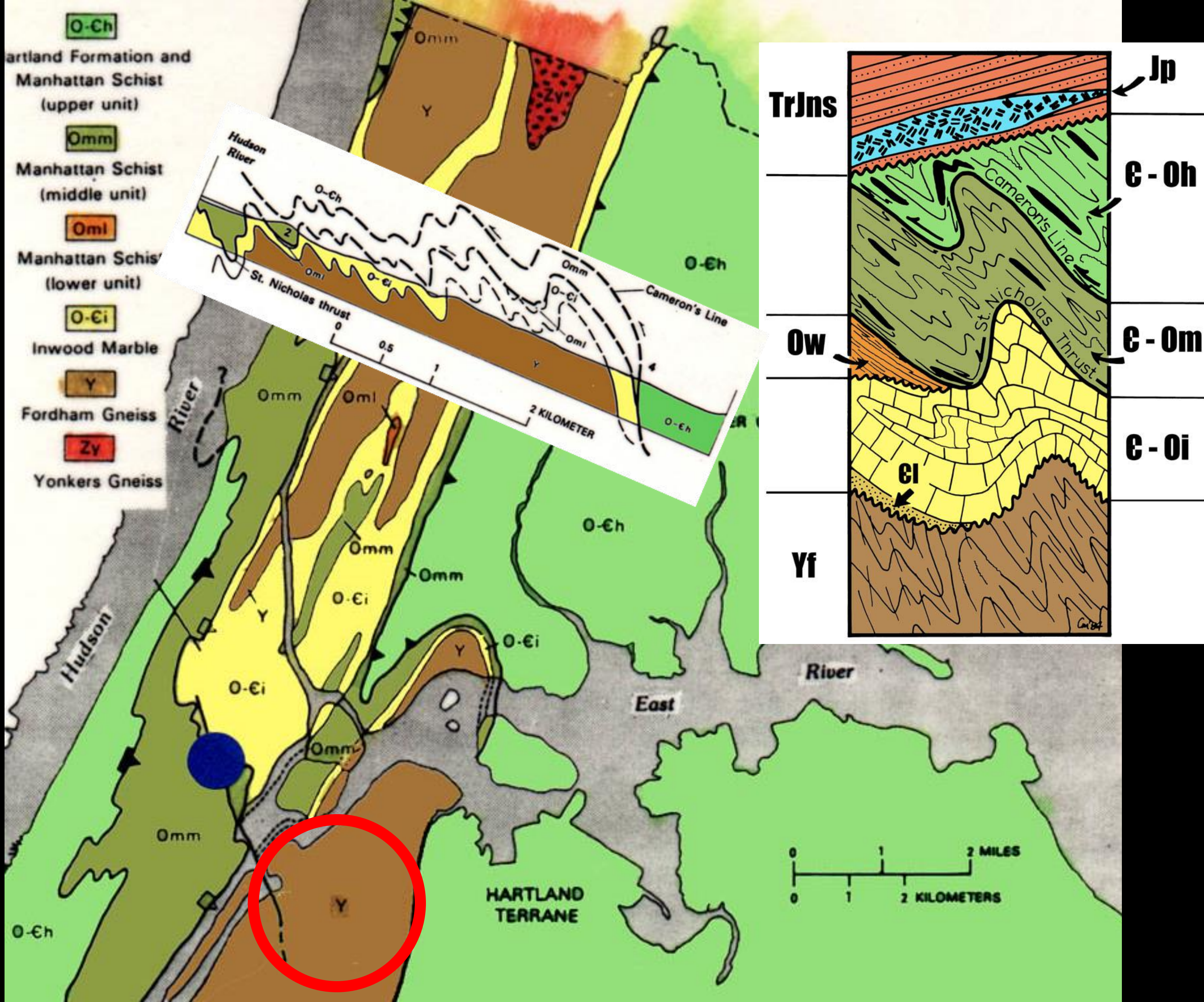
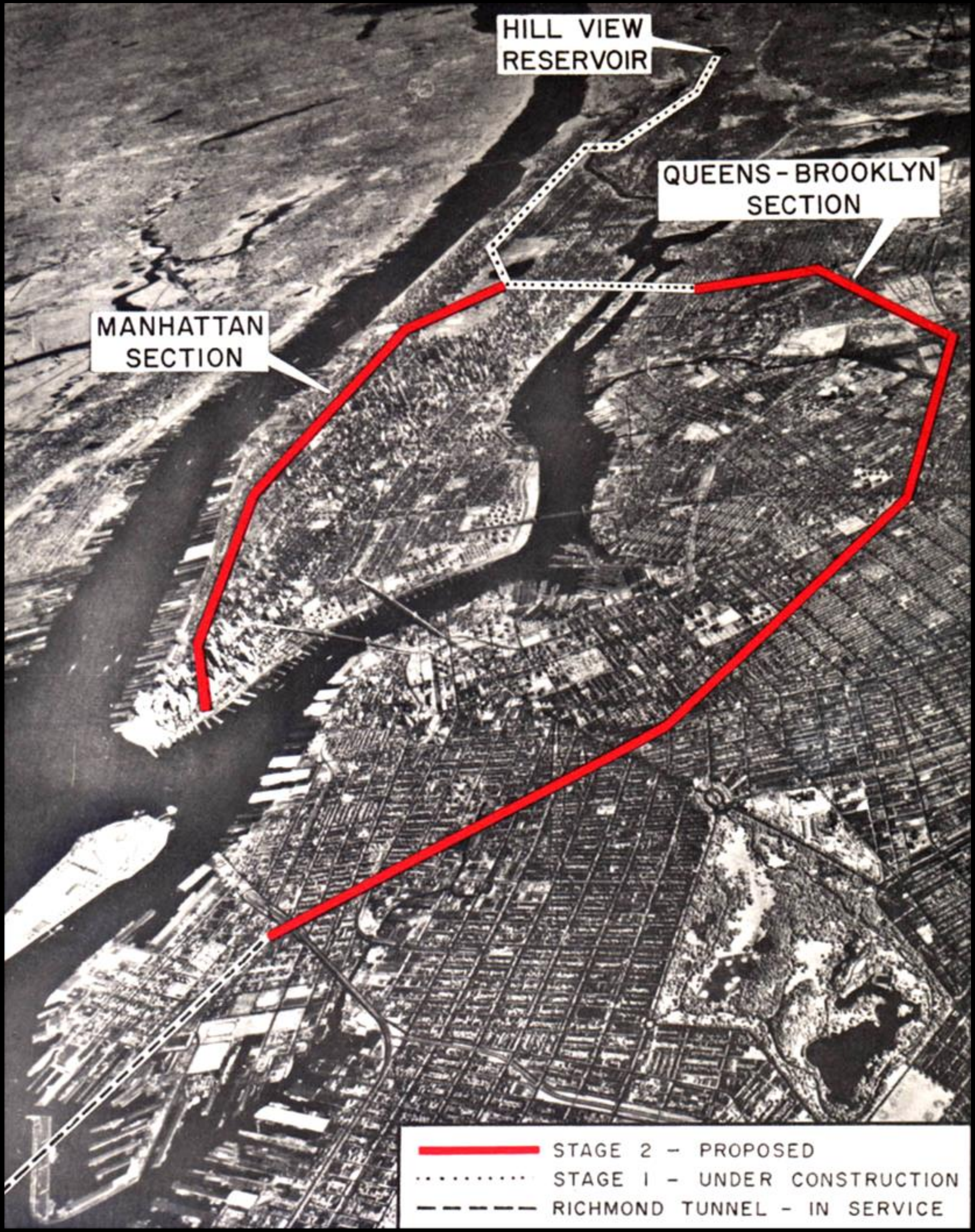
Fault Zone Minerals of the Queens Water Tunnel, NYC, NY

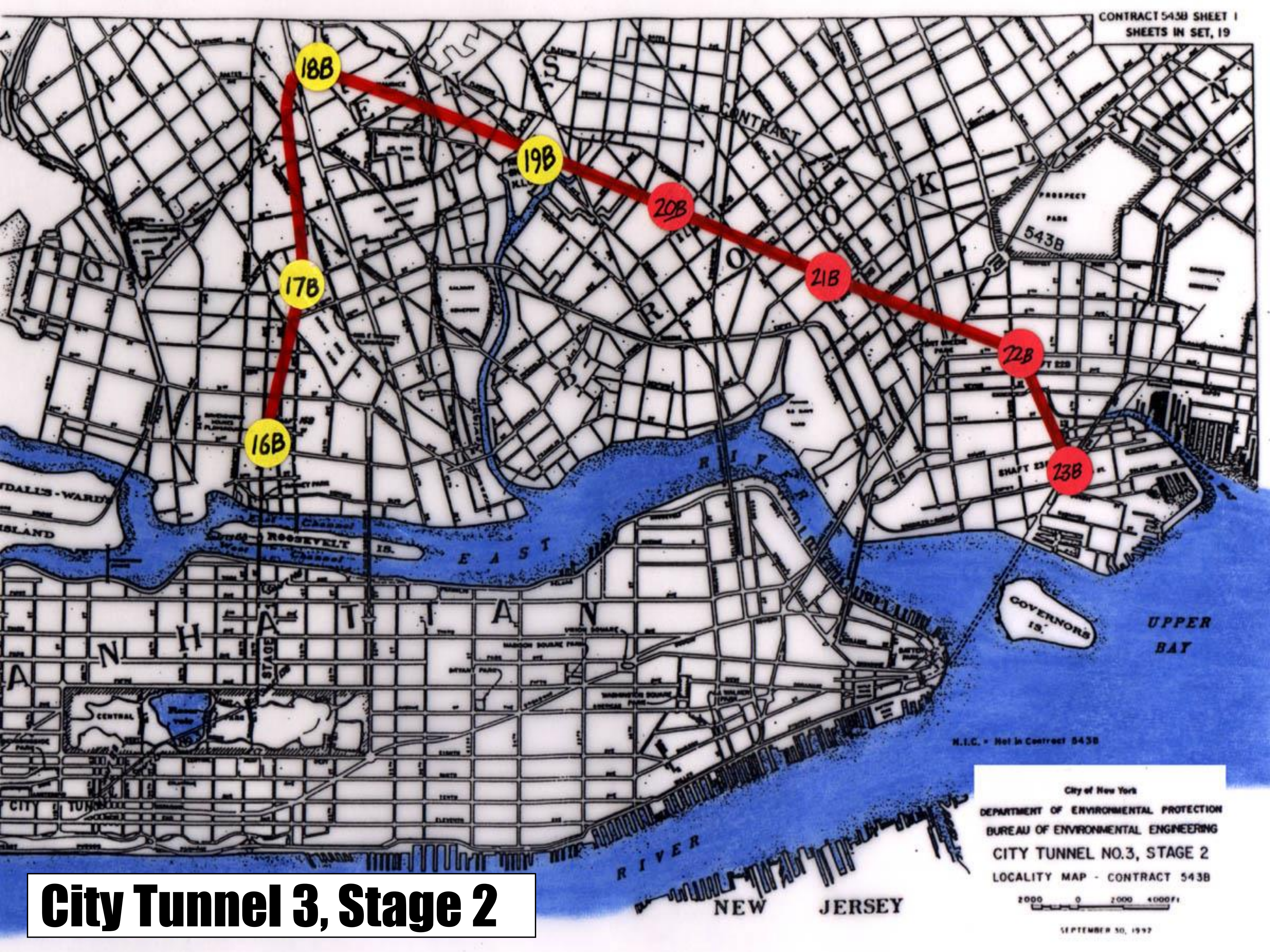
Charles Merguerian

Orange County Mineral Society


O-Ꞓh
artland Formation and Manhattan Schist (upper unit)
Omm
Manhattan Schist (middle unit)
Oml
Manhattan Schis (lower unit)
O-Ꞓi
Inwood Marble
Y
Fordham Gneiss
Zy
Yonkers Gneiss
Hudson River
O-Ꞓh
Omm
Oml
2
O-Ꞓi
Y
4
St. Nicholas thrust
Cameron's Line
0
0.5
1
2 KILOMETER
TrJns
Jp
Ꞓ - Oh
Cameron's Line
St. Nicholas Thrust
Ꞓ - Om
Ow
Ꞓ - Oi
Ꞓl
Yf
Hudson
River
East
River
HARTLAND TERRANE
0 1 2 MILES
0 1 2 KILOMETERS

