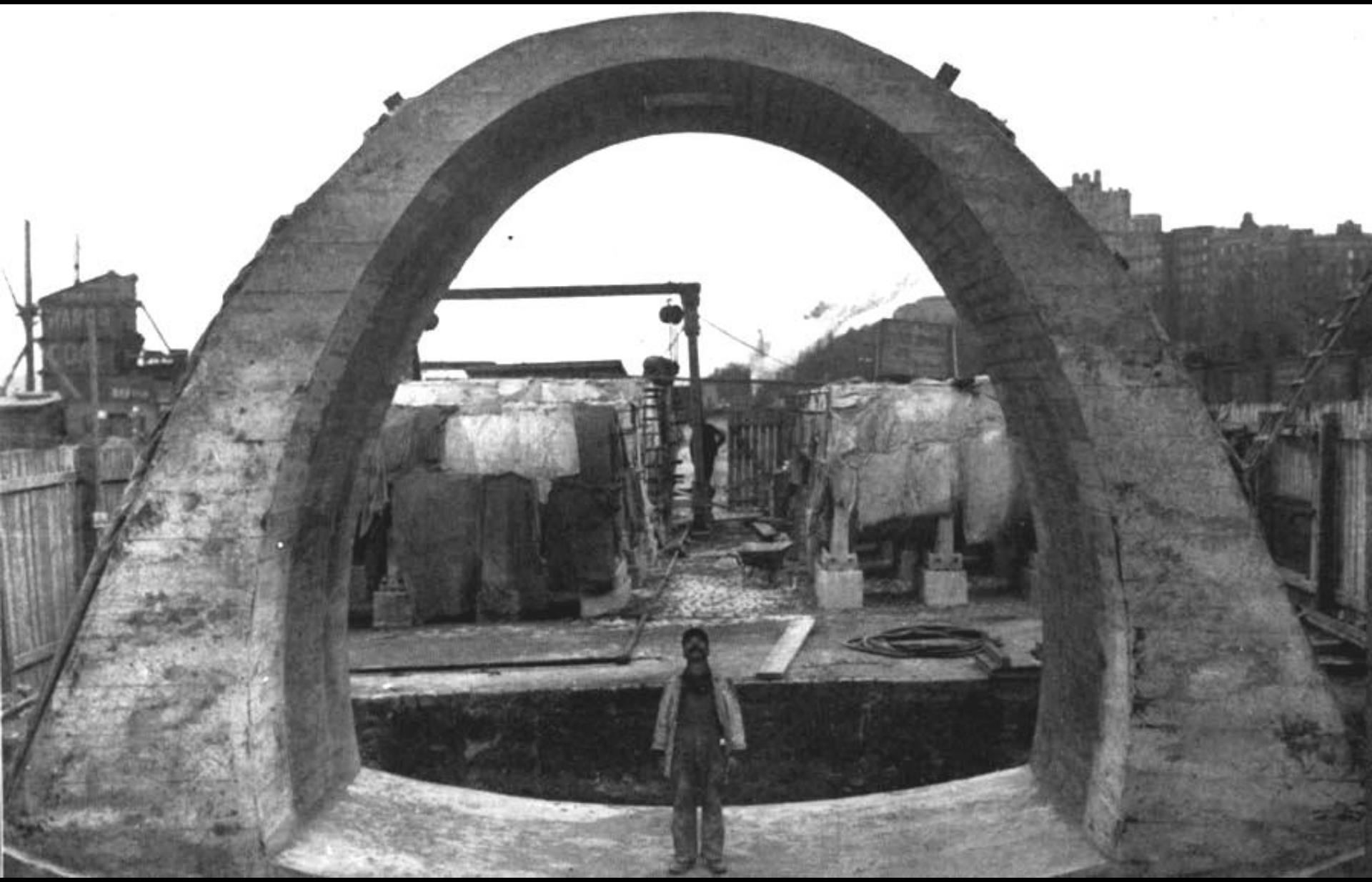


City Tunnel #3 Stage 2

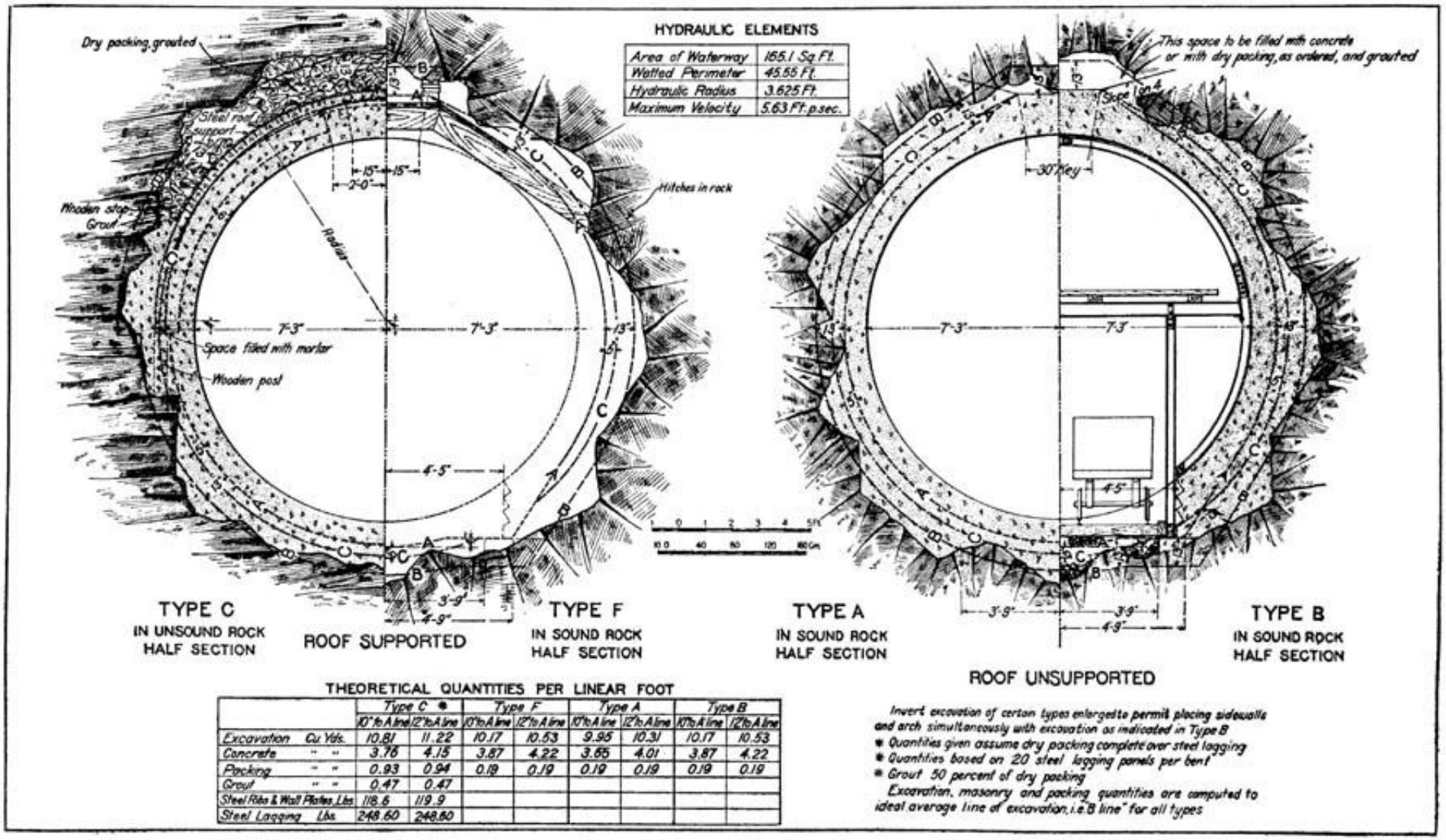
Cut and Cover, NYC Aqueduct



Cut and Cover Construction, NYC Aqueduct System



Catskill Aqueduct - Cut and Cover Support



THEORETICAL QUANTITIES PER LINEAR FOOT

	Type C *		Type F		Type A		Type B	
	10" to A line	12" to A line	10" to A line	12" to A line	10" to A line	12" to A line	10" to A line	12" to A line
Excavation Cu. Yds.	10.81	11.22	10.17	10.53	9.95	10.31	10.17	10.53
Concrete " "	3.76	4.15	3.87	4.22	3.65	4.01	3.87	4.22
Packing " "	0.93	0.94	0.19	0.19	0.19	0.19	0.19	0.19
Grout " "	0.47	0.47						
Steel Ribs & Wall Plates Lbs.	118.6	119.9						
Steel Lagging Lbs.	248.60	248.60						

Invert excavation of certain types enlarged to permit placing sidewalls and arch simultaneously with excavation as indicated in Type B

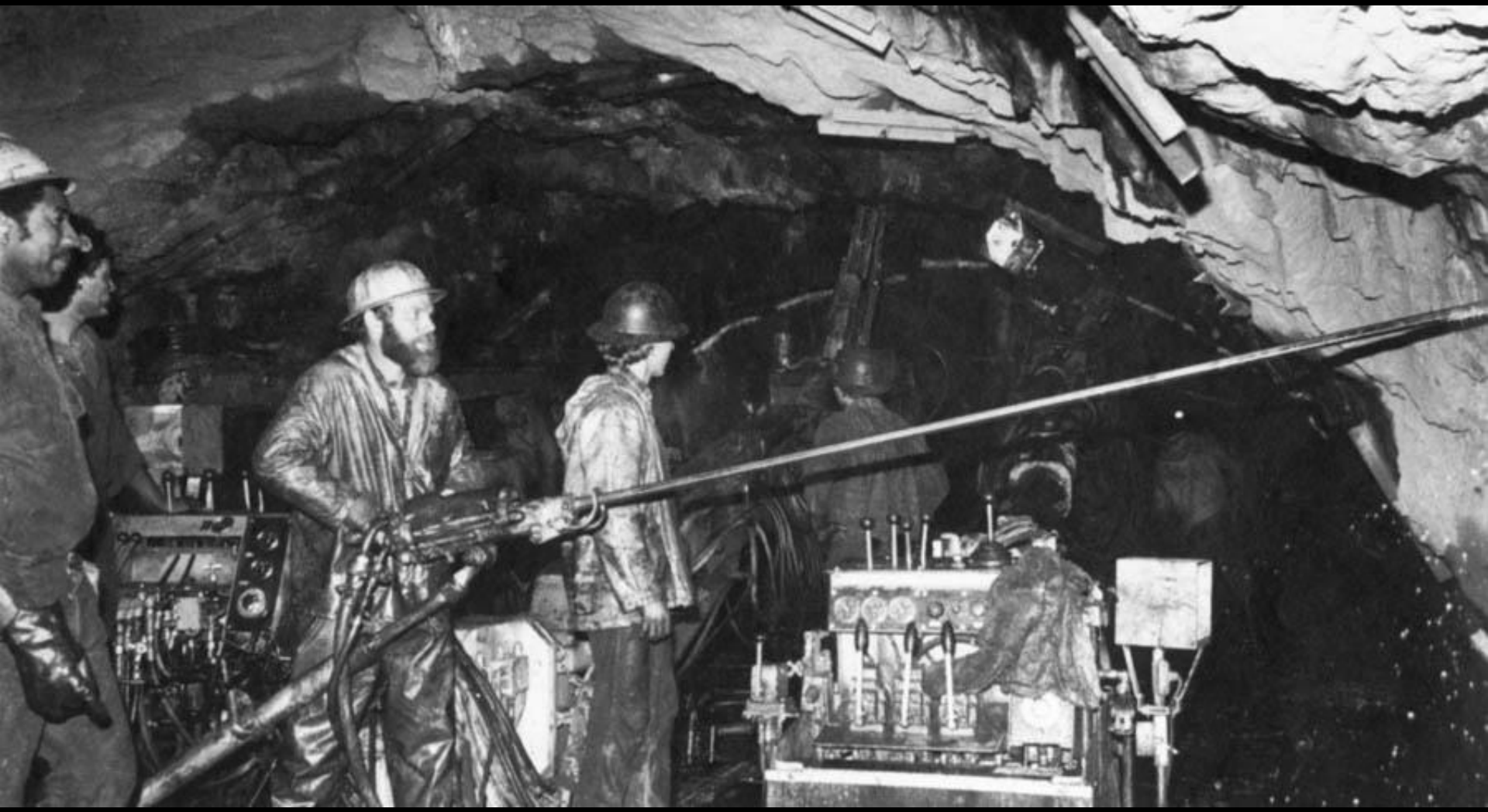
* Quantities given assume dry packing complete over steel lagging

* Quantities based on 20 steel lagging panels per bent

* Grout 50 percent of dry packing

Excavation, masonry and packing quantities are computed to ideal average line of excavation, i.e. "B line" for all types

Pressure Tunnel Construction, NYC Aqueduct System



CT3, Drill and Shoot Tunnel

Holing Through – Delaware Aqueduct Shaft 21 (1940)

