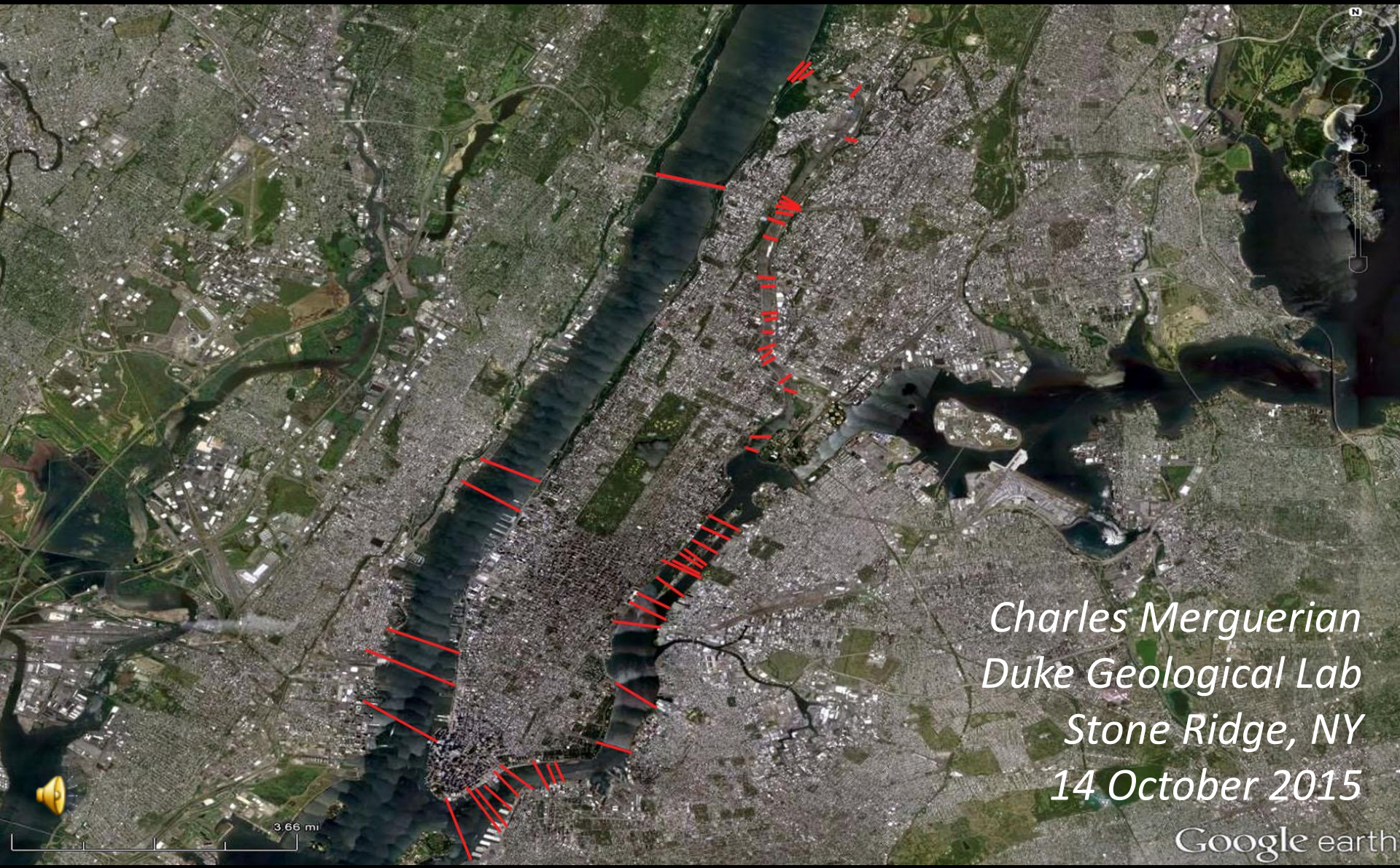
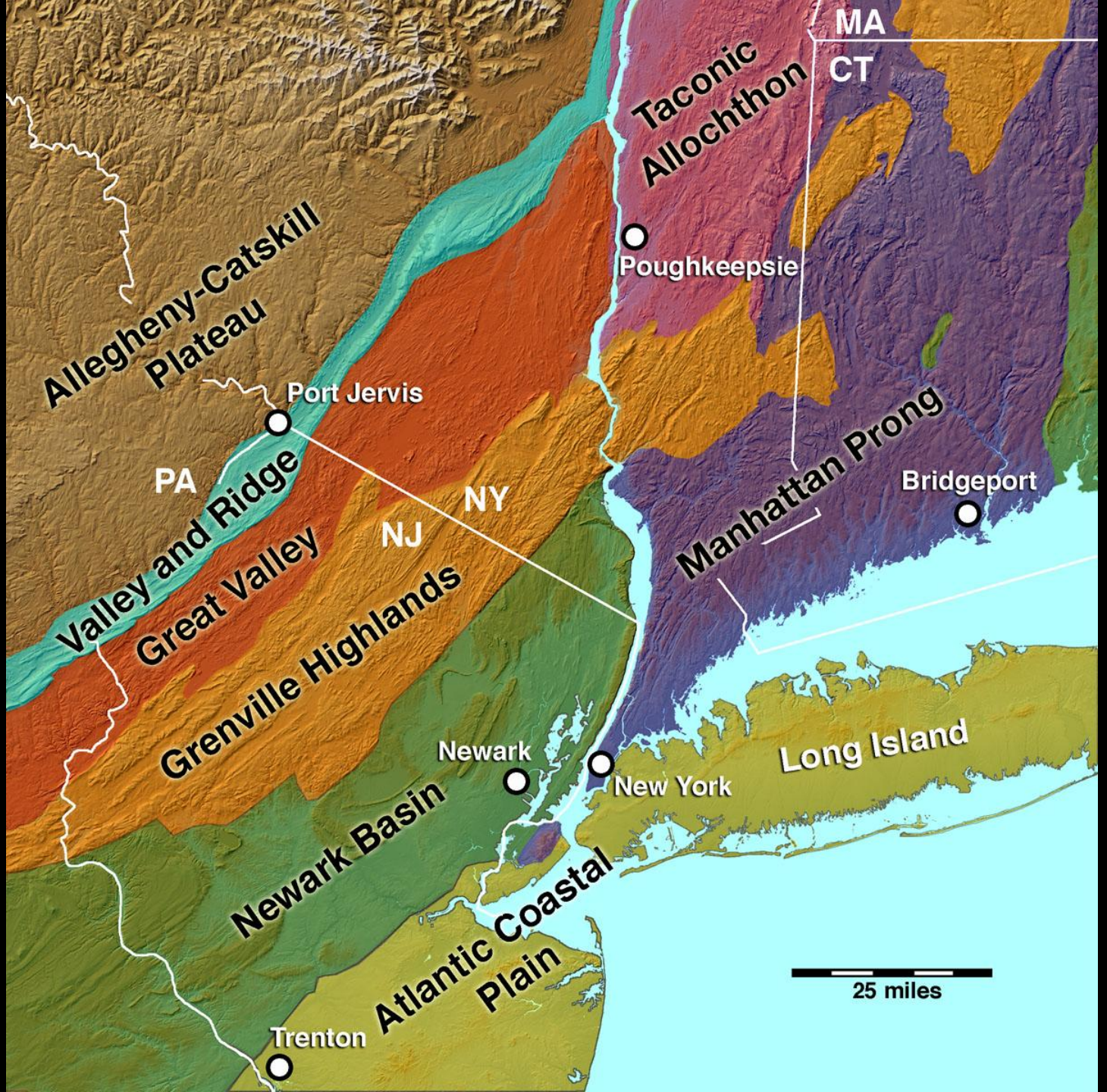
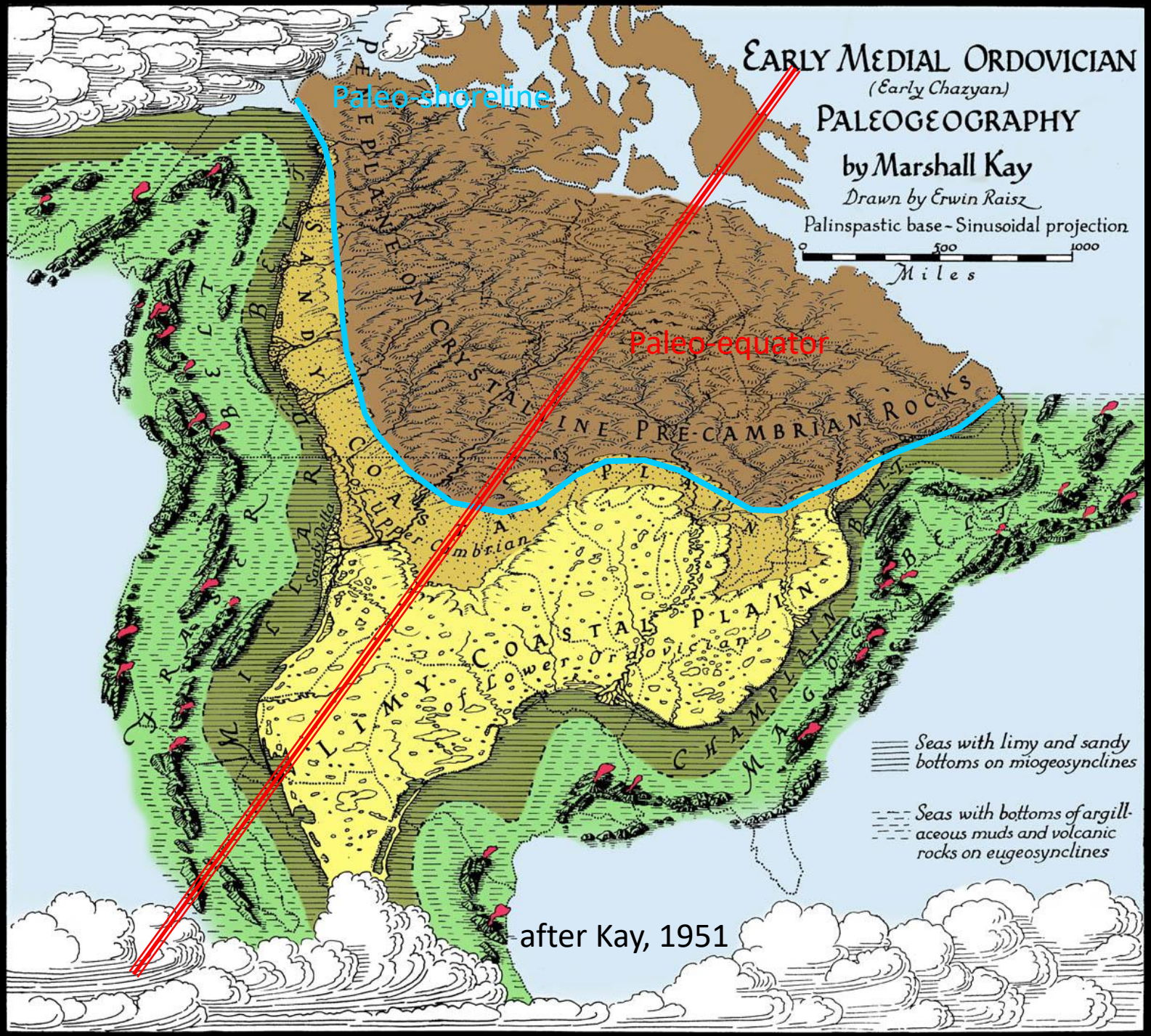
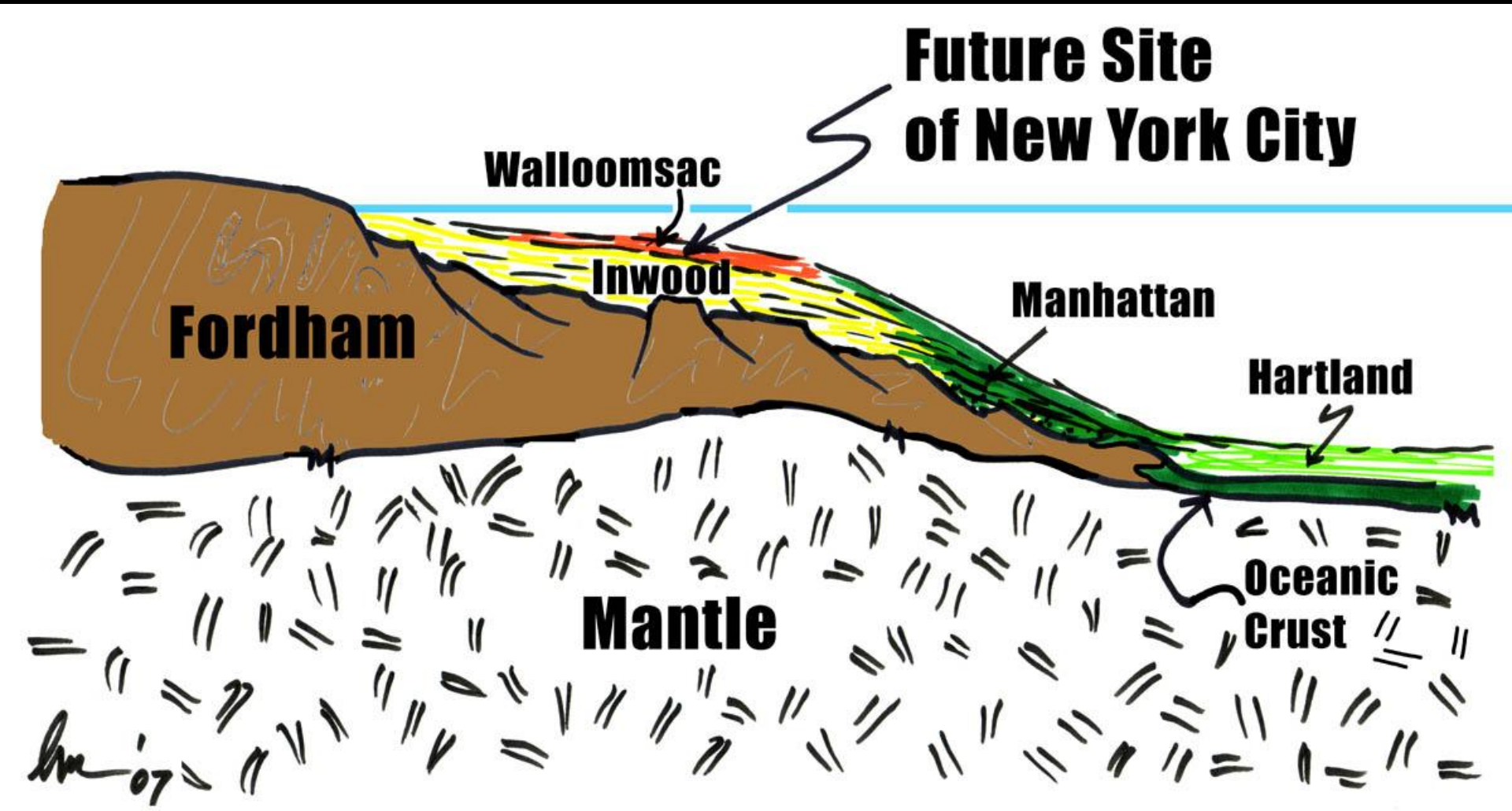
Geology and Mineralogy of the Second Avenue Subway, NYC, NY



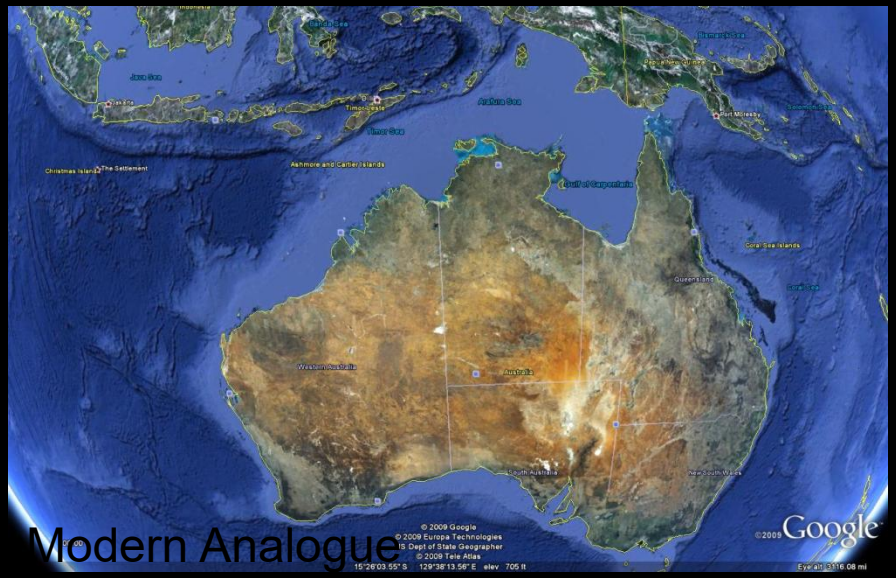
Charles Merguerian
Duke Geological Lab
Stone Ridge, NY
14 October 2015

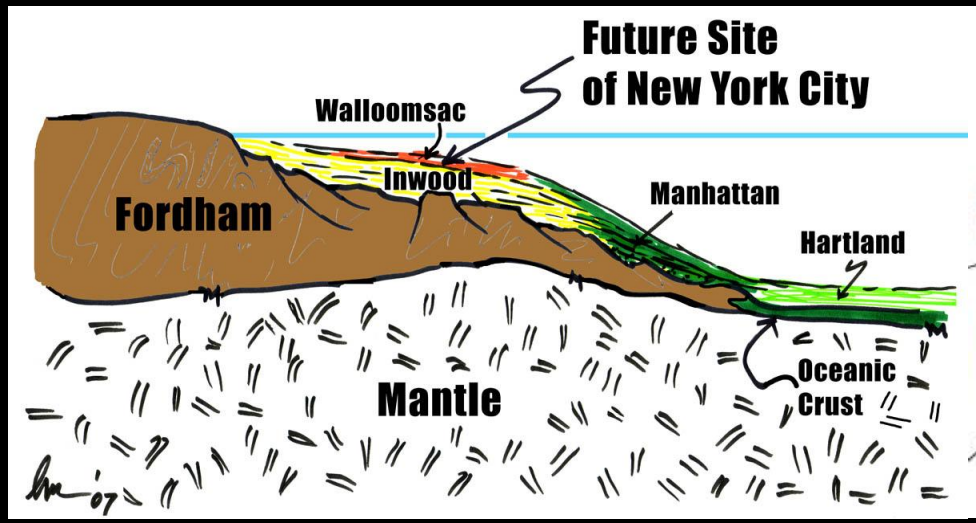

MA
CT
Taconic Allochthon
Poughkeepsie
Allegheny-Catskill Plateau
Port Jervis
PA
NY
NJ
Valley and Ridge
Great Valley
Grenville Highlands
Manhattan Prong
Bridgeport
Newark
New York
Long Island
Newark Basin
Atlantic Coastal Plain
Trenton
25 miles

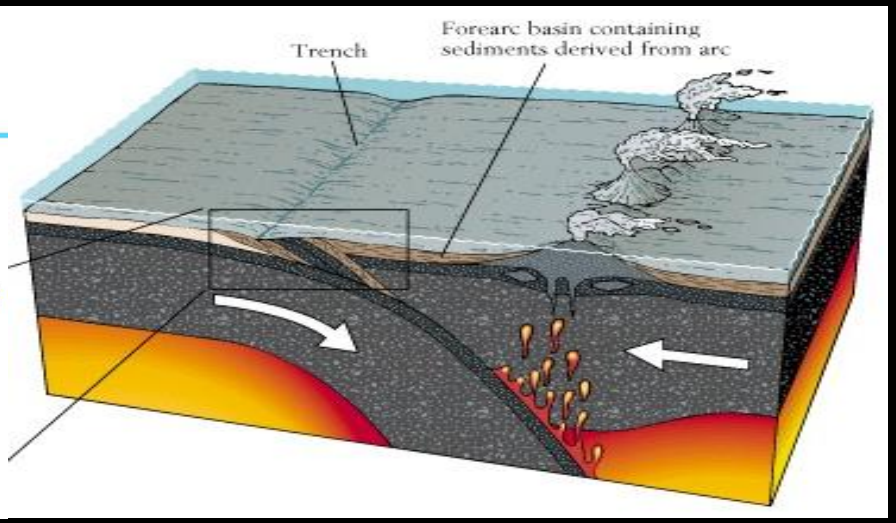

EARLY MEDIAL ORDOVICIAN
(Early Chazyan)
PALEOGEOGRAPHY
by Marshall Kay
Drawn by Erwin Raisz
Palinspastic base - Sinusoidal projection
500
1000
Miles
Paleo-shoreline
Paleo-equator
PENEPLANED CRYSTALLINE PRE-CAMBRIAN ROCKS
SANDY COASTAL PLAIN of Upper Cambrian
LIMY COASTAL PLAIN of Lower Ordovician
CHAMPLAIN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

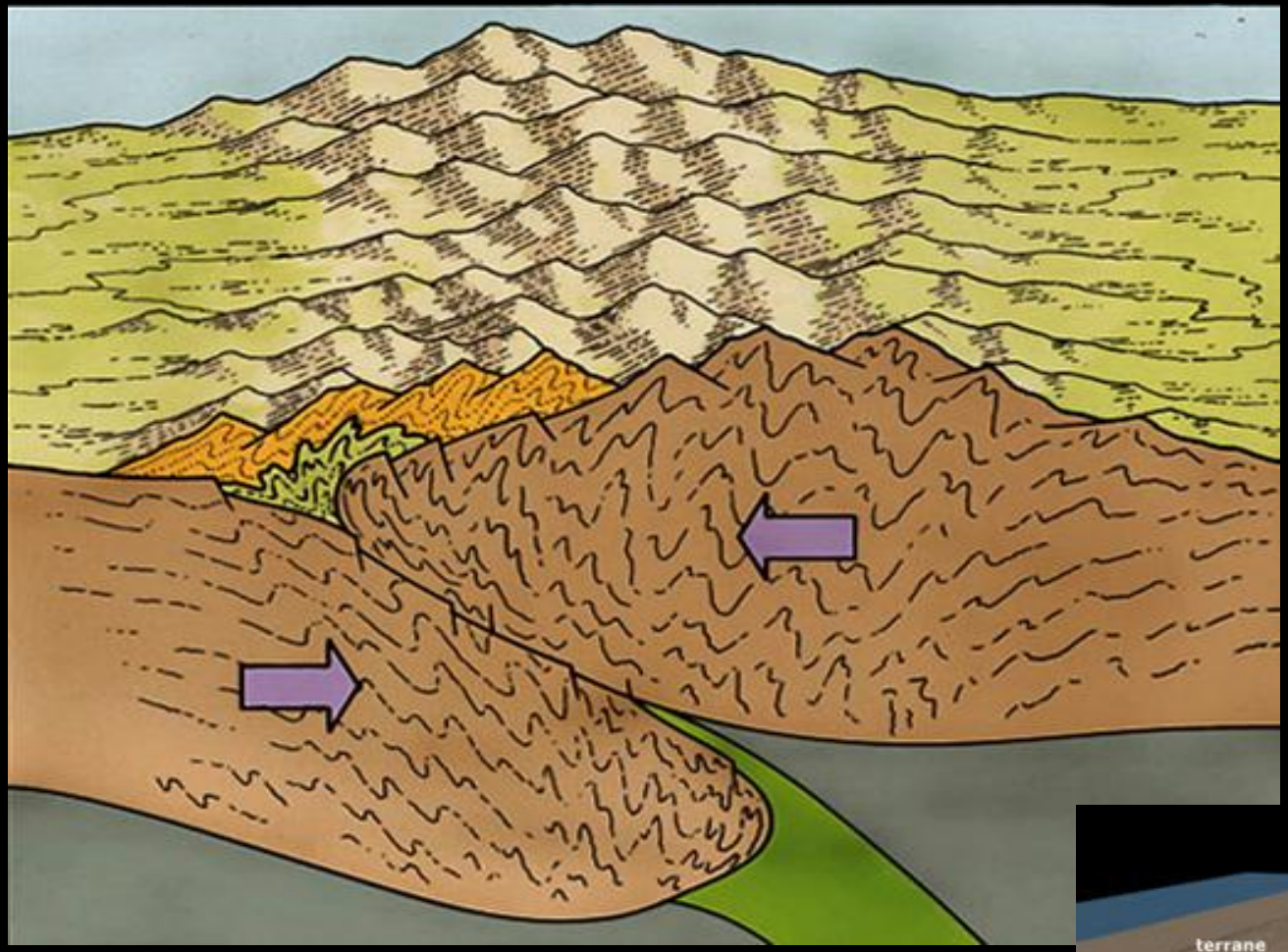

Future Site
of New York City
Walloomsac
Inwood
Fordham
Manhattan
Hartland
Oceanic
Crust
Mantle
'07