City Tunnel #3 Stages 1 and 2

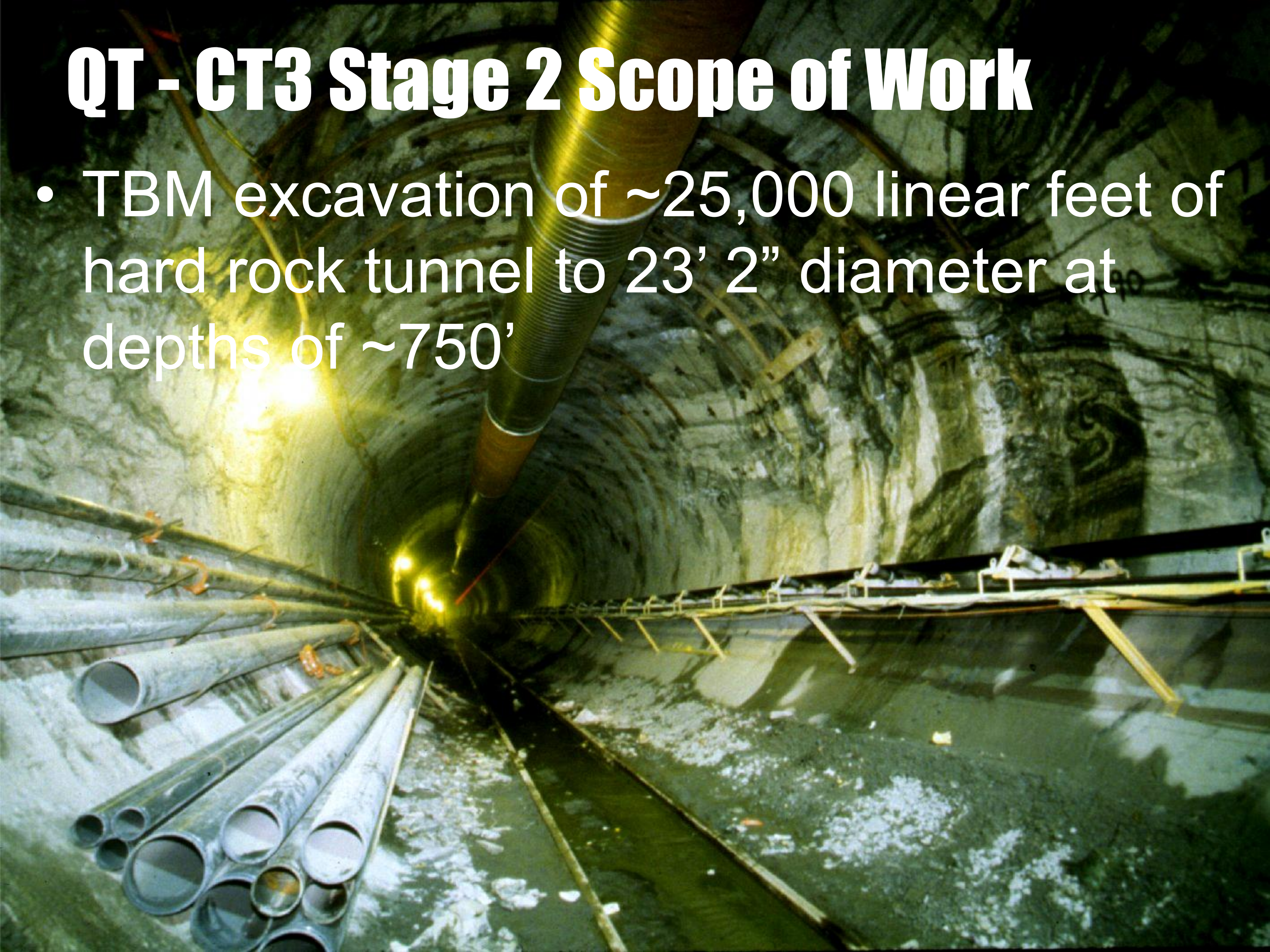




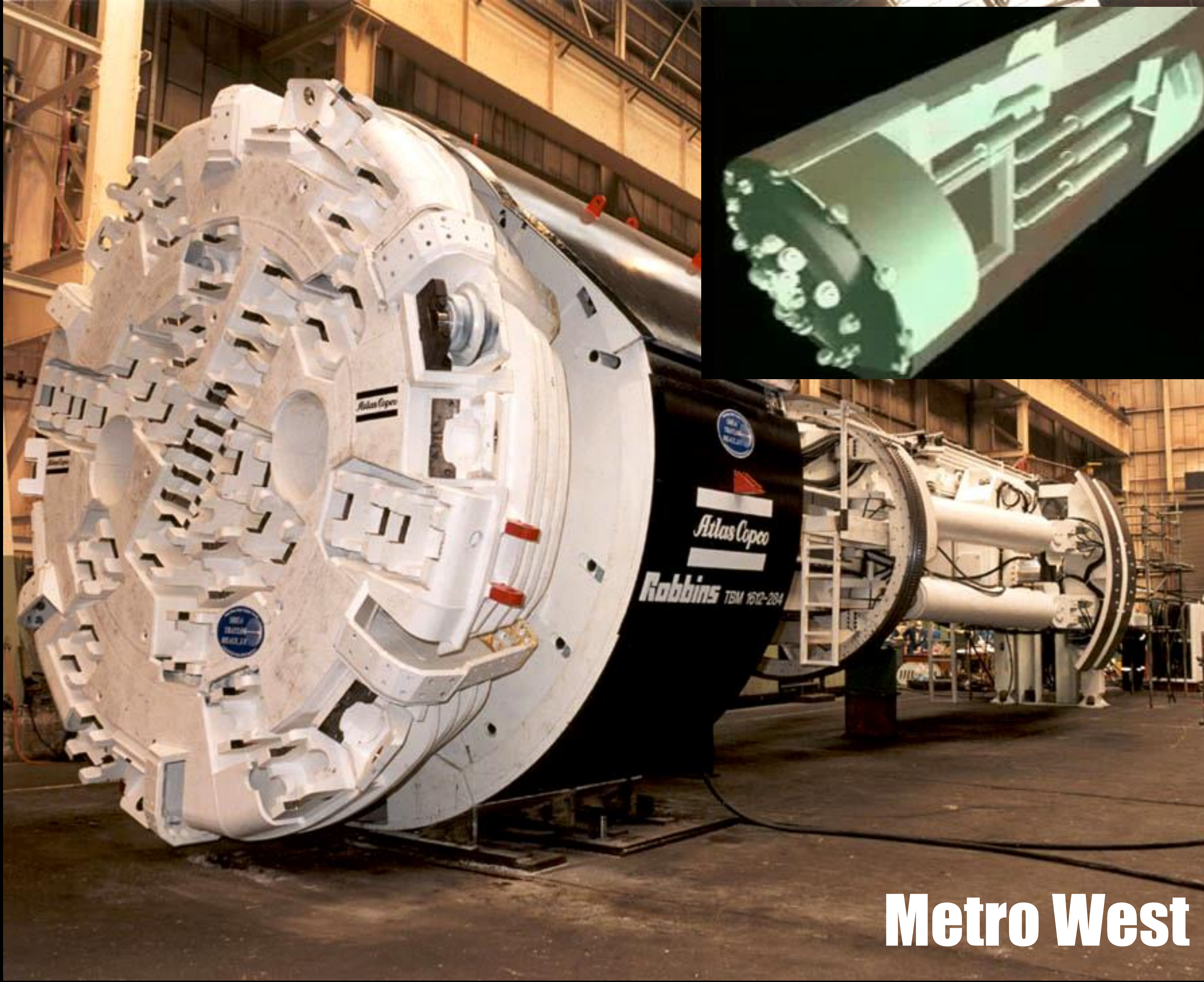
City Tunnel 3, Stage 2

QT - CT3 Stage 2 Scope of Work

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

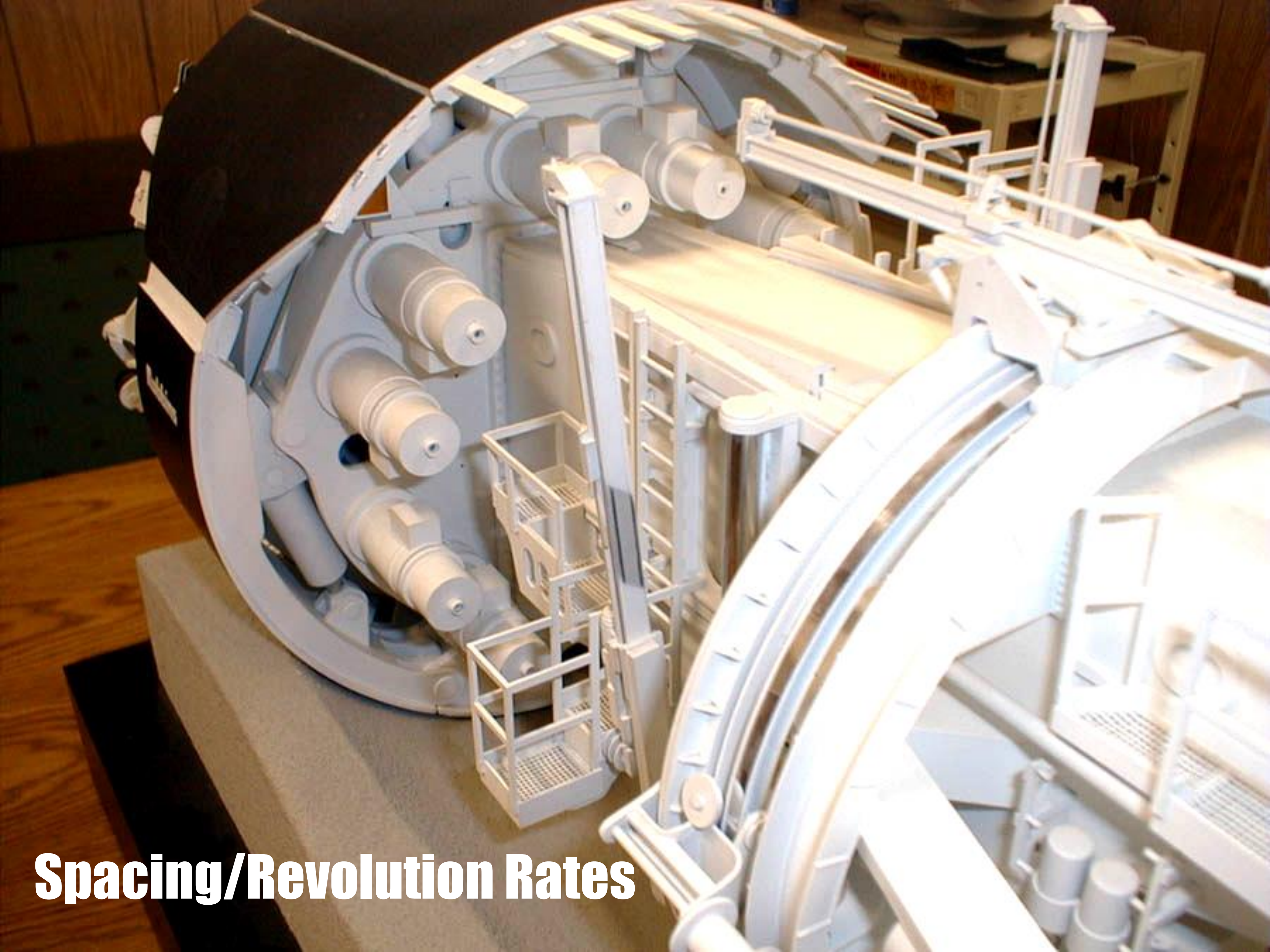


Robbins 235-282 HP TBM



Metro West

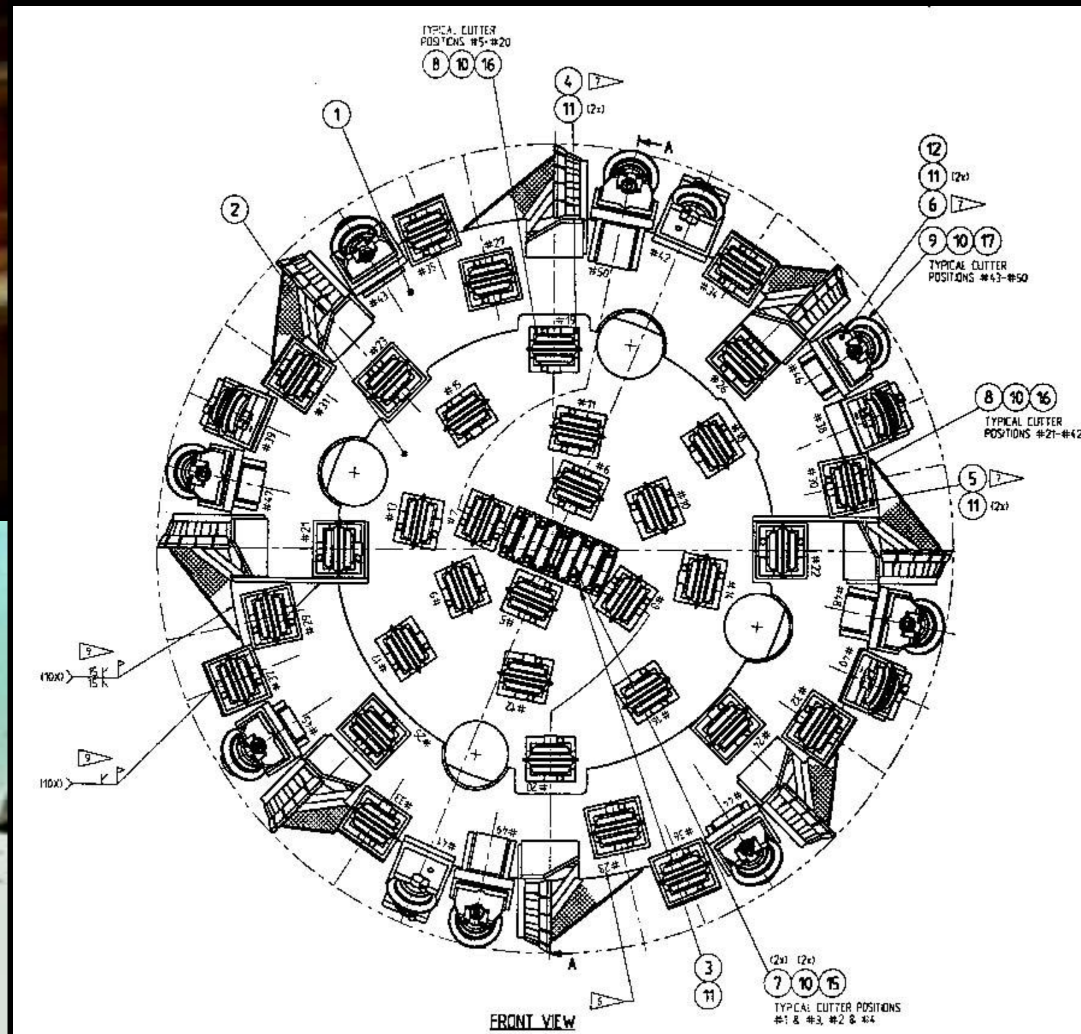
Belly of the Beast


Spacing/Revolution Rates

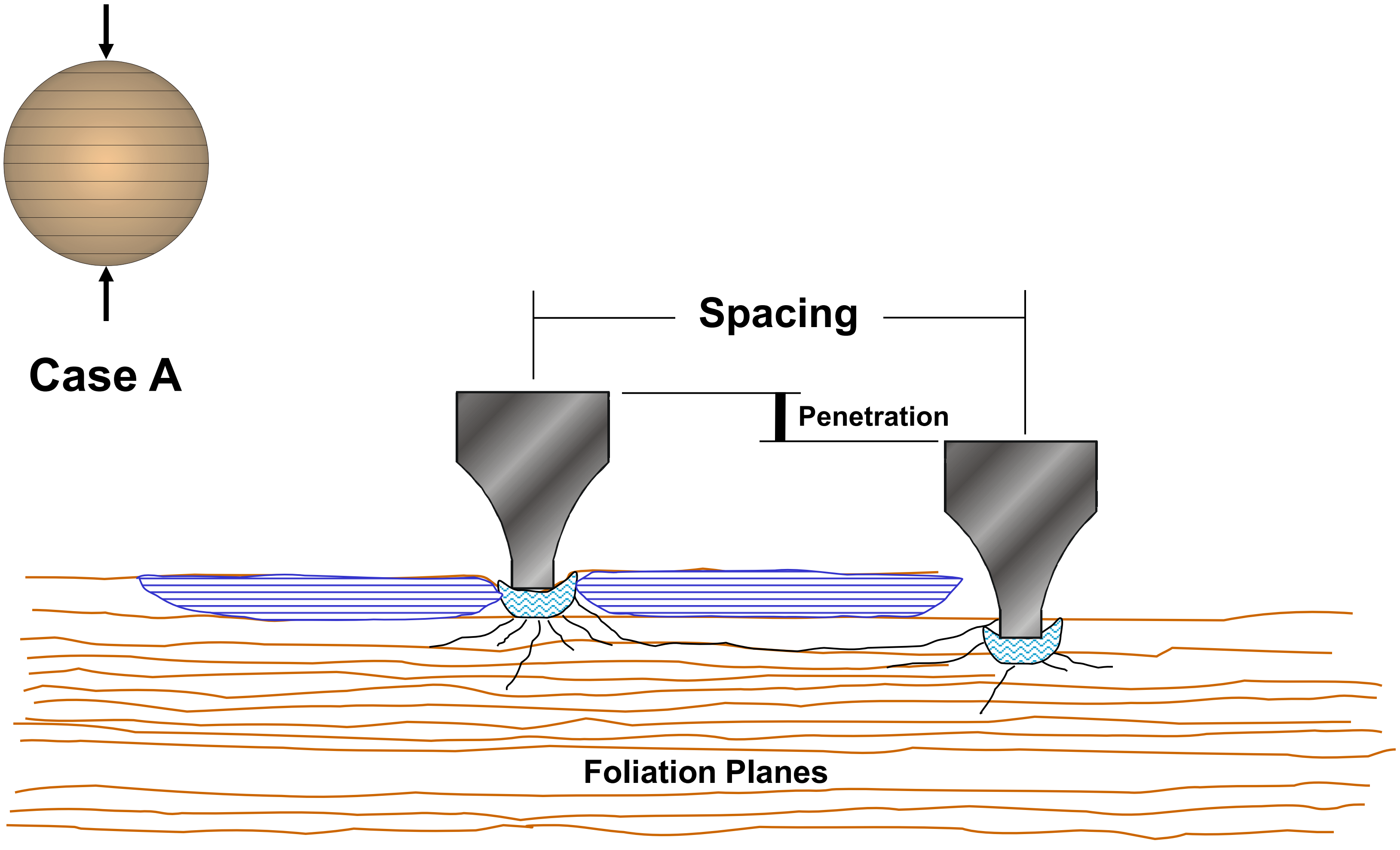
Queens Tunnel TBM
422 HP Electric
Water Cooled,
Three Phase Motors

