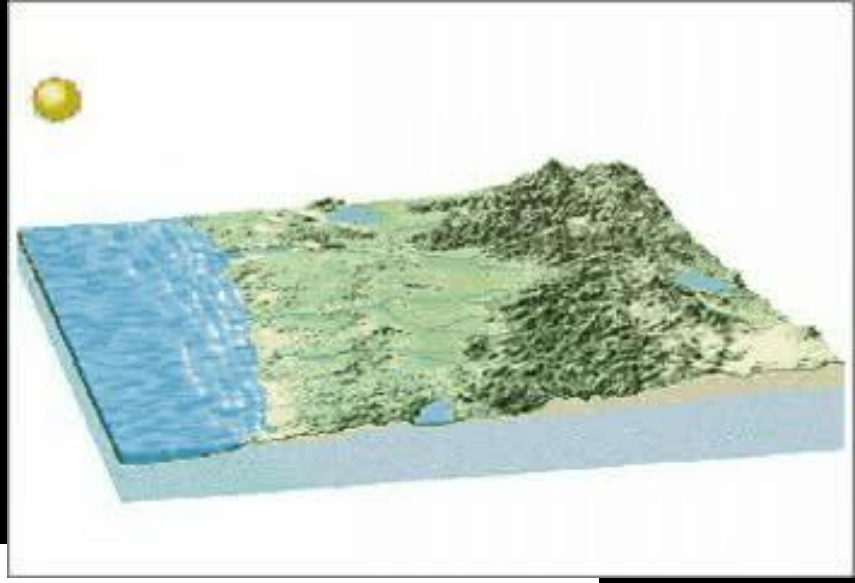
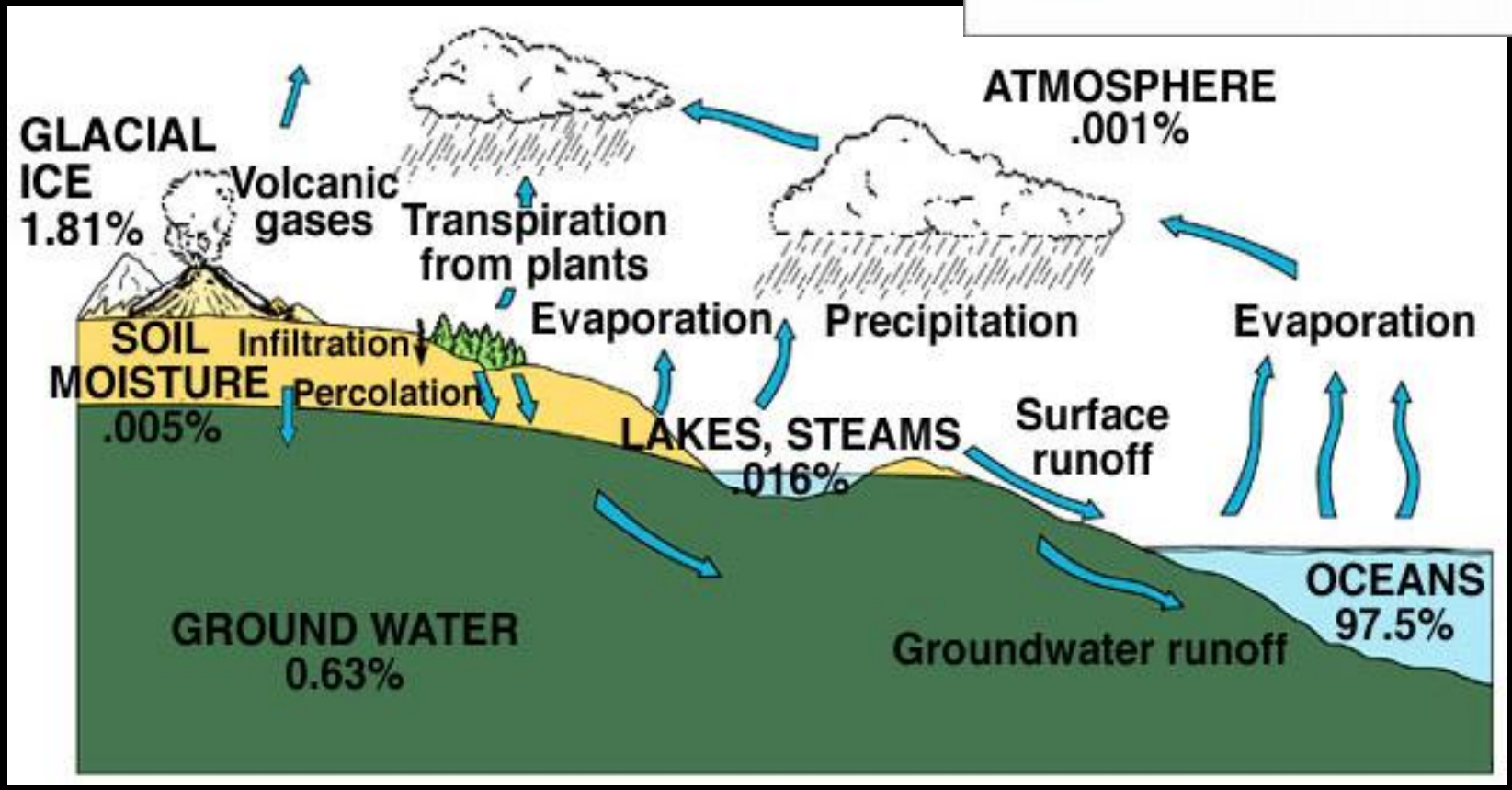
12 Million Thirsty People: Supplying NYC and LI with Fresh Water

Charles Merguerian
Hofstra Geology

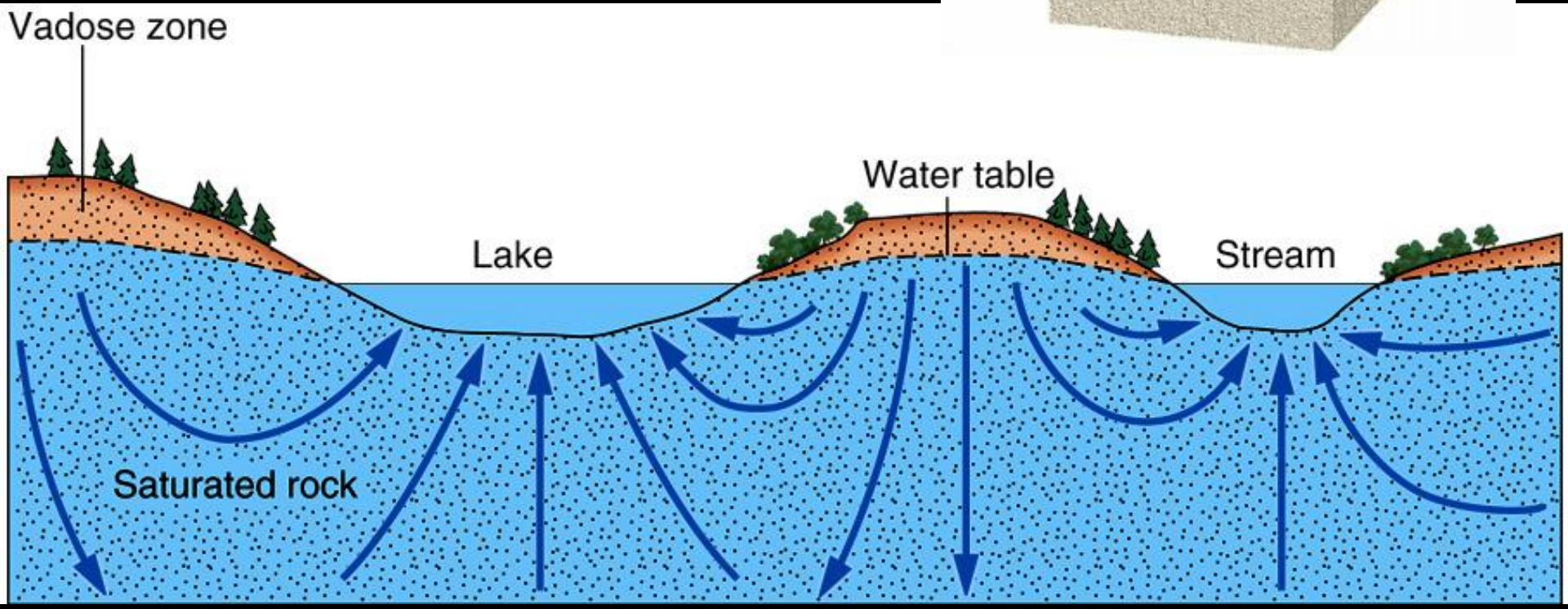

WATER VAPOR 8 km
NOAA
HTTP://WWW.GOES.NOAA.GOV

Hydrologic Cycle

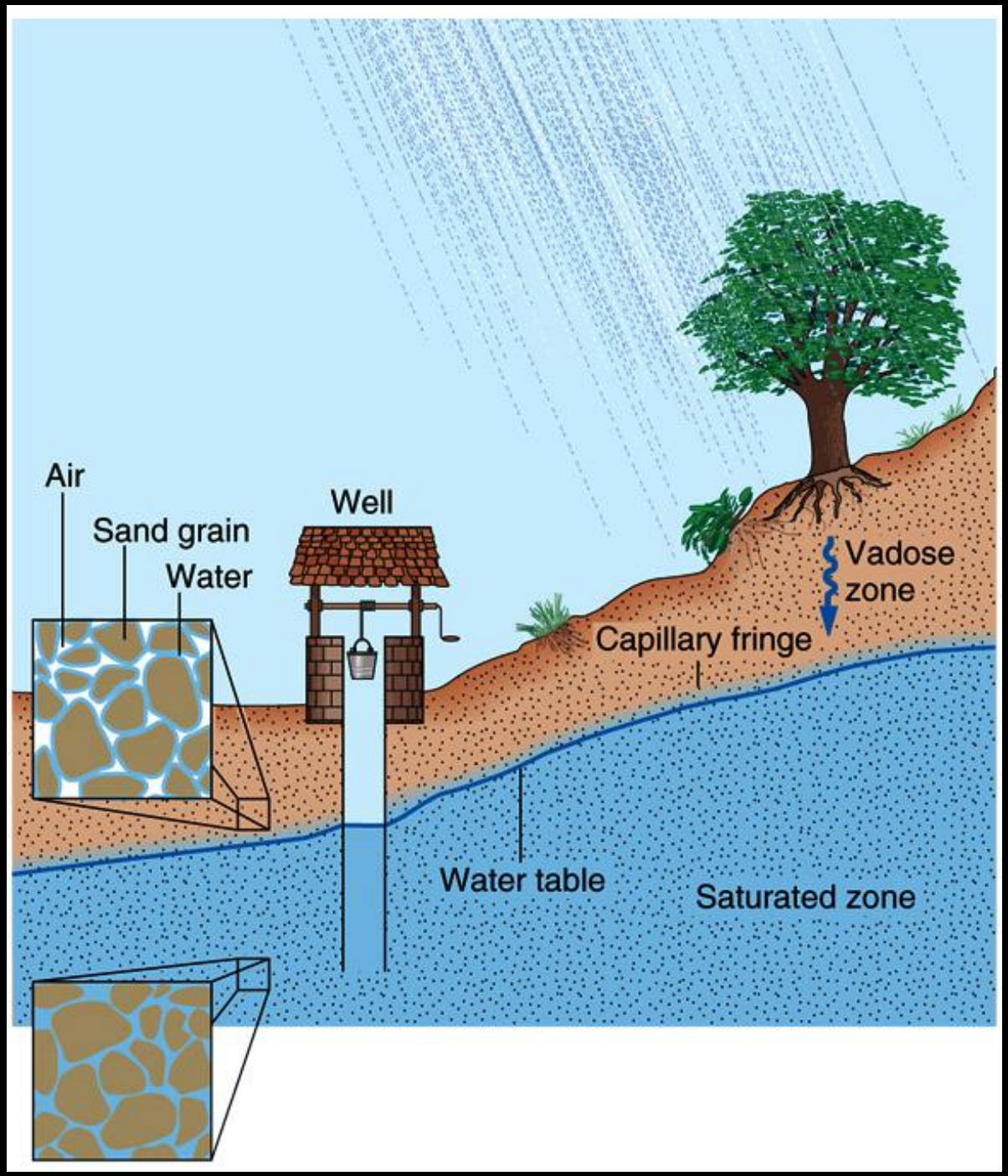




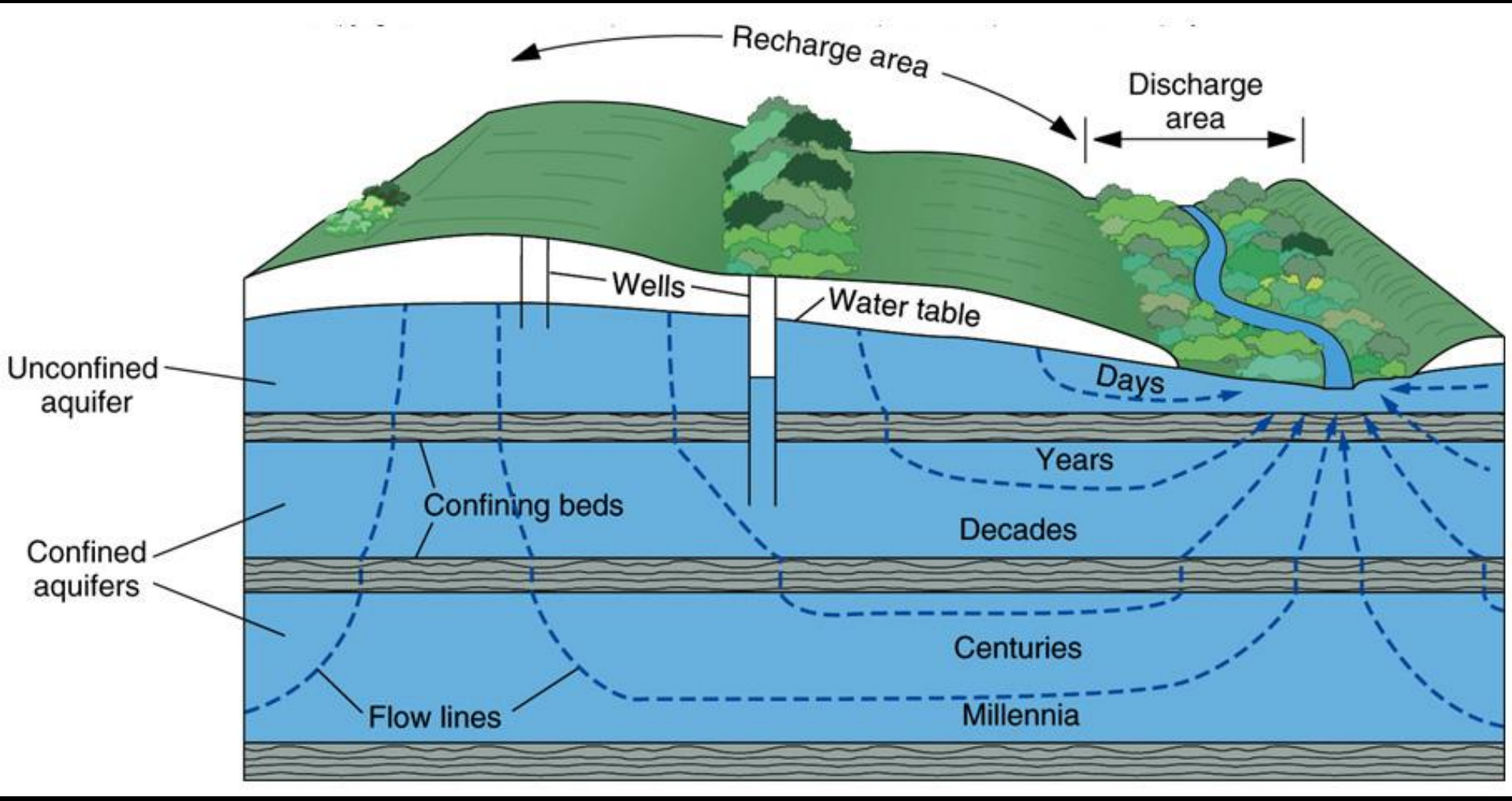
Water Table



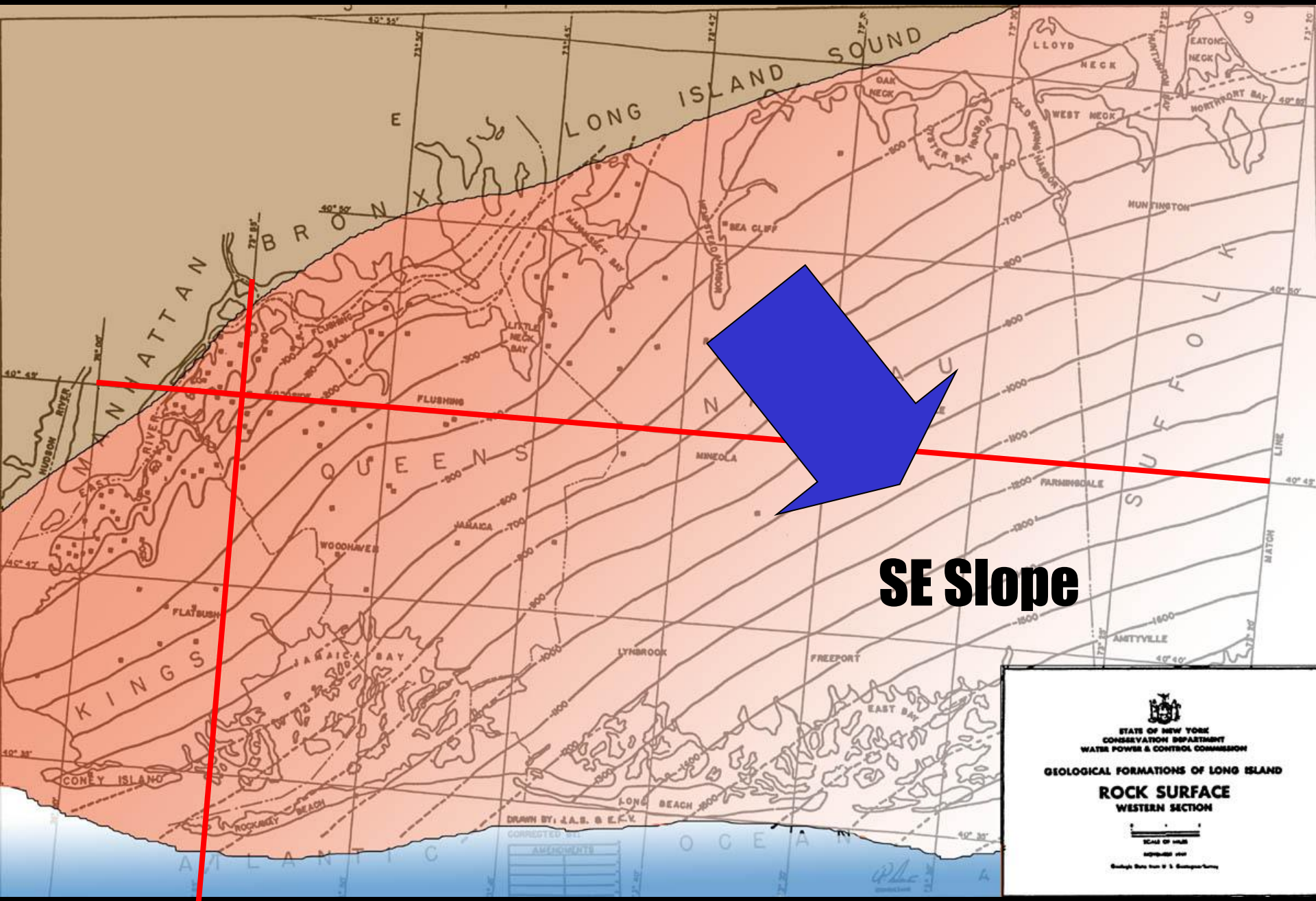
Water Table

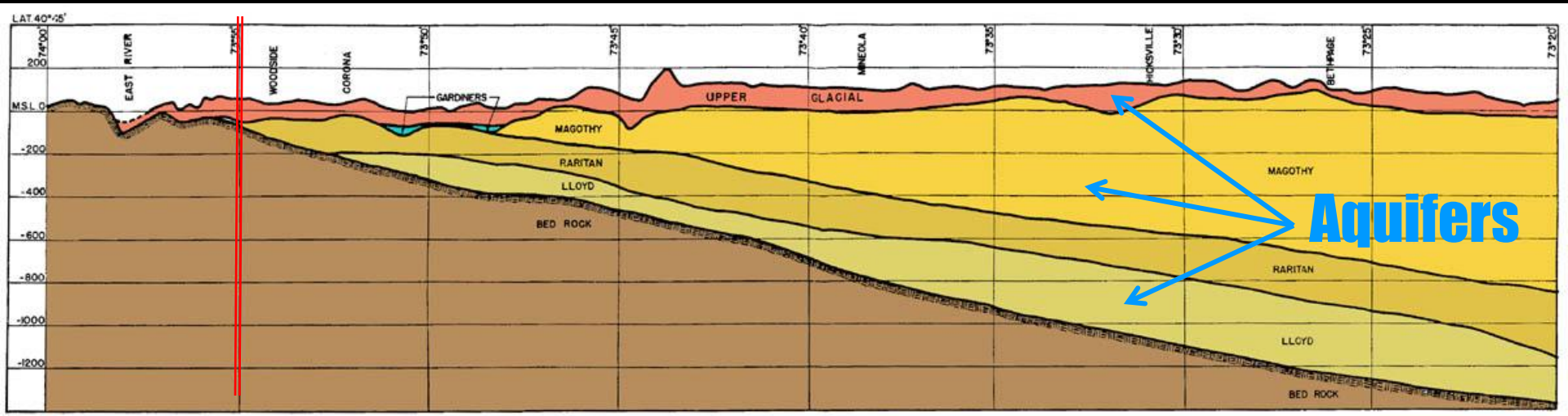

Air
Sand grain
Water
Well
Vadose zone
Capillary fringe
Water table
Saturated zone

Ground Water Flow Regimes

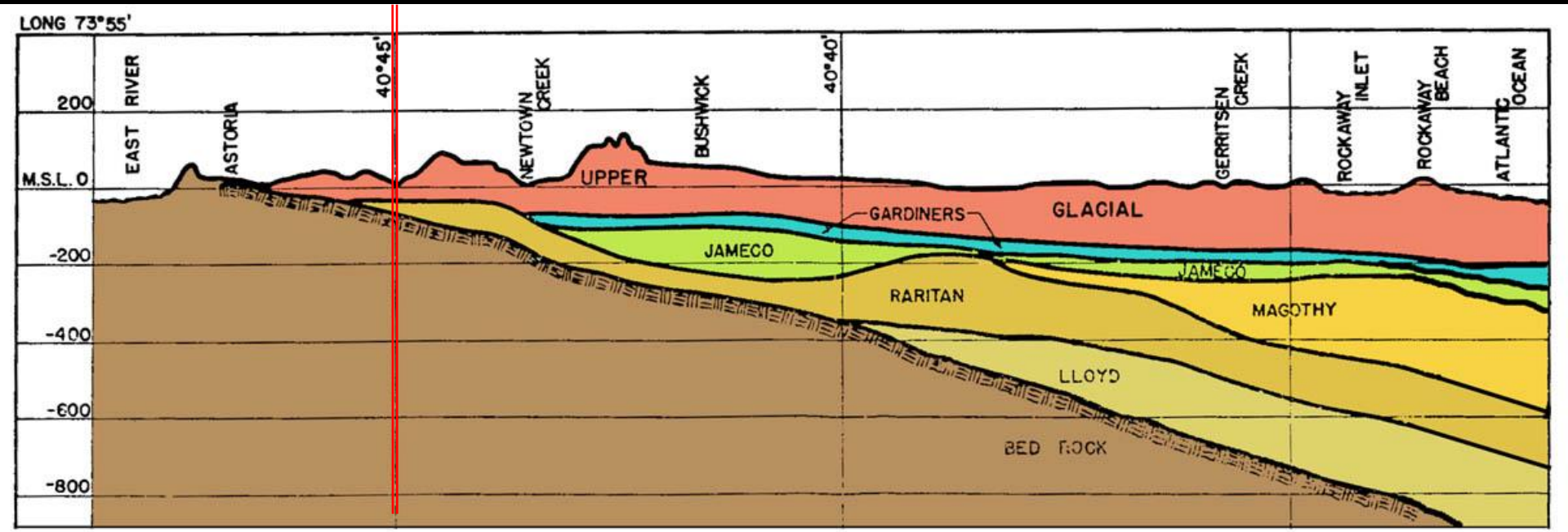



Lon Gisland


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
EAST BAY
AMITYVILLE
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