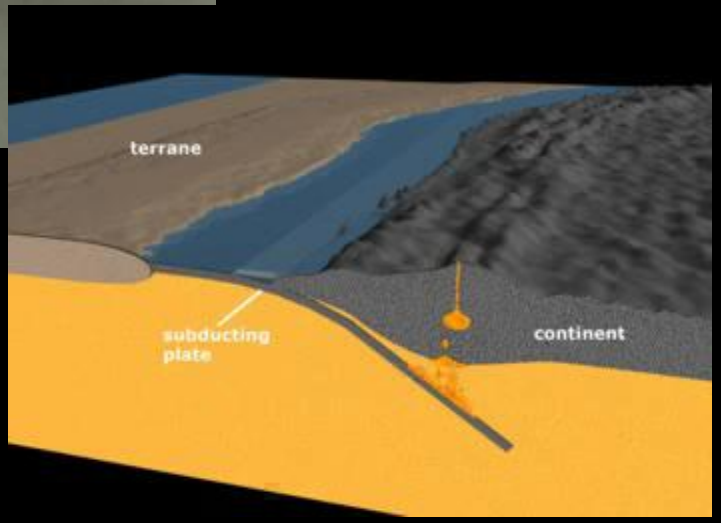
~ 450 Ma Taconian Arc – Passive Margin Collision





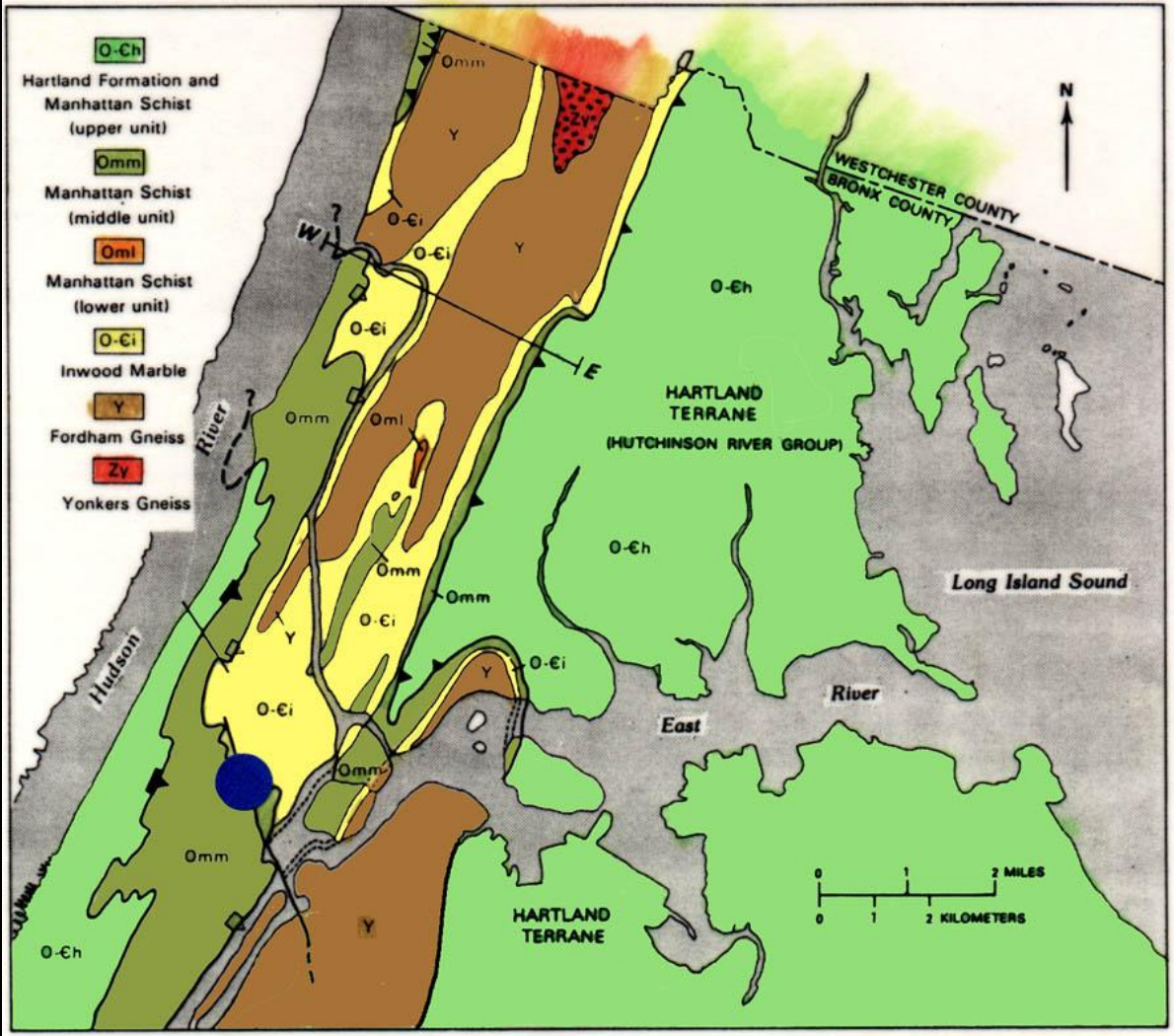


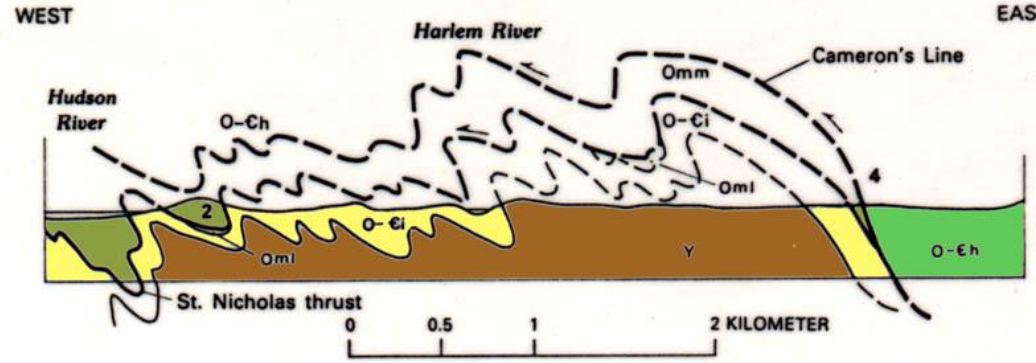


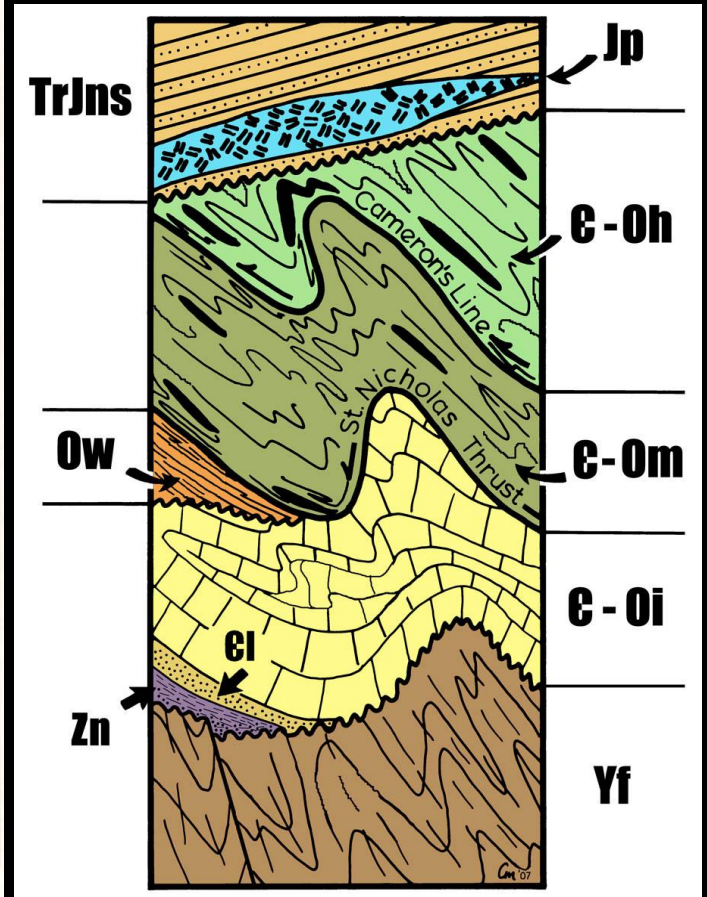


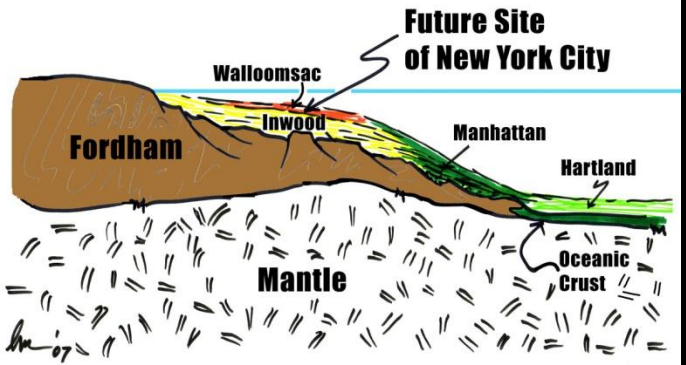
450 Ma to 250 Ma
Protracted Plate Collisions
Produce the Appalachians

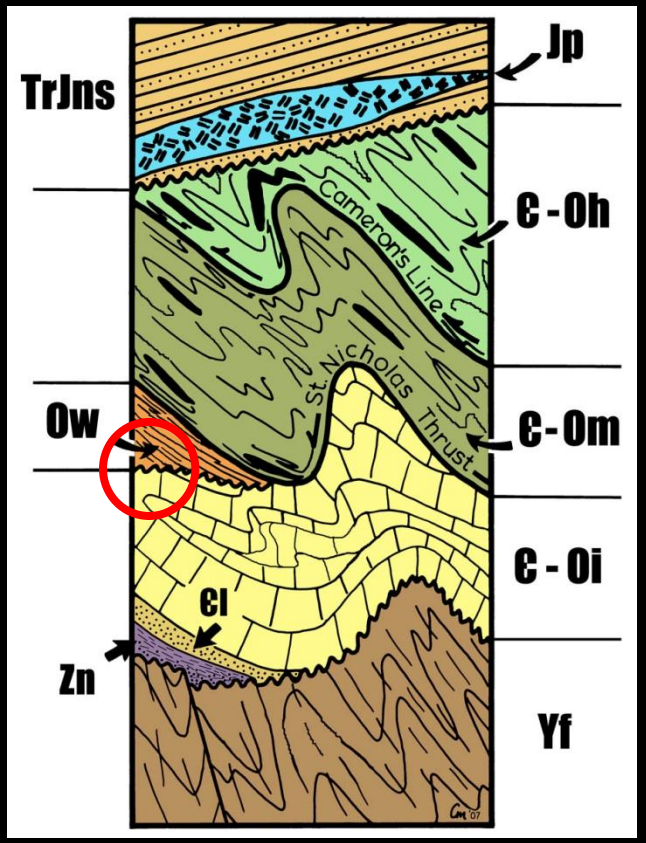
New York City



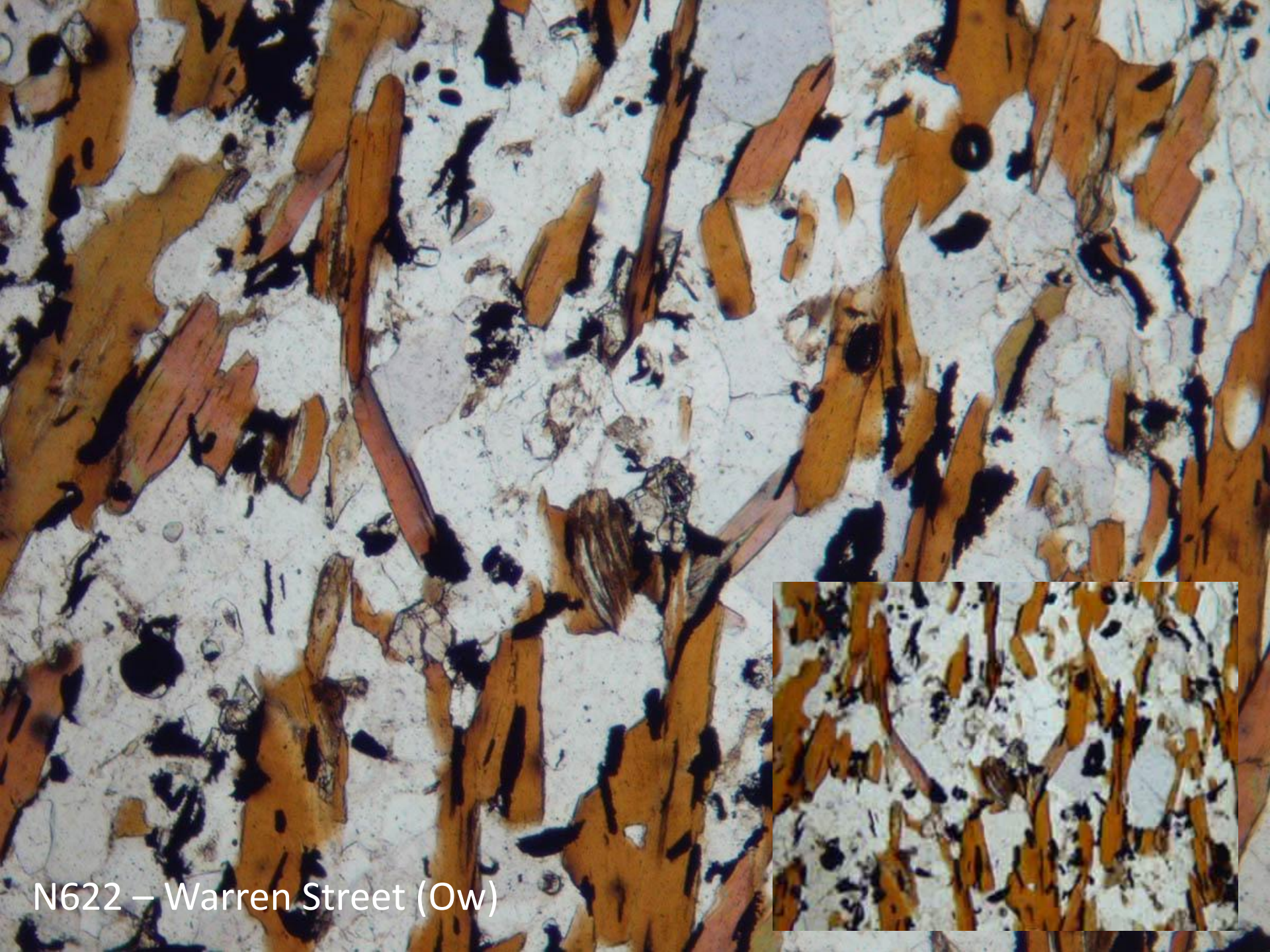




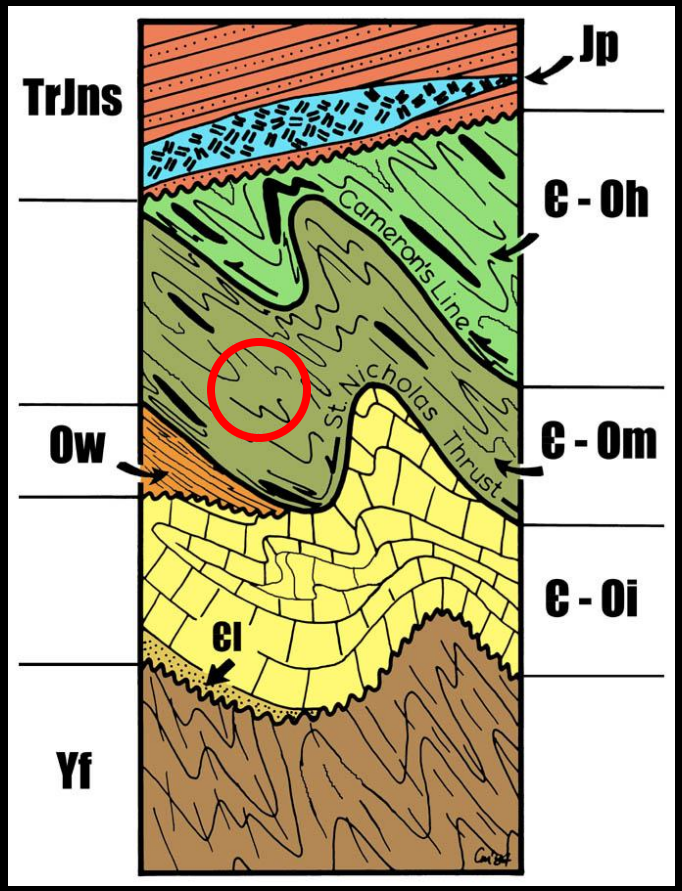




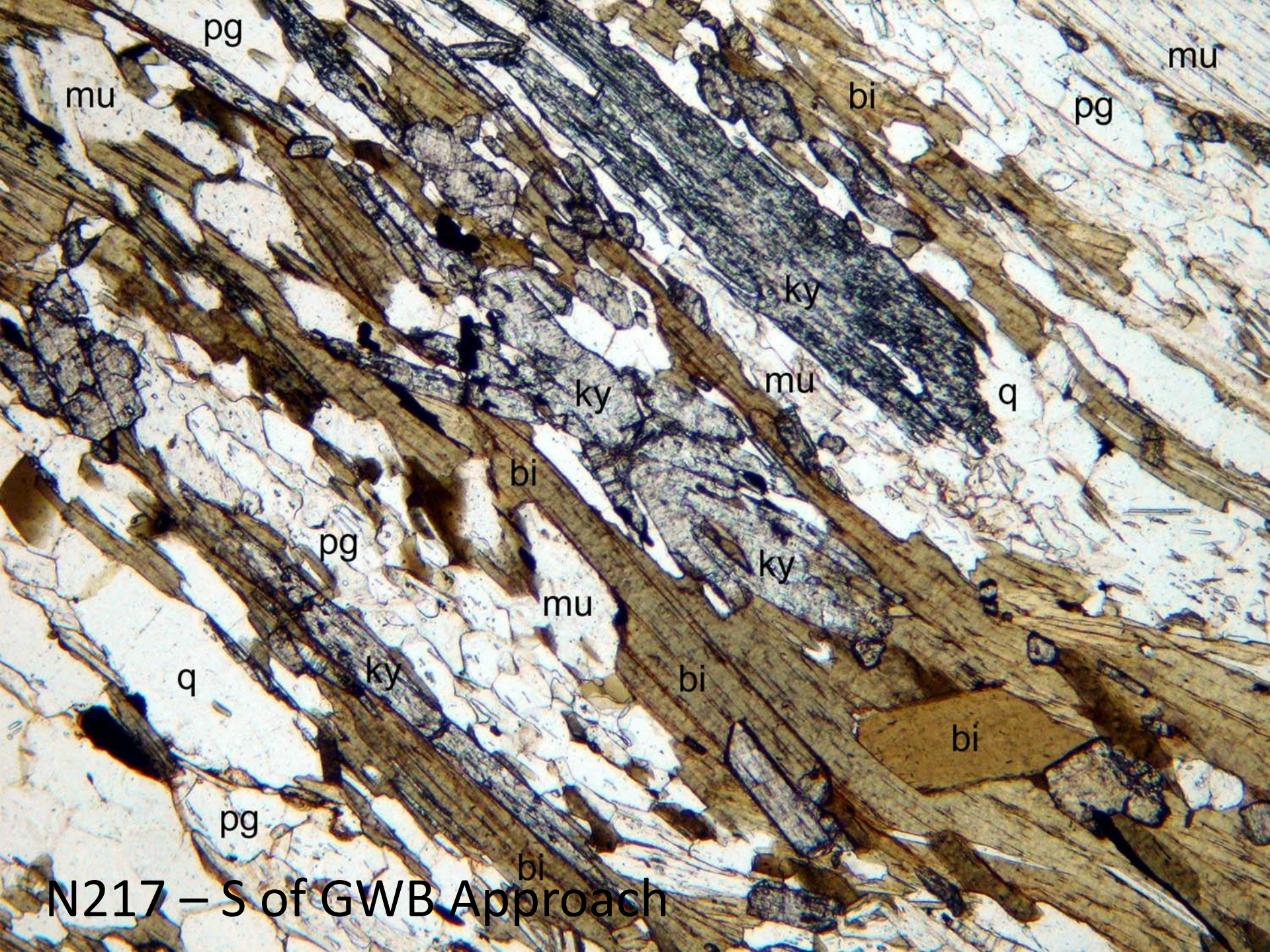
Walloomsac "Balmville" Contact, Grand Concourse, Bronx, NY



N622 – Warren Street (Ow)