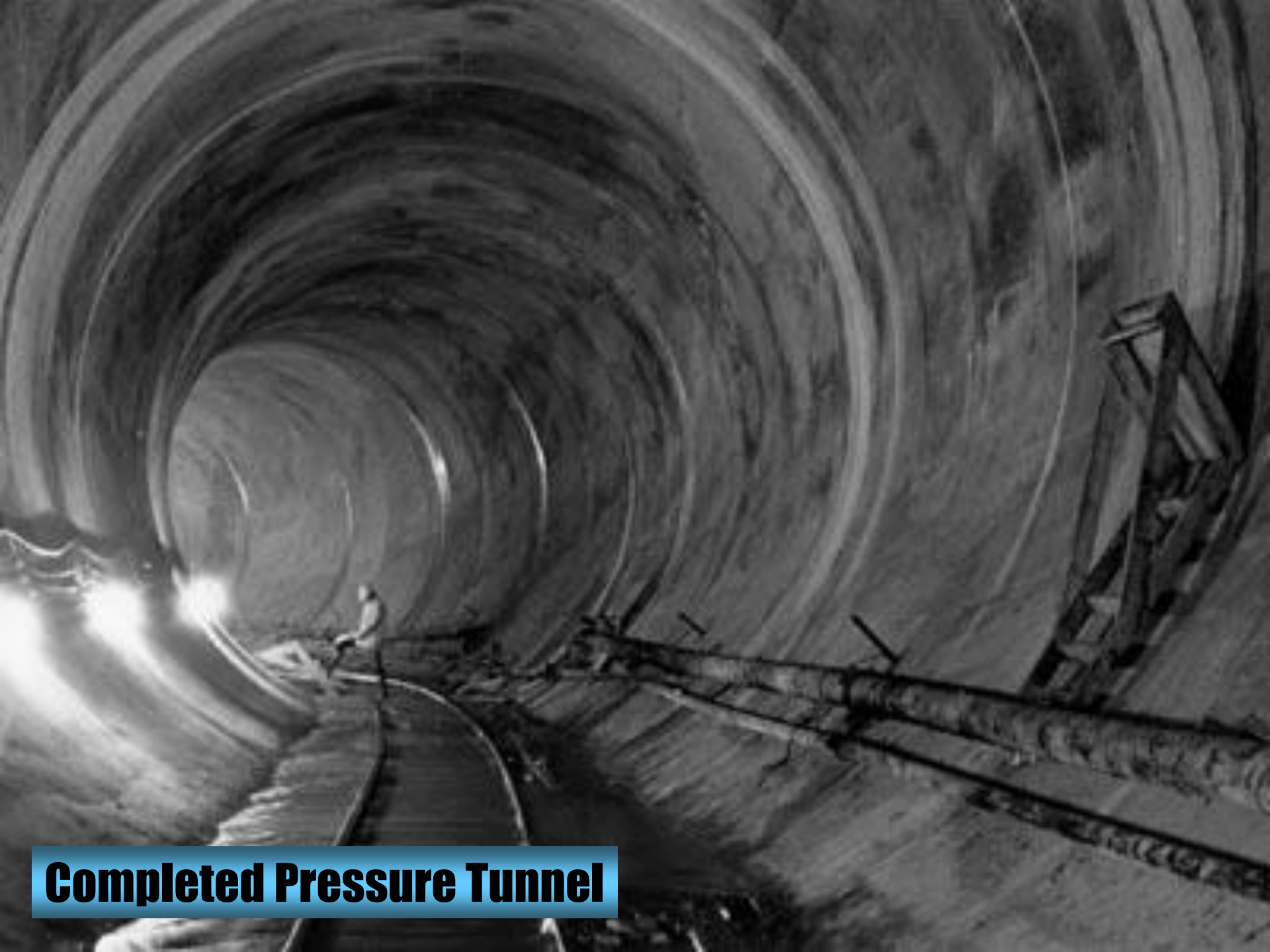

City Tunnel #2


Scaling and Cleaning


Concrete Forms


Concrete Forms Removed

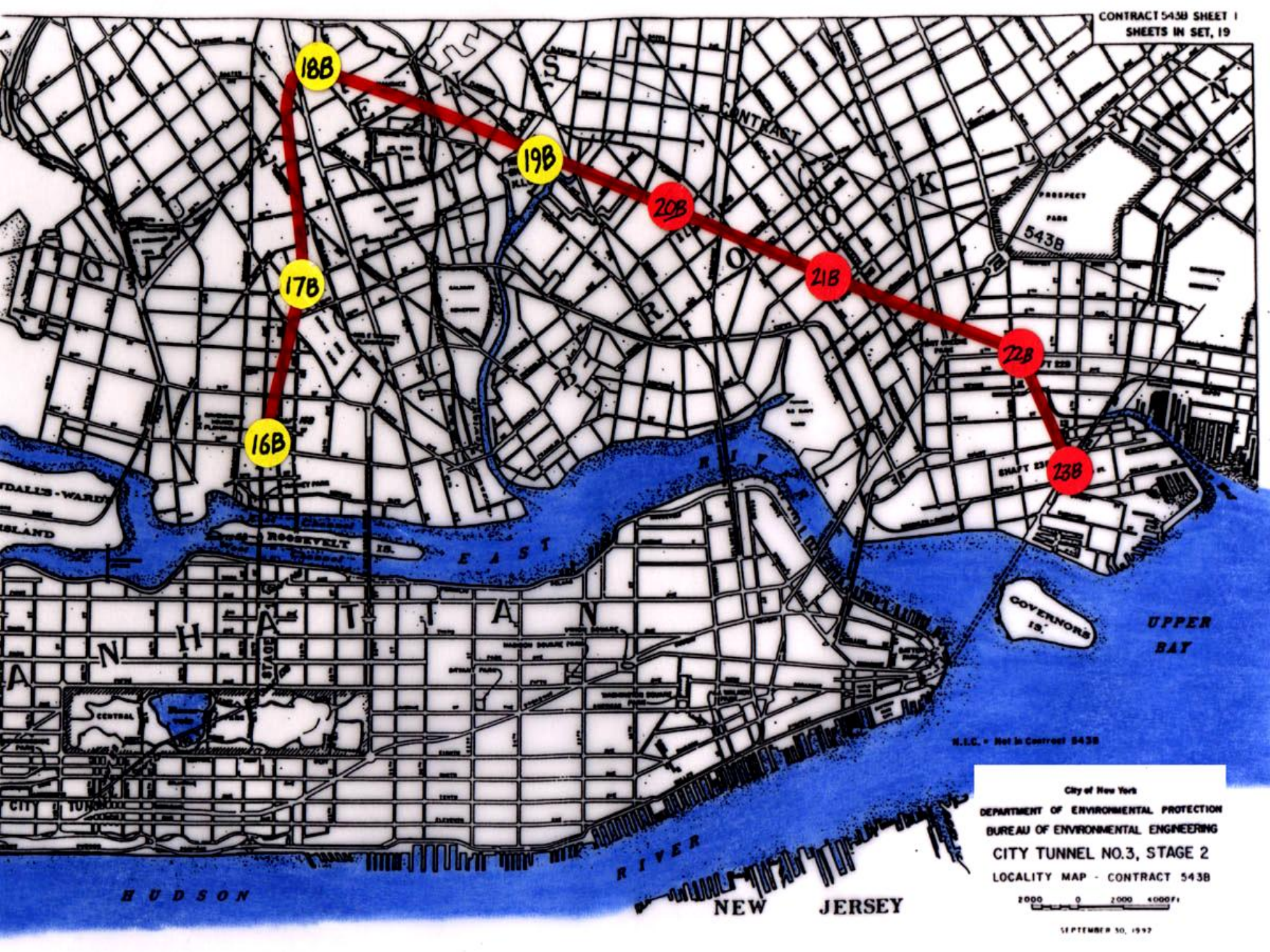
CT3, Scaling Drill and Shoot Tunnel



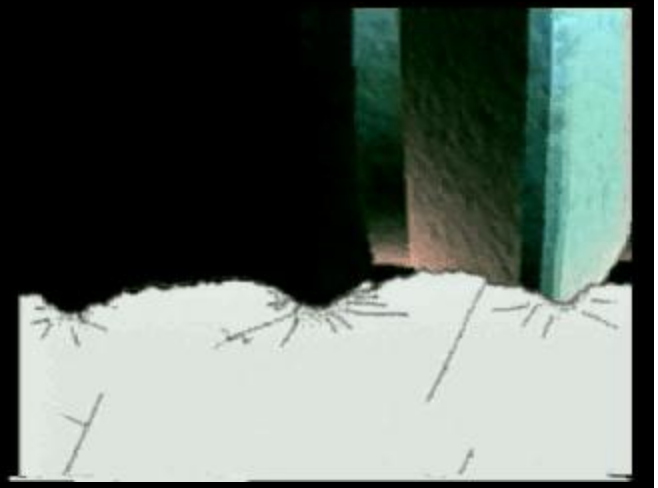
Completed Pressure Tunnel

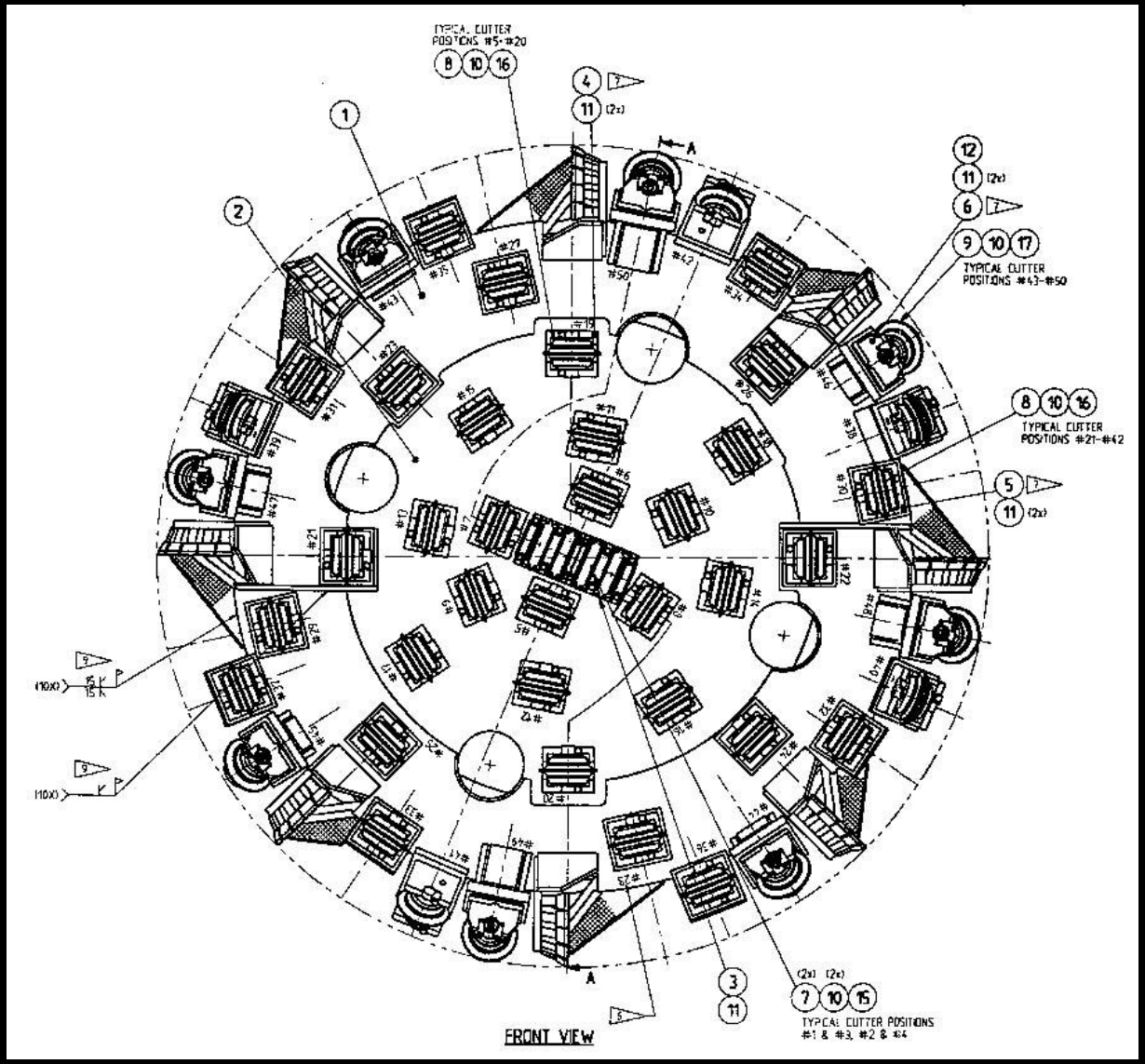

TBM-Bored Tunnel

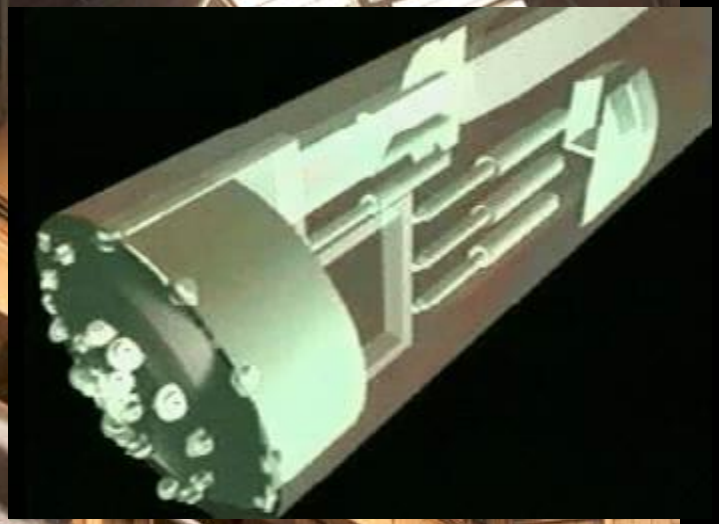
TBM Tunneling


CONTRACT 543B SHEET 1
SHEETS IN SET, 19
18B
19B
20B
21B
22B
23B
17B
16B
543B
CONTRACT
PROSPECT PARK
ROOSEVELT IS.
EAST RIVER
GOVERNORS IS.
UPPER BAY
MANHATTAN
STAGE 2
CENTRAL PARK
CITY TUNNEL
HUDSON RIVER
NEW JERSEY
N.I.C. = Not in Contract 543B
City of New York
DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF ENVIRONMENTAL ENGINEERING
CITY TUNNEL NO.3, STAGE 2
LOCALITY MAP - CONTRACT 543B
2000 0 2000 4000FT
SEPTEMBER 30, 1992

