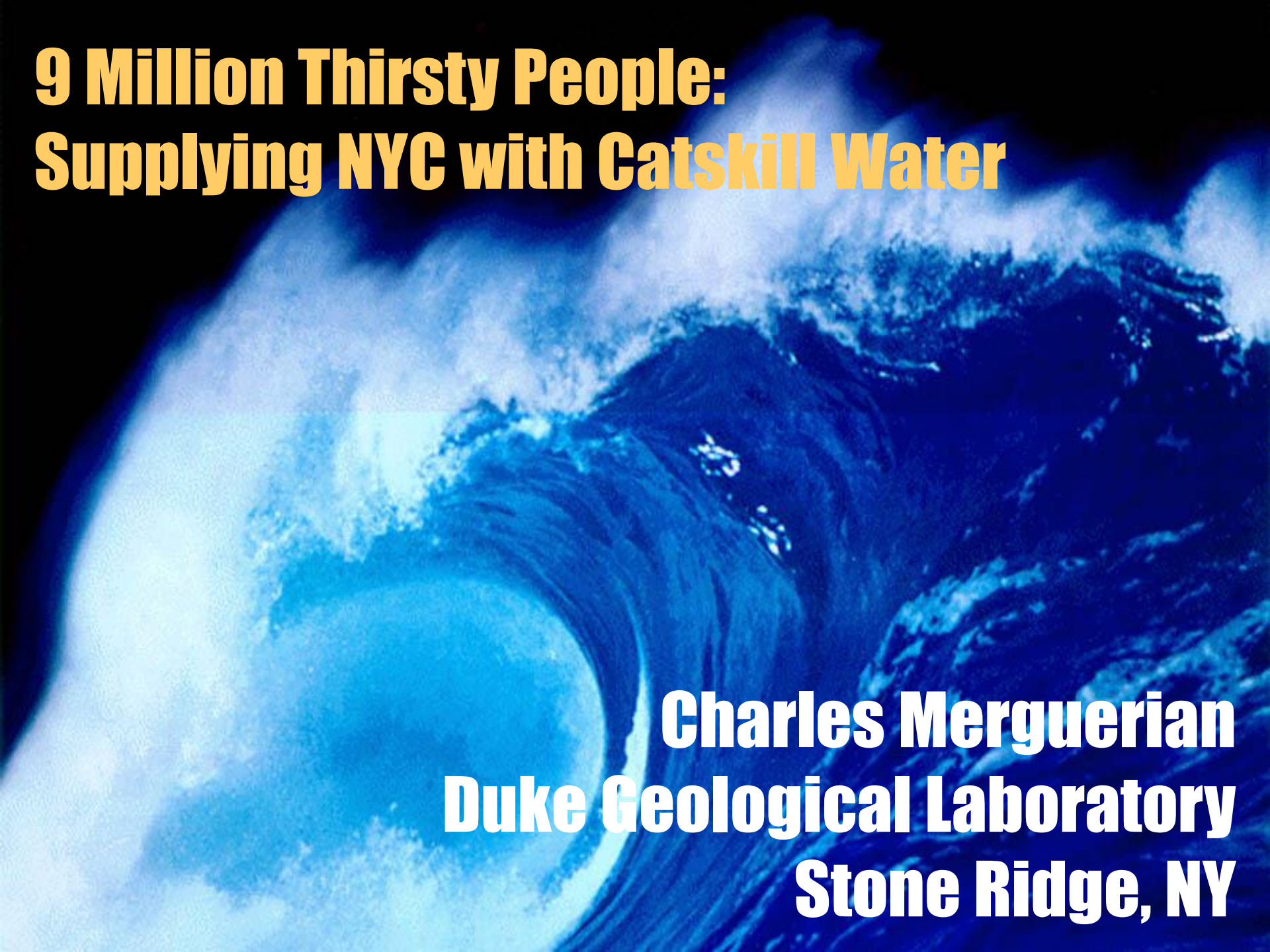
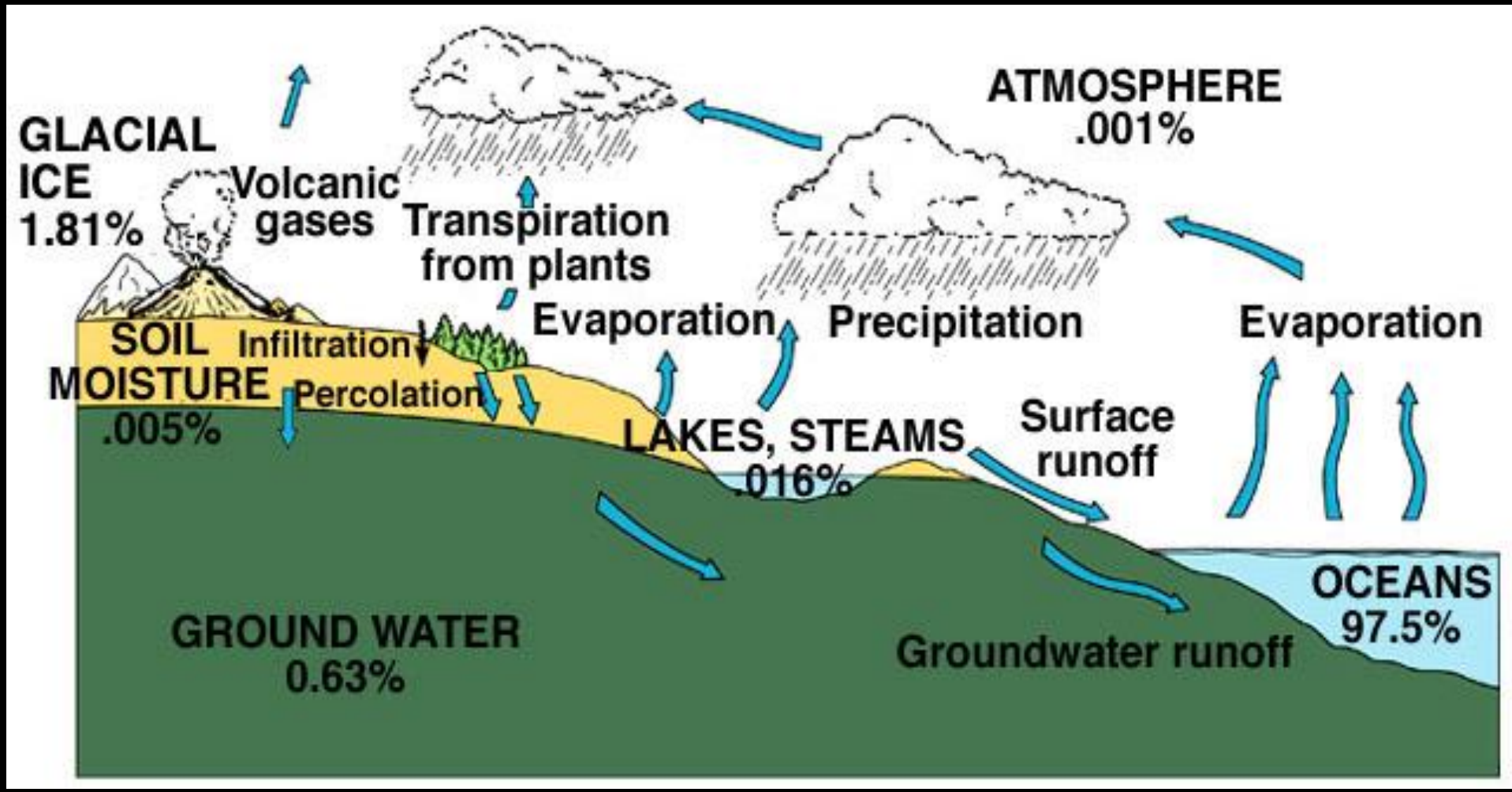
9 Million Thirsty People: Supplying NYC with Catskill Water



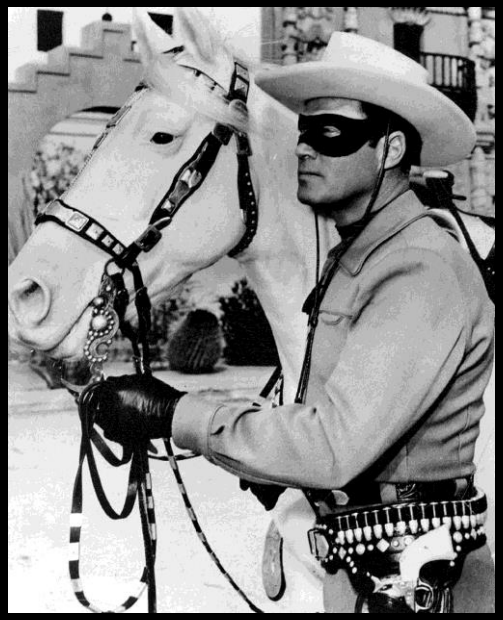
Charles Merguerian
Duke Geological Laboratory
Stone Ridge, NY

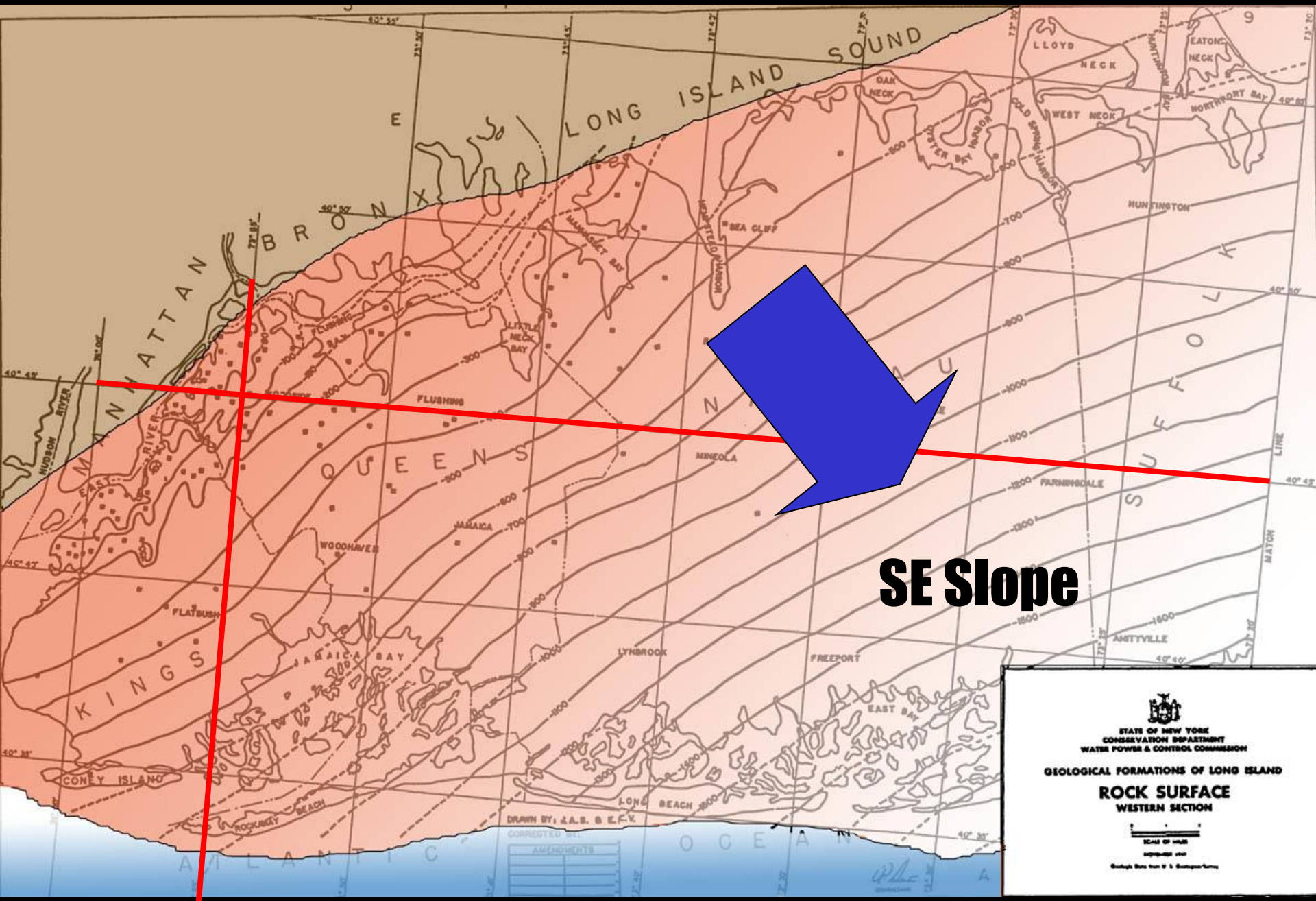

WATER VAPOR 8 km
NOAA
HTTP://WWW.GOES.NDAA.GOV

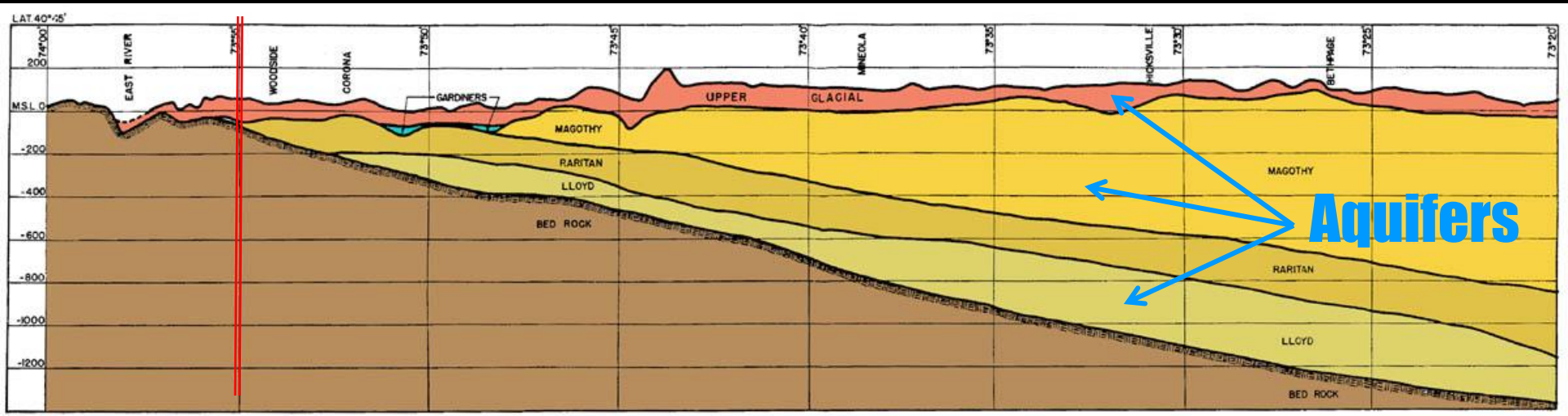
Hydrologic Cycle



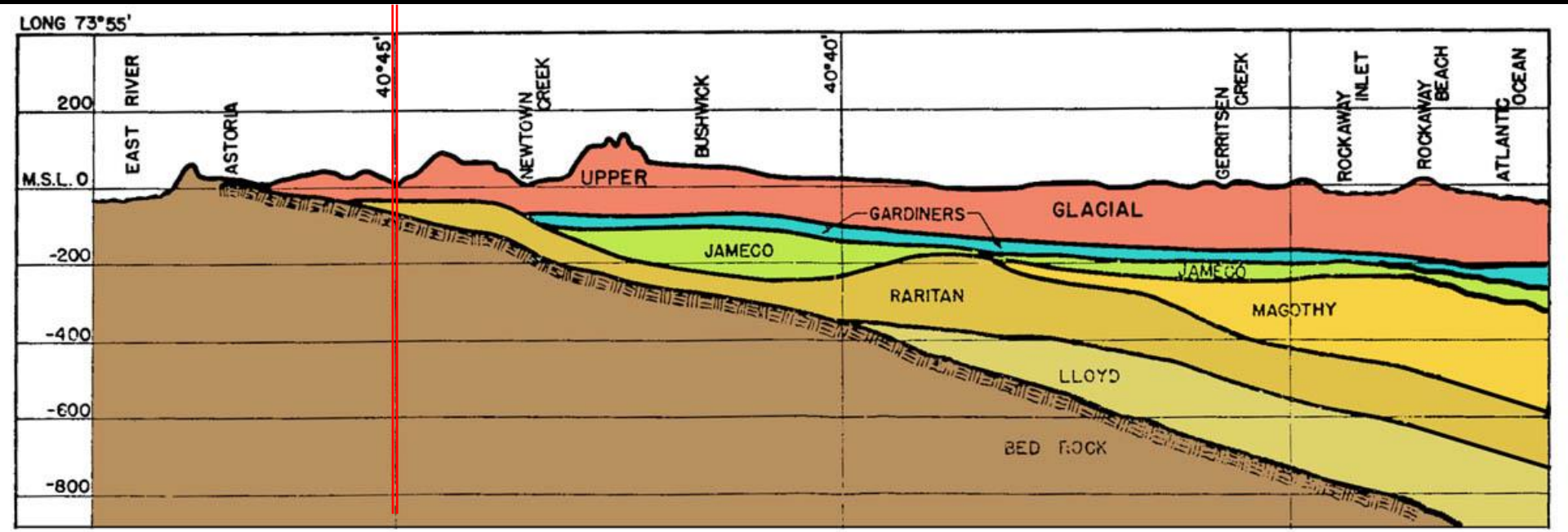
Lon Gisland




LONG ISLAND SOUND
MANHATTAN
BRONX
QUEENS
KINGS
NASSAU
SUFFOLK
LLOYD NECK
EATONS NECK
OAK NECK
WEST NECK
HUNTINGTON
BEA CLIFF
FLUSHING
MINEOLA
FARMINGDALE
JAMAICA
WOODHAVEN
FLATBUSH
JAMAICA BAY
LYNBROOK
FREEPORT
AMITYVILLE
EAST BAY
LONG BEACH
CONEY ISLAND
ROCKAWAY BEACH
ATLANTIC OCEAN
SE Slope
STATE OF NEW YORK
CONSERVATION DEPARTMENT
WATER POWER & CONTROL COMMISSION
GEOLOGICAL FORMATIONS OF LONG ISLAND
ROCK SURFACE
WESTERN SECTION