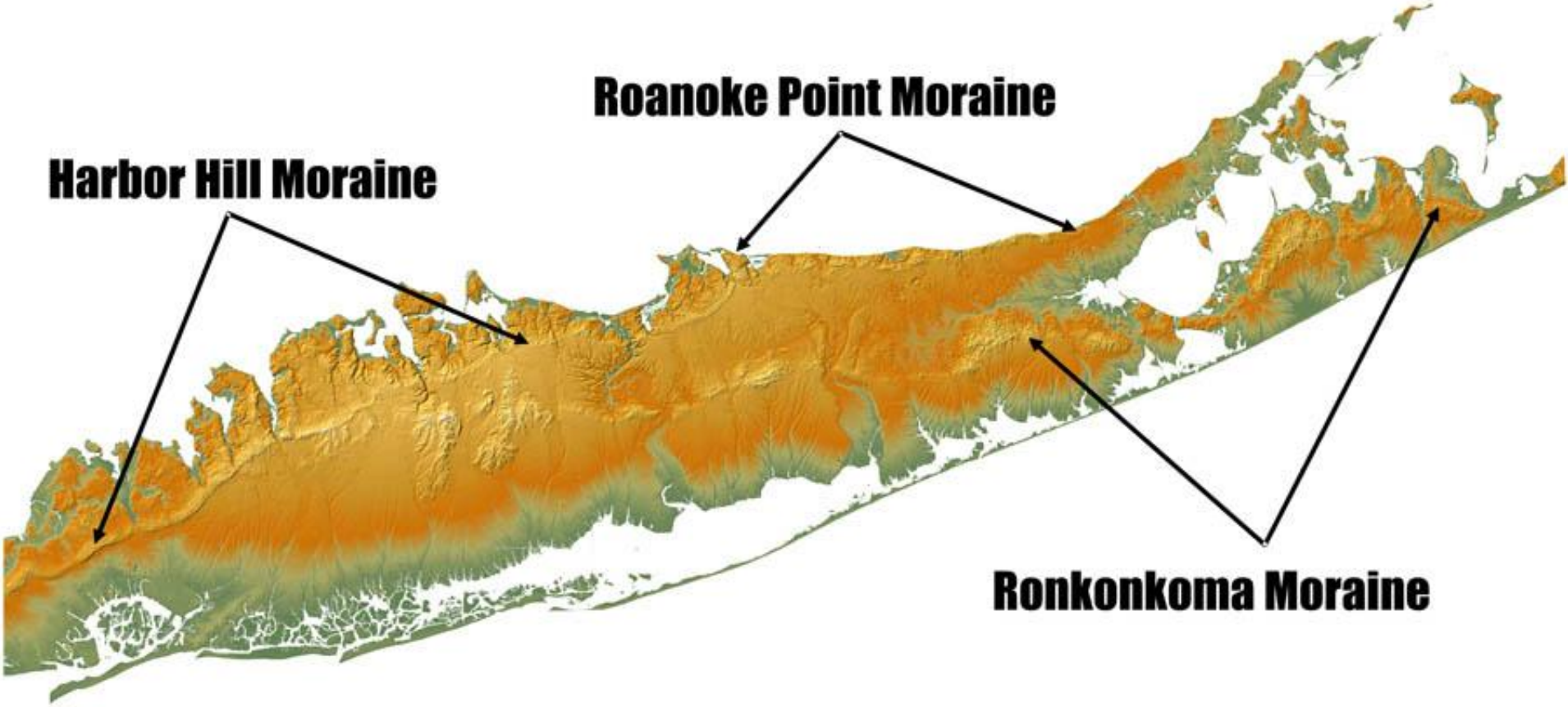
LAT. 40°=45' N



LONG. 73°=55' W

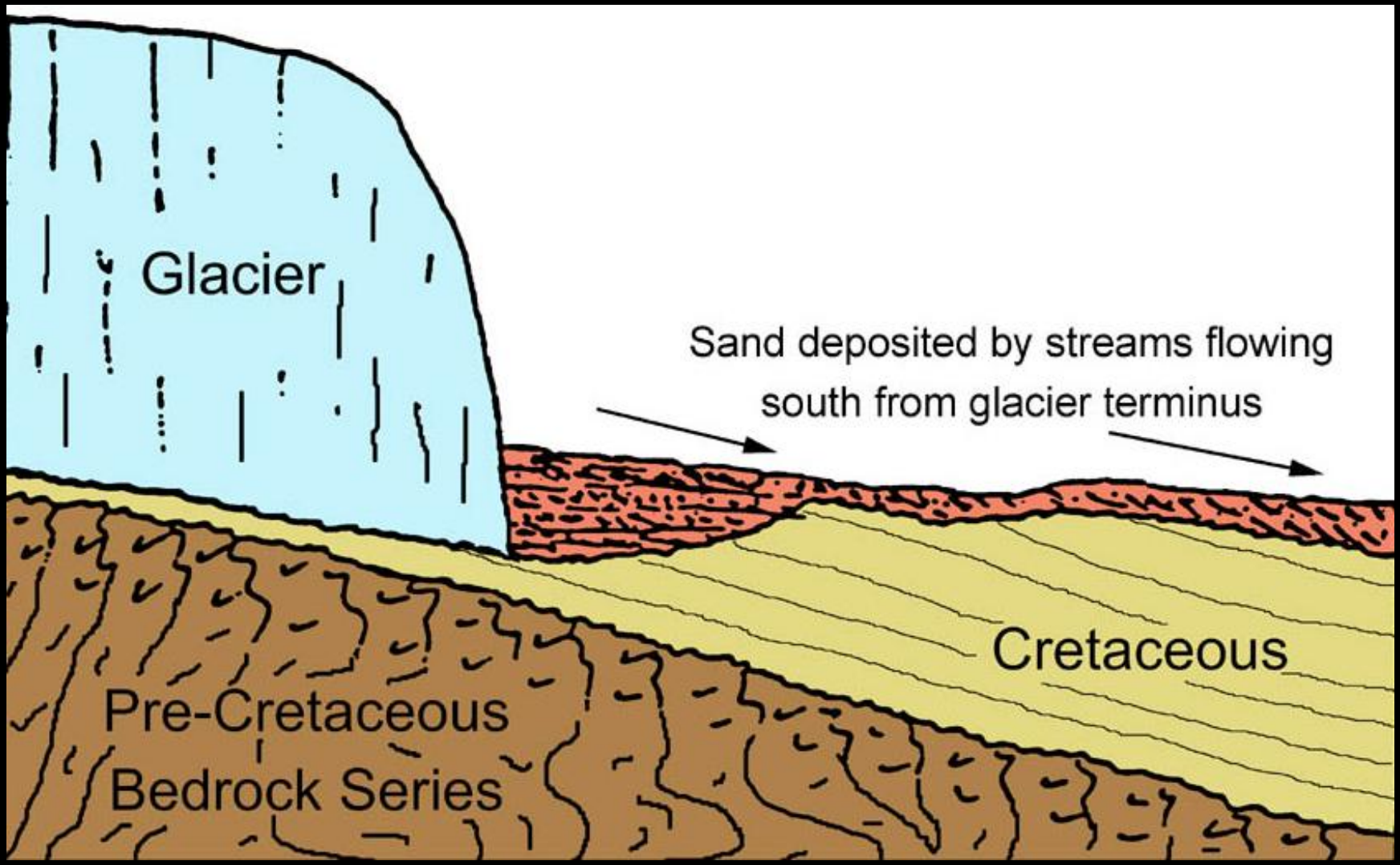
Suter et al, 1949

Long Island's Moraines

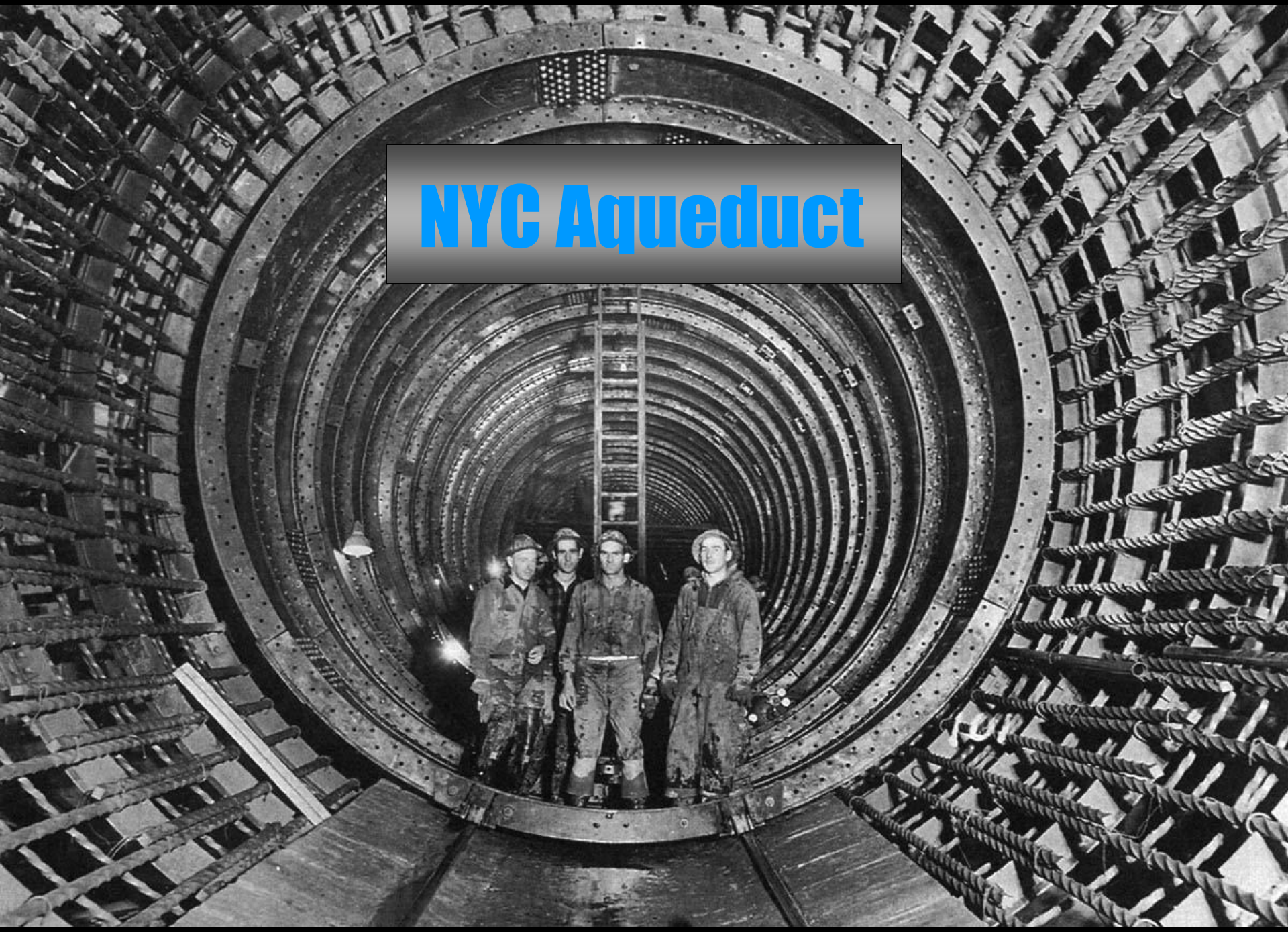


after Bennington, 2003

Long Island Outwash Fans

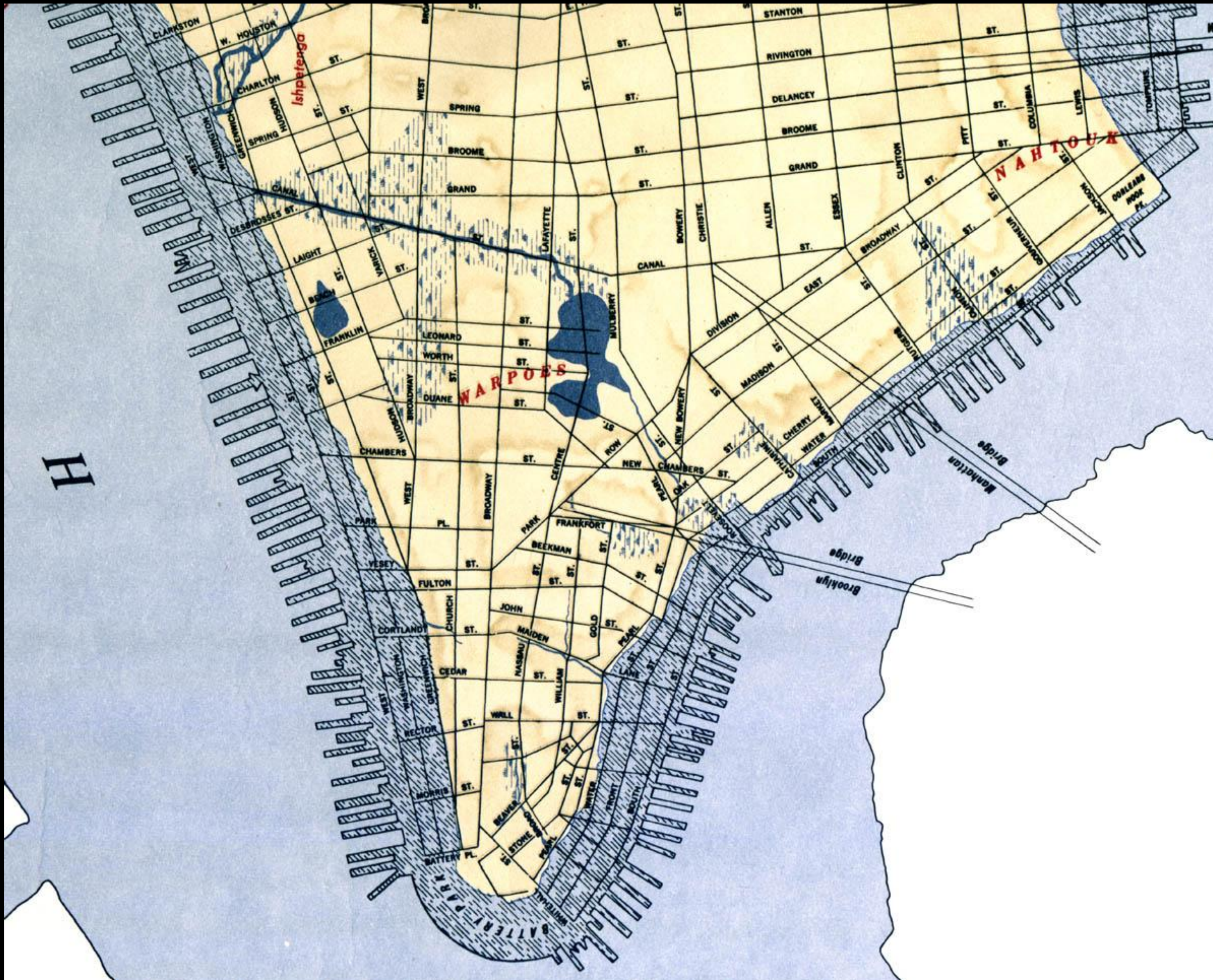


after Merguerian and Sanders 1993

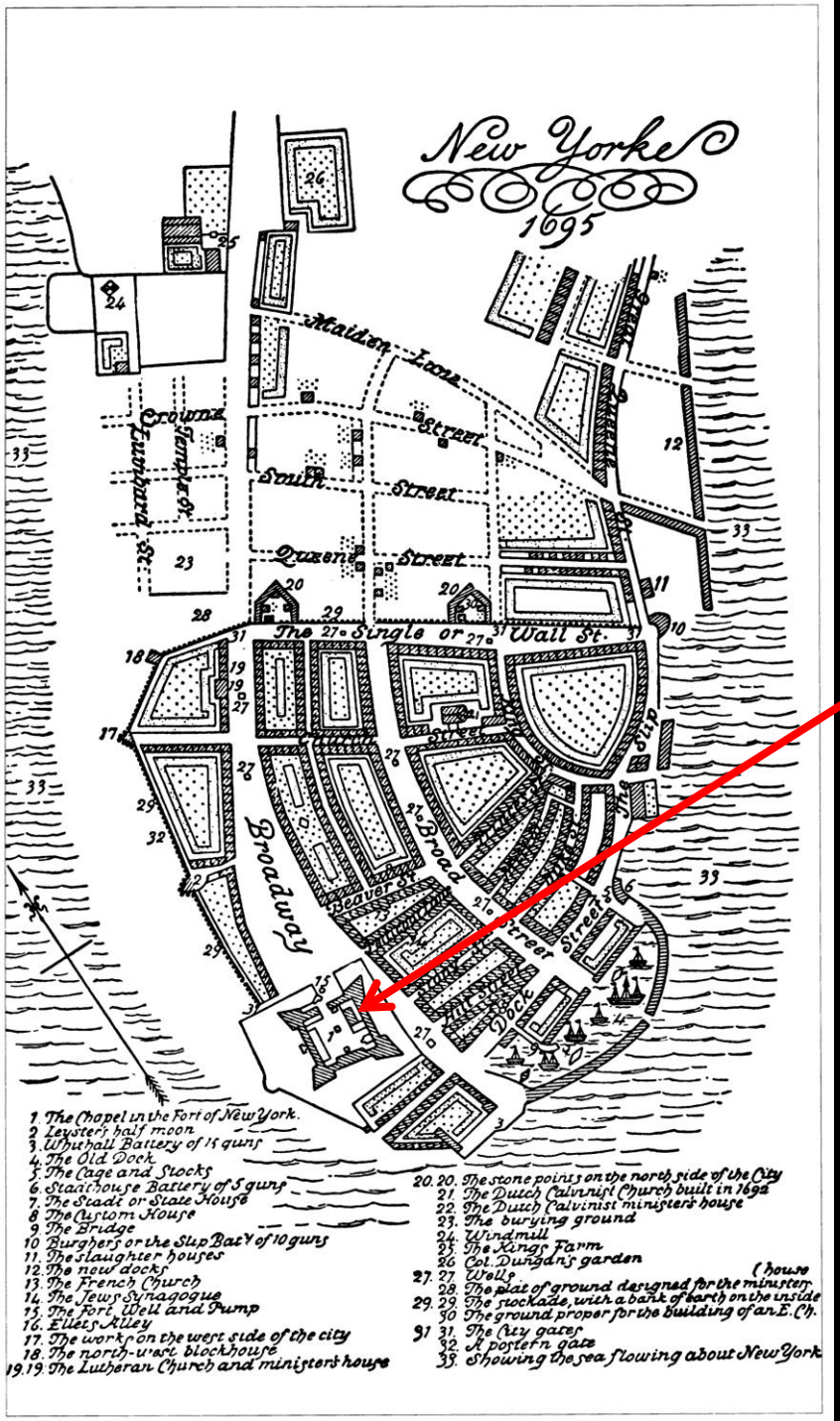

NYC Aqueduct

Dutch Settlers, South Manhattan

Population by 1664 Had Reached 1,500 People


Ishpetenga
WARPOES
NAHTOUK
H
Manhattan Bridge
Brooklyn Bridge
BATTERY PARK
BATTERY PL.
STANTON
RIVINGTON
DELANCEY
BROOME
GRAND
CANAL
CLARKSON
W. HOUSTON
CHARLTON
SPRING
DESBROSSES ST.
LAIGHT
BEACH
FRANKLIN
LEONARD
WORTH
DUANE
CHAMBERS
NEW CHAMBERS
PARK PL.
VESEY
FULTON
CORTLANDT
CEDAR
RECTOR
MORRIS
WALL
JOHN
MAIDEN
LANE
BEEKMAN
FRANKFORT
DIVISION
EAST BROADWAY
MADISON
CHERRY
WATER
SOUTH
FRONT
PEARL
BEAVER
STONE
WHITEHALL
WEST
WASHINGTON
GREENWICH
HUDSON
VARICK
BROADWAY
CHURCH
NASSAU
WILLIAM
GOLD
LAFAYETTE
MULBERRY
CENTRE
PARK ROW
BOWERY
NEW BOWERY
CHRISTIE
ALLEN
ESSEX
CLINTON
PITT
COLUMBIA
LEWIS
TOMPKINS
JACKSON
GOUVERNEUR
RUTGERS
CATHARINE
MARKET
OAK
ROOSEVELT
CORLEARS HOOK PK.

McCoun, 1609



New York in 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

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)

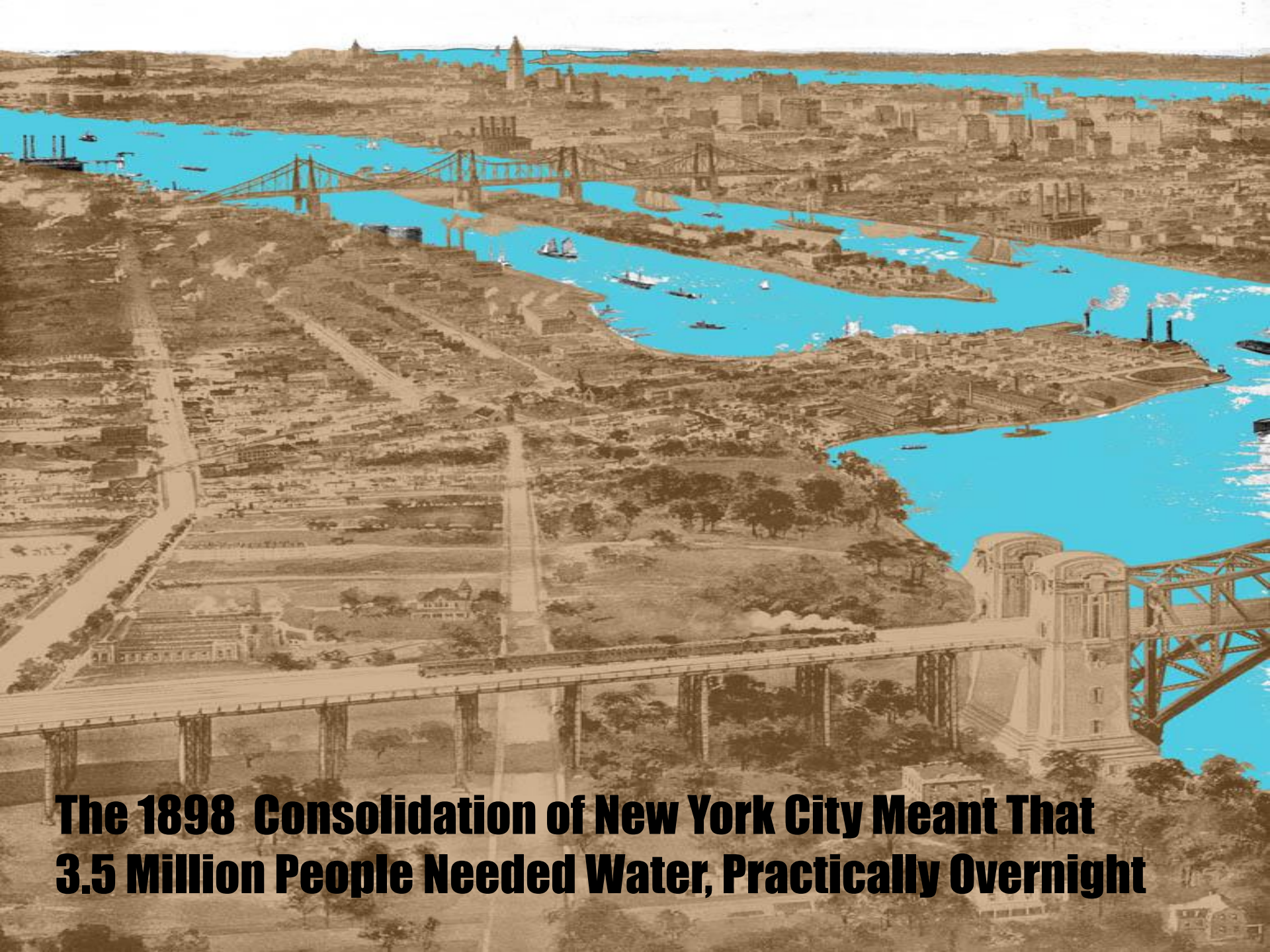
Viele, 1865

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

1837-18 42 Old Croton Reservoir Constructed and by 1881 Supplied 95,000,000 gpd

Old Croton Brick-lined Tunnels Used Until 1907

Crossed Harlem River at High Bridge and Fed Central Park and Bryant Park Reservoirs

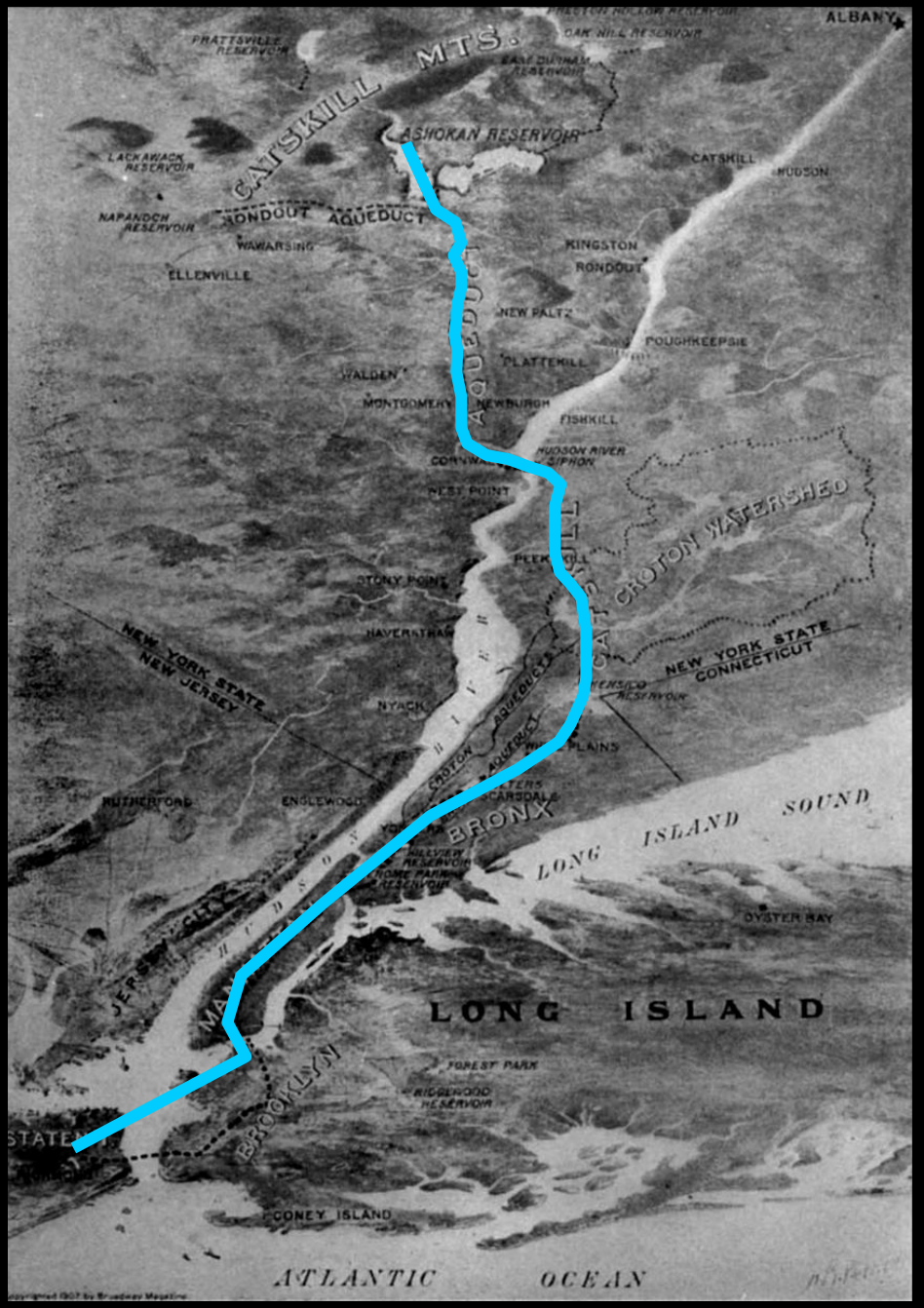

The 1898 Consolidation of New York City Meant That
3.5 Million People Needed Water, Practically Overnight