TBM Chip Production





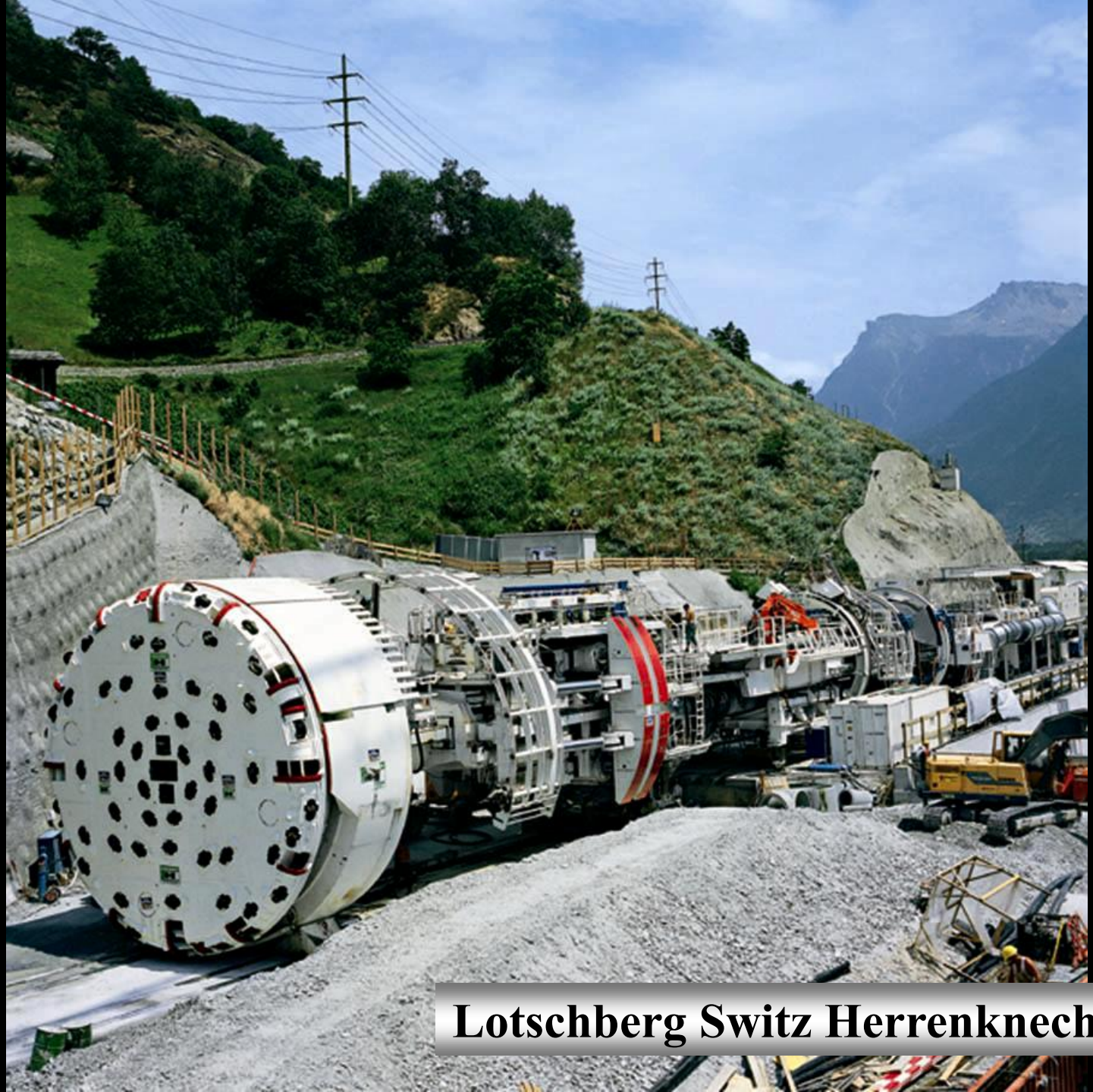


Atlas Copco

Robbins TBM 160-284

MetroWest

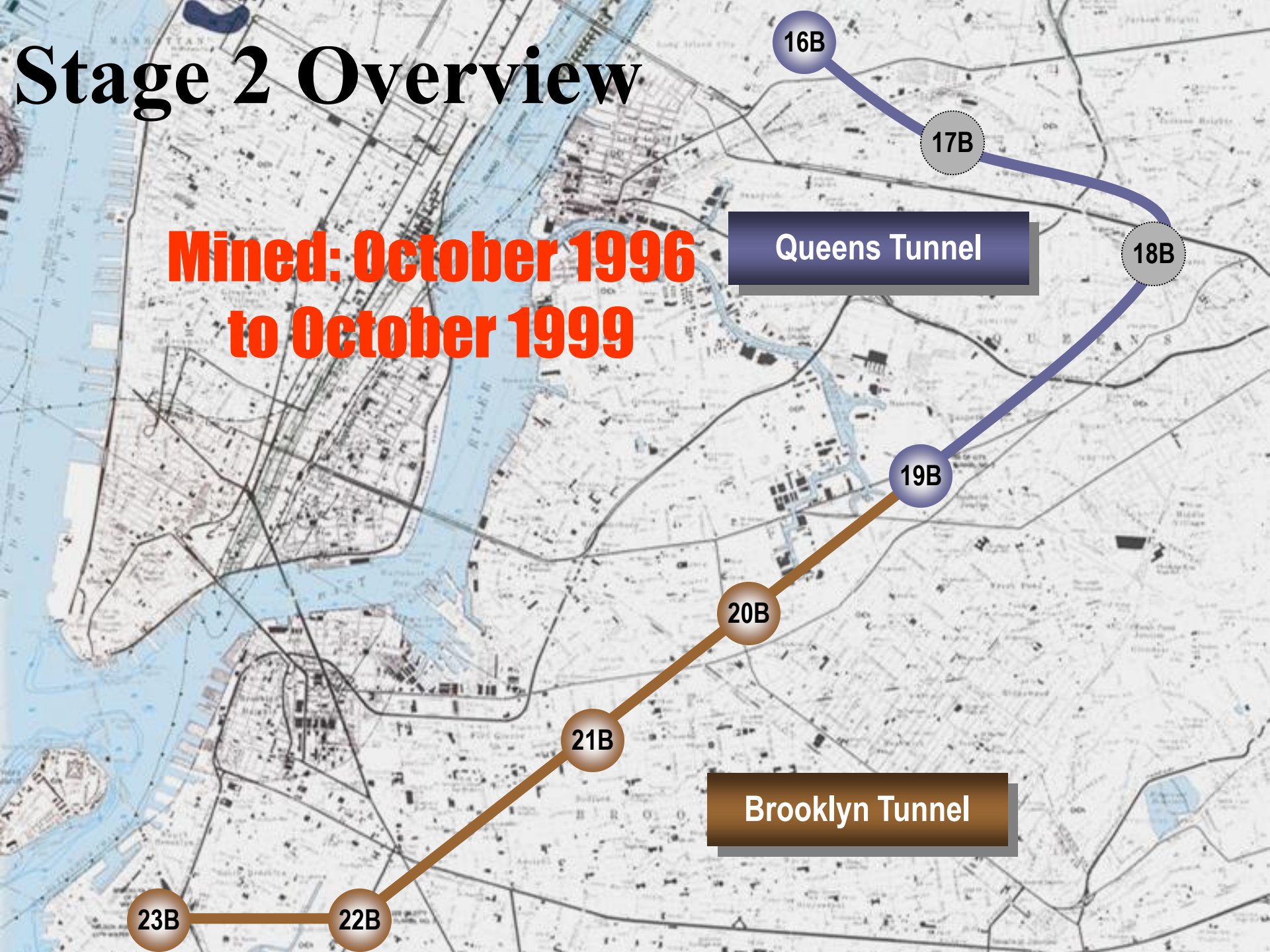
Kerf Pattern in Hard Rock

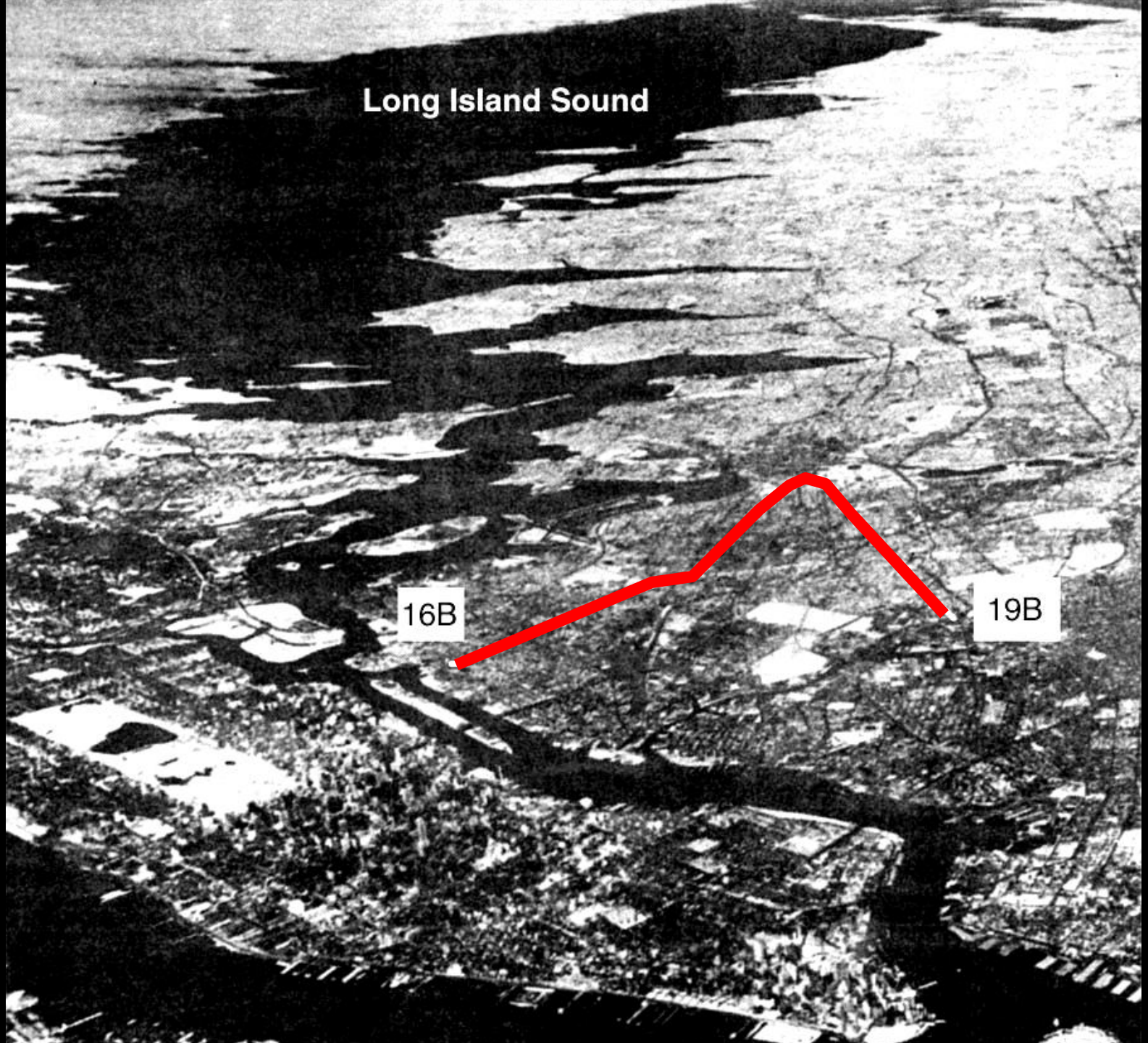


Lotschberg Switz Herrenknecht TBM


Jarva MK 15-52b

Stage 2 Overview




Long Island Sound
16B
19B

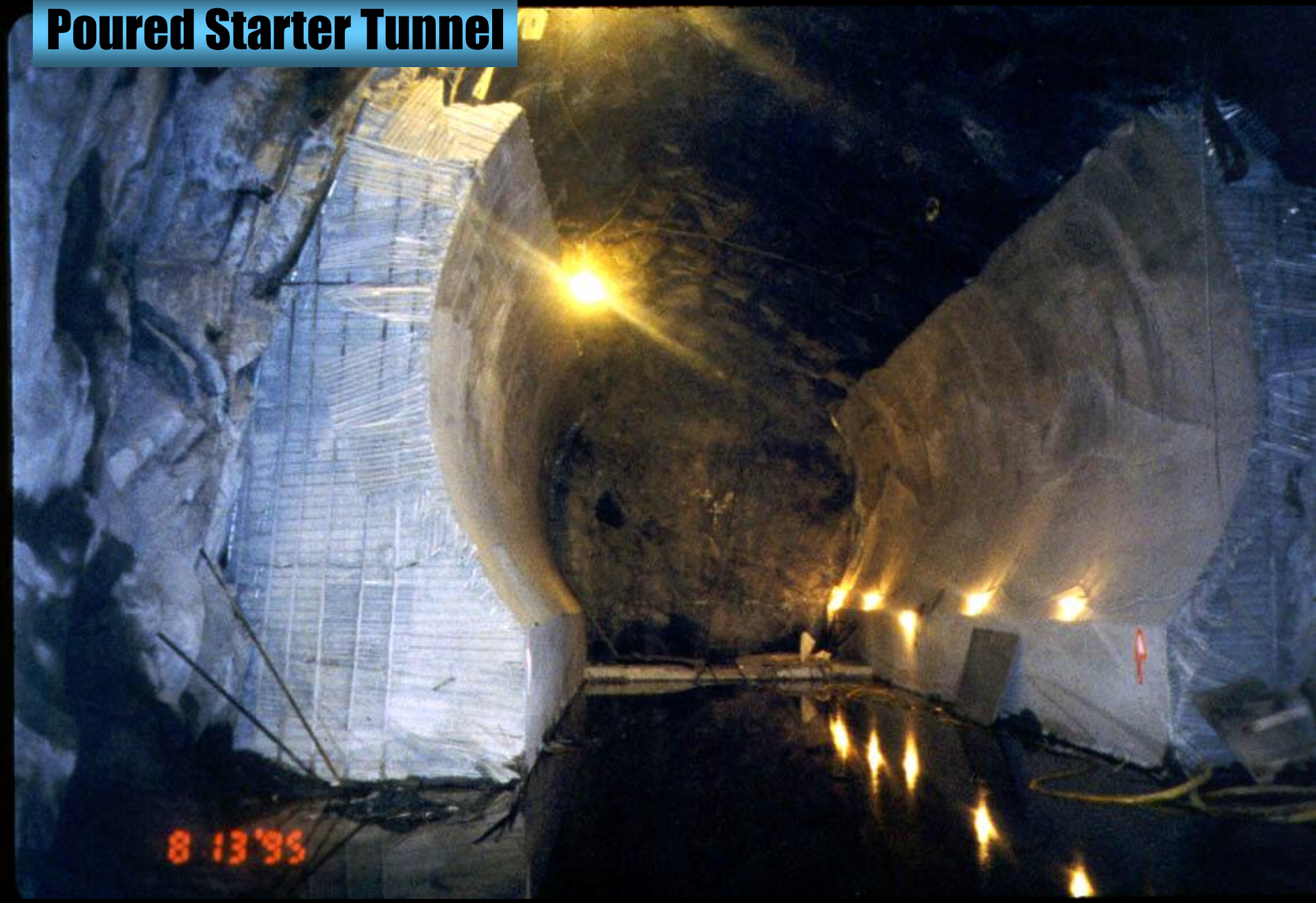
In the Belly of the Beast

Lowering TBM Mainbeam

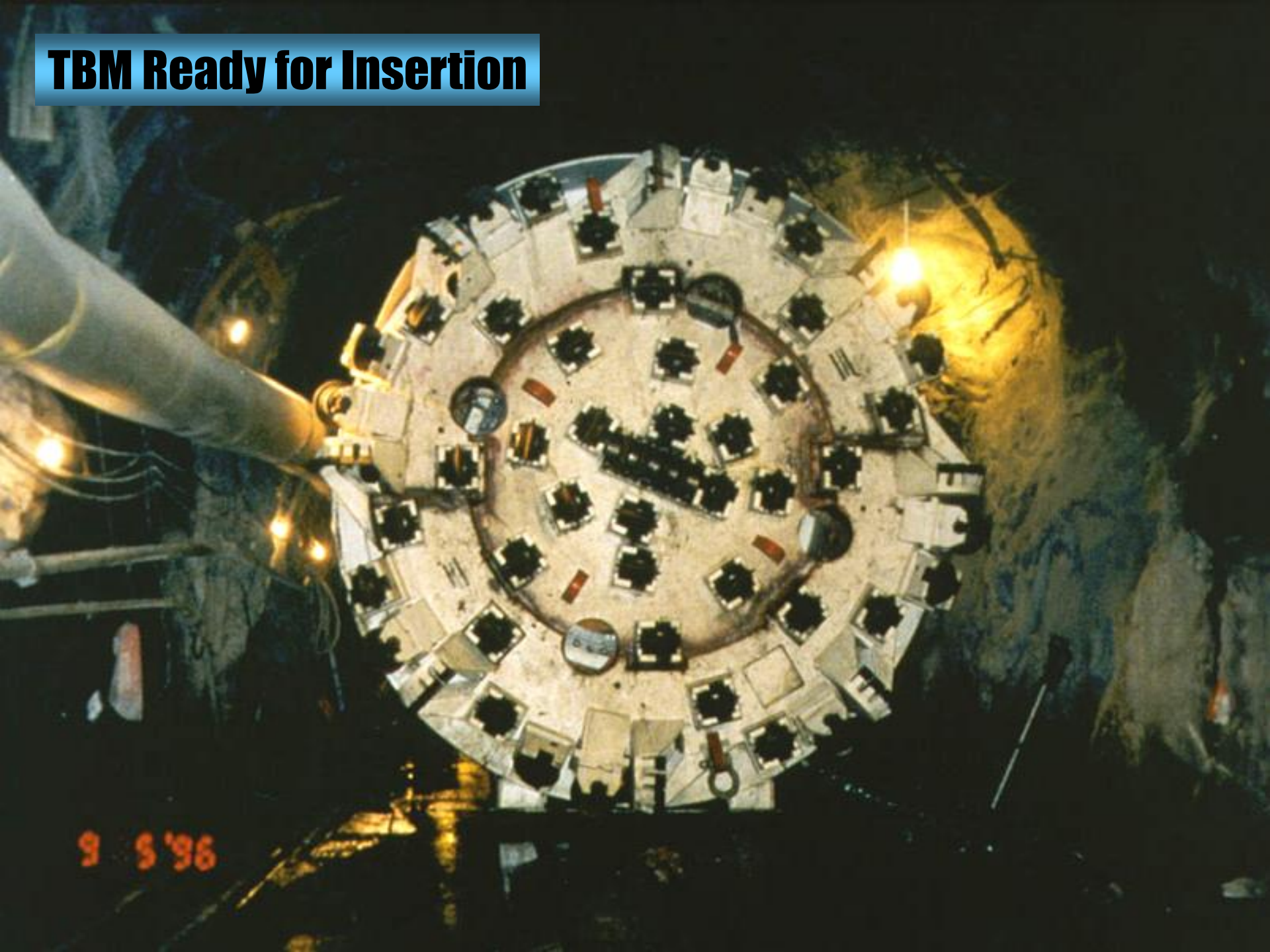
Flipping TBM Cutterhead

Lowering TBM Cutterhead

Poured Starter Tunnel



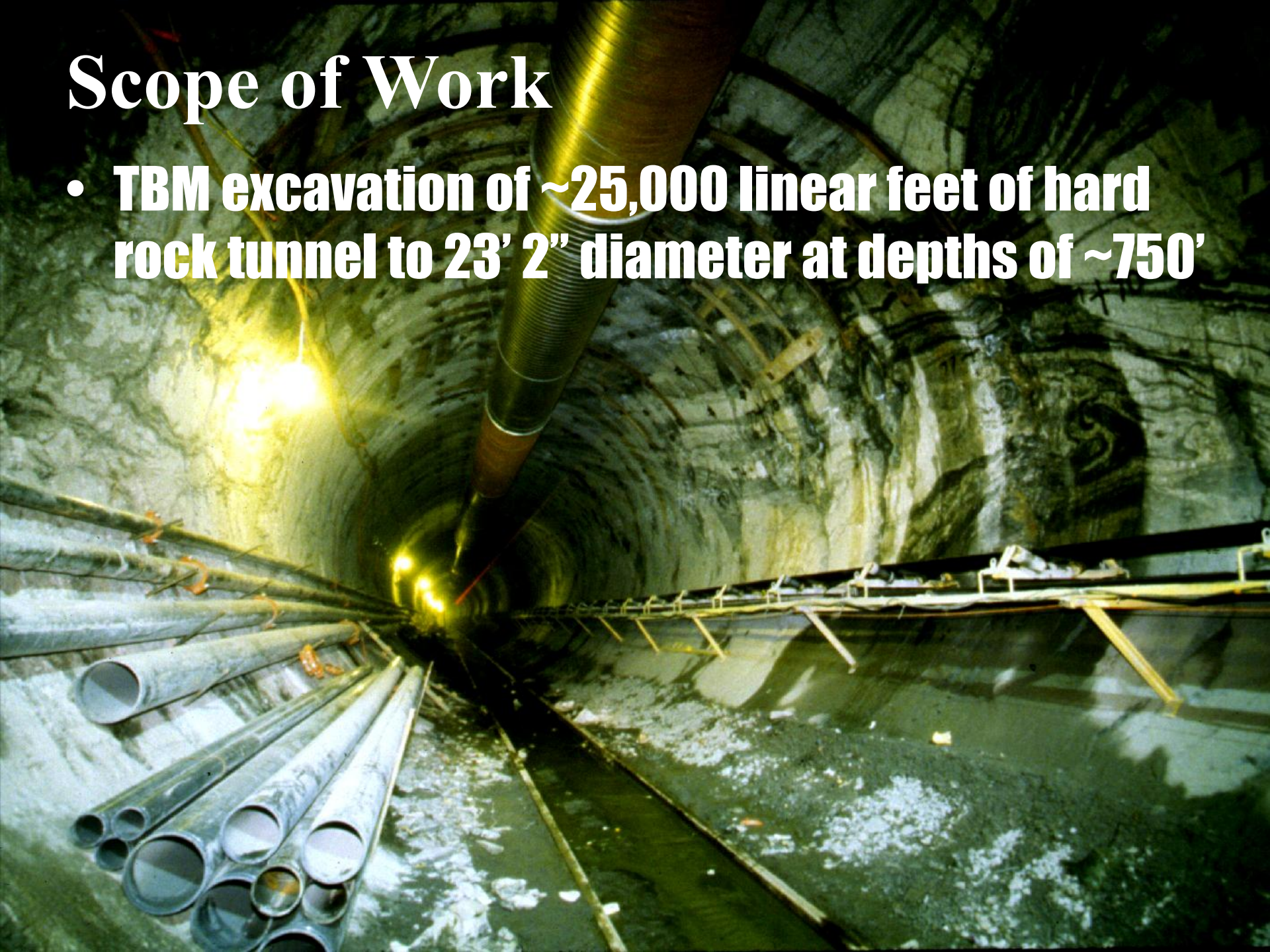
TBM Ready for Insertion



October 1999

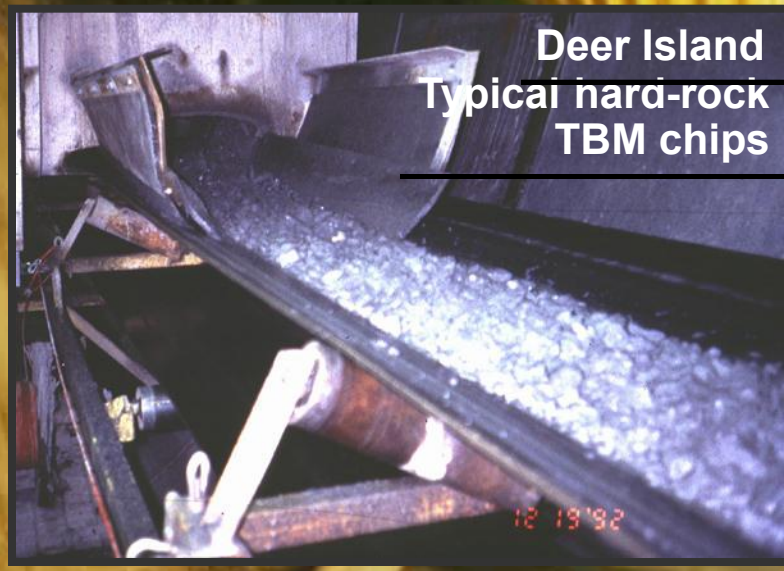
Scope of Work

- TBM excavation of ~25,000 linear feet of hard rock tunnel to 23’ 2” diameter at depths of ~750’



Excessive Fines

Blocky Ground



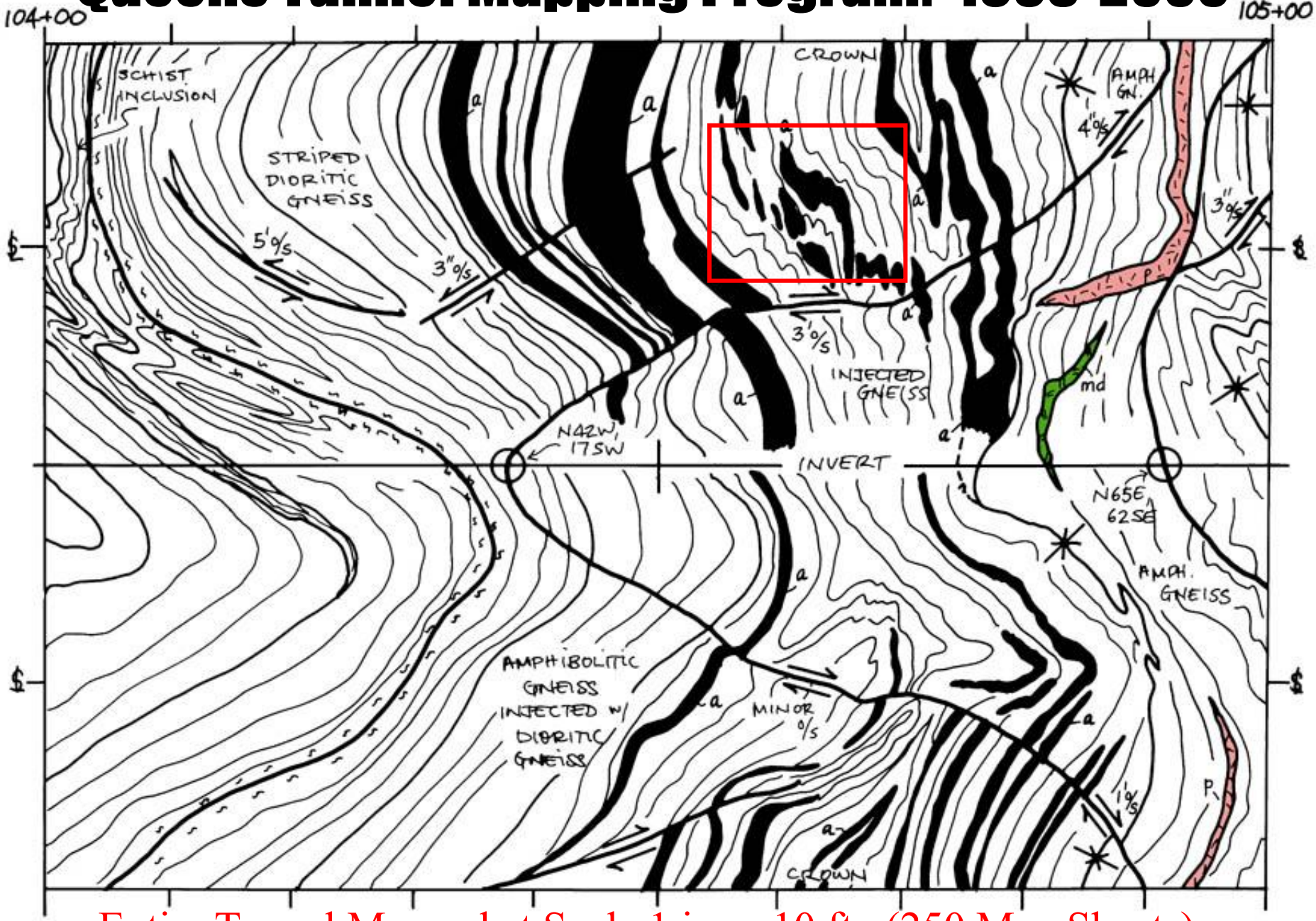
Short Stand-up Times

Anticipated vs. Actual Penetration Rate

Hartland is Micaceous, Well Foliated and Well Layered


Pegmatite?
Garnet?
Hartland?
Schist?
Gneiss?
Hartland ?
Fordham?