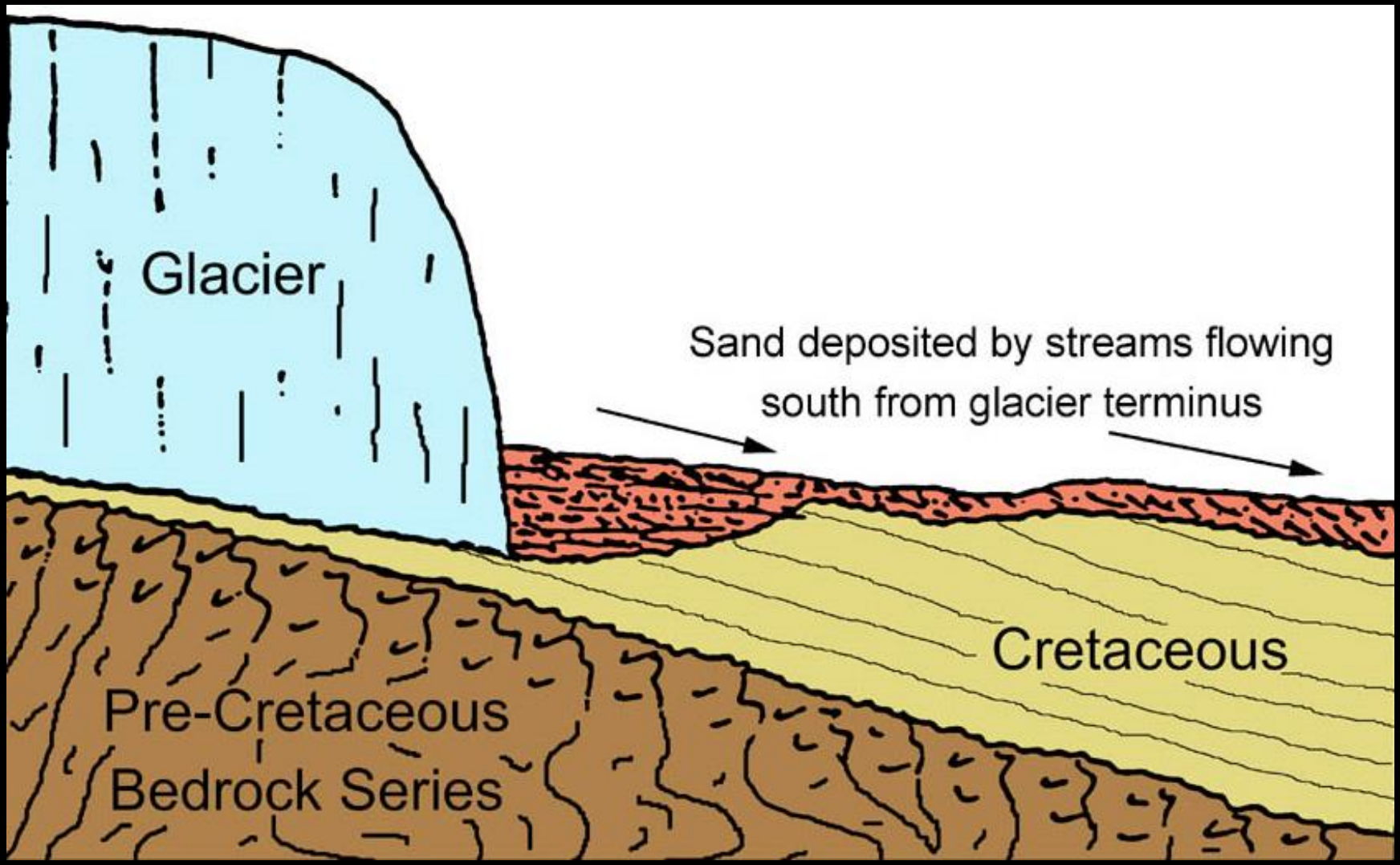
LAT. 40°=45' N



LONG. 73°=55' W

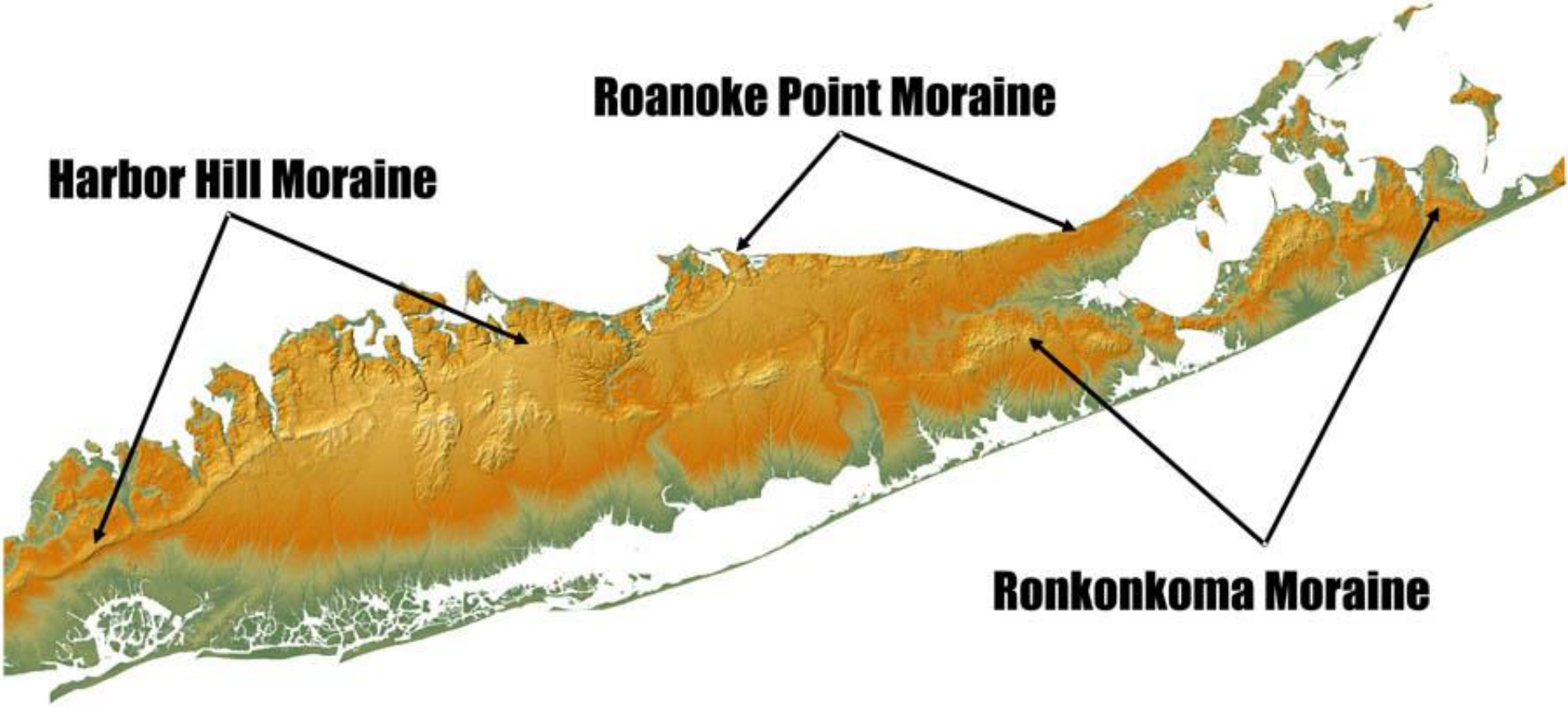
Suter et al, 1949

Long Island Outwash Fans

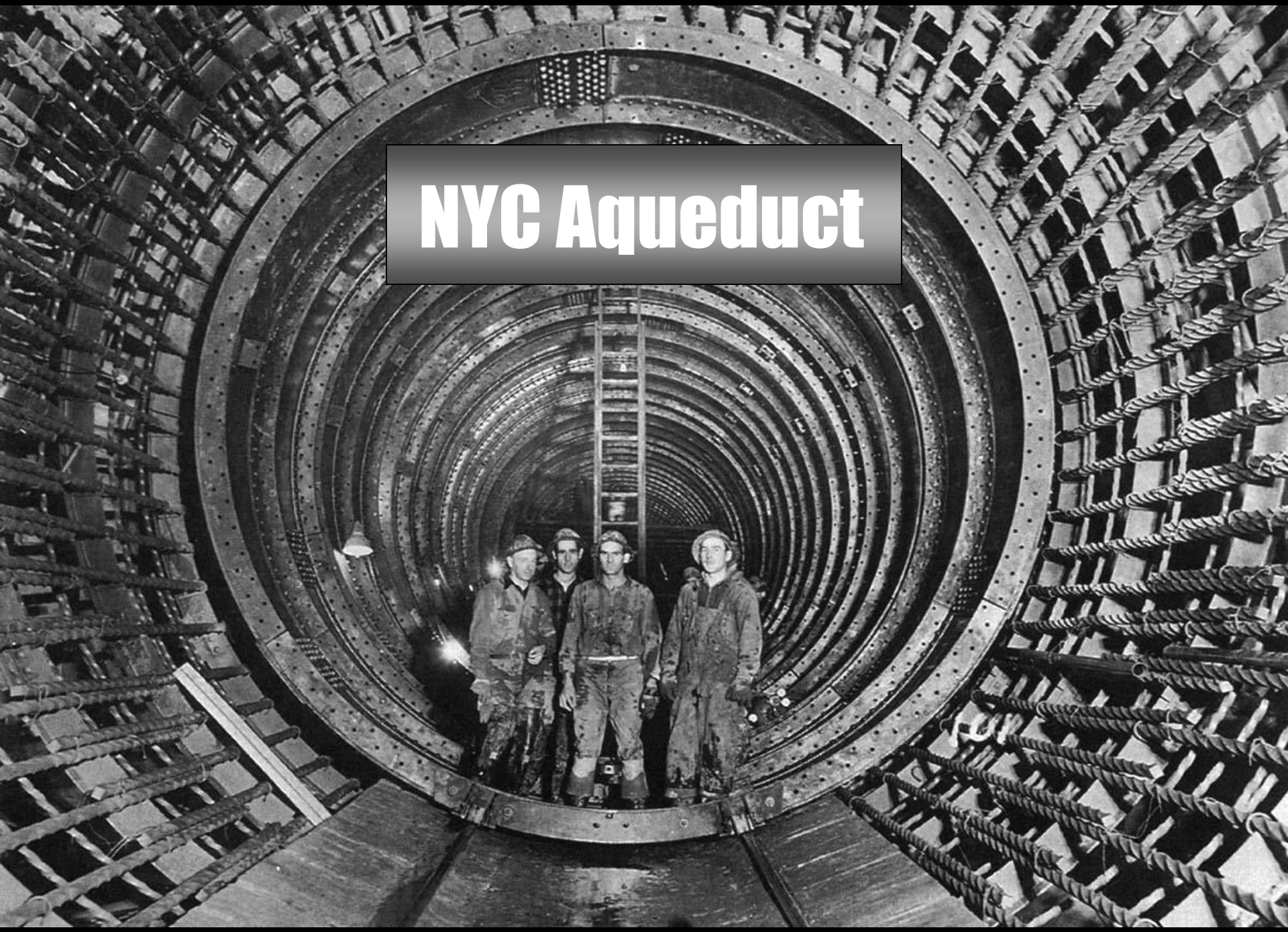


after Merguerian and Sanders 1993

Long Island's Moraines

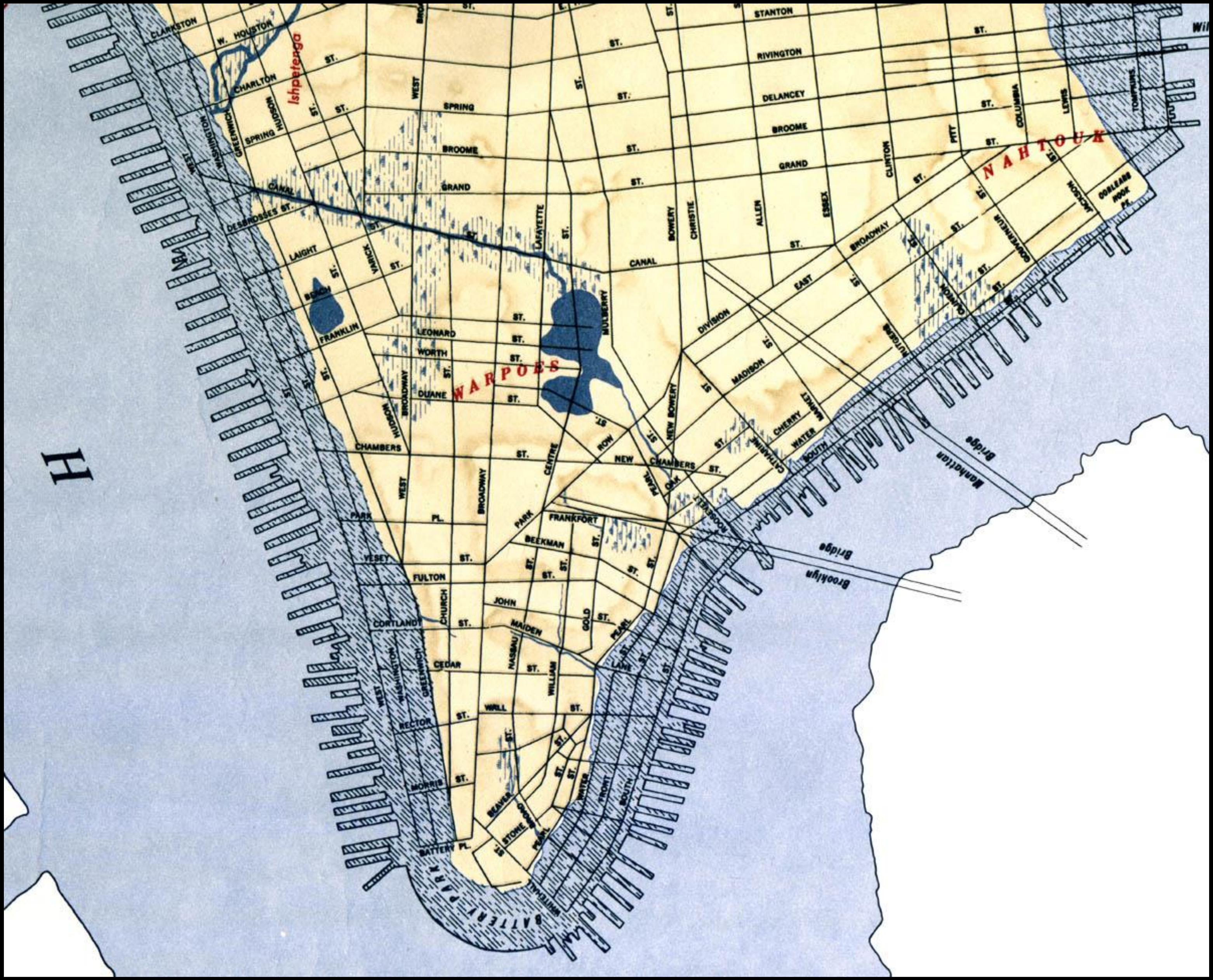


after Bennington, 2003

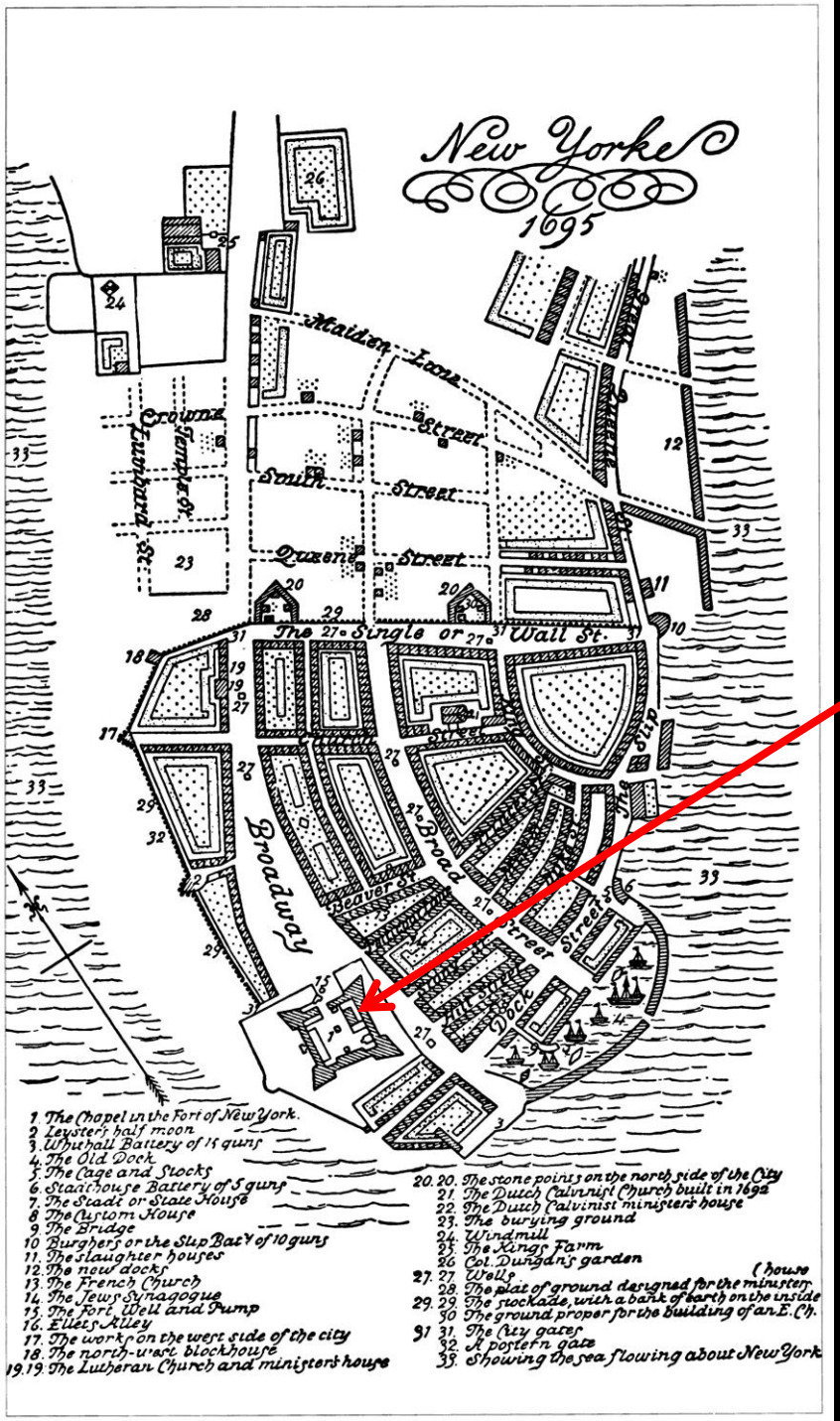

NYC Aqueduct

Dutch Settlers, South Manhattan

Population by 1664 Had Reached 1,500 People


Ishpetenga
WARPOES
NAHTOUK
STANTON
RIVINGTON
DELANCEY
BROOME
GRAND
CANAL
SPRING
CHARLTON
CLARKSON
W. HOUSTON
DESBROSSES ST.
LAIGHT
BEACH
FRANKLIN
LEONARD
WORTH
DUANE
CHAMBERS
NEW CHAMBERS
PARK PL.
VESEY
FULTON
JOHN
MAIDEN
CORTLANDT
CEDAR
WALL
RECTOR
MORRIS
BATTERY PL.
BATTERY PARK
BROADWAY
EAST BROADWAY
DIVISION
MADISON
CHERRY
WATER
SOUTH
FRONT
PEARL
FRANKFORT
BEEKMAN
Manhattan Bridge
Brooklyn Bridge
H

McCoun 1609



New York 1695

First Public Well Constructed 1667 at the Old Fort, Bowling Greene

Collect Pond Till 1800

Population up to 22,000 by 1776

Christopher Colles Built Hollow Log Supply System

after Baskerville 1982

By 1800 with the Population at 60,000
the Collect Pond had Collected Pollutants

In early 1800s Aaron Burr Founded the
Manhattan Company and Sunk a Deep Well
at Reade and Center Streets,
SW of Collect Pond

Utilizing 20 Miles of Wooden
Pipe, over 1,400 Home
Subscribers Were Supplied
with 700,000 gpd

By 1830, First Public Water Supply System Starts with 220,000 Gallon Tank Erected at Broadway and 13th Street

112' Deep Well (98' in Hard Rock)

Viele, 1865

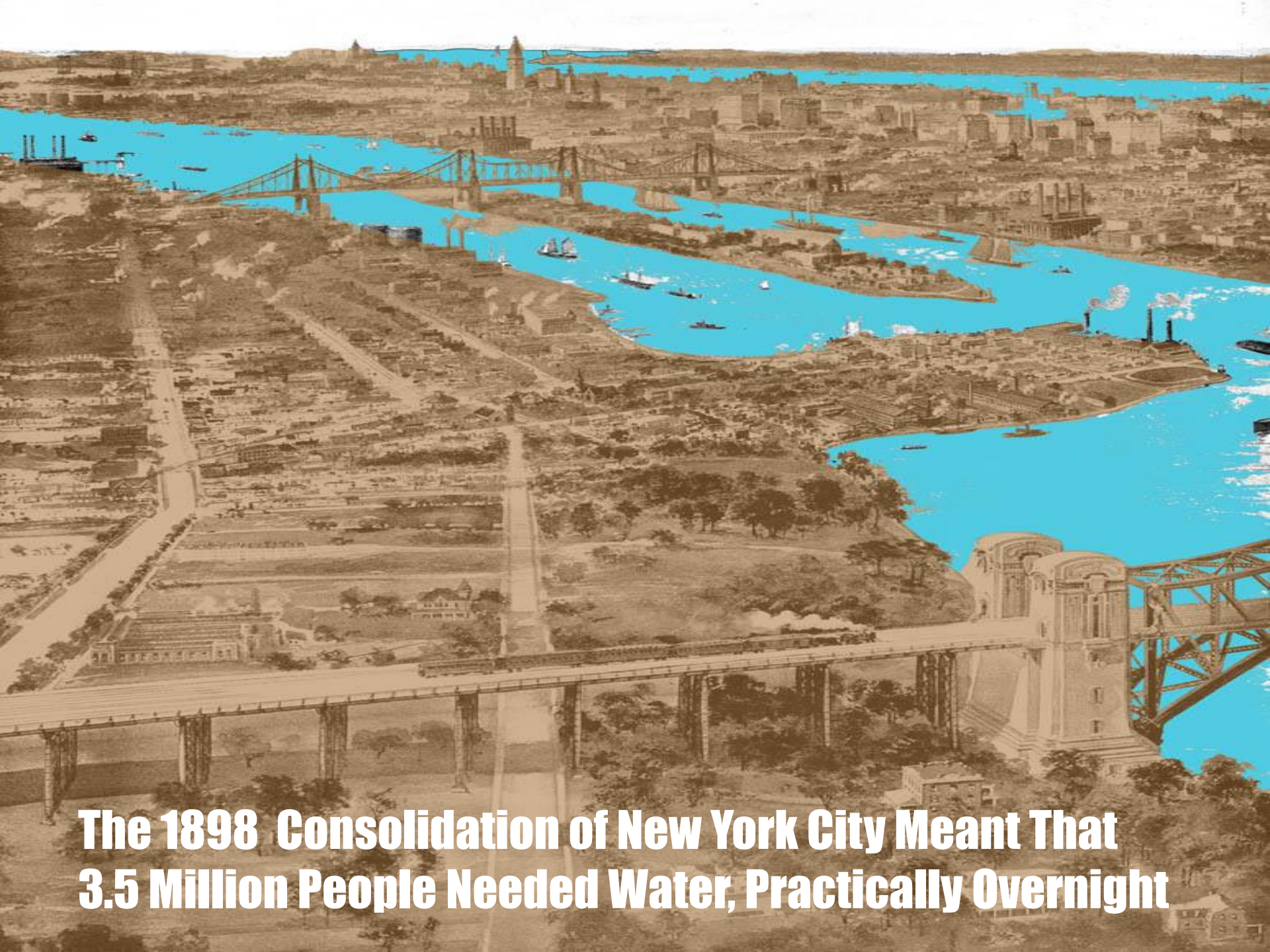
1832 – De Witt Clinton Recommends Use of Croton River to Supply 20,000,000 gpd Using a Gravity Feed System

1837-1842 Old Croton Reservoir Constructed and by 1881 Supplied 95,000,000 gpd

Old Croton 4x Brick-lined Tunnels Used Until 1907

Crosses Harlem River at High Bridge Fed Central Park and Bryant Park Reservoirs In NYC


LWT (NCA) – Jan 2009


The 1898 Consolidation of New York City Meant That
3.5 Million People Needed Water, Practically Overnight

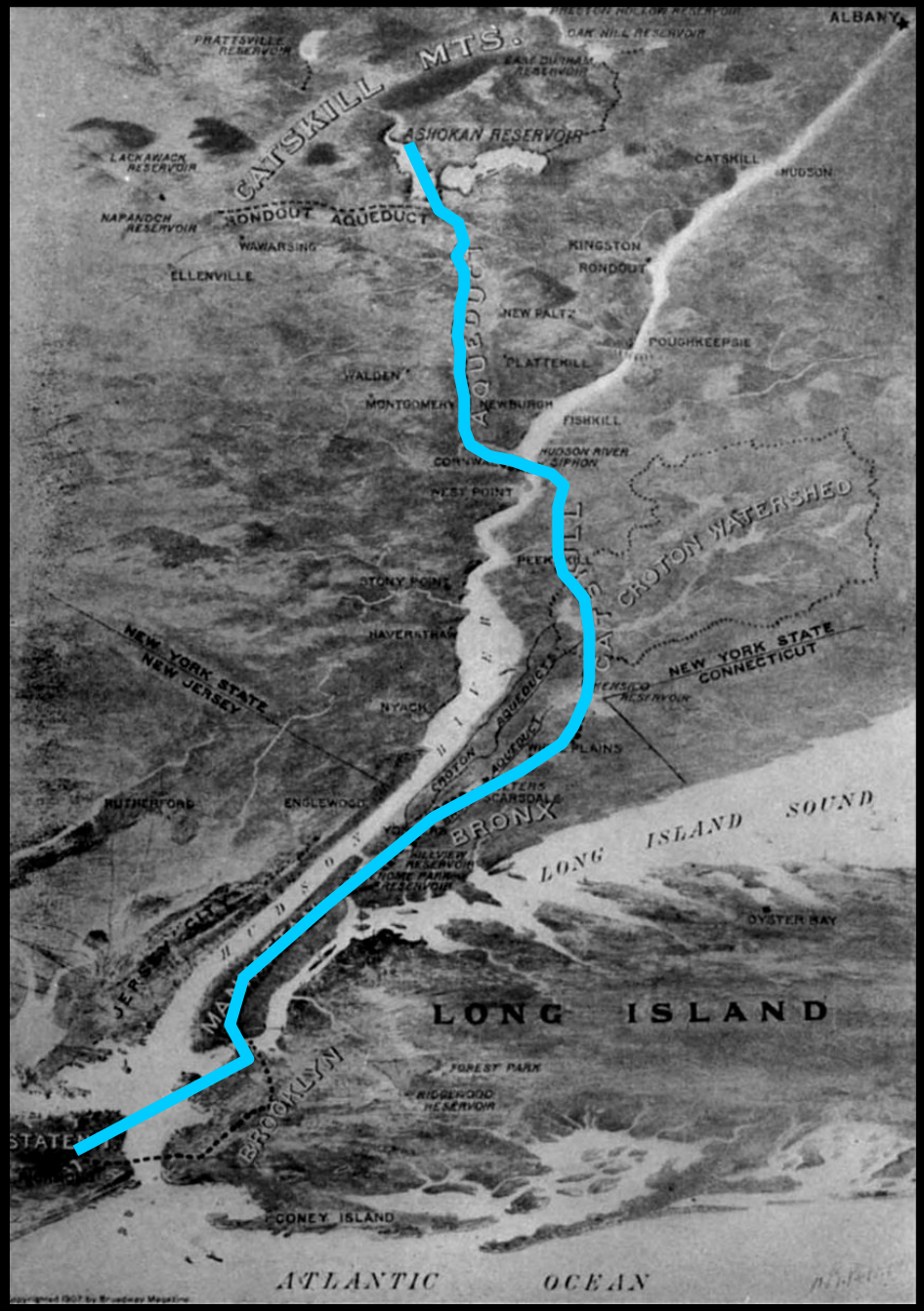
NYC Aqueduct System

Construction of 130 Miles of Tunnels Began in 1907

City Tunnel #1 Completed 1917

City Tunnel #2 Completed 1936

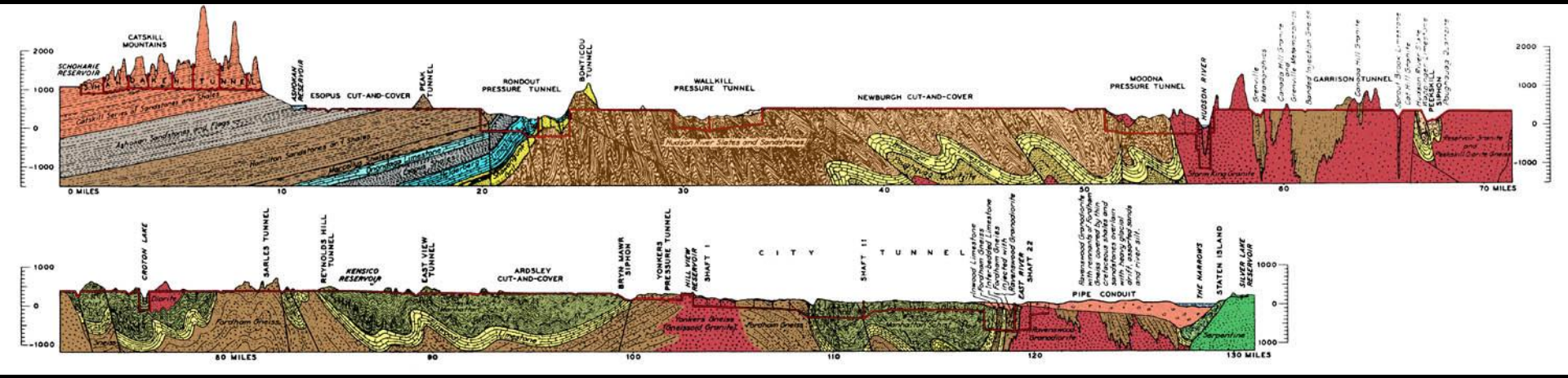
City Tunnel #3 Completed 20??



The Catskill System, which involved the use of 67 shafts varying in depth from 174 to 1,187 feet includes:

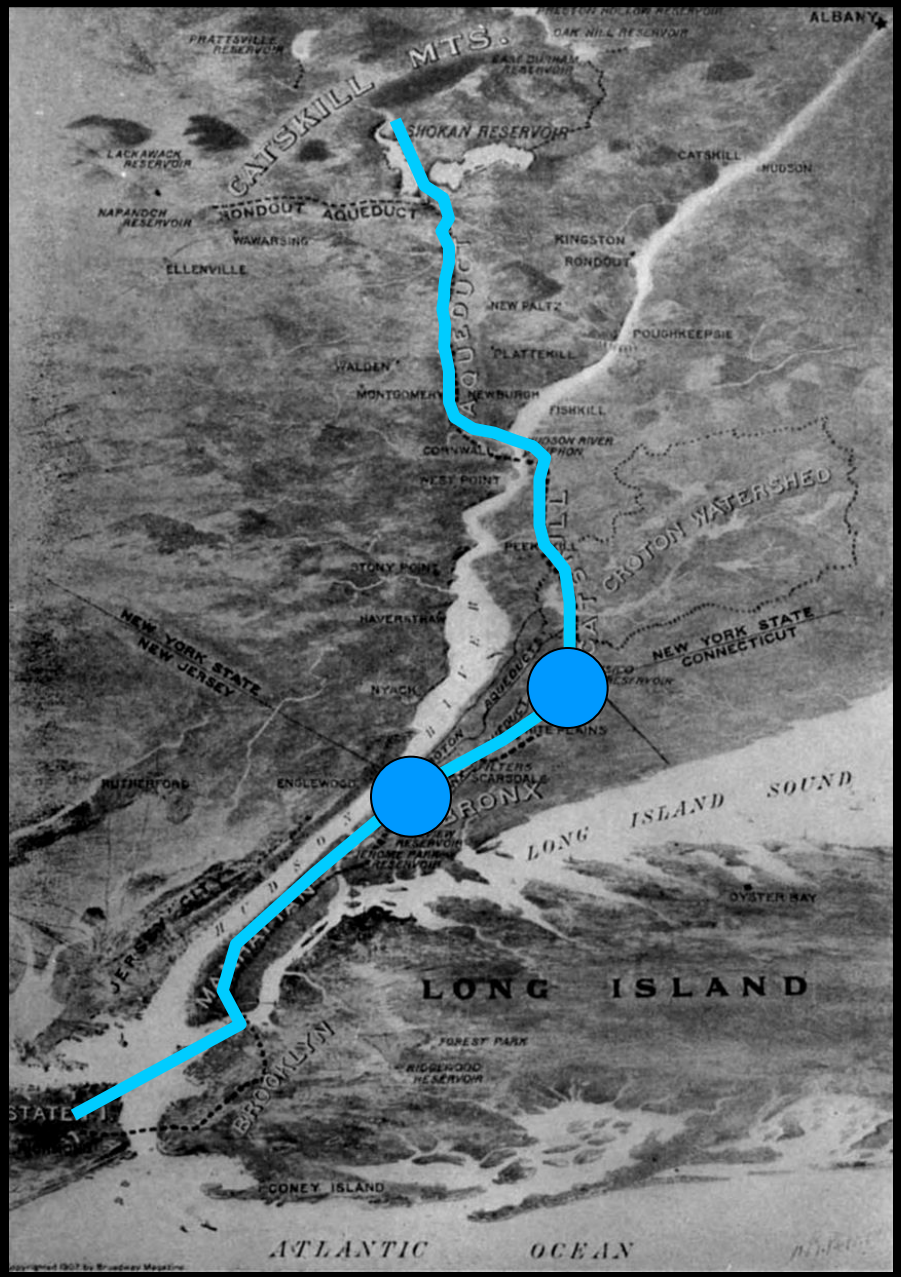
- Three masonry dams
- Several miles of earthen dikes
- Over 163 miles of aqueduct consisting of:
  - 55 miles of cut and cover aqueduct
  - 28.5 miles of grade tunnel
  - 35 miles of pressure tunnel
  - 39 miles of pipe conduit and,
  - 6 miles of steel pipe siphons