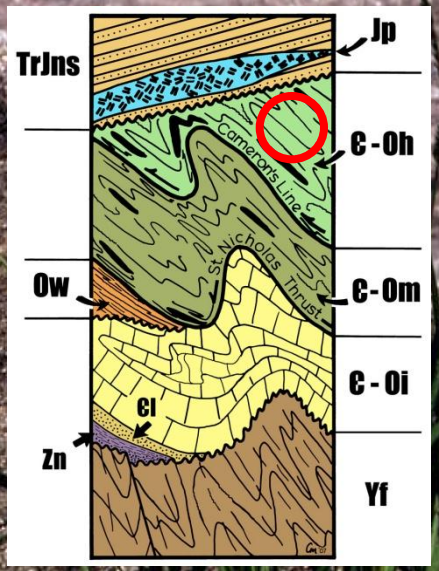


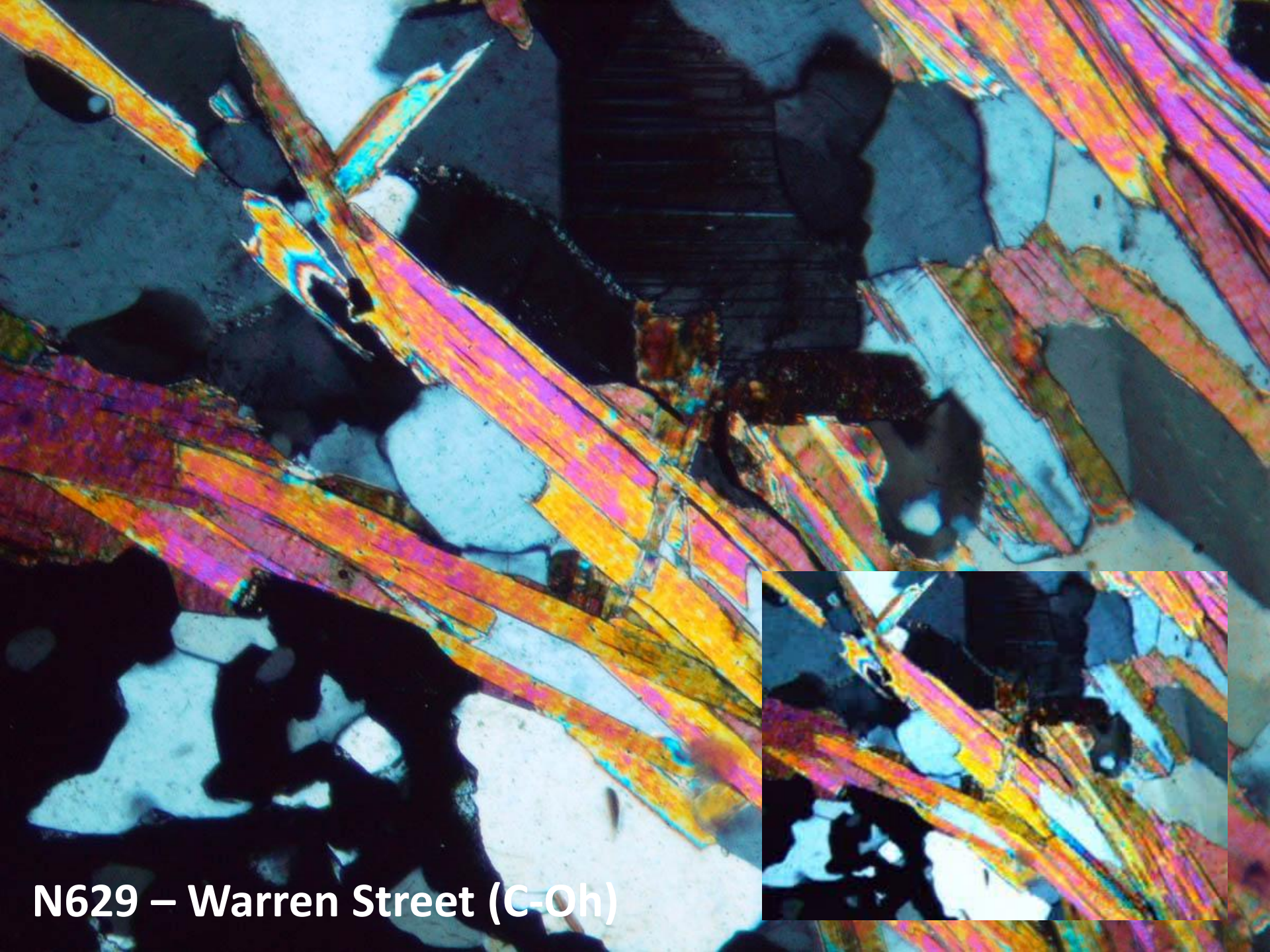
Manhattan Schist
F_3 Folds of S_2
Central Park, NYC



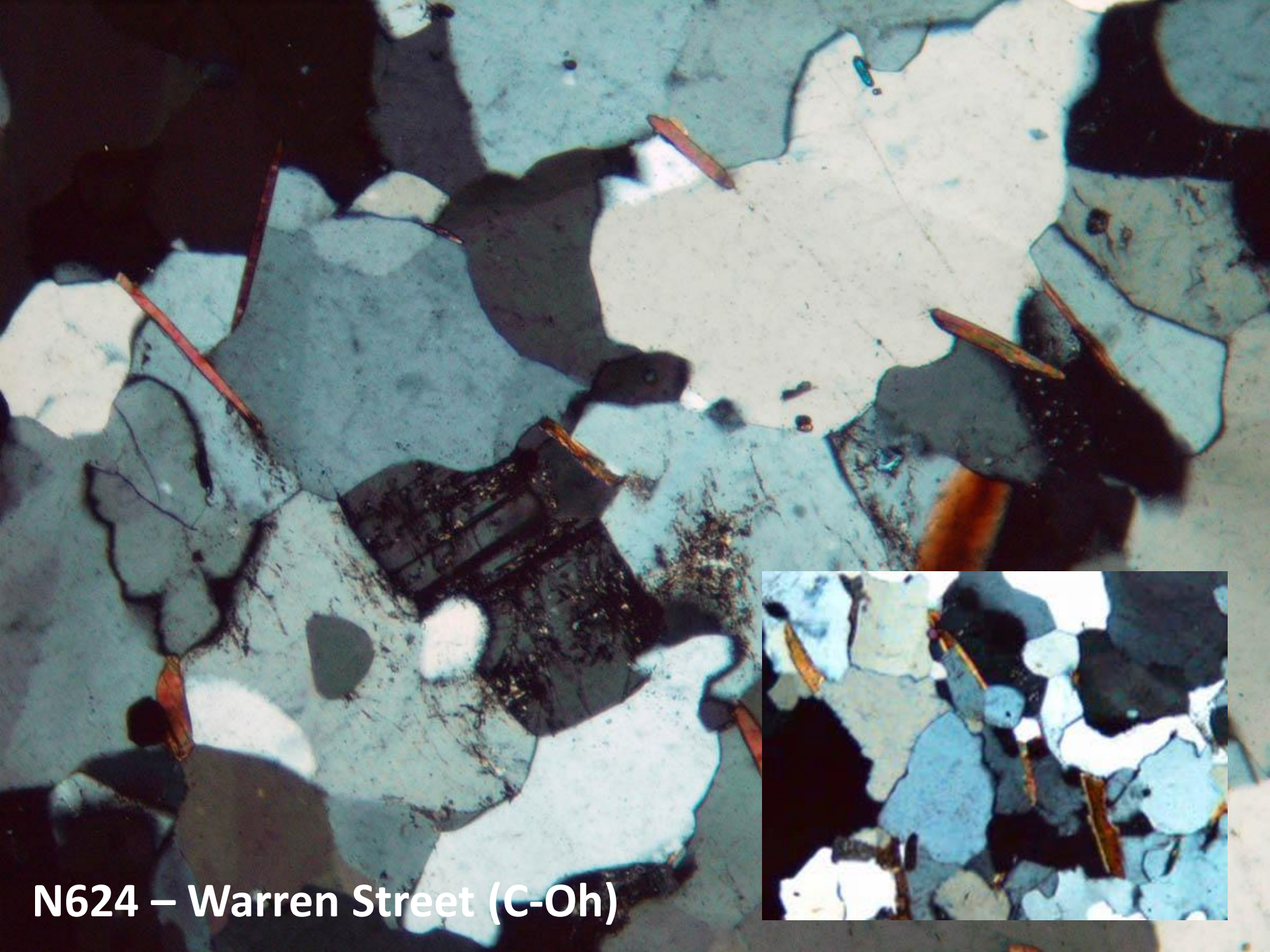
N217 – S of GWB Approach

Hartland Schist, Riverside Park



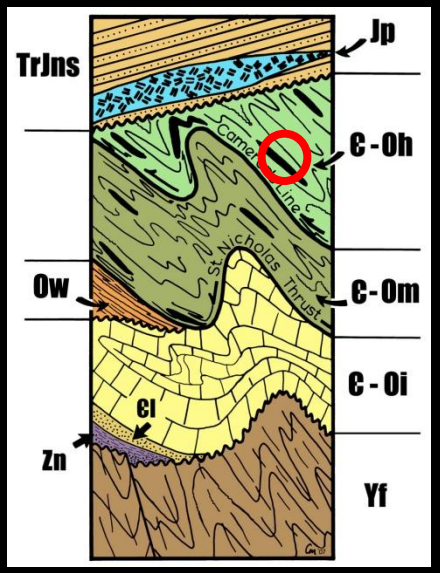


N629 – Warren Street (C-Oh)



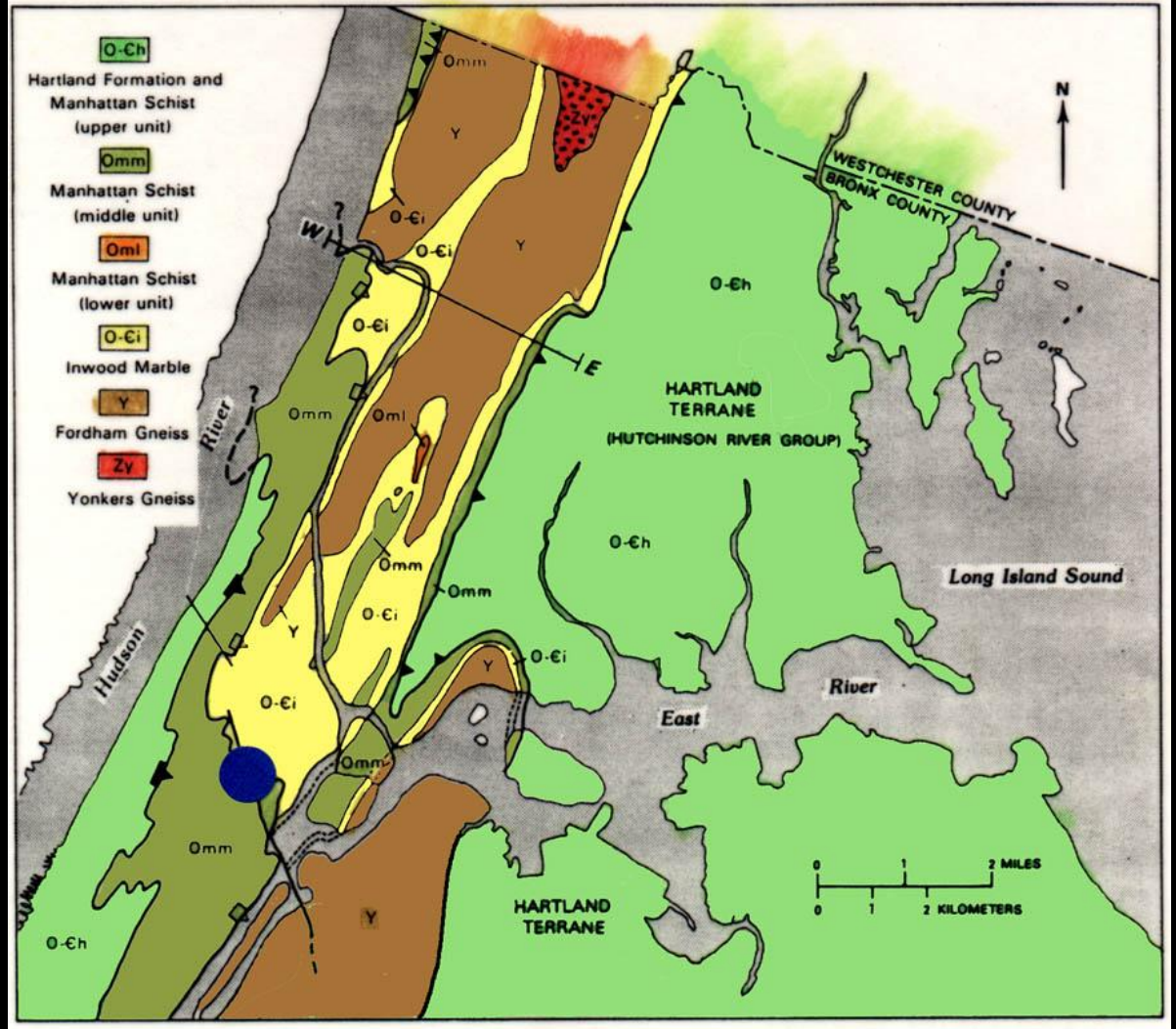
N624 – Warren Street (C-Oh)

