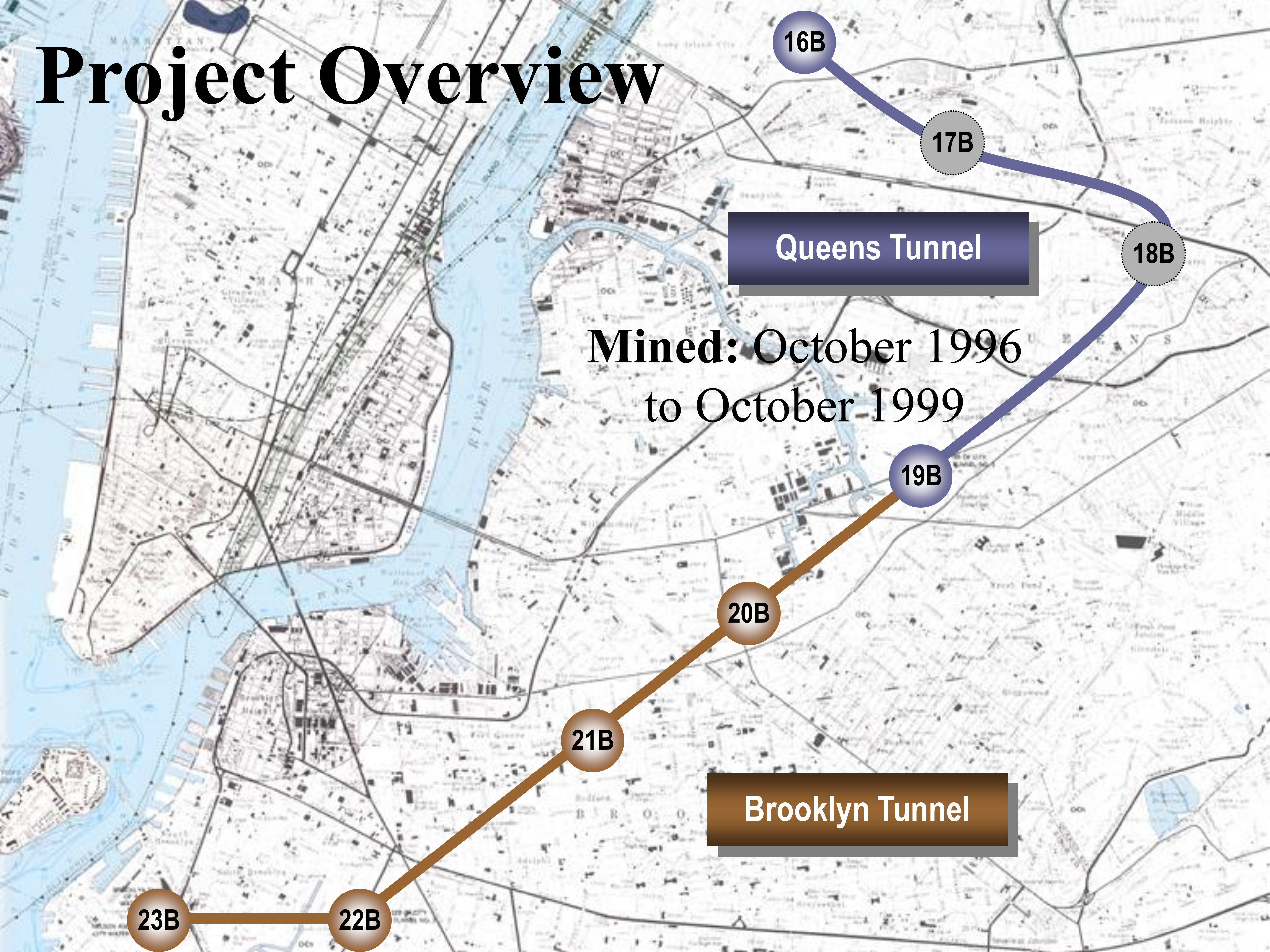
The Queens Tunnel Complex – a Granulite Facies Orthogneiss Terrane Exposed