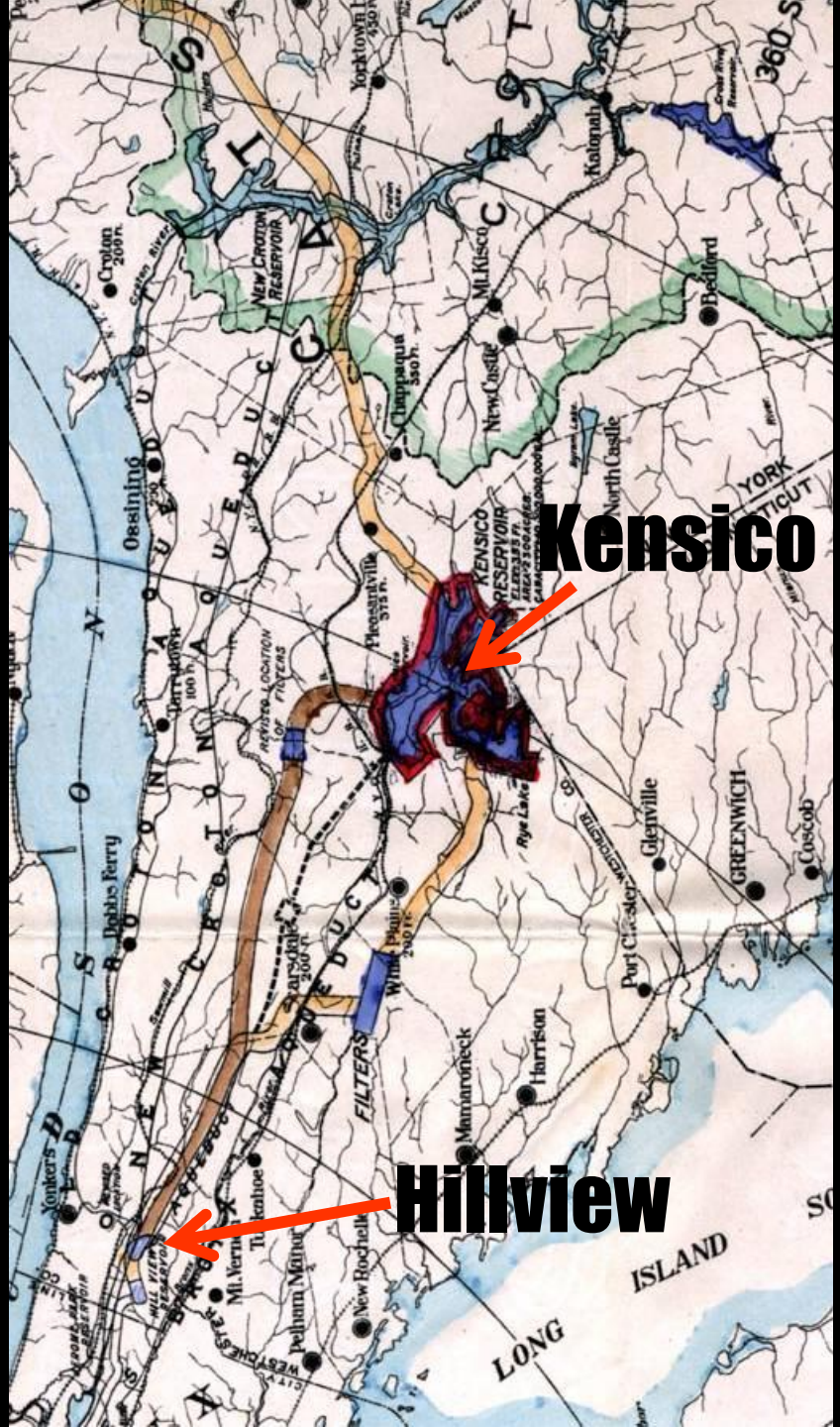
Catskill Aqueduct



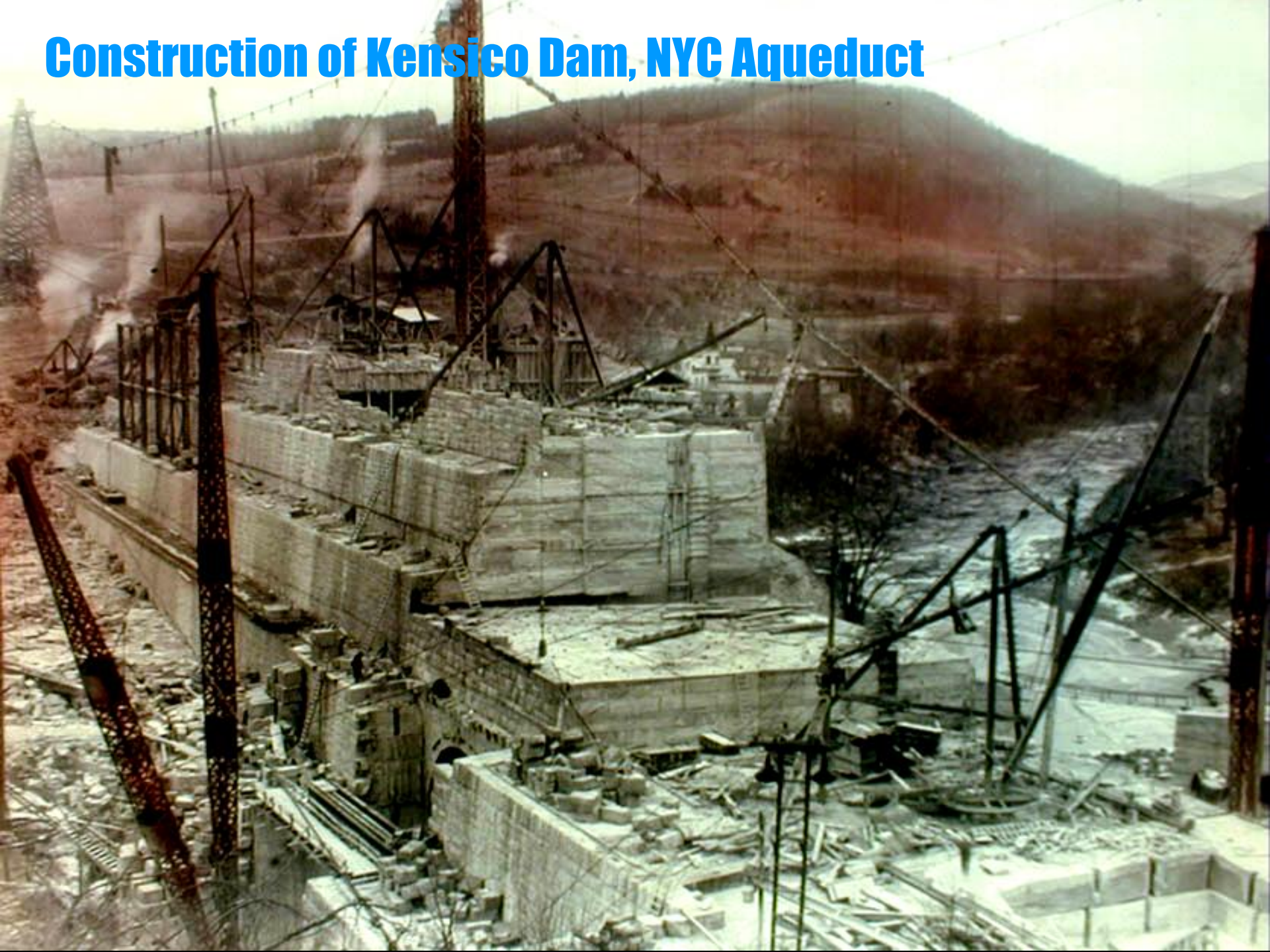
after Berkey, 1933

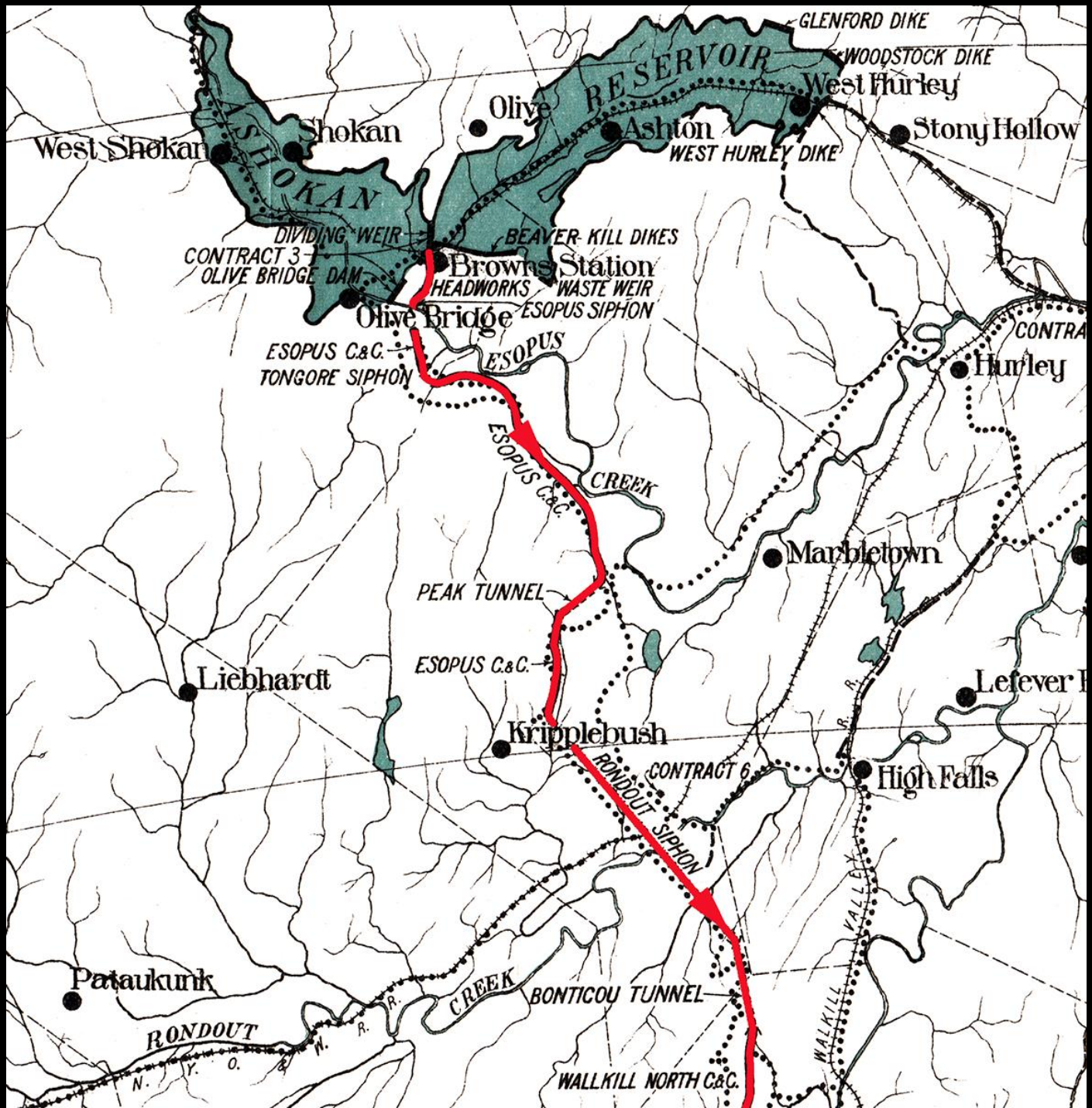
NYC Aqueduct System

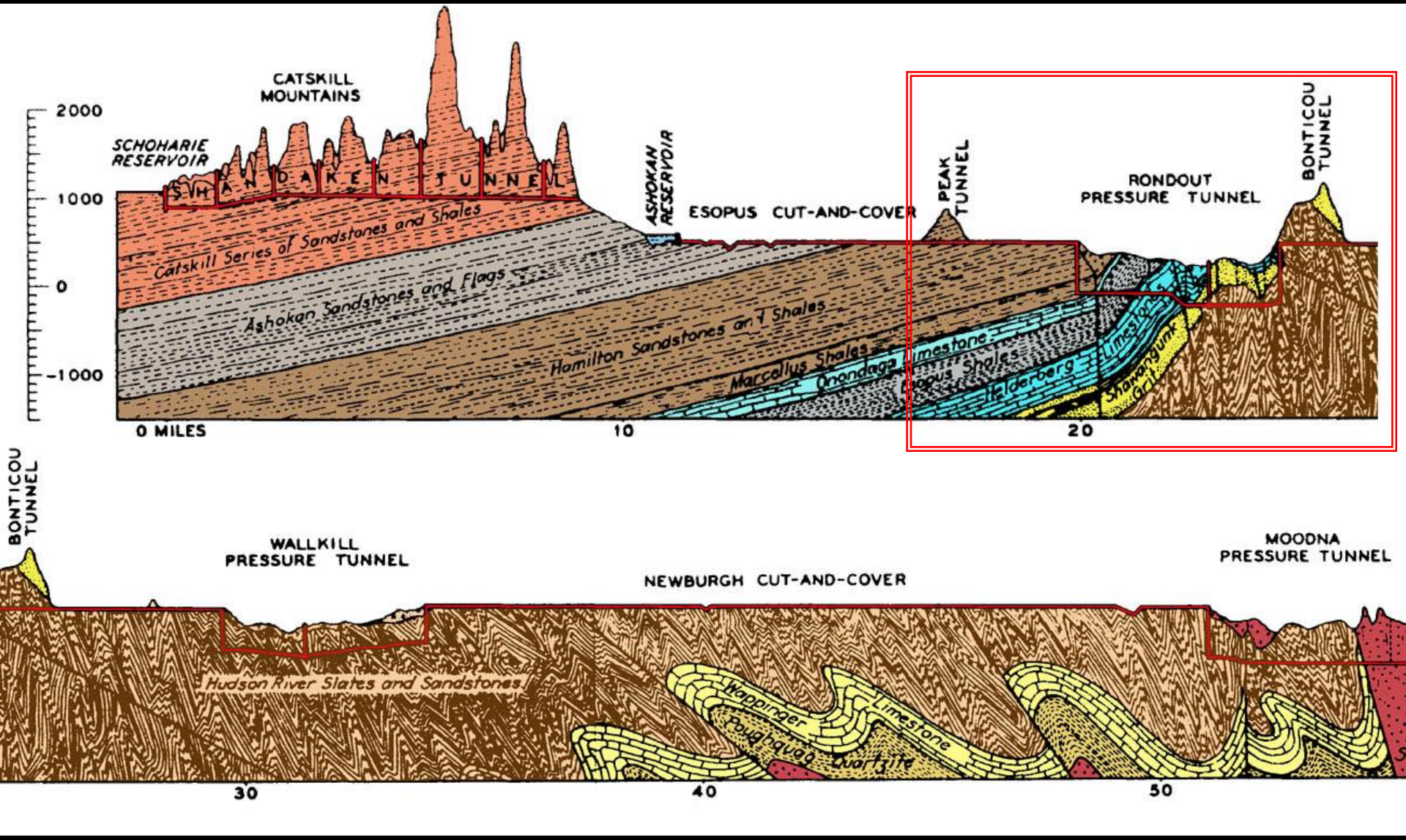


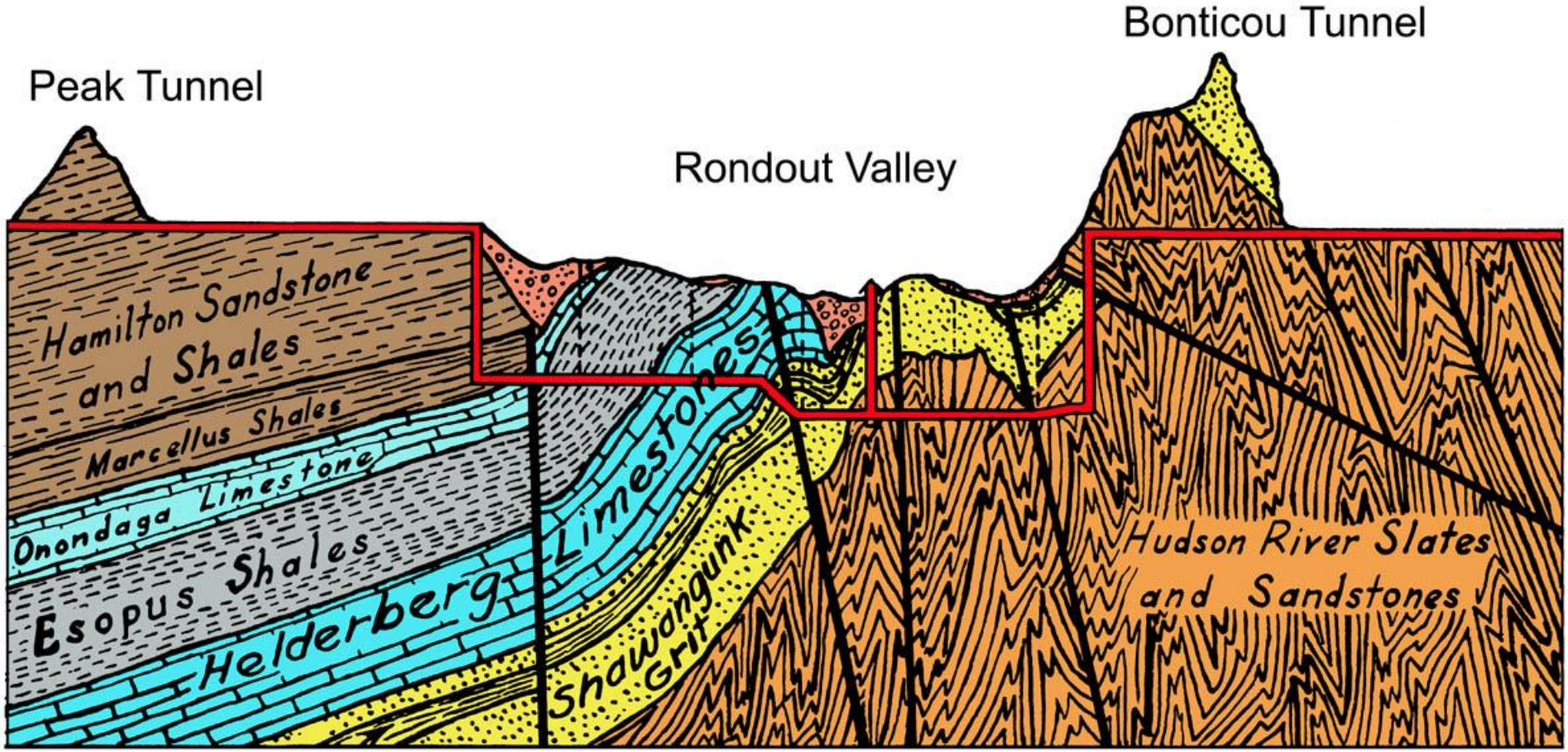


Construction of Kensico Dam, NYC Aqueduct

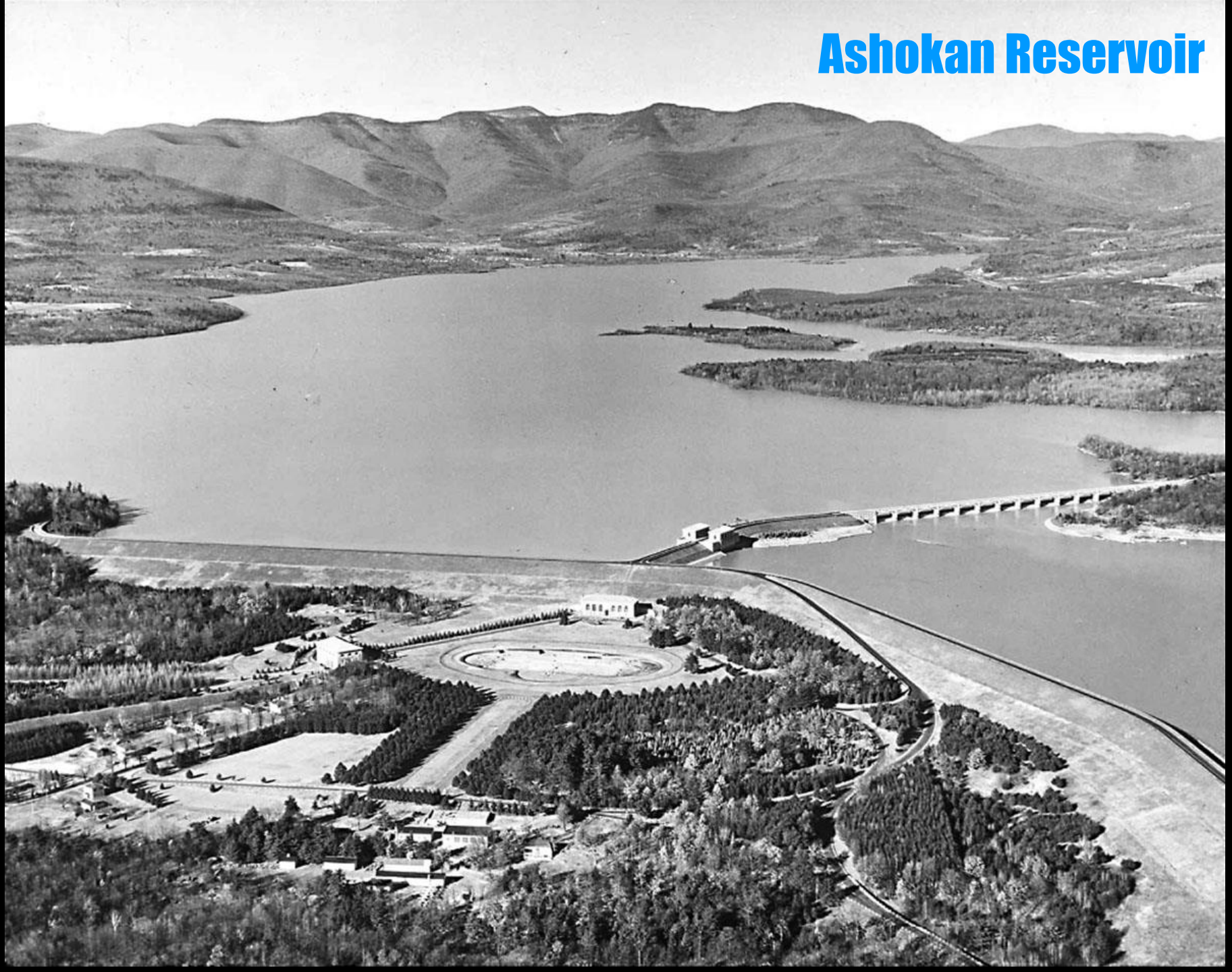



GLENFORD DIKE
WOODSTOCK DIKE
RESERVOIR
West Hurley
Olive
Ashton
Shokan
West Shokan
Stony Hollow
WEST HURLEY DIKE
ASHOKAN
DIVIDING WEIR
BEAVER KILL DIKES
CONTRACT 3
OLIVE BRIDGE DAM
Brownsville Station
HEADWORKS
WASTE WEIR
ESOPUS SIPHON
Olive Bridge
ESOPUS C.&C.
TONGORE SIPHON
ESOPUS
Hurley
ESOPUS C.&C.
CREEK
Marbletown
PEAK TUNNEL
ESOPUS C.&C.
Liebhardt
Kripplebush
RONDOUT SIPHON
CONTRACT 6
High Falls
Pataukunk
CREEK
BONTICOU TUNNEL
RONDOUT
N. Y. O. & W. R.
WALLKILL
WALLKILL NORTH C.&C.

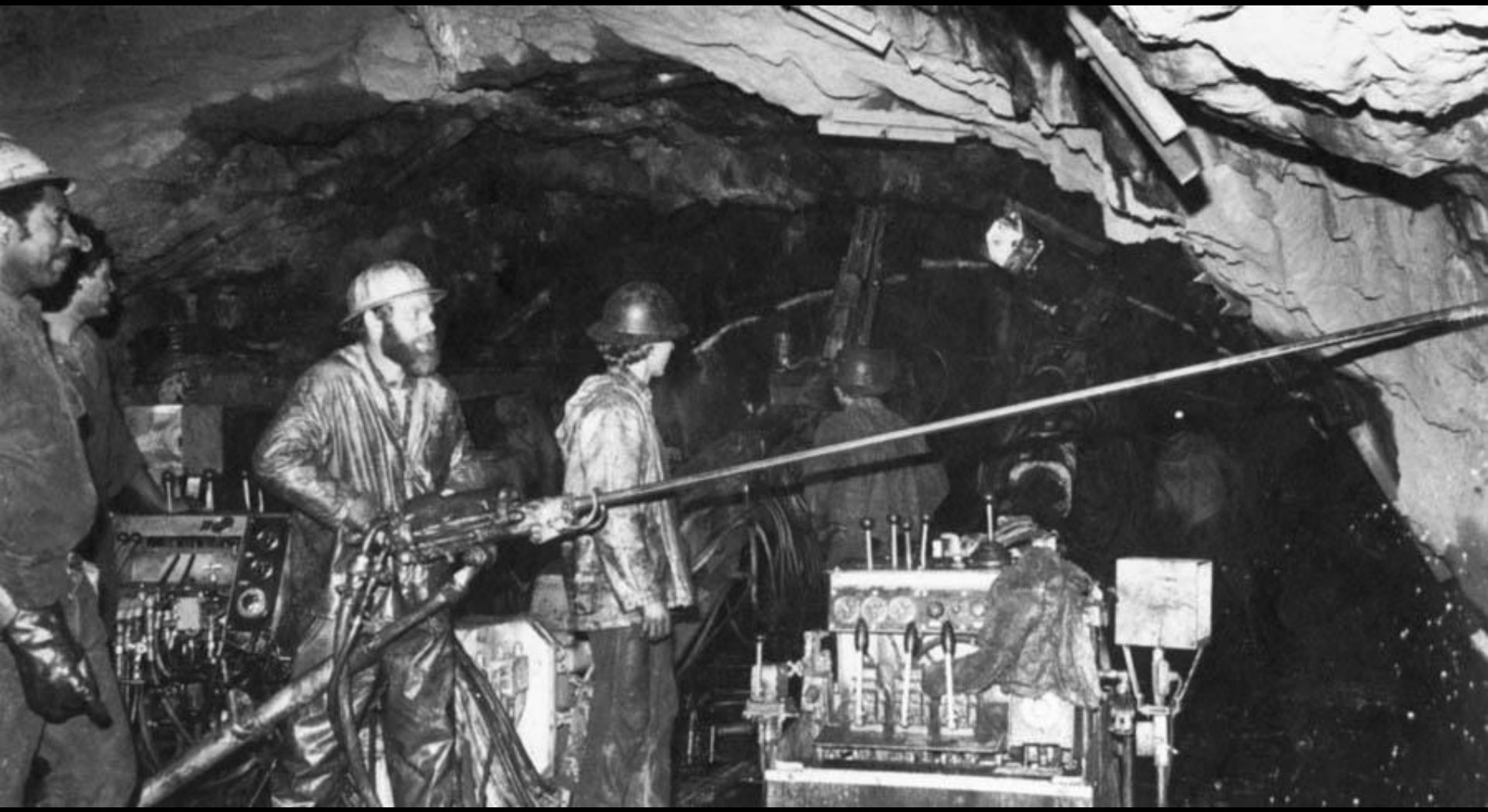

CATSKILL MOUNTAINS
SCHOHARIE RESERVOIR
SHANDAKEN TUNNEL
ASHOKAN RESERVOIR
ESOPUS CUT-AND-COVER
PEAK TUNNEL
RONDOUT PRESSURE TUNNEL
BONTICOU TUNNEL
2000
1000
0
-1000
Catskill Series of Sandstones and Shales
Ashokan Sandstones and Flags
Hamilton Sandstones and Shales
Marcellus Shales
Onondaga Limestone
Esopus Shales
Elderberg Limestone
Shawangunk Grit
0 MILES
10
20
BONTICOU TUNNEL
WALLKILL PRESSURE TUNNEL
NEWBURGH CUT-AND-COVER
MOODNA PRESSURE TUNNEL
Hudson River Slates and Sandstones
Wappinger Limestone
Poughquag Quartzite
30
40
50


Bonticou Tunnel
Peak Tunnel
Rondout Valley
Hamilton Sandstone and Shales
Marcellus Shales
Onondaga Limestone
Esopus Shales
Helderberg Limestones
Shawangunk Grit
Hudson River Slates and Sandstones