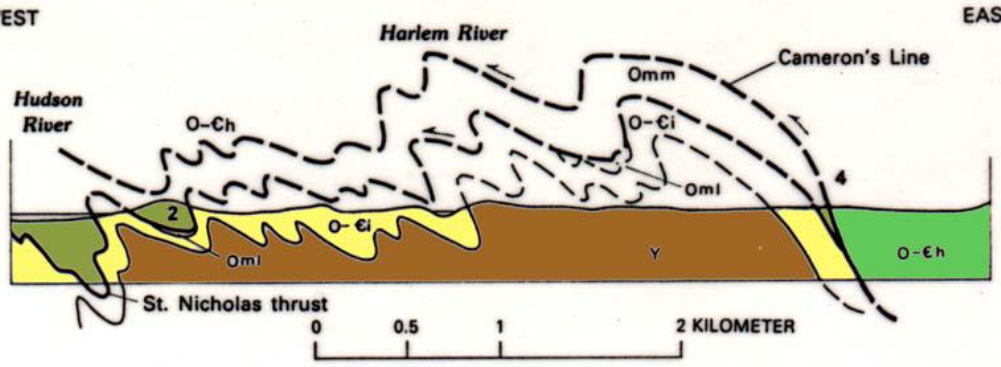
Hartland Amphibolite N567

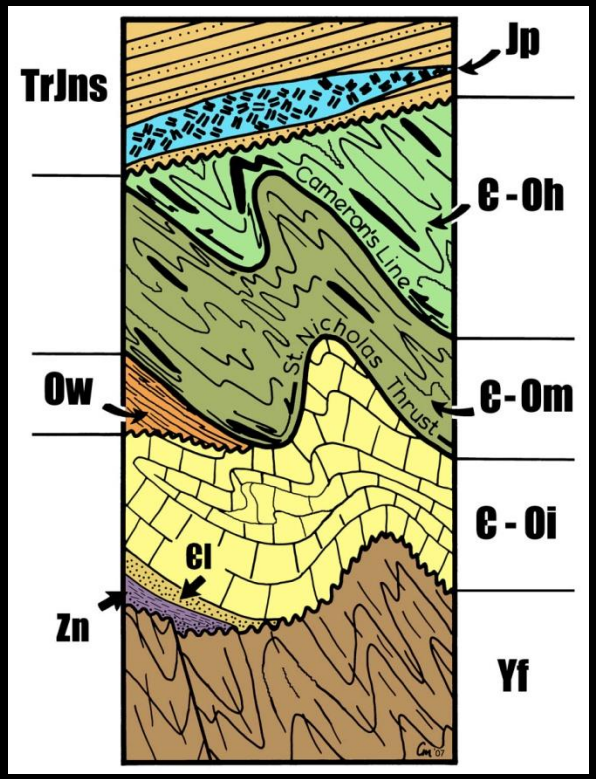


Hartland Coticule

New York City







NYC TBM Projects

Second Avenue Subway

1929 – NYC BOT Proposes Second Avenue Subway

1931 – Plans Postponed for Depression Era

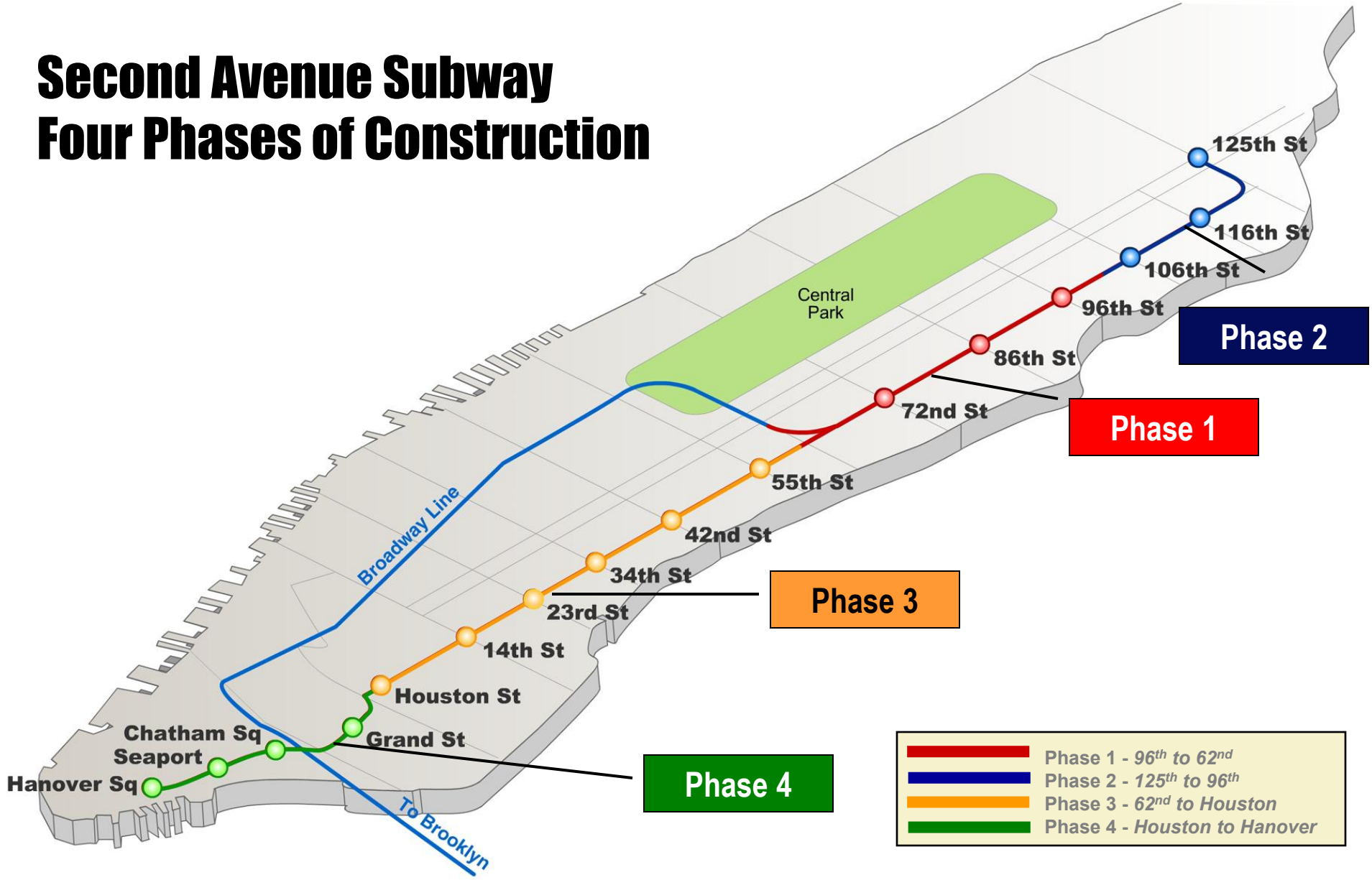
$86M → $249M → $500M

By 1948 – Abandonment

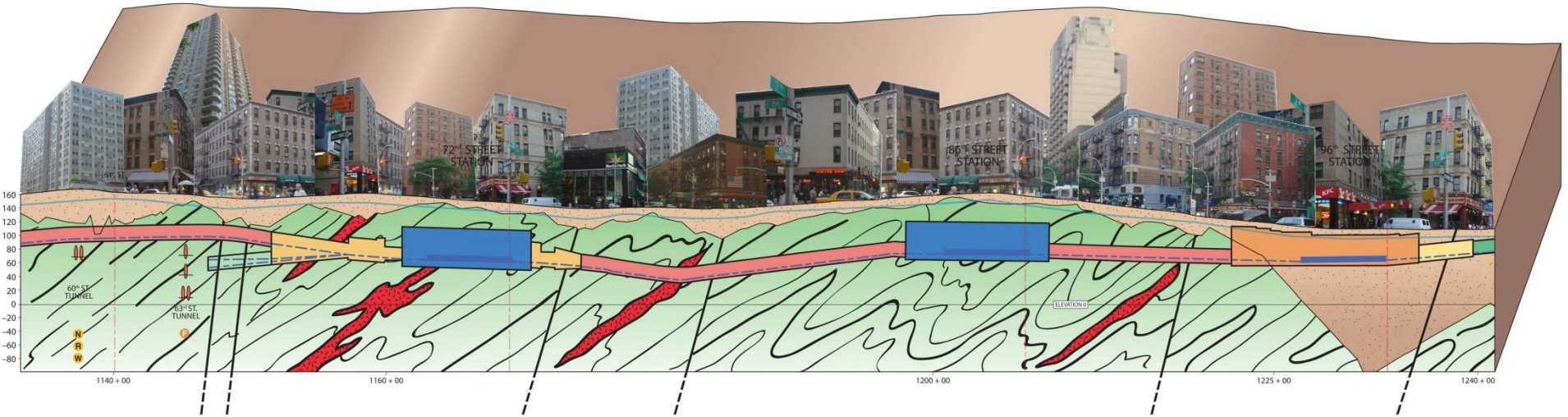
June 2010 – TBM Starts S Tube

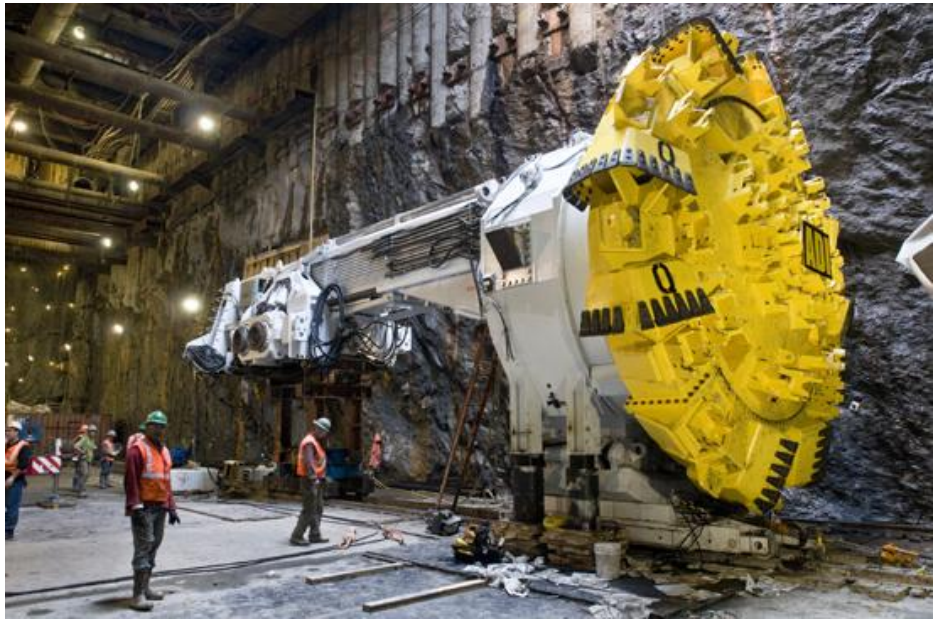
2013 – Station Complexes

Second Avenue Subway
Four Phases of Construction



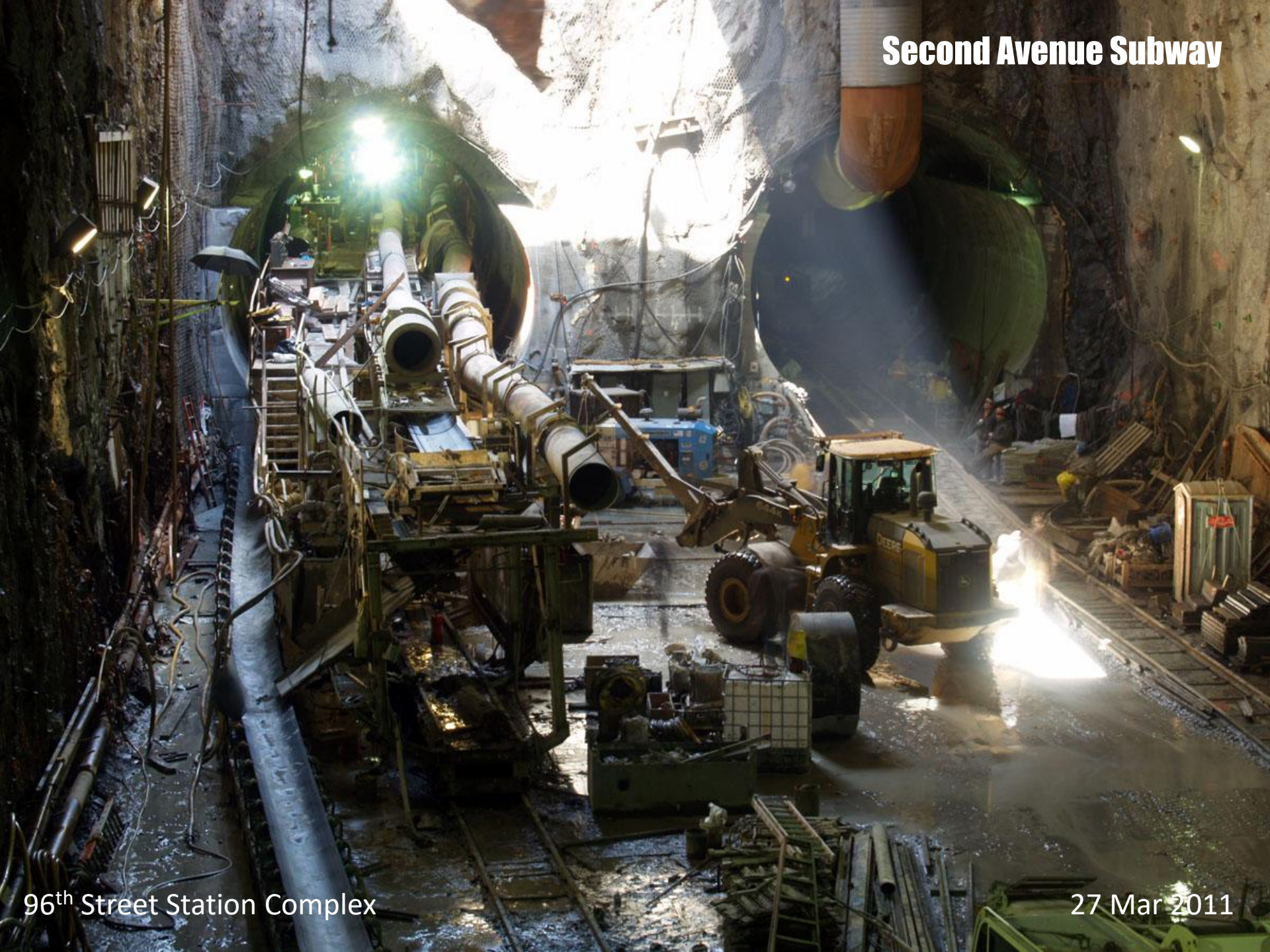
Phase 1 [96th to 59th] - Threading The Needle





April 2010 Insertion


Second Avenue Subway
96th Street Station Complex
27 Mar 2011


Second Avenue Subway
96th Street Station Complex
27 Mar 2011

96th Street Station Complex

27 Mar 2011

Second Avenue Subway

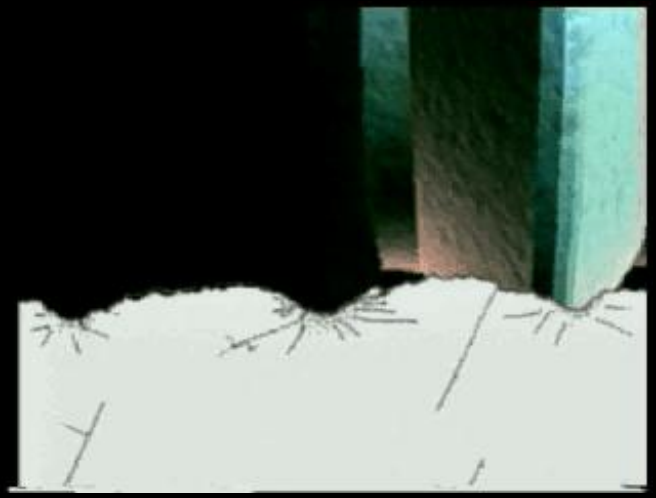
South Tube – Sta. 1172+30 Bulkhead ~72St

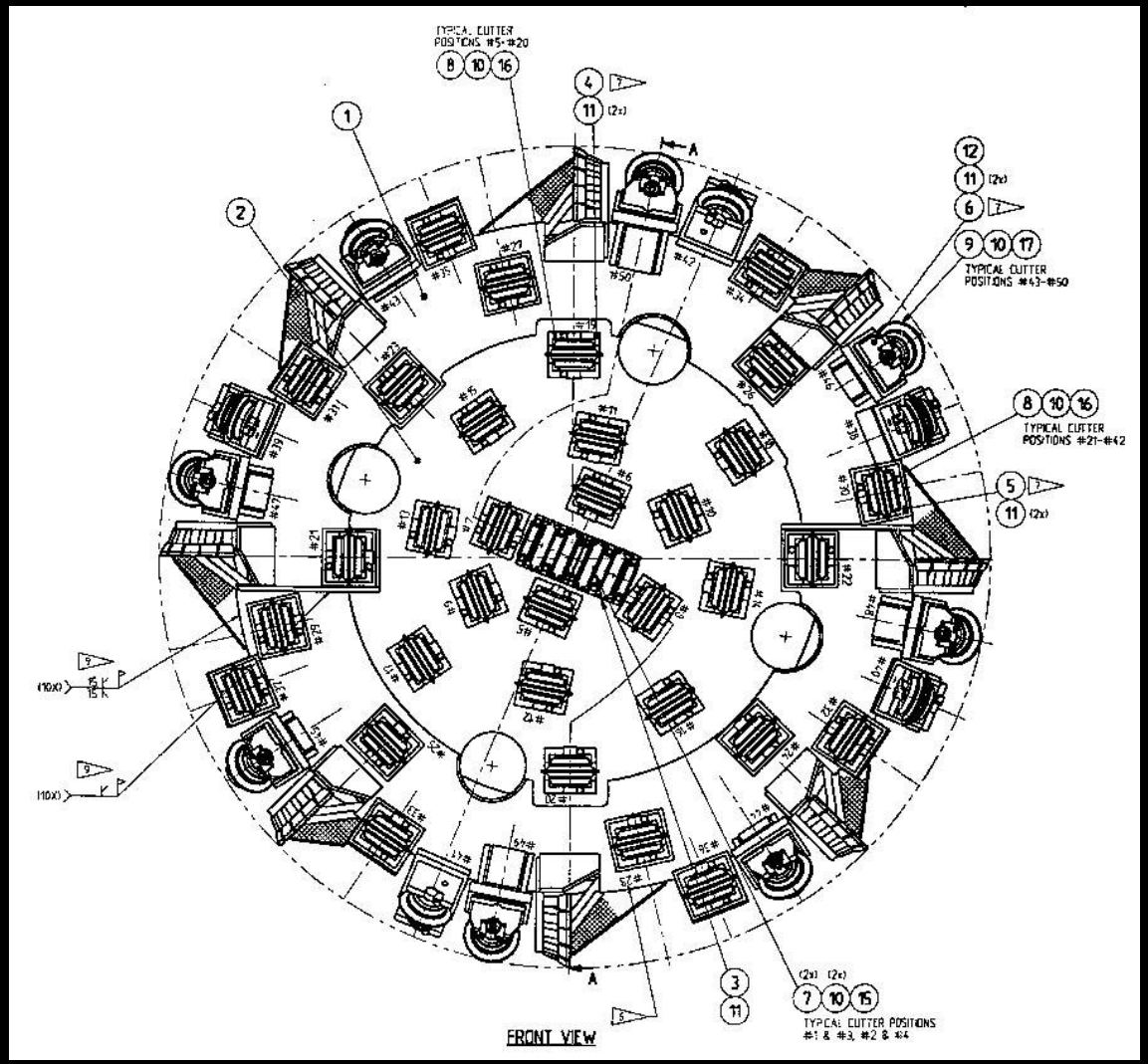
27 Mar 2011


Second Avenue Subway
South Tube - 96th Street
27 Mar 2011


Second Avenue Subway
South Tube – Sta. 1172+80
27 Mar 2011

Dukelabs TBM Research

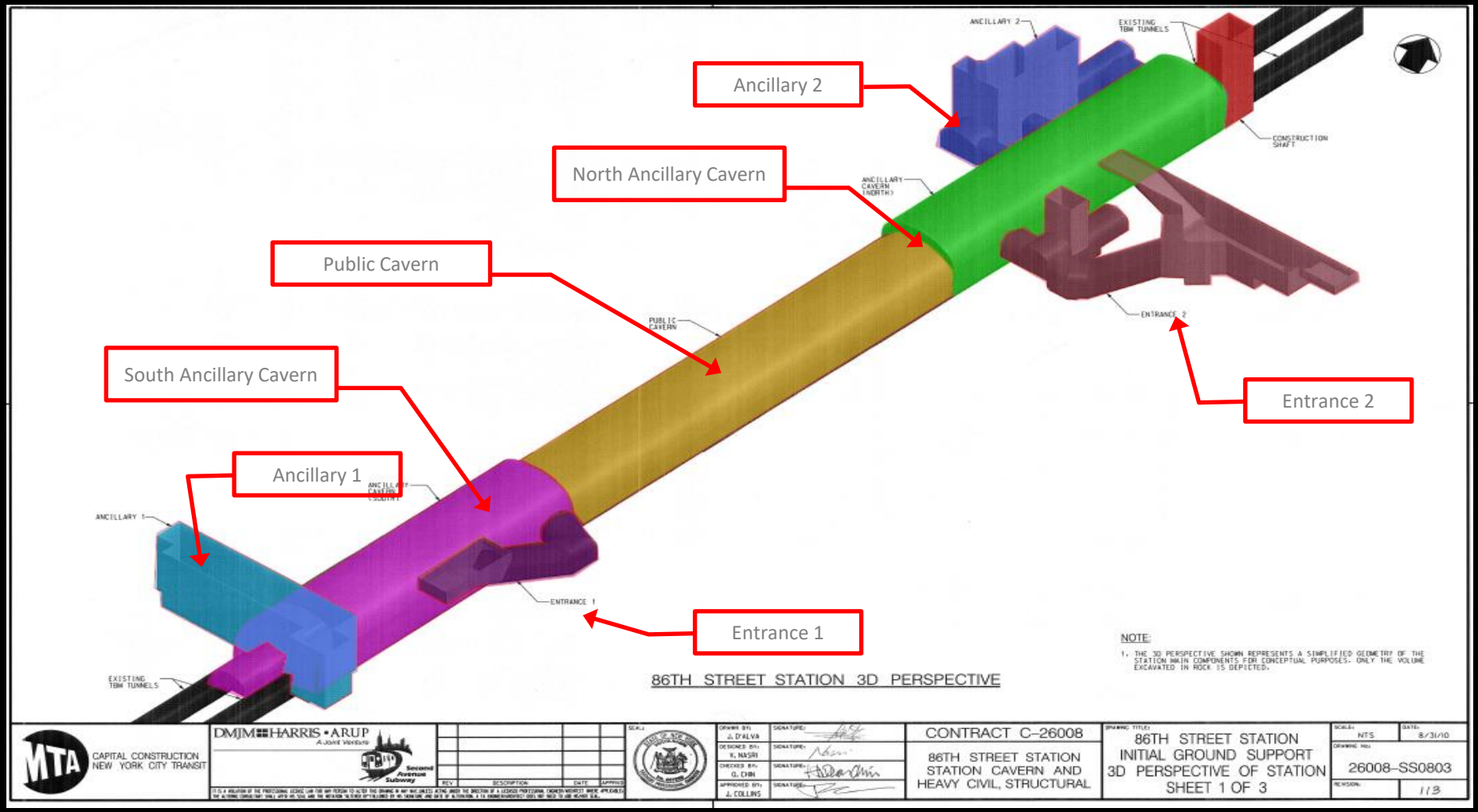




New Research on TBM Cutter Head Torque Dynamics

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

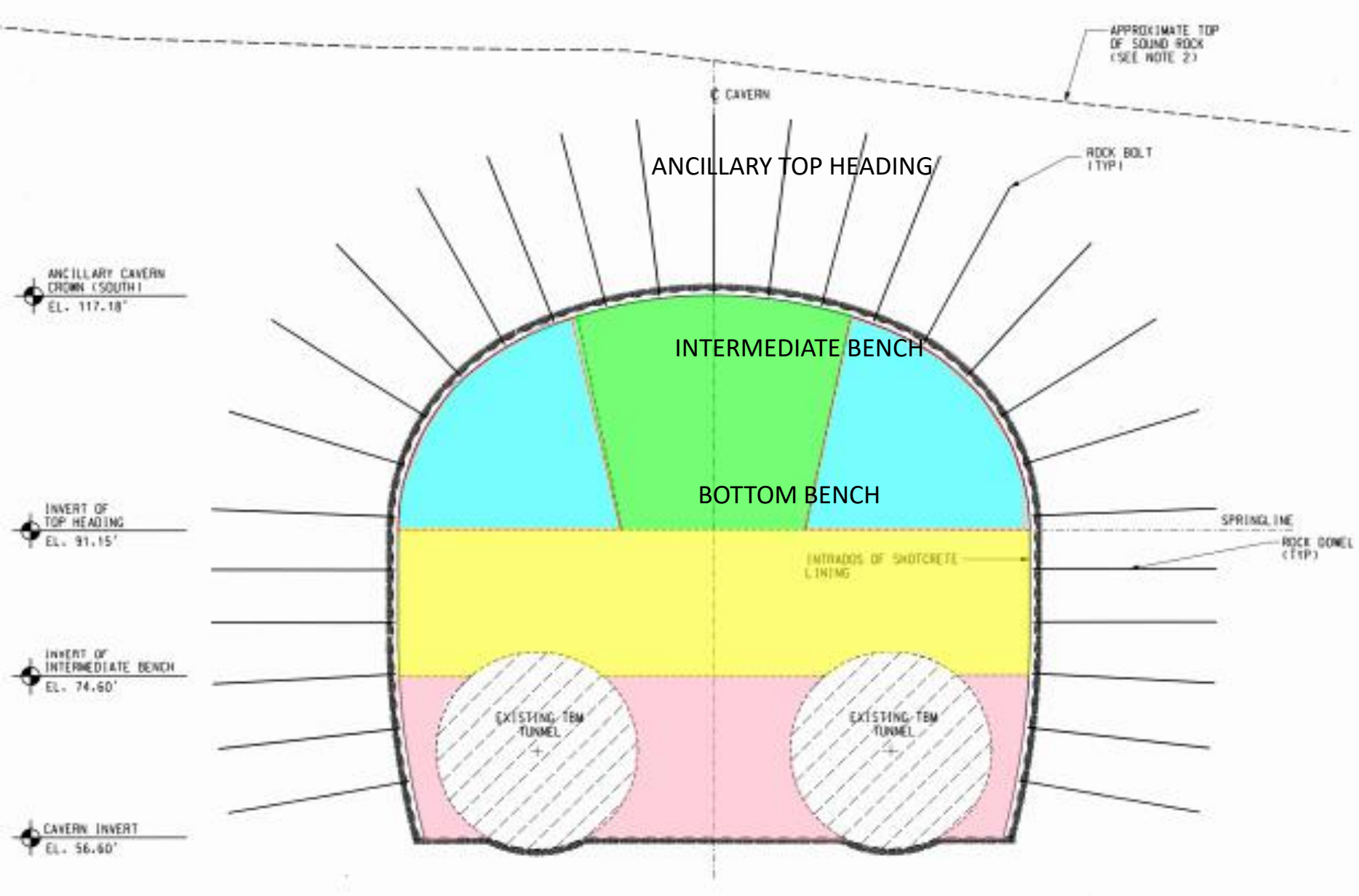
86th Street Station Cavern Excavation



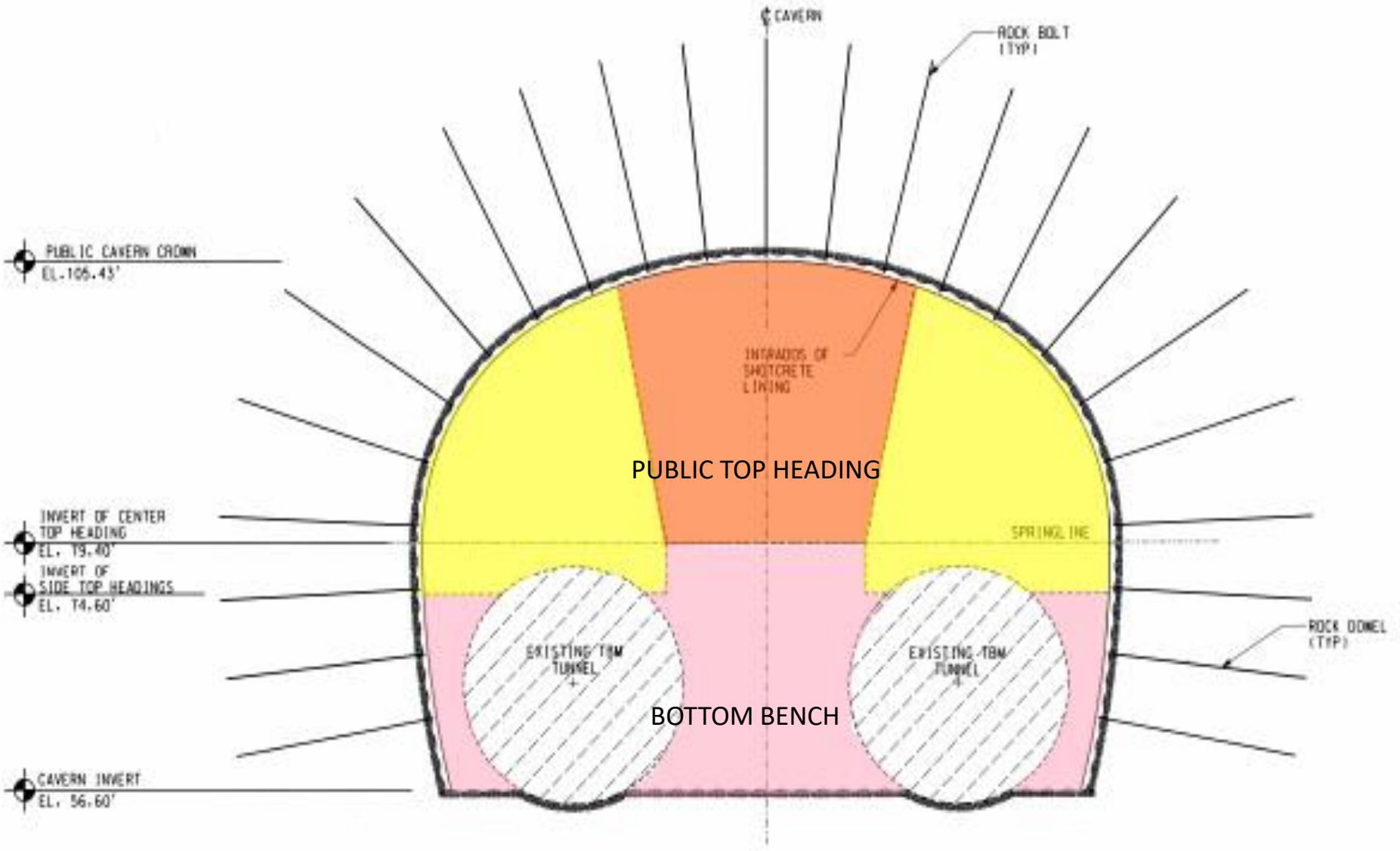
Stations 1198+00 to 1209+00 = ~1,100'