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

TBM Chip Production

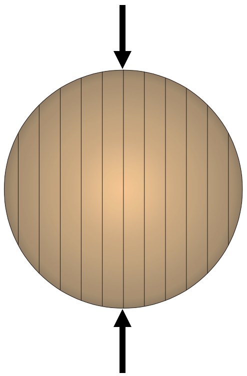


Foliation Planes Perpendicular

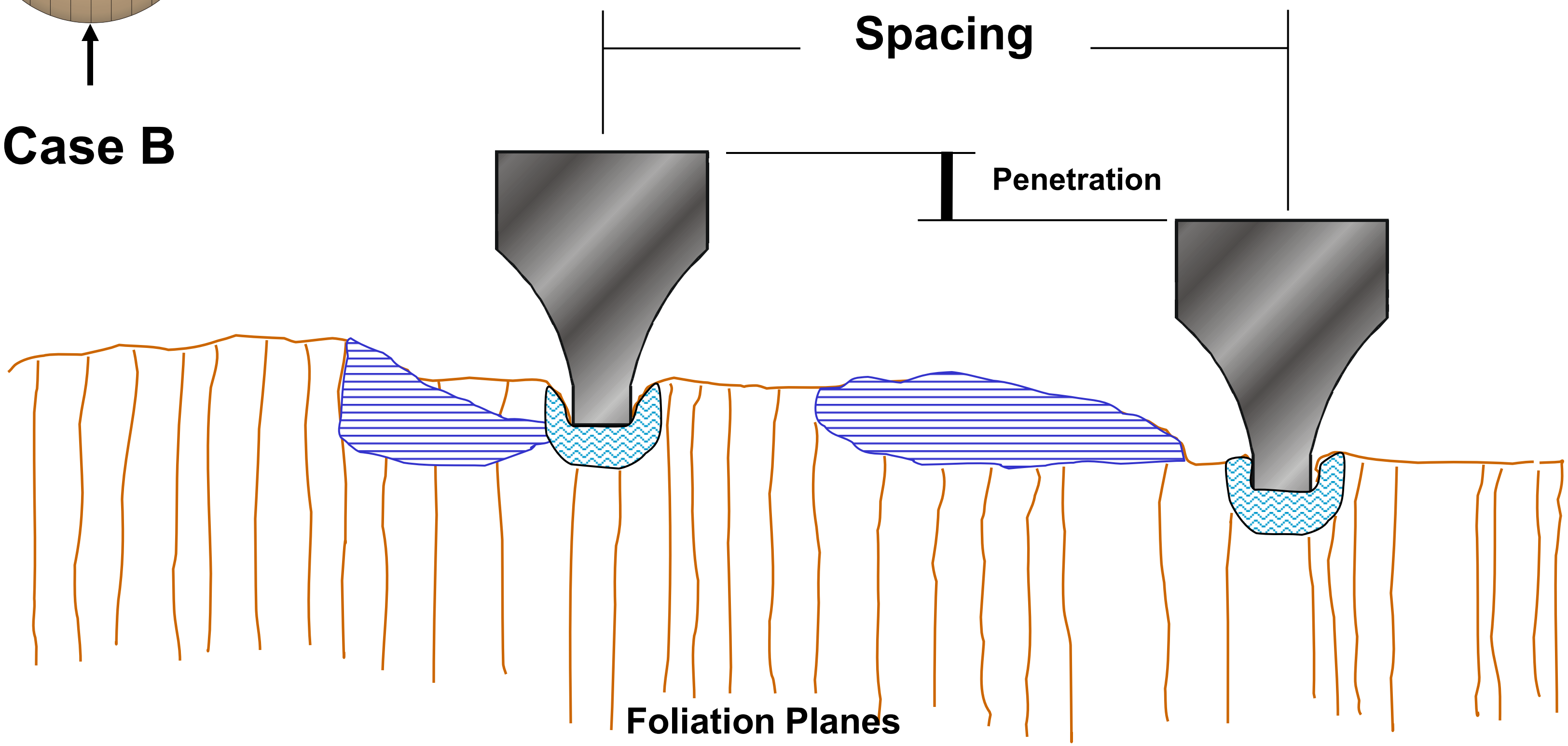


Chipping mechanism when TBM advancing perpendicular to foliation (Case A)