Ashokan Reservoir



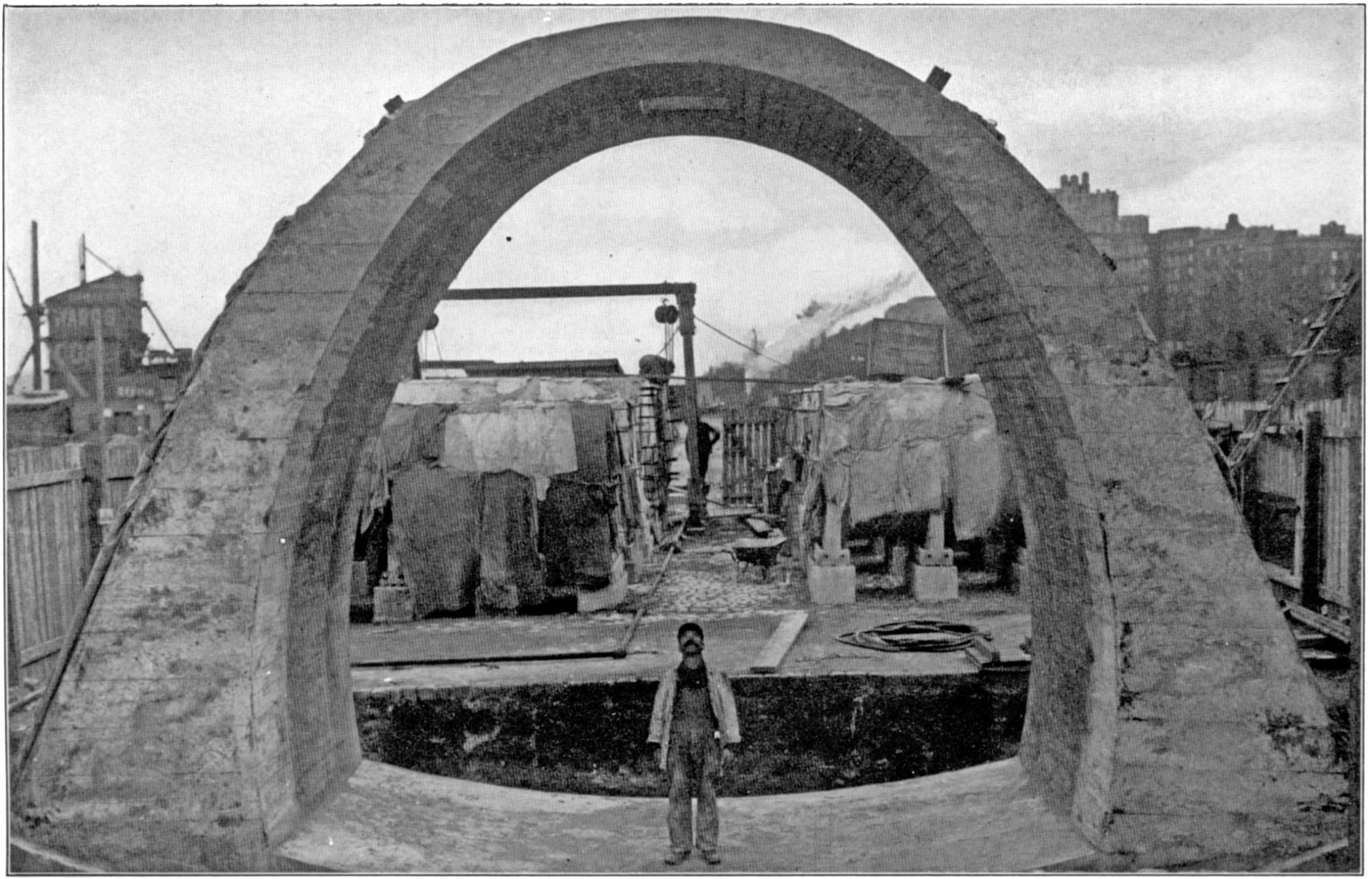

Bluestone Quarry
NW of Kingston



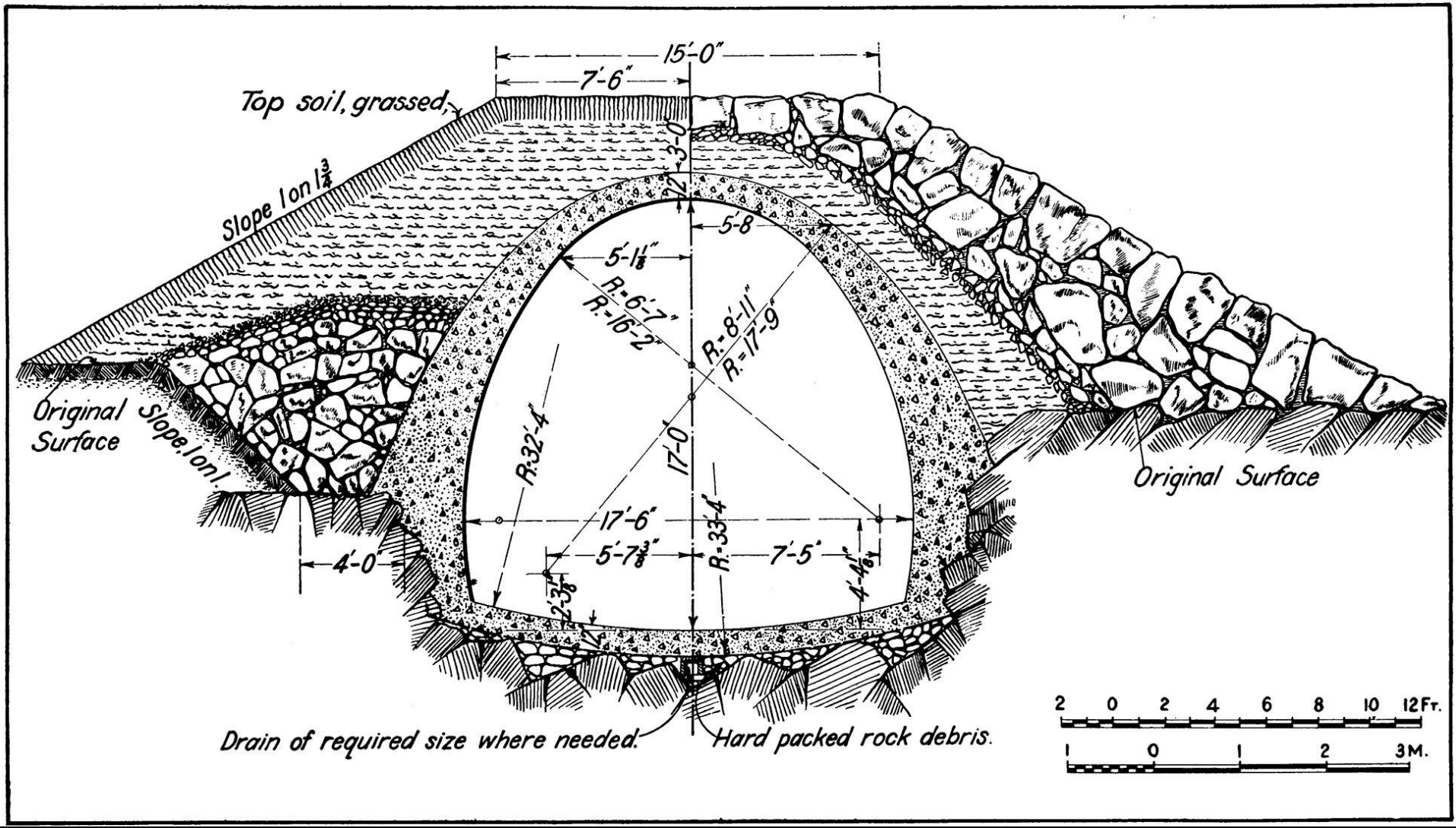
City Tunnel #3, Stage 1 – Drill and Blast Technology

Garrison South Portal, NYC Aqueduct System

Cut and Cover Tunnel, Catskill Aqueduct

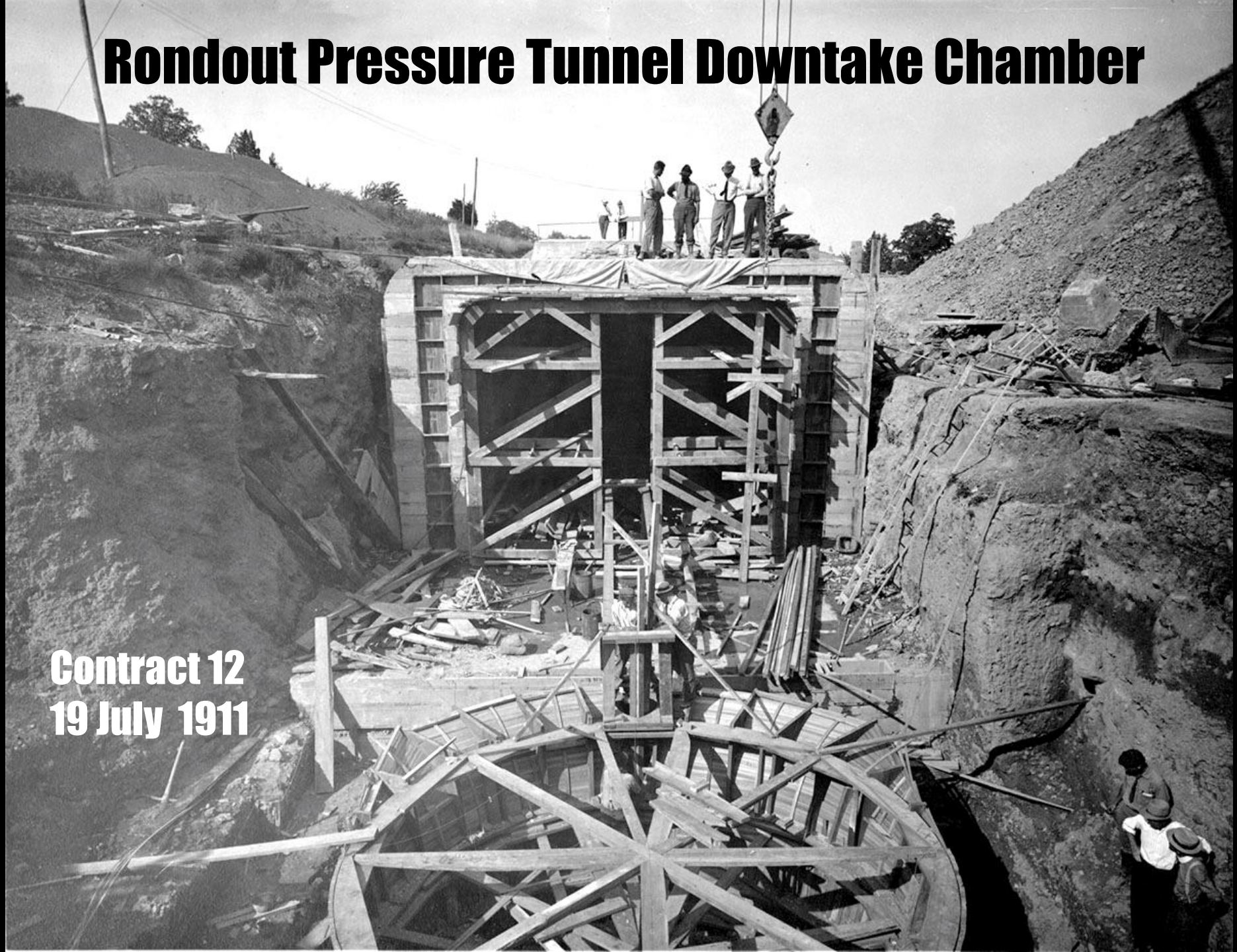


Cut and Cover Tunnel Section (1906)



Cut and Cover Tunnel, Catskill Aqueduct

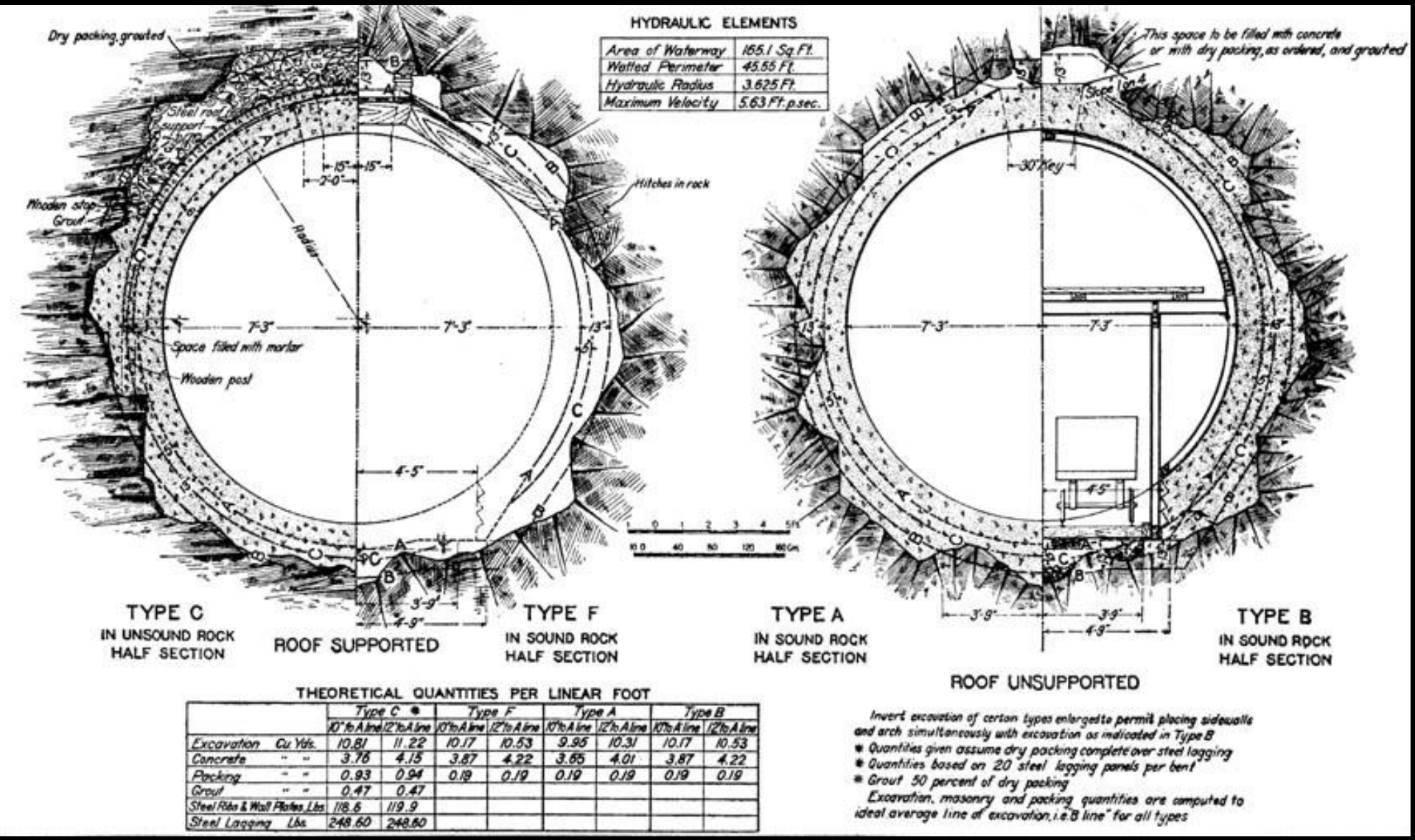
Rondout Pressure Tunnel Downtake Chamber



Contract 12
19 July 1911

Invert Pour, Delaware Aqueduct, Kensico Hill View Tunnel

Rondout - West Branch Tunnel



THEORETICAL QUANTITIES PER LINEAR FOOT

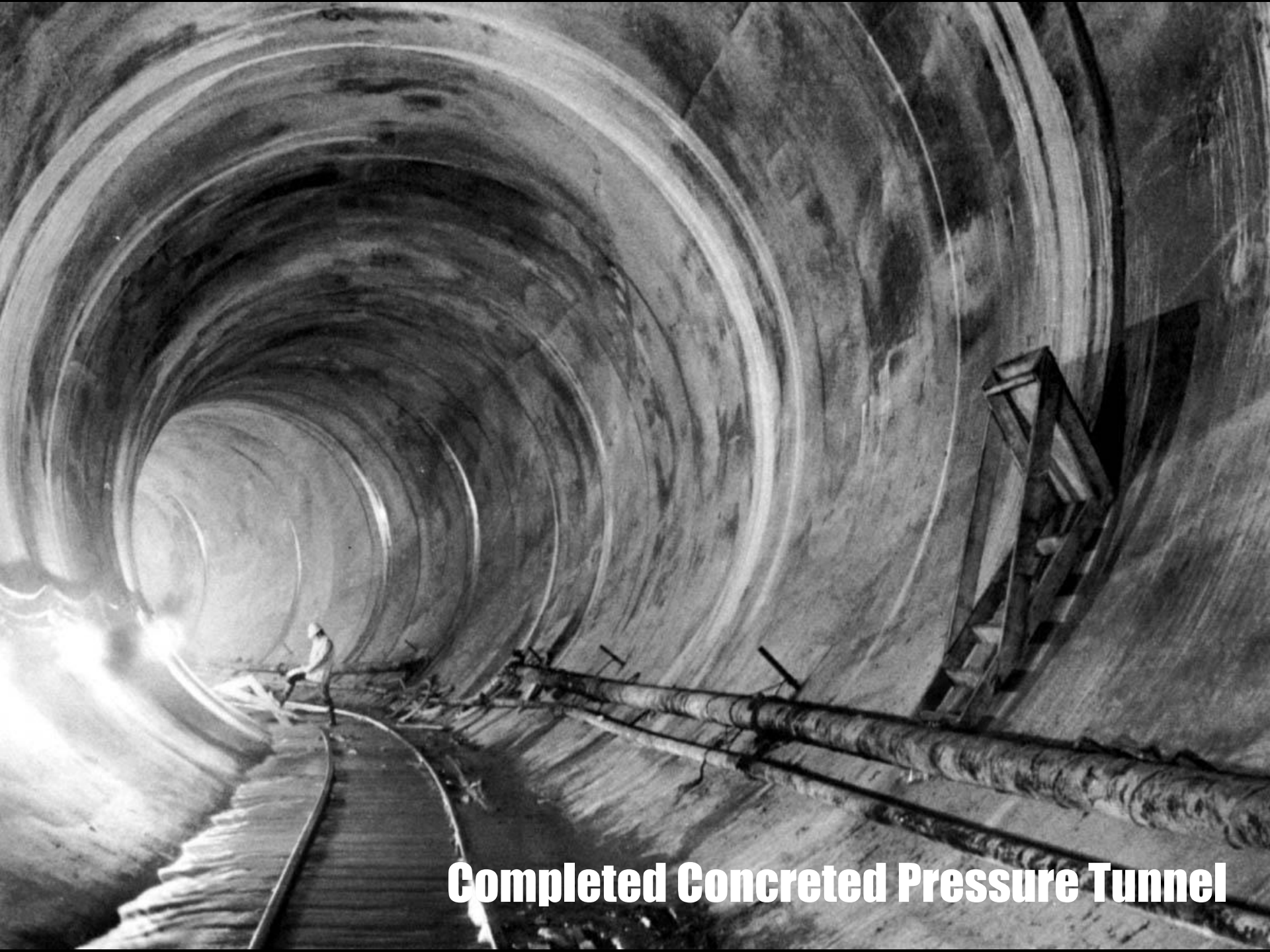
	Type C *		Type F		Type A		Type B	
	10' to A line	12' to A line	10' to A line	12' to A line	10' to A line	12' to A line	10' to A line	12' to A line
Excavation Cu. Yds.	10.81	11.22	10.17	10.53	9.95	10.31	10.17	10.53
Concrete " "	3.76	4.15	3.87	4.22	3.65	4.01	3.87	4.22
Packing " "	0.93	0.94	0.19	0.19	0.19	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						

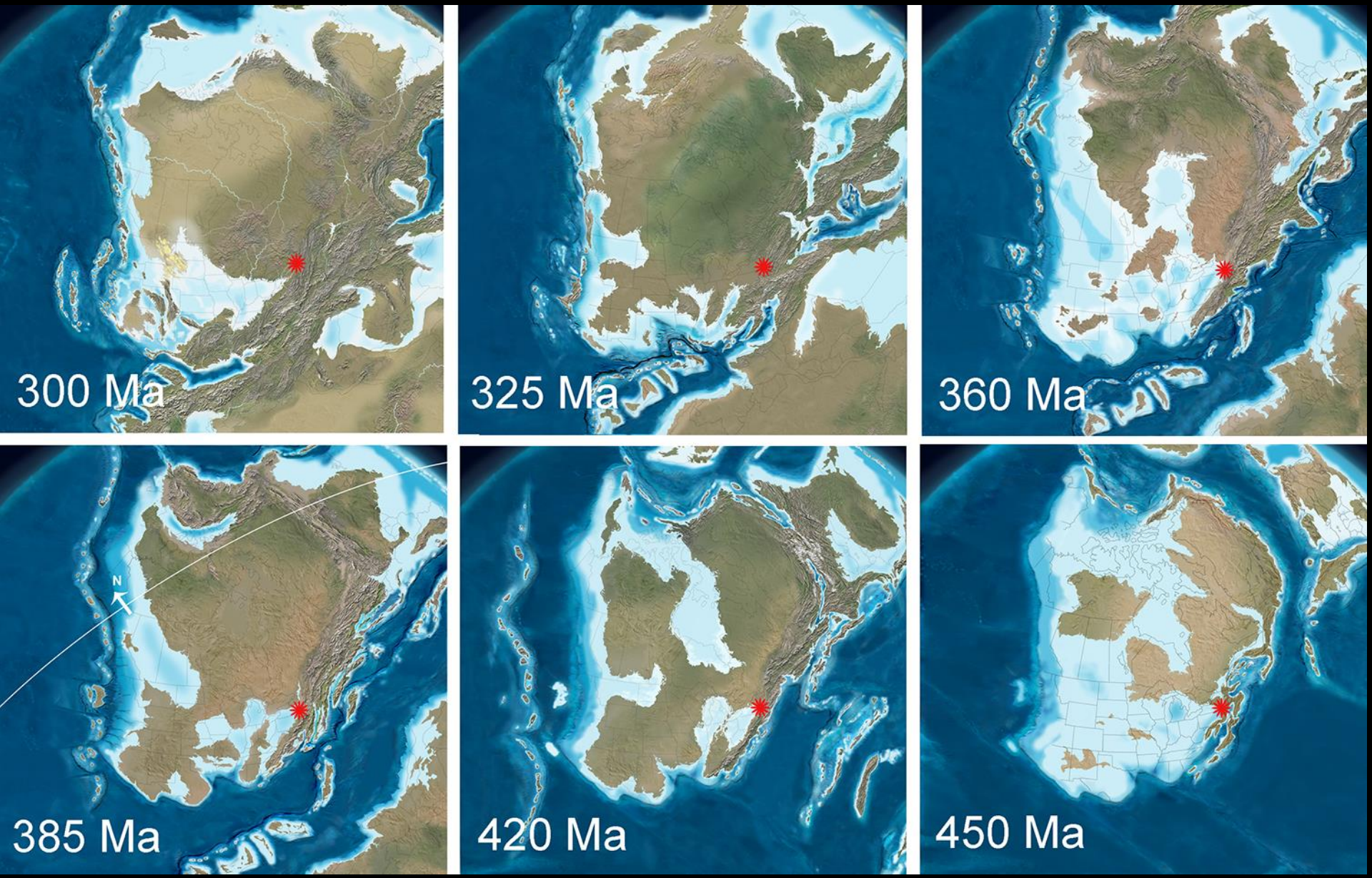
Invert excavation of certain types enlarged to permit placing sidewalls and arch simultaneously with excavation as indicated in Type B

* Quantities given assume dry packing complete over steel lagging
* Quantities based on 20 steel lagging panels per bent
* Grout 50 percent of dry packing

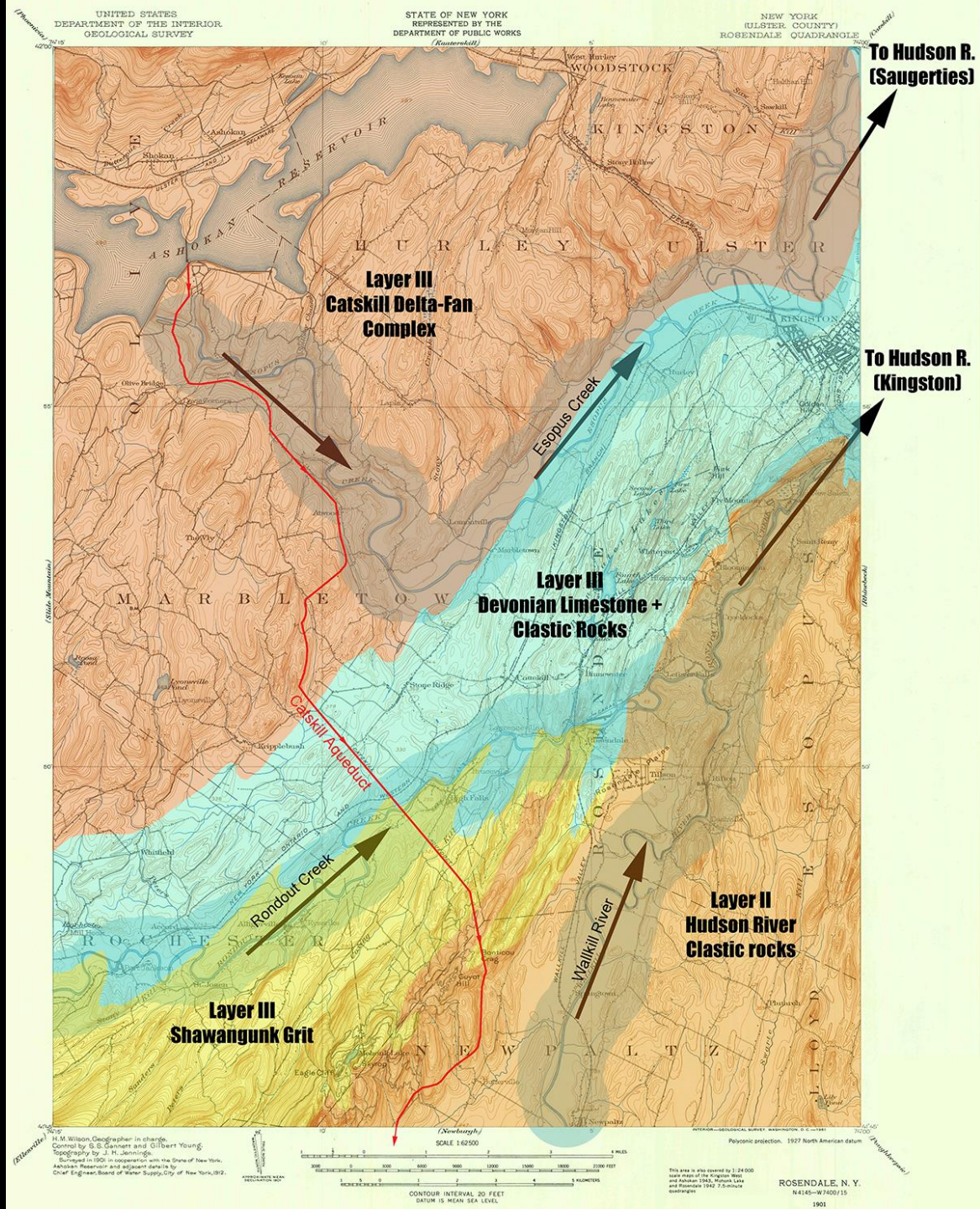
Excavation, masonry and packing quantities are computed to ideal average line of excavation, i.e. B line" for all types

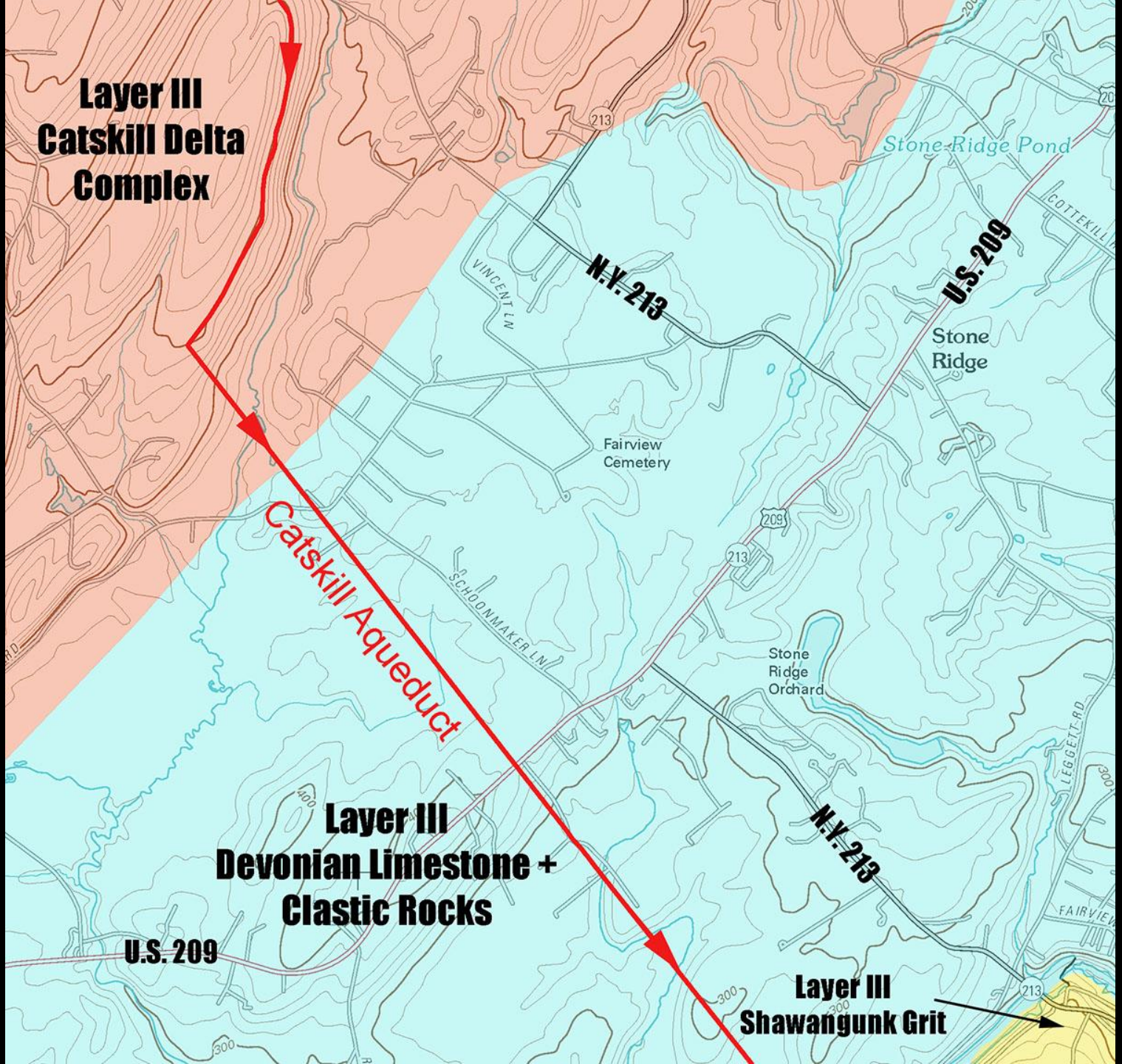
Pressure Tunnel Construction, NYC Aqueduct System