Excavation Methods

86th Street Station – Main Cavern Excavation



86th Street Station – Public Cavern Excavation

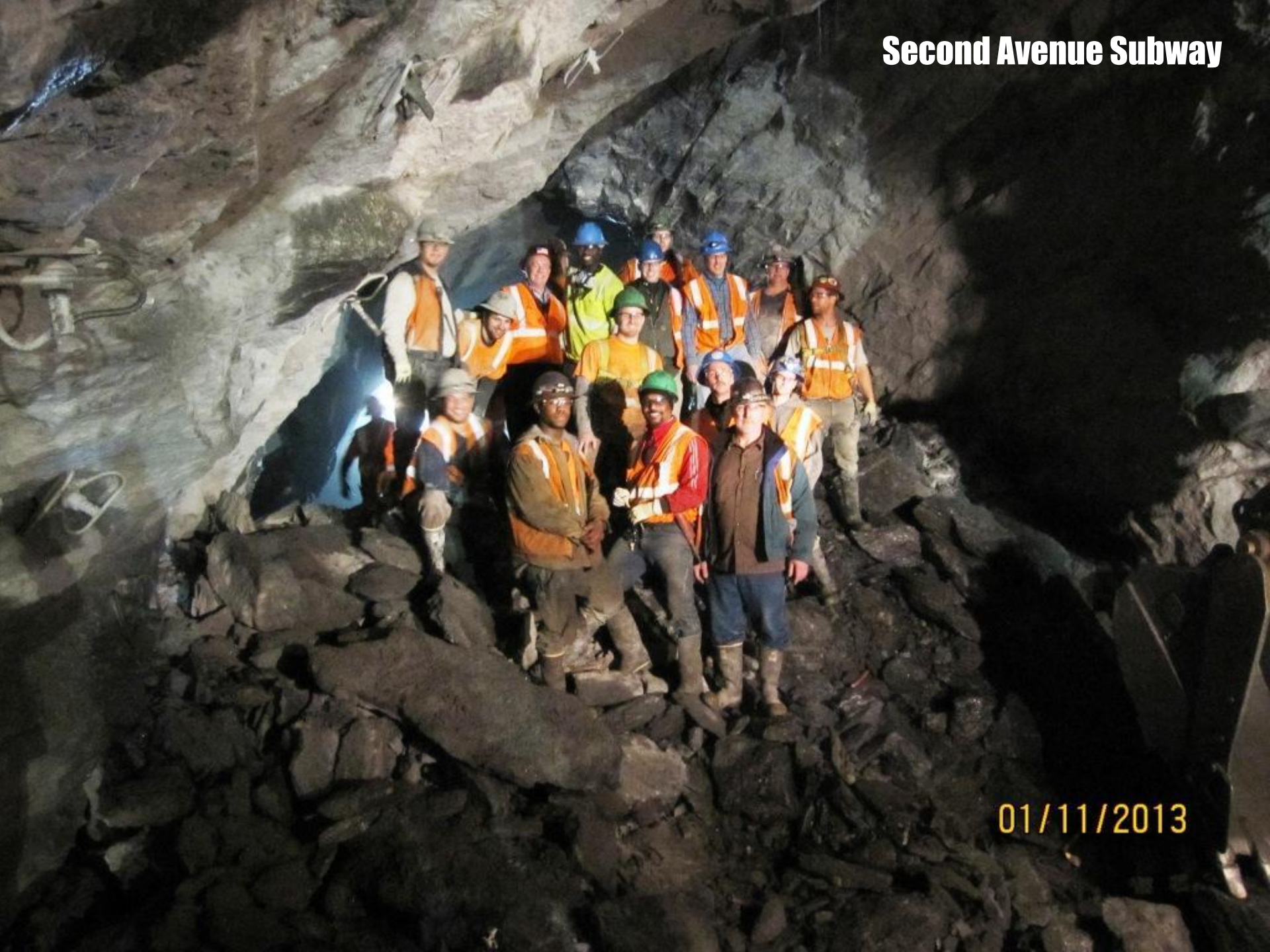



Second Avenue Subway
01/11/2013


Second Avenue Subway
North Cavern

Finished North Ancillary and Public Cavern

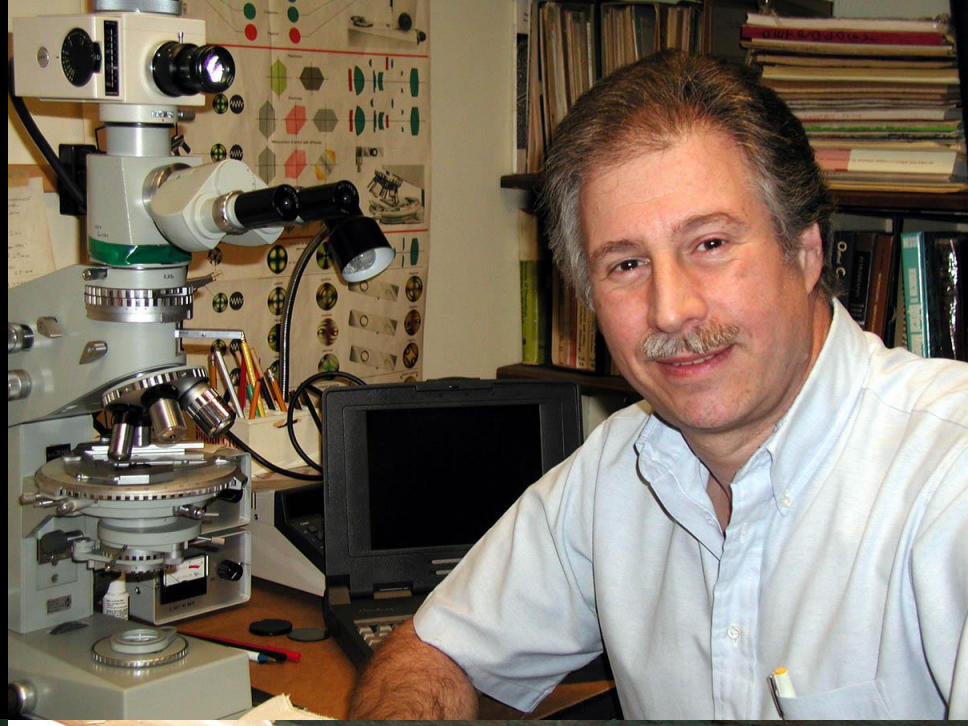

Second Avenue Subway
Unfinished Public Cavern
Sta 1203+95


Second Avenue Subway
01/11/2013

Duke Geological Lab

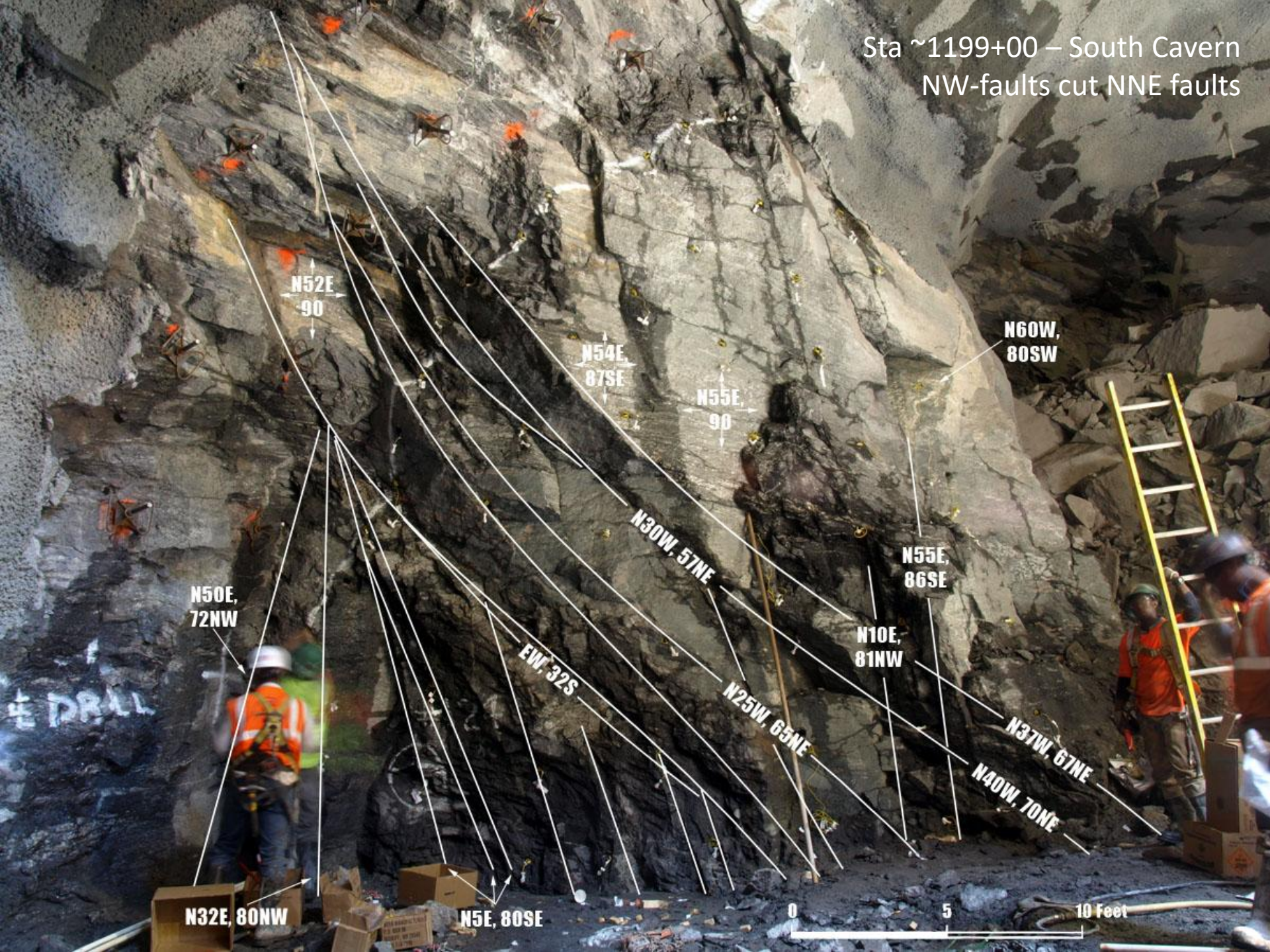
Full Service Geotechnical Tunneling Analysis

www.dukelabs.com

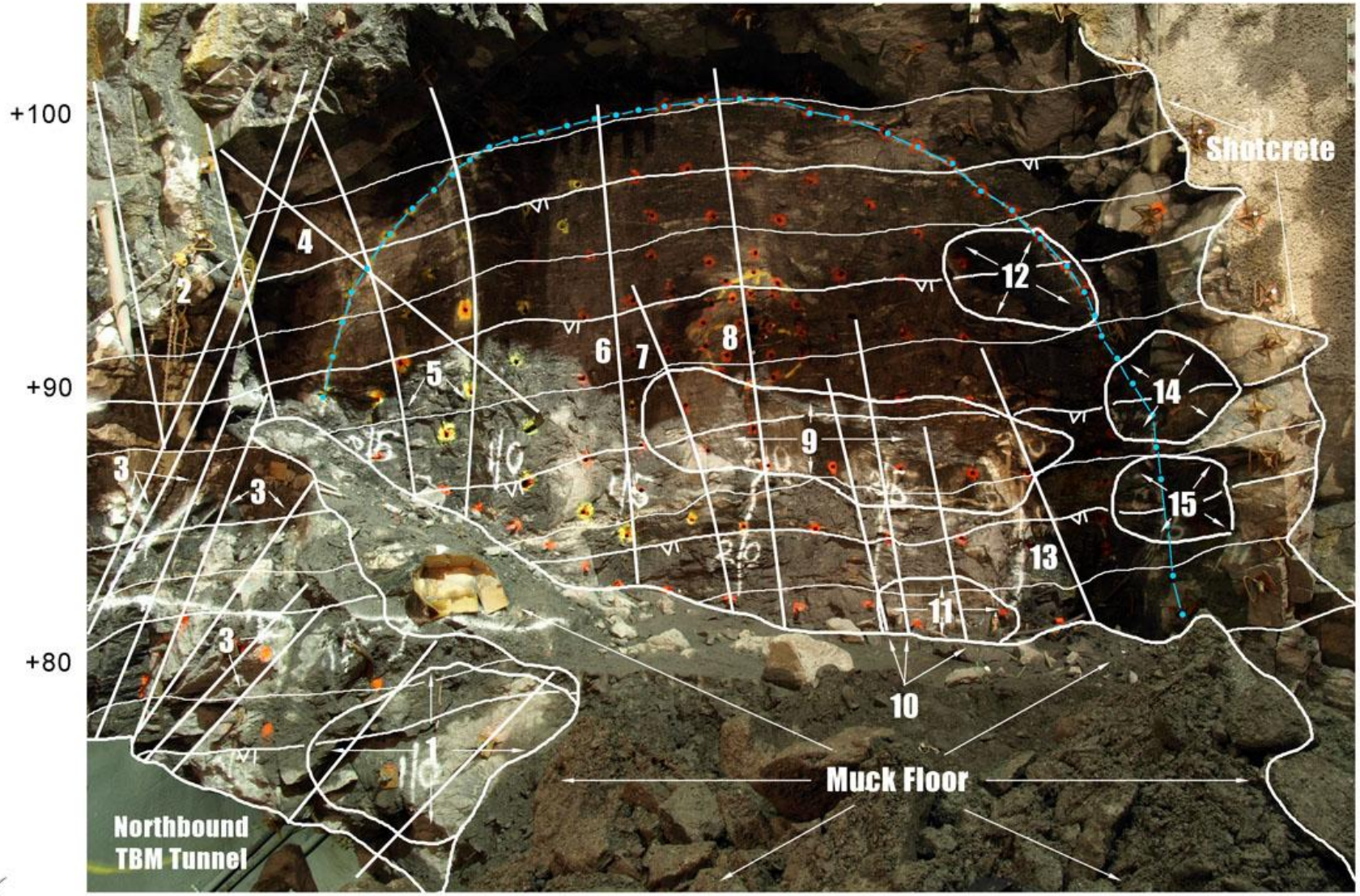


Dukelabs Second Avenue
Subway Field Office
No Windows!


Second Avenue Subway
Sta ~1199+00 – South Cavern
0
5
10 Feet


Sta ~1199+00 – South Cavern
NW-faults cut NNE faults
N52E
90
N54E,
87SE
N55E,
90
N60W,
80SW
N30W, 57NE
N55E,
86SE
N50E,
72NW
N10E,
81NW
EW, 32S
N25W, 65NE
N37W, 67NE
N40W, 70NE
N32E, 80NW
N5E, 80SE
0
5
10 Feet

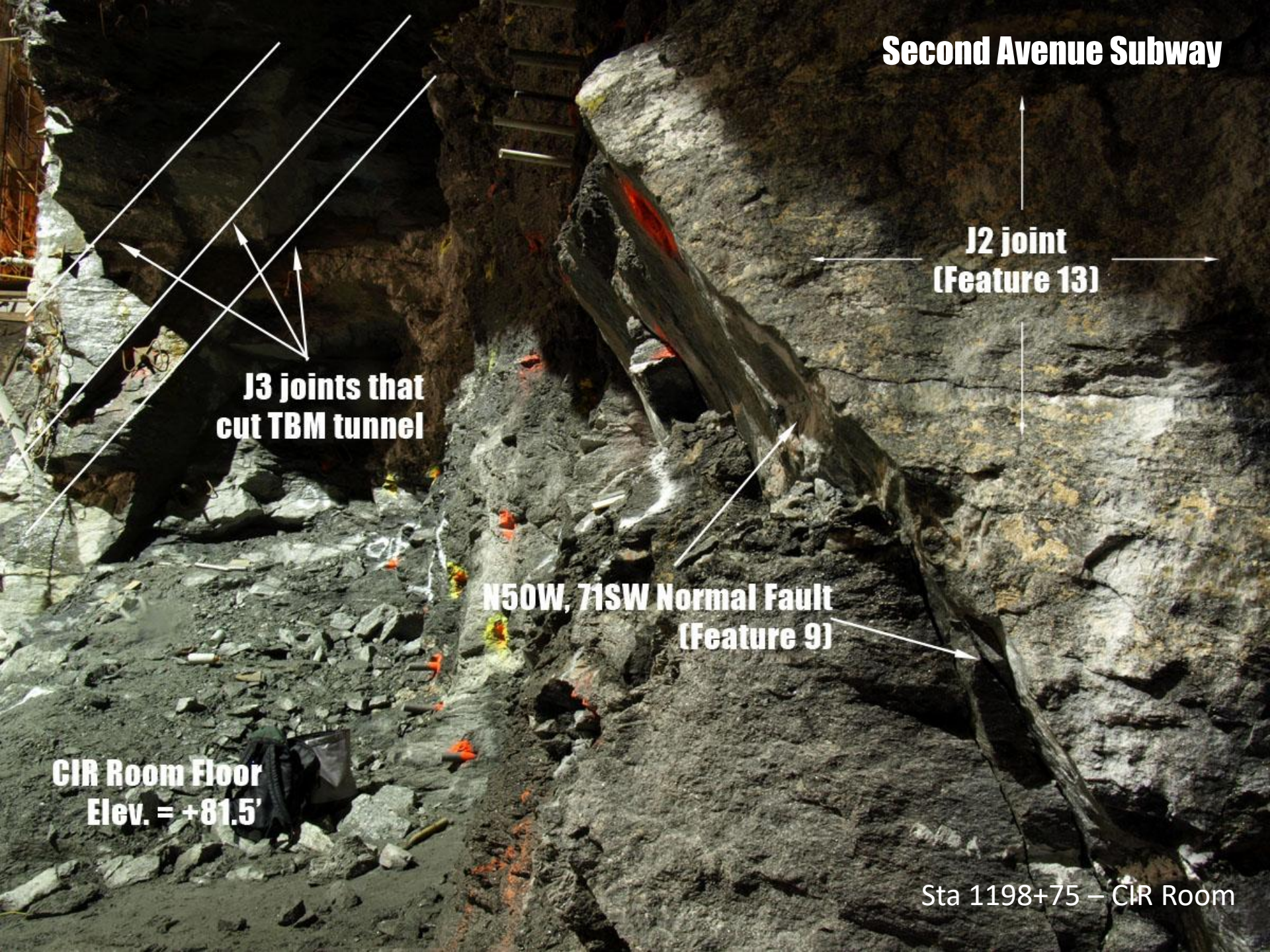

Second Avenue Subway
Sta 1198+75 – CIR Room



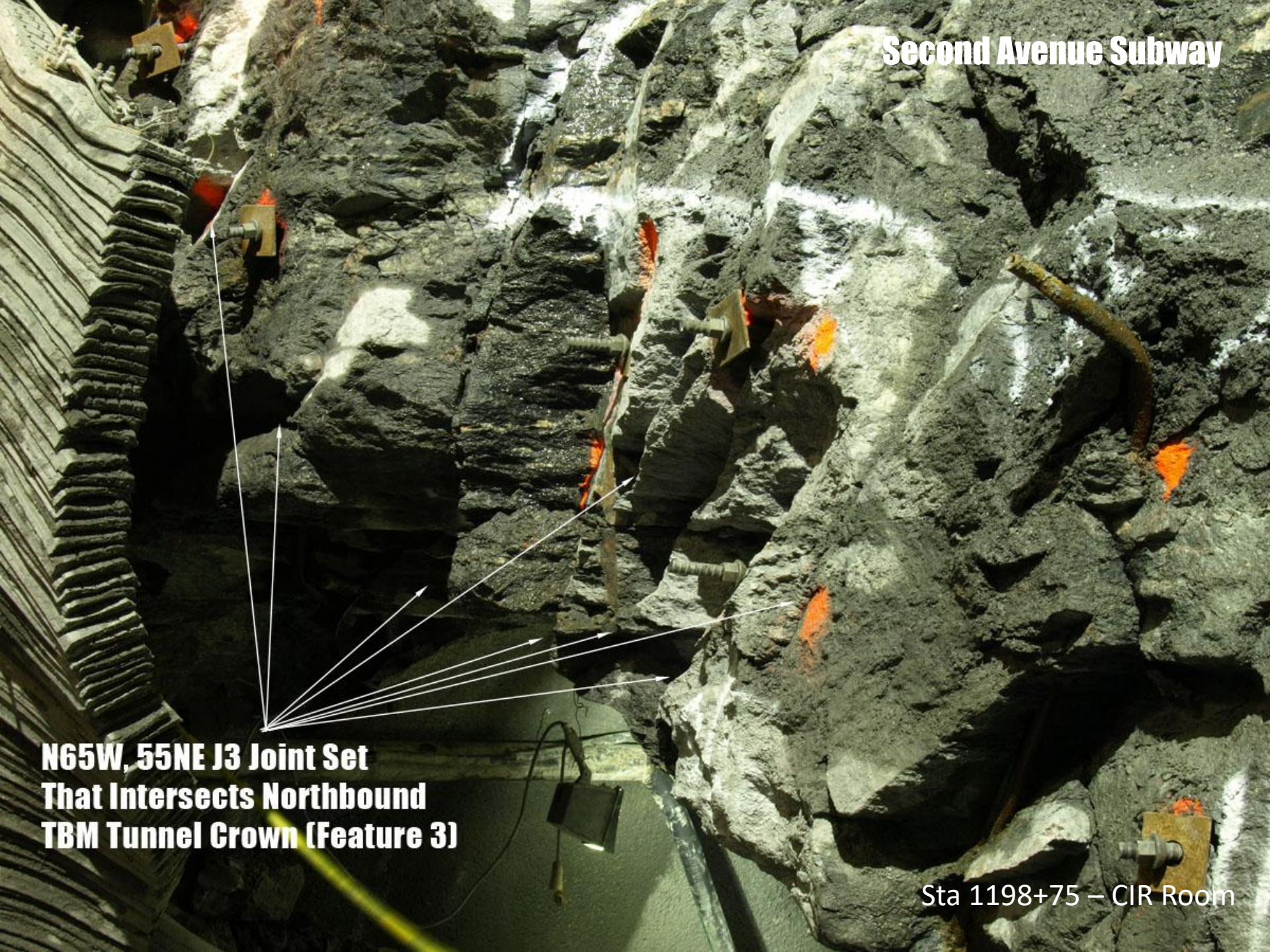
Duke Geological Lab
Westbury, NY 11590
(516) 280-7144
www.dukelabs.com

Mapped 28 February 2013


Second Avenue Subway
CIR Room Floor
Elev. = +81.5'
Sta 1198+75 – CIR Room



Sta 1198+75 – CIR Room


Second Avenue Subway
N65W, 55NE J3 Joint Set
That Intersects Northbound
TBM Tunnel Crown (Feature 3)
Sta 1198+75 – CIR Room