NYC Aqueduct System

Construction of 130 Miles of Tunnels Began in 1907

City Tunnel #1 Completed 1917

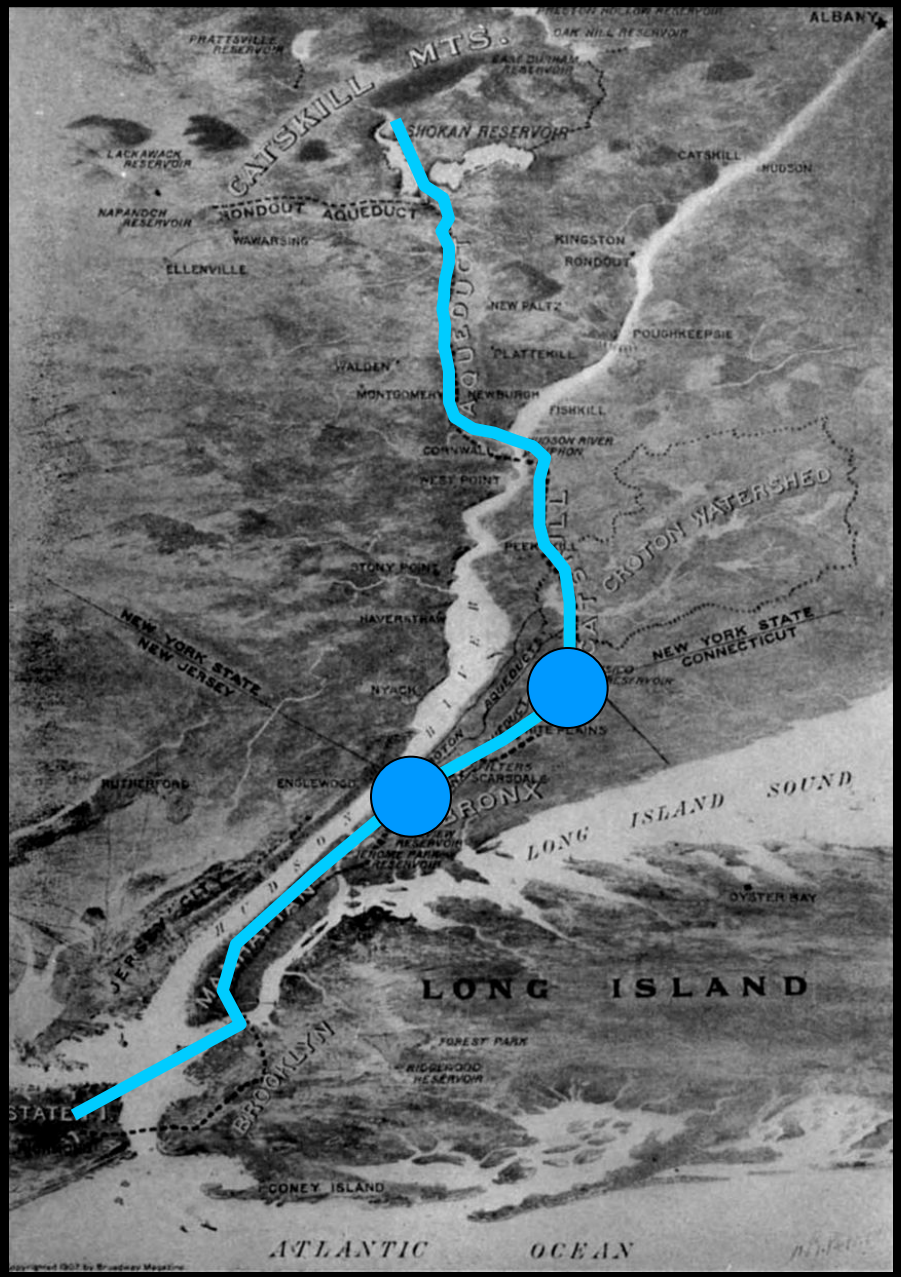
City Tunnel #2 Completed 1936

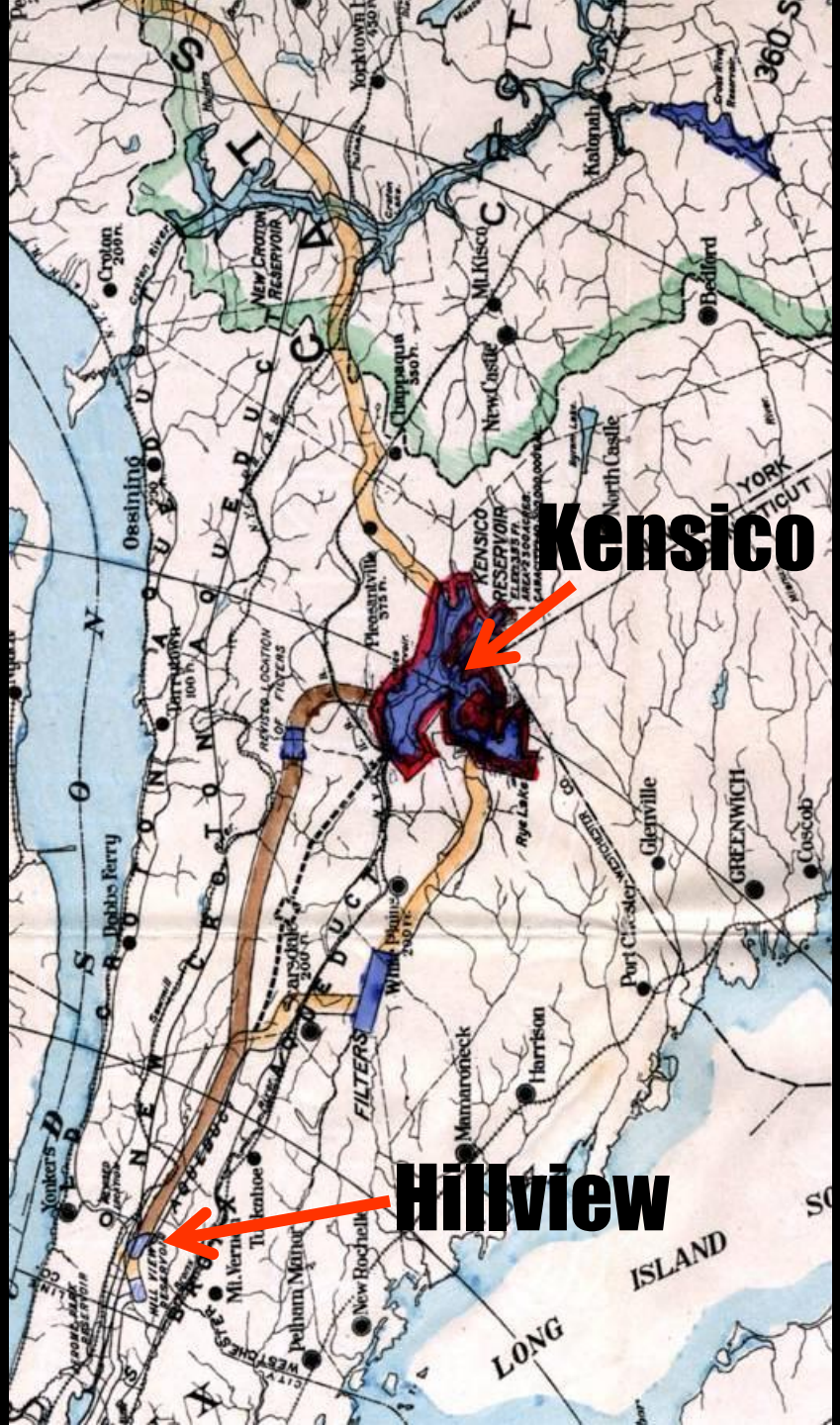


The Catskill System, which involved the use of 67 shafts varying in depth from 174 to 1187 feet, includes:

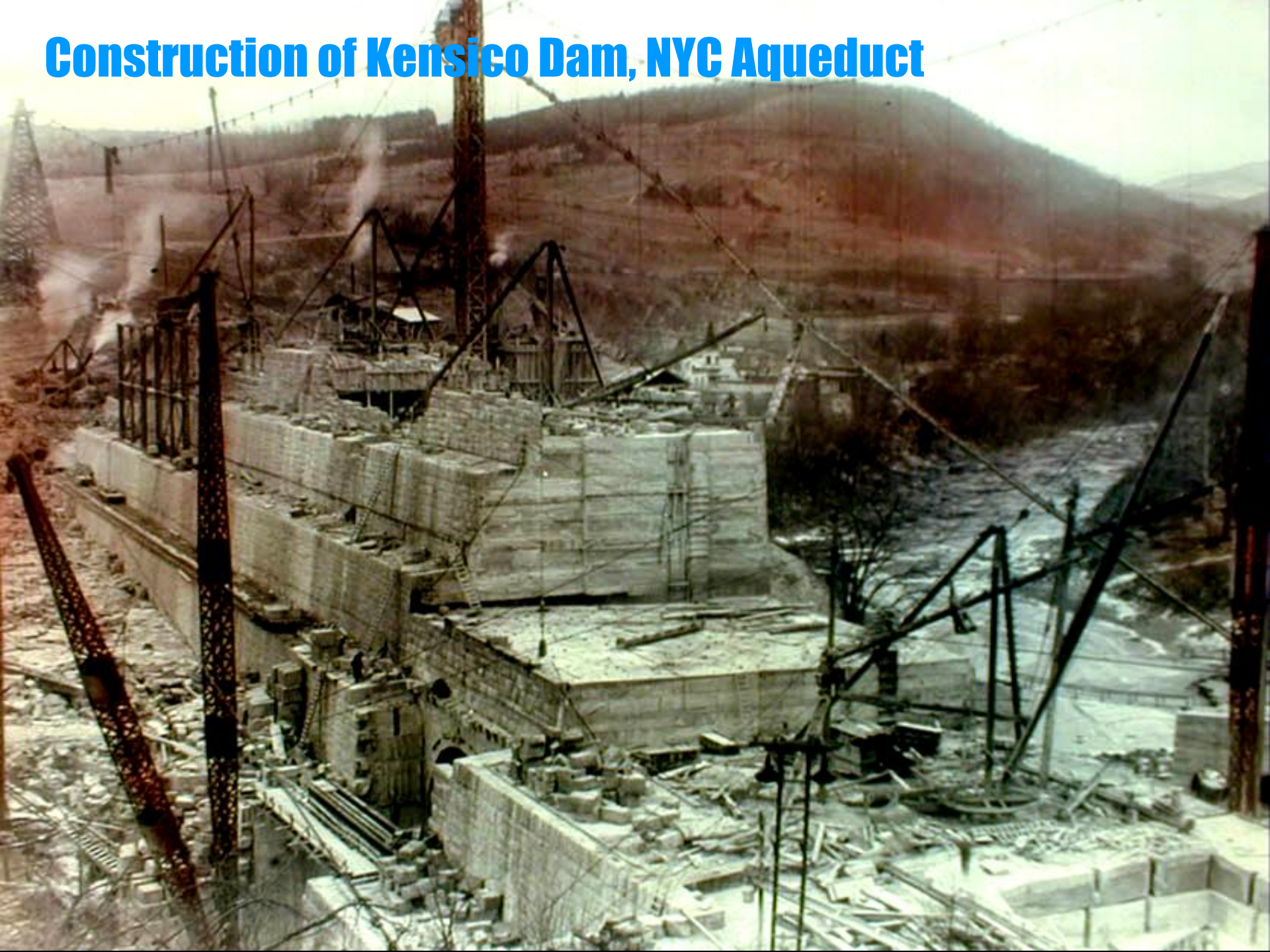
- Three masonry dams
- Several miles of earthen dikes
- Over 163 miles of aqueduct consisting of:
  - 55 miles of cut and cover aqueduct
  - 28.5 miles of grade tunnel
  - 35 miles of pressure tunnel
  - 6 miles of steel pipe siphons, and,
  - 39 miles of pipe conduit

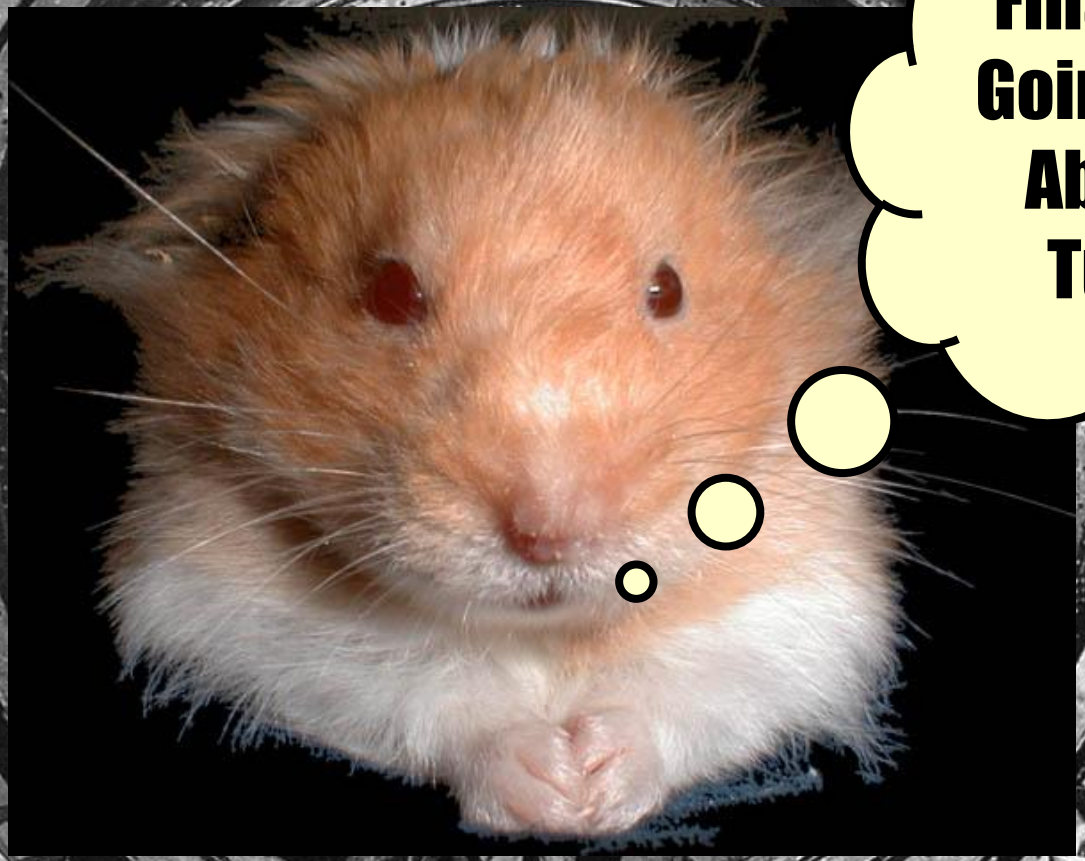
NYC Aqueduct System





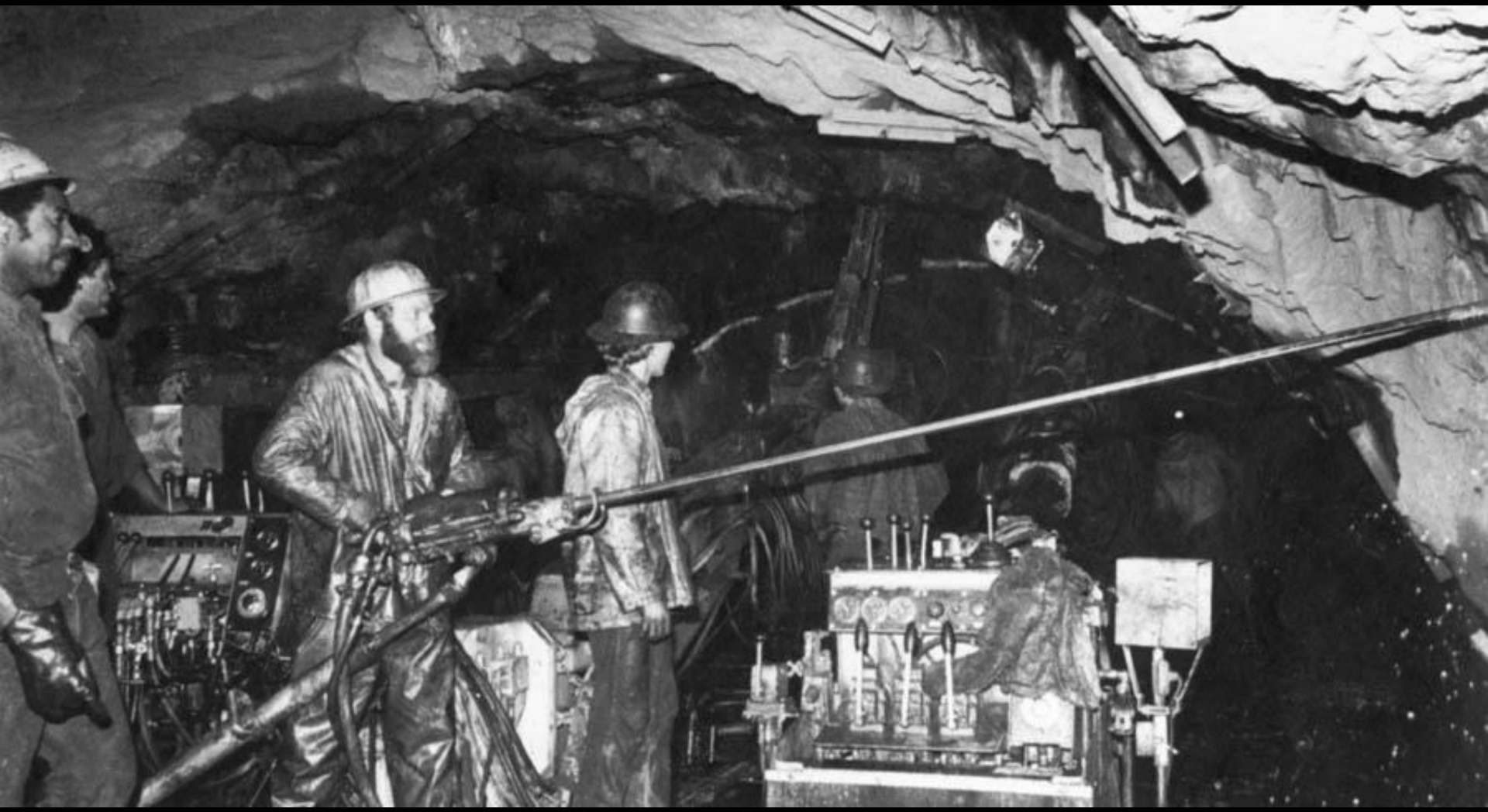
Construction of Kensico Dam, NYC Aqueduct





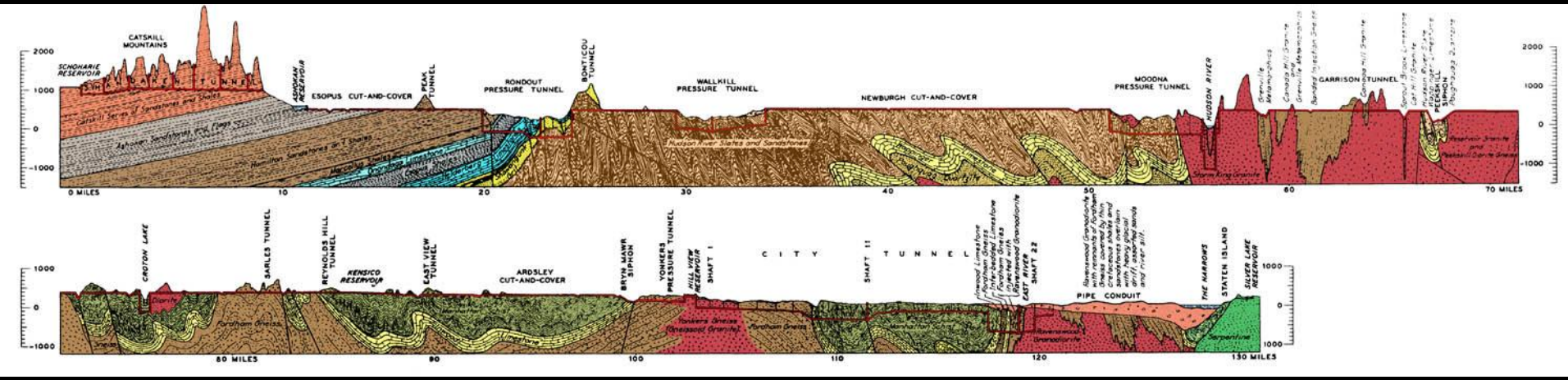
Finally, He's Going to Talk About the Tunnels

Invert Pour, Delaware Aqueduct, Kensico Hill View Tunnel



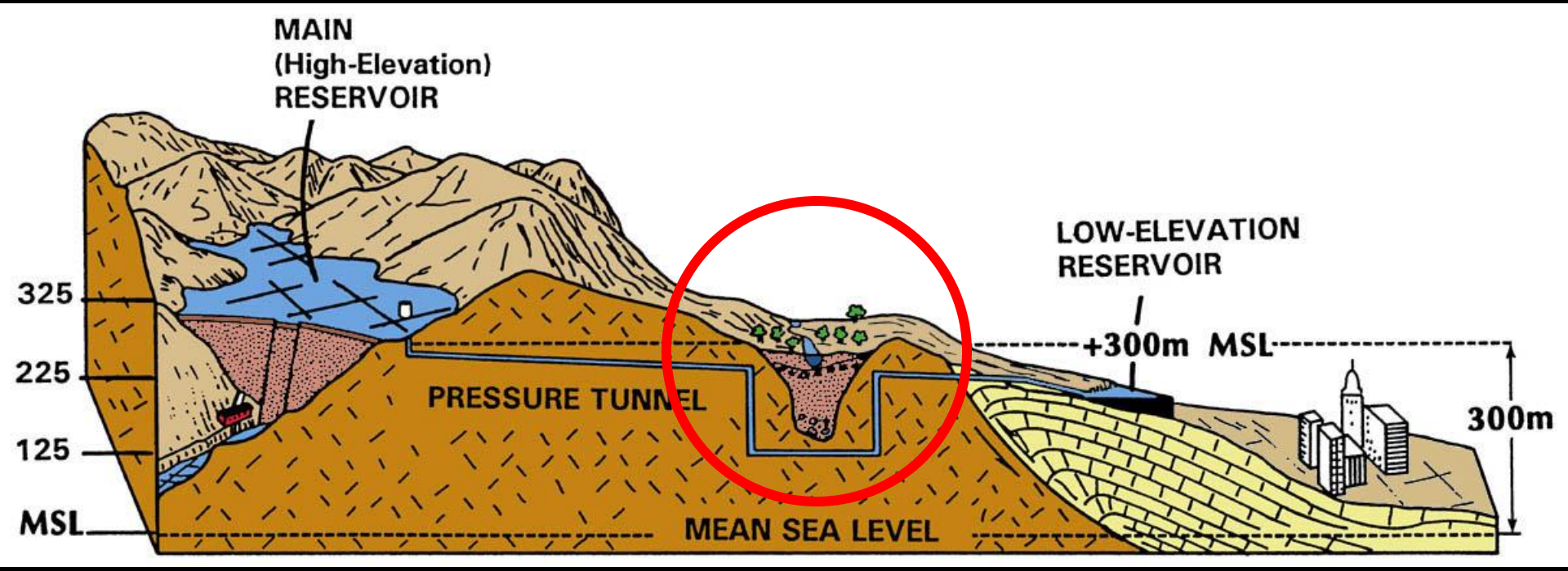
City Tunnel #3, Stage 1 – Drill and Blast Technology