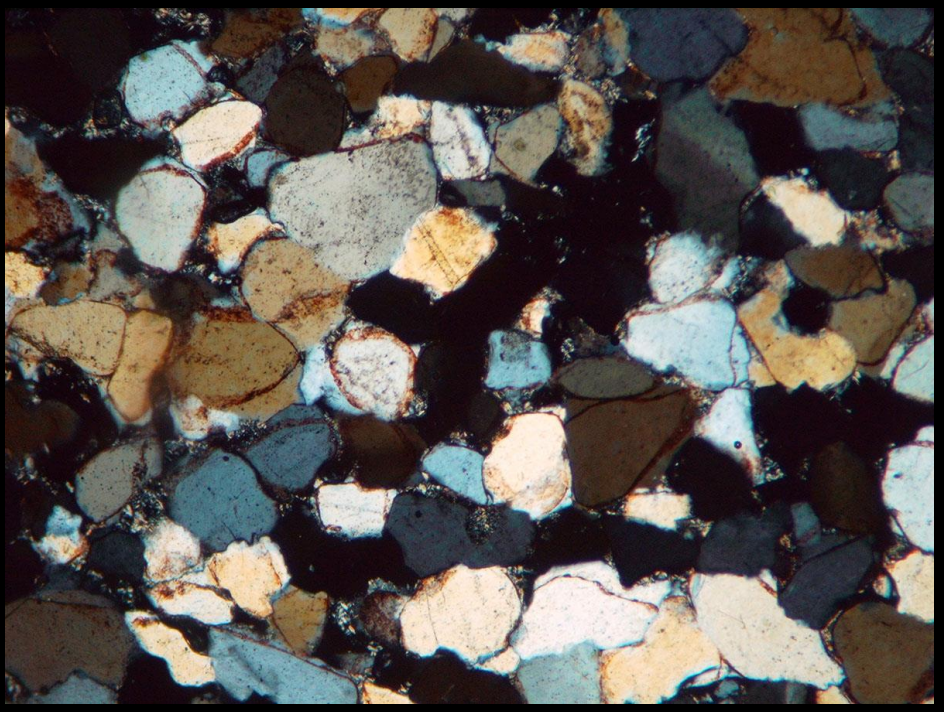

Completed Concreted Pressure Tunnel

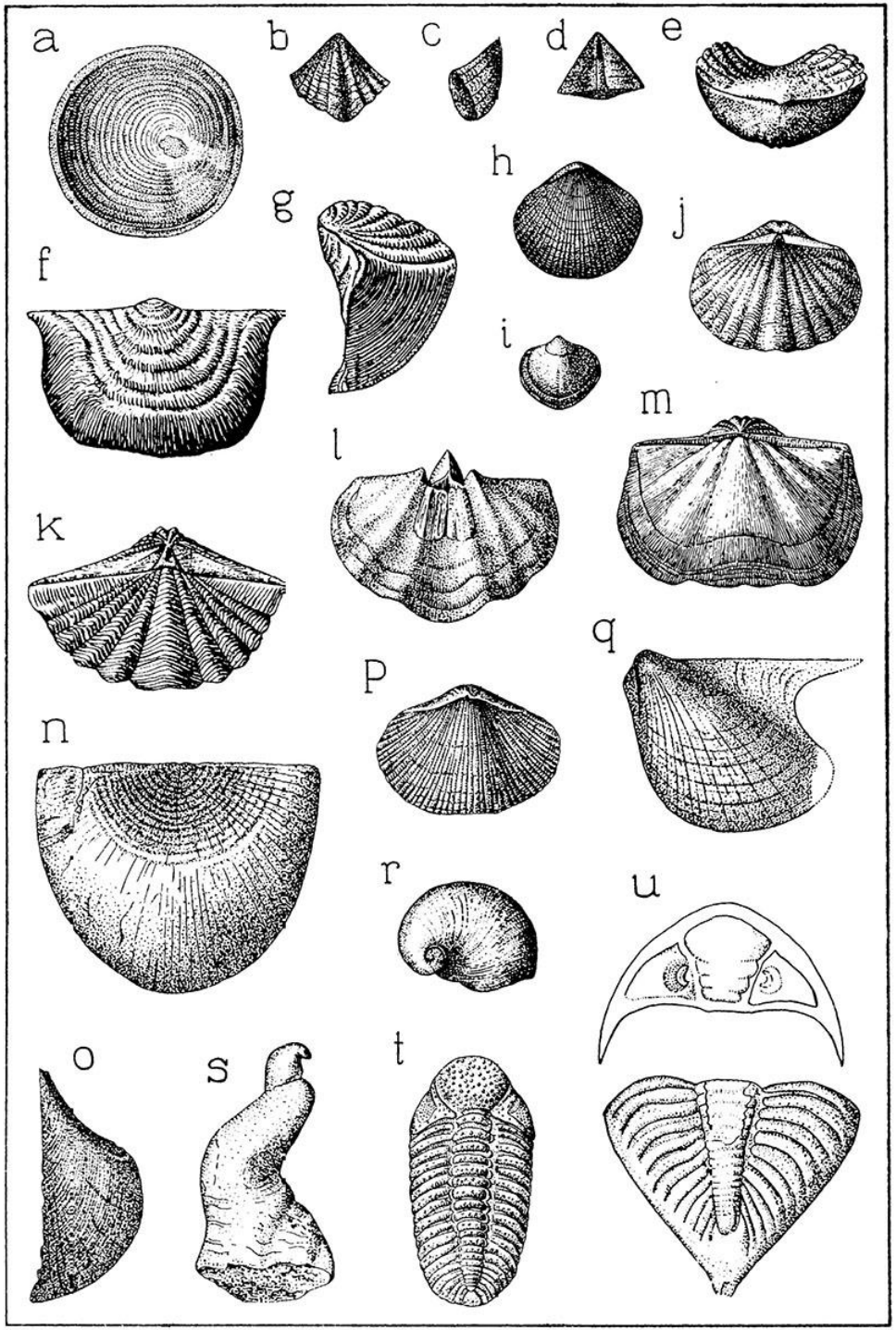


150 Ma


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
STATE OF NEW YORK
REPRESENTED BY THE
DEPARTMENT OF PUBLIC WORKS
NEW YORK
(ULSTER COUNTY)
ROSENDALE QUADRANGLE
To Hudson R.
(Saugerties)
To Hudson R.
(Kingston)
Layer III
Catskill Delta-Fan
Complex
Layer III
Devonian Limestone +
Clastic Rocks
Layer II
Hudson River
Clastic rocks
Layer III
Shawangunk Grit
Esopus Creek
Rondout Creek
Wallkill River
Catskill Aqueduct
WOODSTOCK
KINGSTON
HURLEY
ULSTER
MARBLETOWN
ROCHESTER
NEW PALTZ
ROSENDALE, N. Y.
N4145—W7400/15
1901
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL
SCALE 1:62500
Polyconic projection. 1927 North American datum


Layer III
Catskill Delta
Complex
Stone Ridge Pond
N.Y. 213
U.S. 209
Stone
Ridge
Fairview
Cemetery
Catskill Aqueduct
Stone
Ridge
Orchard
Layer III
Devonian Limestone +
Clastic Rocks
U.S. 209
N.Y. 213
Layer III
Shawangunk Grit

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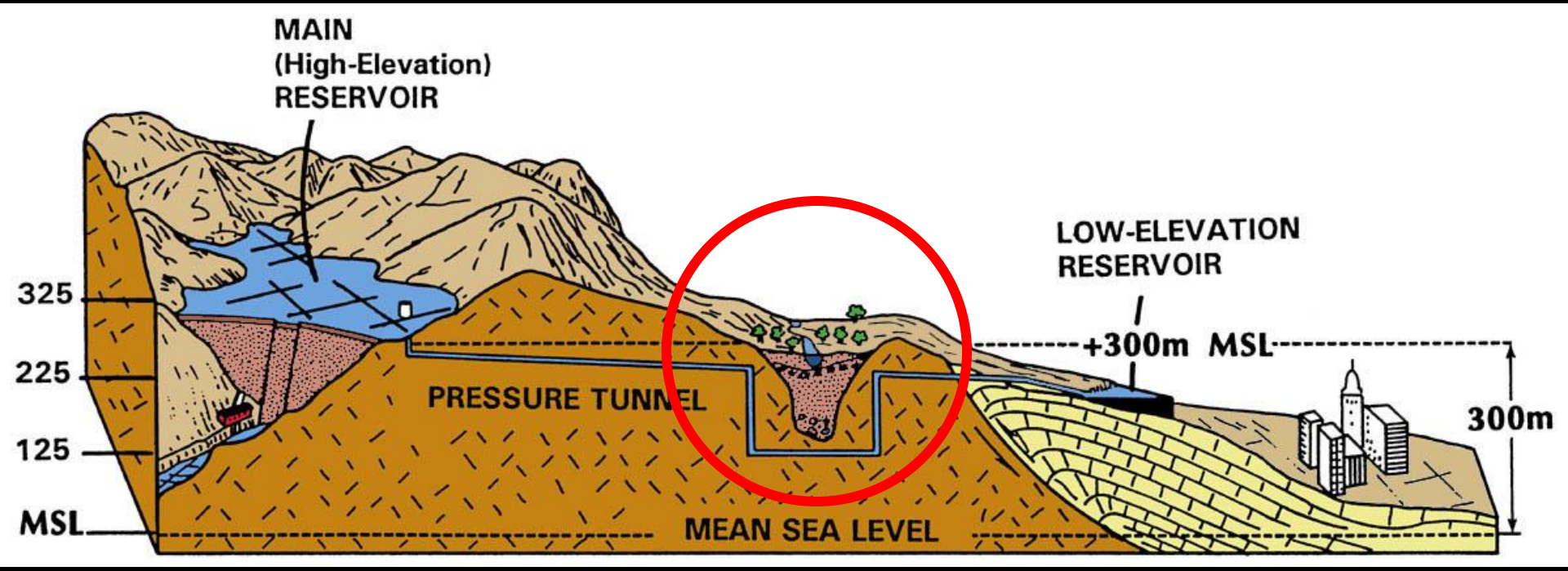
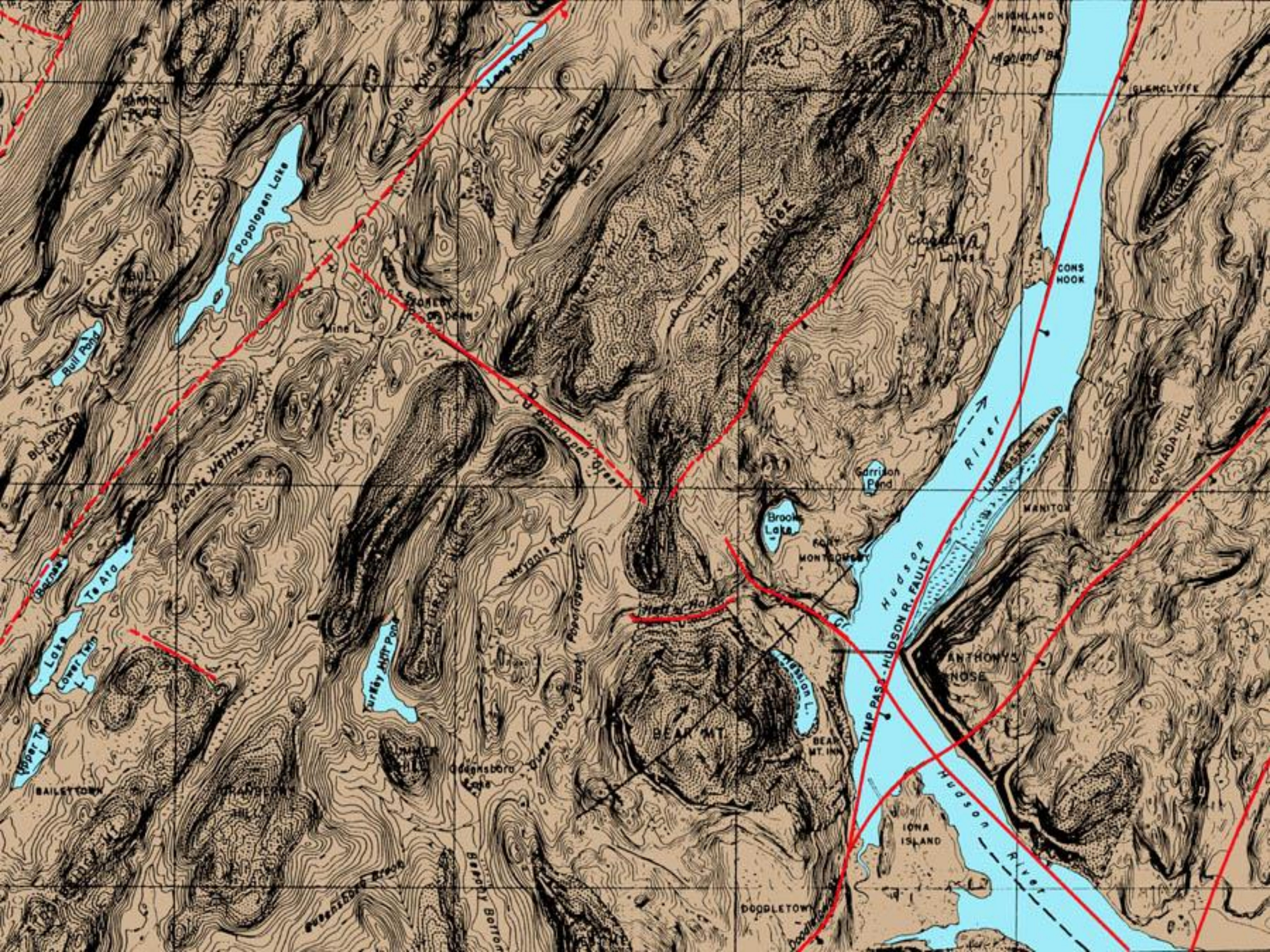
Hudson River Pressure Tunnel



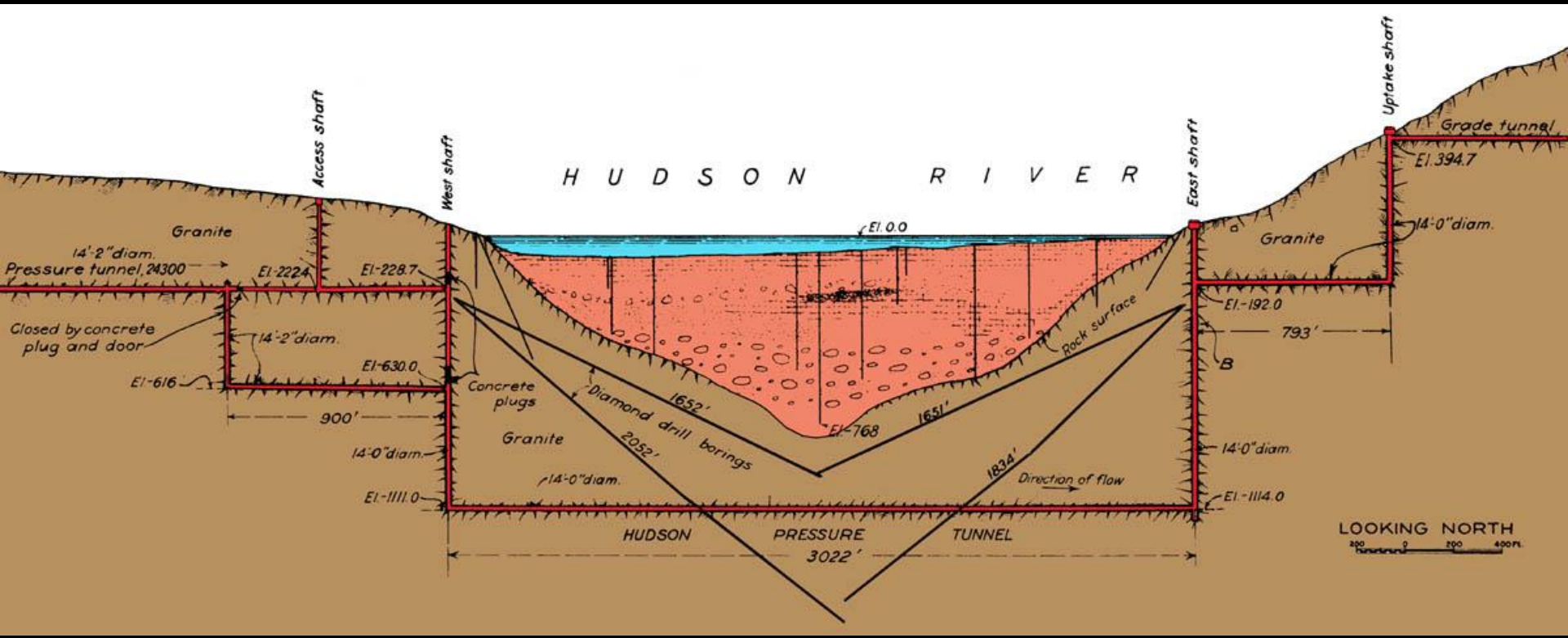
Hudson River Gorge from Bear Mtn., NY



HIGHLAND FALLS
GLENCLYFFE
Long Pond
Popolopen Lake
Bull Pond
CONS HOOK
Garrison Pond
Brooks Lake
FORT MONTGOMERY
Hudson River
HUDSON R. FAULT
ANTHONY'S NOSE
CANADA HILL
MANITOU
Hessian L.
BEAR MT.
BEAR MT. INN
IONA ISLAND
Hudson River
DOODLETOWN
BAILEYTOWN
Te Ata
Lake
Lower Twin
Upper Twin

Exploratory Drilling for Hudson Siphon, NYC Aqueduct

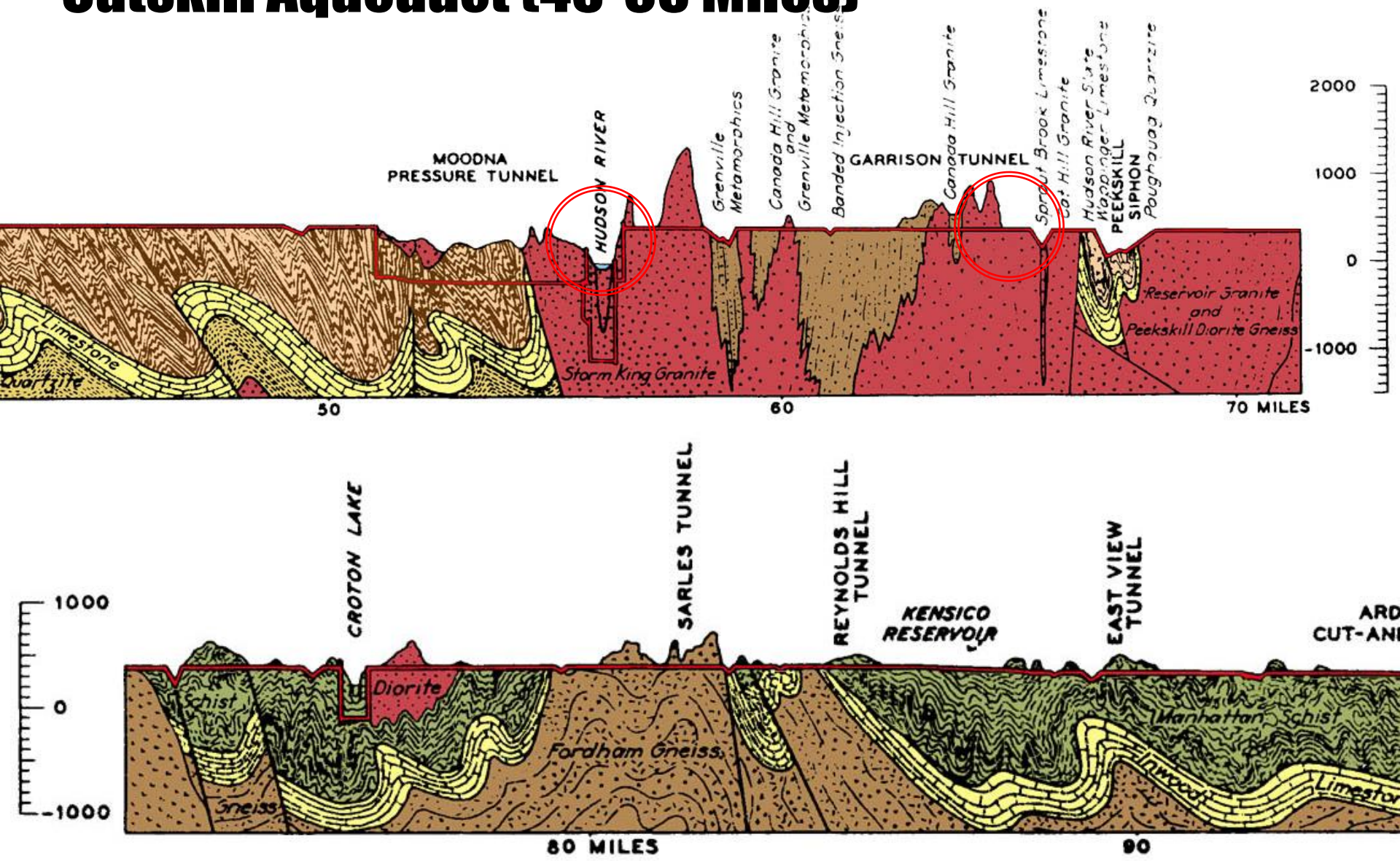
Hudson Siphon [-1,114']



NYC Aqueduct

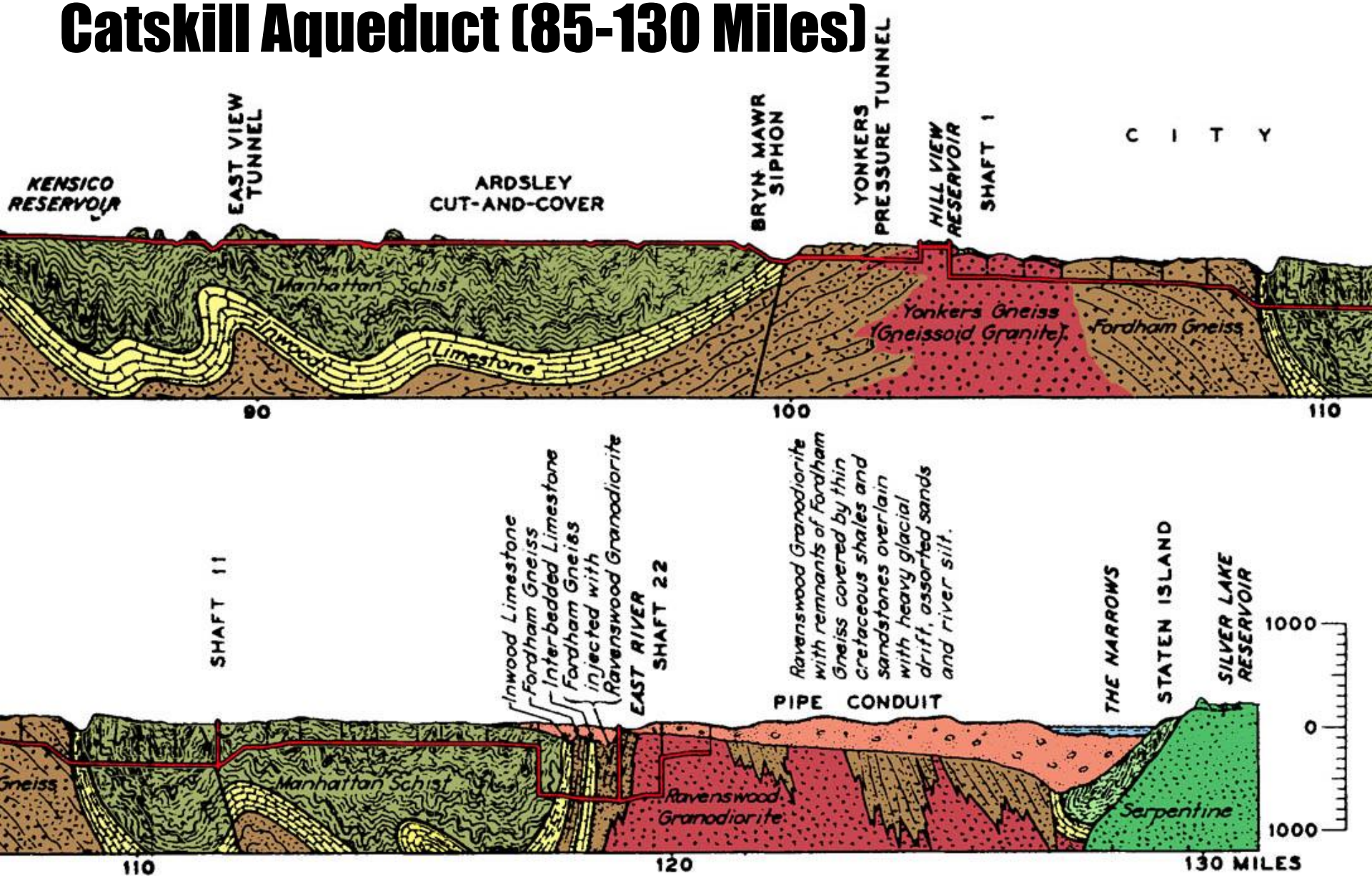
after Berkey, 1911

Catskill Aqueduct (45-95 Miles)