in NYC Water Tunnel #3

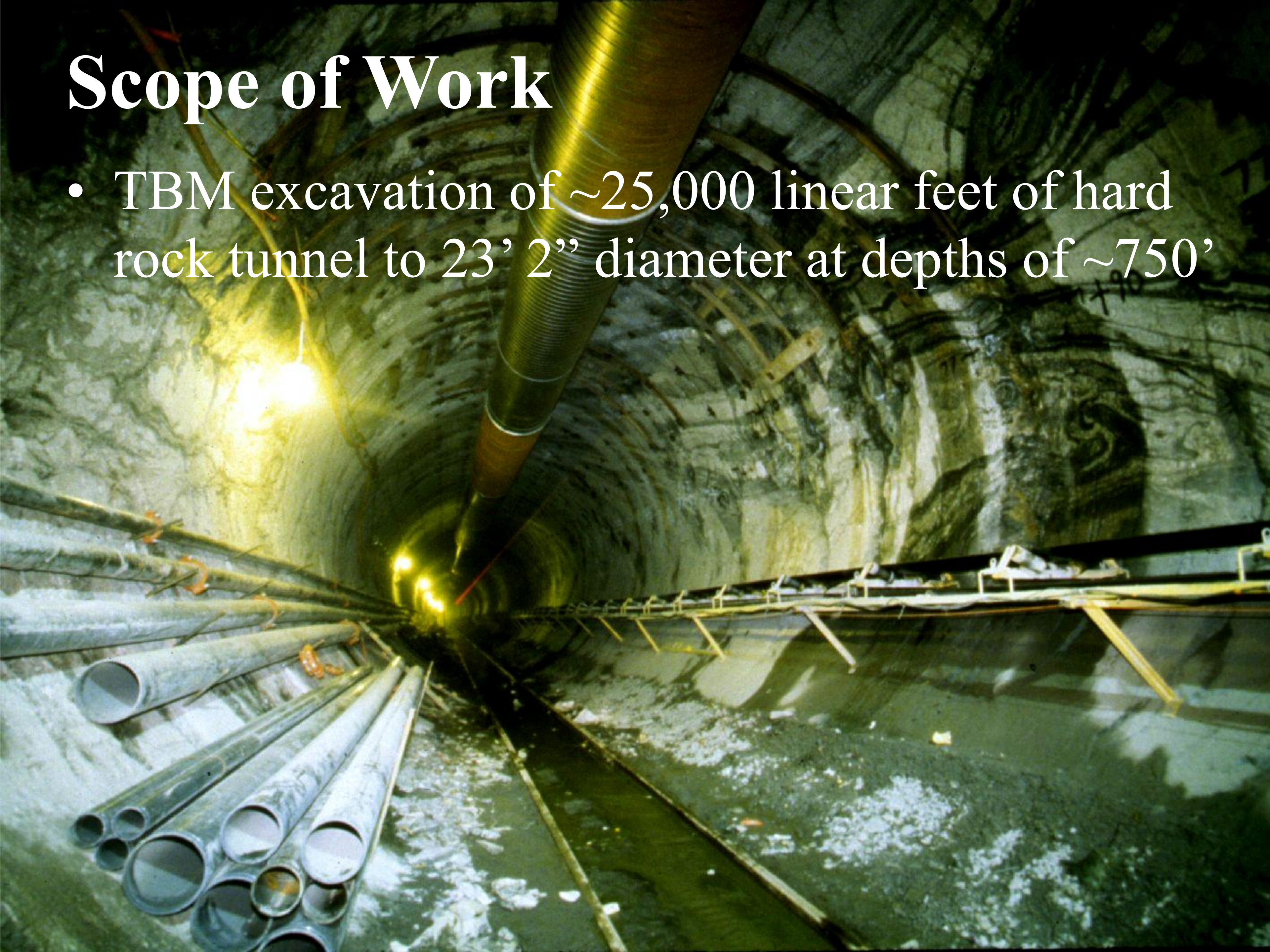
Charles Merguerian - *Hofstra University*