Catskill Aqueduct

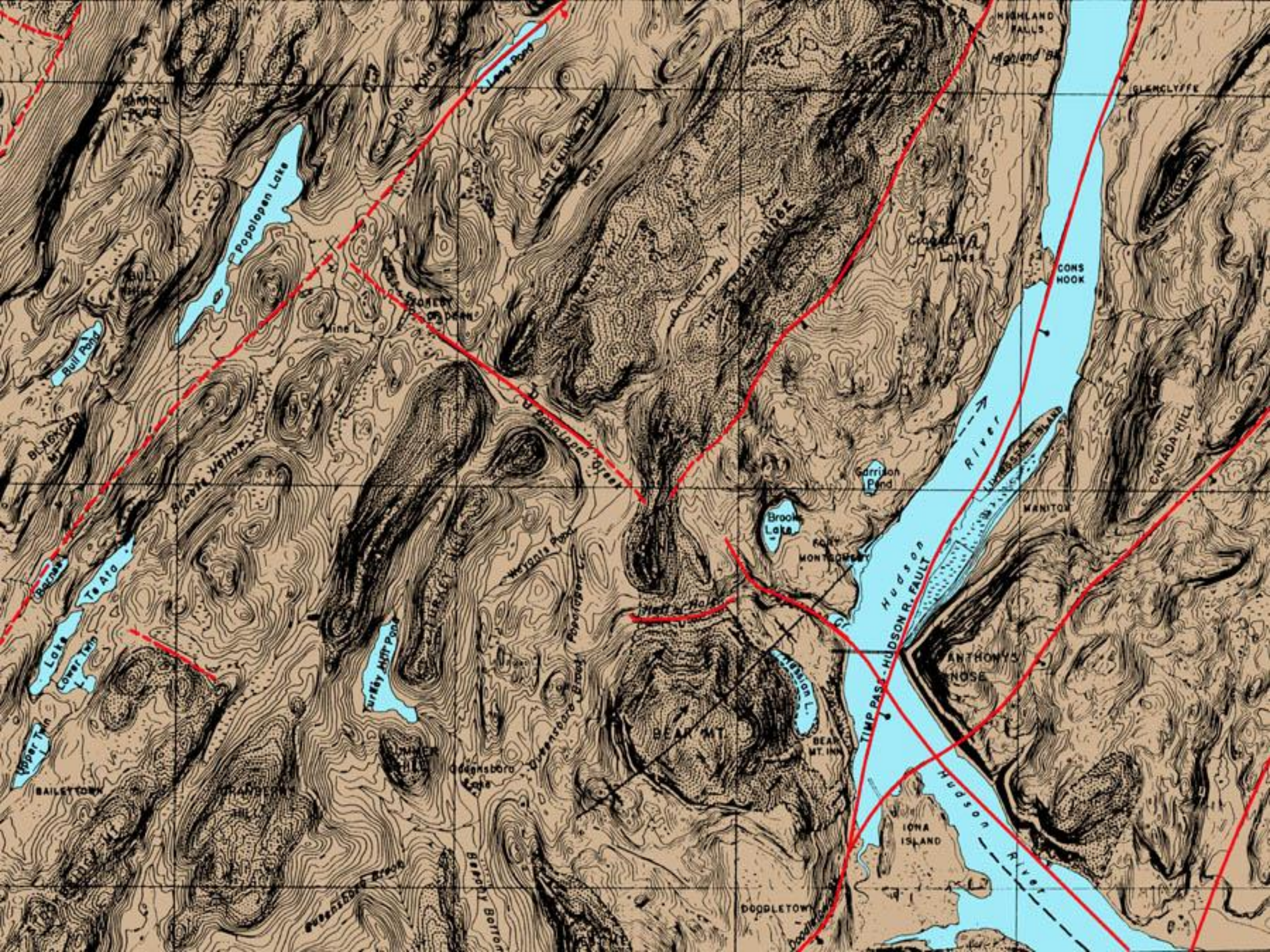


after Berkey, 1933

Gravity Feed System – No Pumps



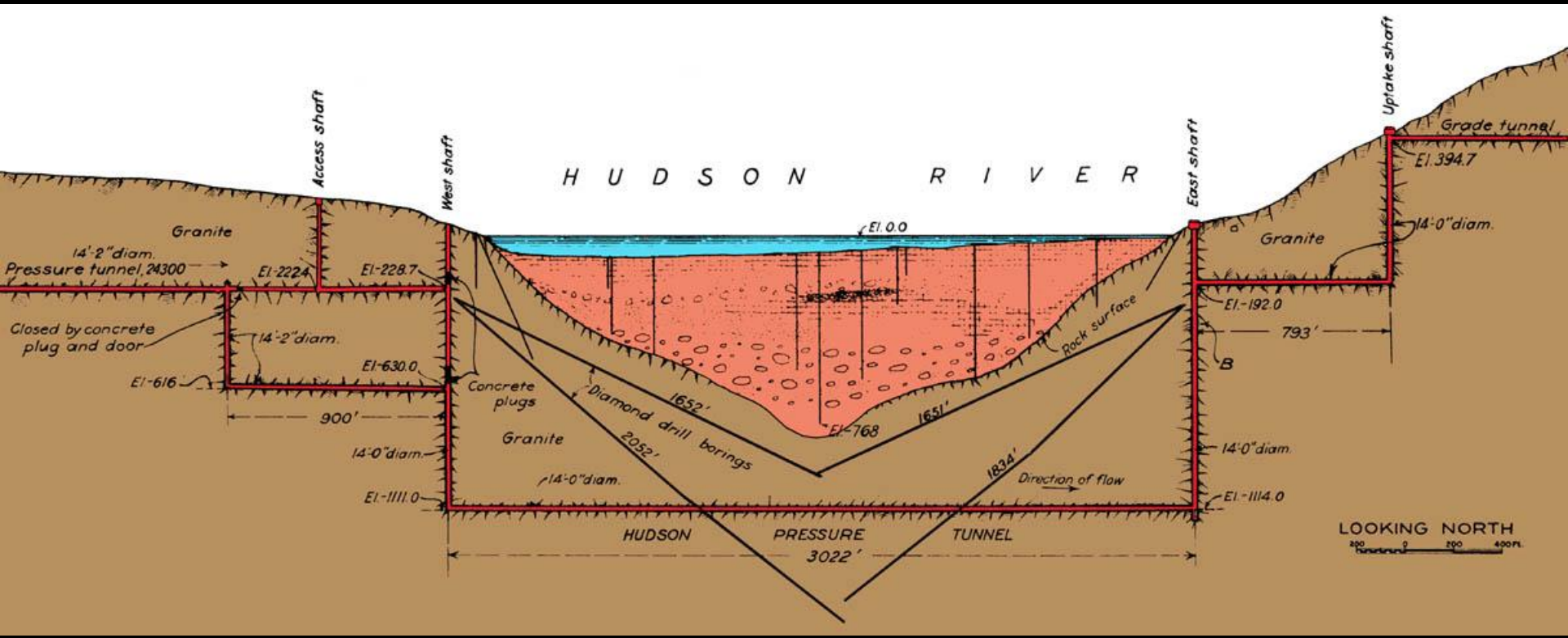
Hudson River Gorge from Bear Mtn., NY



HIGHLAND FALLS
Highland Br.
GLENCLYFFE
Long Pond
LONG POND MT.
LISTENING HILL
Popolopen Lake
Bull Pond
BLACKCAP MT.
Mine L.
Popolopen Creek
Garrison Pond
Brooks Lake
FORT MONTGOMERY
CONS HOOK
River
Hudson
HUDSON R. FAULT
TIMP PASS
MANITOU
CANADA HILL
ANTHONY'S NOSE
BEAR MT.
BEAR MT. INN
Hessian L.
Hell's Hole
Wrights Pond
Turkey Hill Pond
Te Ata
Lake
Lower Twin
Upper Twin
BAILEYTOWN
CRANBERRY HILL
IONA ISLAND
Hudson River
DOODLETOWN

Exploratory Drilling for Hudson Siphon, NYC Aqueduct

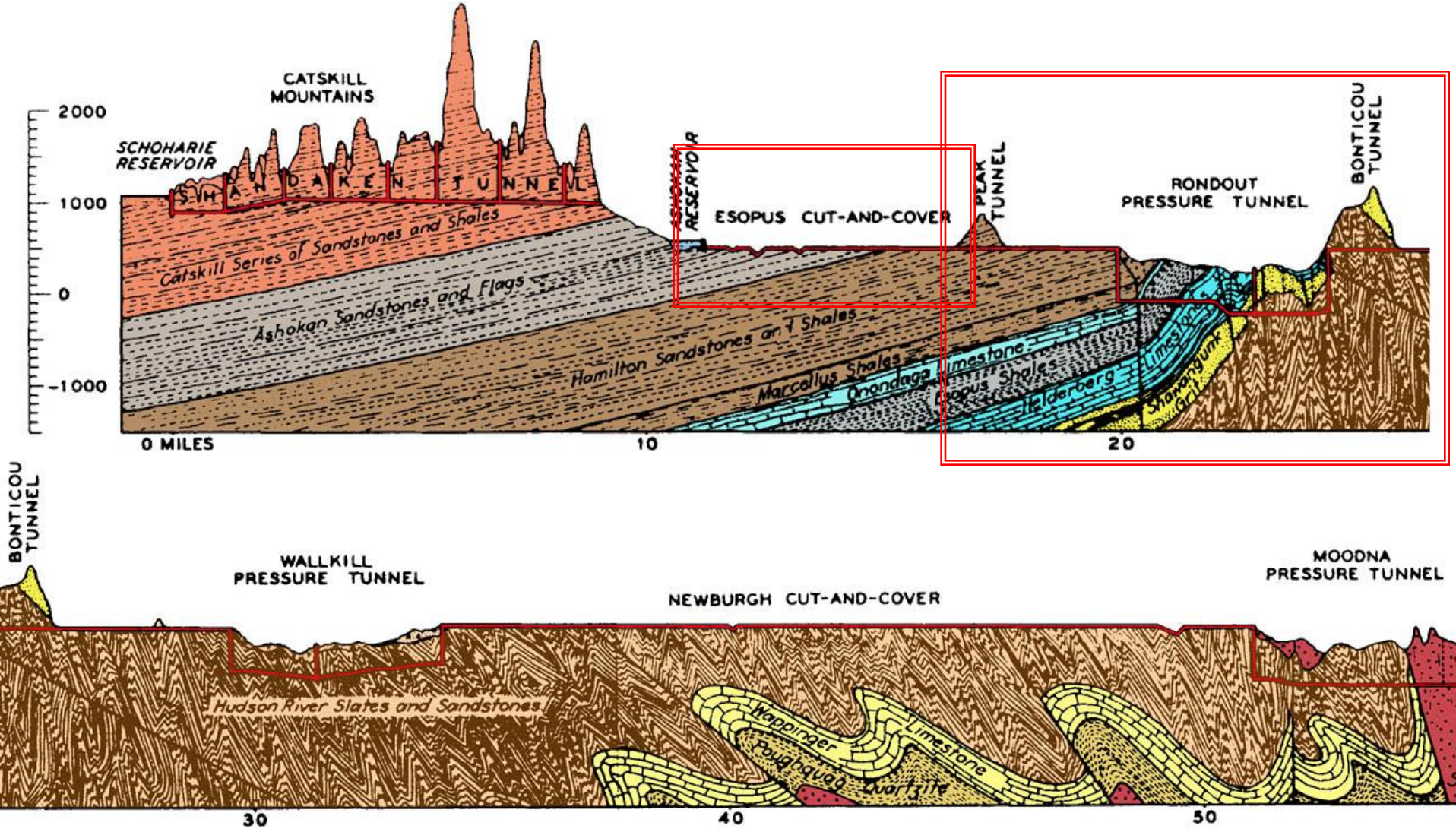
Hudson Siphon [-1,114']



NYC Aqueduct

after Berkey, 1911

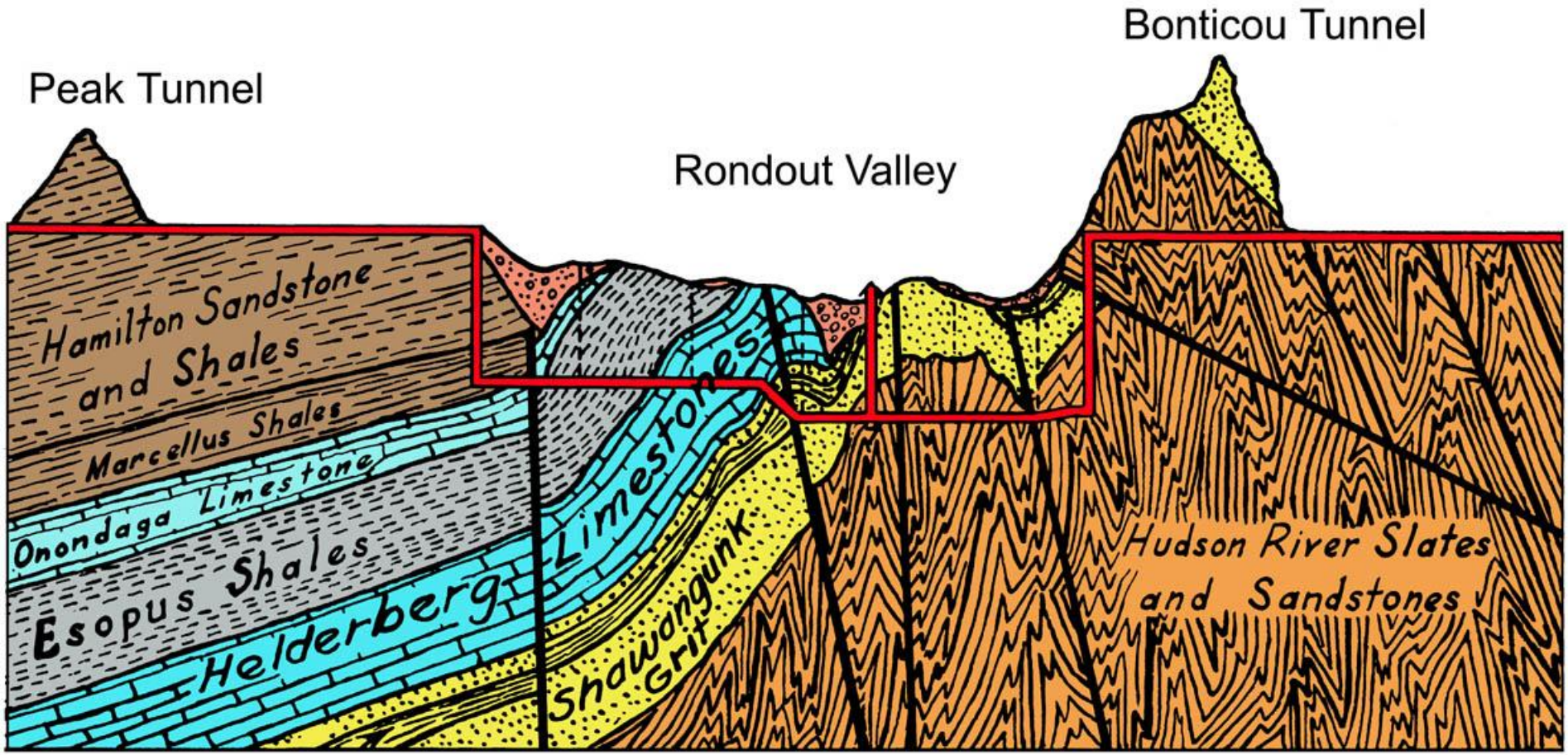
Catskill Aqueduct (0-50 Miles)



after Berkey, 1933

Cut and Cover Tunnel, NYC Aqueduct

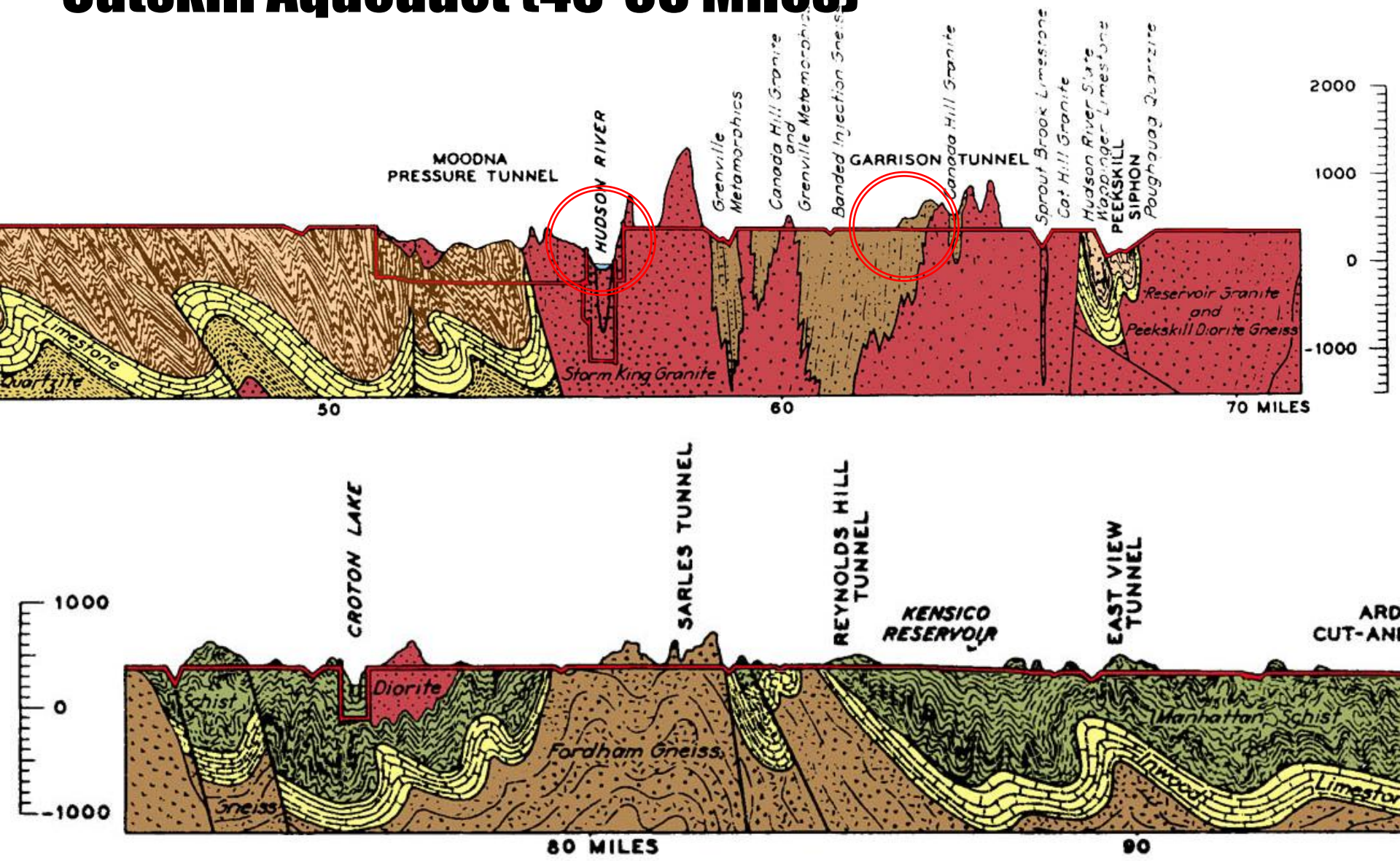
Catskill Aqueduct Rondout Pressure Tunnel



after Berkey, 1933

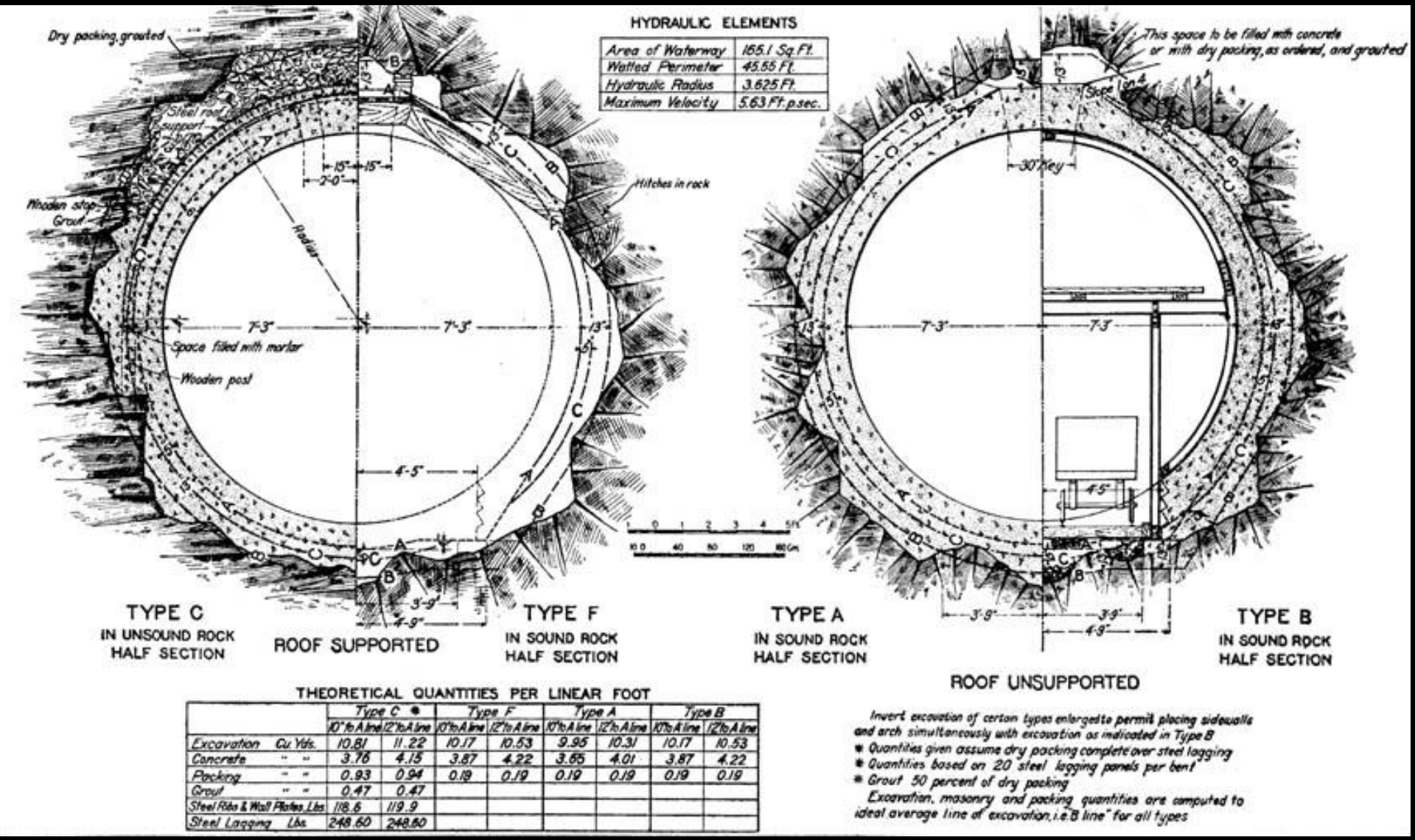
Rondout West Branch Tunnel

Catskill Aqueduct (45-95 Miles)



after Berkey, 1933

Garrison South Portal, NYC Aqueduct System



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

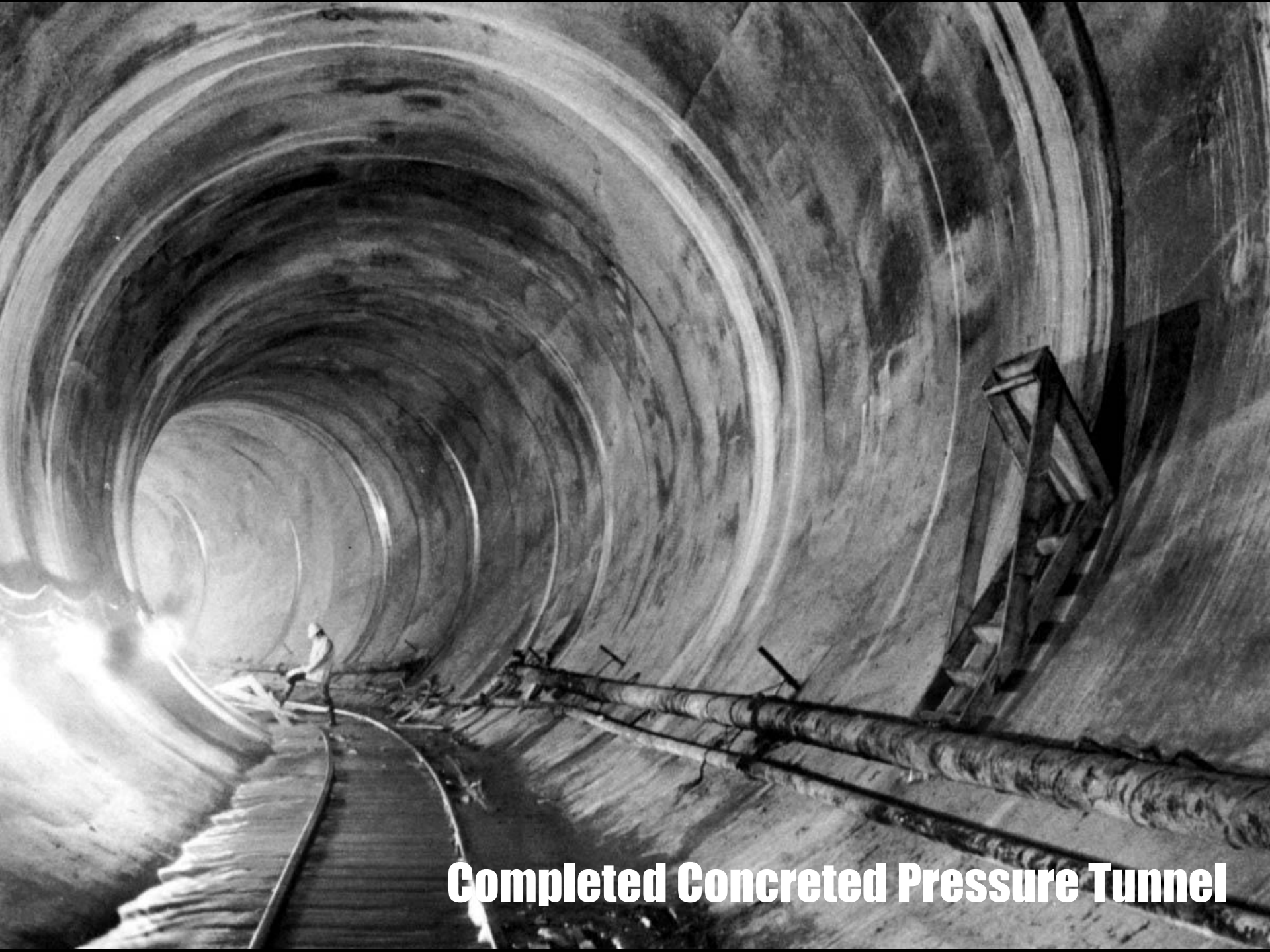
* Quantities given assume dry packing complete over steel lagging