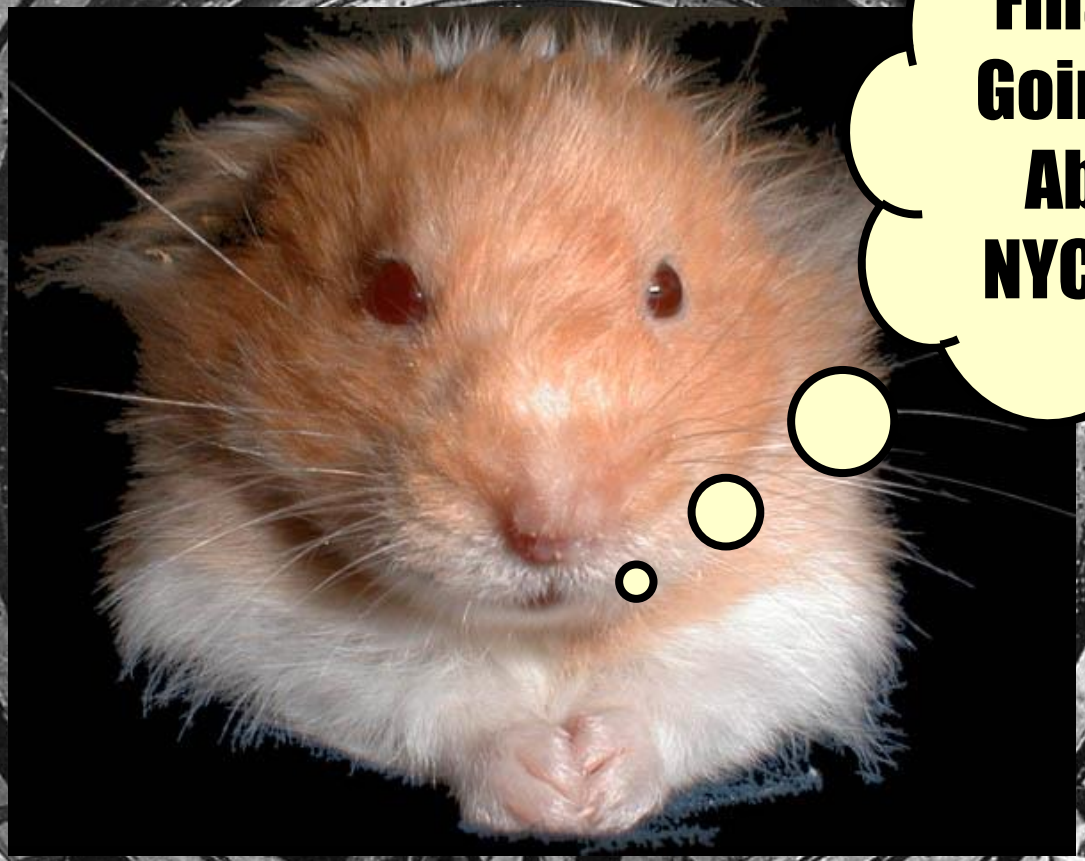


after Berkey, 1933

Catskill Aqueduct (85-130 Miles)



after Berkey, 1933

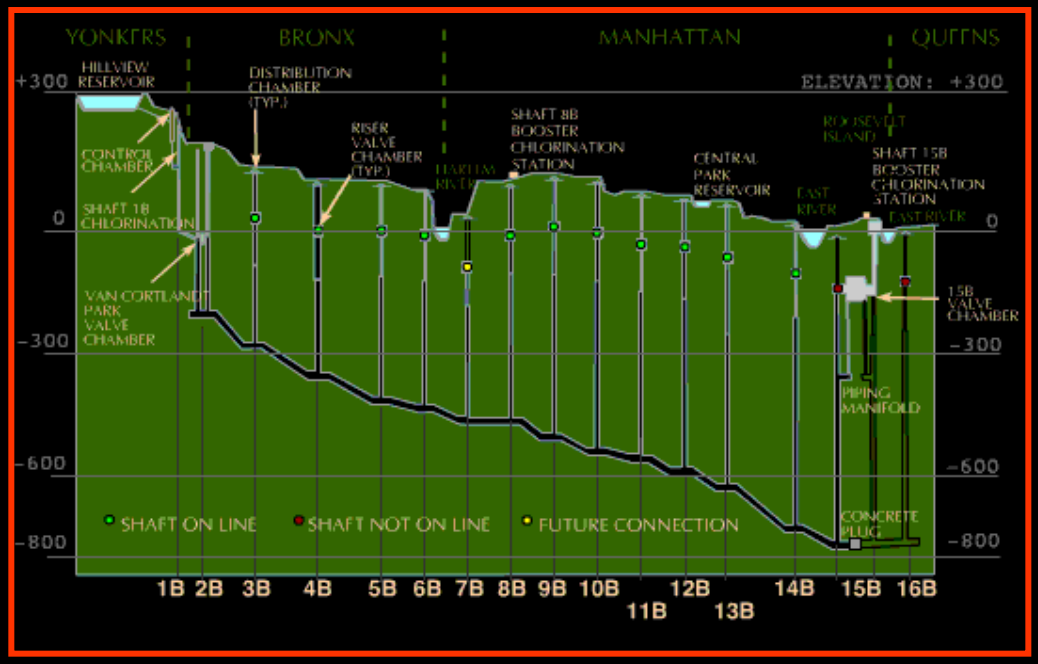


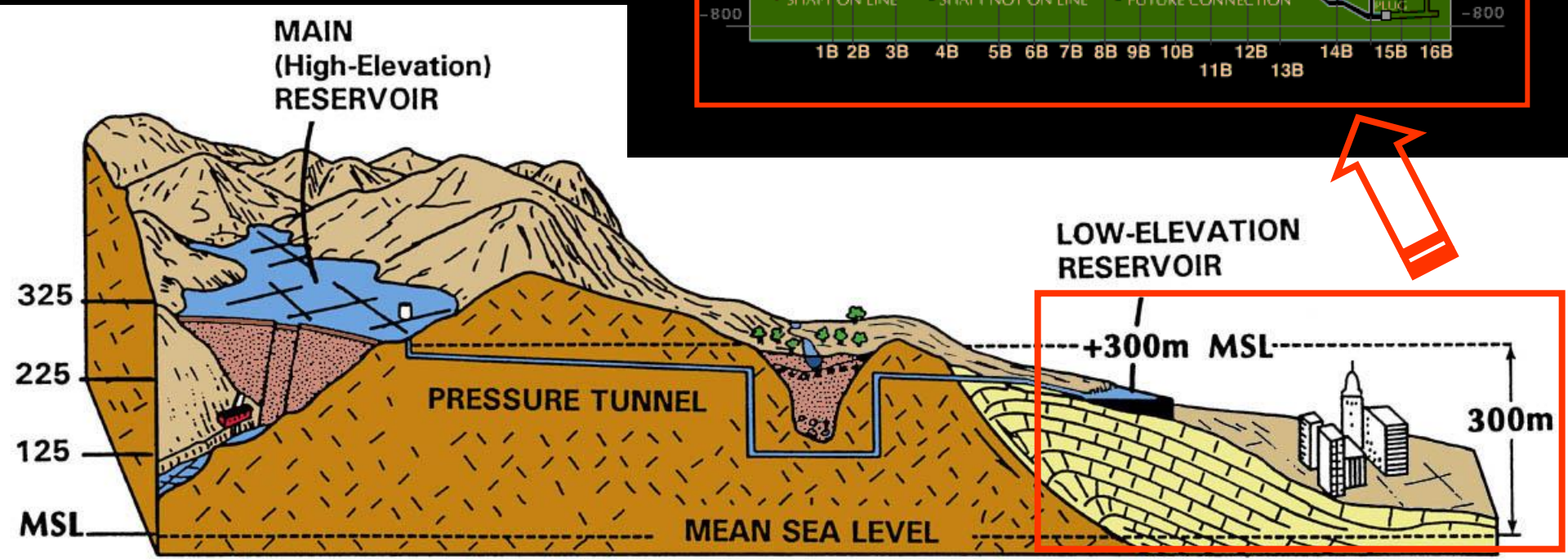
Finally, He's Going to Talk About the NYC Tunnels