Foliation Planes Parallel



Case B



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

Superb Kerf Pattern in Hard Rock

New Dukelabs Research on TBM Cutter Head Torque Dynamics

DUKE

Six-Month Training Period Beset by Aimless, Lackluster Performance

Excessive Fines

Blocky Ground

Damage to Horizontal Conveyor

Worn and Damaged Cutters

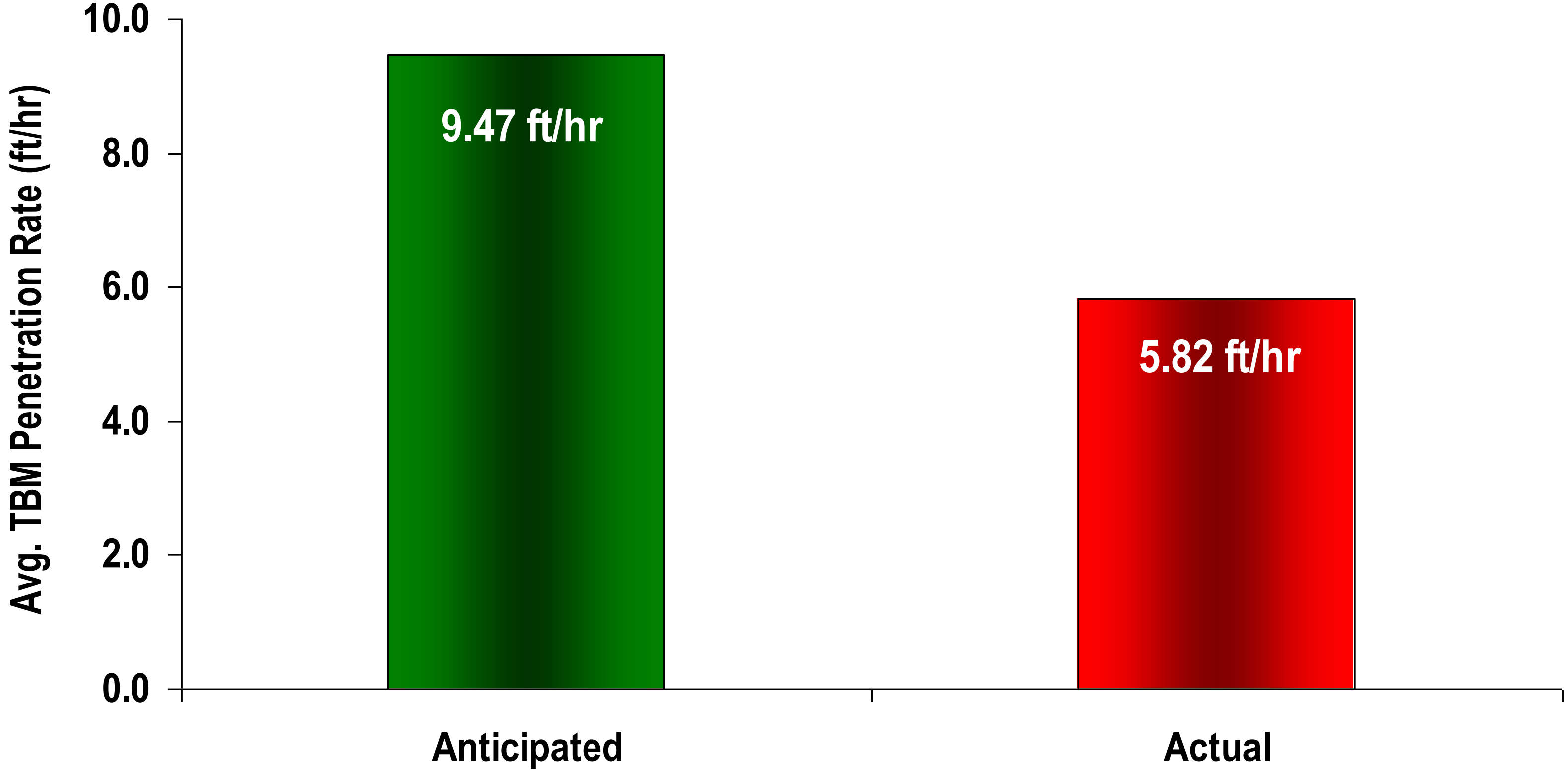

Collapsing Crown and Sidewalls
Short Stand-up Times
Station 153+30

Additional Rock Support

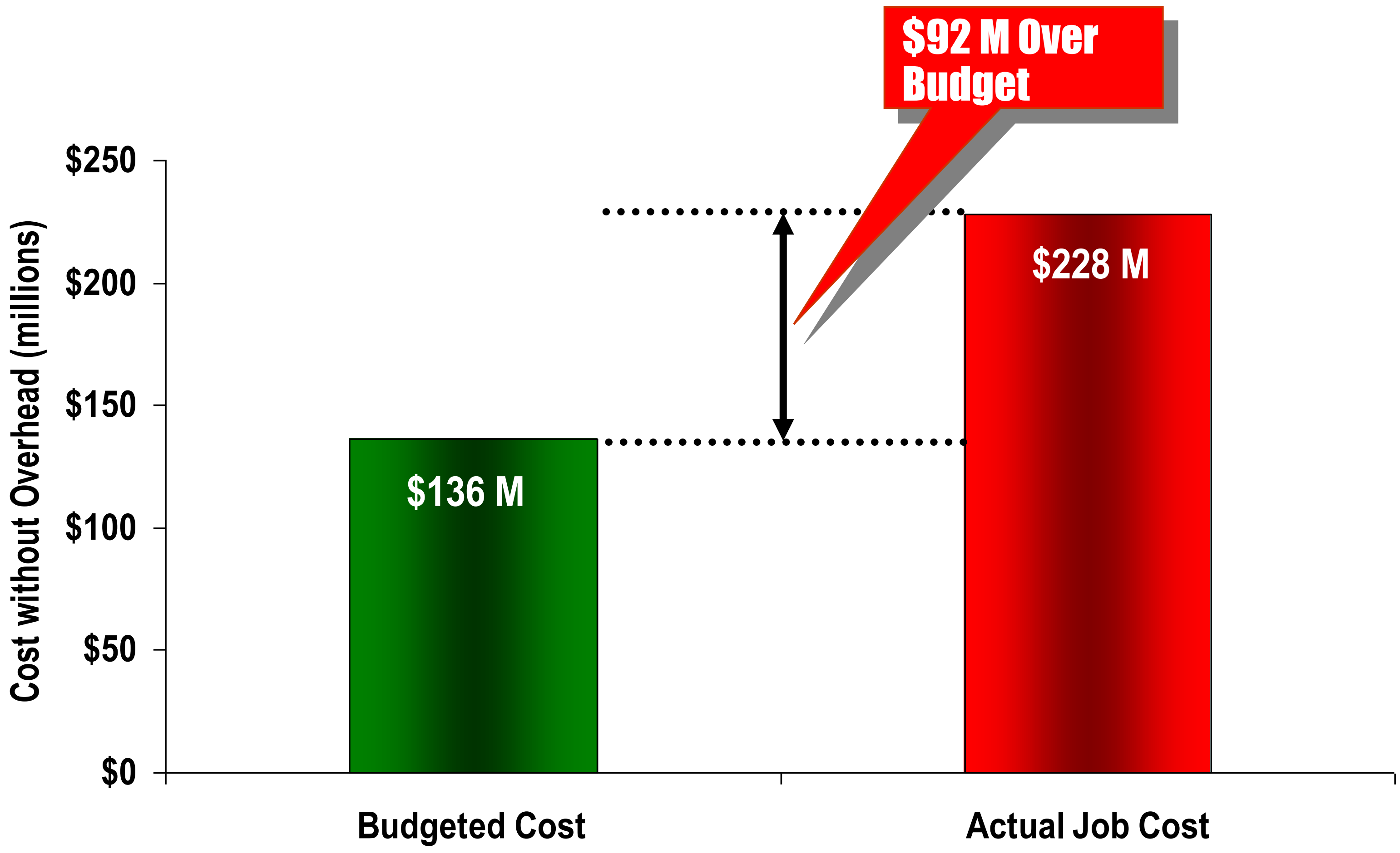

High Water Inflows
Station 140+60

Unforseen Tunneling Problems

Anticipated vs. Actual Penetration Rate



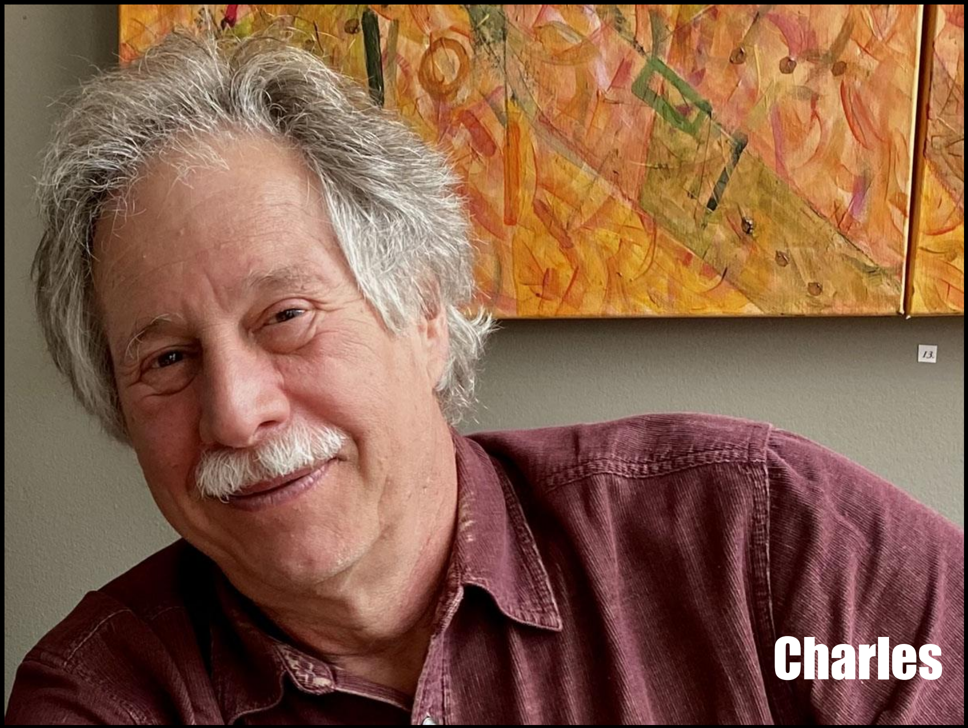
Anticipated vs. Actual Cost



Duke Geological Lab

Full Service Geotechnical and Tunneling Analysis

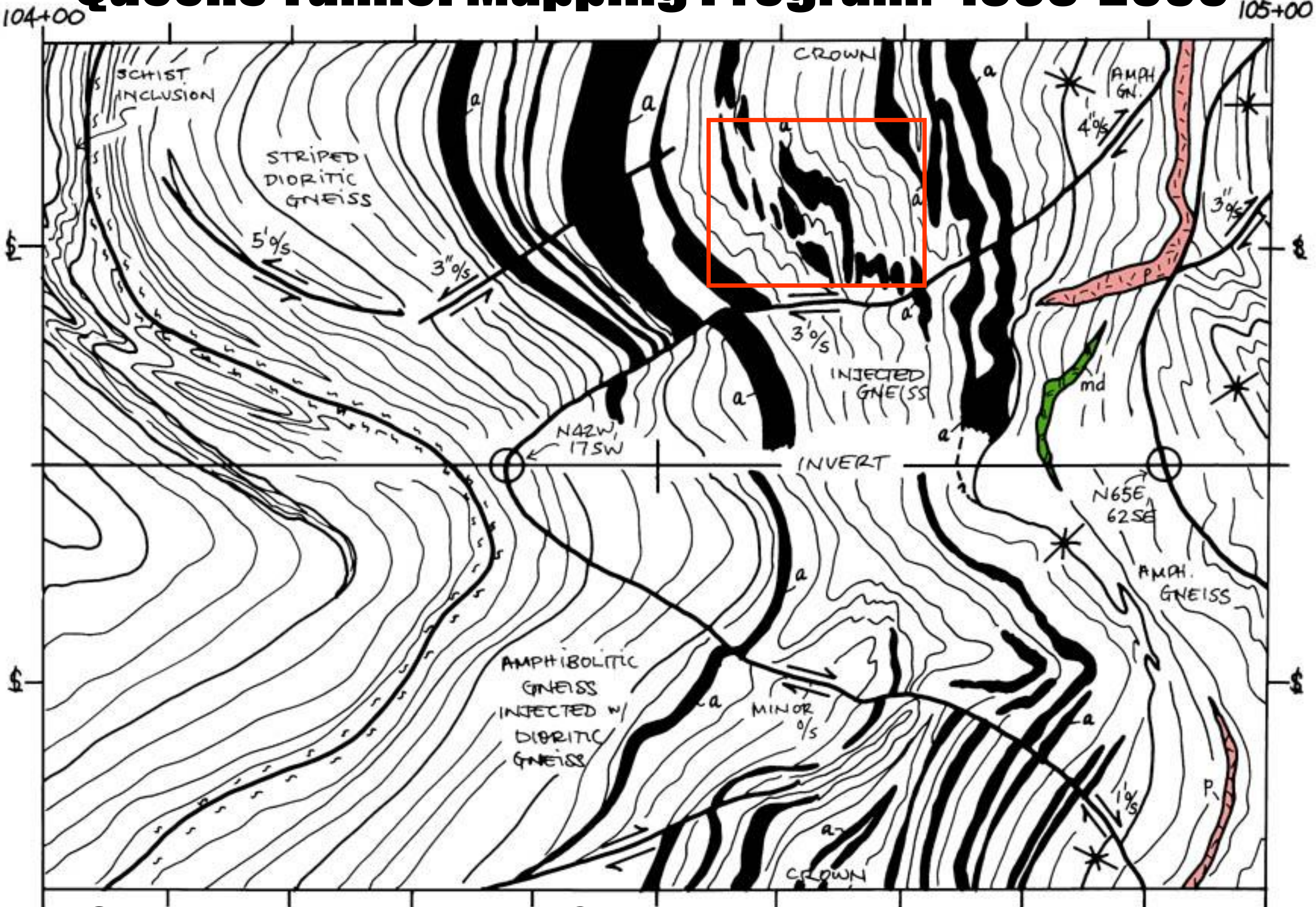
www.dukelabs.com



Office Help

Dukelabs' CT3 Tunnel Field Office

Queens Tunnel Mapping Program: 1998-2000

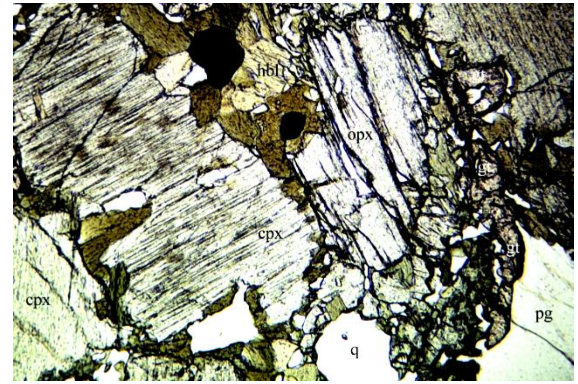


- Scale of Mapping: 1 inch = 10 feet

Mafic Gneiss Xenoliths in Tonalitic Gneiss

Petrographic Analysis (92 Samples)

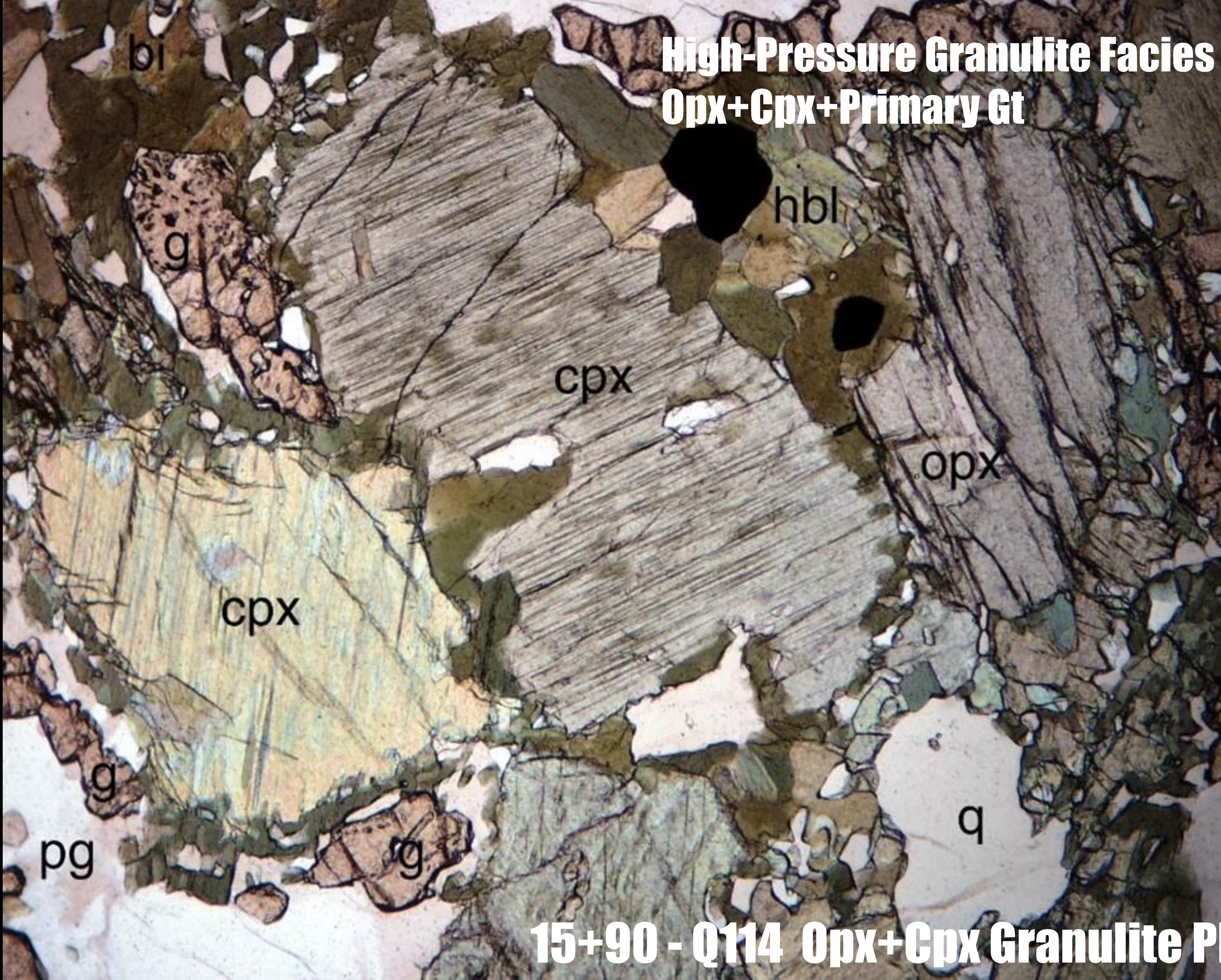
- Texture
- Mineralogy
- Internal Structure
- Metamorphism