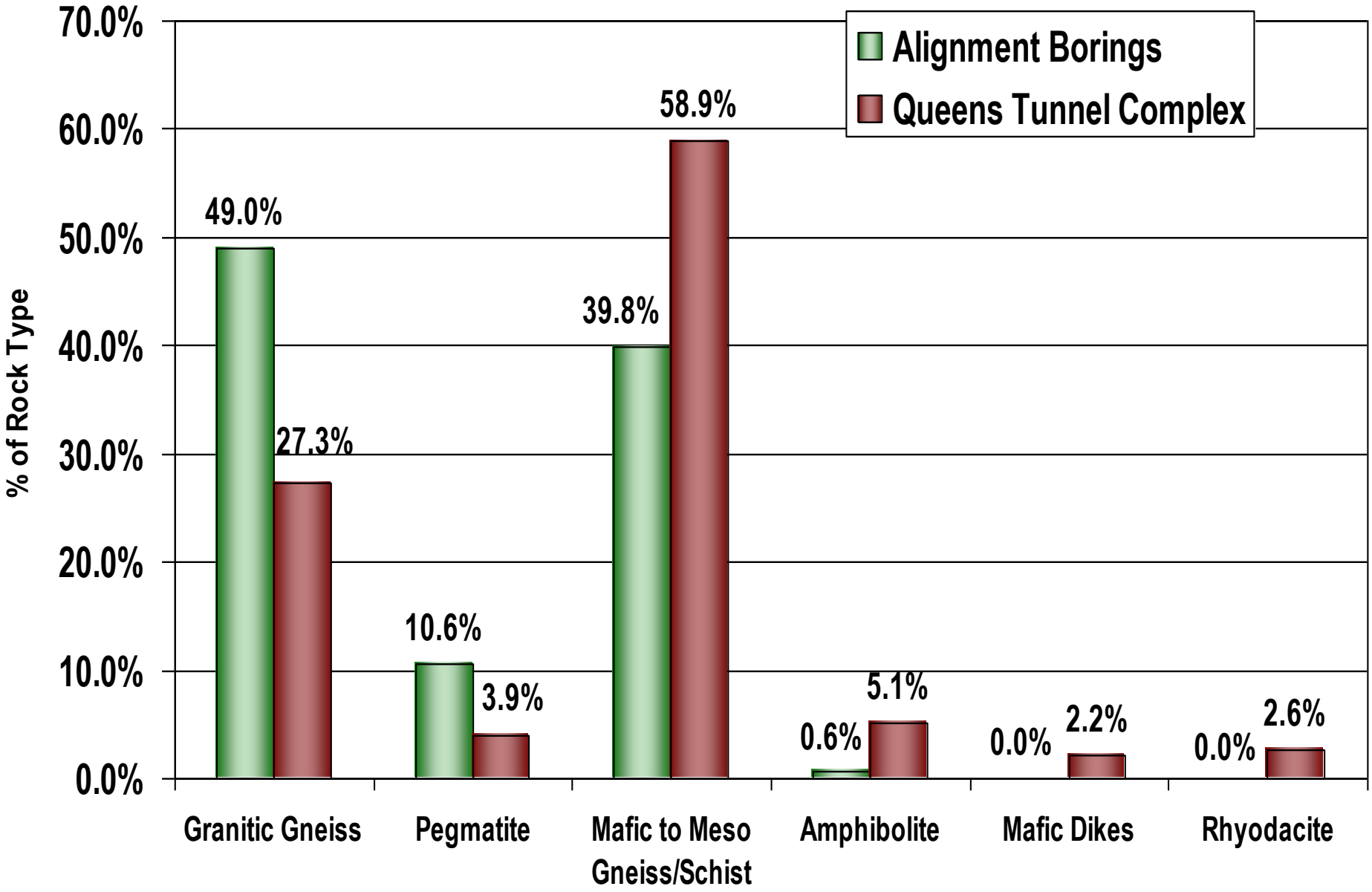
Queens Tunnel Mapping Program: 1998-2000

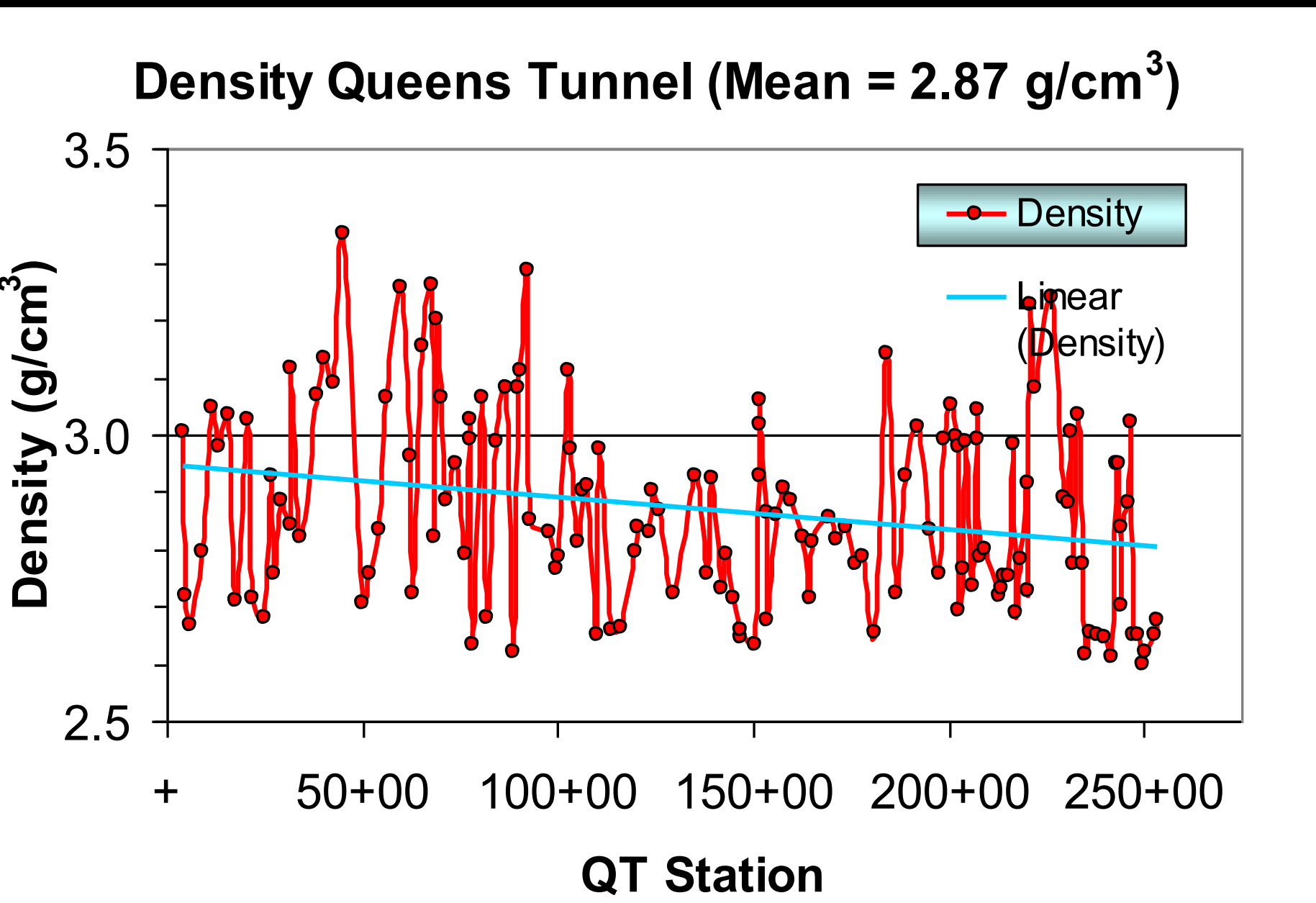


Entire Tunnel Mapped at Scale 1 in. = 10 ft. (250 Map Sheets)


104+55
104+60
104+65

Comparative Lithologic Analysis




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

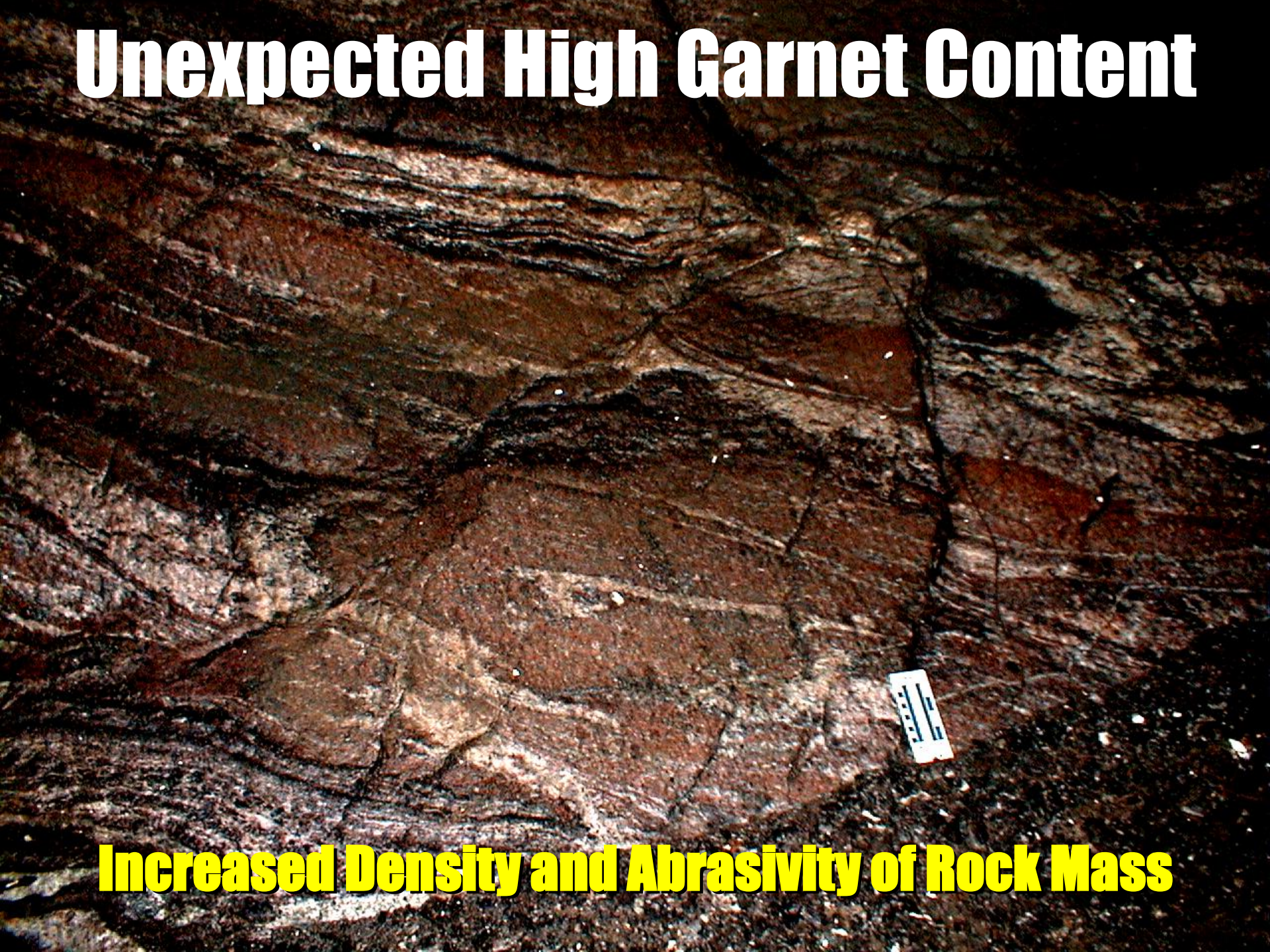
Density Analysis

	Low	High	Mean Density
Granite	2.516	2.809	2.667
Diorite	2.721	2.960	2.839
Gabbro	2.850	3.120	2.976

QT Mean = 2.87 (Dioritic Rock Mass)

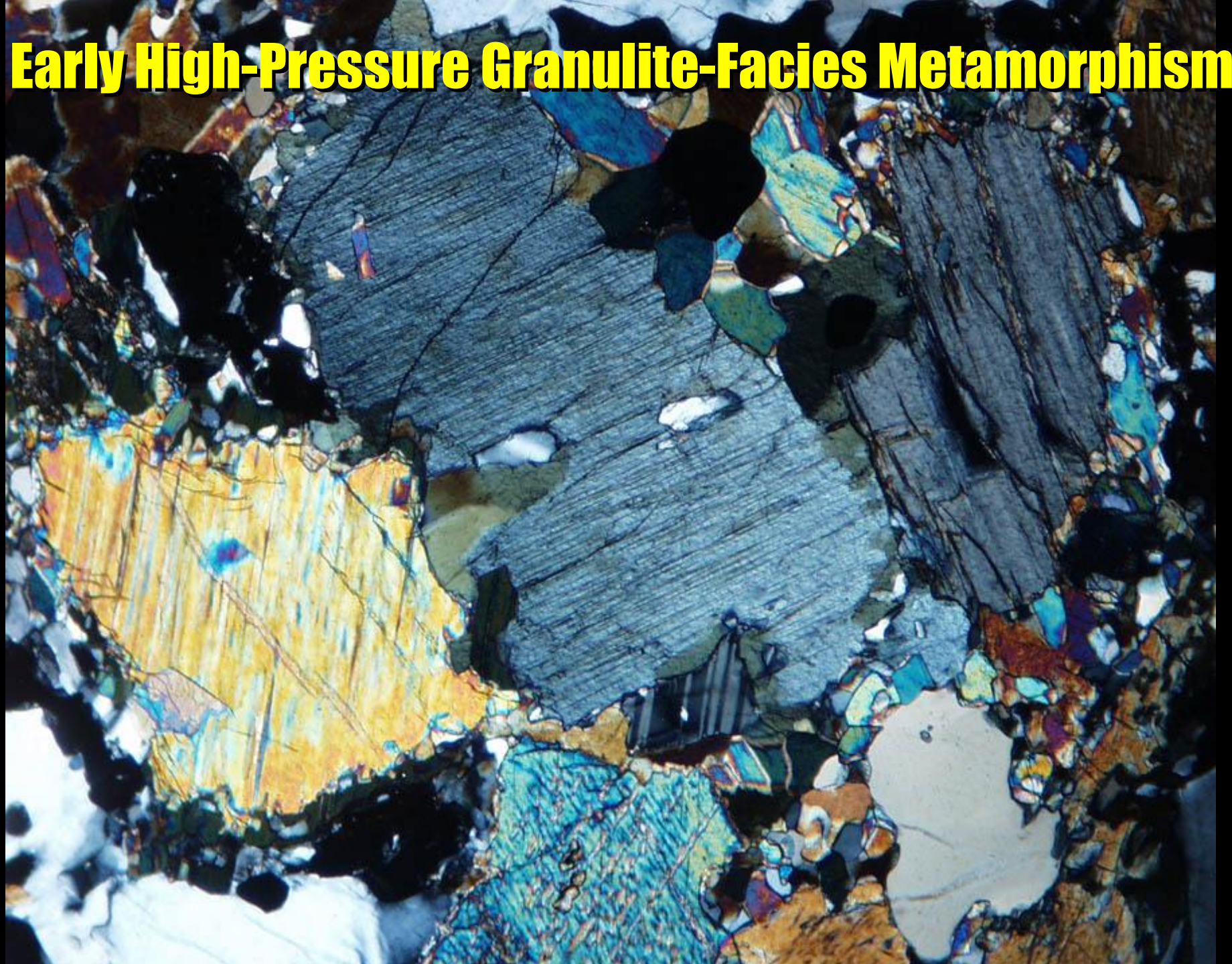
From: Clark (1966, p. 20)

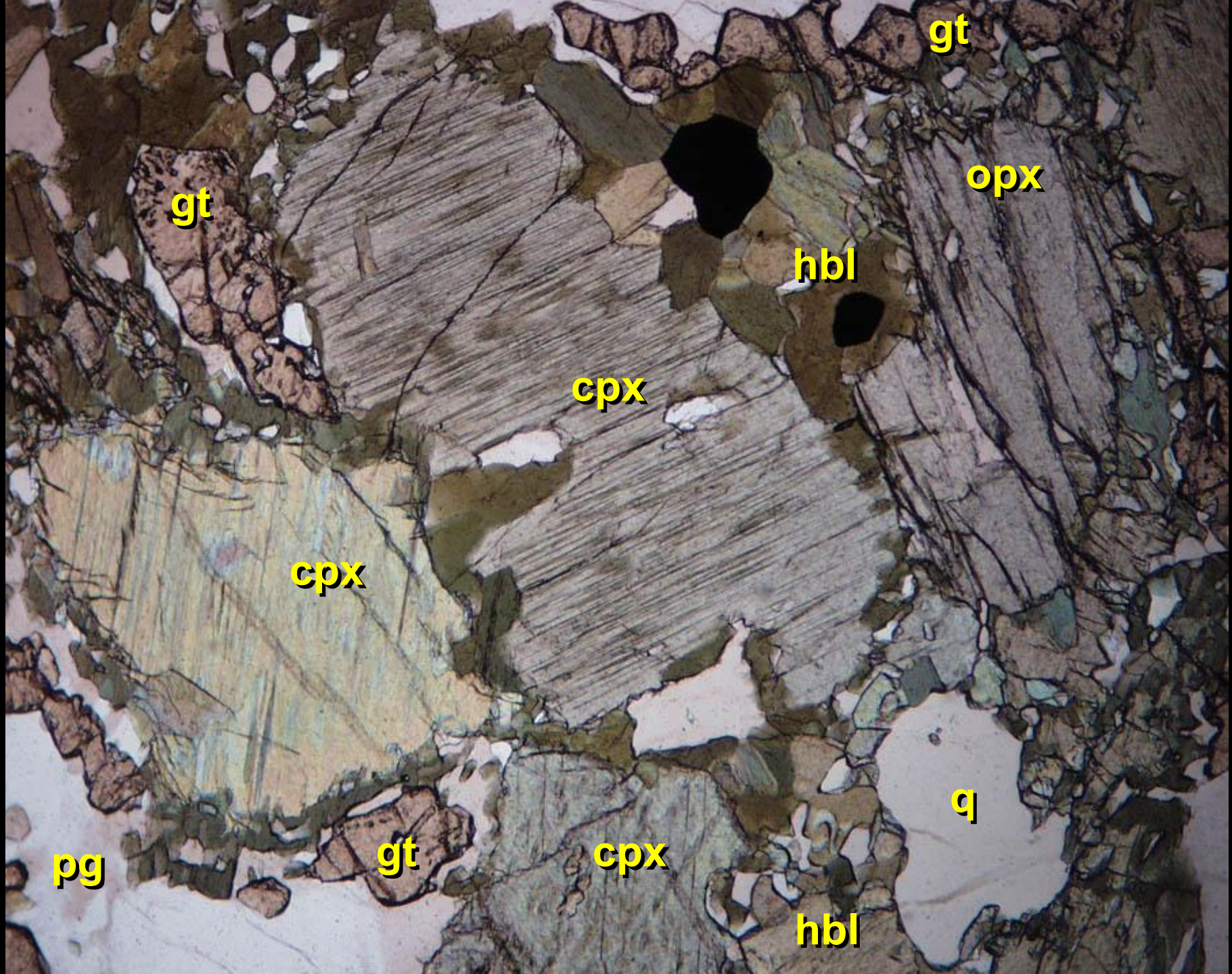
Unexpected High Garnet Content



Increased Density and Abrasivity of Rock Mass

Early High-Pressure Granulite-Facies Metamorphism




gt
opx
gt
hbl
cpx
cpx
q
pg
gt
cpx
hbl

Early M_1 Garnet

Produced during initial (M_1) high-grade metamorphism of Queens Tunnel Plutonic Complex