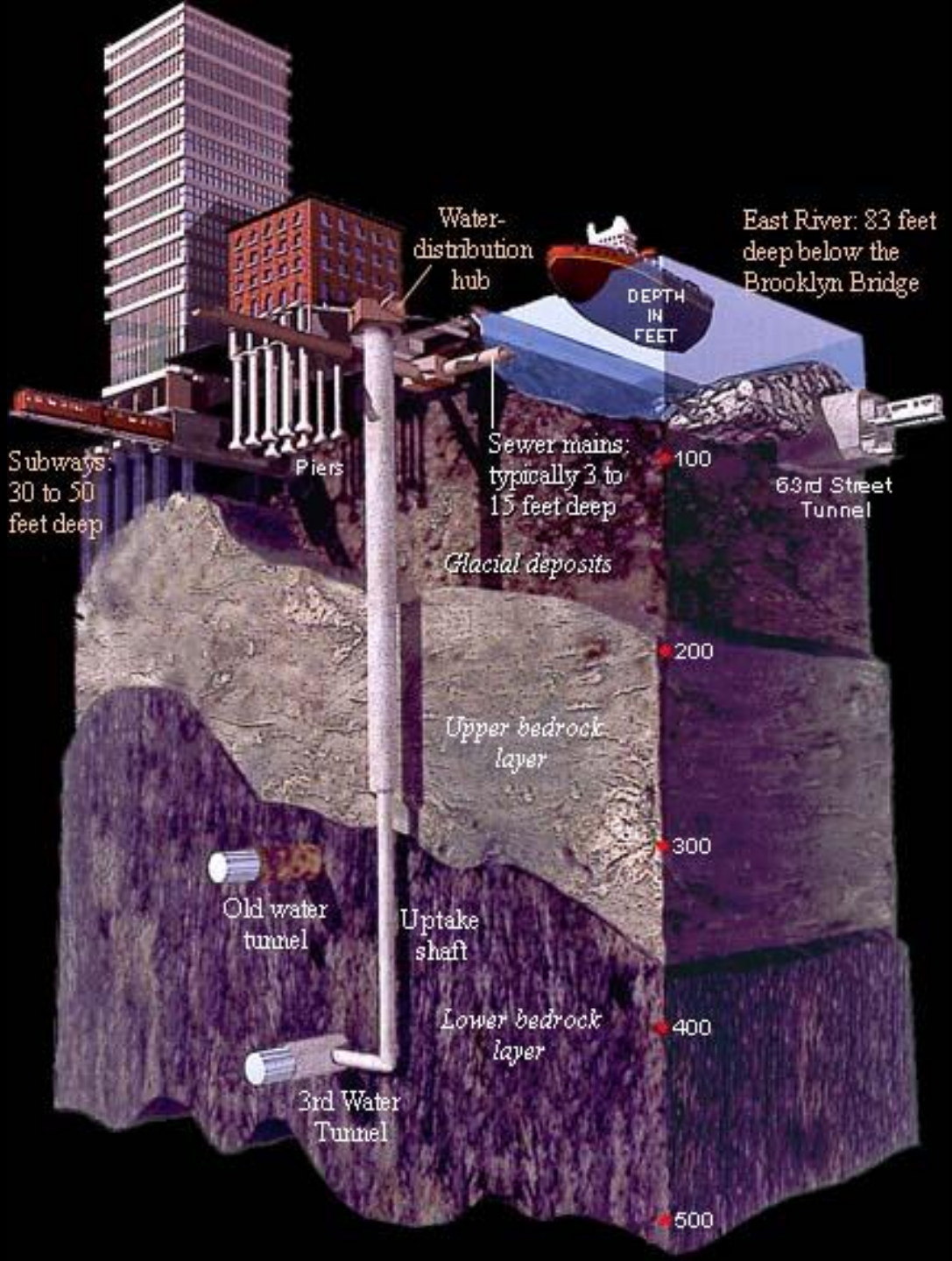
City Tunnel #3 Stage 1


Van Cortlandt Chamber

Gravity Feed System

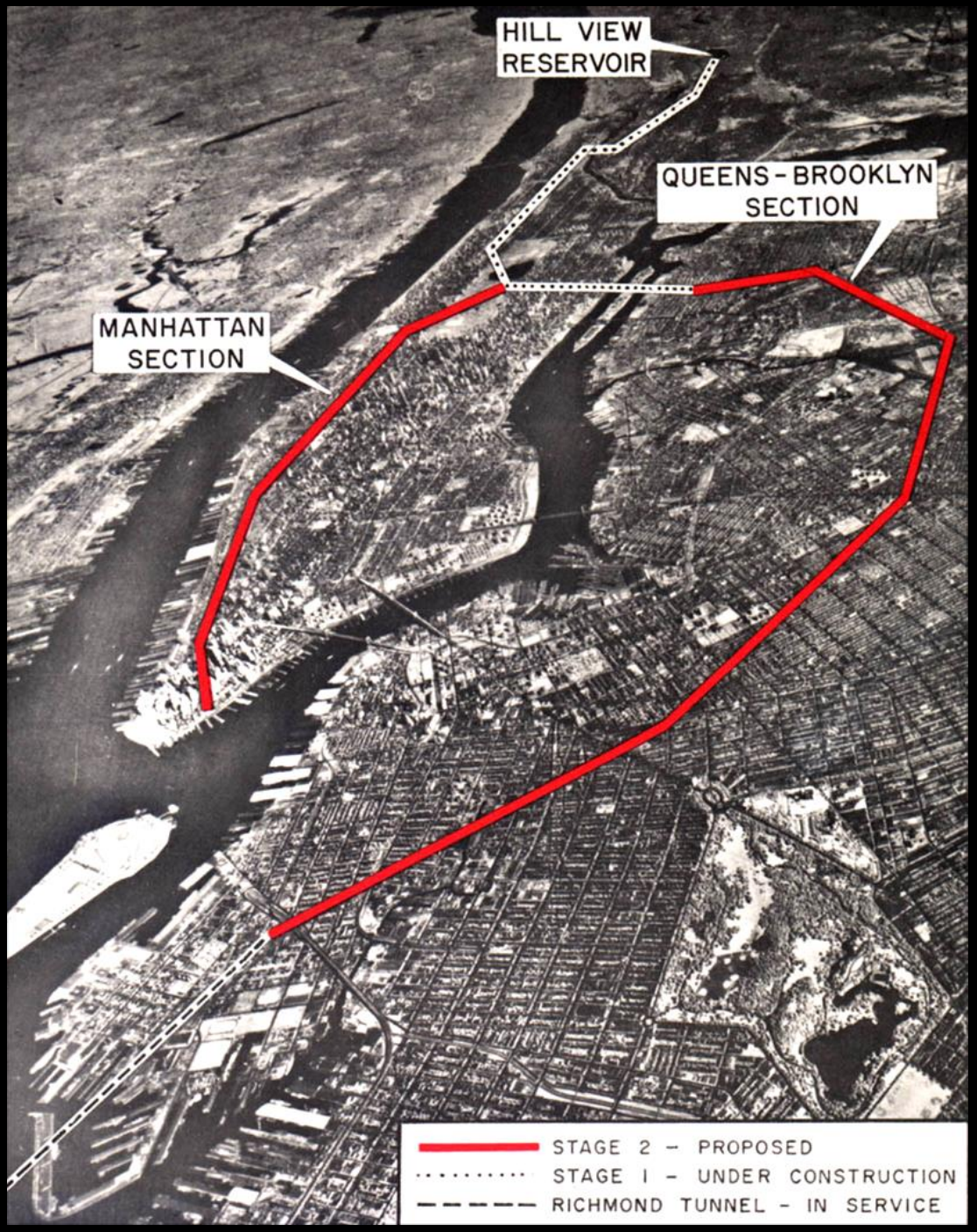


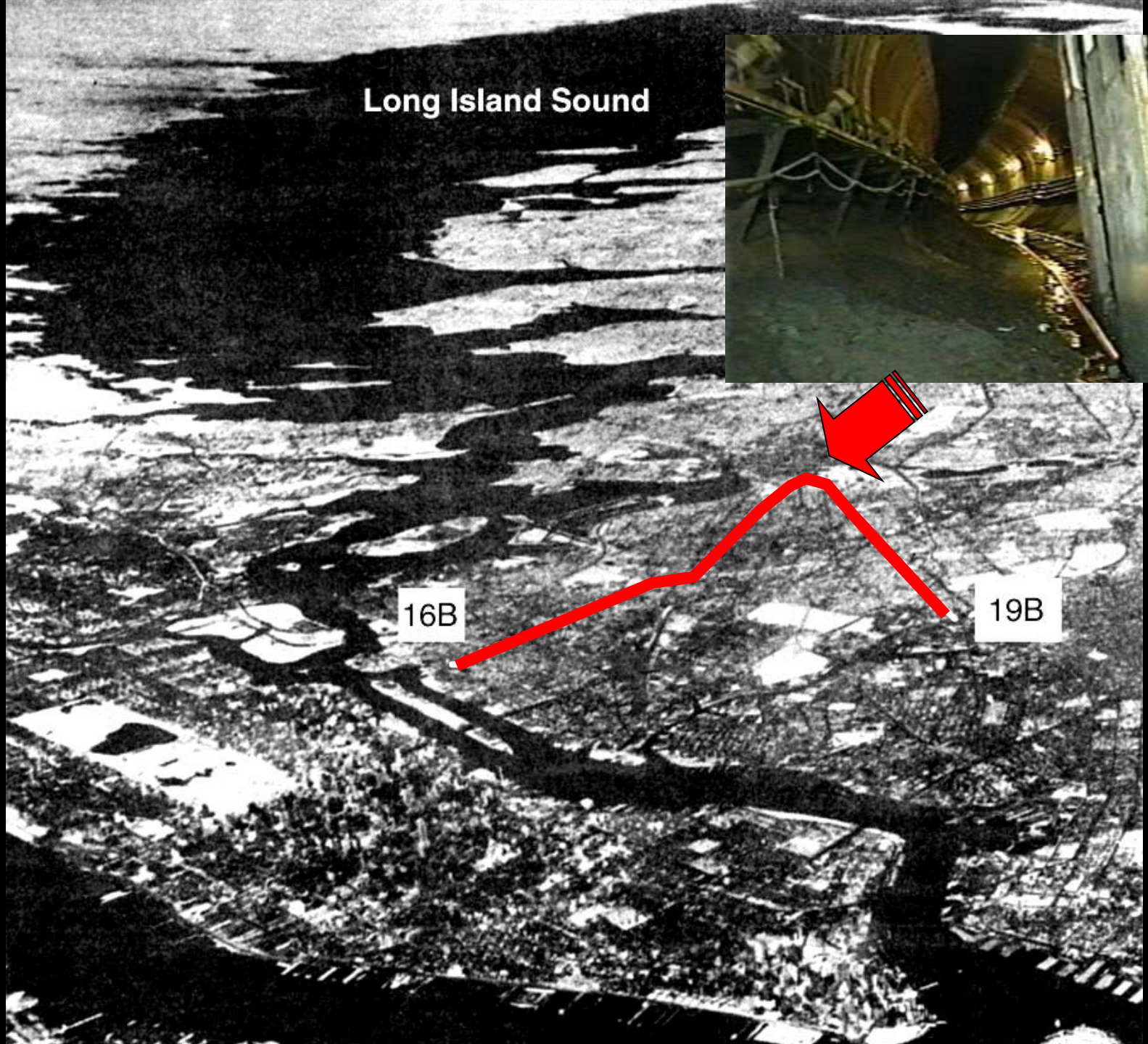




Municipal Subsurface Structure

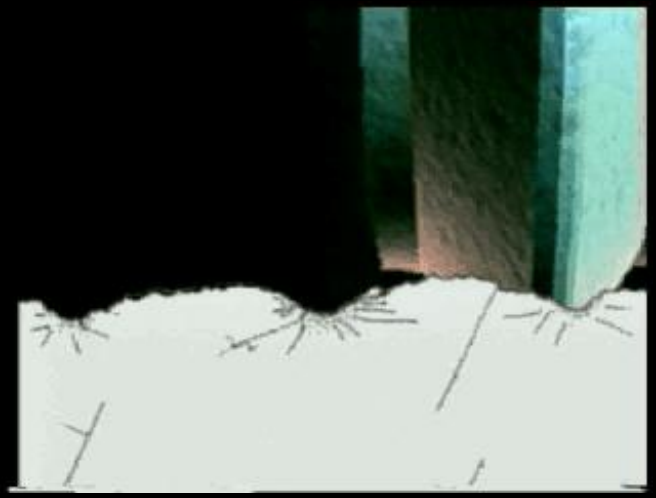
City Tunnel #3
Stages 1 and 2

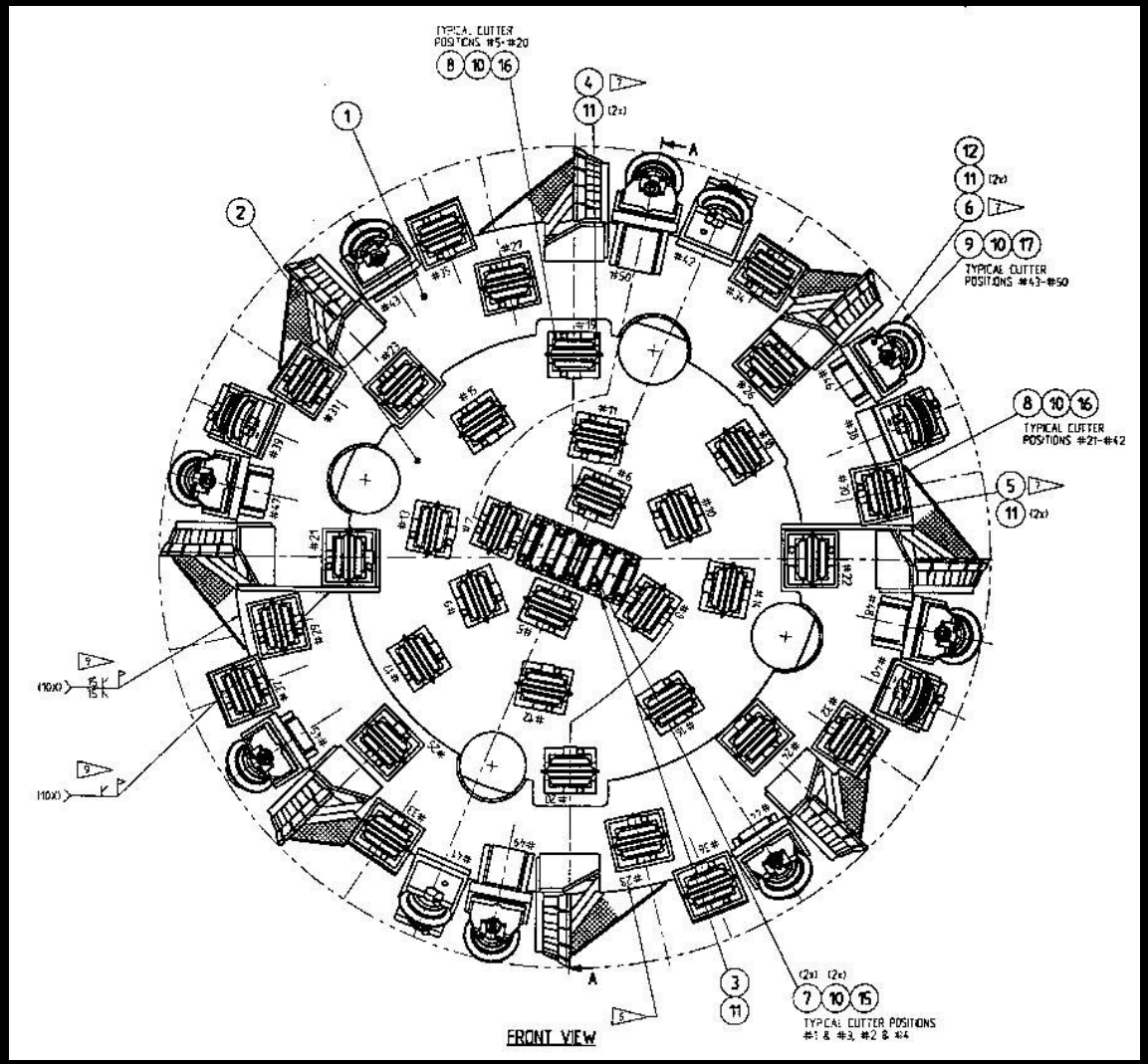



Long Island Sound
16B
19B

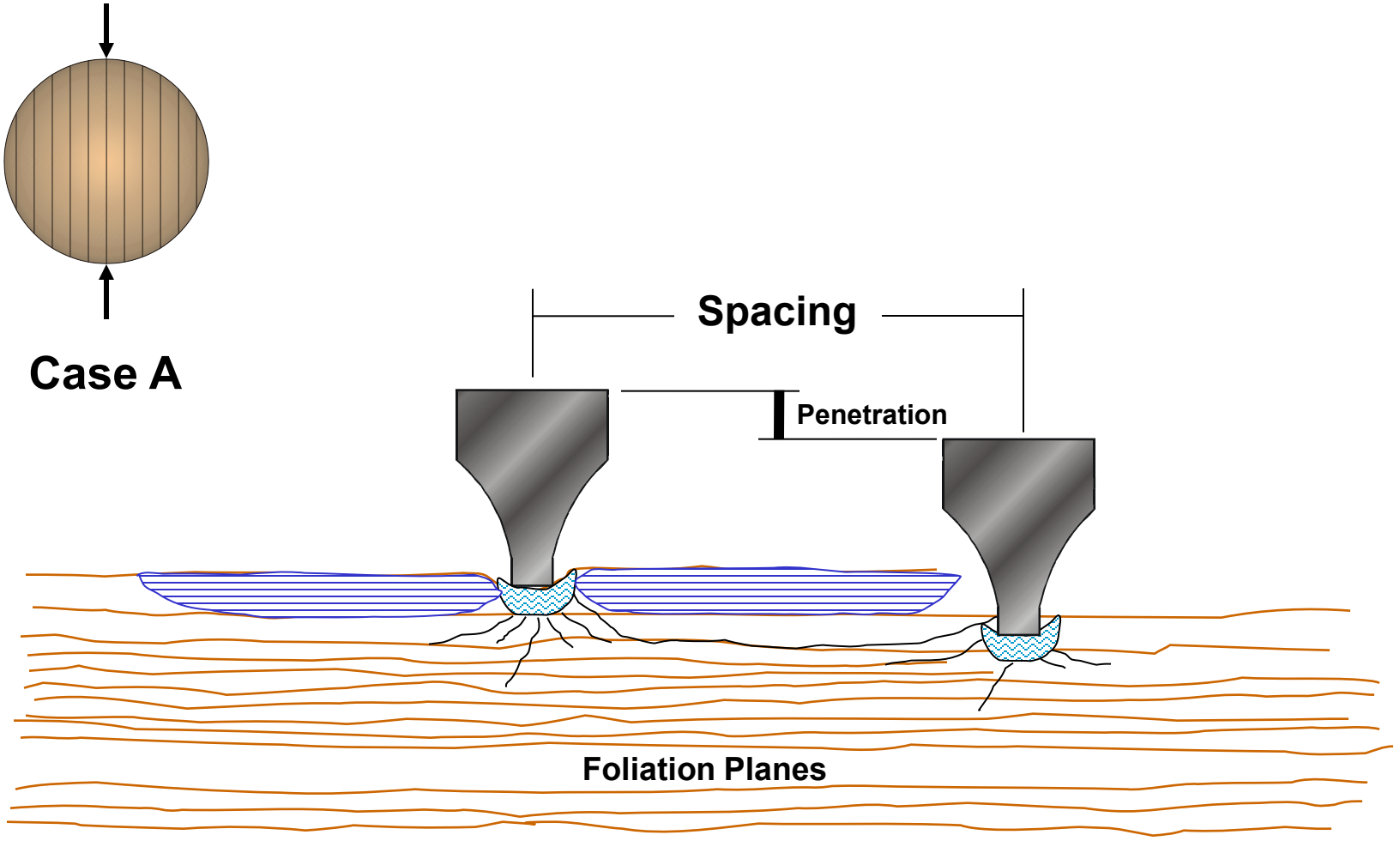
Excavation Methods

Dukelabs TBM Research



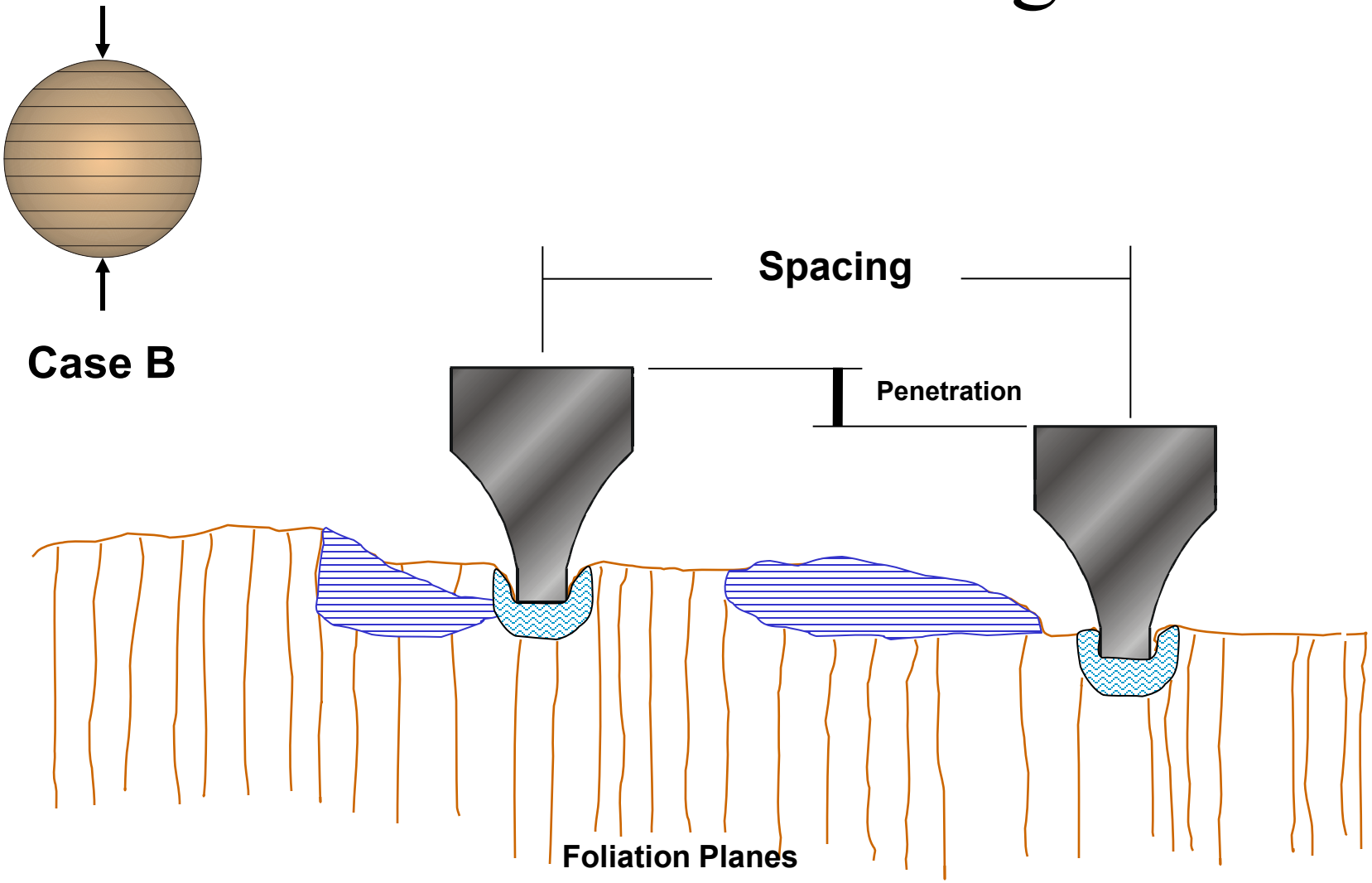


Foliation Planes Parallel



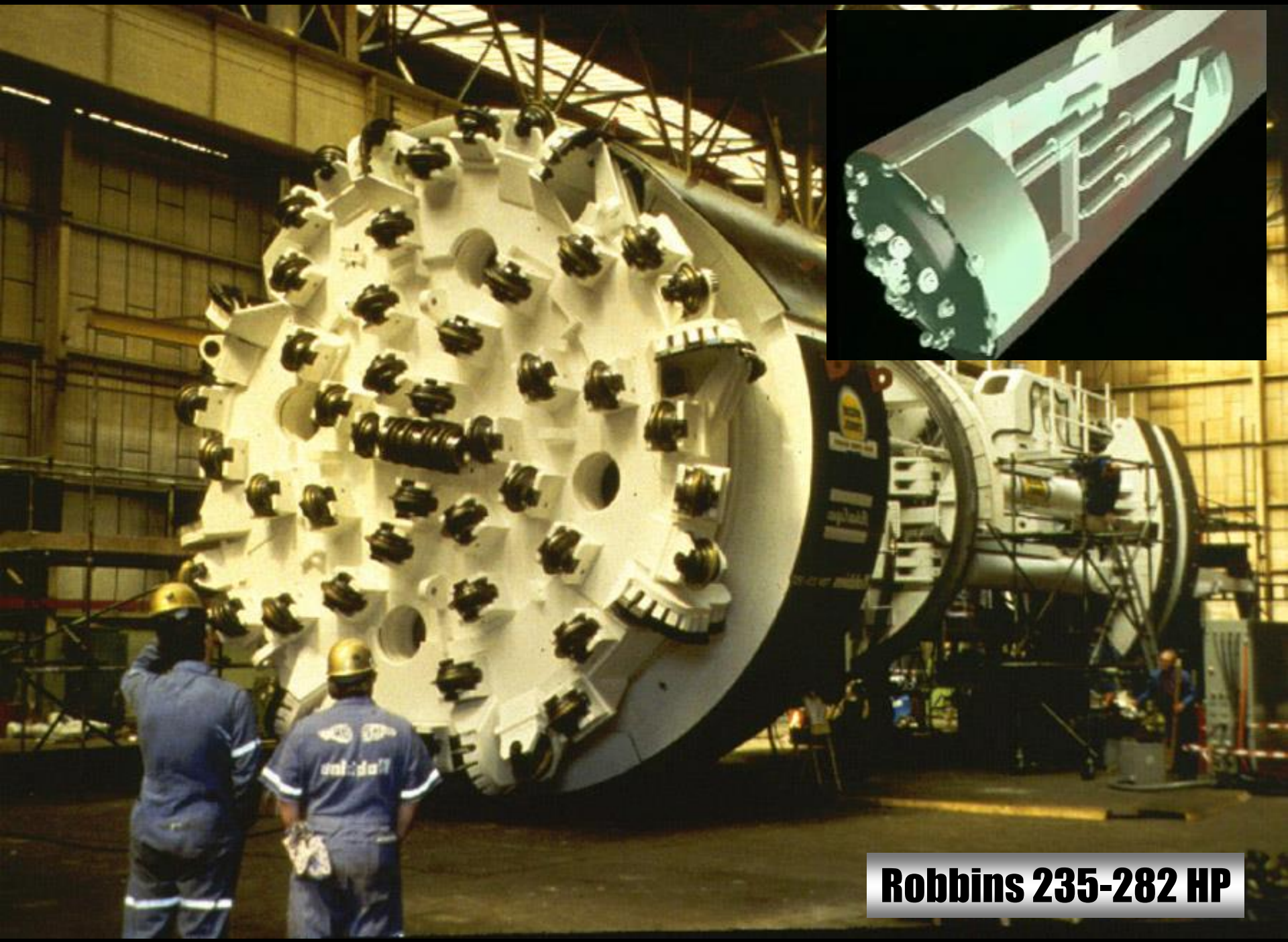
Chipping mechanism when TBM advancing perpendicular to foliation (Case A)

Foliation Planes Orthogonal

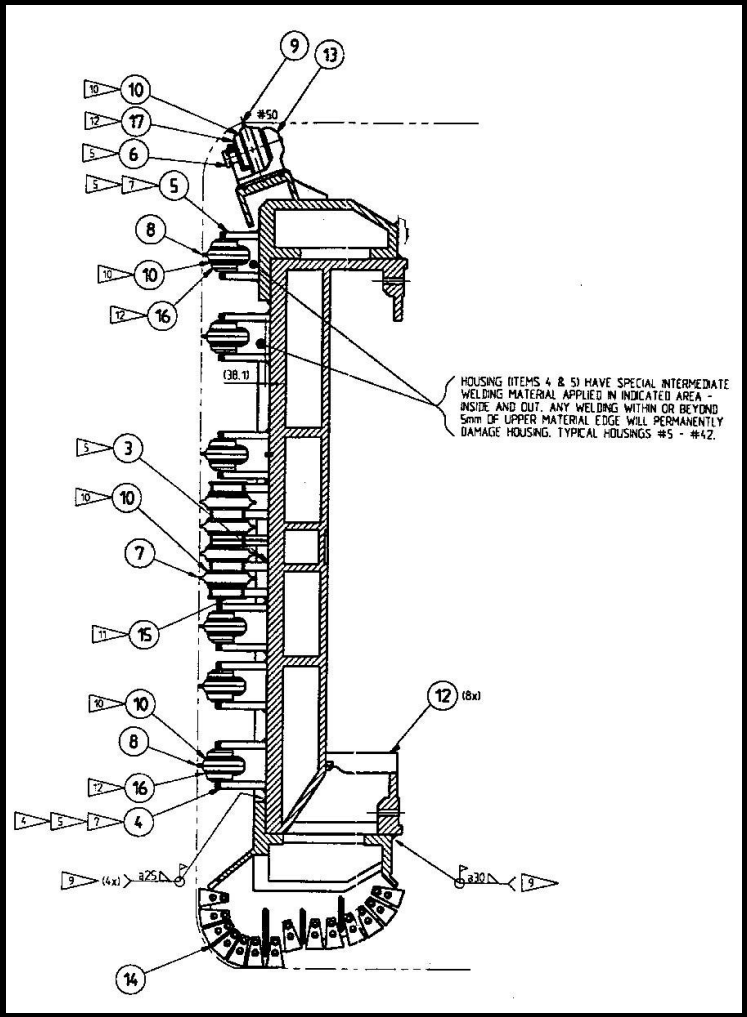


Chipping mechanism when TBM advancing parallel to foliation (Case B)


Normal TBM Chips


Robbins 235-282 HP

Kerf Pattern in Hard Rock



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 Research on TBM Cutter Head Torque Dynamics

Six-Month Training Period Beset by Aimless, Unfocused, Lackluster Performance

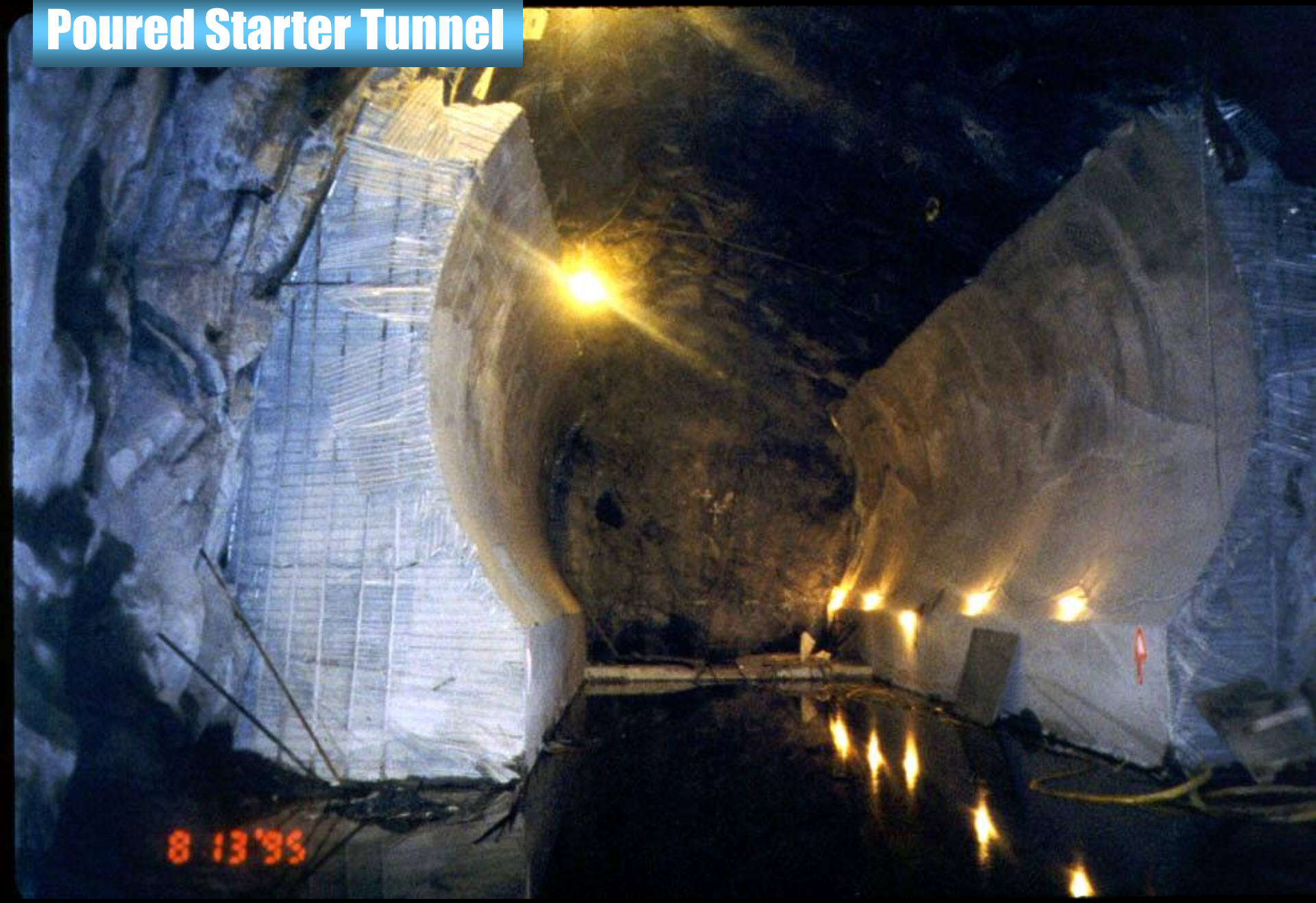
Drilling Bellout for Blasting

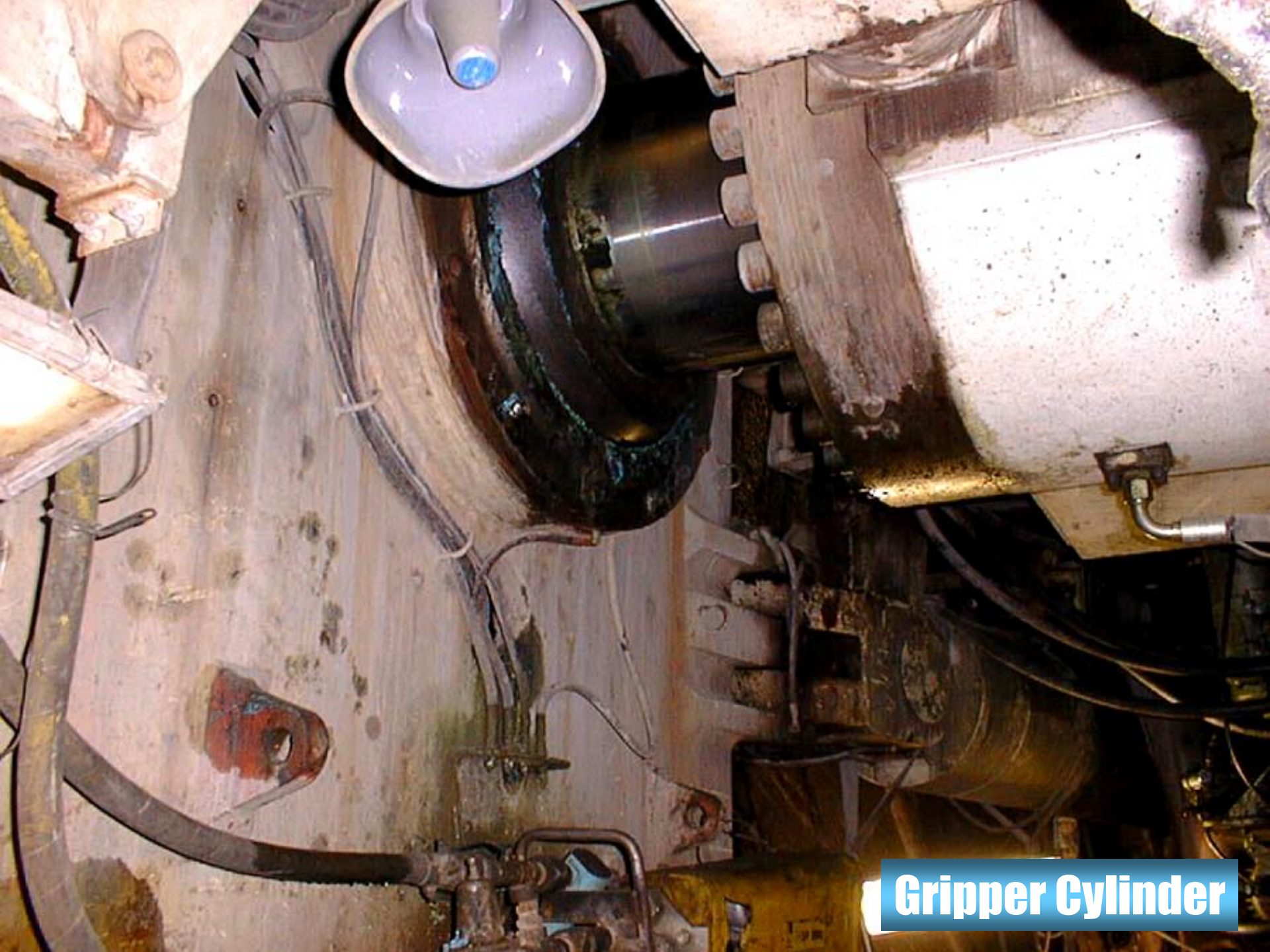
Flipping TBM Cutterhead

Lowering TBM Cutterhead

Lowering TBM Mainbeam

Poured Starter Tunnel




Gripper Cylinder

In the Belly of the Beast

Operator's Cabin


TBM-Bored Tunnel

Tunneling Difficulties


Rainy Conditions
Station 140+60

Faults - Disturbed Ground Zone 59

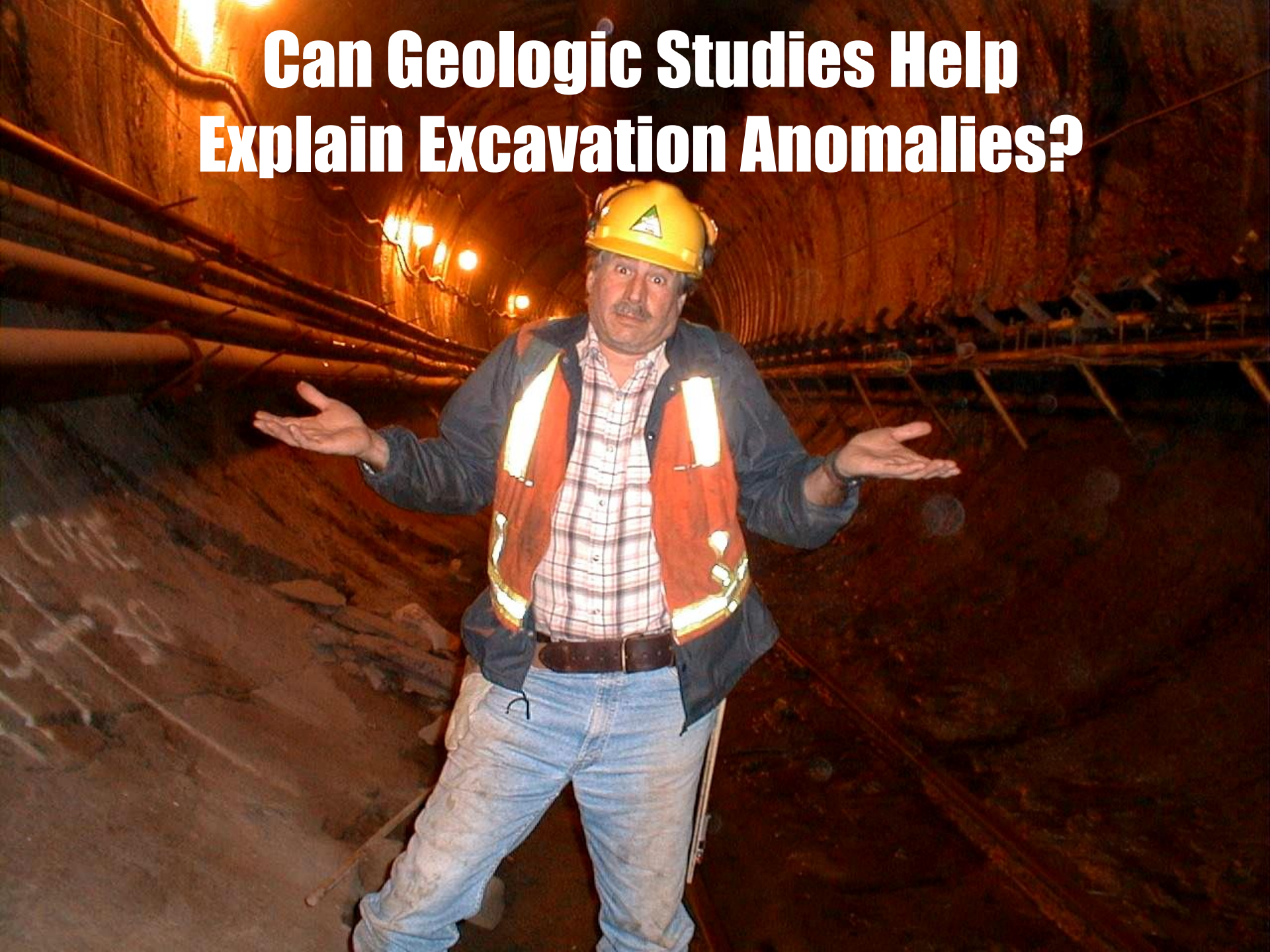
Station 152+90

Excessive Fines

Blocky Ground

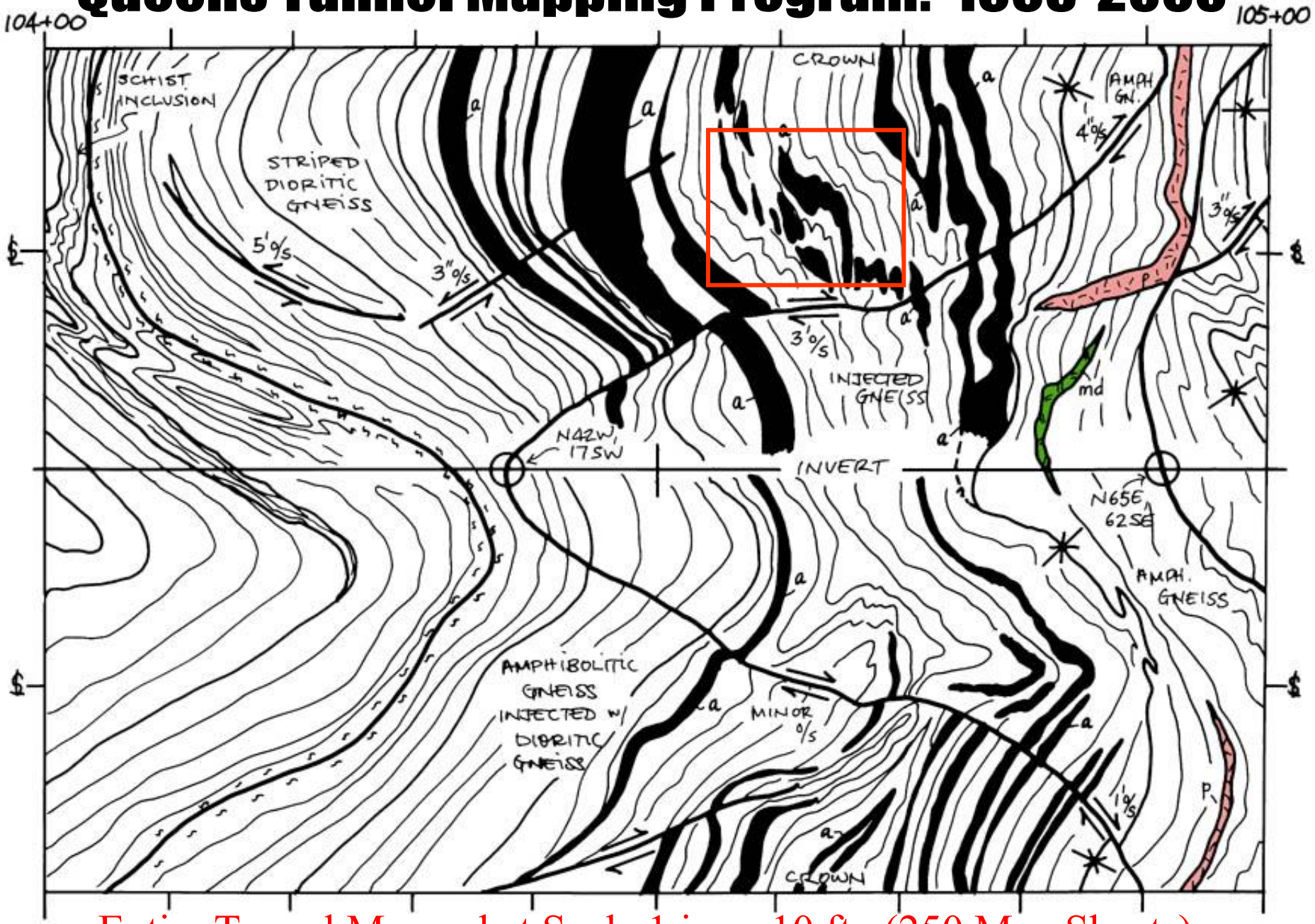
Unforseen Tunneling Problems

Can Geologic Studies Help Explain Excavation Anomalies?