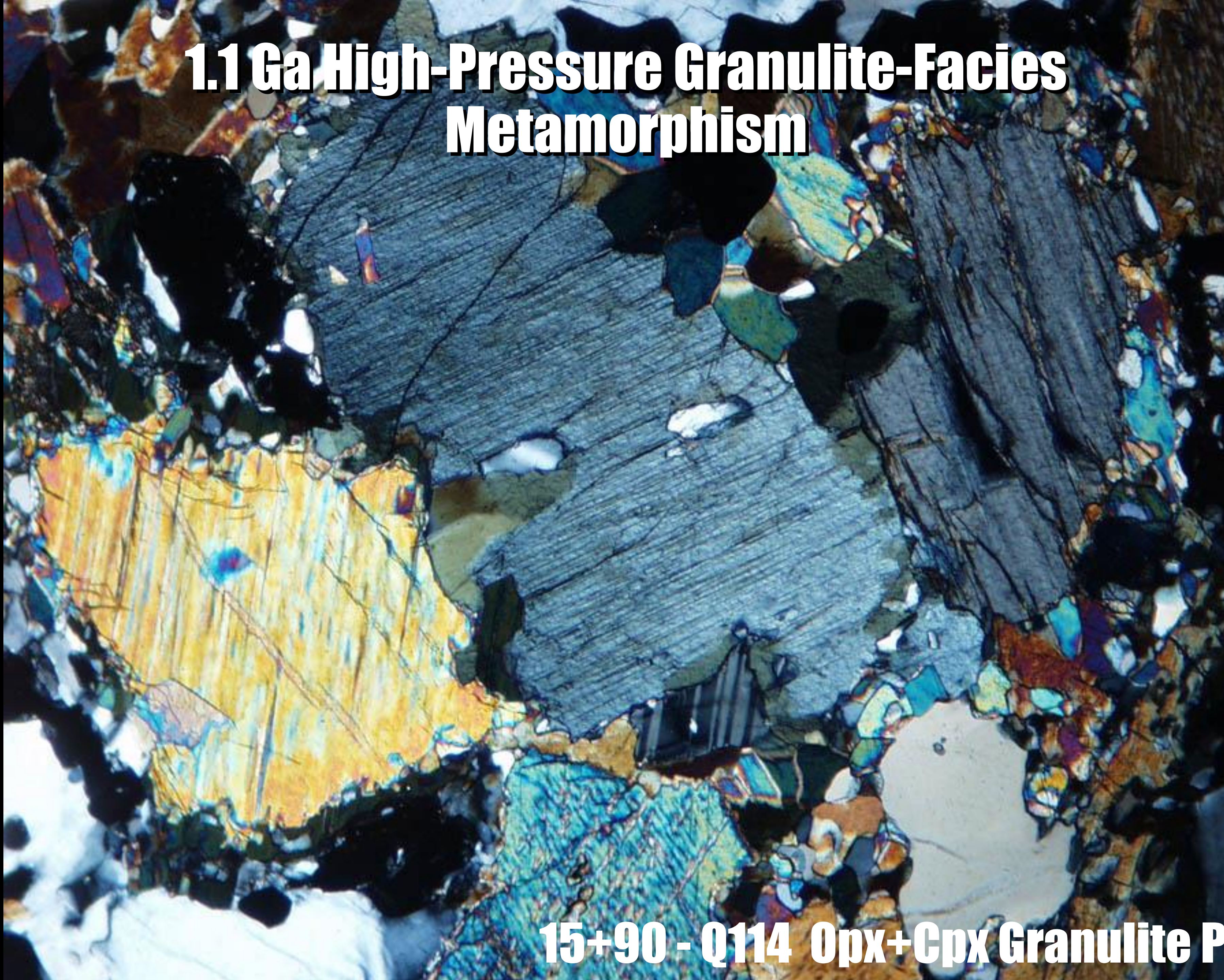


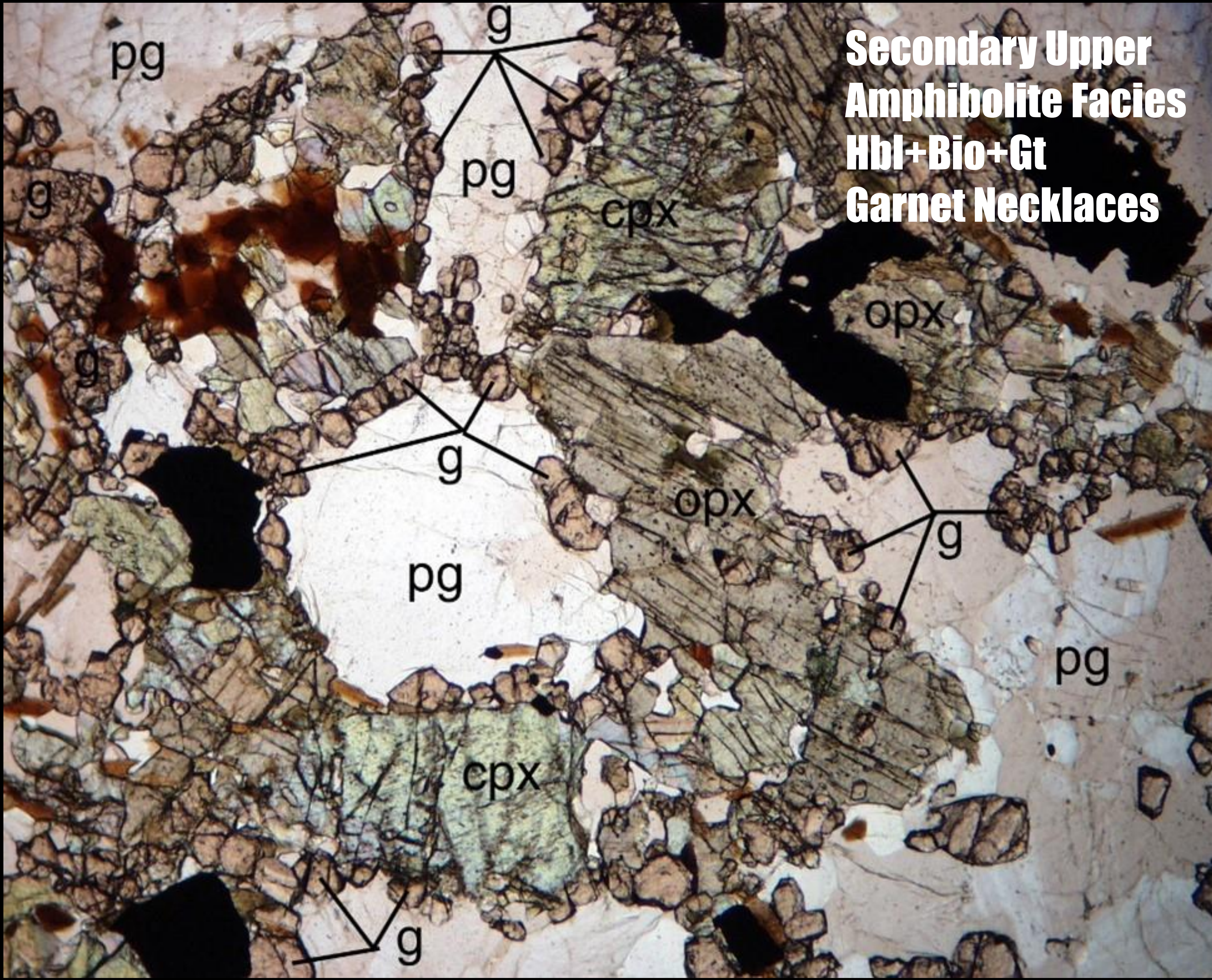
Thin section photomicrograph

Number	Location	Color	Density	Qtz	Kspar	Plagio/ **An**		Opx	Cpx	Hbld	Bio	Garnet	Opaque
Q109	004+80					M	35	M		M			
Q109	004+80	25	2.72	M		M	35			m	m	m	
Q110	006+42	10	2.66	M	tr+AP	M					m gnbk	tr	tr
Q111	009+25	25	2.79	M		M		m		tr	m	M py encl Q	tr
Q112	011+60	35	3.05	m		M	51		M exsol	m gnkh		M py	
Q114	015+90	45	3.03	m		M	53-39norm	M some Ex	M Ex sol	mgnkh		*m necklace*	tr
Q115	017+70	10	2.71	M	tr AP	M				m **bugn** sieve	m rbn	m porange	tr
Q117a	022+25	15	2.72	M	tr	m	27			m **dgygn**	m rbn	m porange sieve	tr
Q119	026+65	45	2.93	m 10-15	m	M	27			M khgn	tr rdbn	m	m
Q123	032+15	60	3.11	m		m	44	m		m gnHB	m rbn	M sieve	tr
Q127	042+67	60	3.09	m		M		tr	M	M gnkh	m red	M	m
Q129	049+95	25	2.71	M	M	M	low				M kh	M	
Q130	051+83	15	2.76	40	tr	M					m obn	M.vermic/sieve rims	tr
Q133	059+95	55	3.26	m		M	38-29		M	Mkhtan	m	M	m
Q134	062+45	60	3.17	m		M	28-40Rev Zoning		M	M **bugn** some vermic wi Qtz		M fine sieve/vermic vermi	10
068+10	068+10	5:50		M		M	55	m	M	m gn		*m vermic with plag*	m
070+60	070+60	45		M		M	45+	?	core?	m. Gn	m	M	m
Q141	071+80	30	2.9	5		M sieve		M sieve		tr gn	M okh	M sieve	2

Typical Petrographic Data Sheet


High-Pressure Granulite Facies
Opx+Cpx+Primary Gt
bi
g
hbl
cpx
opx
cpx
g
pg
g
q
15+90 - Q114 Opx+Cpx Granulite PL

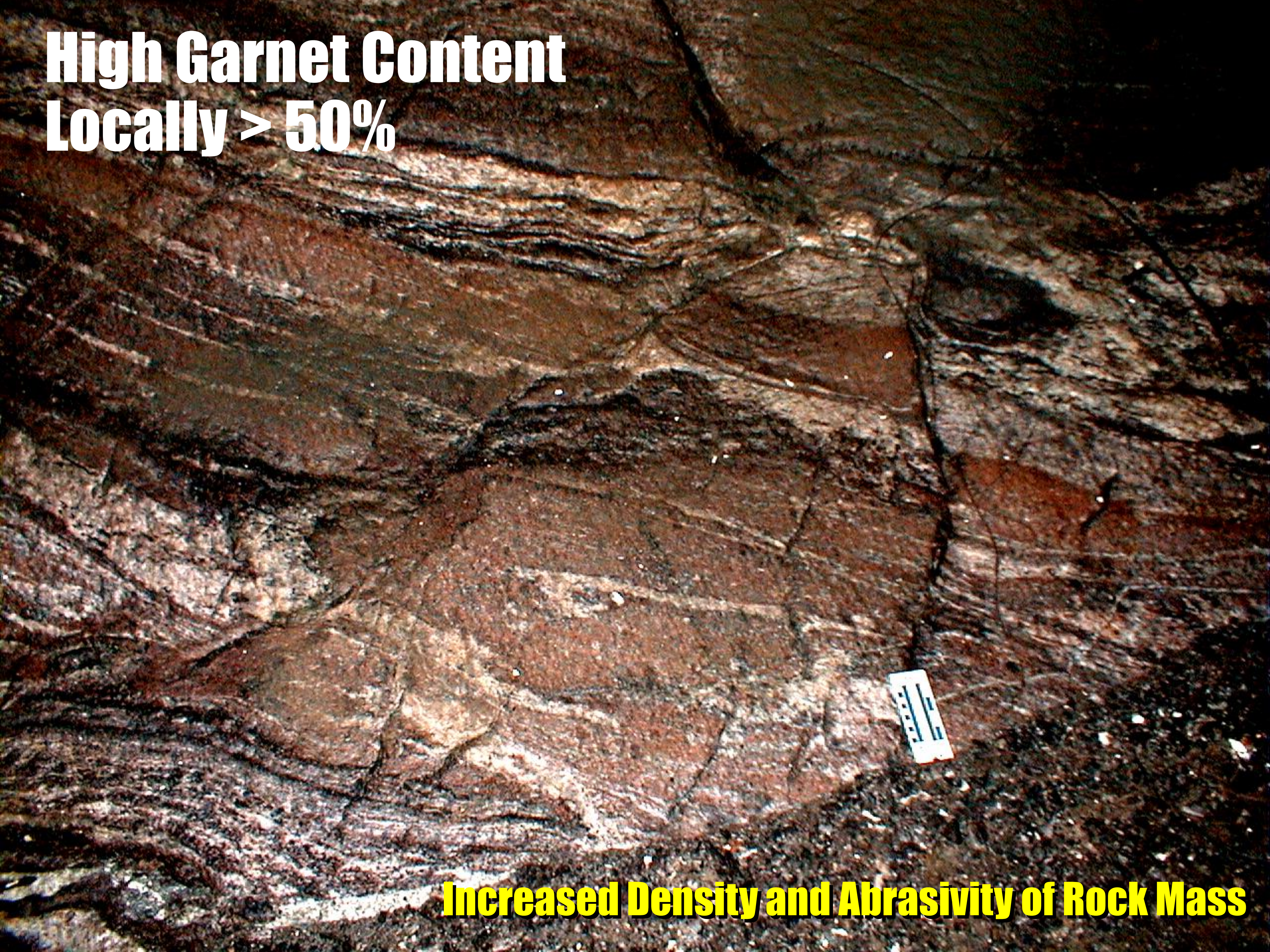

1.1 Ga High-Pressure Granulite-Facies Metamorphism
15+90 - Q114 Opx+Cpx Granulite PL

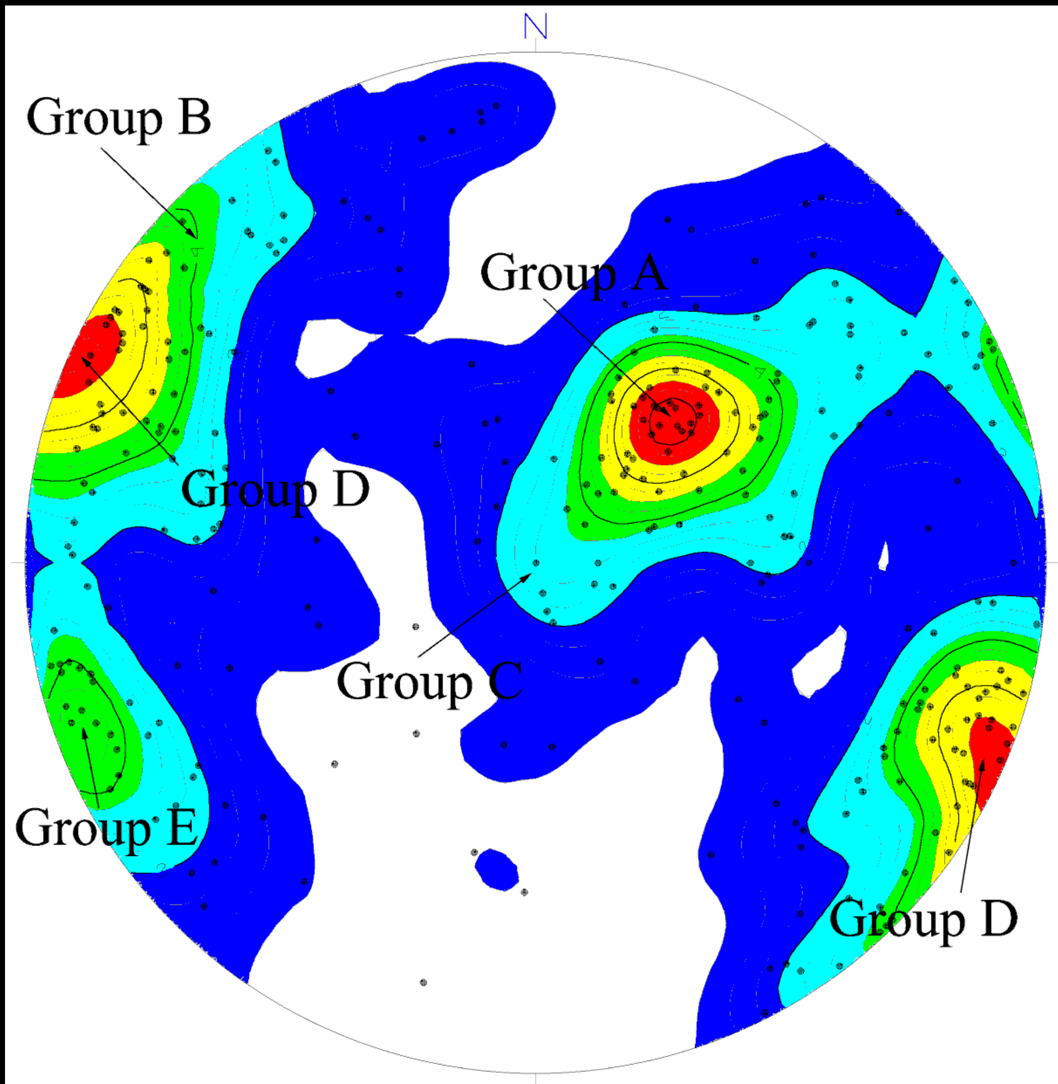

Secondary Upper
Amphibolite Facies
Hbl+Bio+Gt
Garnet Necklaces
g
pg
pg
g
g
cpx
opx
g
opx
g
pg
pg
cpx
g

High-Pressure Granulite Facies Metamorphism Produced Broad Zones of Anomalous Garnet, Higher Density, Lower Production, Excessive Fines

Anomalous Garnet Concentrations, Layers, Lenses, and Laminae					
Tunnel #1					
Tunnel Station		**Length**	**Garnet**	**Field Description**	**Samples (Q-)**
Start	**End**	**(Feet)**	**Zone No.**		
27+45	27+80	35	**1**	Garnet layer a few feet thick in migmatitic mafic gneiss, LW only	120
36+18	37+70	152	**2**	Garnet layers and laminae in injected mafic gneiss	
45+00	46+48	148	**3**	Garnetiferous mafic schist, gneiss and amphibolite	128
53+87	54+80	93	**4**	Two garnetiferous layers a few feet thick in mafic gneiss	131A, B
68+03	68+50	47	**5**	Garnetiferous zone in mafic gneiss, RW only	137, 138
68+78	69+84	106	**6**	Garnetiferous mafic schist, gneiss and amphibolite	139
70+27	70+78	51	**7**	10' thick garnet layer in mafic gneiss, schist, and amphibolite	140
71+01	71+18	17	**8**	Thin garnet lenses in mafic orthogneiss	
77+75	79+10	135	**9**	Broad zone of garnetiferous layers, lenses, and laminae	08, 144, 145
95+82	96+22	40	**10**	Garnetiferous leucosome in mafic gneiss, LW only	
96+77	99+25	248	**11**	Broad zone of garnetiferous mafic gneiss, schist, and amphibolite	153
100+13	102+46	233	**12**	Broad zone of garnetiferous mafic gneiss, schist, and amphibolite	155
103+43	103+62	19	**13**	Laminated garnet zone in mafic gneiss, schist, and amphibolite	
104+95	105+43	48	**14**	Laminated garnet zone in mafic gneiss, schist, and amphibolite	158
106+50	108+70	220	**15**	Broad zone of garnetiferous mafic gneiss, schist, and amphibolite	11
109+30	109+35	5	**16**	Blocks of garnetiferous gneissic rock in shear zone	
111+35	111+45	10	**17**	Laminated garnetiferous zone in mafic gneiss, LW only	
123+55	123+70	15	**18**	Laminated garnetiferous zone in mafic gneiss	101
151+80	152+20	40	**19**	Garnetiferous biotite schist and gneiss in contact with dacite	89A, B; 90A, B
171+15	173+78	263	**20**	Broad zone of highly garnetiferous migmatitic mafic rocks	80A, B
175+53	176+45	92	**21**	Broad zone of highly garnetiferous migmatitic mafic rocks	78
180+75	181+48	73	**22**	Garnet lenses and laminae in mafic schist, gneiss, and amphibolite	76
183+10	183+57	47	**23**	Garnet layer and laminae in mafic schist, gneiss, and amphibolite	
183+98	184+57	59	**24**	Garnet layer in mafic schist, gneiss, and amphibolite	75A, B
198+26	198+35	9	**25**	Sheared and rotated block containing garnet layers, RW only	
199+94	201+00	106	**26**	Garnetiferous layers in sheared mafic gneiss	68
201+80	202+05	25	**27**	Garnetiferous layer in mafic gneiss, RW only	14
207+18	207+95	77	**28**	Zone of garnet with layers, lenses, and laminae in mafic gneiss	20, 21
221+12	221+95	83	**29**	Thin garnet layers in mafic gneiss, schist, and amphibolite	33A, B
225+07	225+38	31	**30**	Garnetiferous granitoid at mafic gneiss/orthogneiss contact	
229+72	229+97	25	**31**	Garnetiferous zone in mafic gneiss and schist	
231+25	232+36	111	**32**	Laminated garnetiferous zone in mafic gneiss	38A, B
TOTAL ⟹		**2663**	**Linear Feet of Tunnel #1 with Highly Garnetiferous Rocks = (2663/25035) = 10.64%**		