Second Avenue Subway

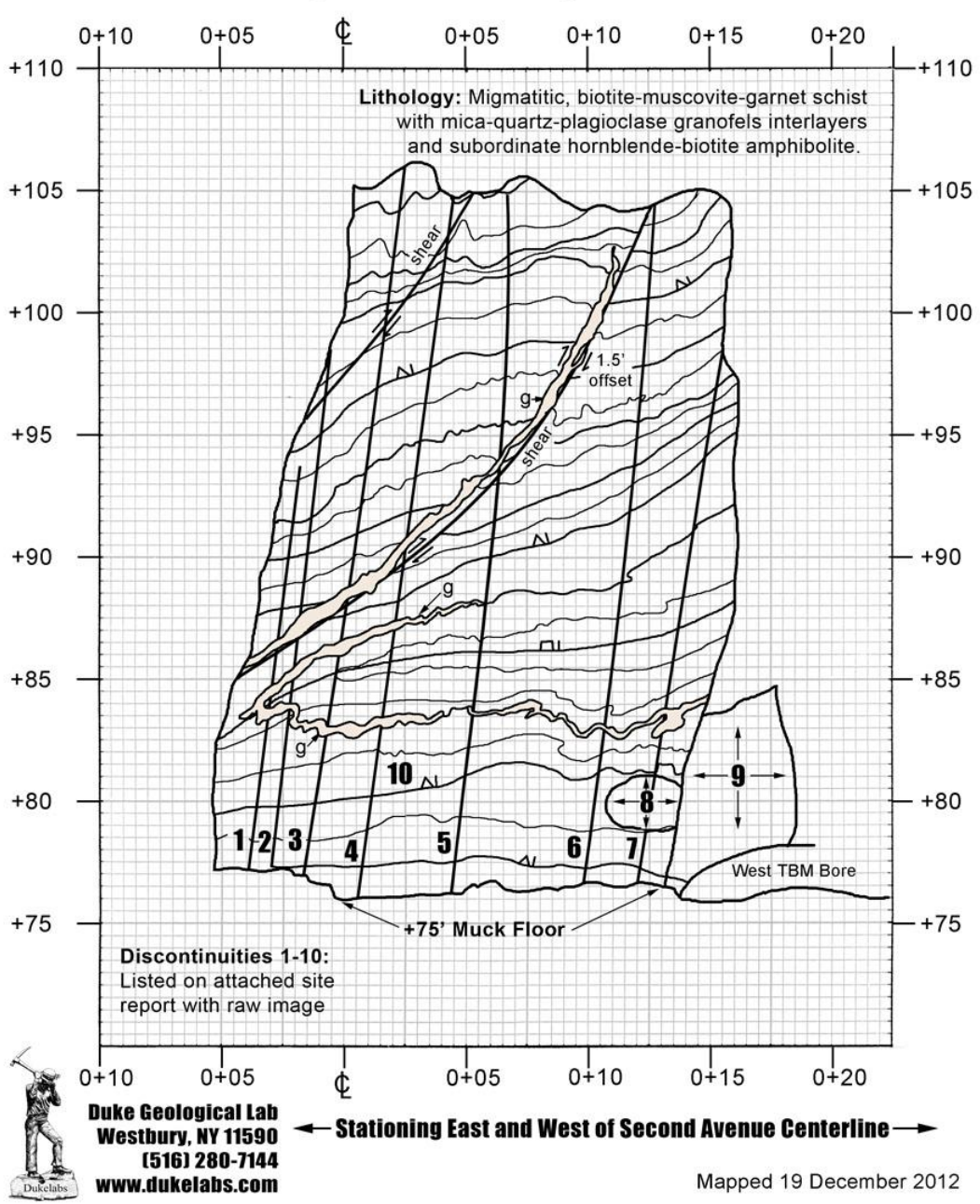
Sta ~1205+00 – North Cavern


Second Avenue Subway
Sta ~1205+00 – North Cavern

Second Avenue Subway

Sta 1204+90
North Cavern Center Slash

Second Avenue Subway



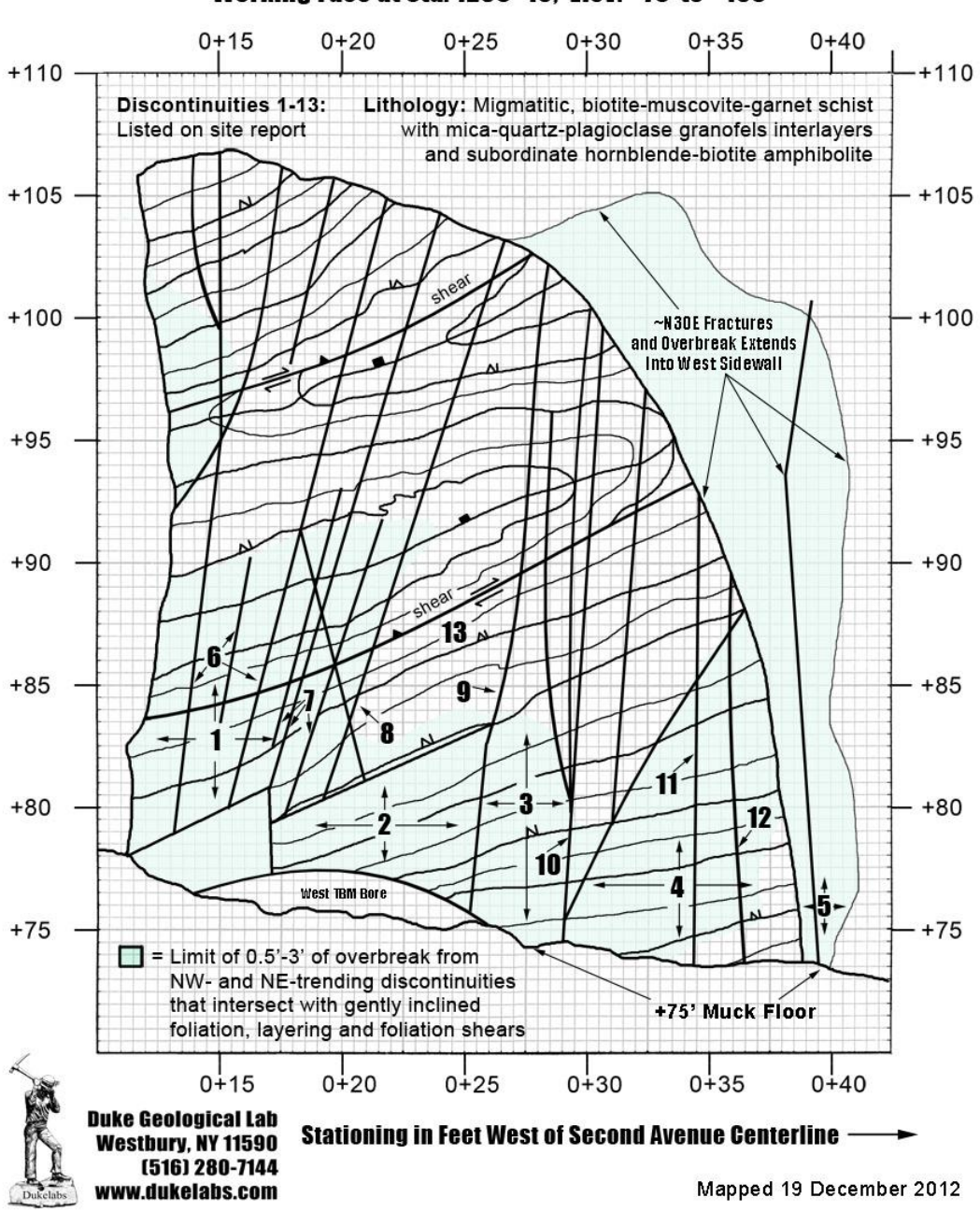
Sta 1204+90
North Cavern Center Slash


Second Avenue Subway
Sta ~1205+00 – North Cavern

Second Avenue Subway

Sta 1205+10
North Cavern West Slash

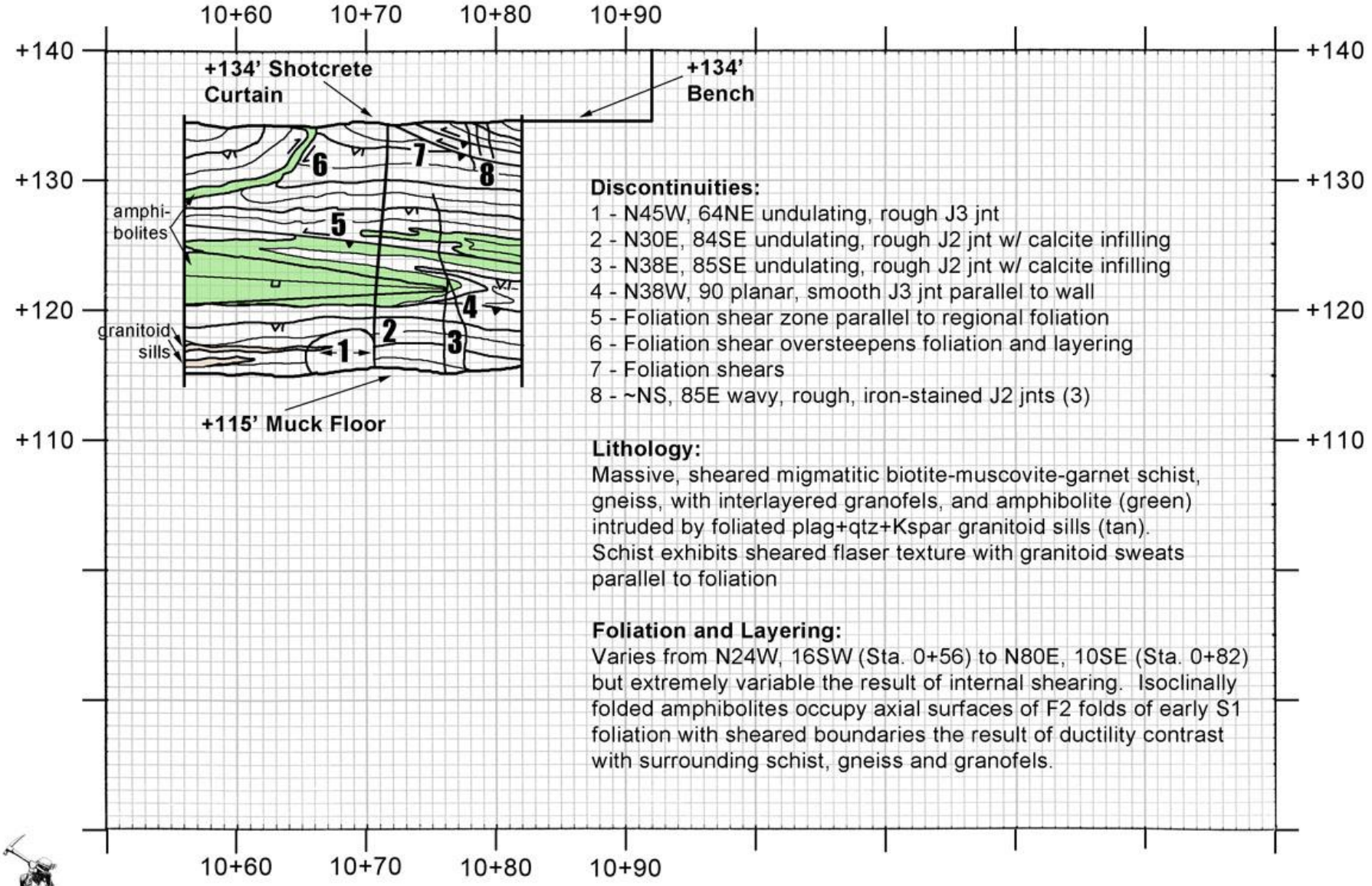
Second Avenue Subway



Sta 1205+10
North Cavern West Slash


Second Avenue Subway
Sta 1205+10 – North Cavern

Second Avenue Subway - Elevator Shaft 86th Street, North Wall, Sta. 10+56 to 10+82 East of Centerline



Discontinuities:
1 - N45W, 64NE undulating, rough J3 jnt
2 - N30E, 84SE undulating, rough J2 jnt w/ calcite infilling
3 - N38E, 85SE undulating, rough J2 jnt w/ calcite infilling
4 - N38W, 90 planar, smooth J3 jnt parallel to wall
5 - Foliation shear zone parallel to regional foliation
6 - Foliation shear oversteepens foliation and layering
7 - Foliation shears
8 - ~NS, 85E wavy, rough, iron-stained J2 jnts (3)

Lithology:
Massive, sheared migmatitic biotite-muscovite-garnet schist, gneiss, with interlayered granofels, and amphibolite (green) intruded by foliated plag+qtz+Kspar granitoid sills (tan). Schist exhibits sheared flaser texture with granitoid sweats parallel to foliation

Foliation and Layering:
Varies from N24W, 16SW (Sta. 0+56) to N80E, 10SE (Sta. 0+82) but extremely variable the result of internal shearing. Isoclinally folded amphibolites occupy axial surfaces of F2 folds of early S1 foliation with sheared boundaries the result of ductility contrast with surrounding schist, gneiss and granofels.

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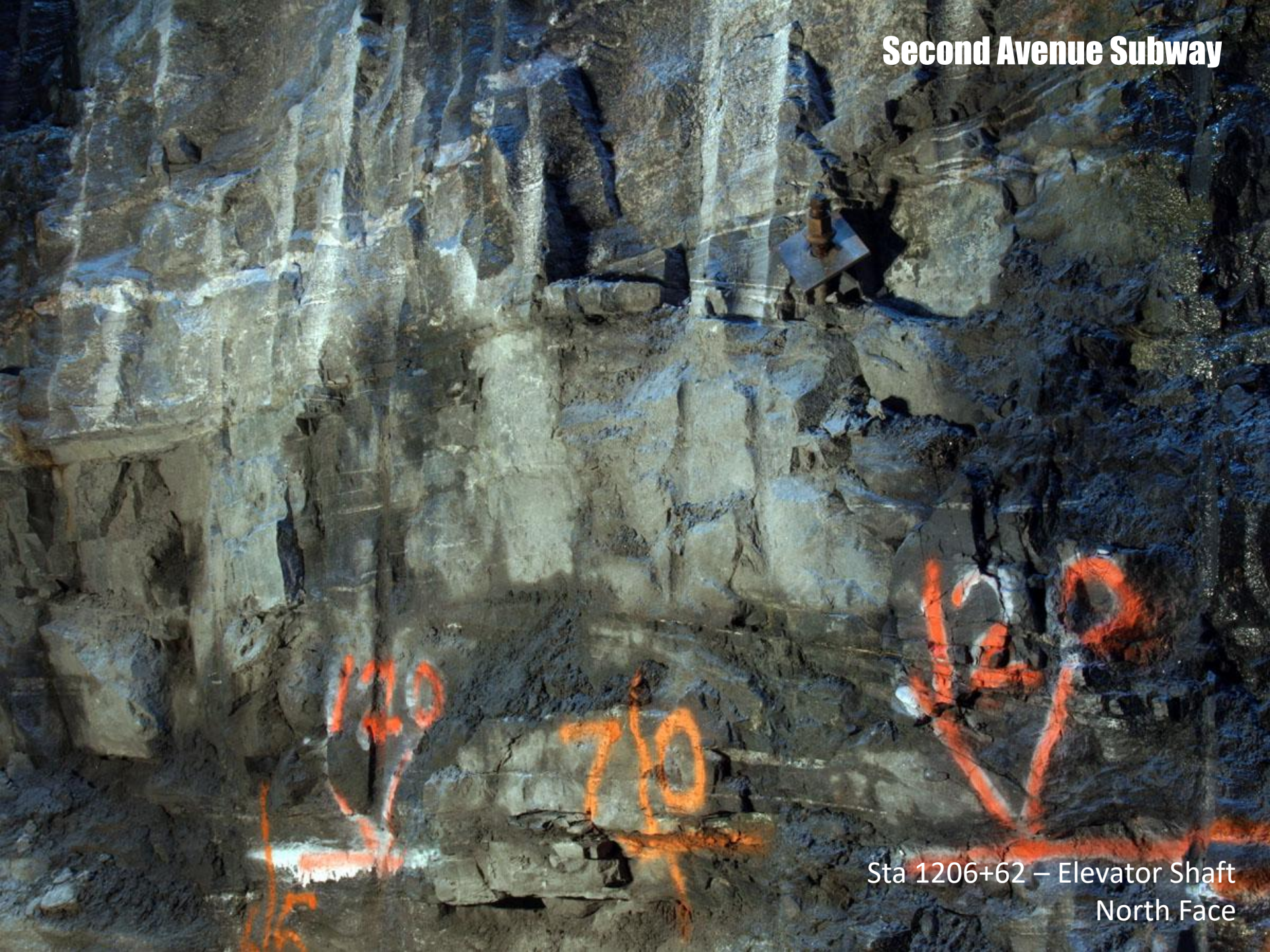
Stationing in Feet East of 86th Street Centerline →

Mapped 21 January 2013

Sta 1206+62 – Elevator Shaft

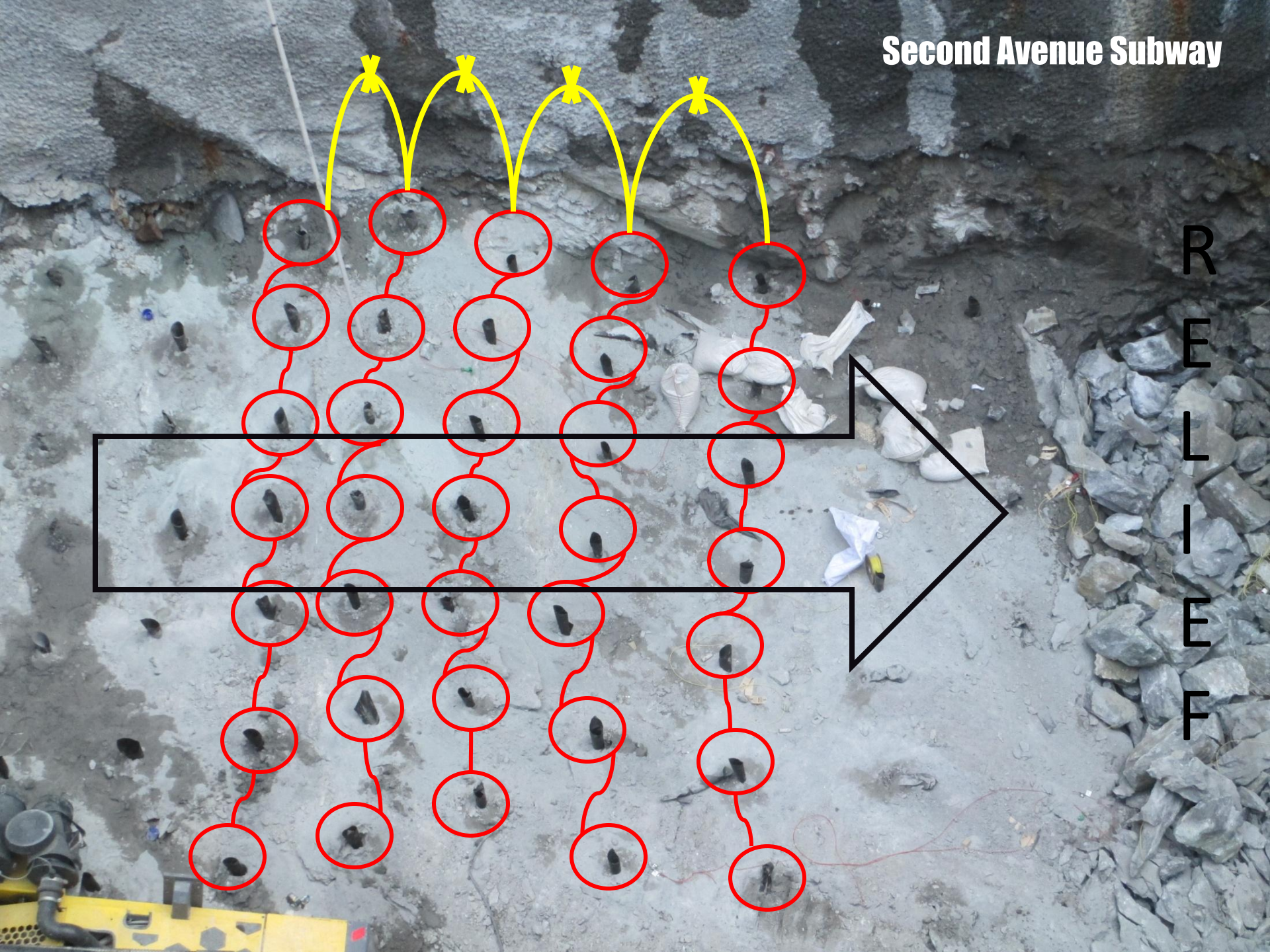

Second Avenue Subway
Sta 1206+62 – Elevator Shaft
North Face

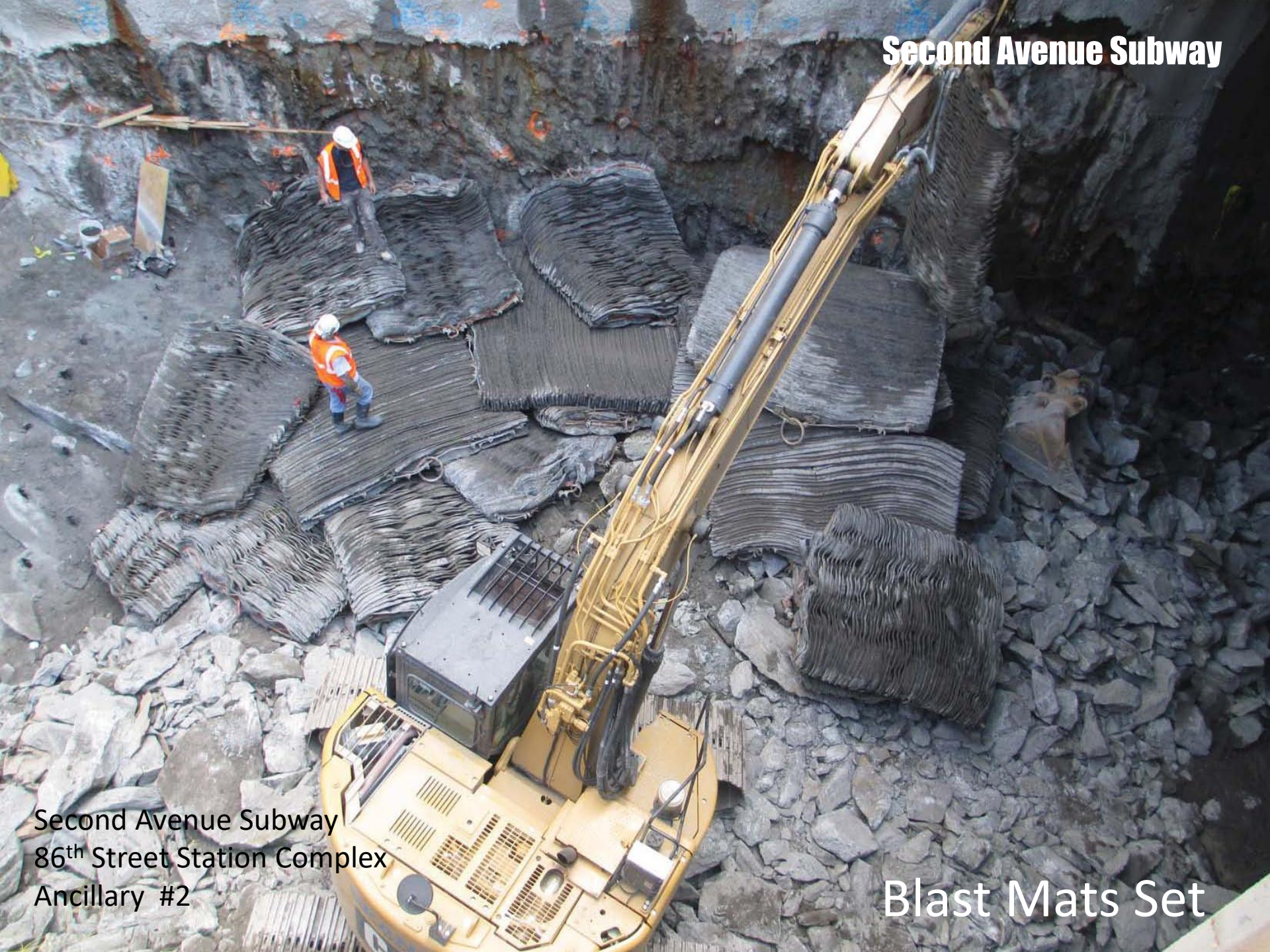

Second Avenue Subway
Sta 1206+62 – Elevator Shaft

Second Avenue Subway
86th Street Station Complex
Ancillary #2

06 Nov 2012

Second Avenue Subway
86th Street Station Complex
Ancillary #2


Second Avenue Subway
RELIEF


Second Avenue Subway
Second Avenue Subway
86th Street Station Complex
Ancillary #2
Blast Mats Set