Merguerian's Field Office and Assistant

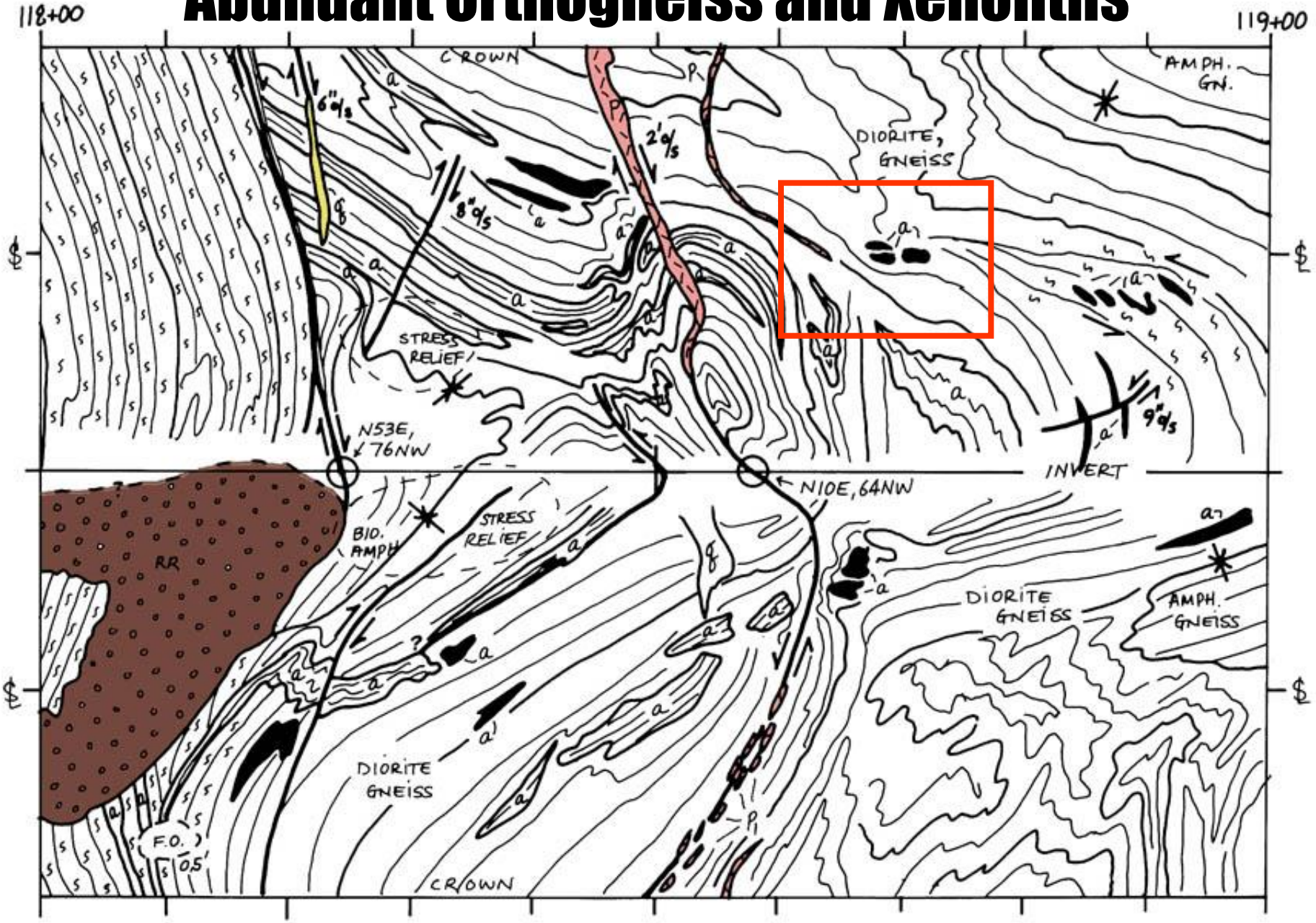
Queens Tunnel Mapping Program: 1998-2000



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


104+55
104+60
104+65

Abundant Orthogneiss and Xenoliths

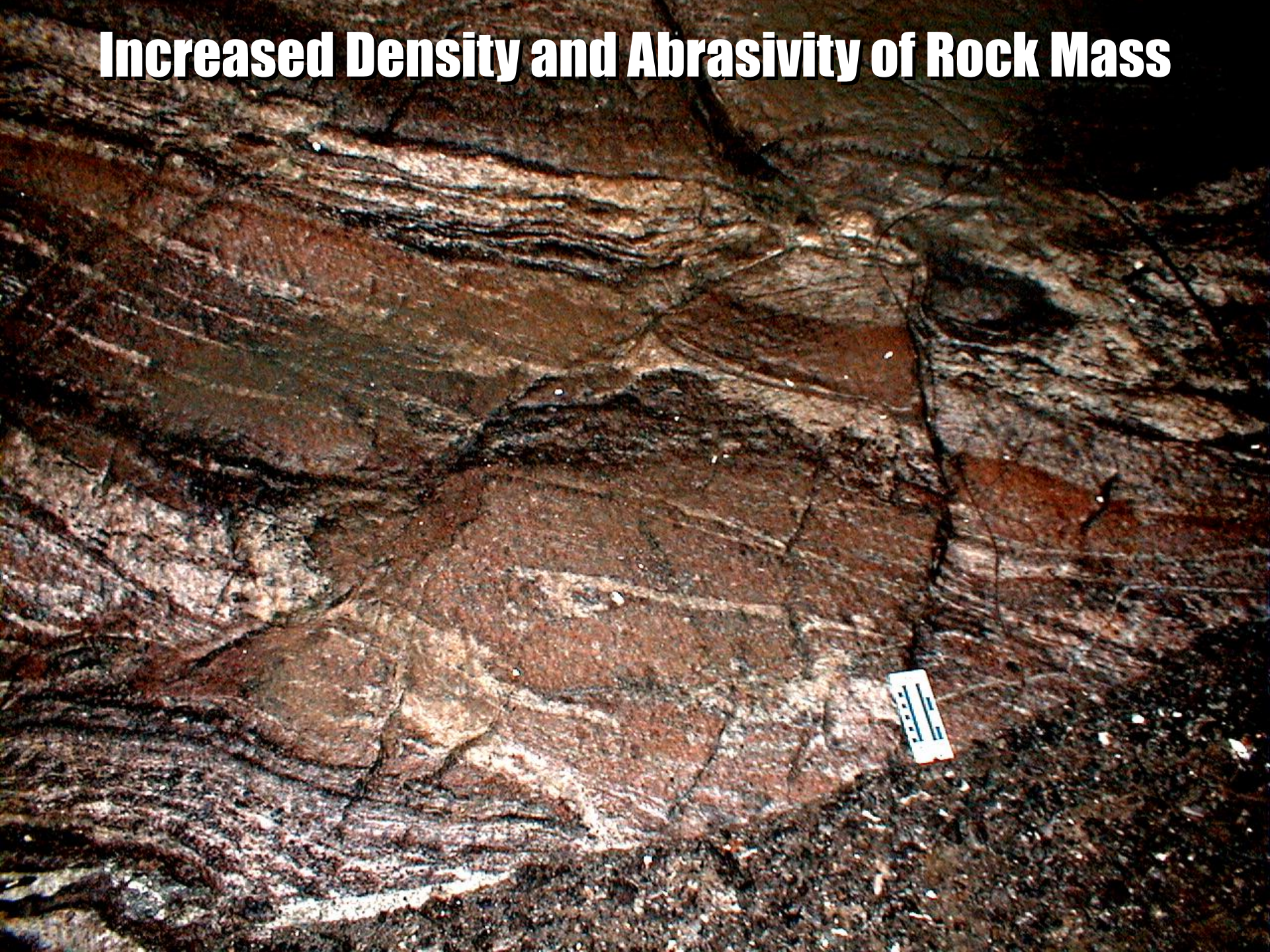


- **Scale of Mapping: 1 in. = 10 ft**

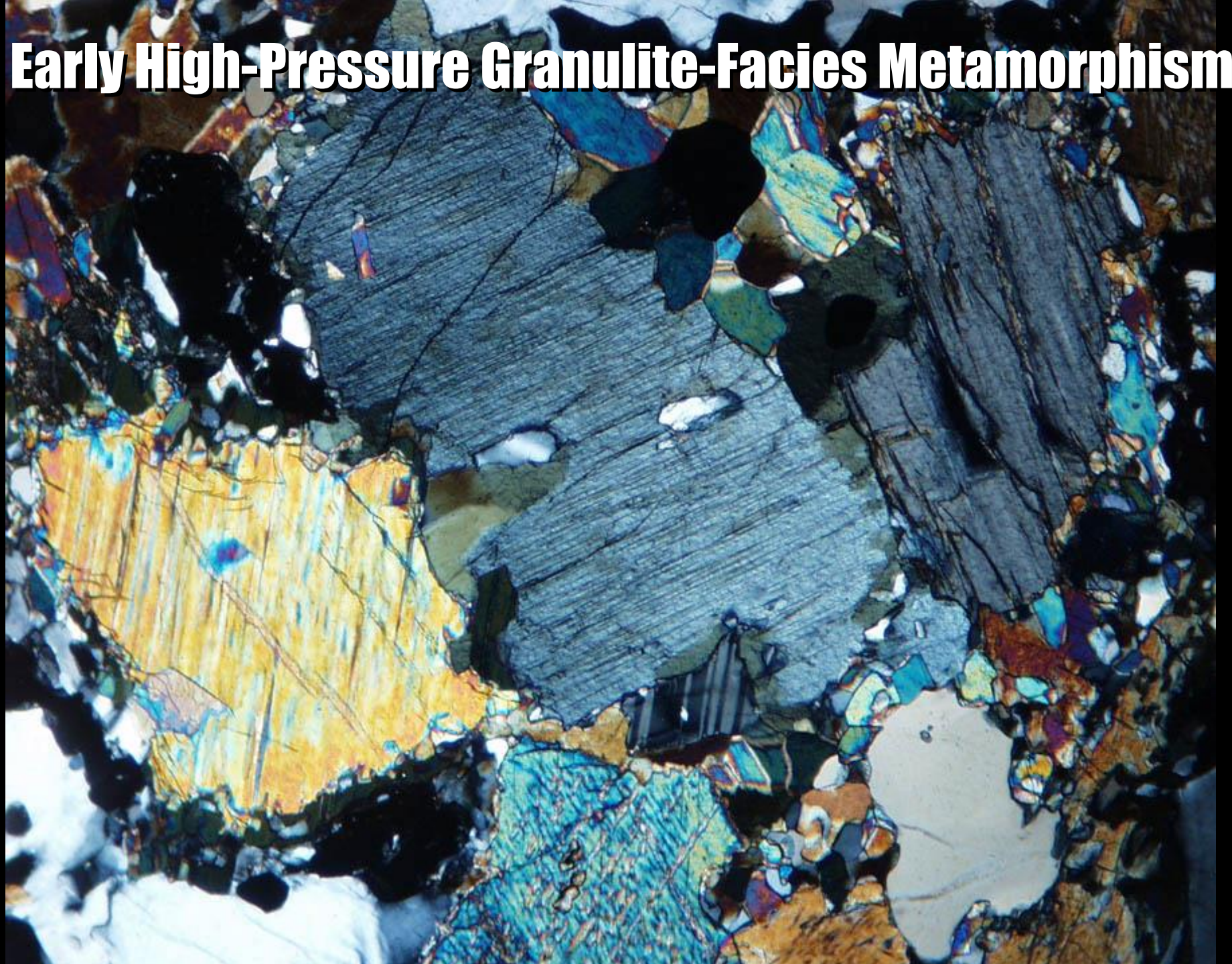

ADJ
118+
118

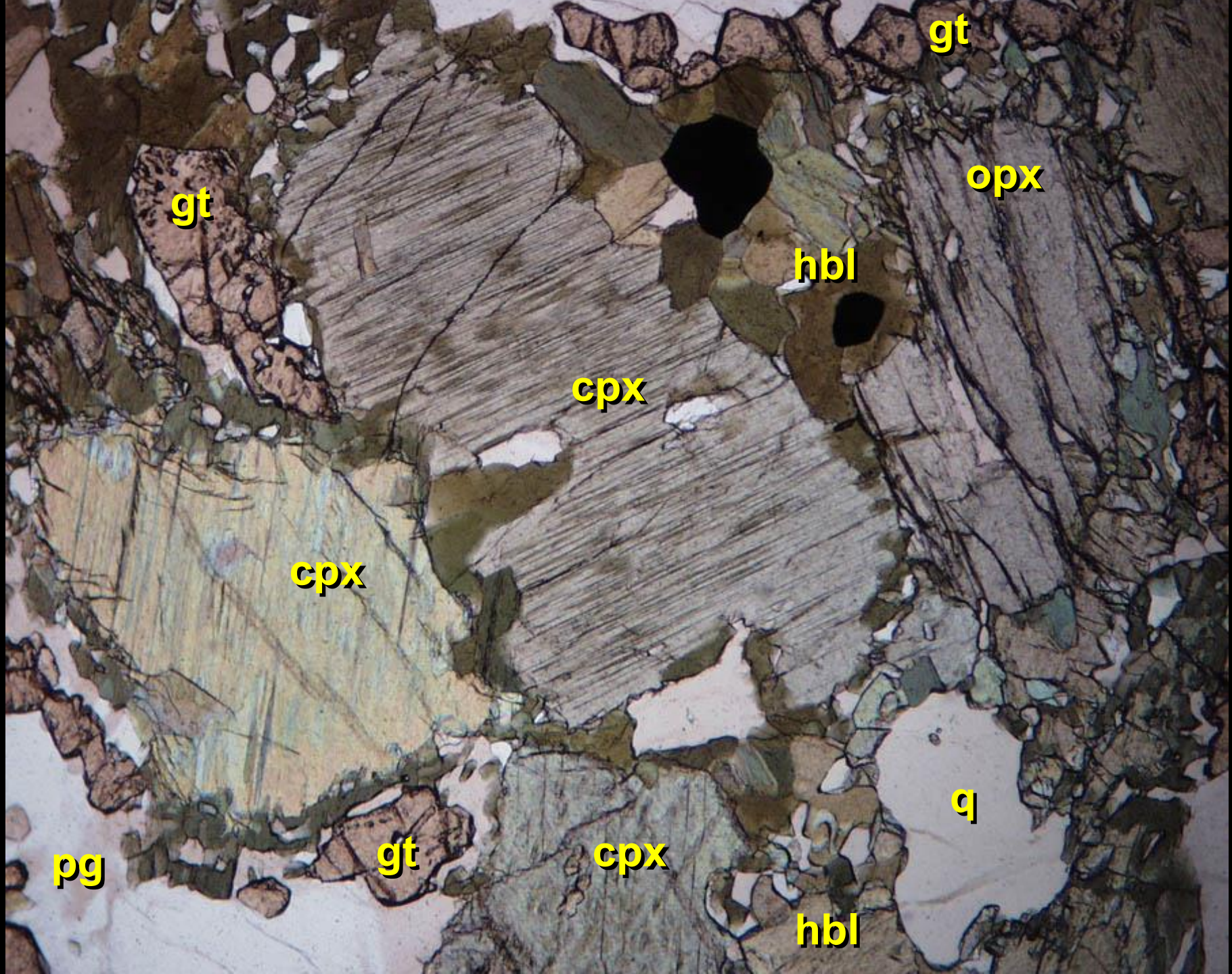
Folded Garnet-Plagioclase Segregations in Mafic Gneiss

Increased Density and Abrasivity of Rock Mass



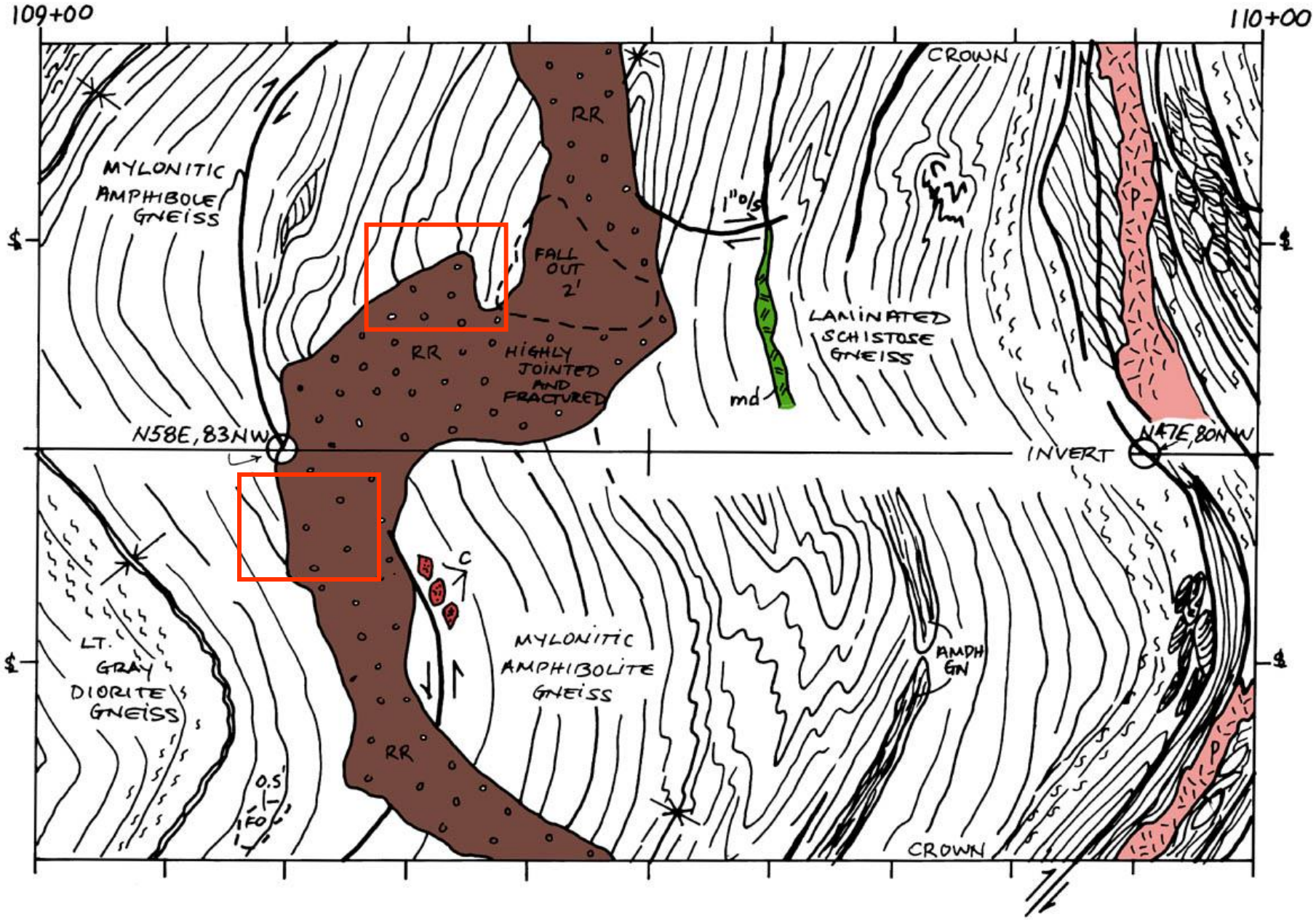
Early High-Pressure Granulite-Facies Metamorphism




gt
opx
gt
hbl
cpx
cpx
q
pg
gt
cpx
hbl

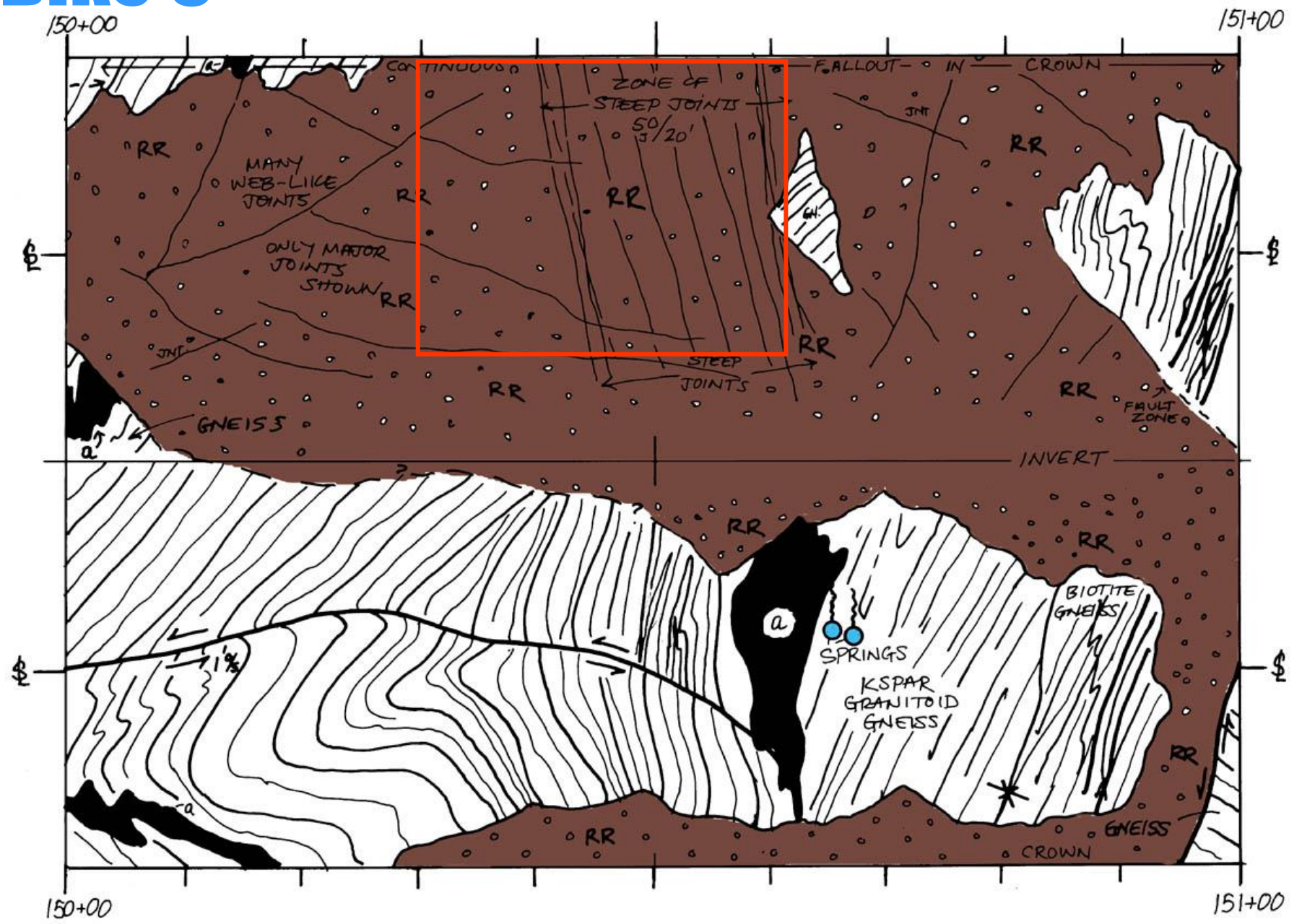
Stage 2, City Tunnel 3

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

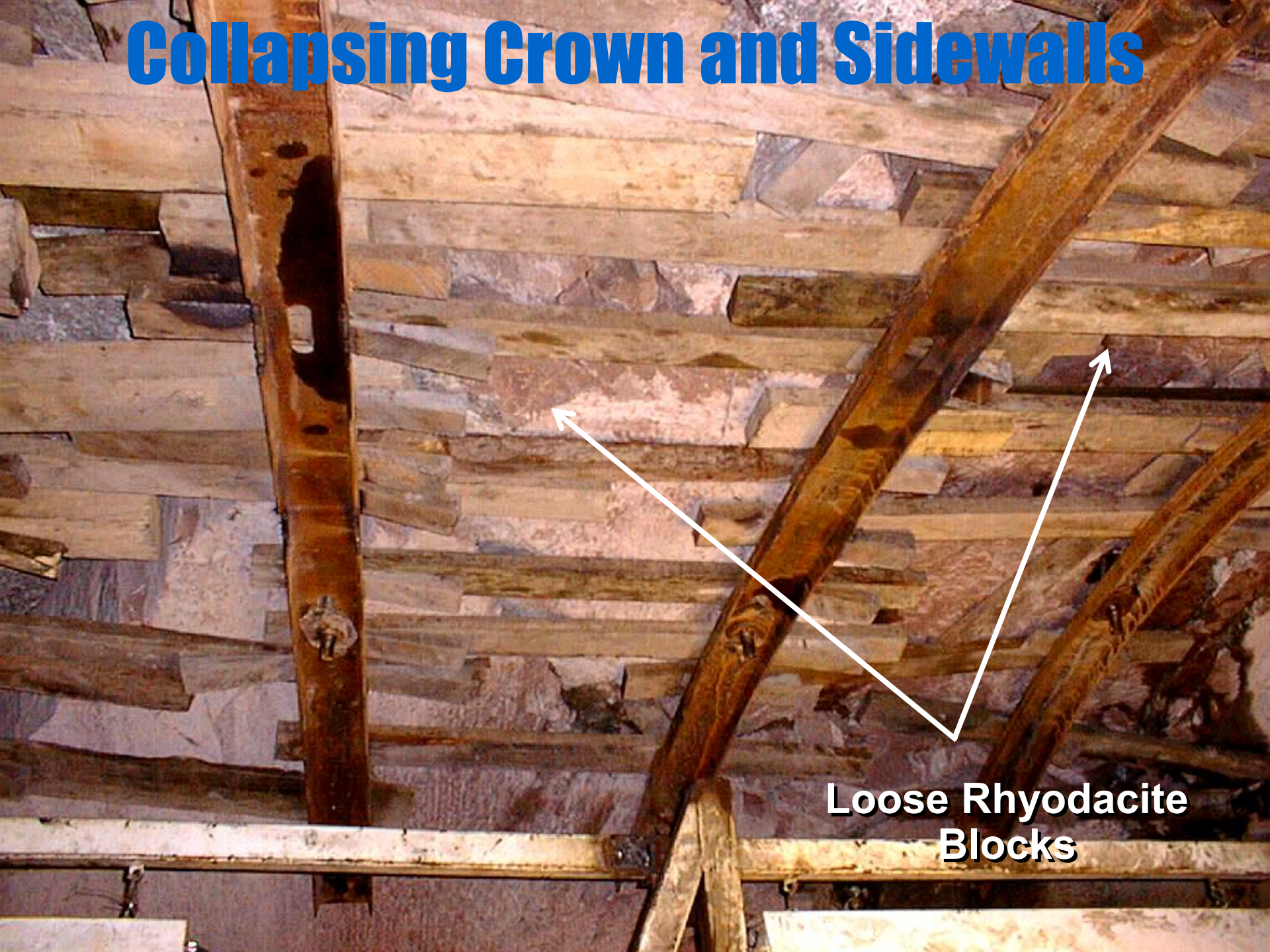

Station 109+20, Right Wall
Cooling joints extend 10' into country rock

Dike 5


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


12:05PM
5/15/1998
00:15

Collapsing Crown and Sidewalls



Major Lithologic Contrasts

Lava Flows in Woodside, Queens?


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

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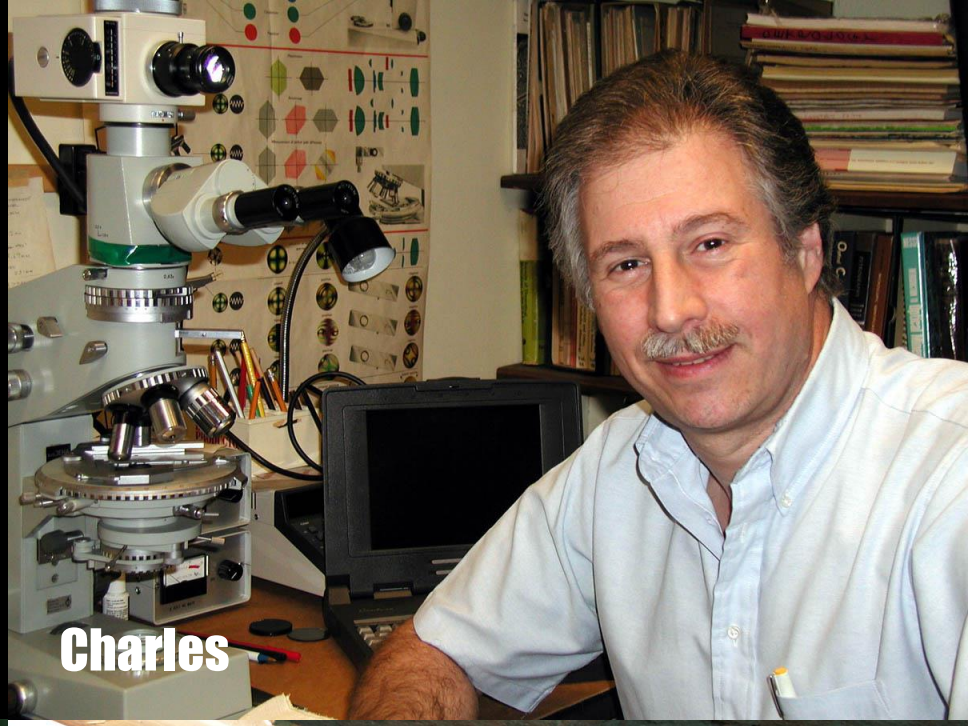
Stone Ridge, NY




Biting?
There's No
Biting in the
Hamster
Industry!
Thanks For Attending
Questions Please ??
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