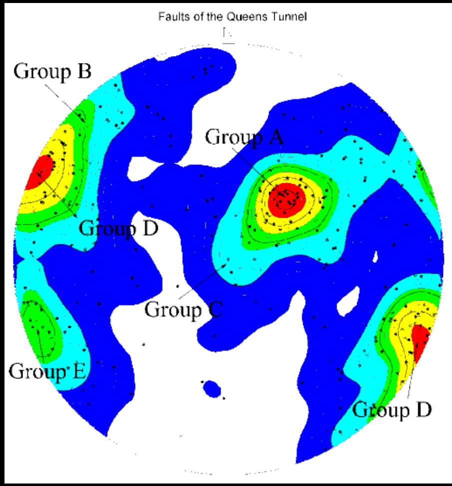

Folded Garnet Segregations in Mafic Gneiss
Sta 36+60


High Garnet Content
Locally > 50%
Increased Density and Abrasivity of Rock Mass



Queens Tunnel Faults

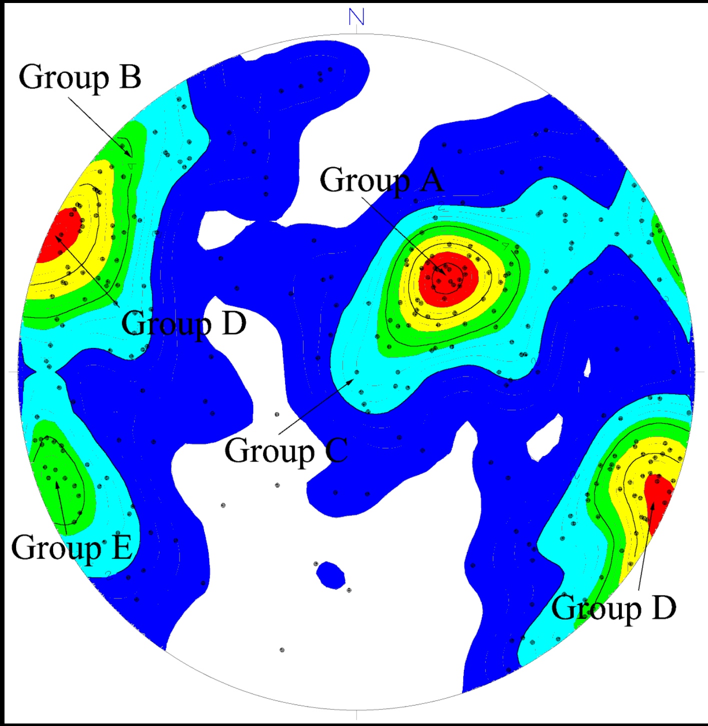
Queens Tunnel Faults



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

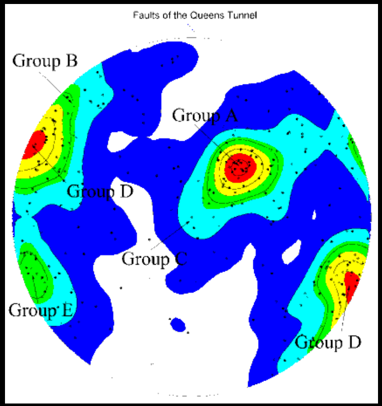
Group A = NW strike and gentle SW dipping faults
Group B = ENE-trending steeply dipping faults
Group C = Subhorizontal fractures and faults
Group D = NNE-trending steeply dipping fault system
Group E = NNW-trending “Manhattanville” fault system

QT Faults


N
Group B
Group A
Group D
Group C
Group E
Group D

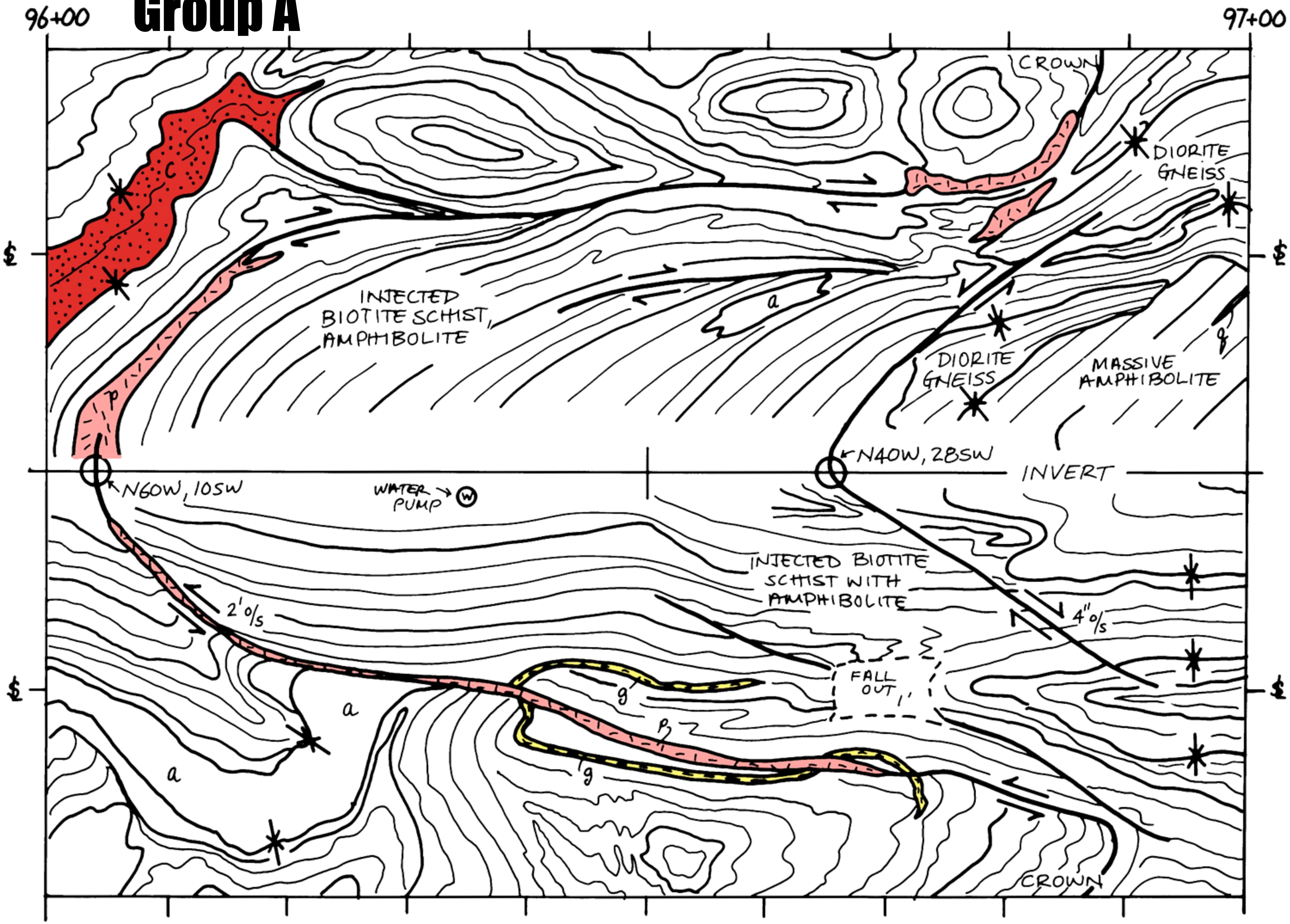

N
640 m
Google earth
Tour Guide
10/11/1995
lat 40.728998° lon -73.904487° elev 8 m eye alt 3.28 km

Gently-dipping Faults of Group A



- NW strike and gentle SW dip
- Both normal and reverse offset
- Typically reactivate older, D_4 ductile shears
- Thin zones of fault breccia and crush zones
- Commonly contain sheared pegmatite
- Laterally extensive features that persist for 100s of feet
- Abruptly terminate by ramping steeply into crown and down into invert
- Wet features that resulted in collapsed tunnel heading

Group A


96+00
97+00
CROWN
DIORITE GNEISS
INJECTED BIOTITE SCHIST, AMPHIBOLITE
a
q
DIORITE GNEISS
MASSIVE AMPHIBOLITE
p
c
N40W, 28SW
INVERT
N60W, 10SW
WATER PUMP
W
INJECTED BIOTITE SCHIST WITH AMPHIBOLITE
2' o/s
4" o/s
FALL OUT
g
a
p
a
g
CROWN


Shear Zone
Queens Tunnel Station 196+85

Steeply-dipping Brittle Faults of Group B

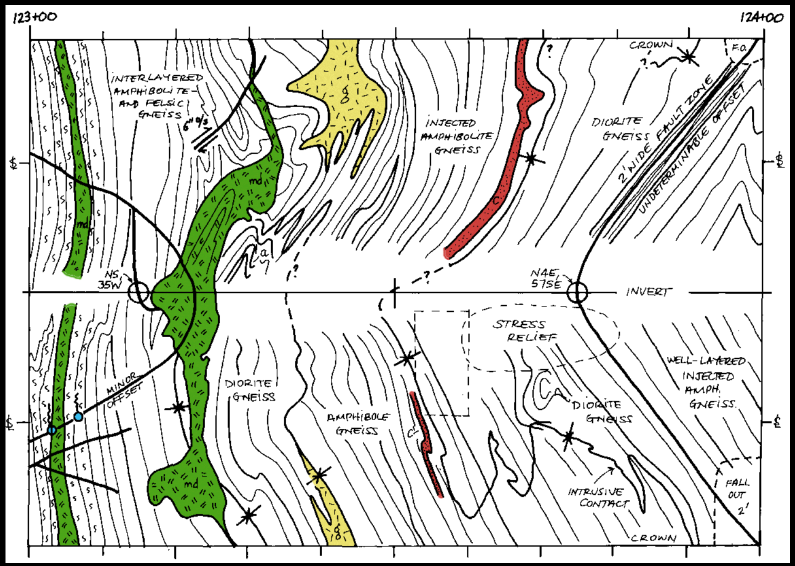
- ENE strike and steep NW and SE dips
- Reactivate Group A faults and older ductile shears
- Thin zones of fault breccia and crush zones
- Cut by subhorizontal fractures (Group C) and younger faults (Groups D and E)

Subhorizontal Brittle Faults of Group C

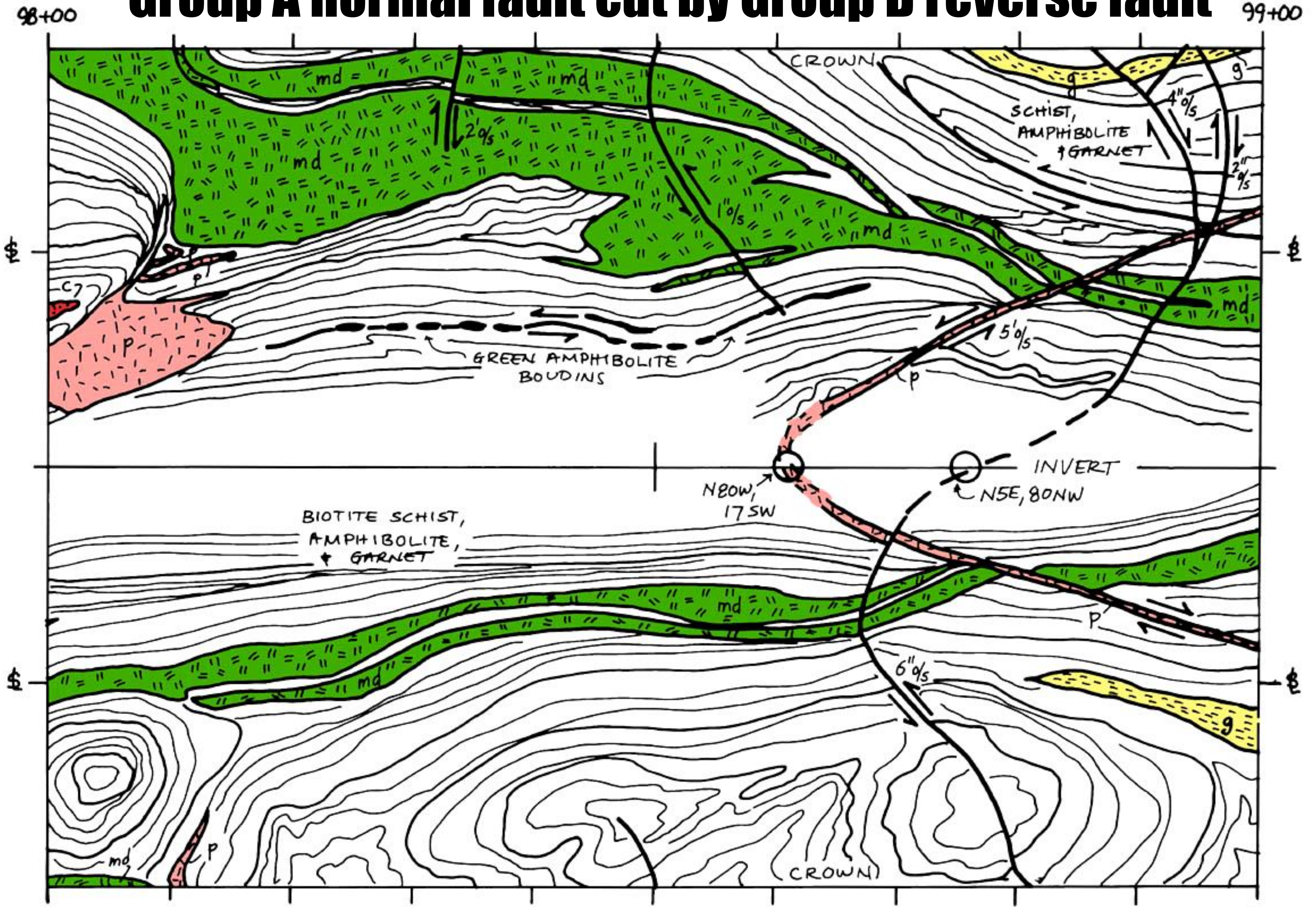
- Cut Group A and B faults and older ductile shears
- Thin zones of fault breccia and crush zones
- Cut by Group D and E faults