Coarse- grained and inclusion free with orangey cast

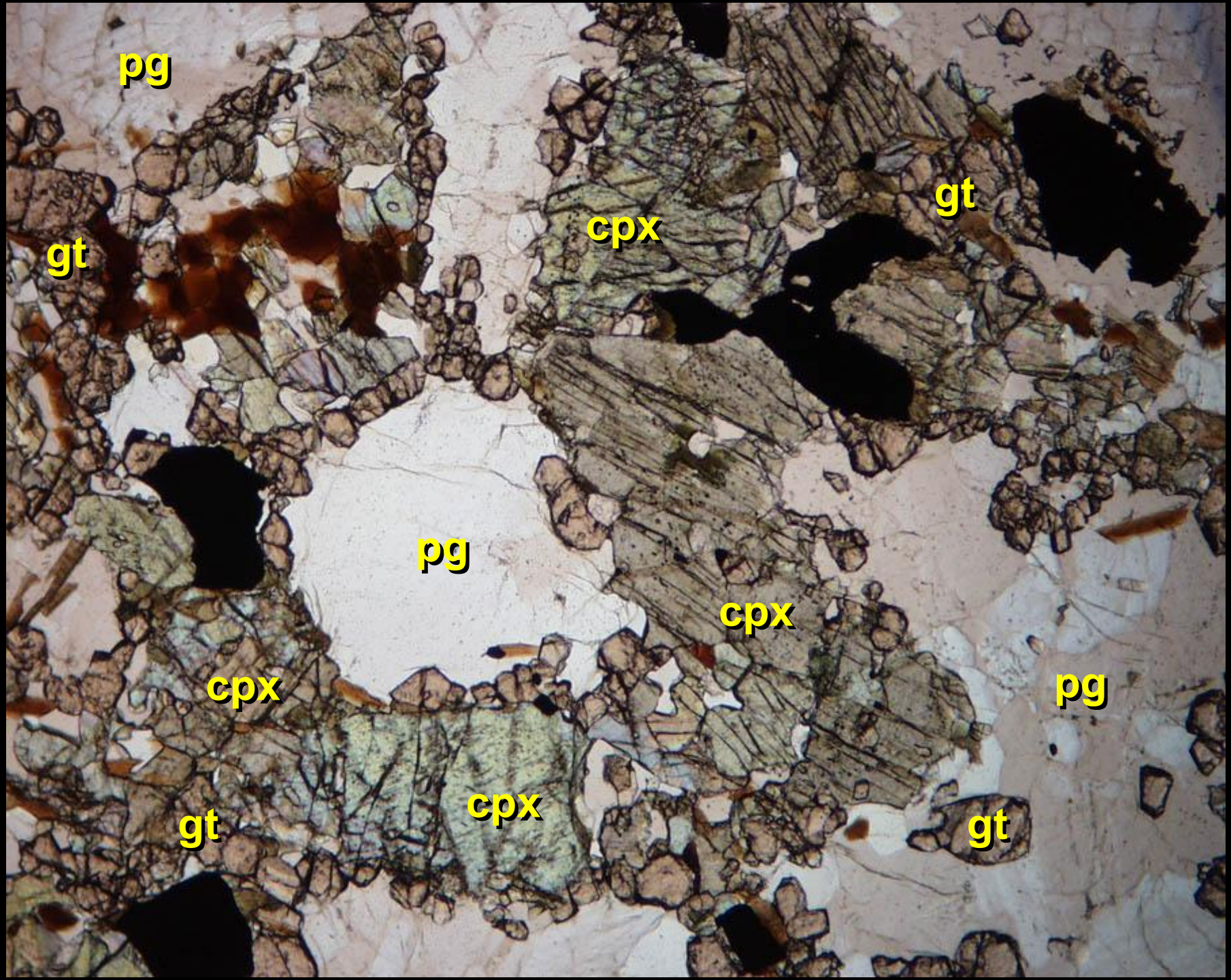
Intergrown with clino- and orthopyroxenes

Secondary M_2 Garnet

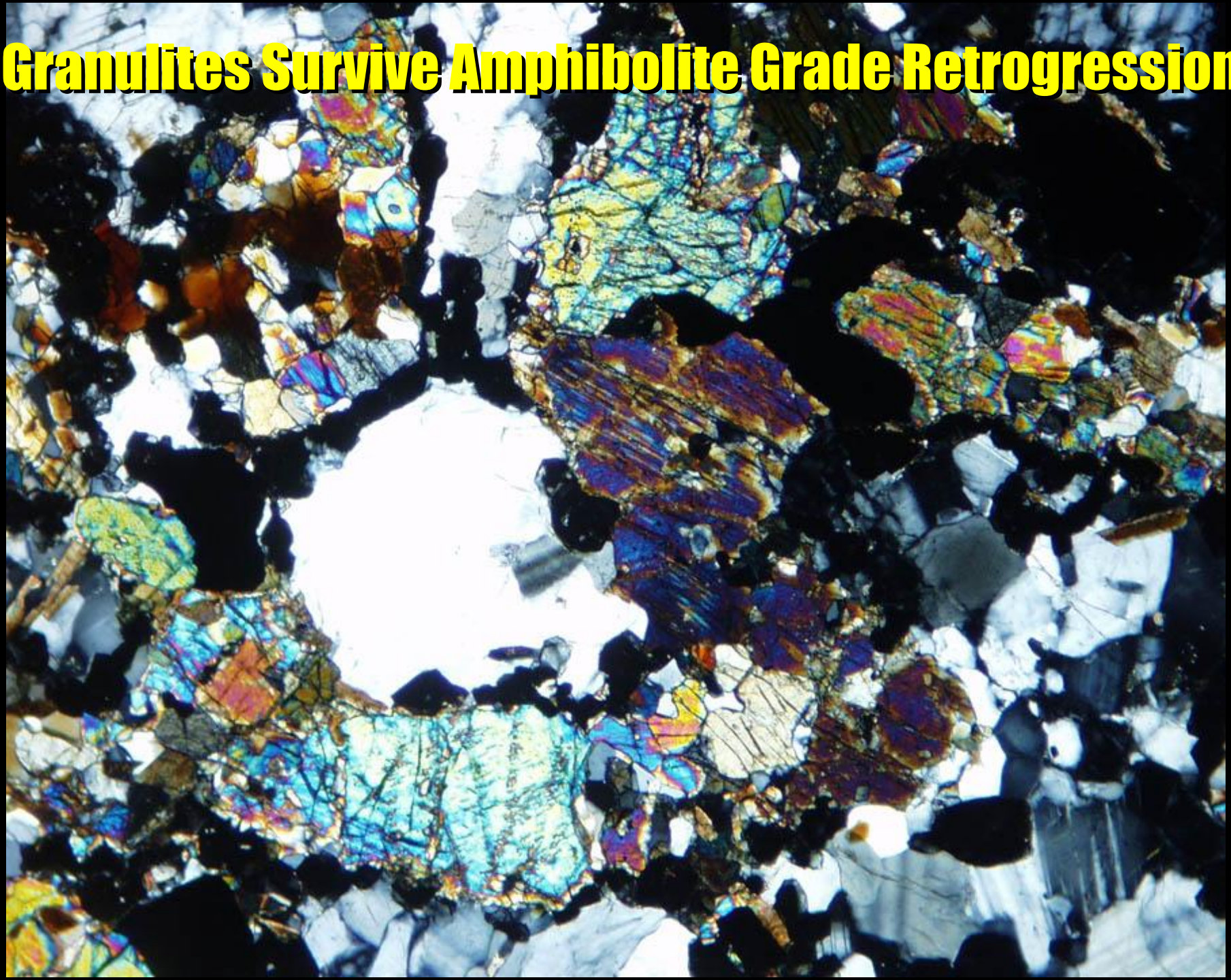
Finer- grained and pale-pink in color

Poikiloblastic habit with abundant inclusions

Forms symplectic rims around plagioclase and pyroxene

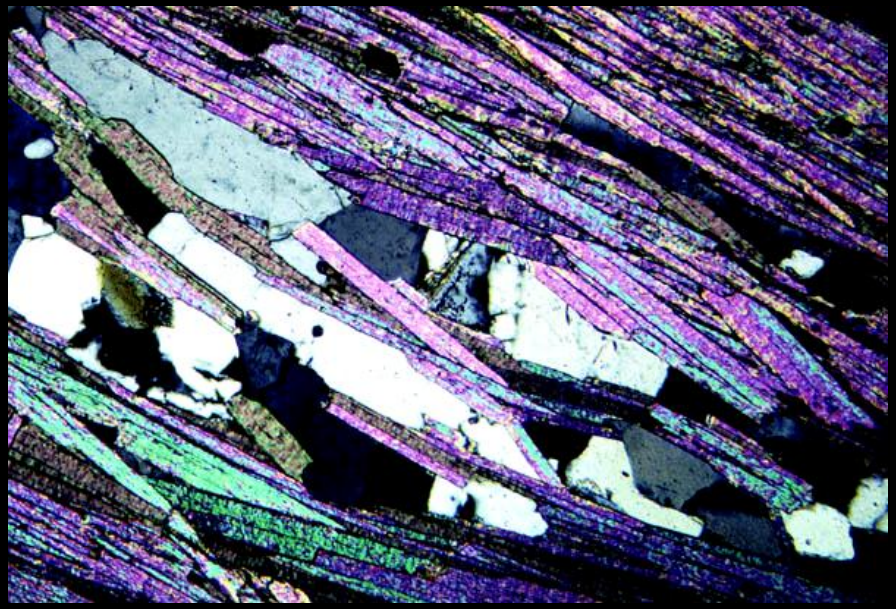

pg
gt
cpx
gt
pg
cpx
cpx
pg
gt
cpx
gt

Granulites Survive Amphibolite Grade Retrogression

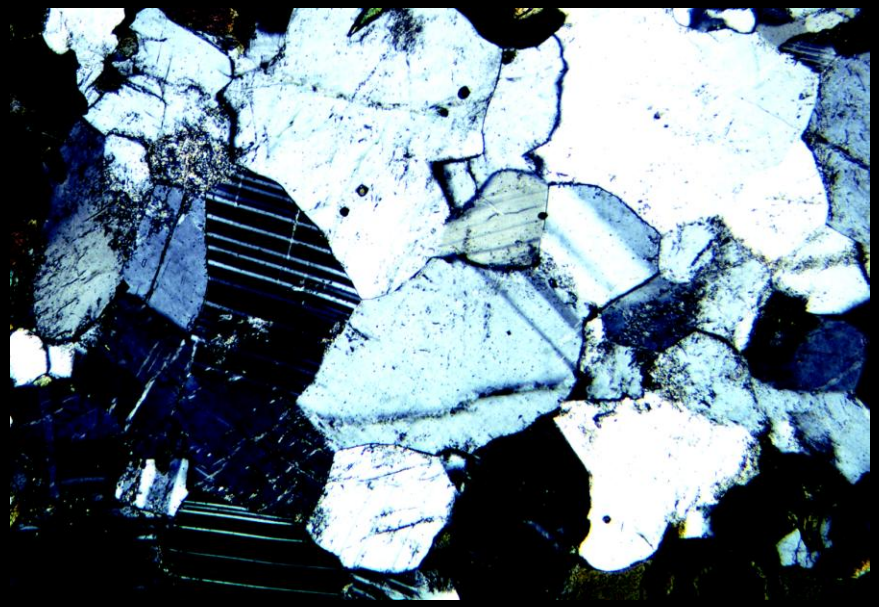


Hartland vs. Fordham Rock Fabric

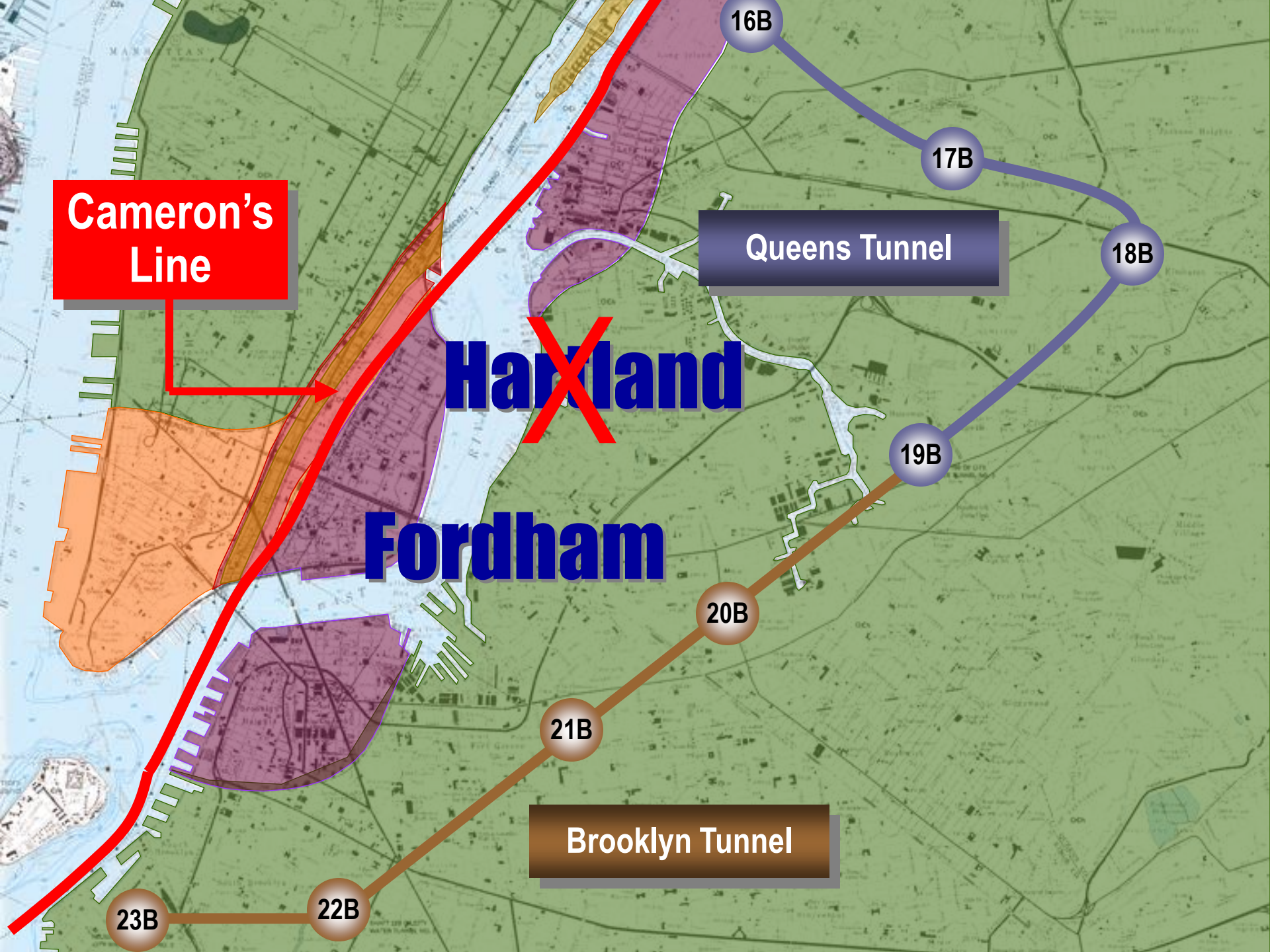
- Micaceous (+/- hornblende) penetrative foliation anticipated
  - Based on boring logs, pre-bid reports
- Weakly to non-foliated "granoblastic" rock mass found

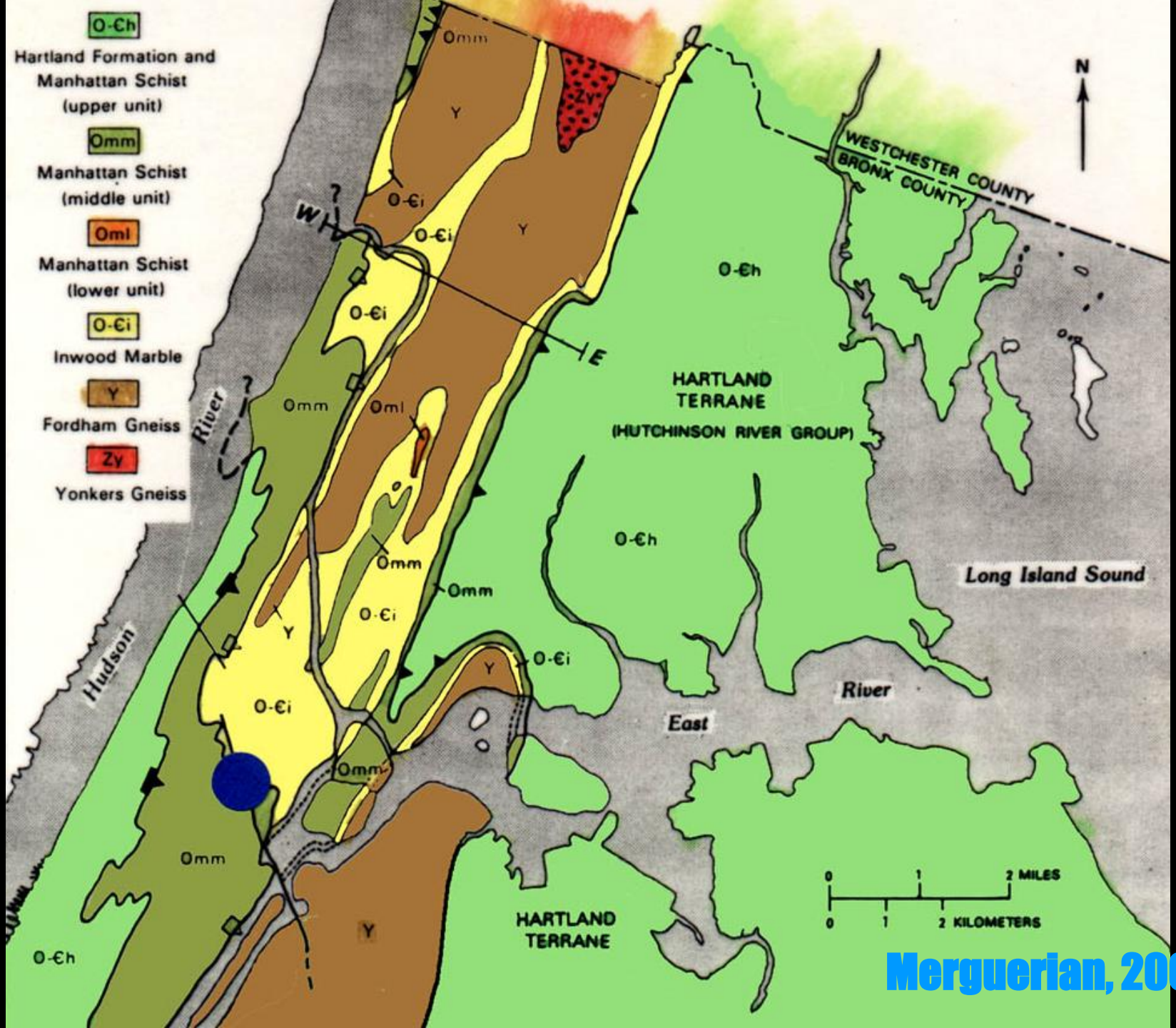


Typical Hartland

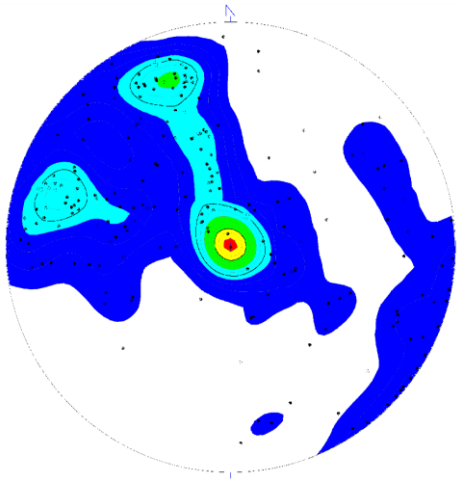


Typical Fordham


Cameron's Line
Harland
Fordham
16B
17B
18B
19B
20B
21B
22B
23B
Queens Tunnel
Brooklyn Tunnel