Second Avenue Subway
86th Street Station Complex
Ancillary #2

Second Avenue Subway
86th Street Ancillary #2
Southward View of South Wall
Elevation +155' to +133'

Plate 2

Duke Geological Lab
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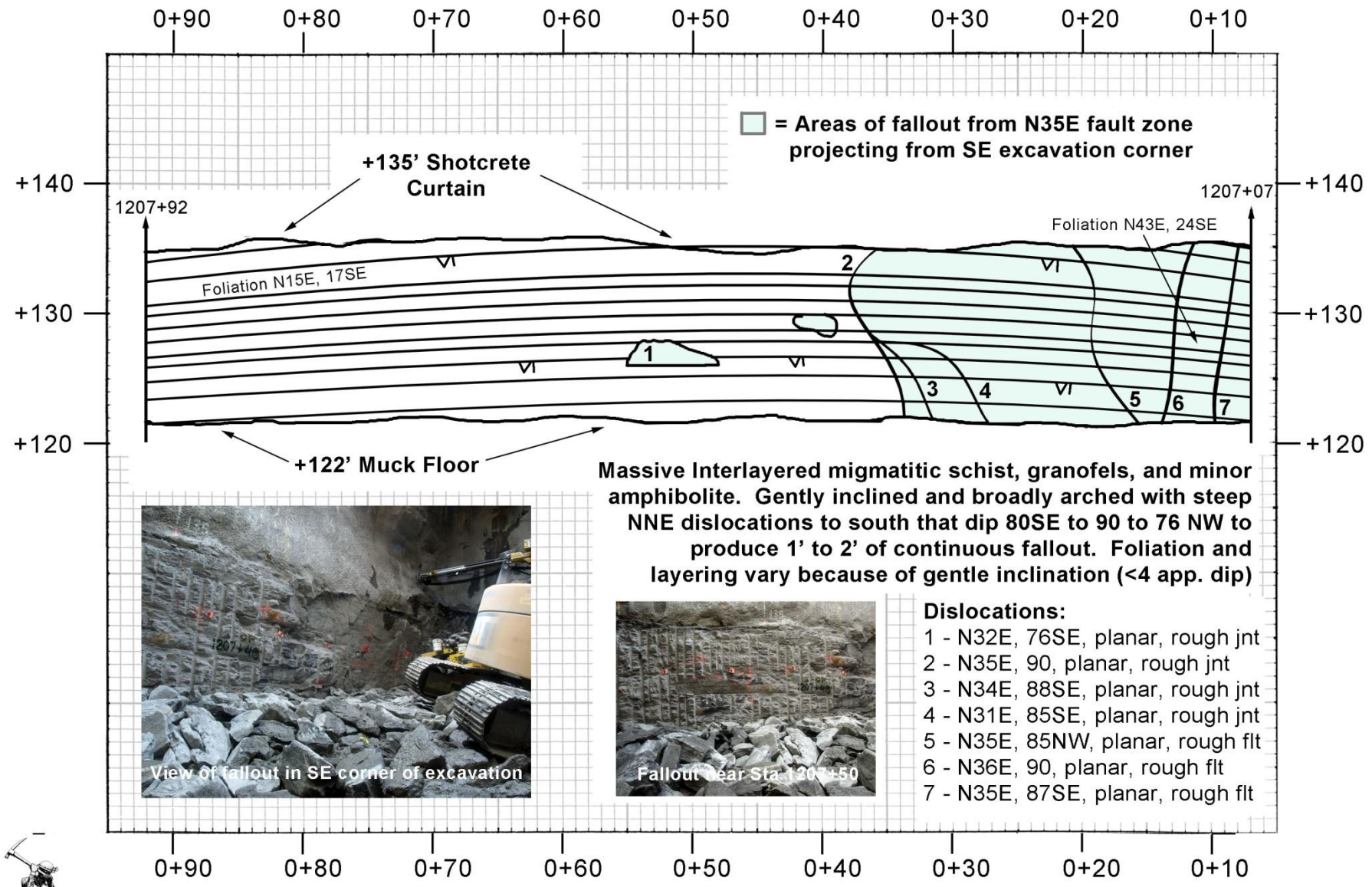
Second Avenue Subway - Ancillary #2 East Wall (Sta. 1207+07 to 1207+92); Elev. +135' to +122'



Massive Interlayered migmatitic schist, granofels, and minor amphibolite. Gently inclined and broadly arched with steep NNE dislocations to south that dip 80SE to 90 to 76 NW to produce 1' to 2' of continuous fallout. Foliation and layering vary because of gentle inclination (<4 app. dip)

View of fallout in SE corner of excavation

Fallout near Sta 1207+50

Dislocations:

1 - N32E, 76SE, planar, rough jnt
2 - N35E, 90, planar, rough jnt
3 - N34E, 88SE, planar, rough jnt
4 - N31E, 85SE, planar, rough jnt
5 - N35E, 85NW, planar, rough flt
6 - N36E, 90, planar, rough flt
7 - N35E, 87SE, planar, rough flt

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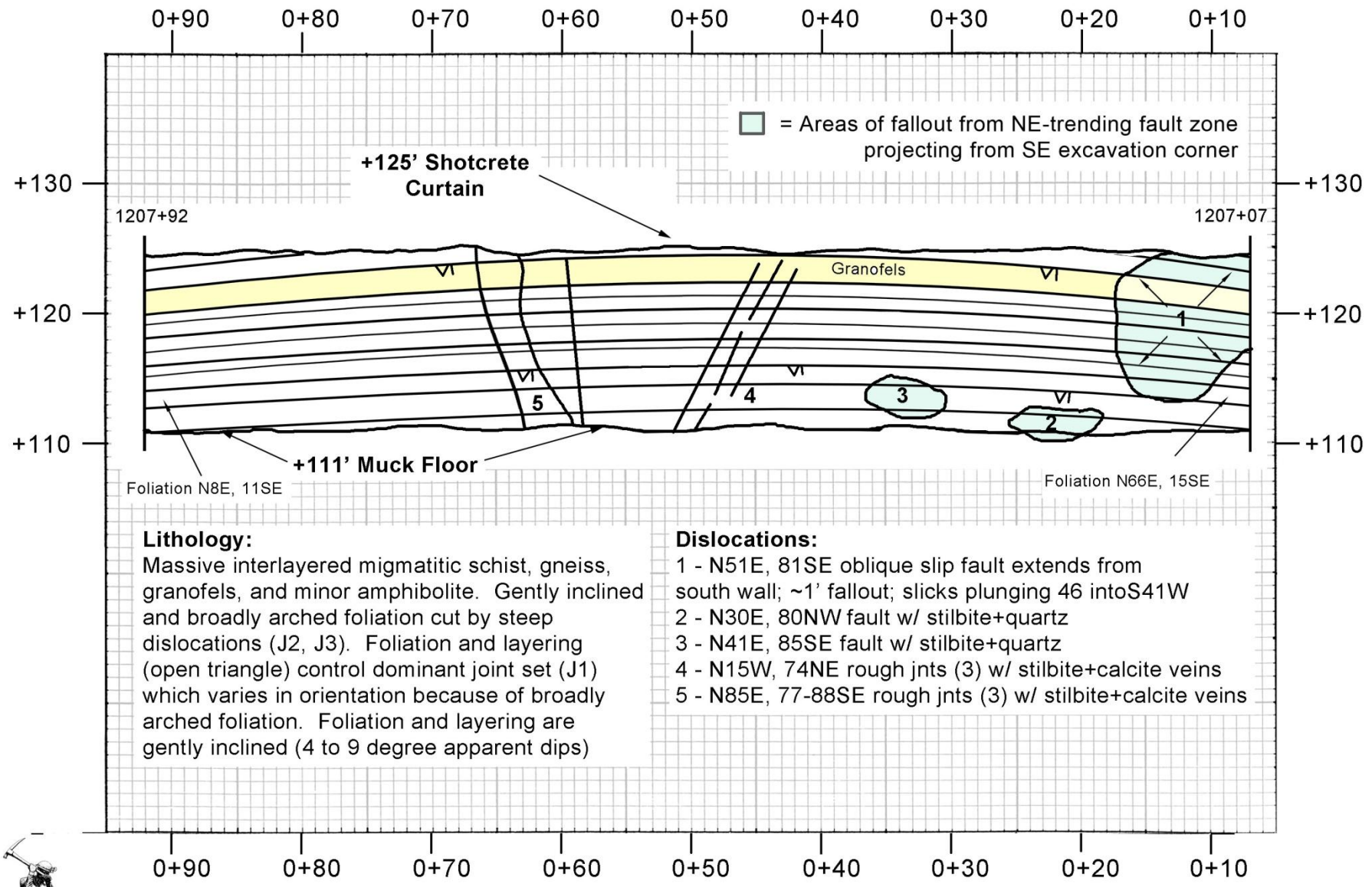
Stationing in Feet North Along East Wall

(Map Drawn Parallel to Sta 0+50 West of Second Avenue Centerline)

Mapped 21 November 2012

Second Avenue Subway - Ancillary #2 East Wall Sta. 1207+07 to 1207+92; Elev. +125' to +111'



Lithology:
Massive interlayered migmatitic schist, gneiss, granofels, and minor amphibolite. Gently inclined and broadly arched foliation cut by steep dislocations (J2, J3). Foliation and layering (open triangle) control dominant joint set (J1) which varies in orientation because of broadly arched foliation. Foliation and layering are gently inclined (4 to 9 degree apparent dips)

Dislocations:
1 - N51E, 81SE oblique slip fault extends from south wall; ~1' fallout; slicks plunging 46 intoS41W
2 - N30E, 80NW fault w/ stilbite+quartz
3 - N41E, 85SE fault w/ stilbite+quartz
4 - N15W, 74NE rough jnts (3) w/ stilbite+calcite veins
5 - N85E, 77-88SE rough jnts (3) w/ stilbite+calcite veins

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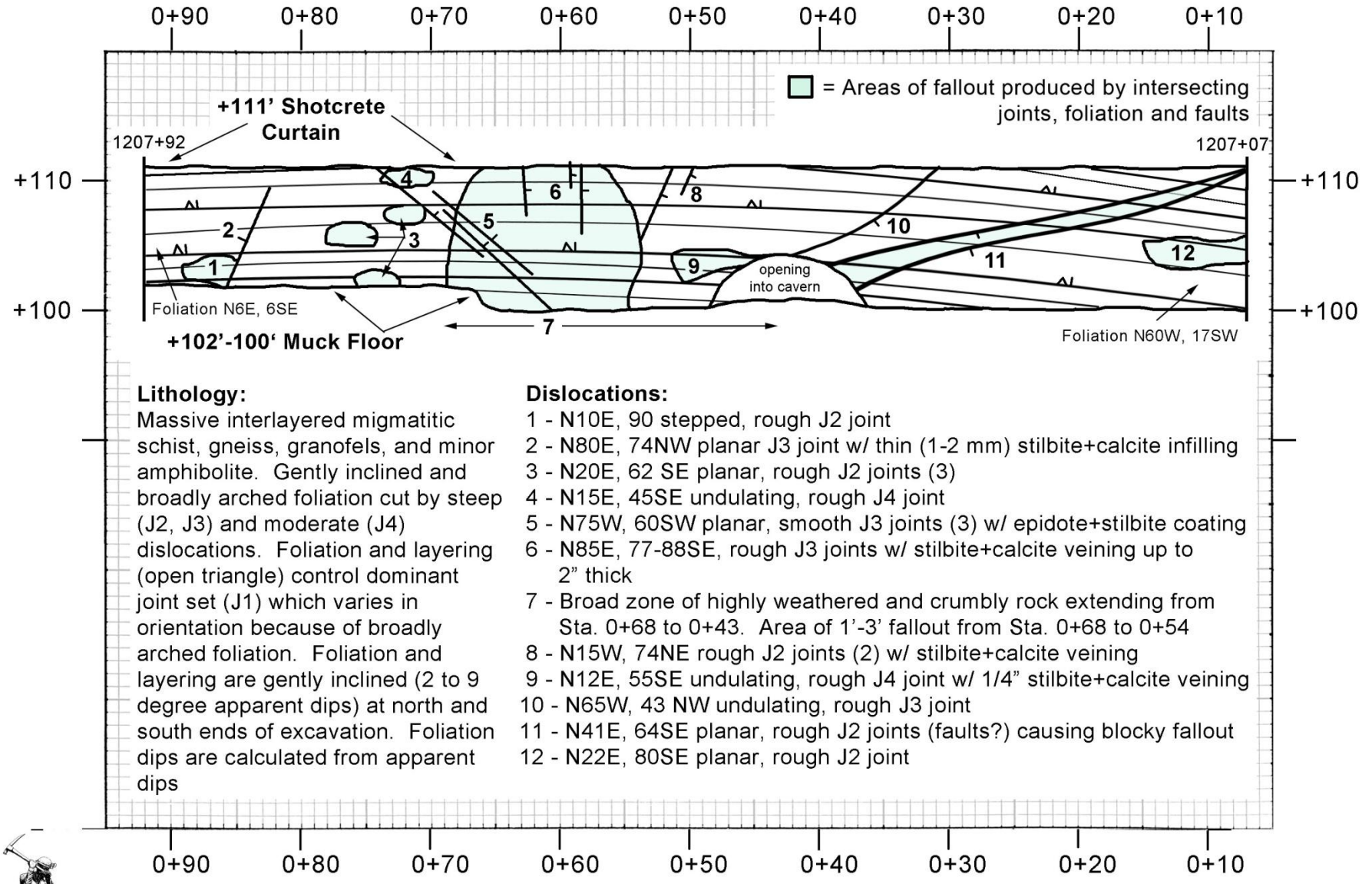
Stationing in Feet North Along East Wall
(Map Drawn Parallel to Sta 0+50 West of Second Avenue Centerline)

Mapped 15 January 2013

Second Avenue Subway - Ancillary #2 East Wall Sta. 1207+07 to 1207+92; Elev. +111' to +100'



Lithology:

Massive interlayered migmatitic schist, gneiss, granofels, and minor amphibolite. Gently inclined and broadly arched foliation cut by steep (J2, J3) and moderate (J4) dislocations. Foliation and layering (open triangle) control dominant joint set (J1) which varies in orientation because of broadly arched foliation. Foliation and layering are gently inclined (2 to 9 degree apparent dips) at north and south ends of excavation. Foliation dips are calculated from apparent dips

Dislocations:

1 - N10E, 90 stepped, rough J2 joint
2 - N80E, 74NW planar J3 joint w/ thin (1-2 mm) stilbite+calcite infilling
3 - N20E, 62 SE planar, rough J2 joints (3)
4 - N15E, 45SE undulating, rough J4 joint
5 - N75W, 60SW planar, smooth J3 joints (3) w/ epidote+stilbite coating
6 - N85E, 77-88SE, rough J3 joints w/ stilbite+calcite veining up to 2" thick
7 - Broad zone of highly weathered and crumbly rock extending from Sta. 0+68 to 0+43. Area of 1'-3' fallout from Sta. 0+68 to 0+54
8 - N15W, 74NE rough J2 joints (2) w/ stilbite+calcite veining
9 - N12E, 55SE undulating, rough J4 joint w/ 1/4" stilbite+calcite veining
10 - N65W, 43 NW undulating, rough J3 joint
11 - N41E, 64SE planar, rough J2 joints (faults?) causing blocky fallout
12 - N22E, 80SE planar, rough J2 joint

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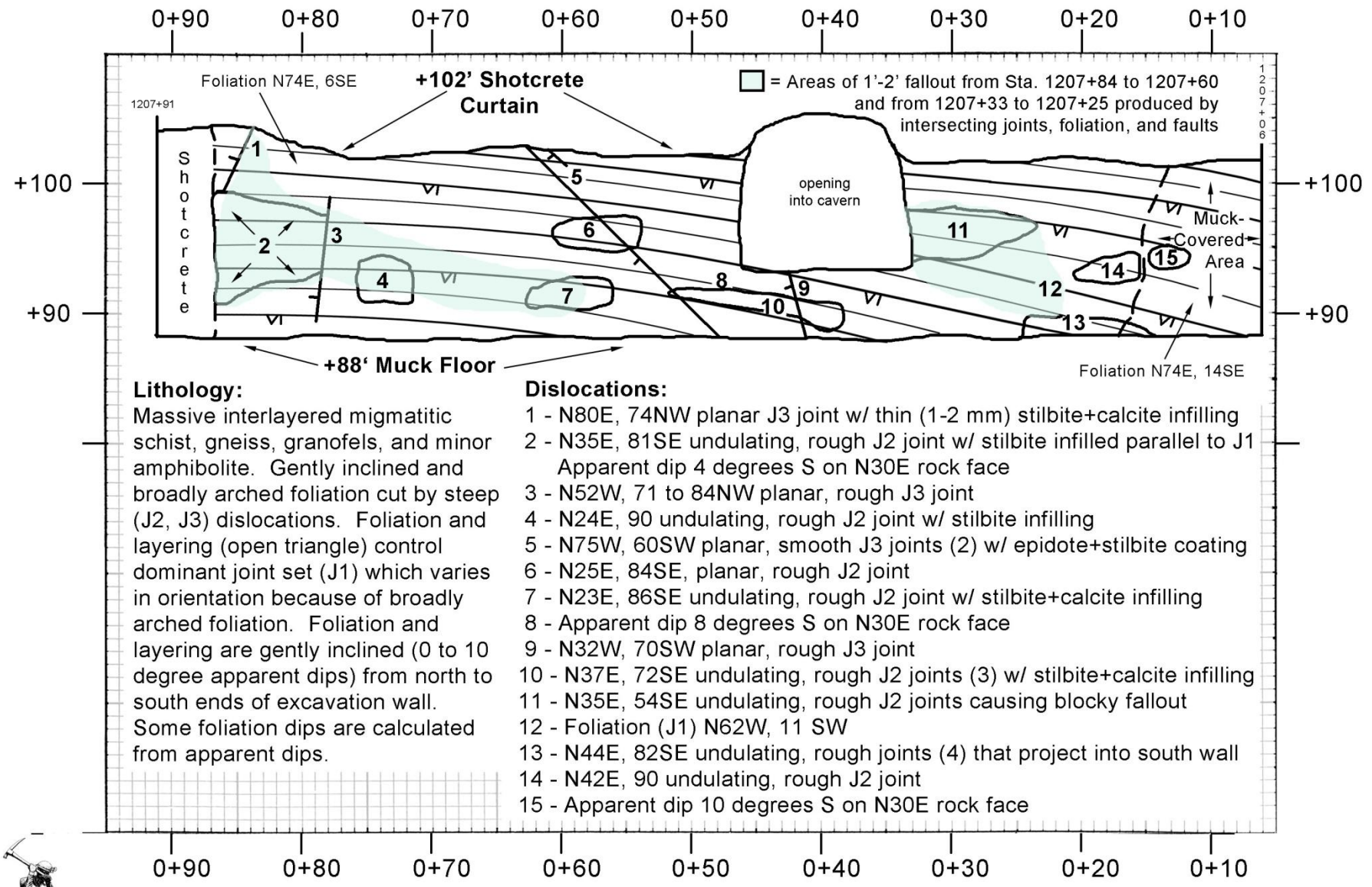
Stationing in Feet North Along East Wall

(Map Drawn Parallel to Sta 0+50 West of Second Avenue Centerline)

Mapped 06 February 2013

Second Avenue Subway - Ancillary #2 East Wall Sta. 1207+06 to 1207+91; Elev. +102' to +88'



Lithology:

Massive interlayered migmatitic schist, gneiss, granofels, and minor amphibolite. Gently inclined and broadly arched foliation cut by steep (J2, J3) dislocations. Foliation and layering (open triangle) control dominant joint set (J1) which varies in orientation because of broadly arched foliation. Foliation and layering are gently inclined (0 to 10 degree apparent dips) from north to south ends of excavation wall. Some foliation dips are calculated from apparent dips.