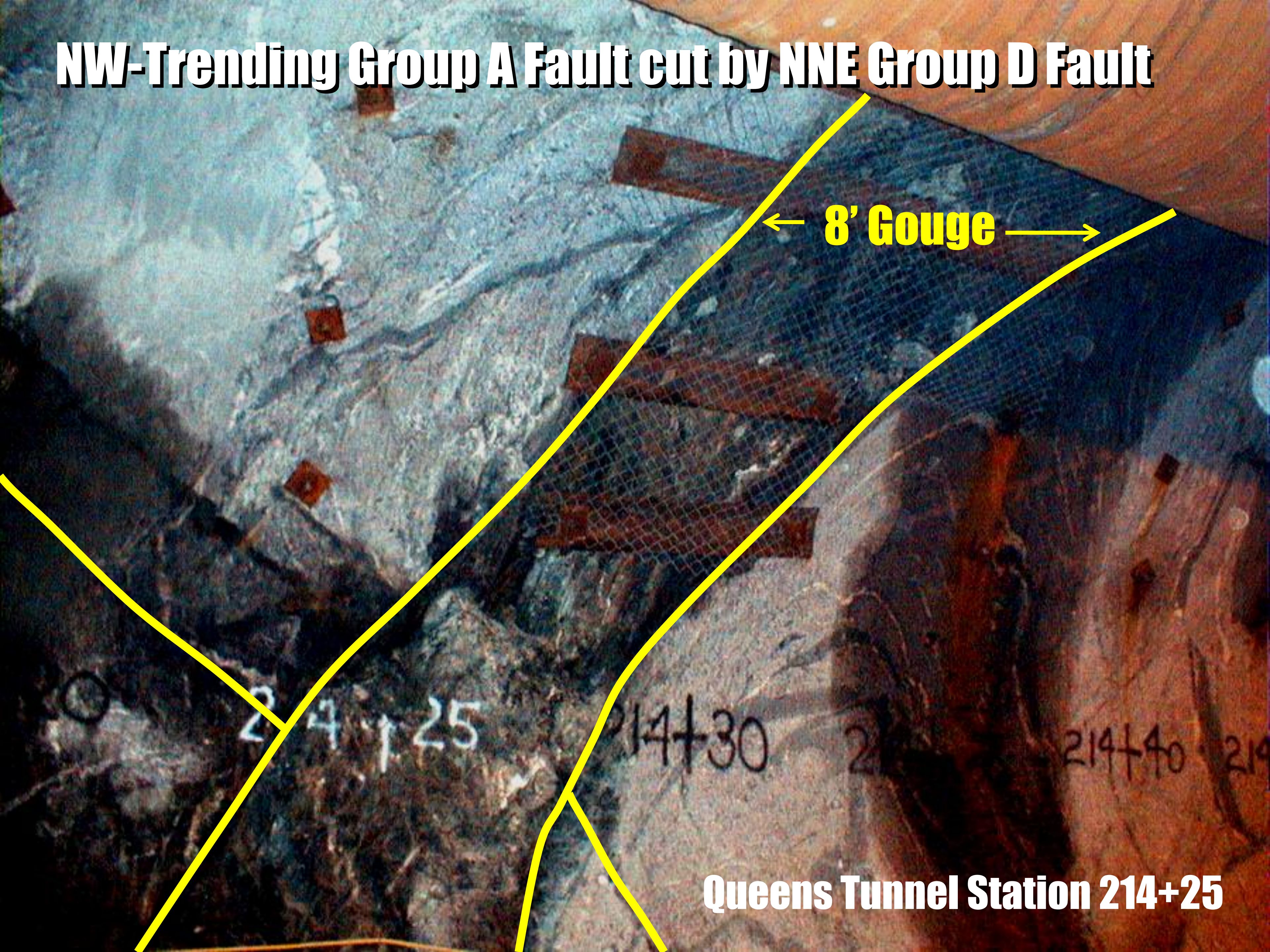
NNE-Trending Fault System of Group D

- NNE strike and steep dips; dip-slip mechanisms
- Structural control – parallel to Pz regional S_3 foliation
- Thick zones of fault gouge and breccia
- Clay-, zeolite-, and chlorite-rich gouge zones
- Stilbite – Calcite – Chabazite – Analcime - Apophyllite
- Relatively young – they cut 295 Ma rhyodacite dikes



Group A normal fault cut by Group D reverse fault




NW-Trending Group A Fault cut by NNE Group D Fault
8’ Gouge
214+30
214+40
Queens Tunnel Station 214+25