O-Ch
Hartland Formation and Manhattan Schist (upper unit)
Omm
Manhattan Schist (middle unit)
Oml
Manhattan Schist (lower unit)
O-Ci
Inwood Marble
Y
Fordham Gneiss
Zy
Yonkers Gneiss
N
WESTCHESTER COUNTY
BRONX COUNTY
HARTLAND TERRANE
(HUTCHINSON RIVER GROUP)
HARTLAND TERRANE
Long Island Sound
Hudson River
East River
W
E
0 1 2 MILES
0 1 2 KILOMETERS
Merguerian, 2002

Orientation of Rock Layering



NE strike and moderate 57 degree dip anticipated

- **[Based on borings, Chesman, Tarkoy]**

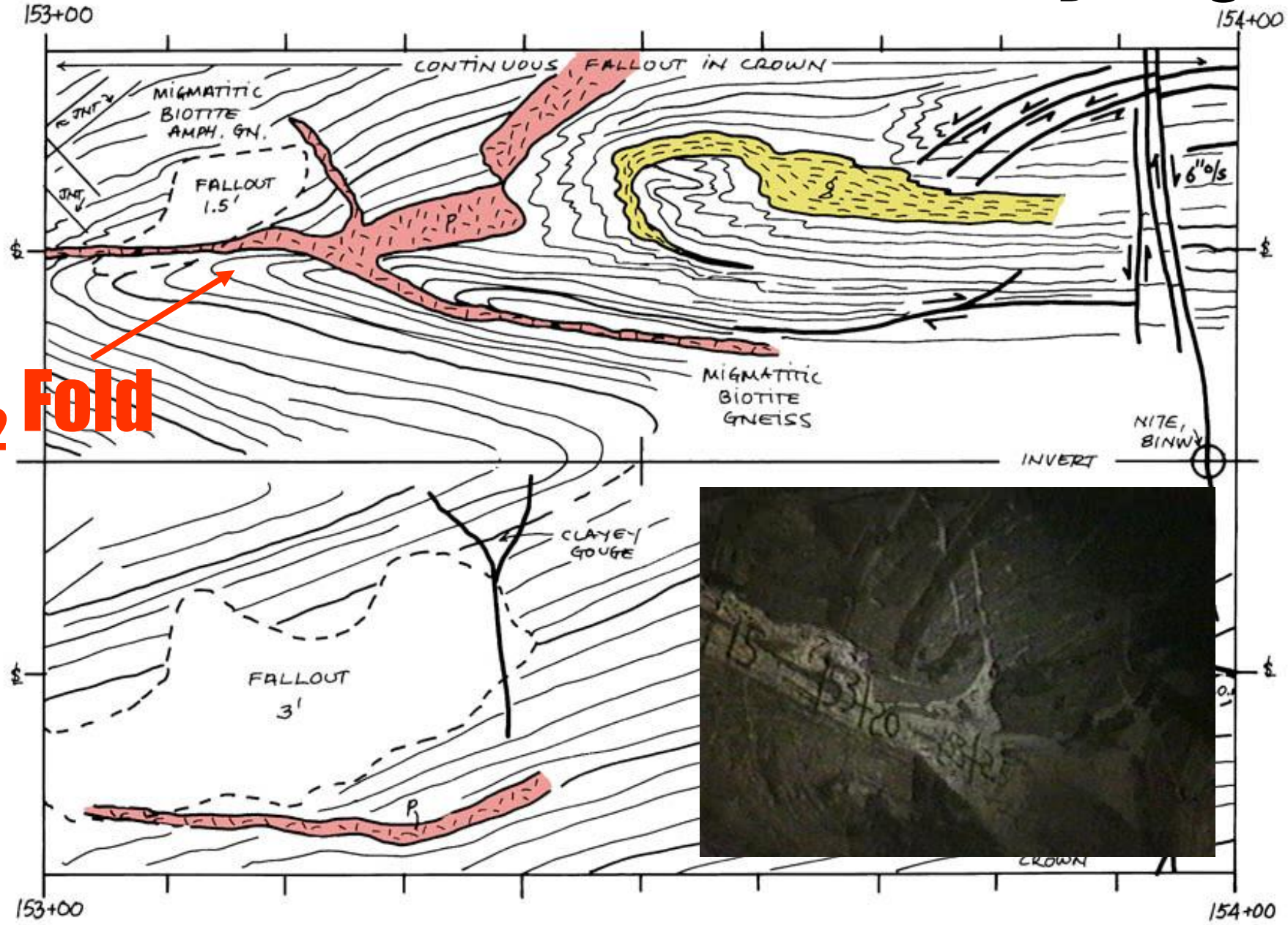
Highly variable trends found

- **Extended reaches of tunnel exhibit gentle dips**

Only one boring (QTL-12) exhibited gentle dips at tunnel horizon

		NE Leg		NW Leg	
Gentle Dips		17/93	18%	44/139	32%
Moderate Dips		34/93	37%	28/139	20%
Steep Dips		42/93	45%	67/139	48%

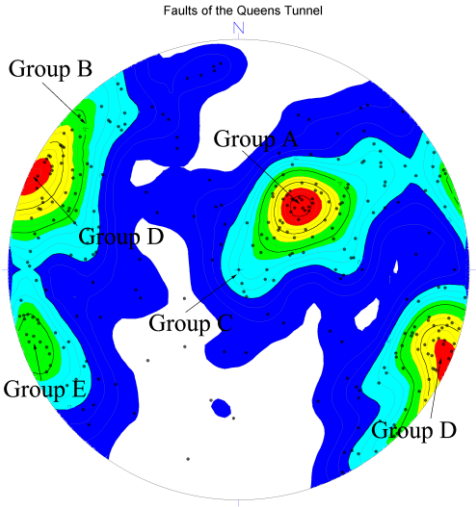
Fallout from Reclined Folds and Flat Layering



F_2 Fold

Brittle Faults

- Hundreds of faults mapped in five major groups
- From oldest to youngest:



Group A = NW strike and gentle SW dip

Group B = ENE strike and steep dips

Group C = Subhorizontal fractures, faults, and shears

Group D = NNE-trending fault system (hitherto unknown)

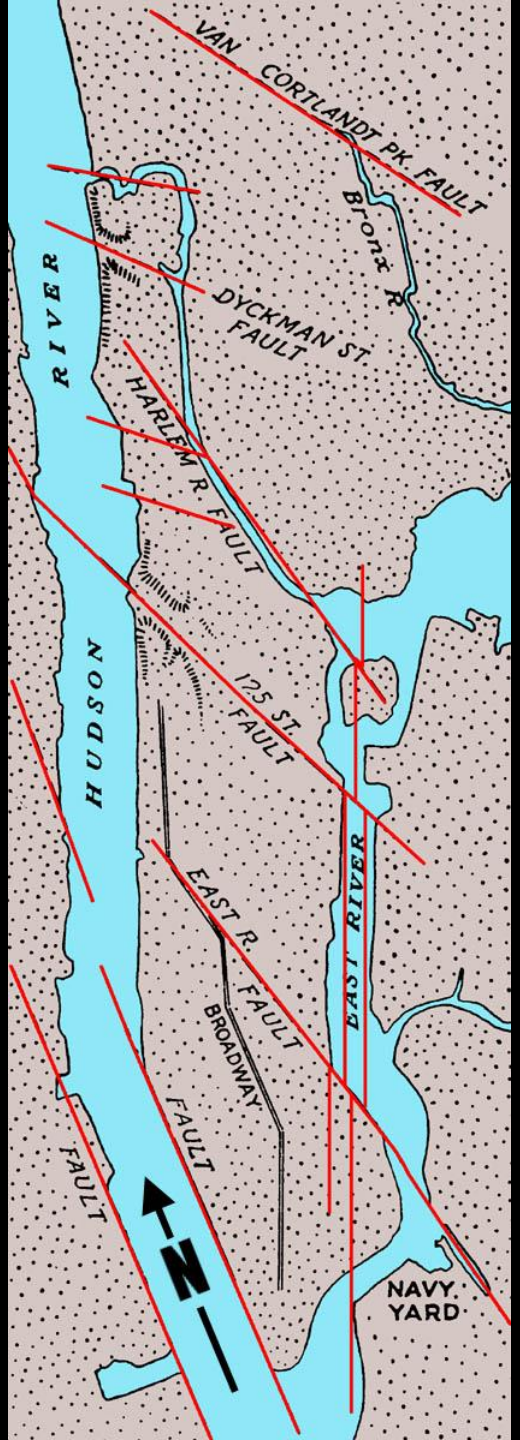
Group E = NNW-trending “Manhattanville” fault system

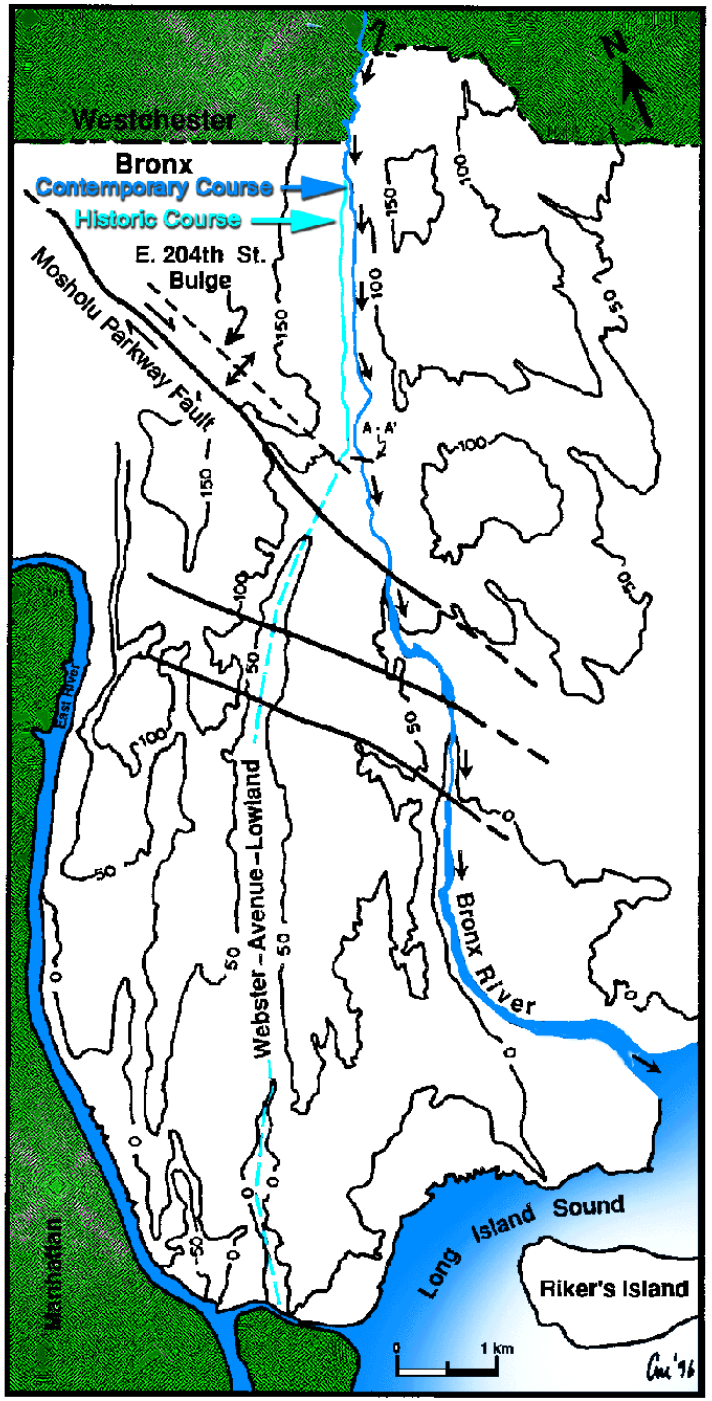

NW-Trending Fault Cut by NNE Fault
8' Gouge
214+25
214+30
214+40
Queens Tunnel Sta. 214+25

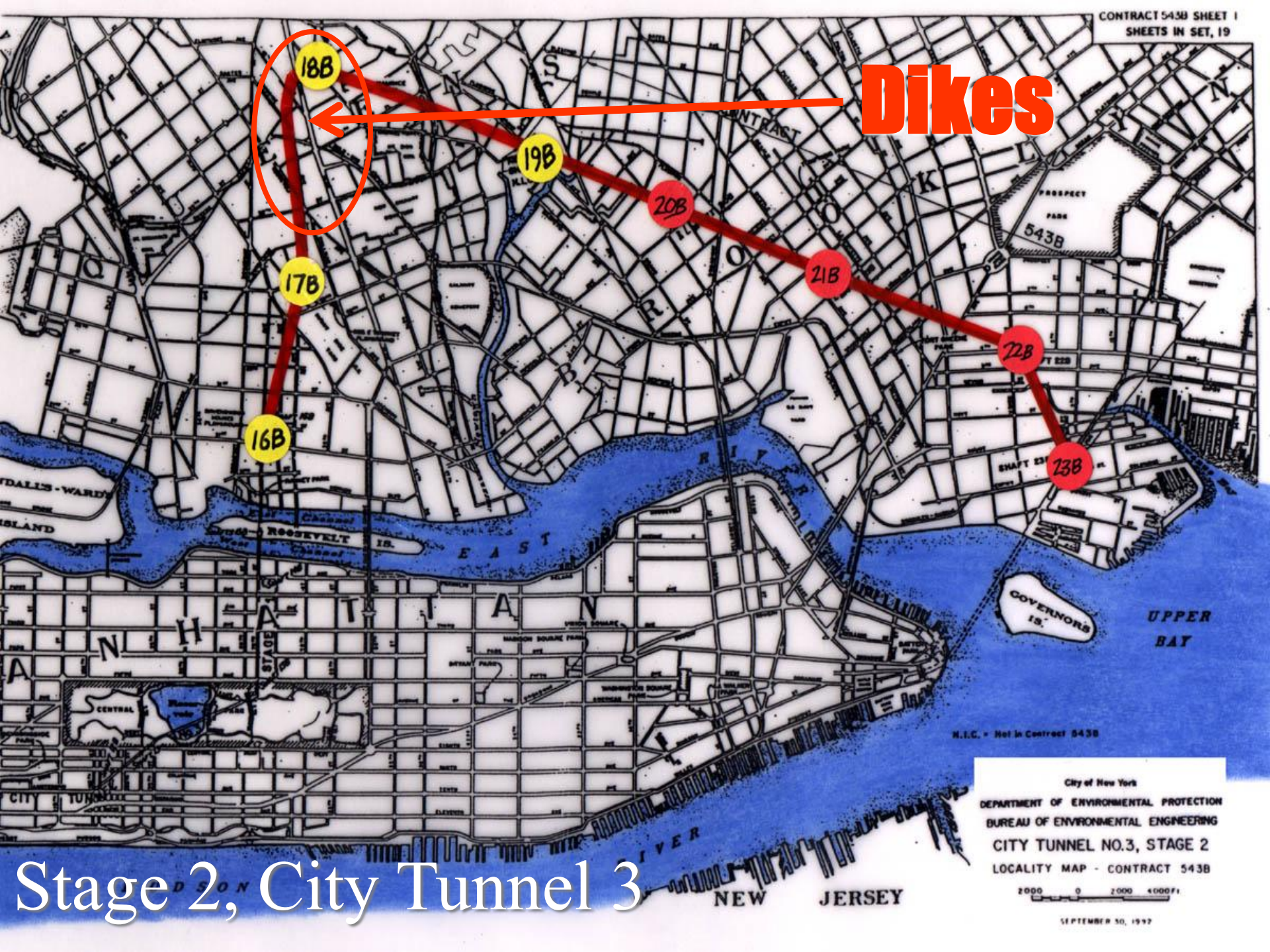
Gently Dipping NW-Trending Fault

Queens Tunnel Sta. 196+85

Fallout from Intersecting Joints and Layering


VAN CORTLANDT PK. FAULT
Bronx R.
DYCKMAN ST. FAULT
HARLEM R. FAULT
125 ST. FAULT
EAST R. FAULT
BROADWAY FAULT
FAULT
HUDSON RIVER
EAST RIVER
NAVY YARD
N


Westchester
Bronx
Contemporary Course
Historic Course
E. 204th St. Bulge
Mosholu Parkway Fault
A
A'
Webster-Avenue-Lowland
East River
Bronx River
Manhattan
Long Island Sound
Riker's Island
1 km
'96