* Quantities based on 20 steel lagging panels per bent

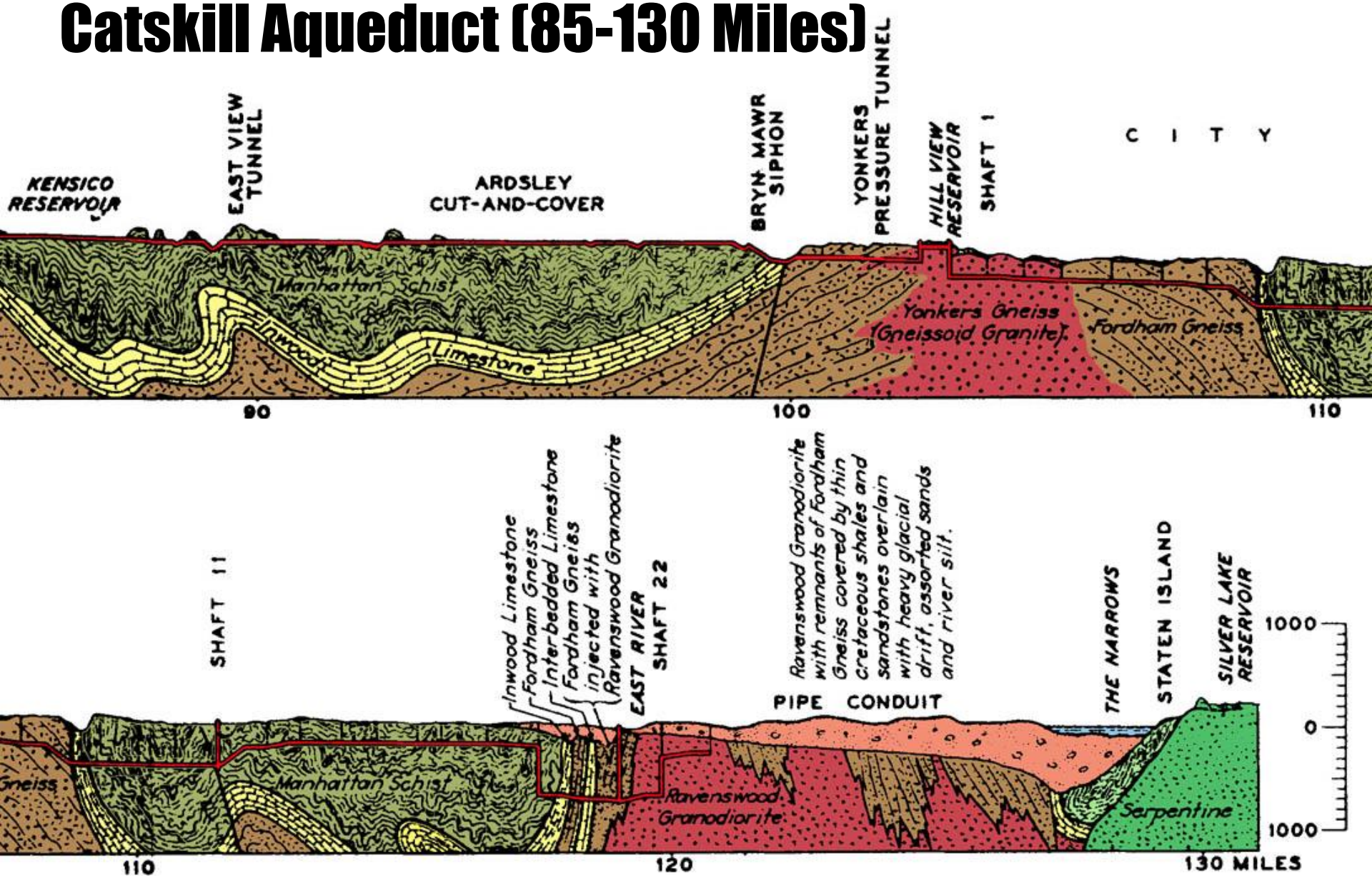
* Grout 50 percent of dry packing

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

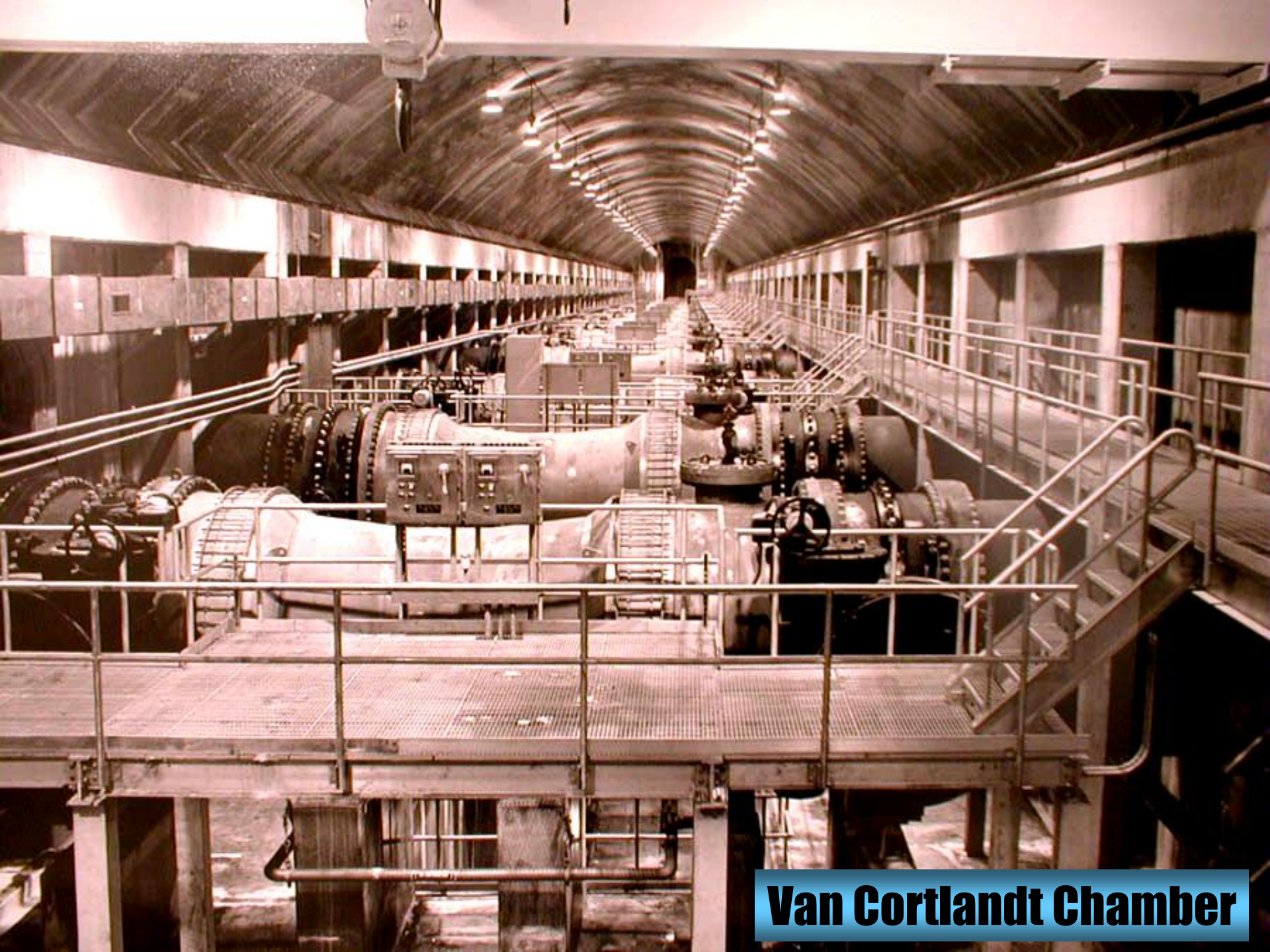

Completed Concreted Pressure Tunnel

Catskill Aqueduct (85-130 Miles)