with P. C. Brock, and P. W. G. Brock
Queens College

Project Overview

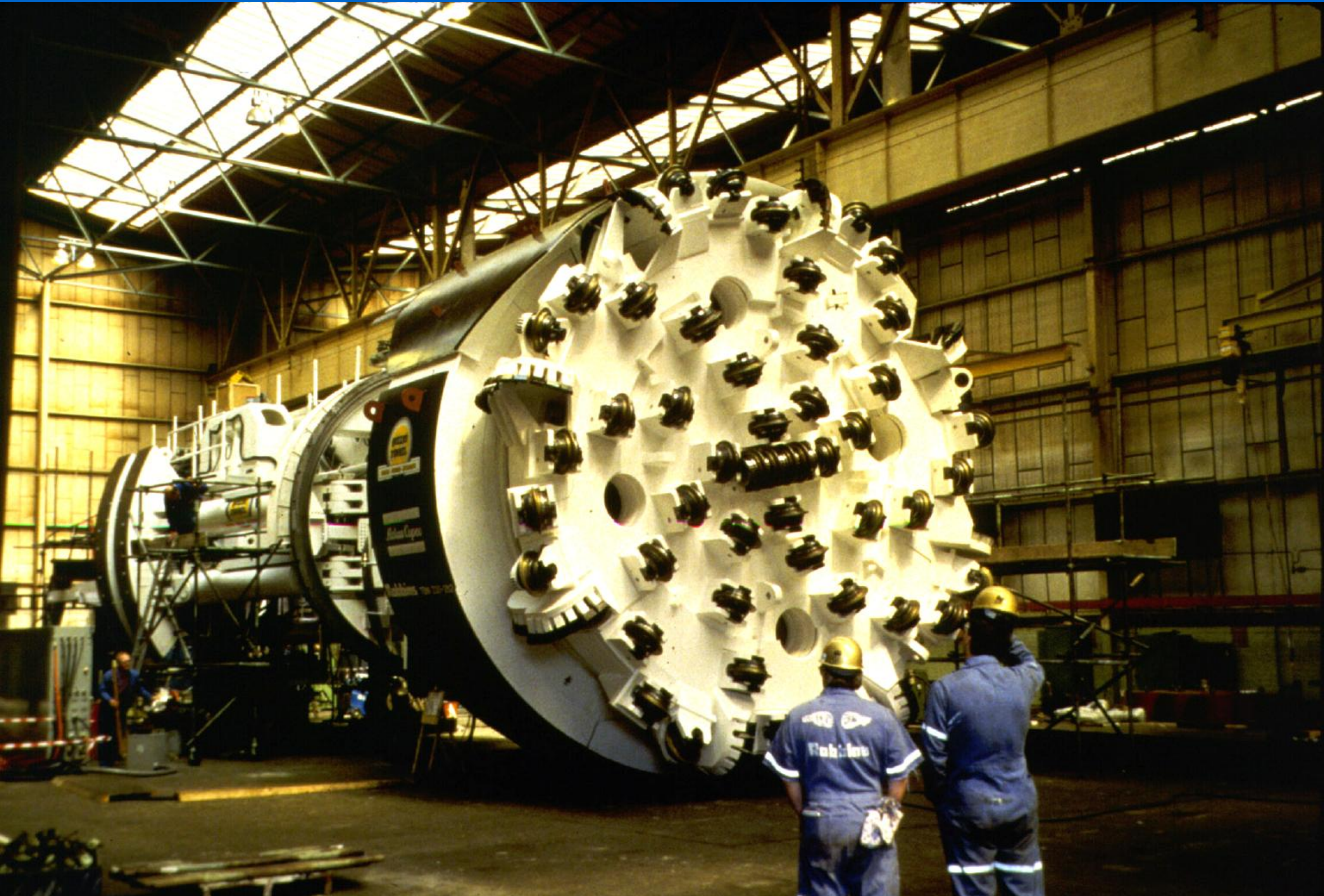