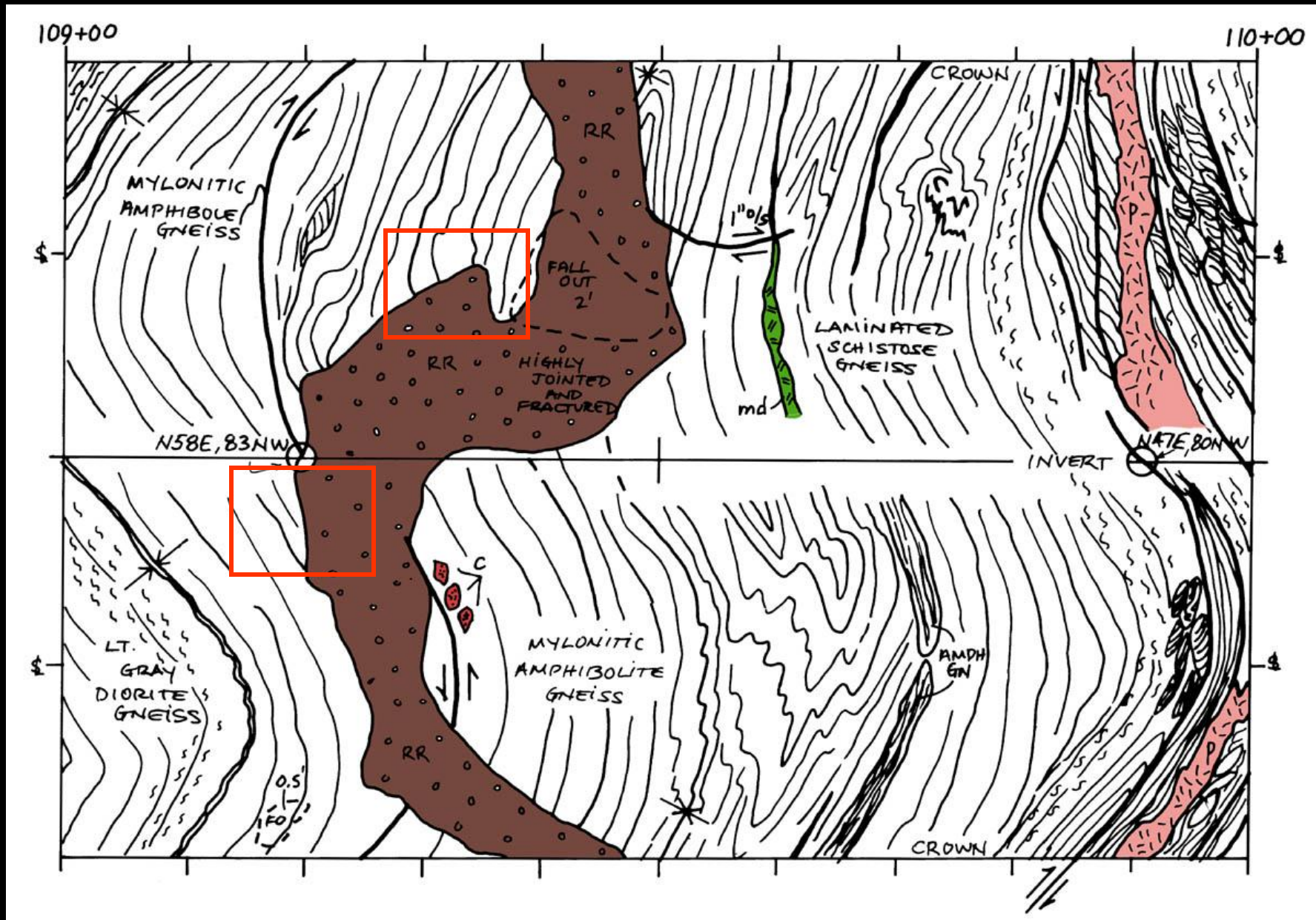


Stage 2, City Tunnel 3

Five Laterally Extensive Dikes

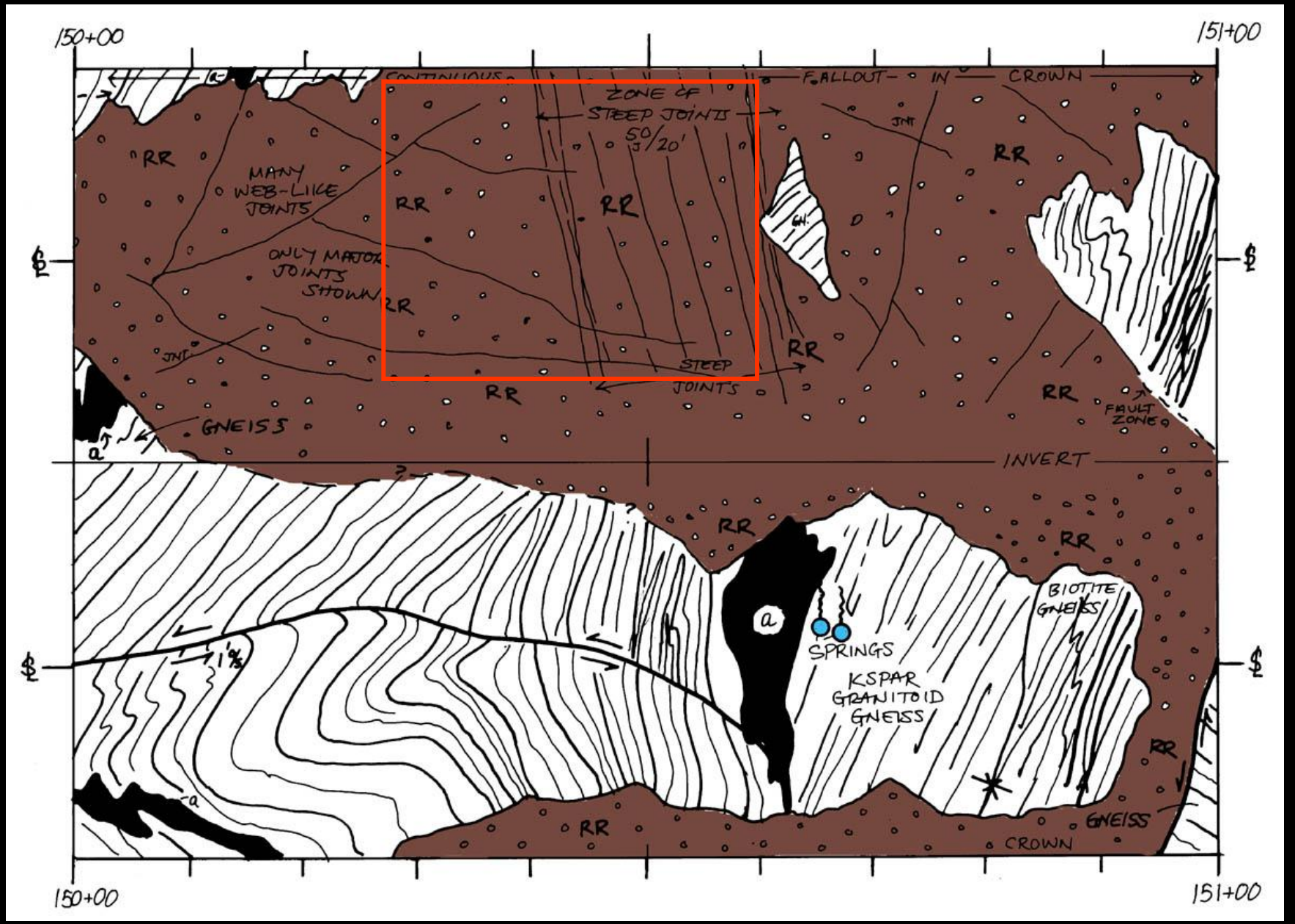
	Stationing	Orientation	Exposed Length	Thick-ness	Brief Comments
1	109+20 - 109+52	N65°W, 57°NE	32'	12'	cuts N58°E, 83°NW normal fault
2	117+58 - 118+24	? - RW Only	66'	>8'	cuts N52°E, 76°NW normal fault and shear zone
3	128+70 - 129+21	? - LW Only	51‘	7'	cuts D_3 shear zone
	129+53 - 130+41	N48°W, 78°SW	88'	11'	cuts N20°E, 10°NW thrusts and older F_3 fold
4	131+70 - 132+42	? - LW Only	72‘	6'	cuts N30°W, 23°SW thrust fault
	132+40 - 132+56	? - RW Only	16‘	3'	thin selvage cuts thrust fault and shear zone
	132+58 - 133+62	N61°W, 81°NE	104'	5'-10'	cuts N44°E, 83°SE reverse shear zone; fractured
5	149+93 - 151+36	N52°W, 90°	143‘	16'	cut by N20°E, 70°NW normal fault; clay-rich gouge
	151+45 - 152+40	N40°W, 83°SW	95‘	14'	cut by N18°E, 70°NW normal fault; clay-rich gouge

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
LT. GRAY DIORITE GNEISS
C
MYLONITIC AMPHIBOLITE GNEISS
AMDH GN
RR
0.5'
FO
CROWN
P


Station 109+20, Right Wall
Cooling joints extend 10' into country rock

Dike 5

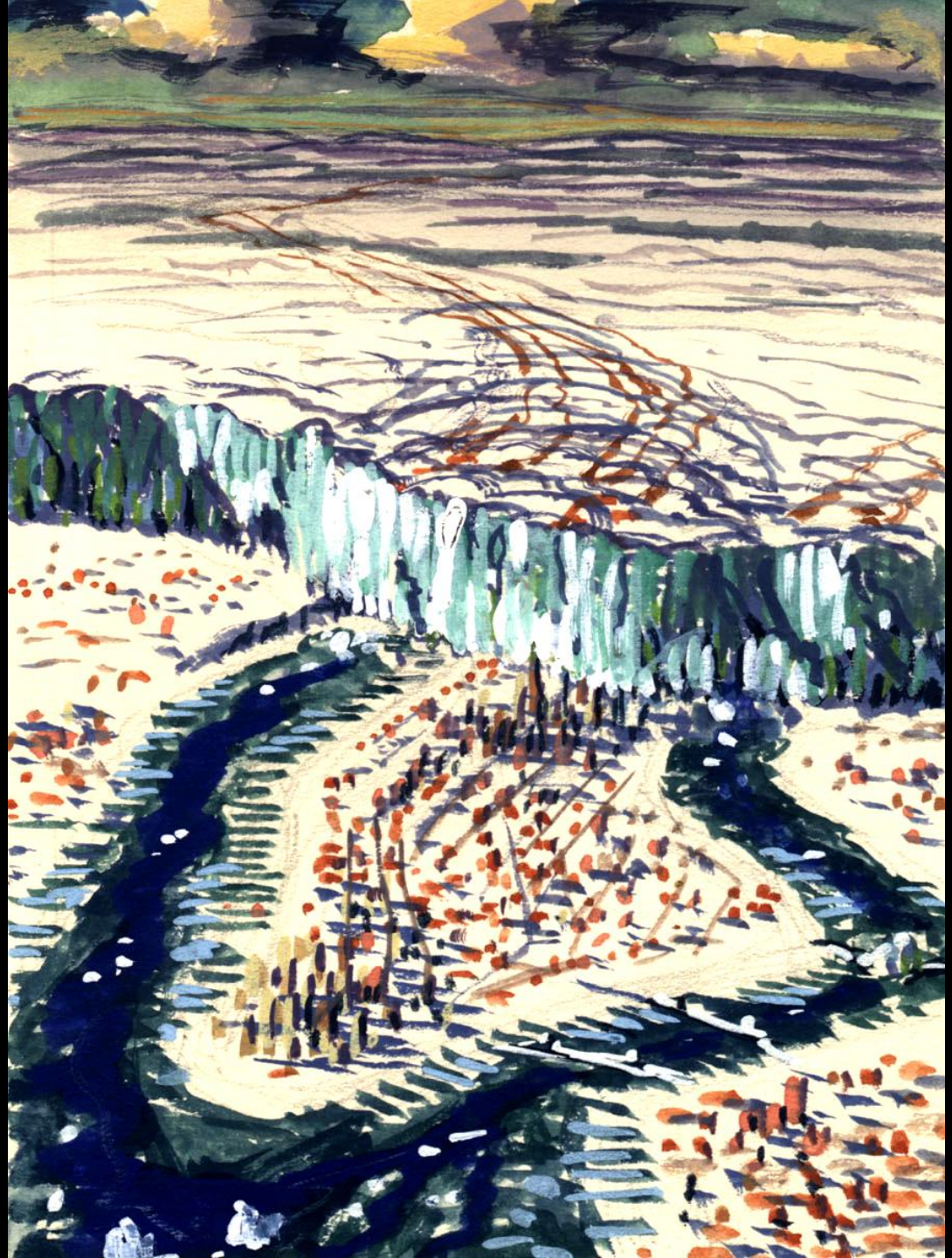

150+00
151+00
FALLOUT IN CROWN
ZONE OF STEEP JOINTS
50/20'
RR
MANY WEB-LIKE JOINTS
ONLY MAJOR JOINTS SHOWN
JNT
STEEP JOINTS
GNEISS
FAULT ZONE
INVERT
SPRINGS
KSPAR GRANITOID GNEISS
BIOTITE GNEISS
CROWN
1%

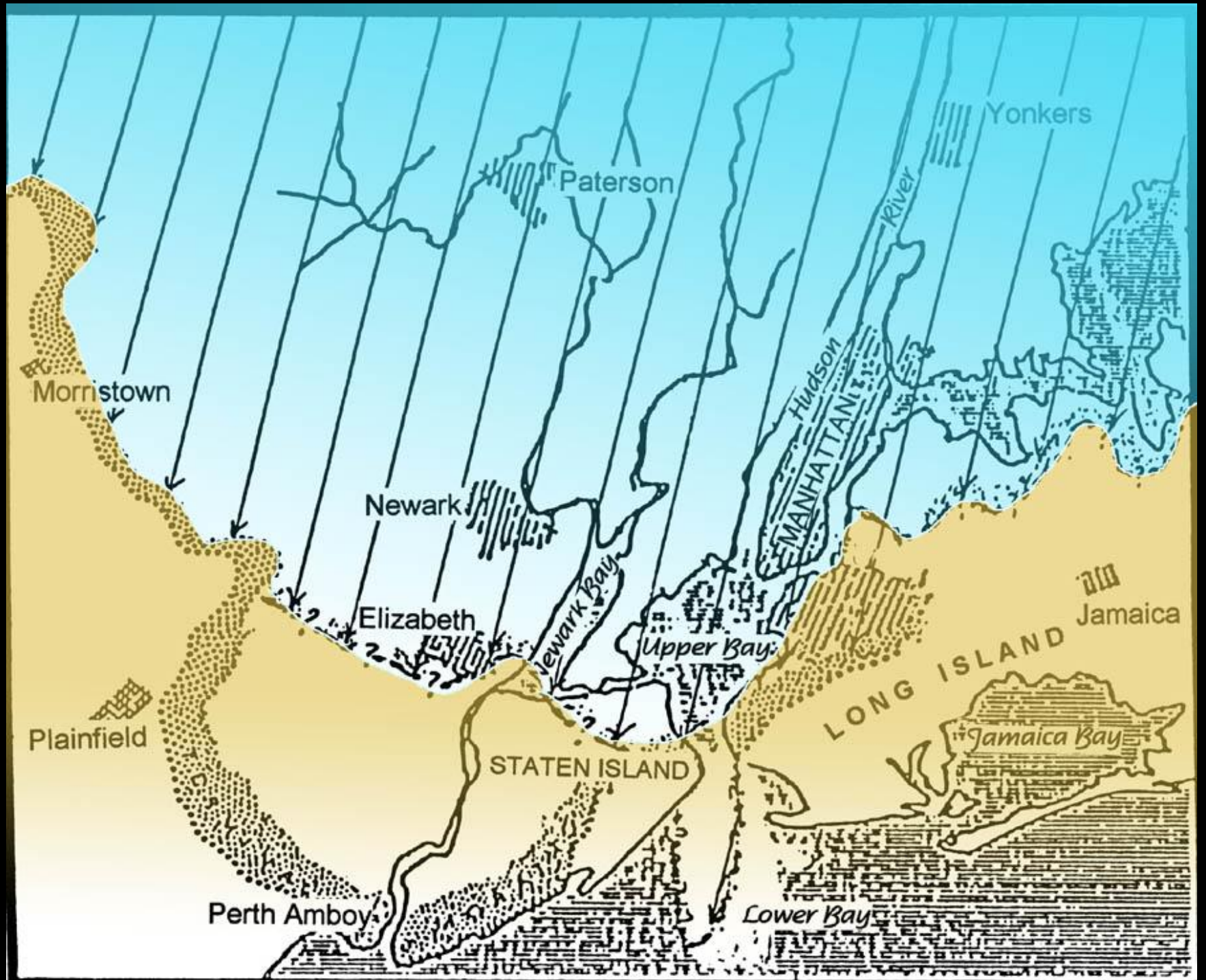
Tunneling Difficulties

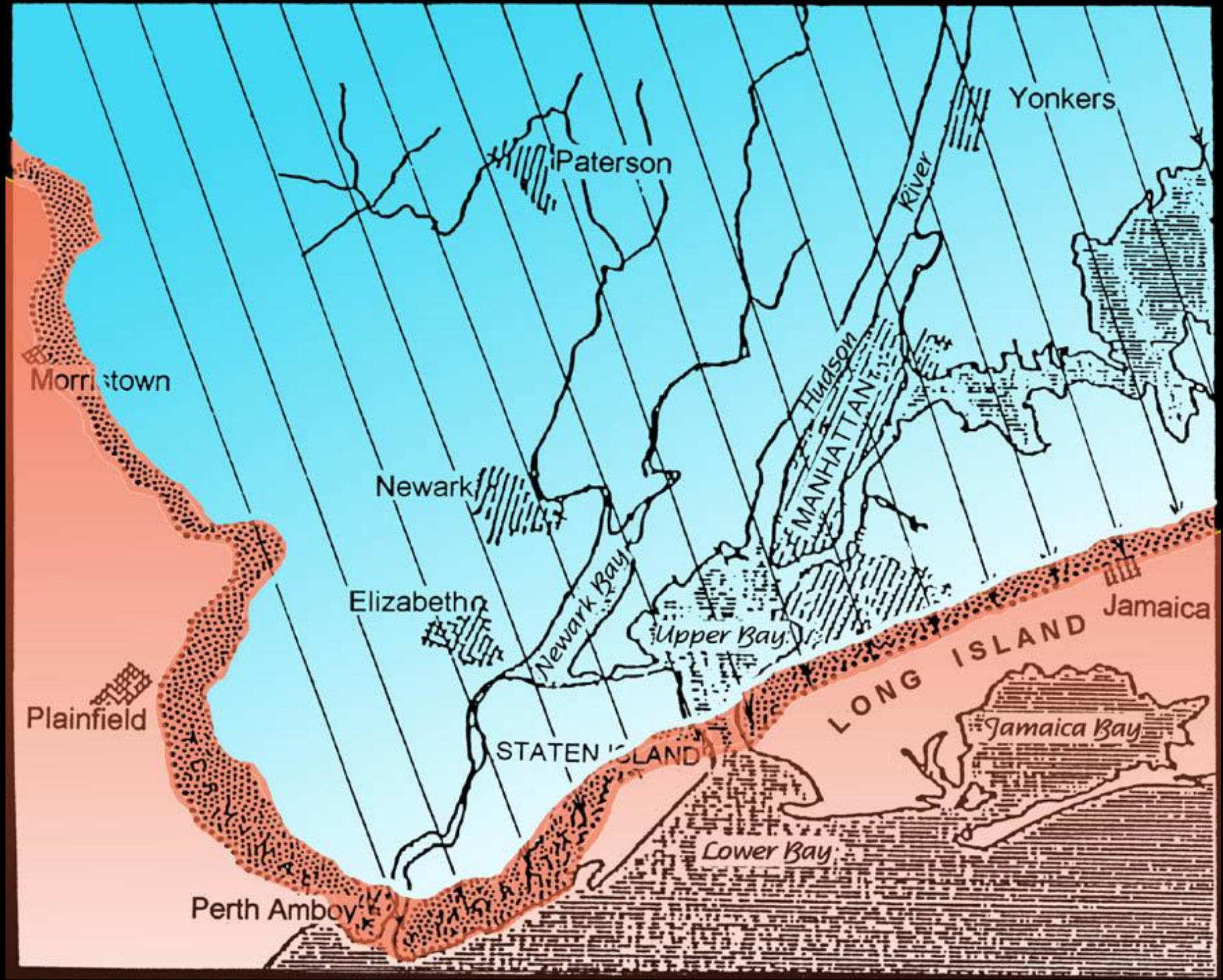
DEP Borings – QTL-13

Permian Lava Flows in Woodside?