Dislocations:

1 - N80E, 74NW planar J3 joint w/ thin (1-2 mm) stilbite+calcite infilling
2 - N35E, 81SE undulating, rough J2 joint w/ stilbite infilled parallel to J1
Apparent dip 4 degrees S on N30E rock face
3 - N52W, 71 to 84NW planar, rough J3 joint
4 - N24E, 90 undulating, rough J2 joint w/ stilbite infilling
5 - N75W, 60SW planar, smooth J3 joints (2) w/ epidote+stilbite coating
6 - N25E, 84SE, planar, rough J2 joint
7 - N23E, 86SE undulating, rough J2 joint w/ stilbite+calcite infilling
8 - Apparent dip 8 degrees S on N30E rock face
9 - N32W, 70SW planar, rough J3 joint
10 - N37E, 72SE undulating, rough J2 joints (3) w/ stilbite+calcite infilling
11 - N35E, 54SE undulating, rough J2 joints causing blocky fallout
12 - Foliation (J1) N62W, 11 SW
13 - N44E, 82SE undulating, rough joints (4) that project into south wall
14 - N42E, 90 undulating, rough J2 joint
15 - Apparent dip 10 degrees S on N30E rock face

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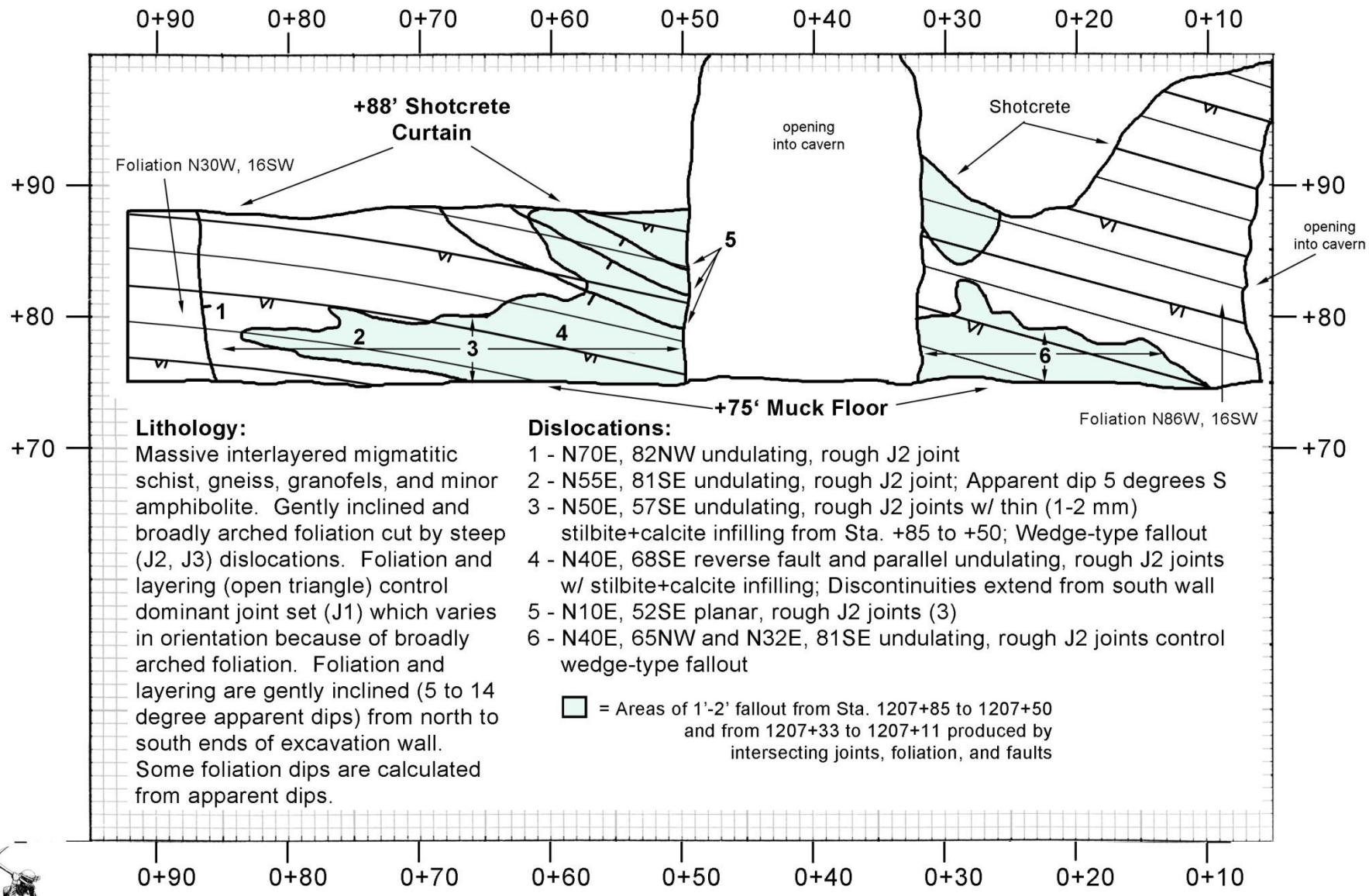
Stationing in Feet North Along East Wall

(Map Drawn Parallel to Sta 0+50 West of Second Avenue Centerline)

Mapped 05 March 2013

Second Avenue Subway - Ancillary #2 East Wall Sta. 1207+05 to 1207+92; Elev. +88' to +75'



Lithology:
Massive interlayered migmatitic schist, gneiss, granofels, and minor amphibolite. Gently inclined and broadly arched foliation cut by steep (J2, J3) dislocations. Foliation and layering (open triangle) control dominant joint set (J1) which varies in orientation because of broadly arched foliation. Foliation and layering are gently inclined (5 to 14 degree apparent dips) from north to south ends of excavation wall. Some foliation dips are calculated from apparent dips.

Dislocations:
1 - N70E, 82NW undulating, rough J2 joint
2 - N55E, 81SE undulating, rough J2 joint; Apparent dip 5 degrees S
3 - N50E, 57SE undulating, rough J2 joints w/ thin (1-2 mm) stilbite+calcite infilling from Sta. +85 to +50; Wedge-type fallout
4 - N40E, 68SE reverse fault and parallel undulating, rough J2 joints w/ stilbite+calcite infilling; Discontinuities extend from south wall
5 - N10E, 52SE planar, rough J2 joints (3)
6 - N40E, 65NW and N32E, 81SE undulating, rough J2 joints control wedge-type fallout

☐ = Areas of 1'-2' fallout from Sta. 1207+85 to 1207+50 and from 1207+33 to 1207+11 produced by intersecting joints, foliation, and faults

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Stationing in Feet North Along East Wall
(Map Drawn Parallel to Sta 0+50 West of Second Avenue Centerline)

Mapped 22 April 2013

Sta 1207+50 – Ancillary #2 West Wall


Second Avenue Subway
Sta 1207+50 – Ancillary #2 West Wall


1075b_Calcite_86th St 2nd Ave Subway


1075c_Calcite_86th St 2nd Ave Subway

1104_Calcite_86th St 2nd Ave Subway


2689_Stilbite+Calcite_86th St 2nd Ave Subway


2825_Stilbite_86th St 2nd Ave Subway


2840_Epidote_86th St 2nd Ave Subway


12845_Epidote+Calcite_86th St 2nd Ave Subway

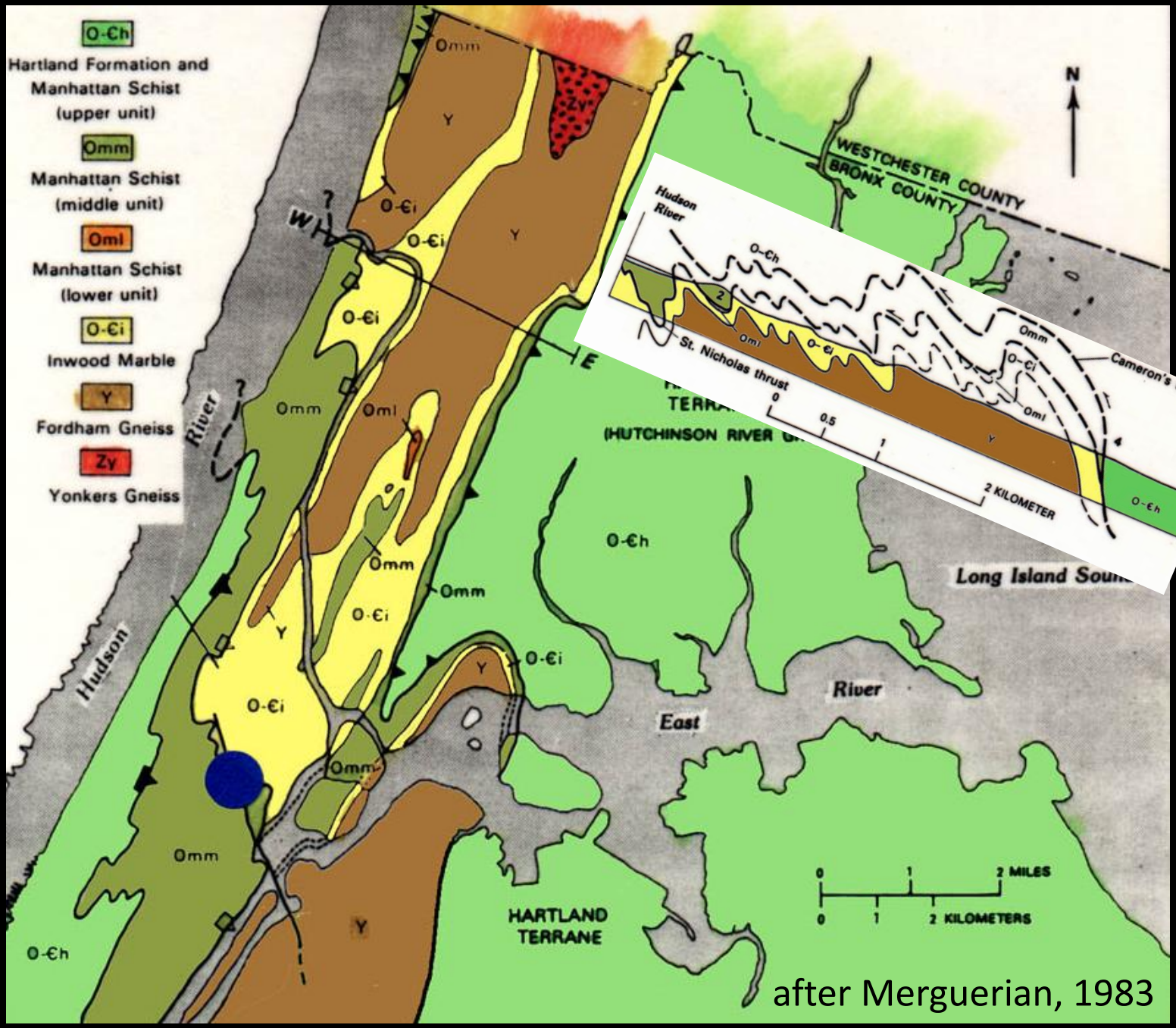
2851_Pyrite+Stilbite_86th St 2nd Ave Subway


2853_Stilbite_86th St 2nd Ave Subway


2857_Stilbite_86th St 2nd Ave Subway

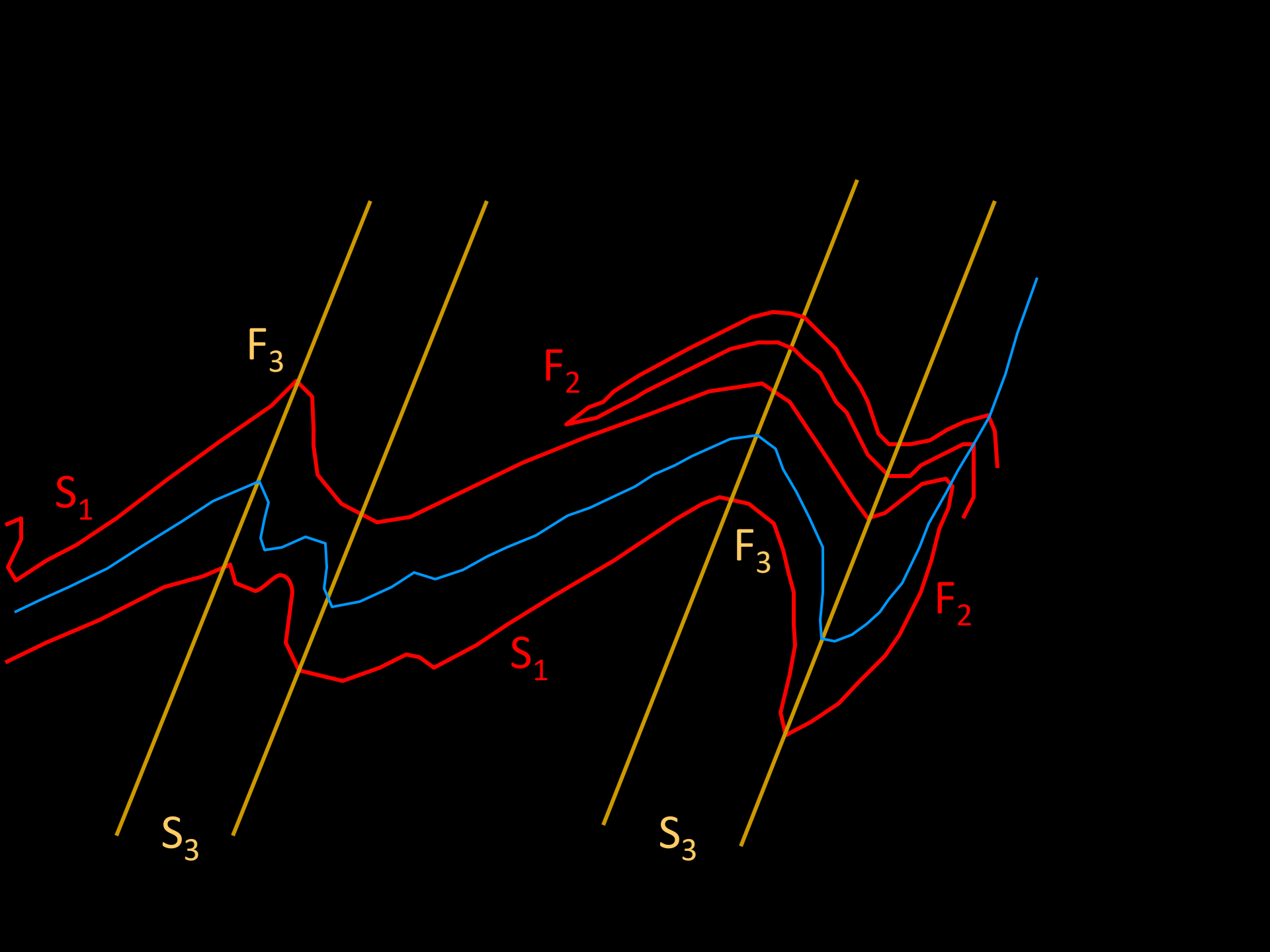
2852_Calcite+Stilbite_86th St 2nd Ave Subway

2863_Stilbite+Calcite_86th St 2nd Ave Subway


O-Ch
Hartland Formation and Manhattan Schist (upper unit)
Omm
Manhattan Schist (middle unit)
Oml
Manhattan Schist (lower unit)
O-Ei
Inwood Marble
Y
Fordham Gneiss
Zy
Yonkers Gneiss
N
WESTCHESTER COUNTY
BRONX COUNTY
Hudson River
St. Nicholas thrust
Cameron's Line
2 KILOMETER
HARTLAND TERRANE
0 1 2 MILES
0 1 2 KILOMETERS
after Merguerian, 1983

Polydeformed Bedrock – Central Park, NYC

Polydeformed Bedrock – Central Park, NYC


F3
F2
S1
S3
S1
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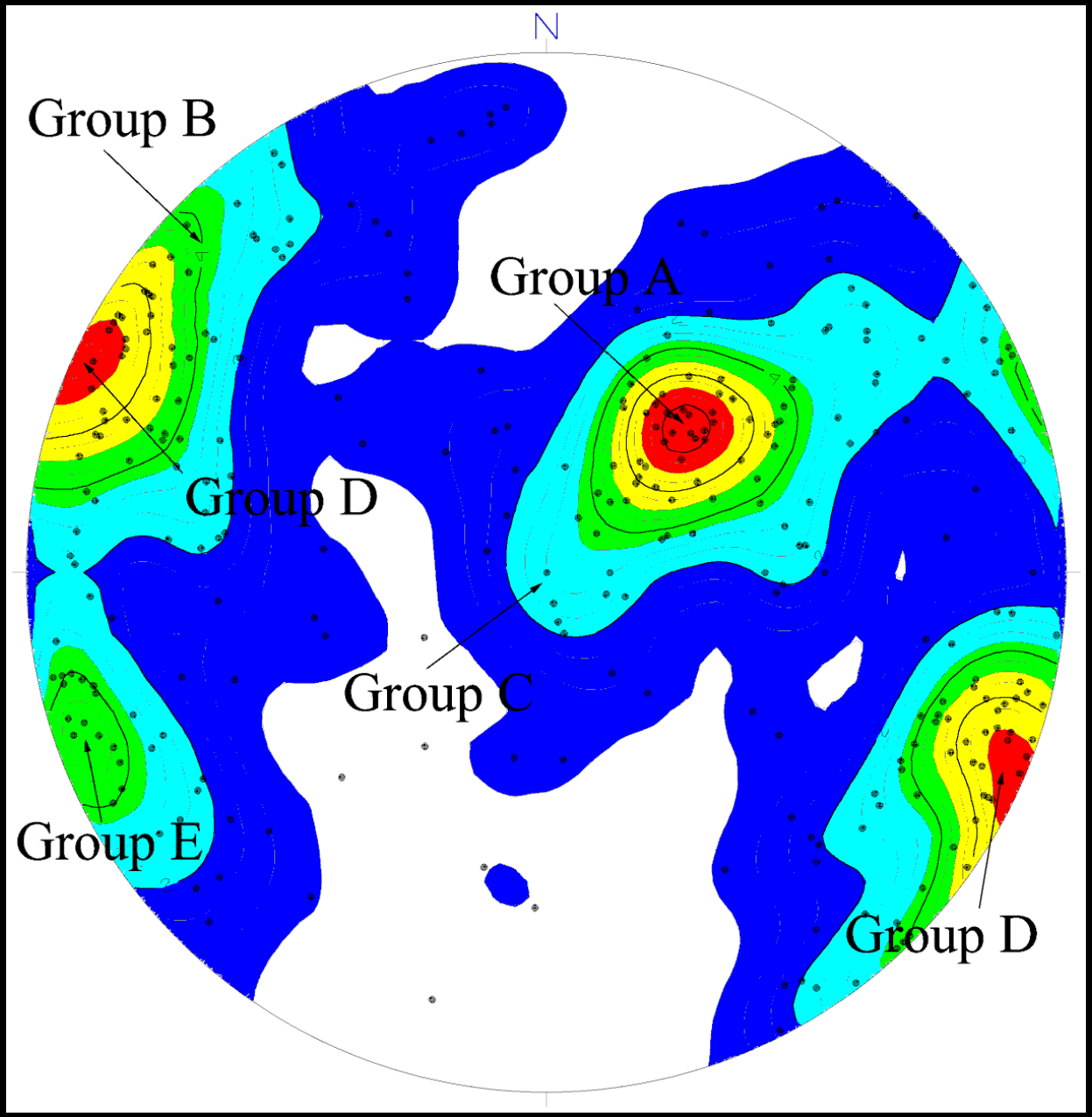
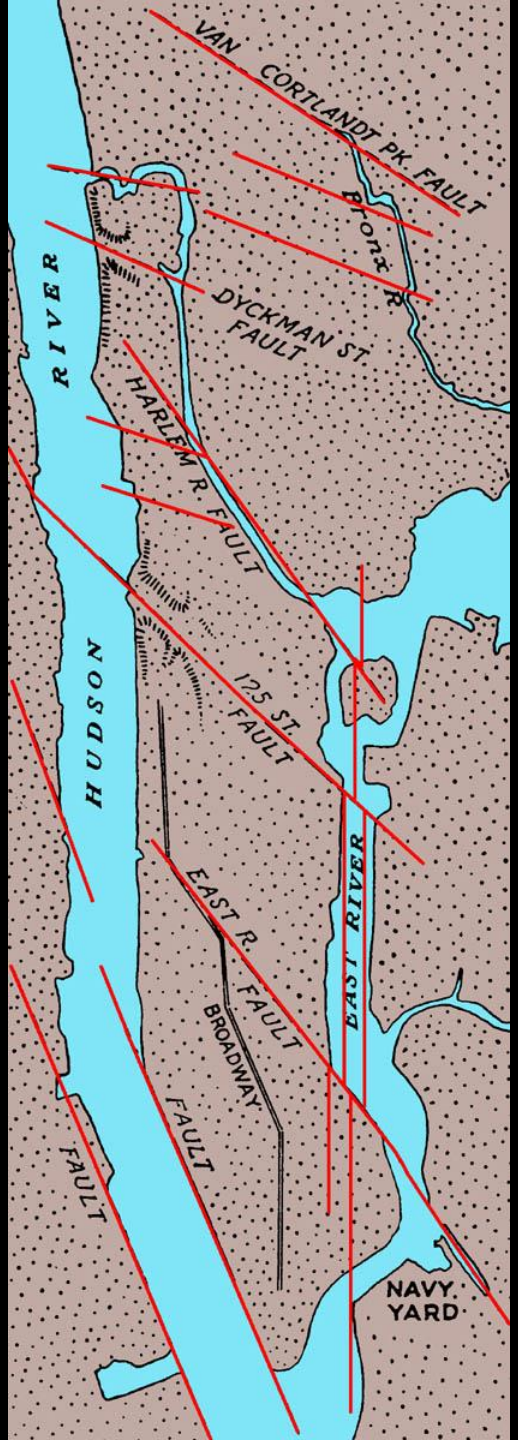
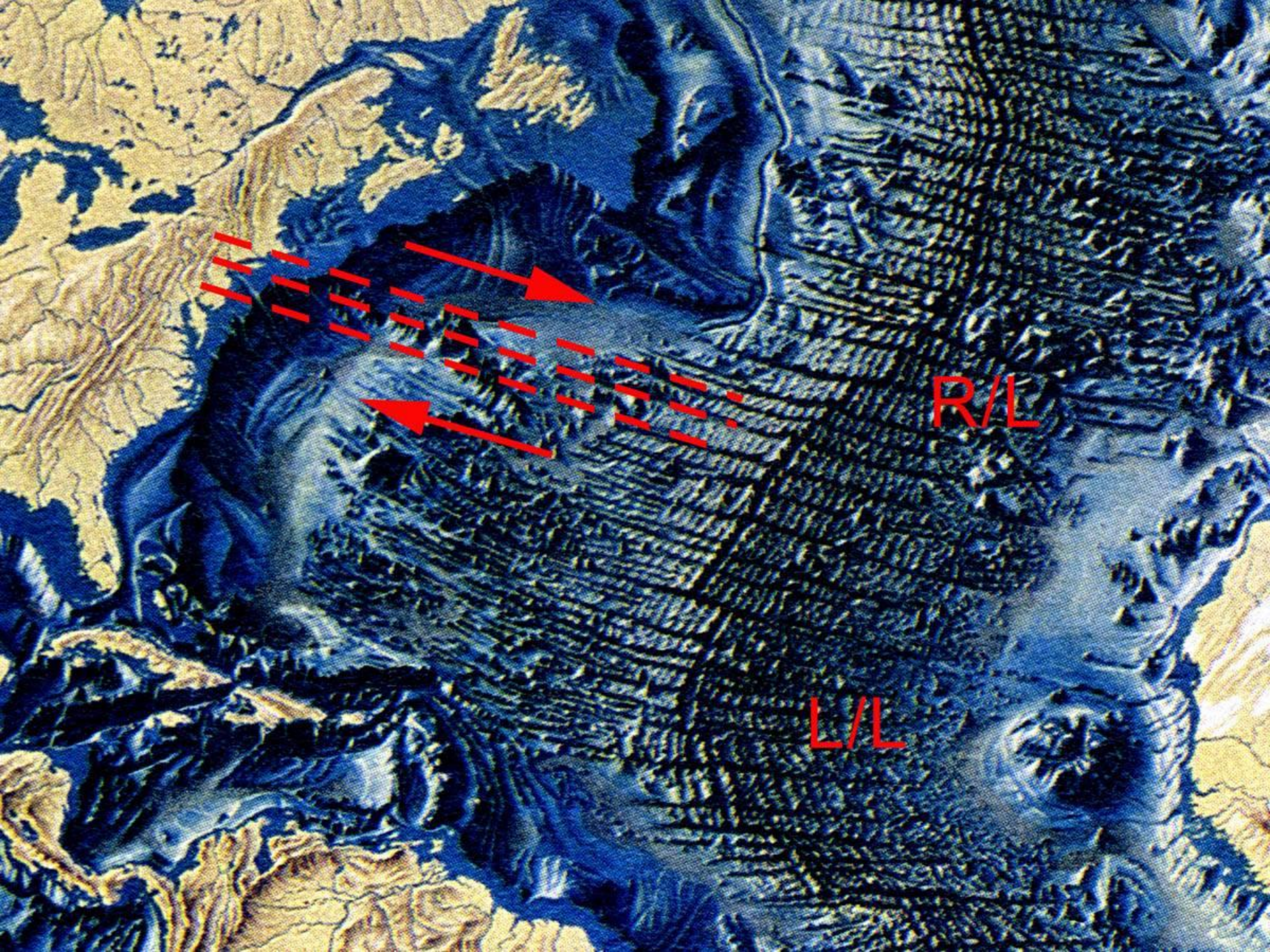
S3

NYC Faults and Joints




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


R/L
L/L

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