Scope of Work

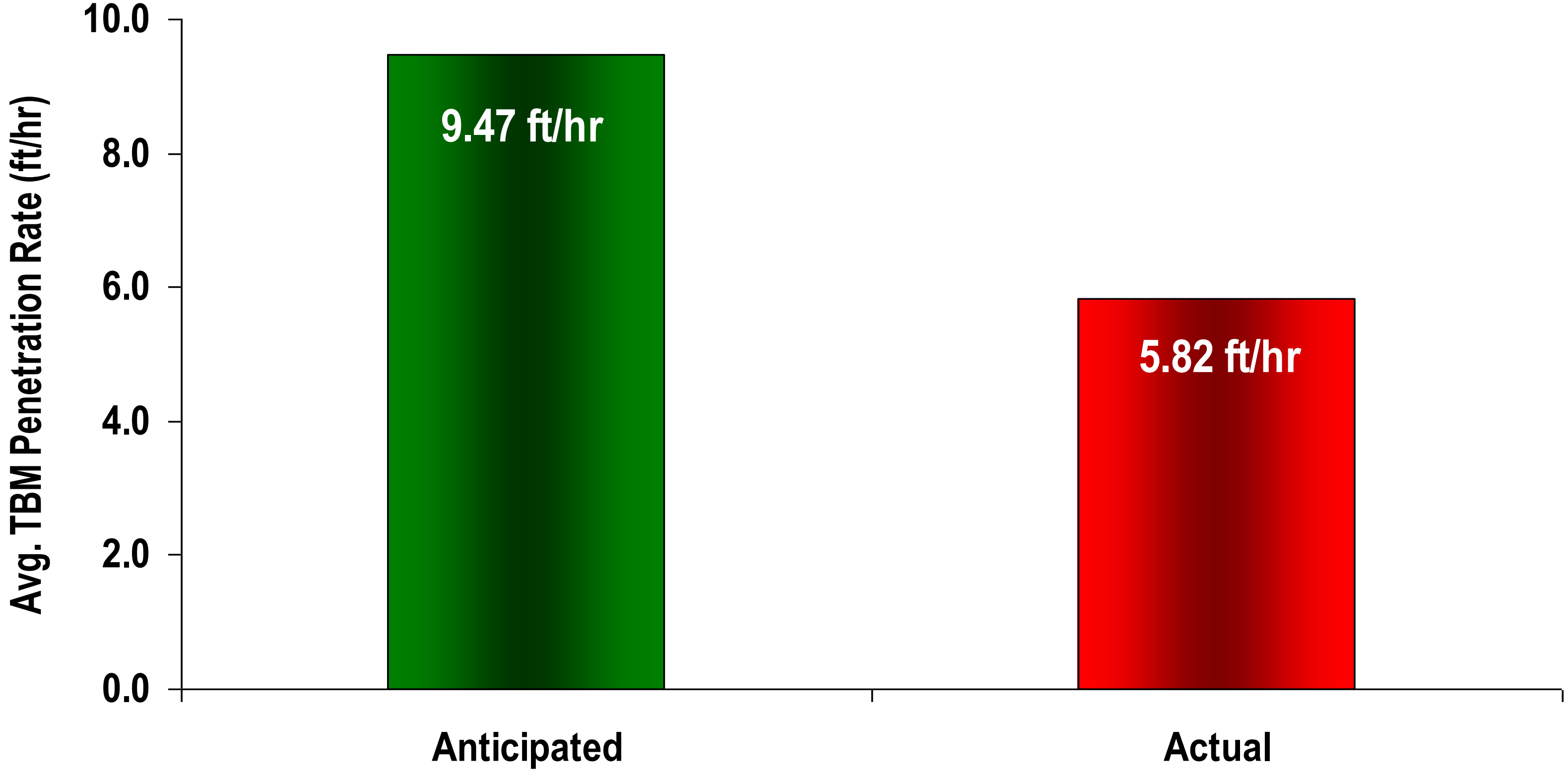
- TBM excavation of ~25,000 linear feet of hard rock