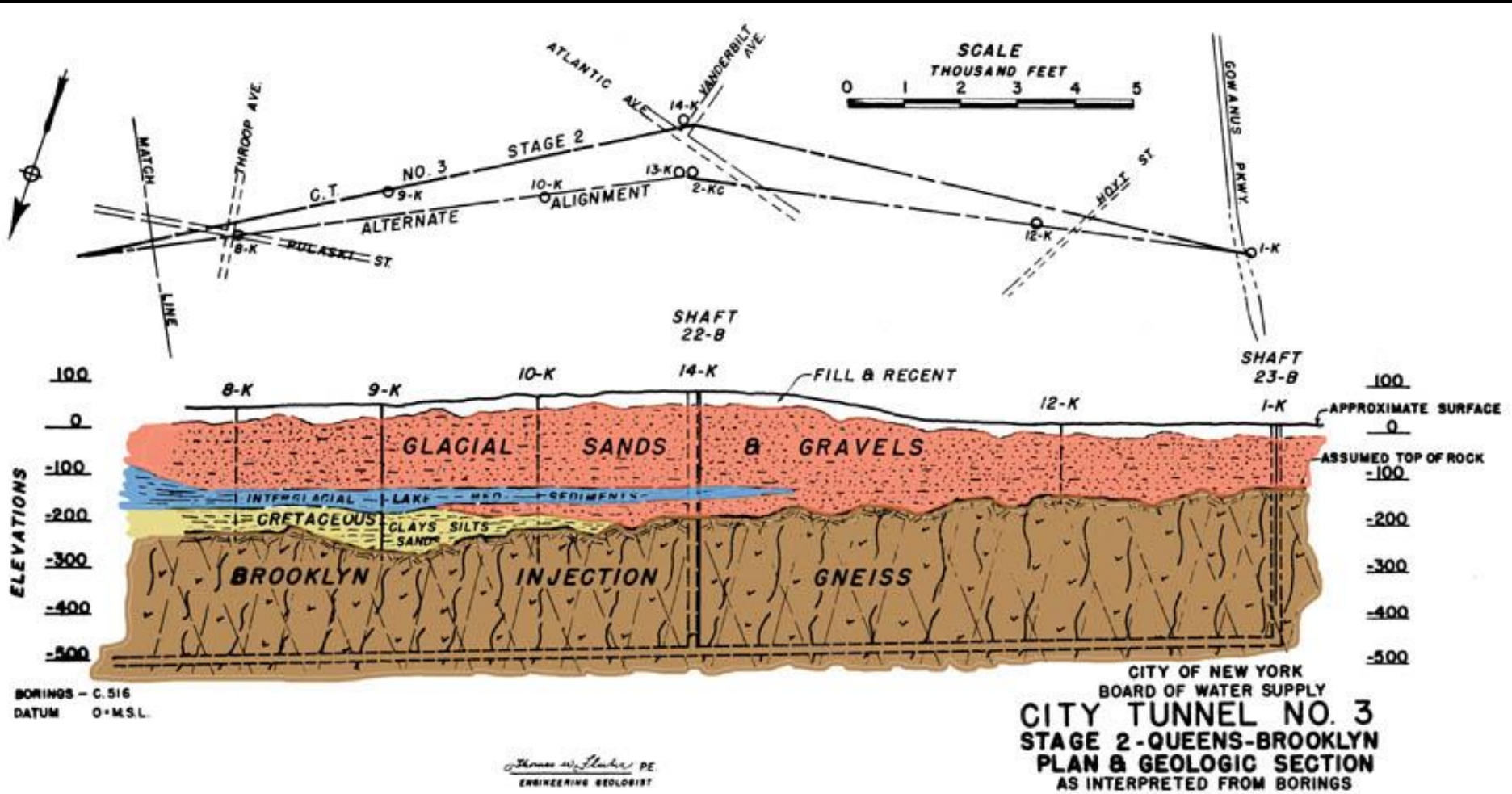
Ready For Some More Winter?




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


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

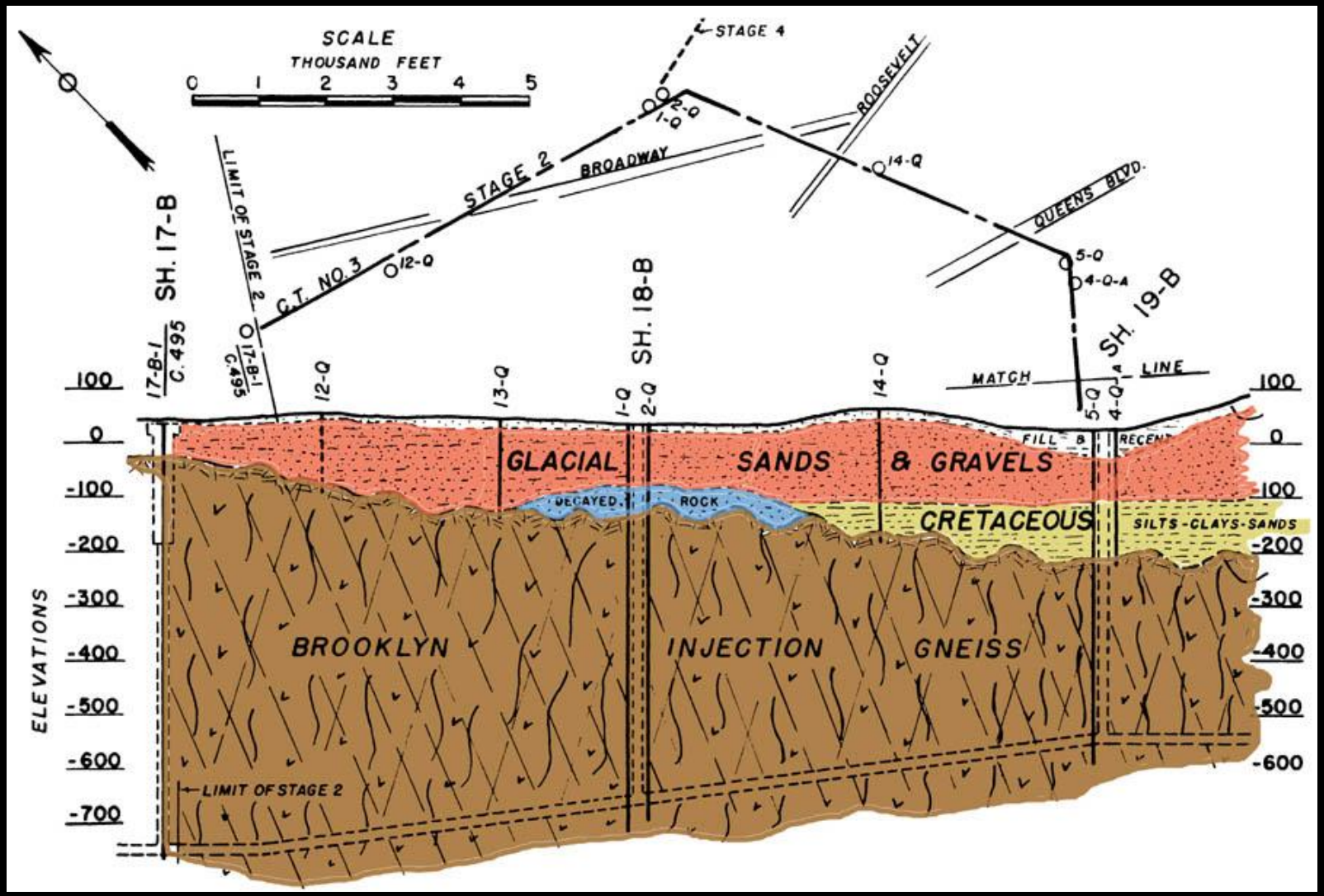
Edge of Buried Cretaceous



Atlantic Avenue, Brooklyn

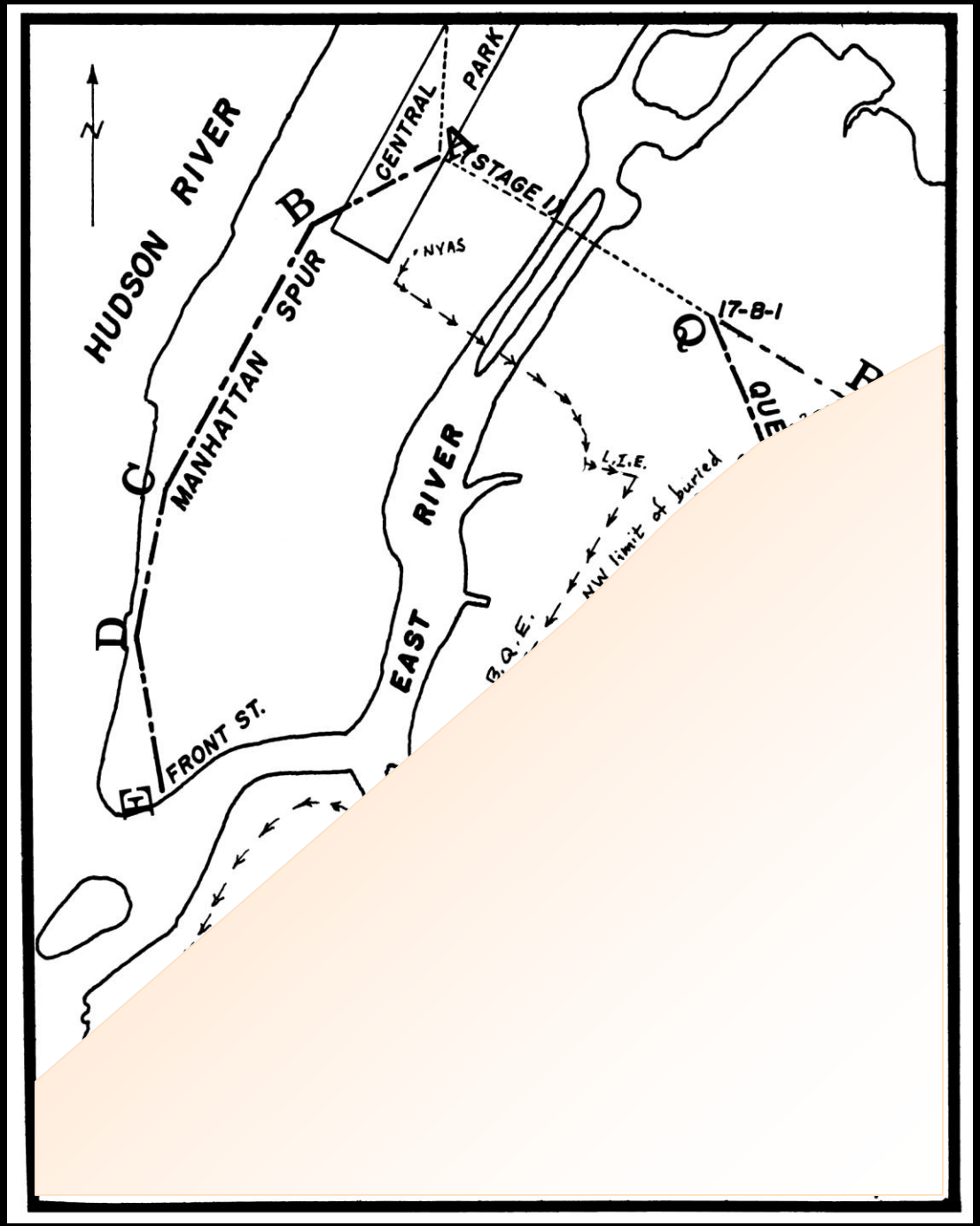
After Fluhr and Ternzio 1984

Edge of Buried Cretaceous



Woodside, Queens

After Fluhr and Ternzio 1984



CT3 Stage 2 Borings Define the NW Limit of The Buried Cretaceous

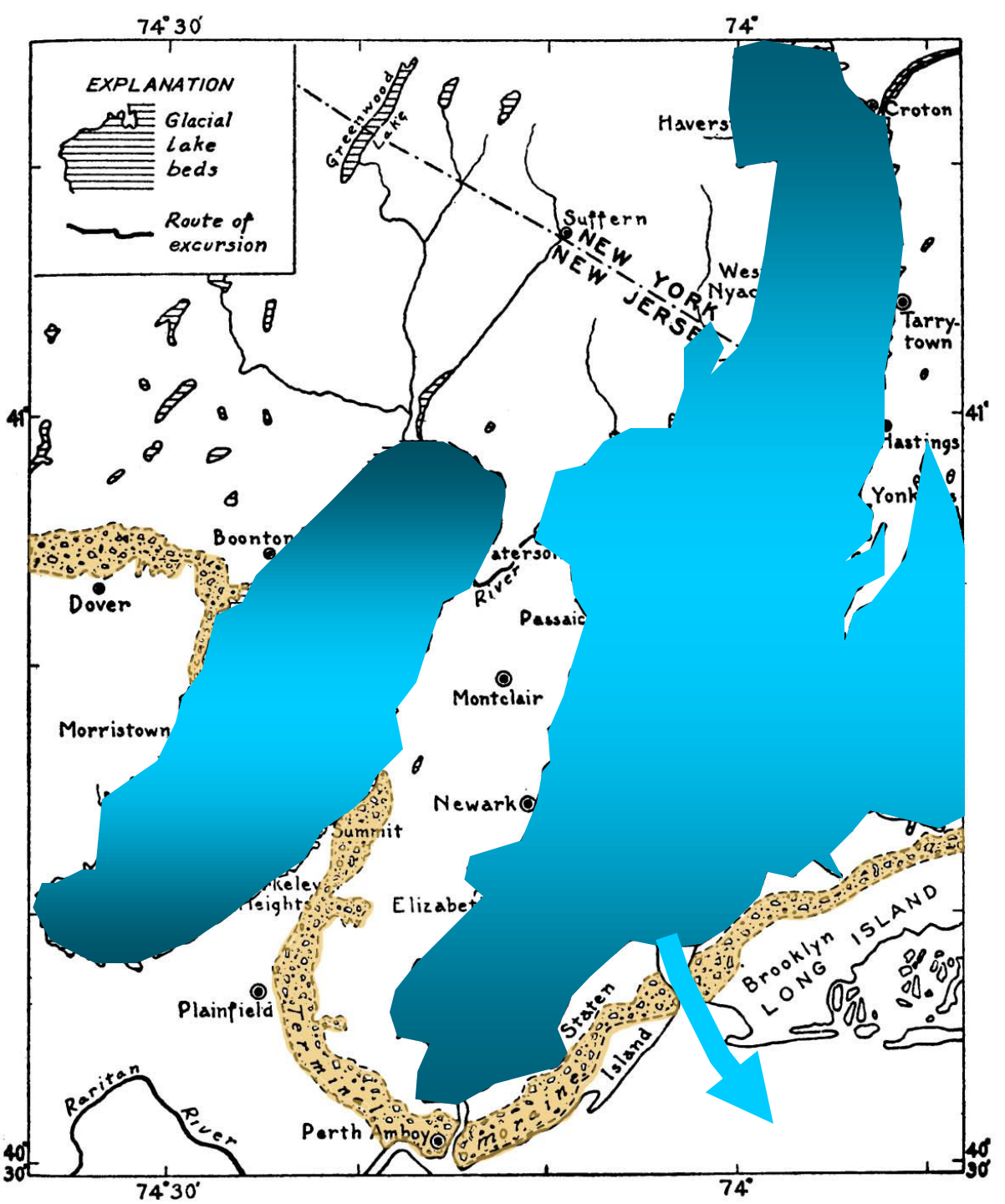
Edge of Buried Cretaceous Underlies The Harbor Hill Moraine

Fluhr and Terenzio (1984)

Glacial Lake Strata and the Harbor Hill Moraine

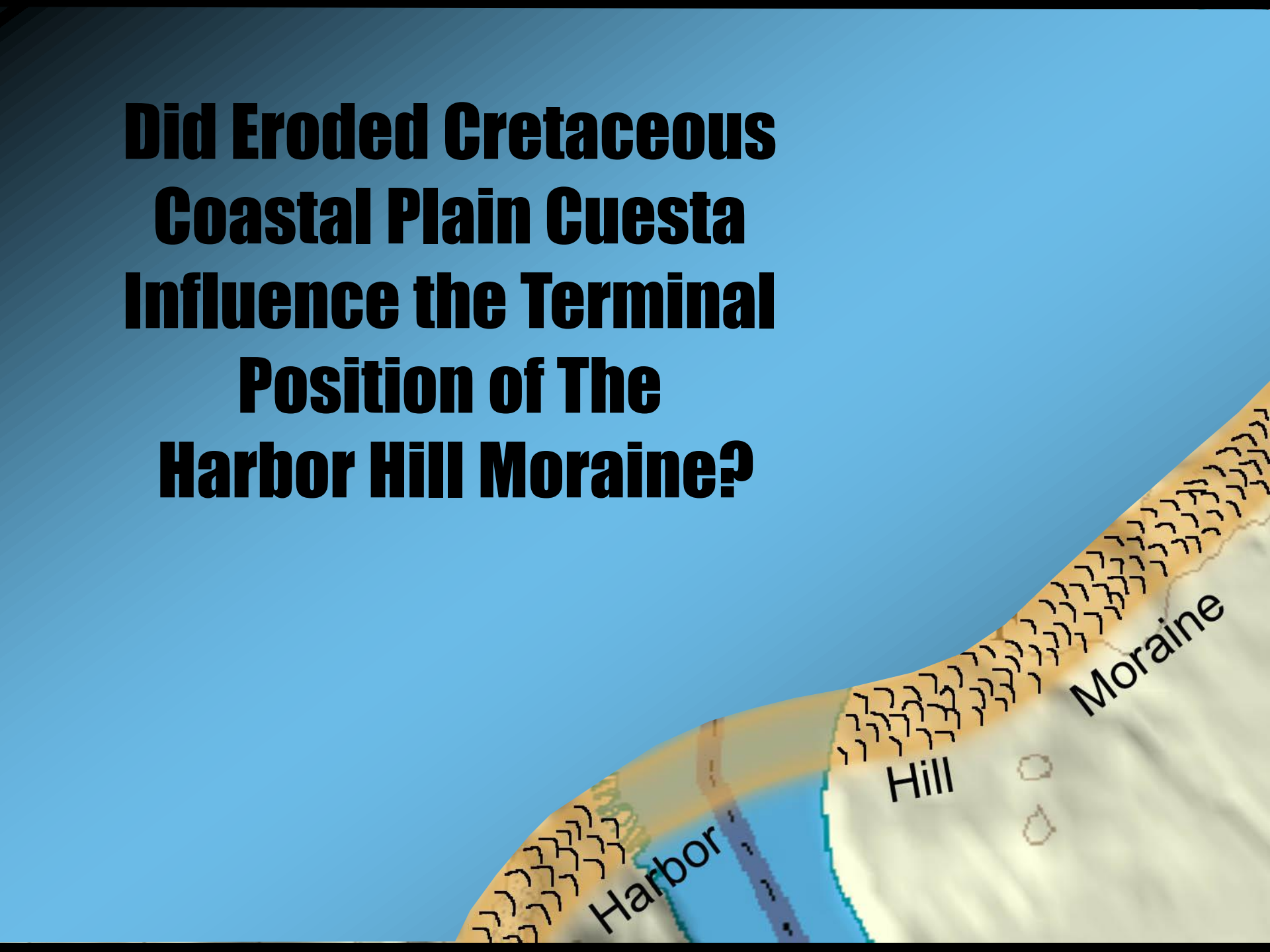
Post-Woodfordian Drainage Through The Narrows

After Berkey (1933)



Hudson Abandons Former Channel – Floods Through Narrows

Did Eroded Cretaceous Coastal Plain Cuesta Influence the Terminal Position of The Harbor Hill Moraine?



For many free publications on the Geology of New York City Visit www.dukelabs.com

An Unauthorized Lunch Break at Dukelabs