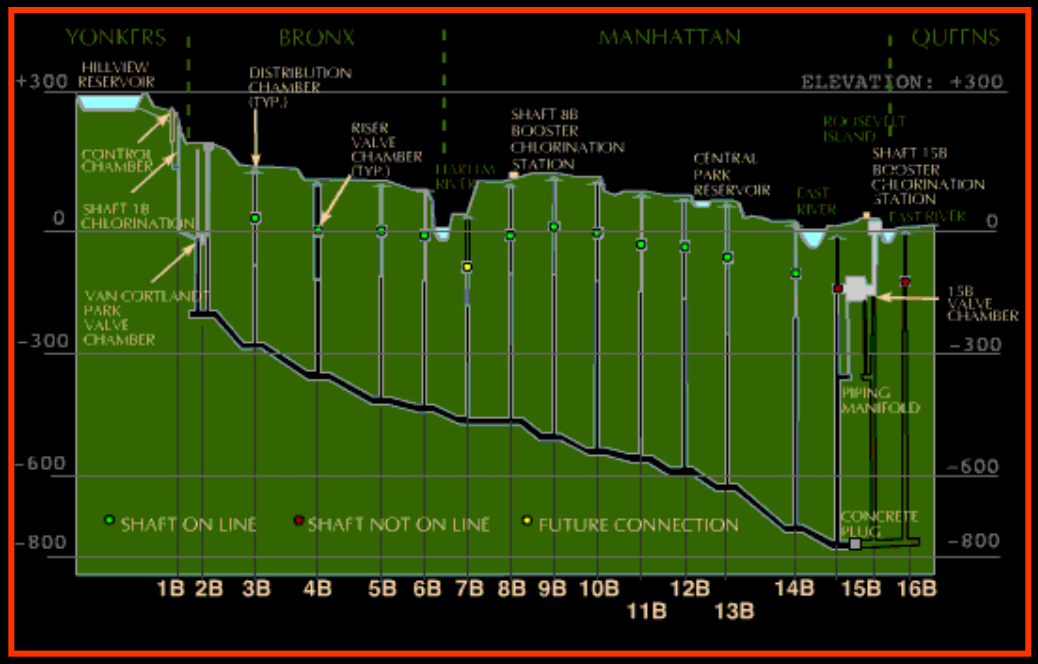


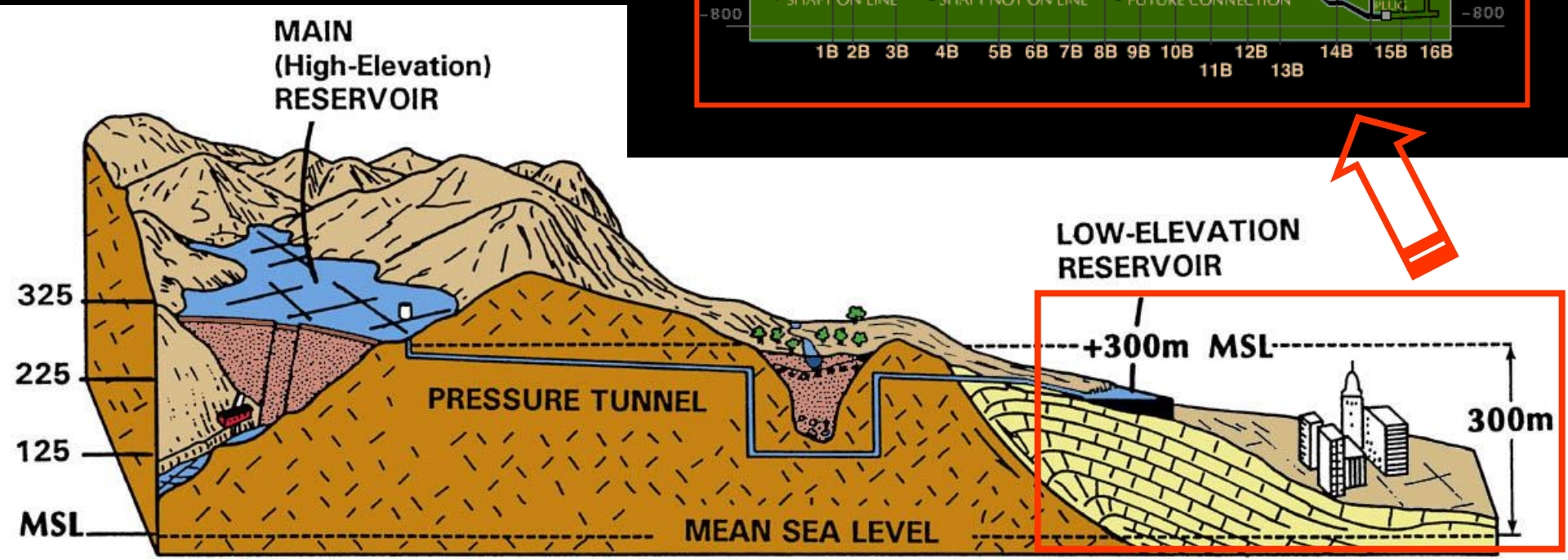
after Berkey, 1933

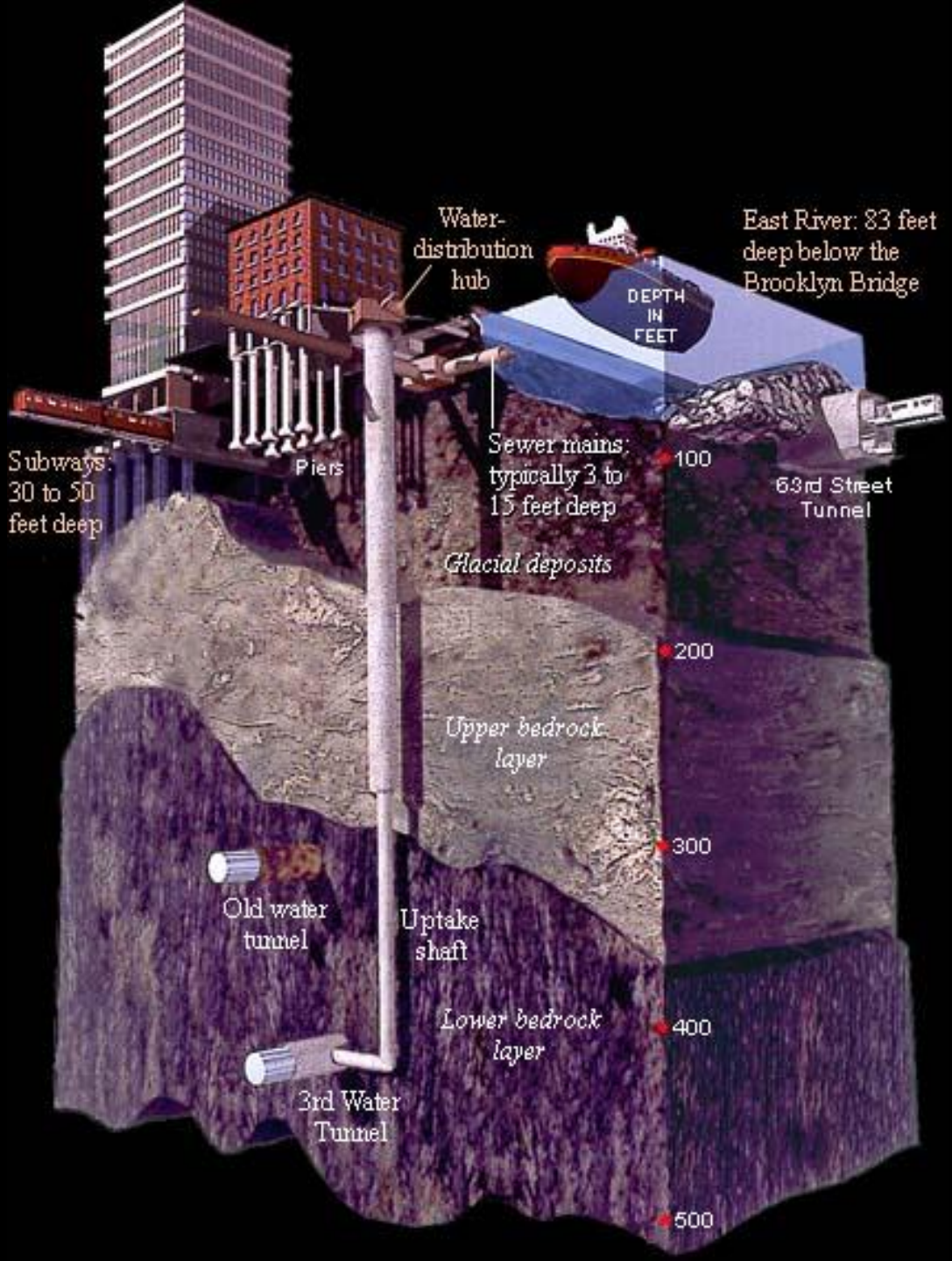
City Tunnel #3 Stage 1


Van Cortlandt Chamber

Gravity Feed System

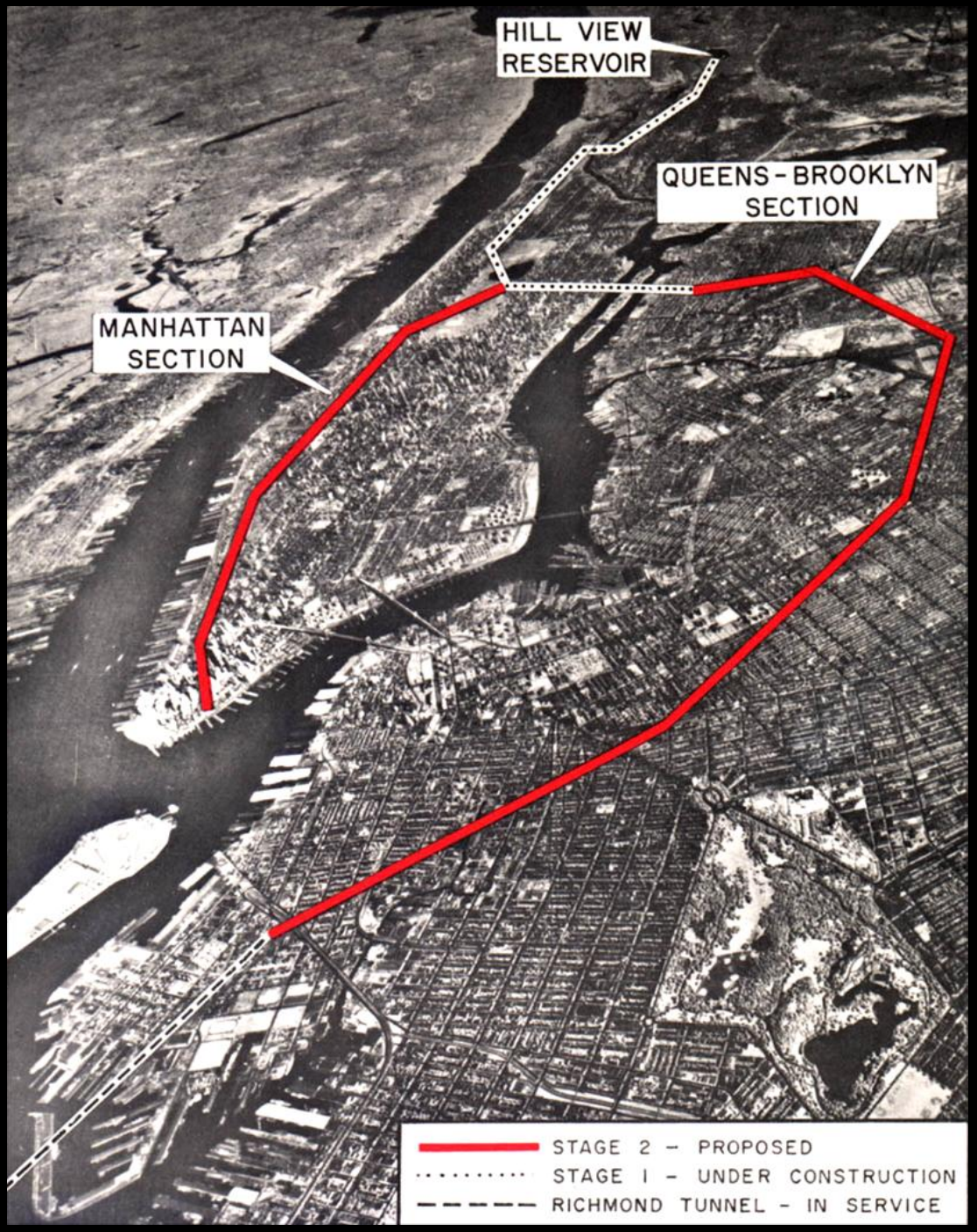


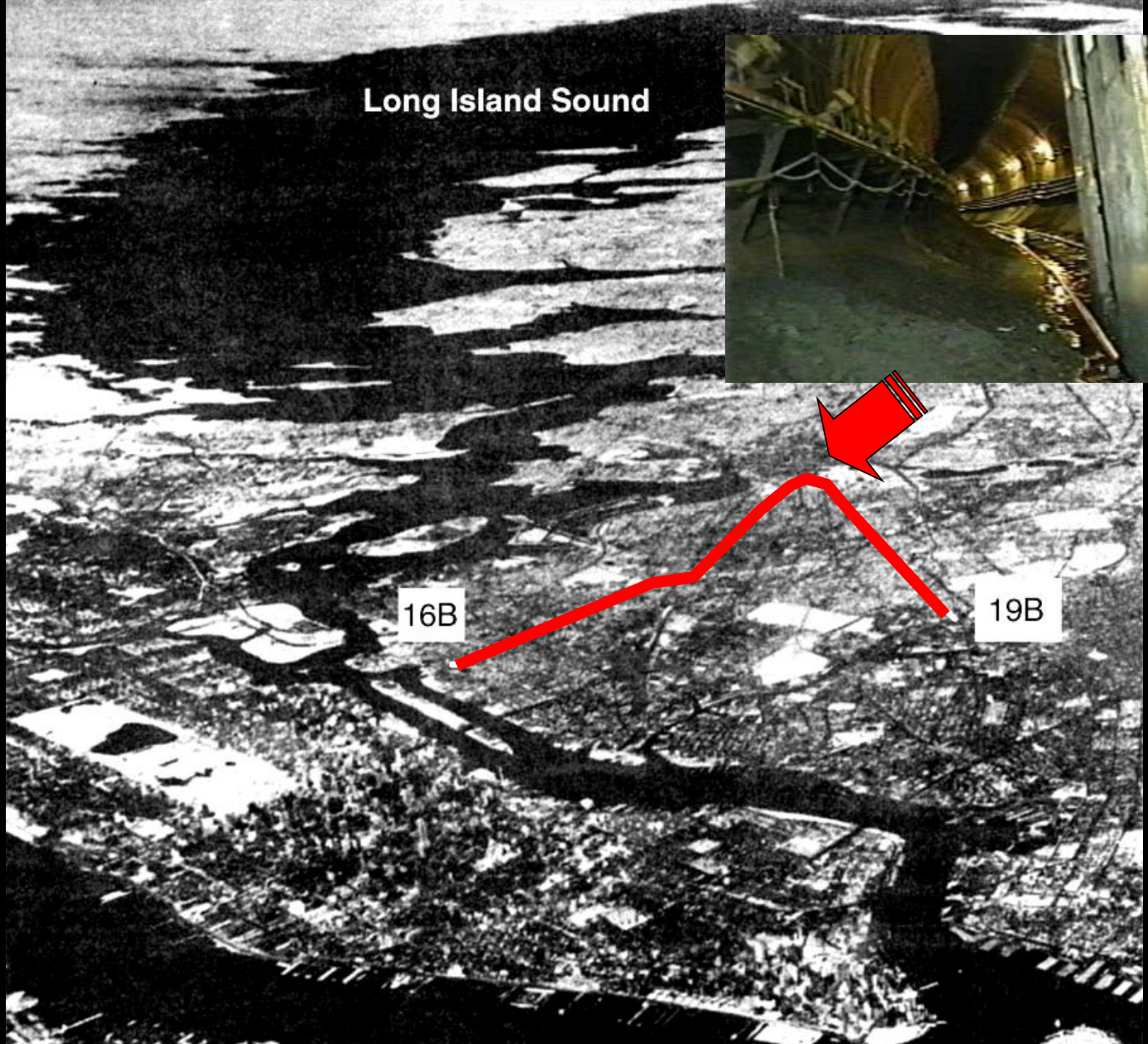


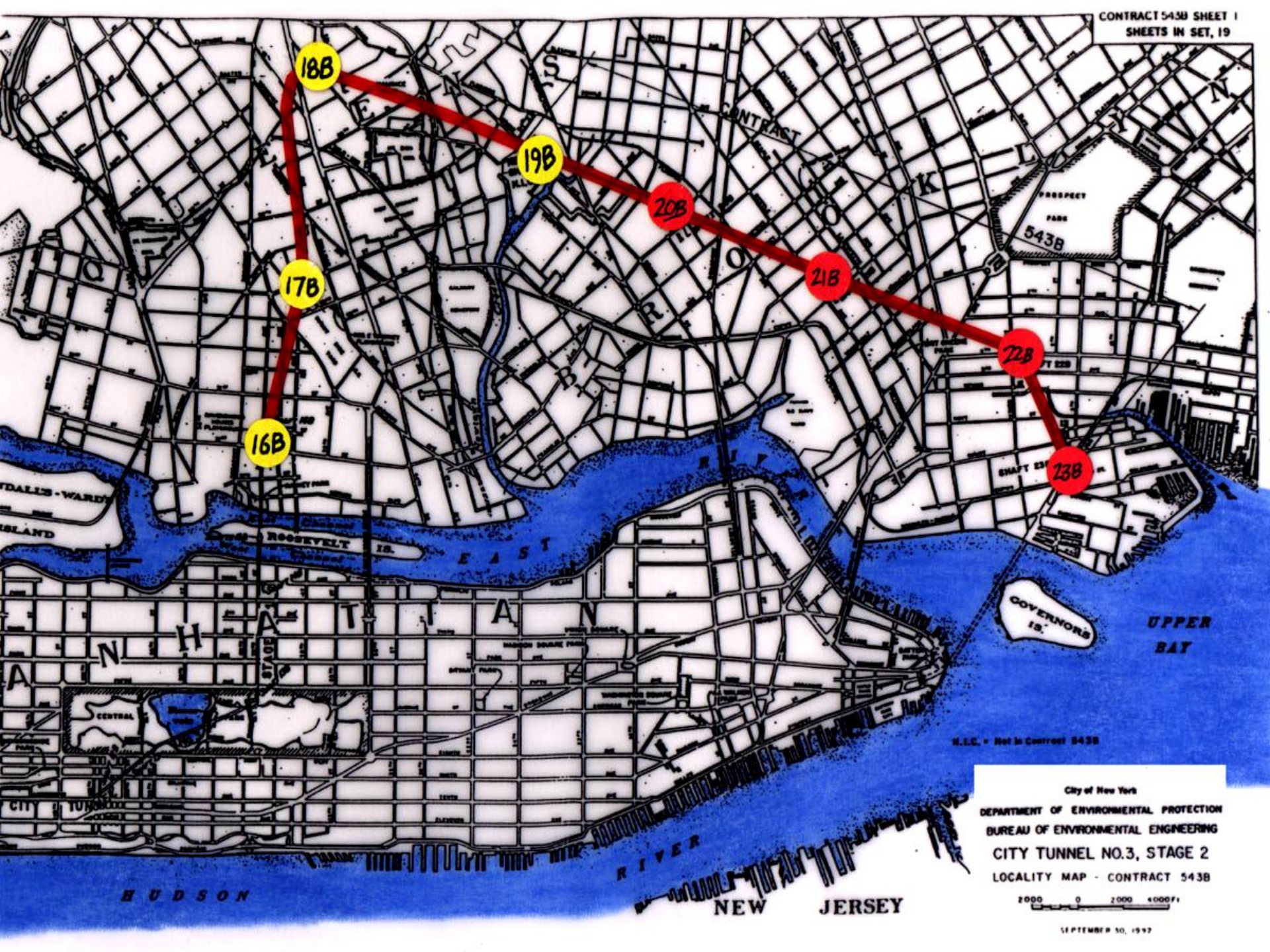


Municipal Subsurface Structure

City Tunnel #3
Stages 1 and 2

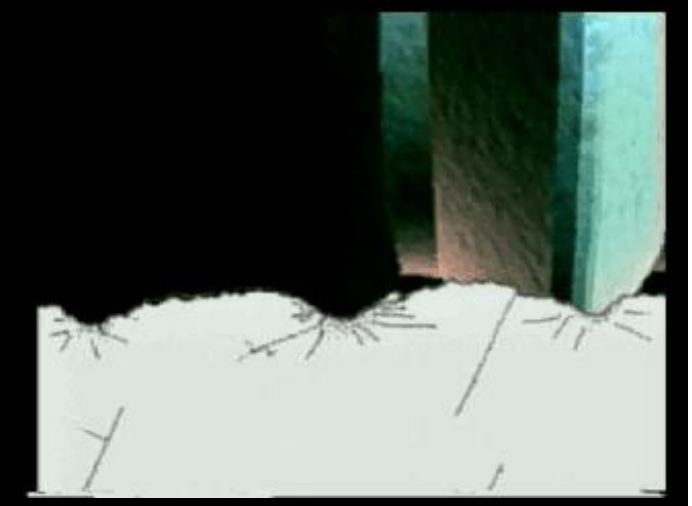


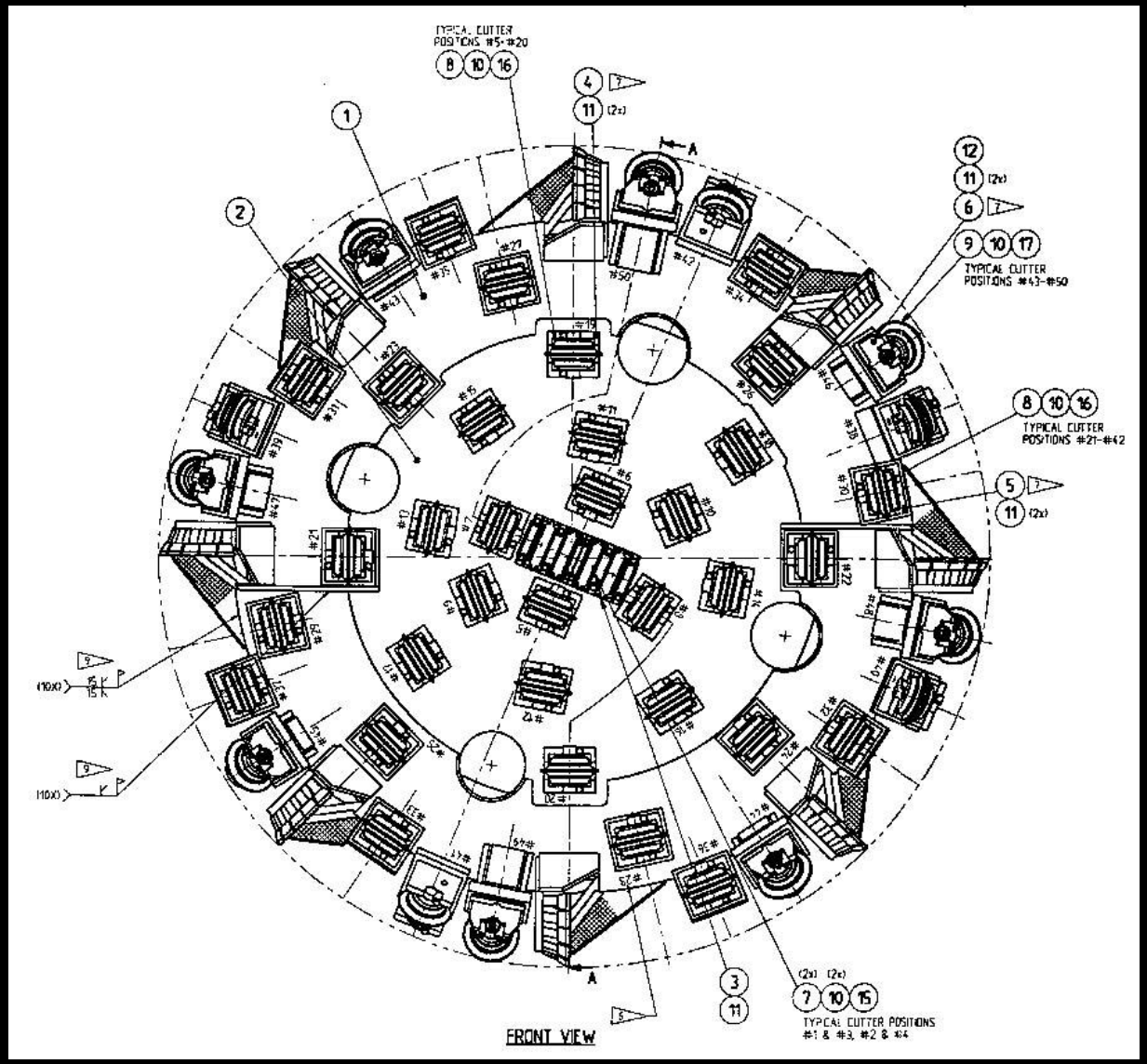

Long Island Sound
16B
19B

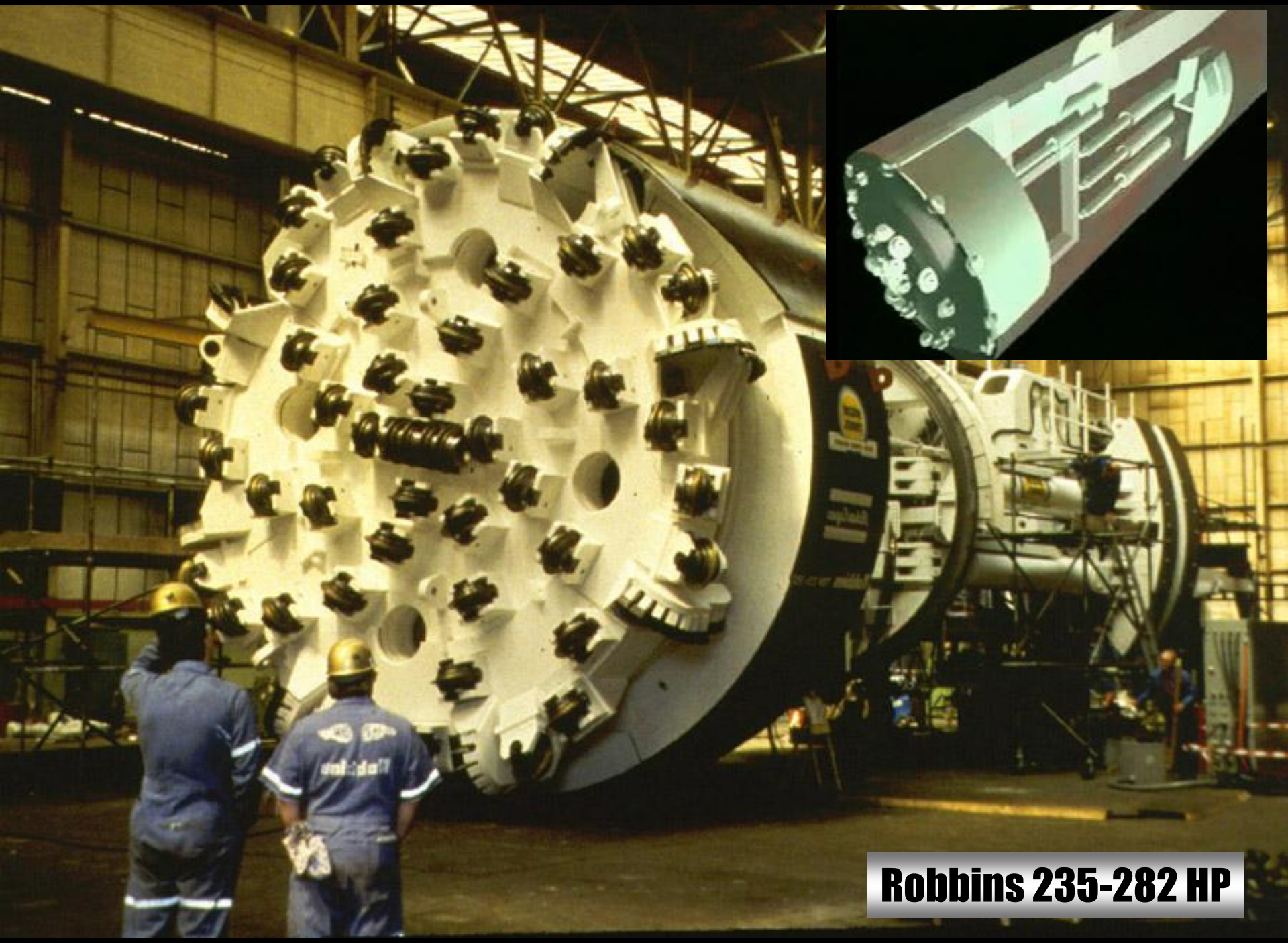

CONTRACT 543B SHEET 1
SHEETS IN SET, 19
18B
19B
20B
21B
22B
23B
17B
16B
543B
CONTRACT
PROSPECT PARK
ROOSEVELT IS.
EAST RIVER
GOVERNORS IS.
UPPER BAY
MANHATTAN
STAGE 2
CENTRAL PARK
CITY TUNNEL
HUDSON RIVER
NEW JERSEY
N.I.C. = Not in Contract 543B
City of New York
DEPARTMENT OF ENVIRONMENTAL PROTECTION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

Robbins 235-282 HP TBM

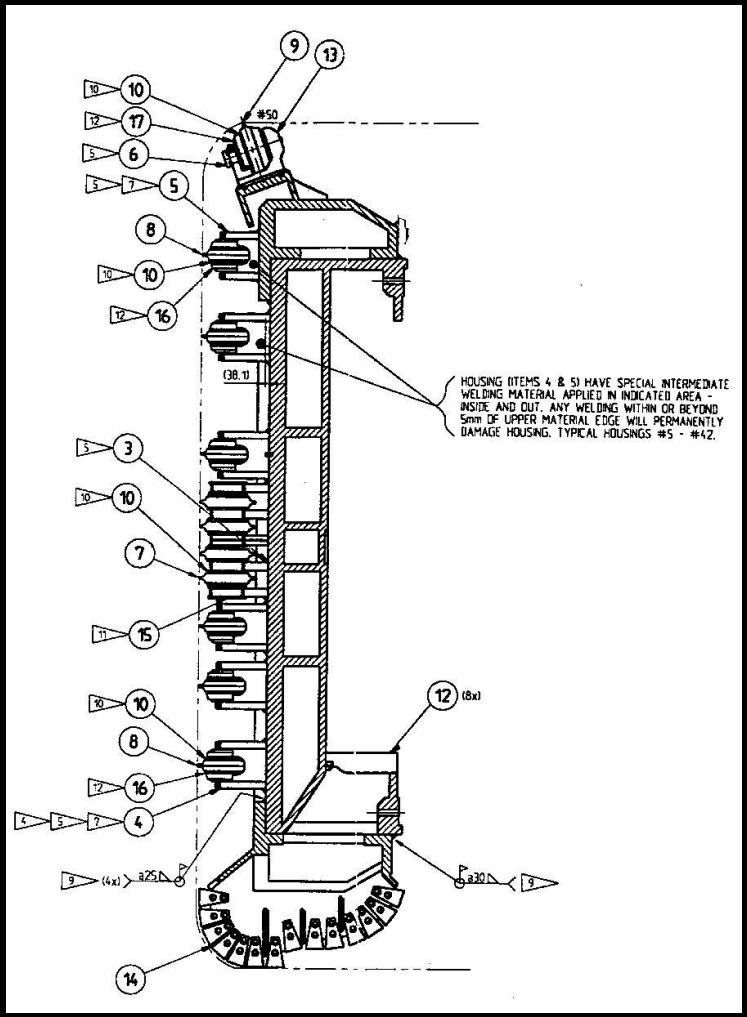
TBM Chip Production






Robbins 235-282 HP

Kerf Pattern in Hard Rock




Chemical Grout in Wet, Blocky Heading

Drilling Bellout for Blasting

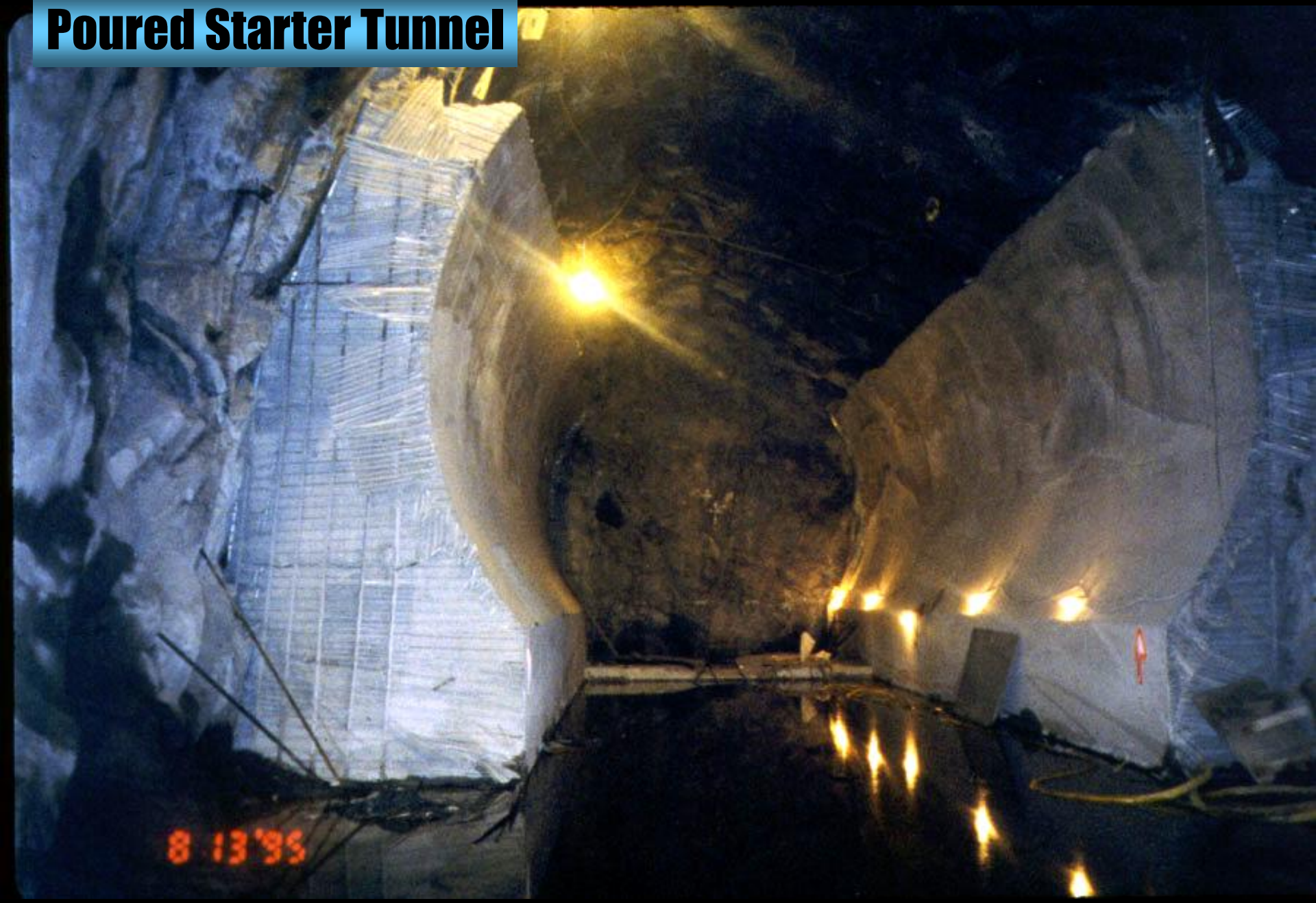
Flipping TBM Cutterhead

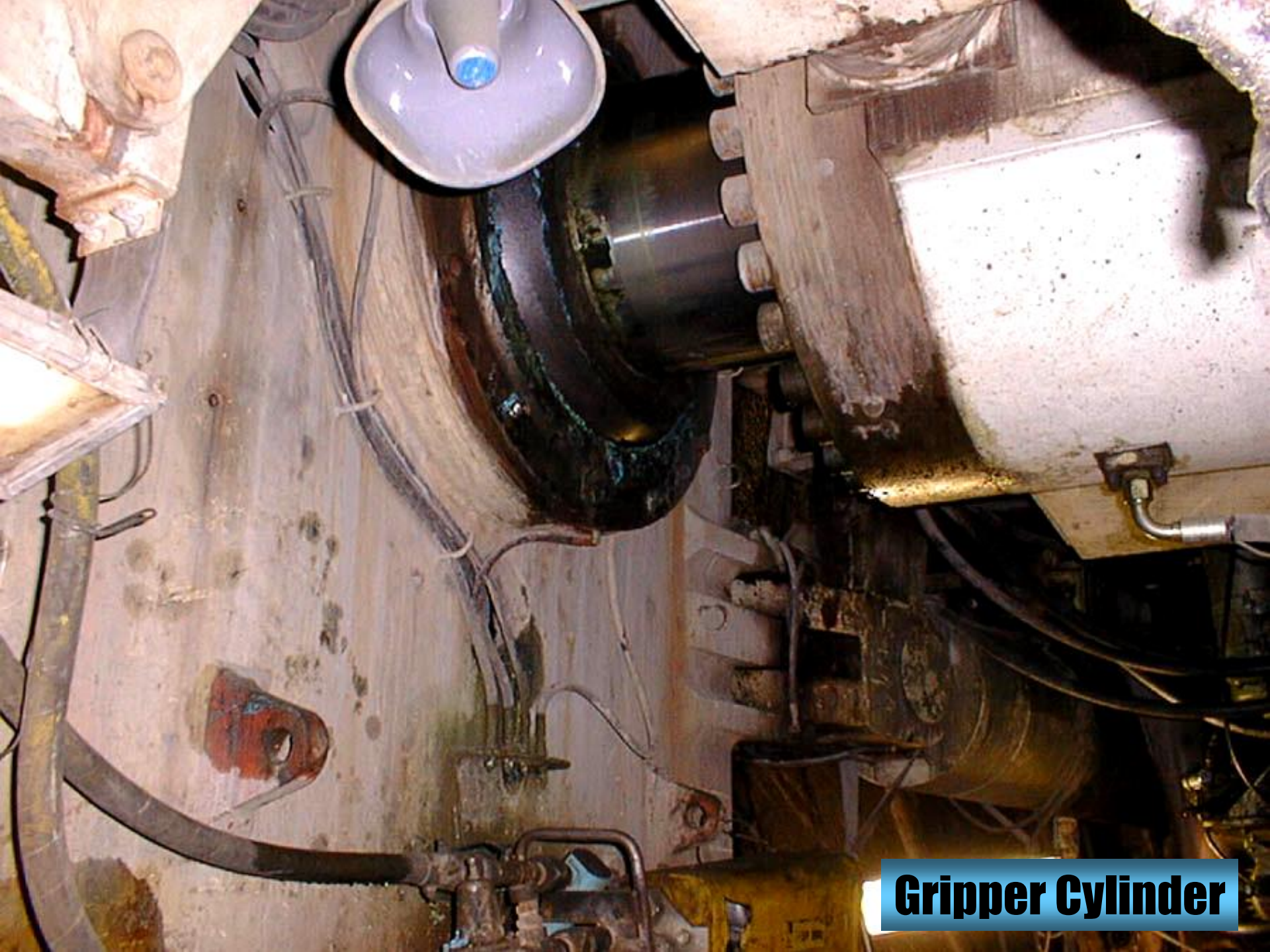
Lowering TBM Cutterhead

Lowering TBM Mainbeam

Walking TBM Mainbeam

Poured Starter Tunnel




Gripper Cylinder


In the Belly of the Beast

In the Belly of the Beast

Operator's Cabin


TBM-Bored Tunnel

Tunneling Difficulties

Rainy Conditions

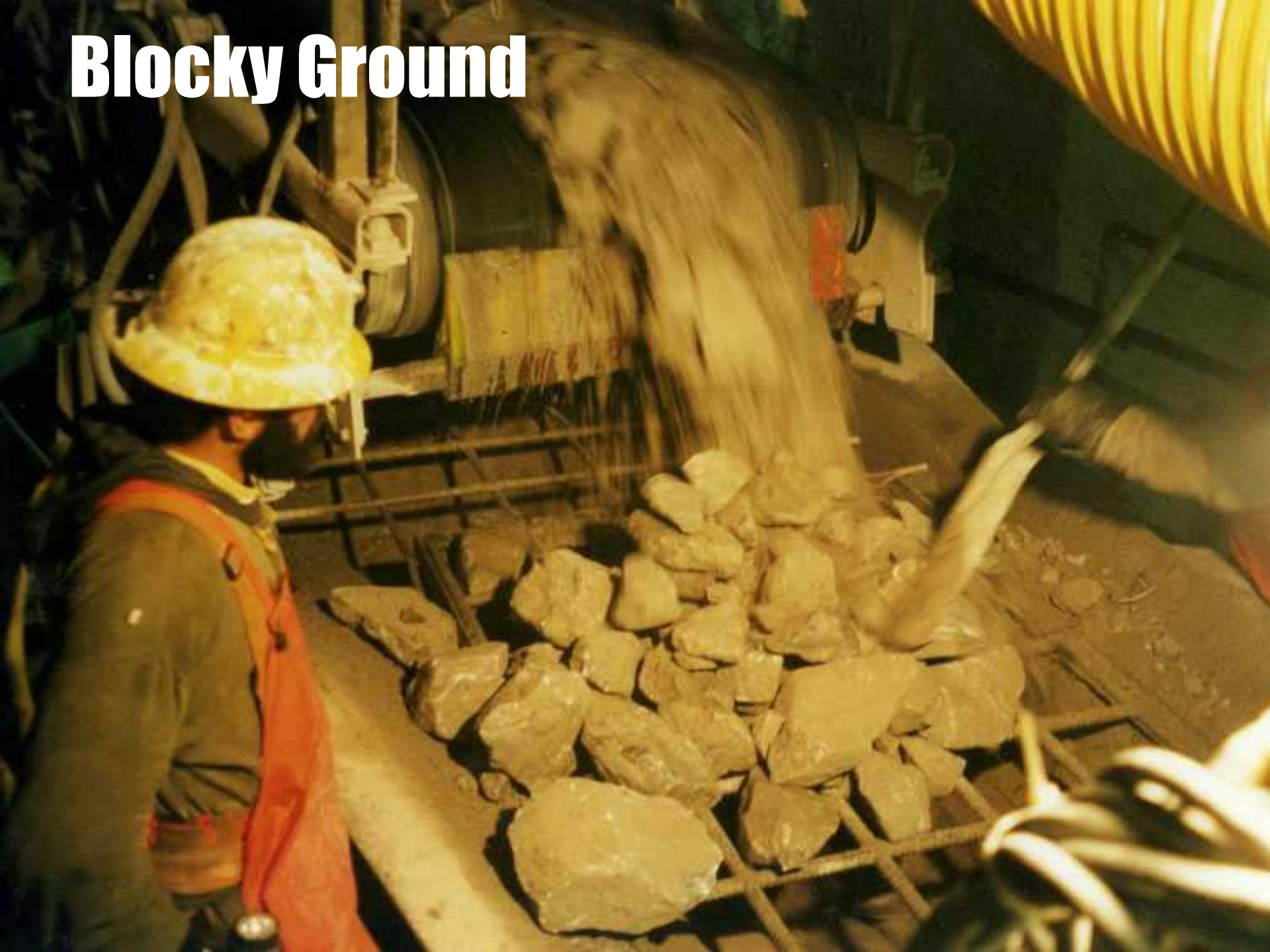
Station 140+60

Faults - Disturbed Ground Zone 59

Station 152+90

Excessive Fines

Blocky Ground

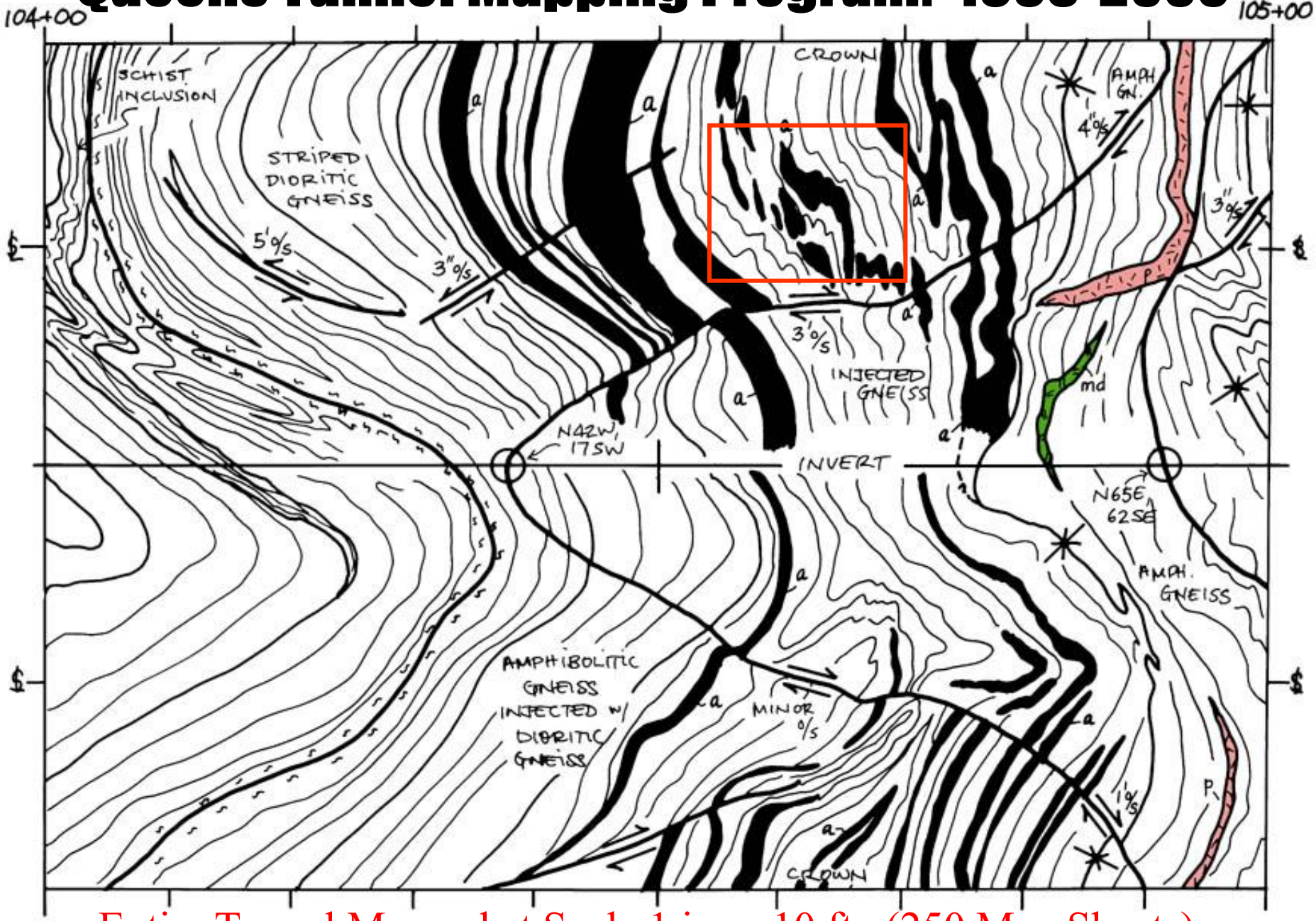


Hartland is Micaceous, Well Foliated and Well Layered


Pegmatite?
Garnet?
How the hell should I know?
Hartland?
Schist?
Gneiss?
Hartland ?
Fordham?