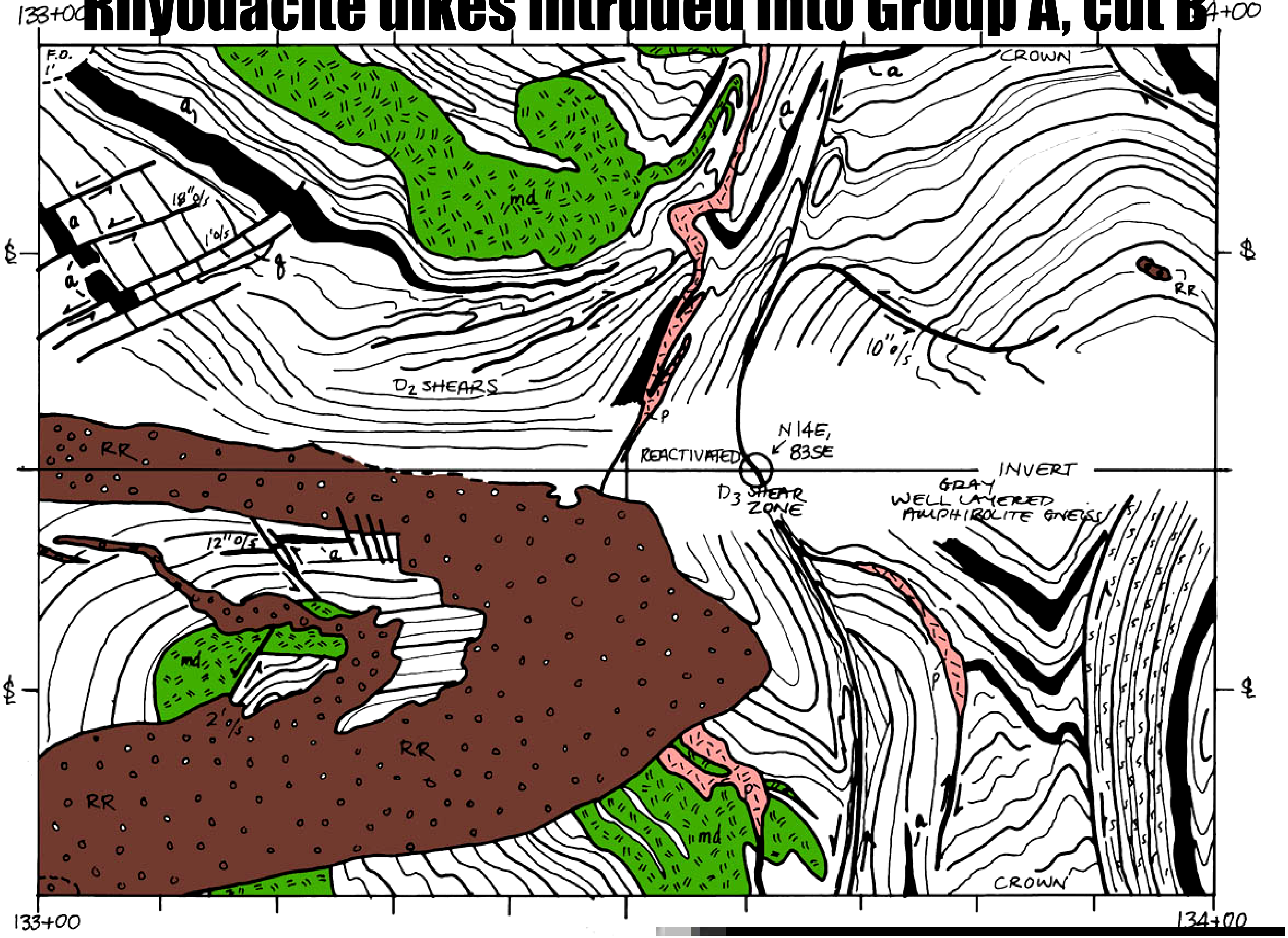
Crush Breccia Group B NNE Fault

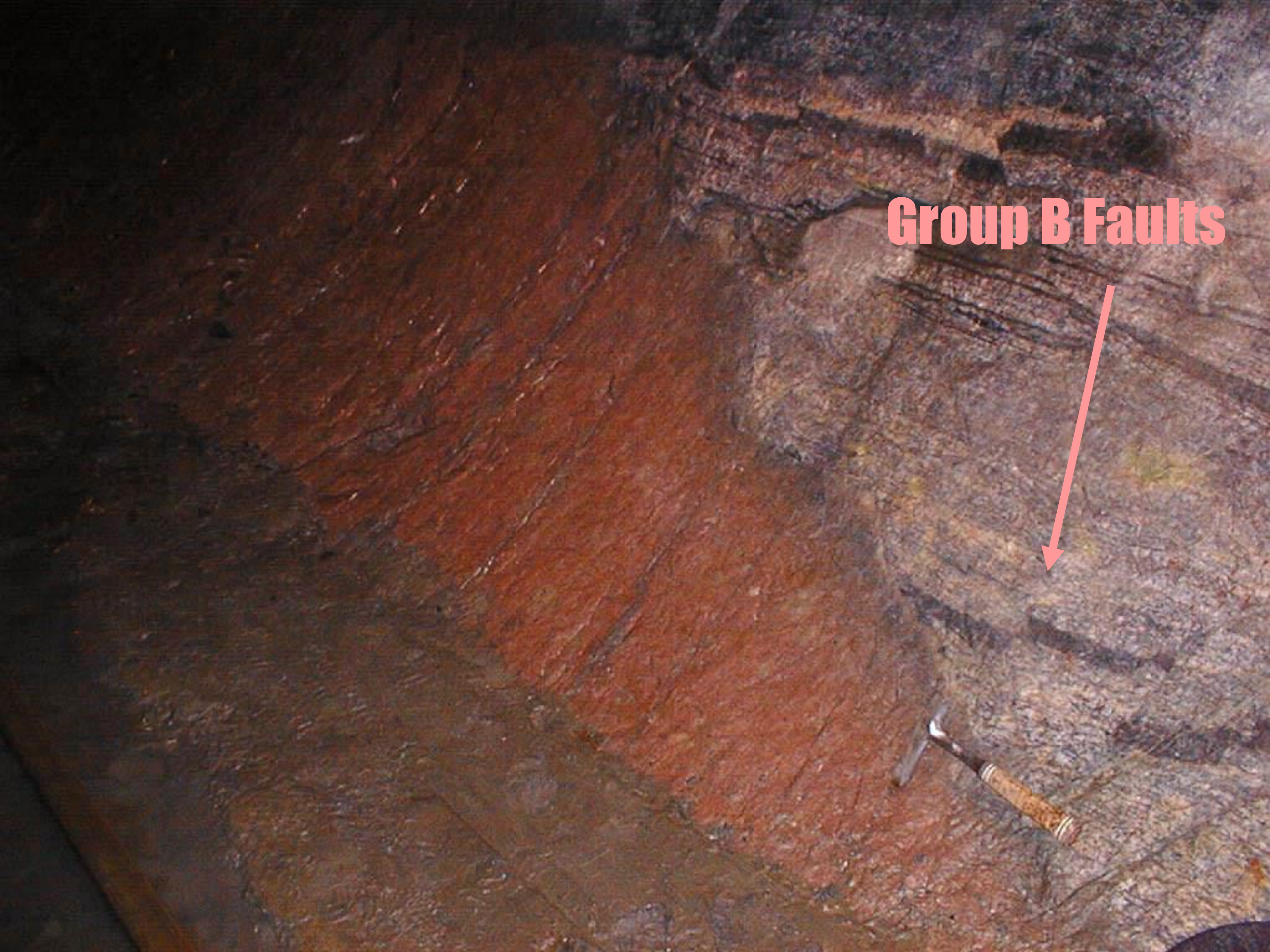
Sta. 137+30

Queens Tunnel Sta. 93+60

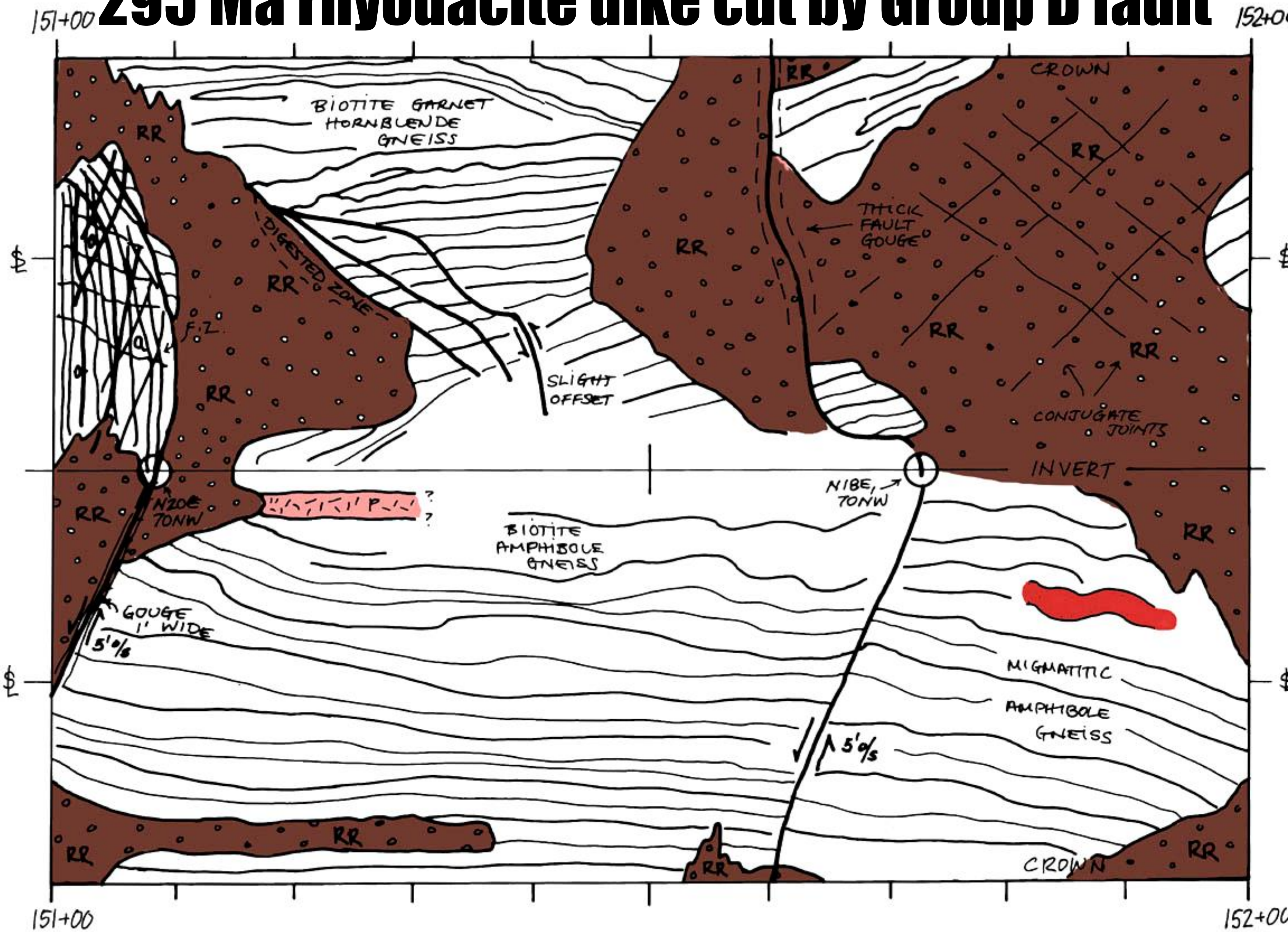

Station 130+40, Right Wall
Multidirectional cooling joints in rhyodacite

Rhyodacite dikes intruded into Group A, cut B




Group B Faults

295 Ma rhyodacite dike cut by Group D fault



NNW-Trending Fault System of Group E

- NNW strike with steep dips; R/L and L/L strike-slip offset
- Follow S_4 traces of open cross folds (F_4)
- Commonly healed with quartz +/- pyrite
- Youngest fault group – they cut all tunnel structures
- Reactivate many older faults
- Persistent features in west part of NW-leg of tunnel
- Associated with areas of stress relief
- Produce wet zones in areas of fault convergence


NNW-Trending "Manhattanville" Strike-Slip Faults
Splays and Conjugate Joints
Queens Tunnel Sta. 156+35

Mineralized Brittle Fault Zones of the Queens Tunnel


Stilbite on Heulandite
Station 77+85


Stilbite on Heulandite
Station 77+85


Stilbite and Heulandite
Station 77+85


Stilbite var. Epidesmine
Station 77+85


Calcite and Pyrite on Stilbite var. Epidesmine
Station 77+85

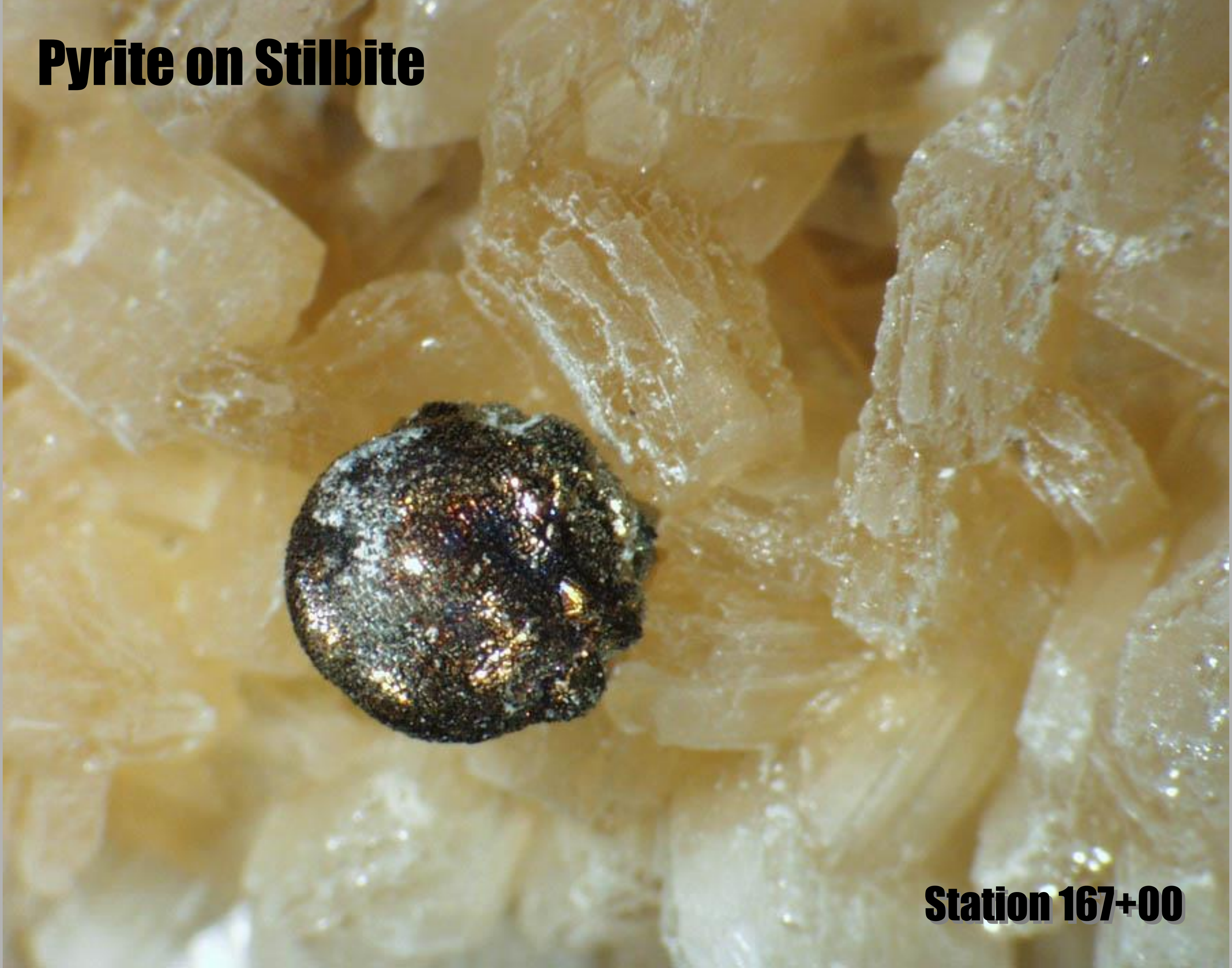

Pyrite Calcite Apophyllite on Prehnite
Station 150+00

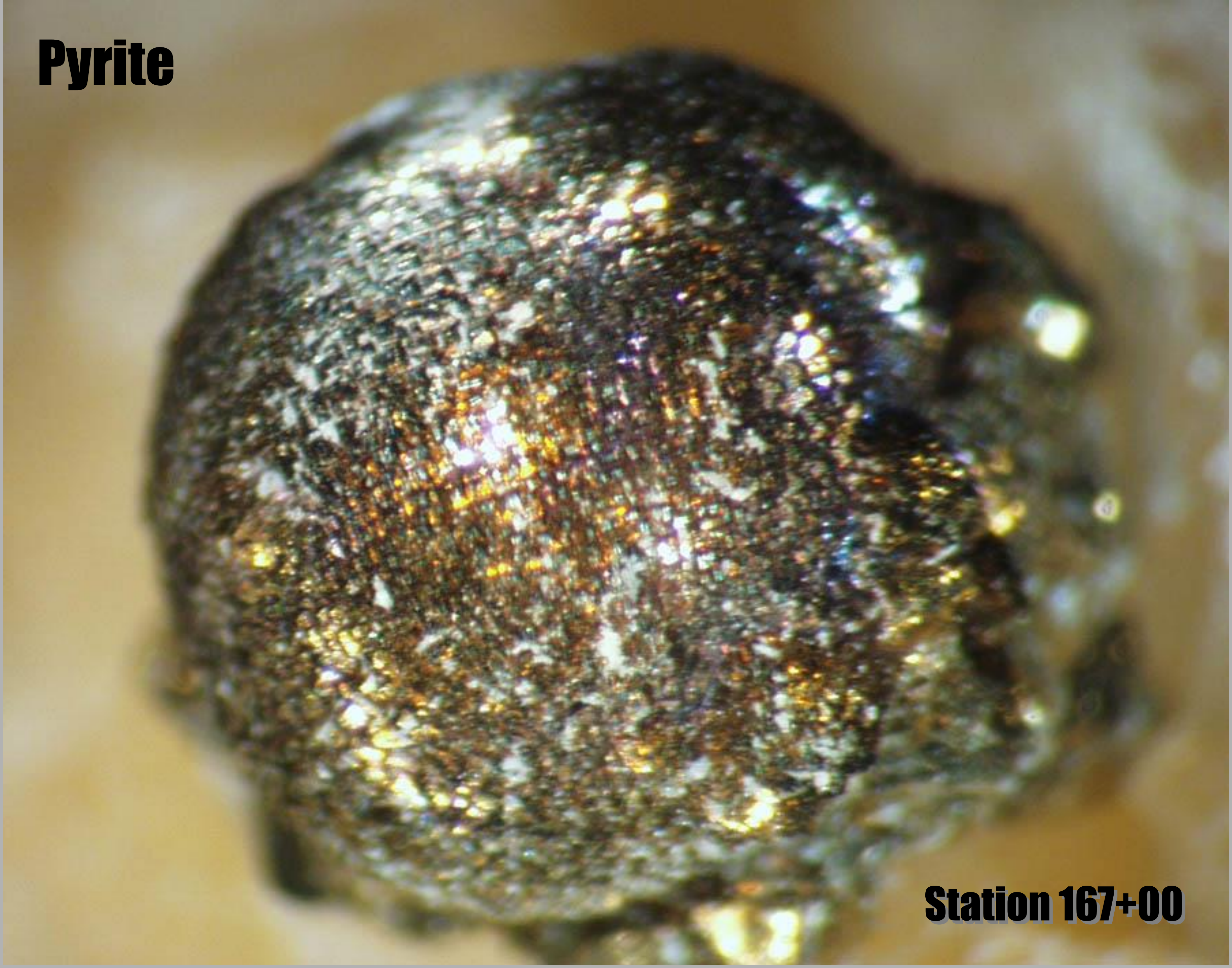

Chabazite on Calcite on Stilbite
Station 162+30


Chabazite on Calcite on Stilbite
Station 162+30

Chabazite on Calcite on Stilbite


Chabazite on Calcite
Station 162+30


Pyrite on Stilbite
Station 167+00

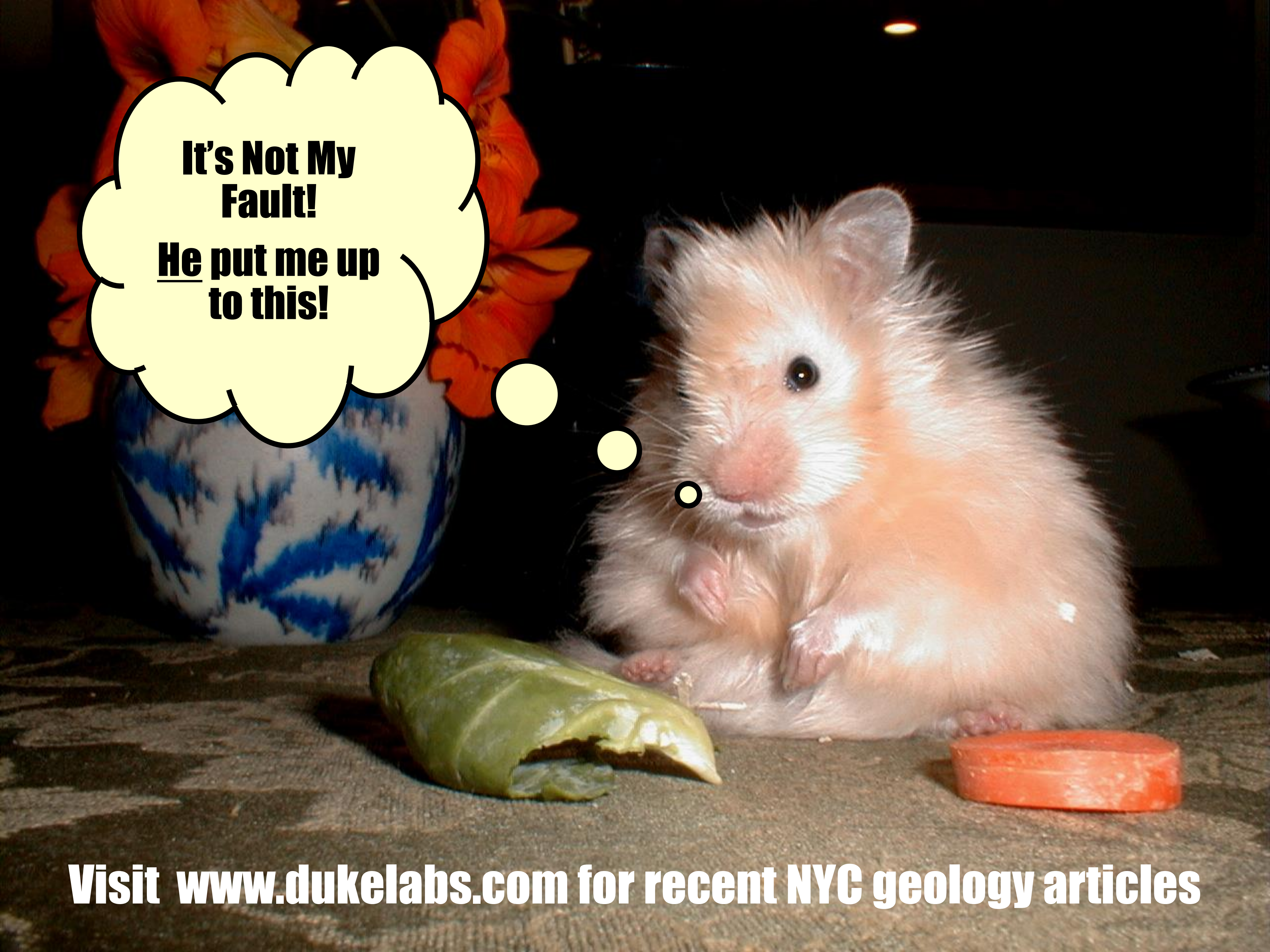

Pyrite
Station 167+00


Calcite on Stilbite
Station 167+00


Pyrite on Stilbite
Station 169+37


Apophyllite Stilbite
Station 190+15


Analcime Apophyllite Stilbite
Station 190+15


It's Not My Fault!
He put me up to this!
Visit www.dukelabs.com for recent NYC geology articles


602


PLURIBUS

Stop 44

Re-equilibrated WTC Mineral Assemblage

Plagioclase
Garnet
Staurolite
Kyanite