Merguerian's Field Office

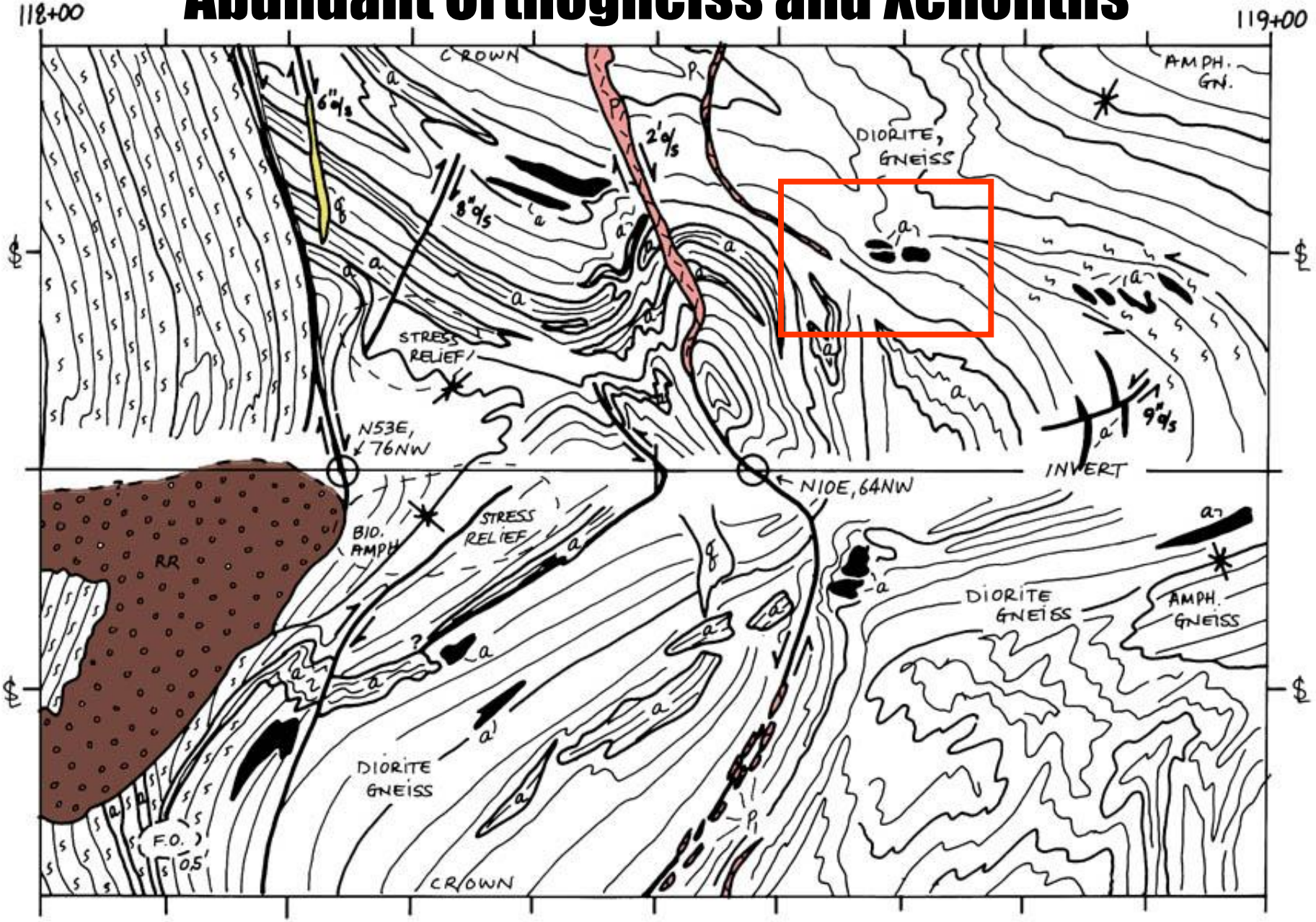
Queens Tunnel Mapping Program: 1998-2000



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


104+55
104+60
104+65

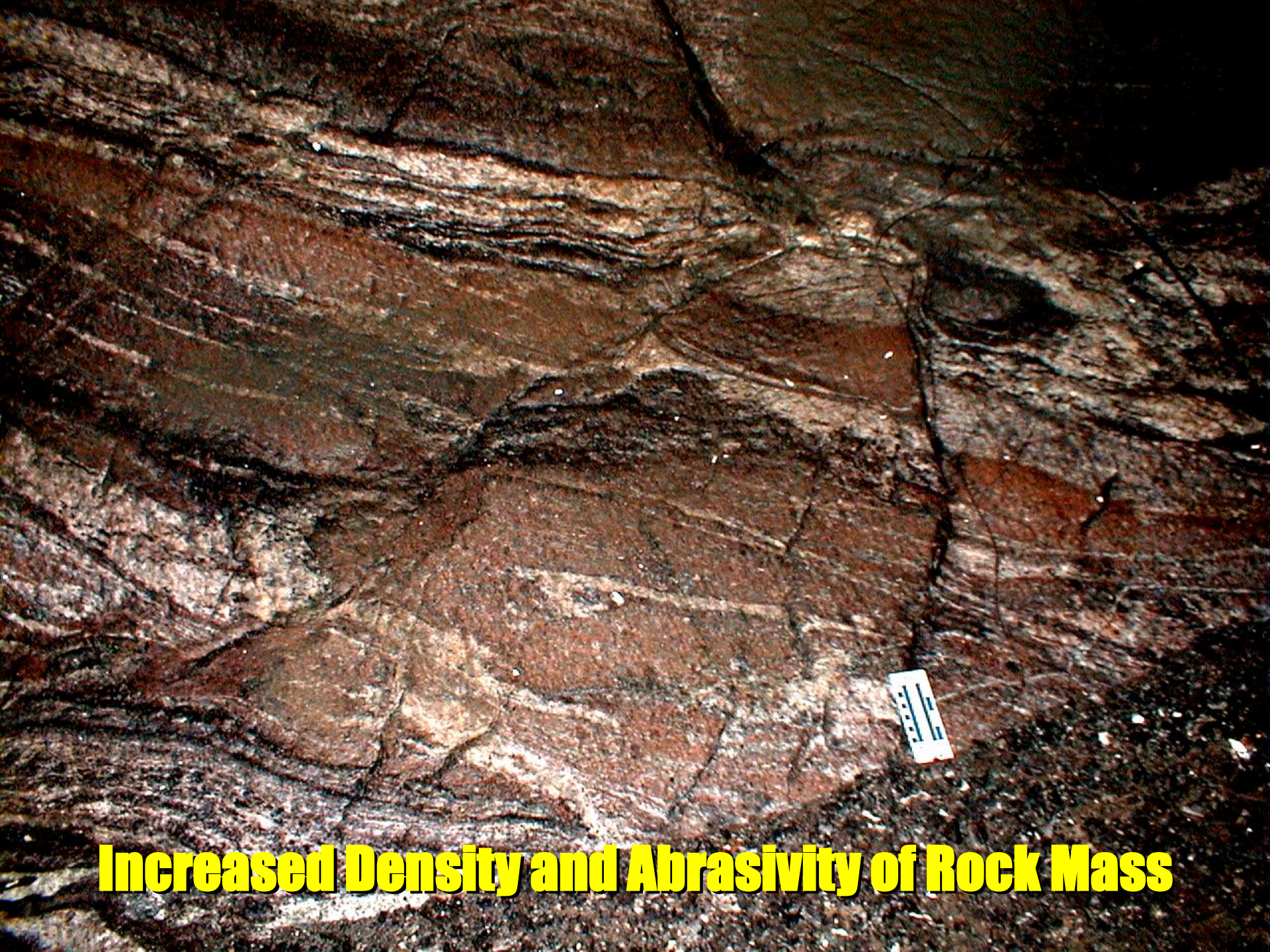
Abundant Orthogneiss and Xenoliths



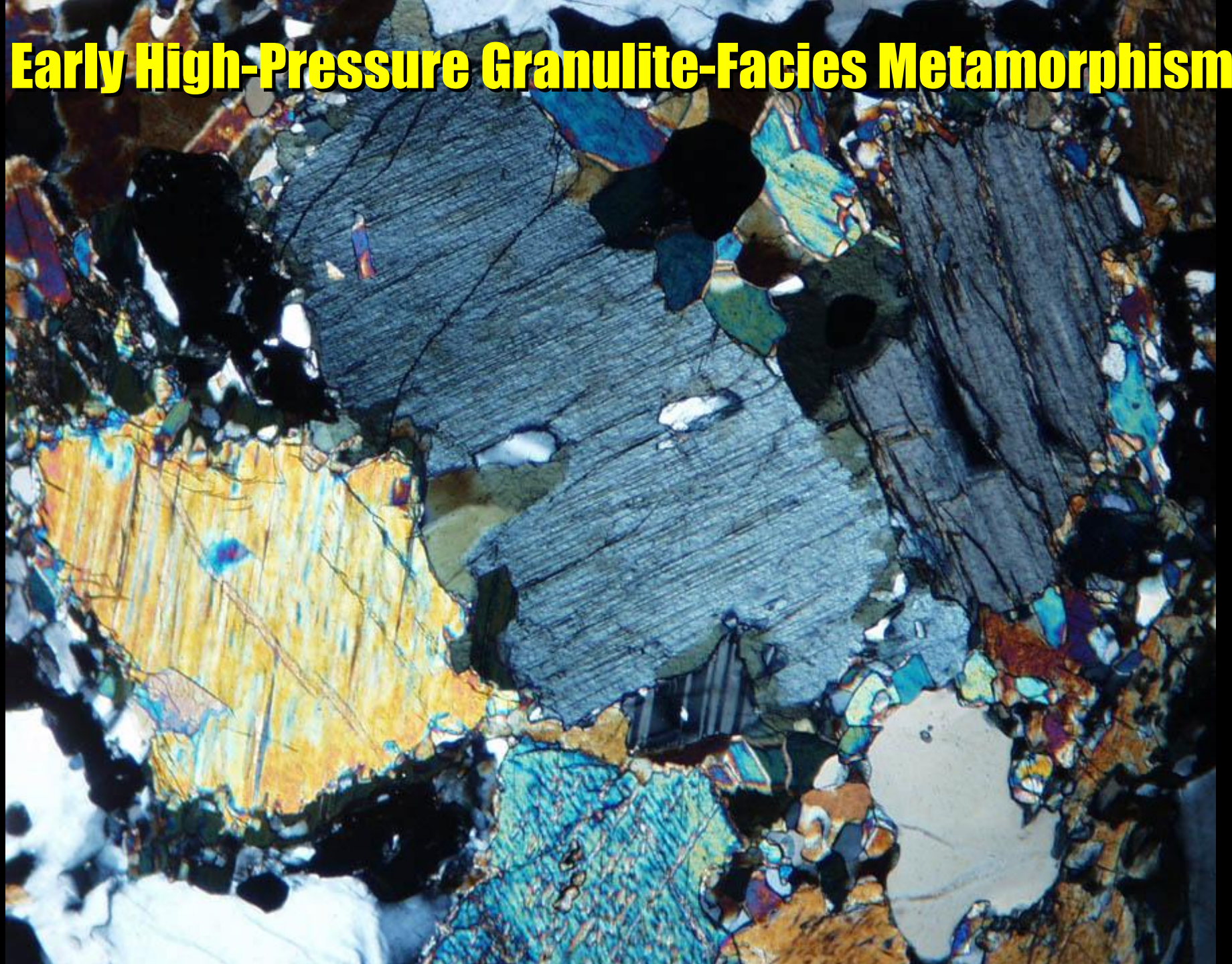
- **Scale of Mapping: 1 in. = 10 ft**

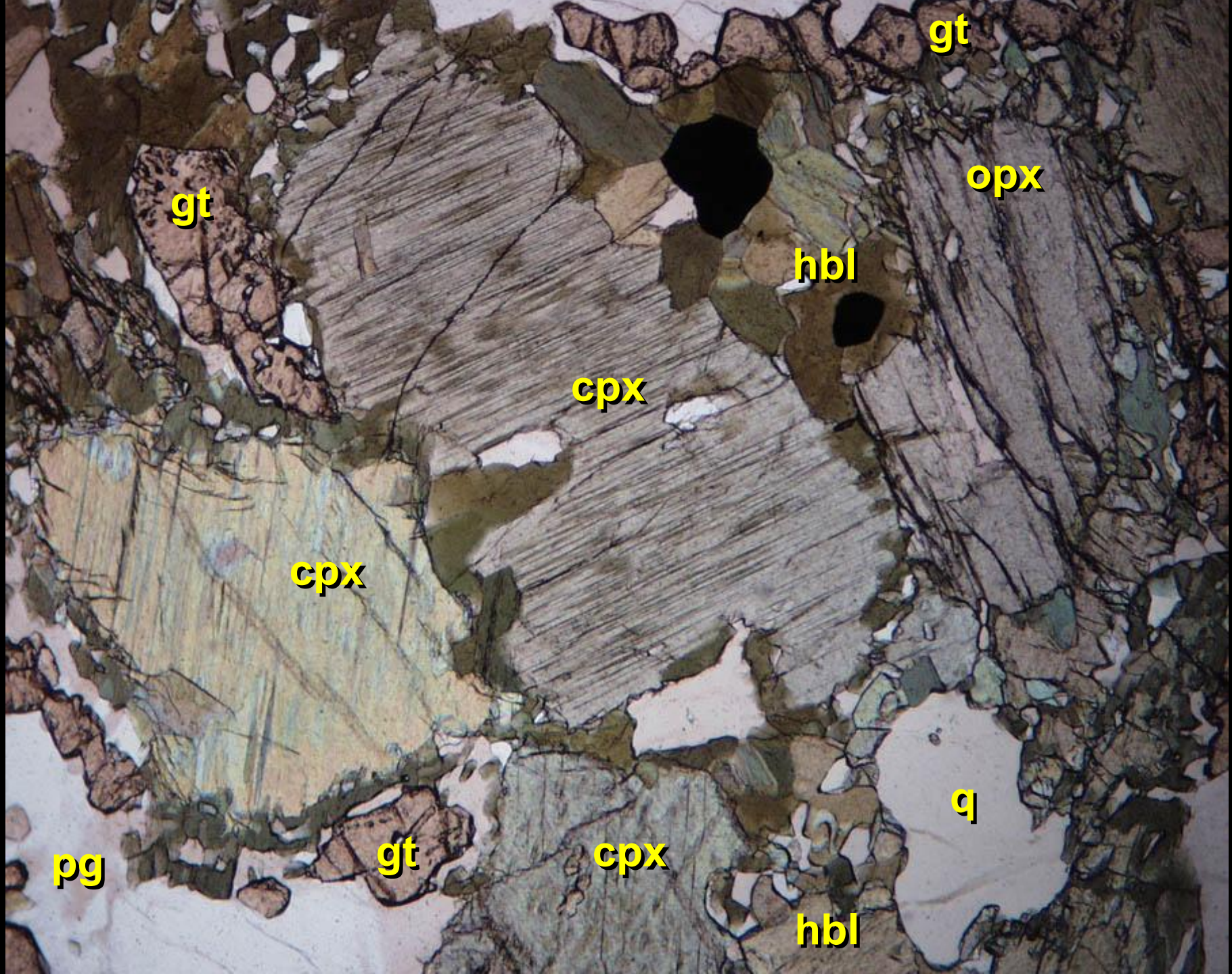

ADJ
118+
118

Folded Garnet-Plagioclase Segregations in Mafic Gneiss


Increased Density and Abrasivity of Rock Mass

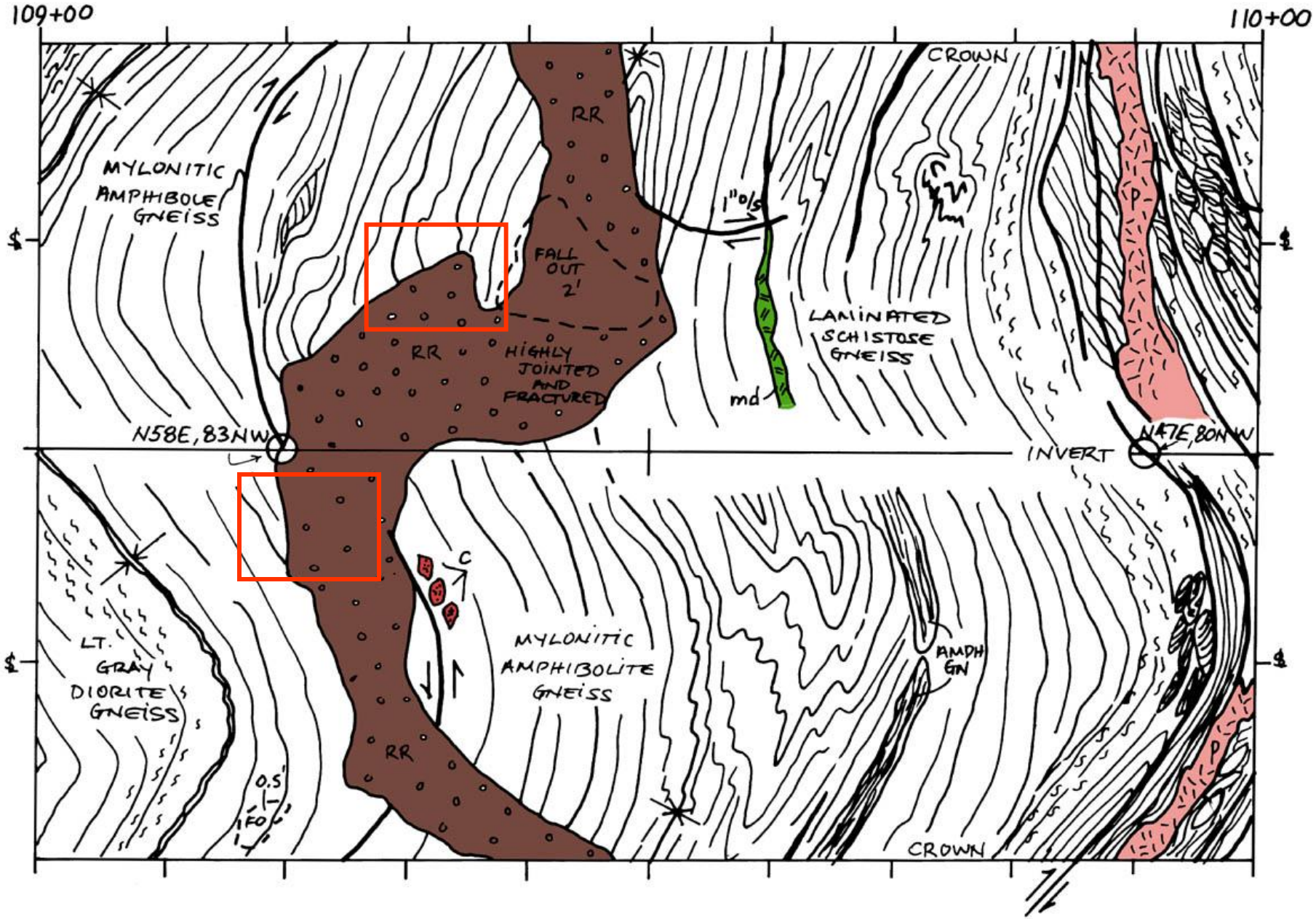
Early High-Pressure Granulite-Facies Metamorphism




gt
opx
gt
hbl
cpx
cpx
q
pg
gt
cpx
hbl

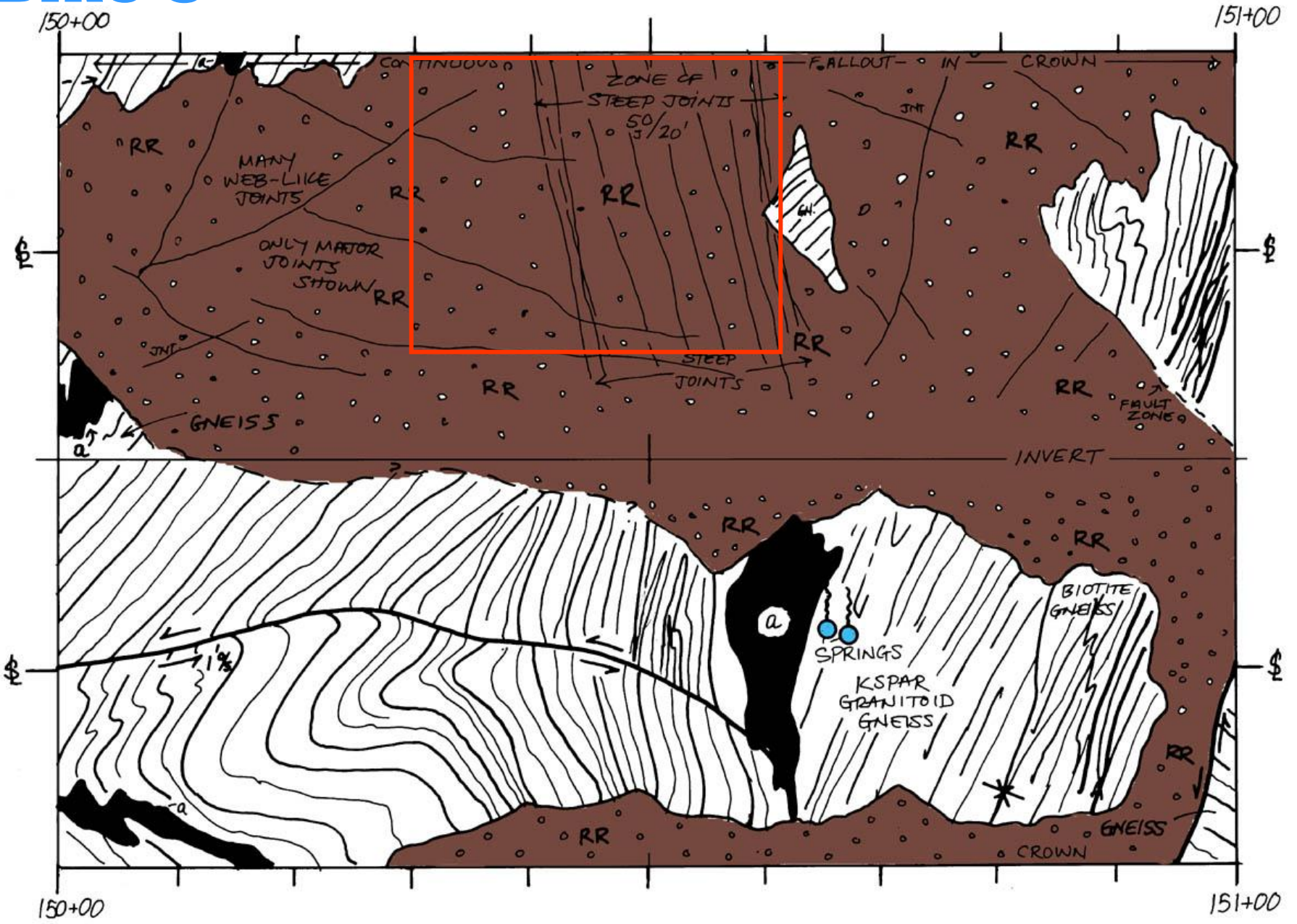
Stage 2, City Tunnel 3

Dike 1


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

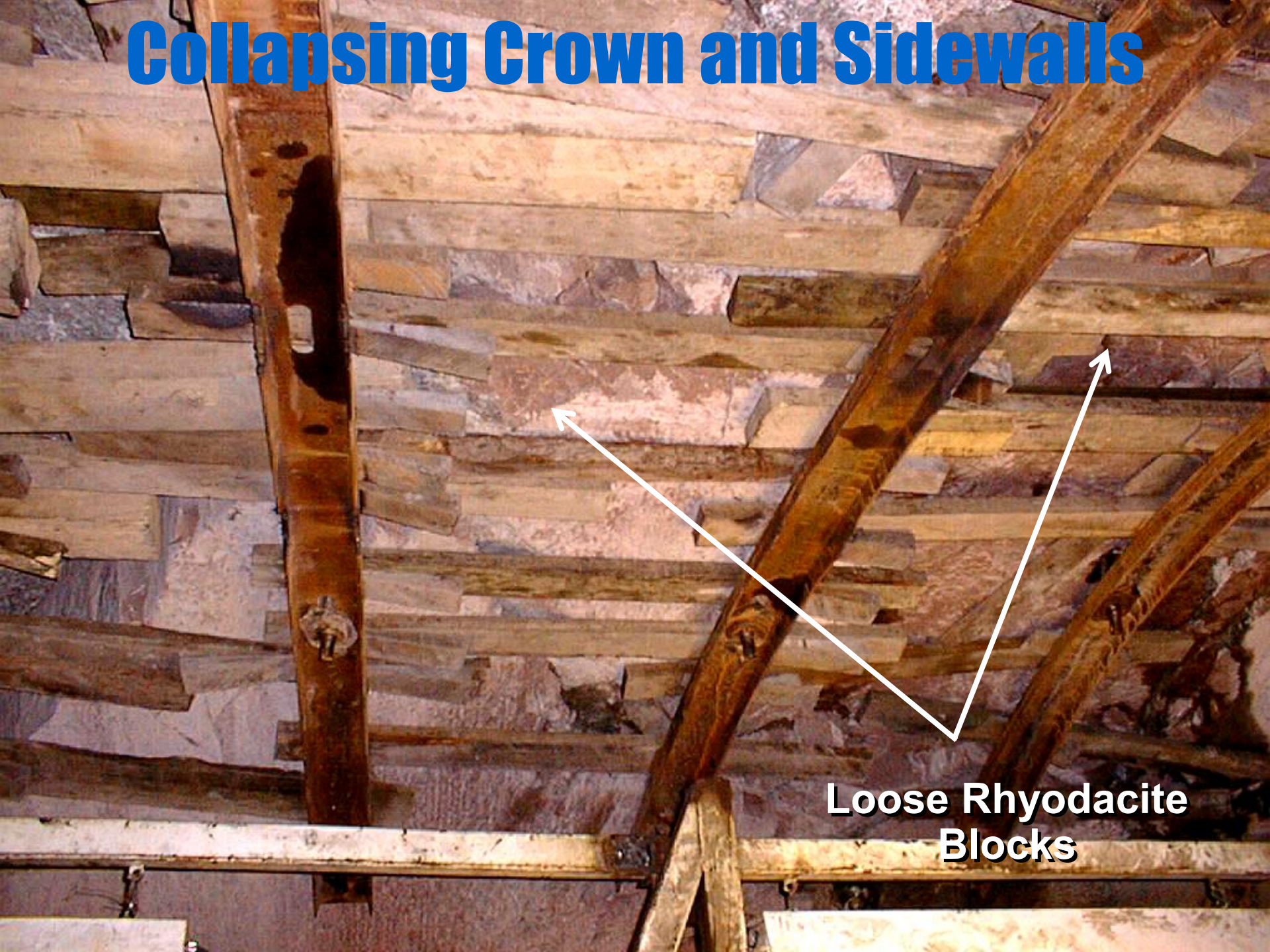

Station 109+20, Right Wall
Cooling joints extend 10' into country rock

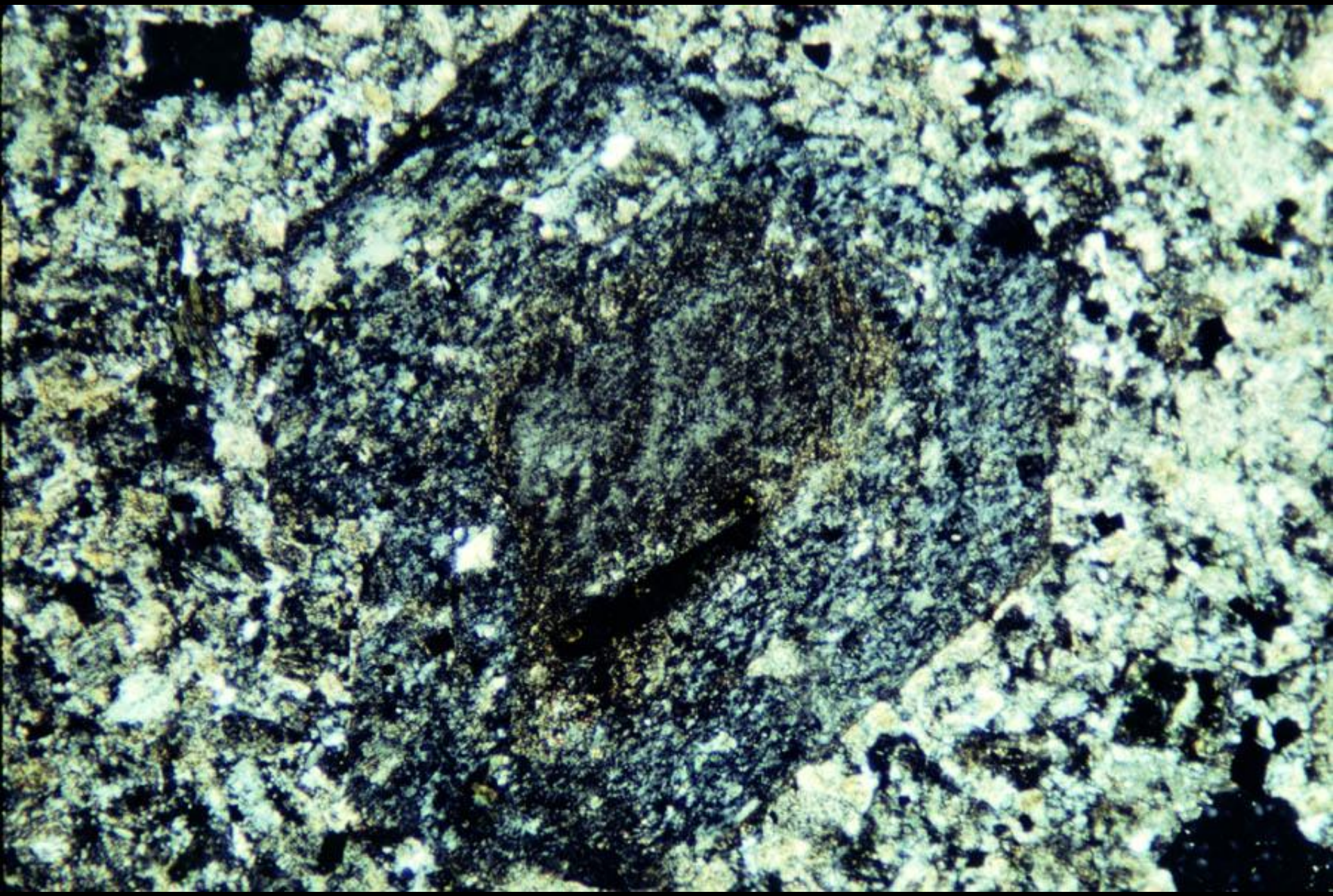
Dike 5


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

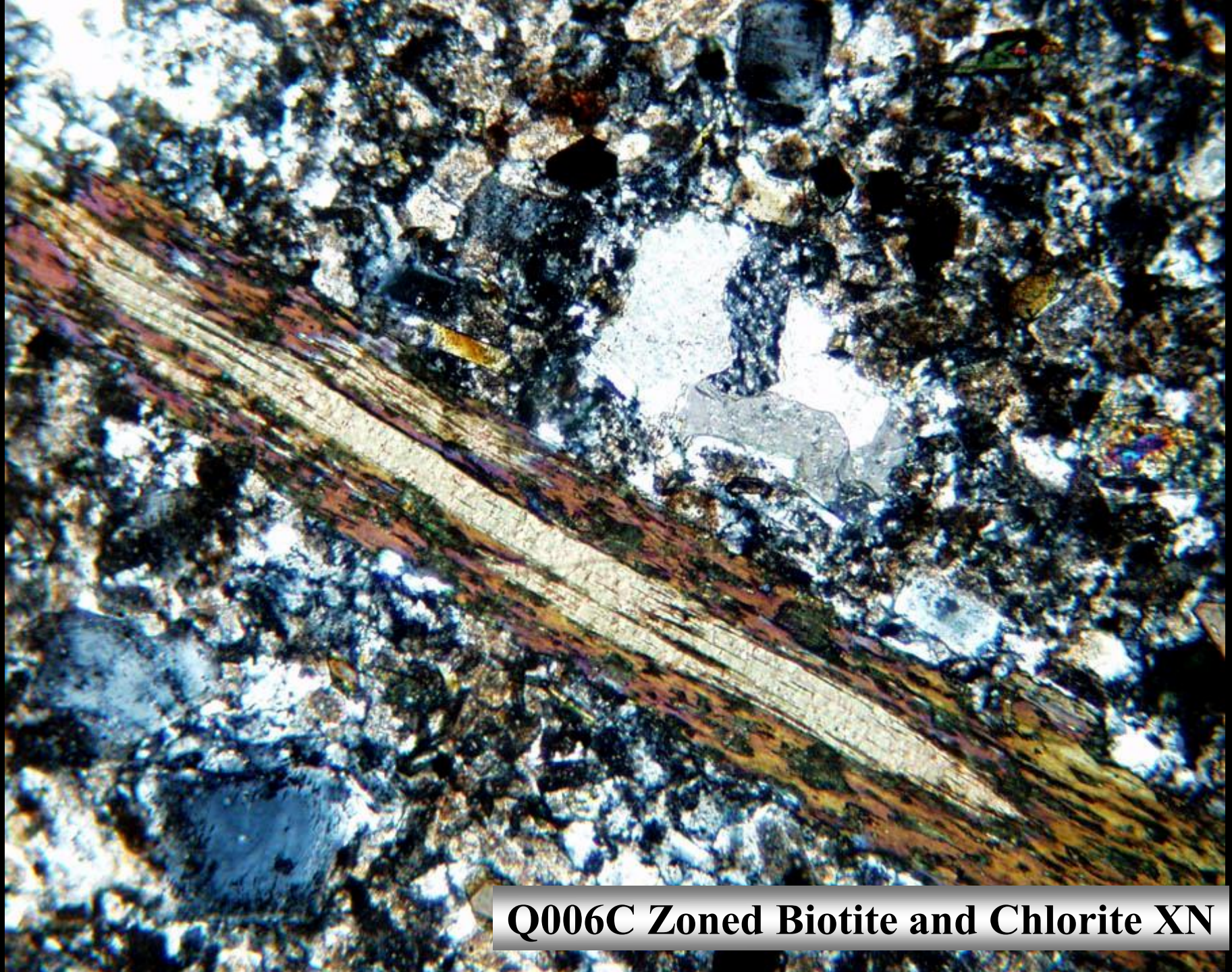

12:05PM
5/15/1998
00:15

Collapsing Crown and Sidewalls

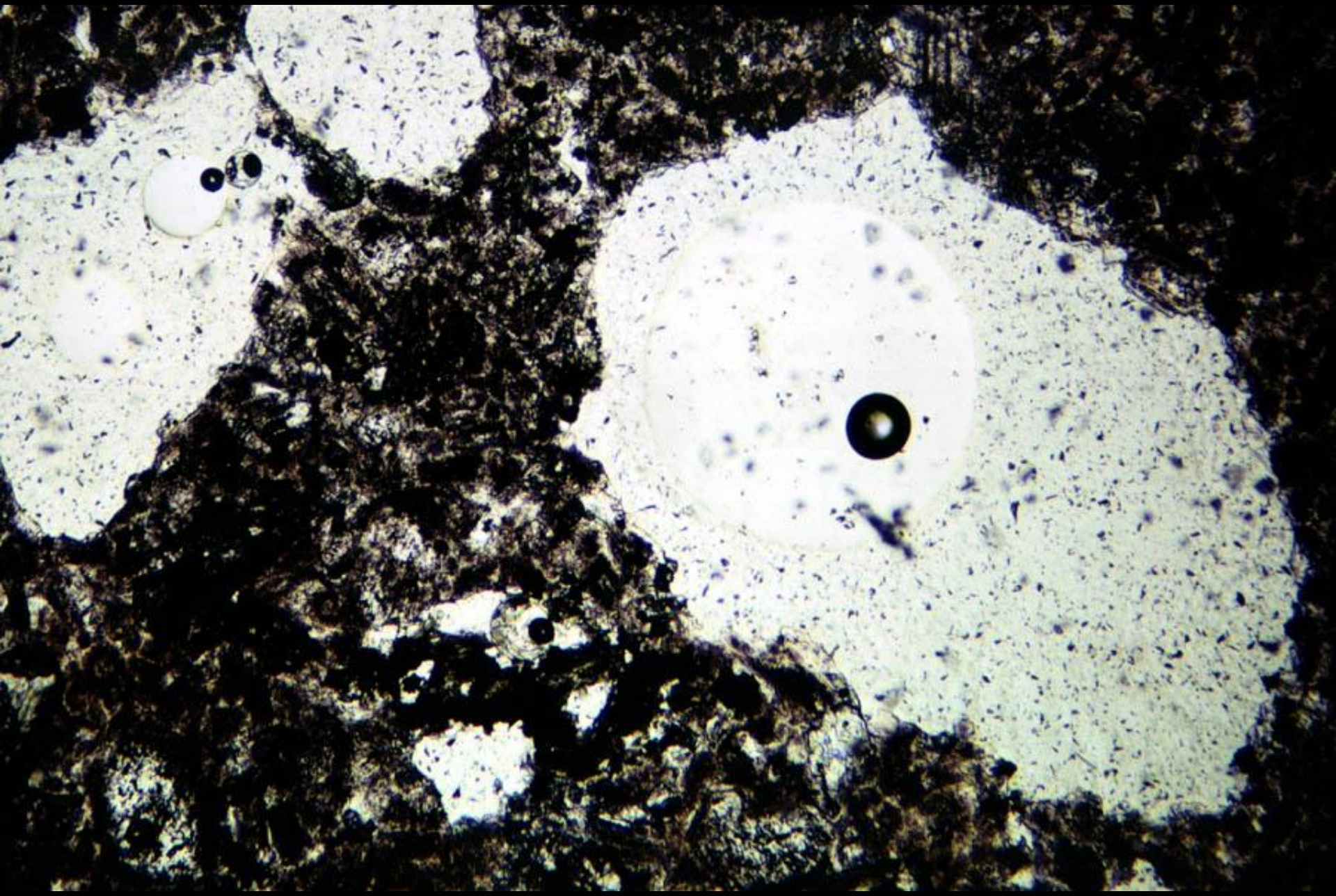




Q006C Zoned Hornblende Phenocryst PL



Q006C Zoned Biotite and Chlorite XN



Major Lithologic Contrast

DEP Borings – QTL-13

Lava Flows in Woodside?


Download Geology Publications:
www.hofstra.edu
www.dukelabs.com
What's That Noise?

Bonus Materials

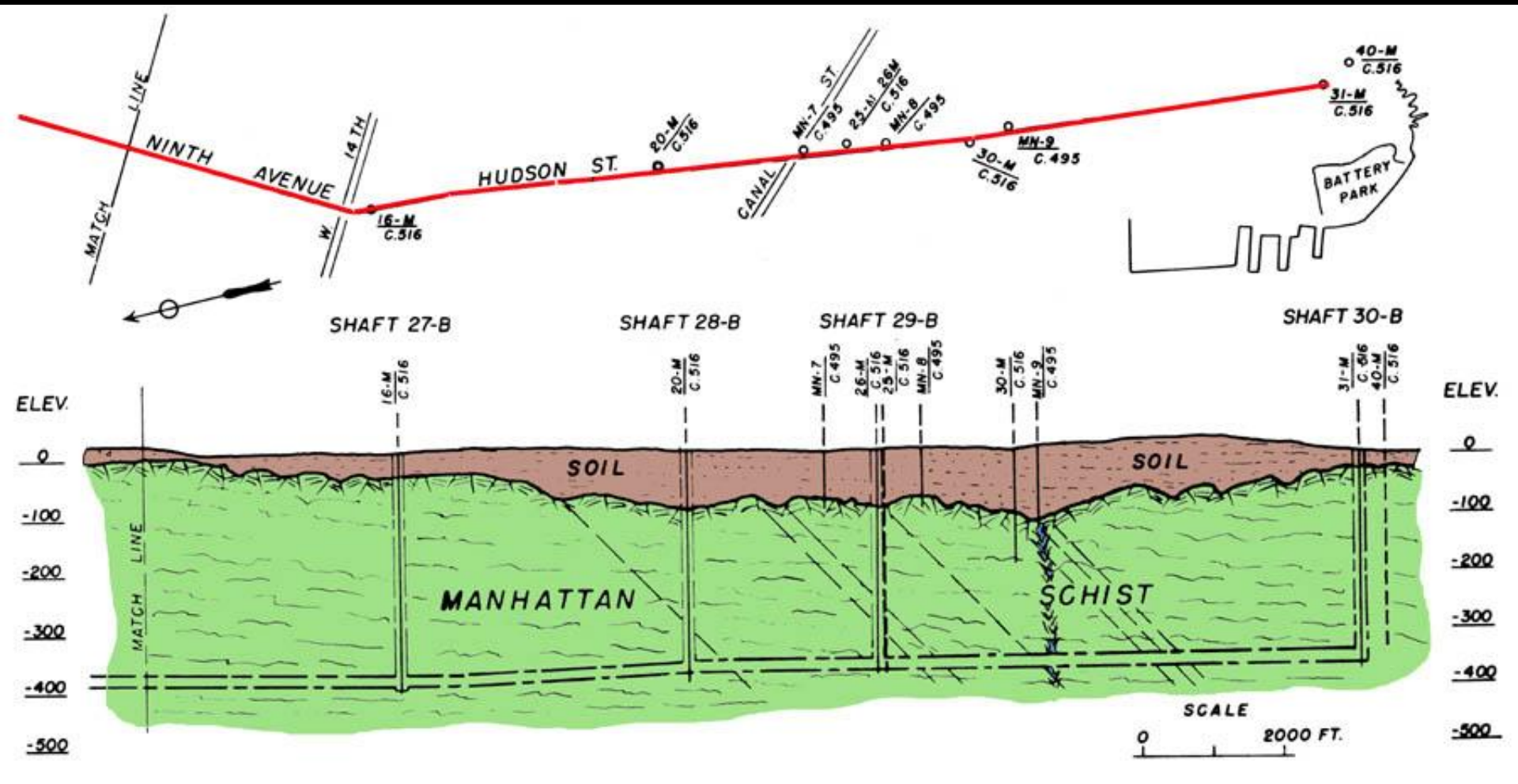
CT3, Stage2 Manhattan Water Tunnel

Shaft 26B

10 Oct 2002


NEW JERSEY
13B
24B
25B
33B
26B
32B
27B
MANHATTAN
28B
31B
29B
30B
MAIN TUNNEL (Central Park)
MAIN TUNNEL (West Side)
CROSSTOWN TUNNEL (Mid-town)
MAIN TUNNEL (West Side)
MAIN TUNNEL (South Loop)
Excavated
To be Excavated
Shafts

Manhattan Tunnel South



CT3, Stage 2

after Fluhr and Terenzio, 1984

Manhattan Tunnel

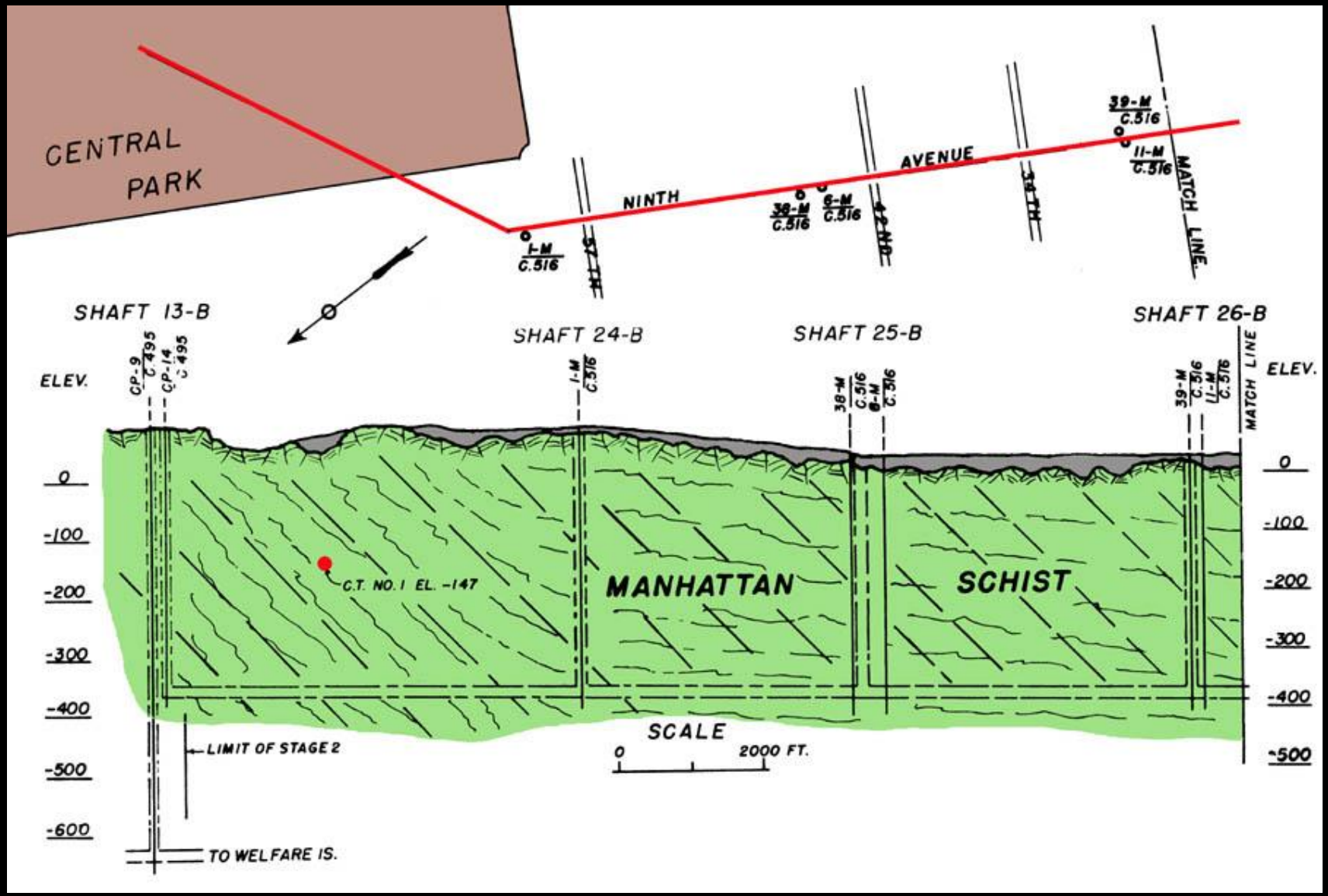
First Construction Leg

Southern leg is 11,331’ of 12’4” tunnel

TBM will be backed up and reconstructed underground to cut northern leg.

Northern leg is 10’4” diameter and will extend 7,543’ into the Central Park Valve Chamber.

Manhattan Tunnel North



CT3, Stage 2

after Fluhr and Terenzio, 1984


South Heading

Bottom of Shaft 26B

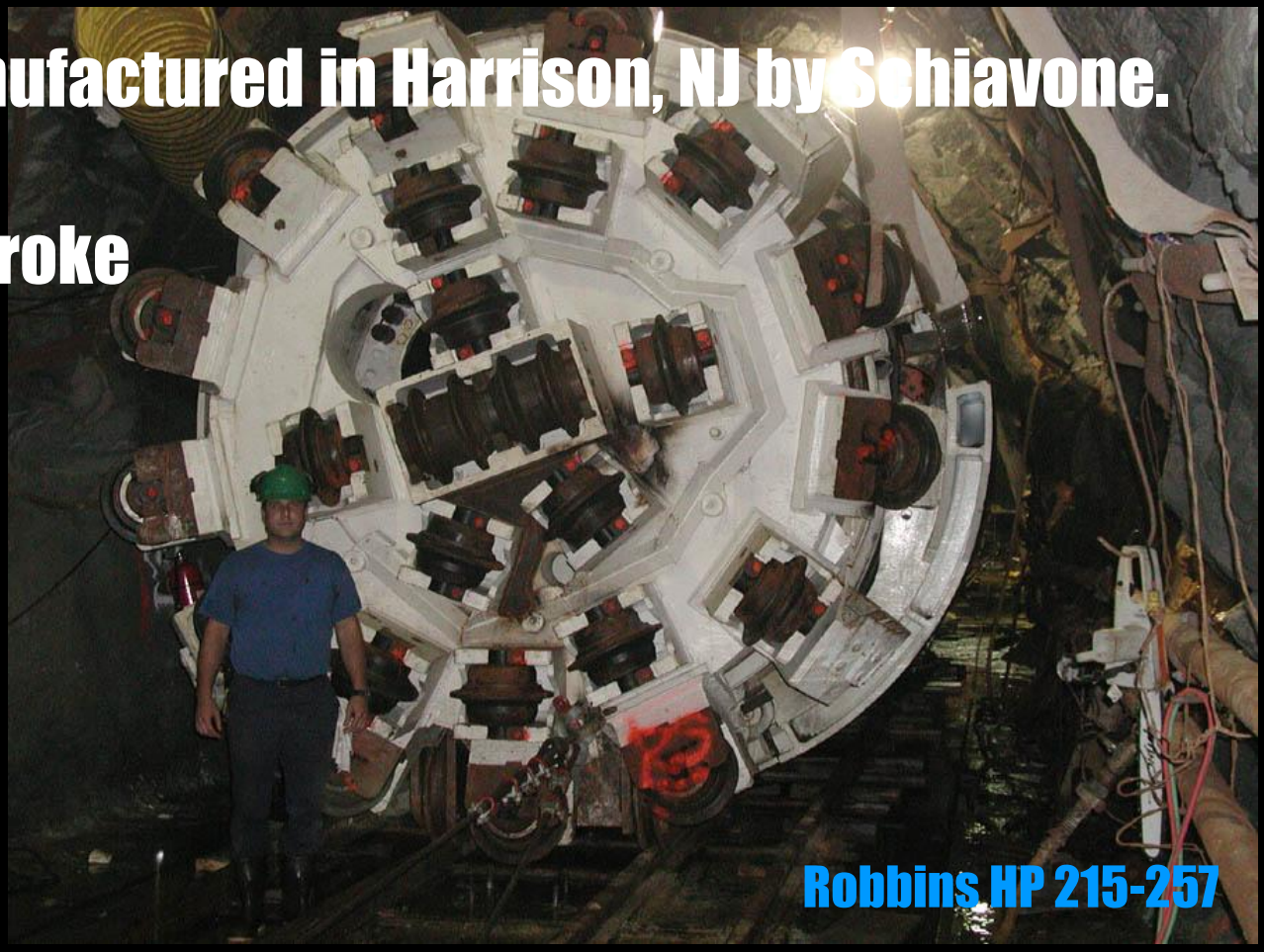
580’ Deep

Manhattan Tunnel TBM

Rebuilt Robbins HP 215-257 hard rock machine (used first on Con Ed Utility Tunnel on 1st Avenue).

TBM was remanufactured in Harrison, NJ by Schiavone.

Capable of 5' stroke



Robbins HP 215-257

Robbins HP 215-257

TBM at Con Ed Tunnel

30 Street and 1st Avenue

Muck Buckets

The New York Times