tunnel to 23’ 2” diameter at depths of ~750’



Robbins 235-282 HP TBM

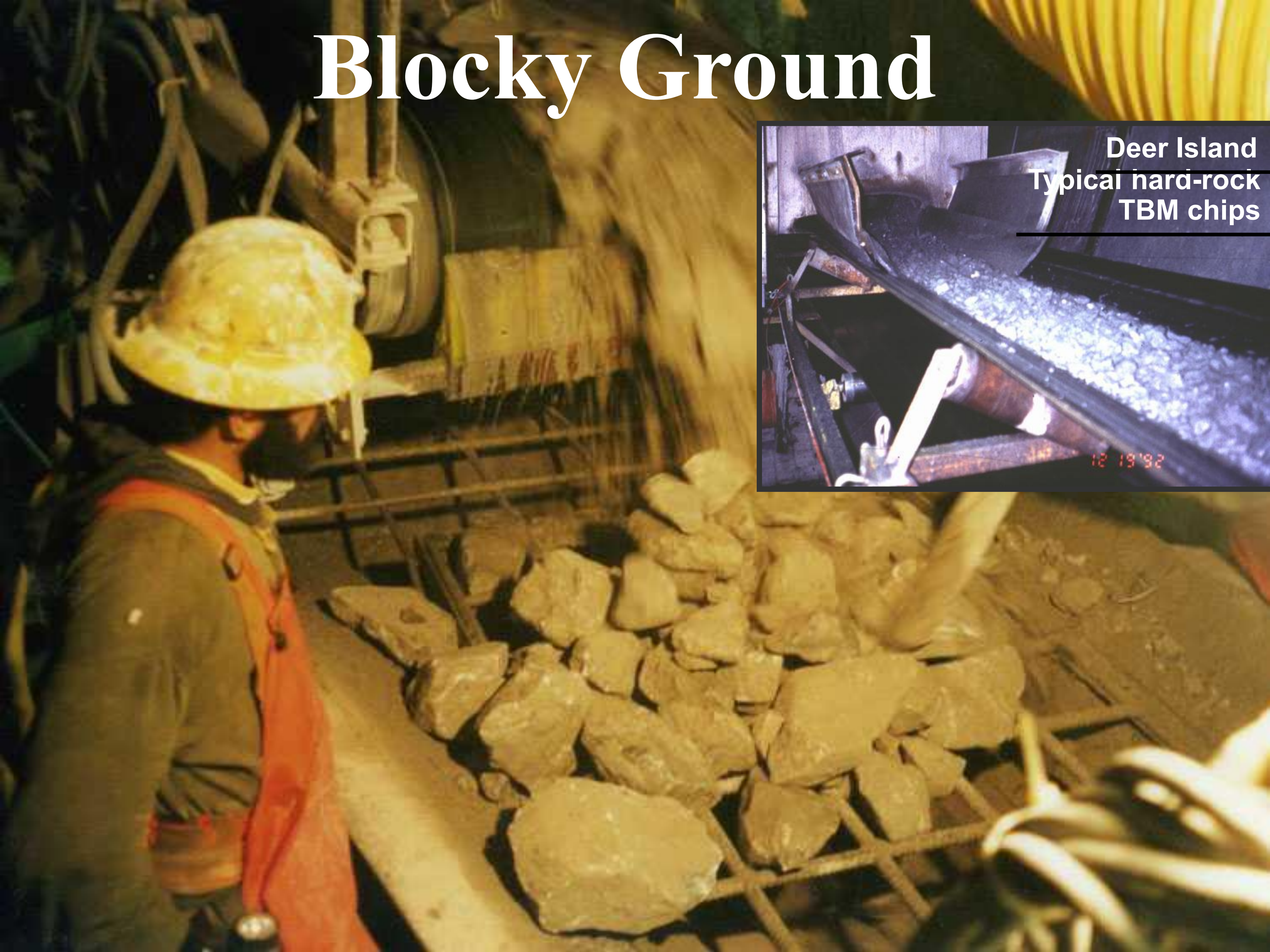


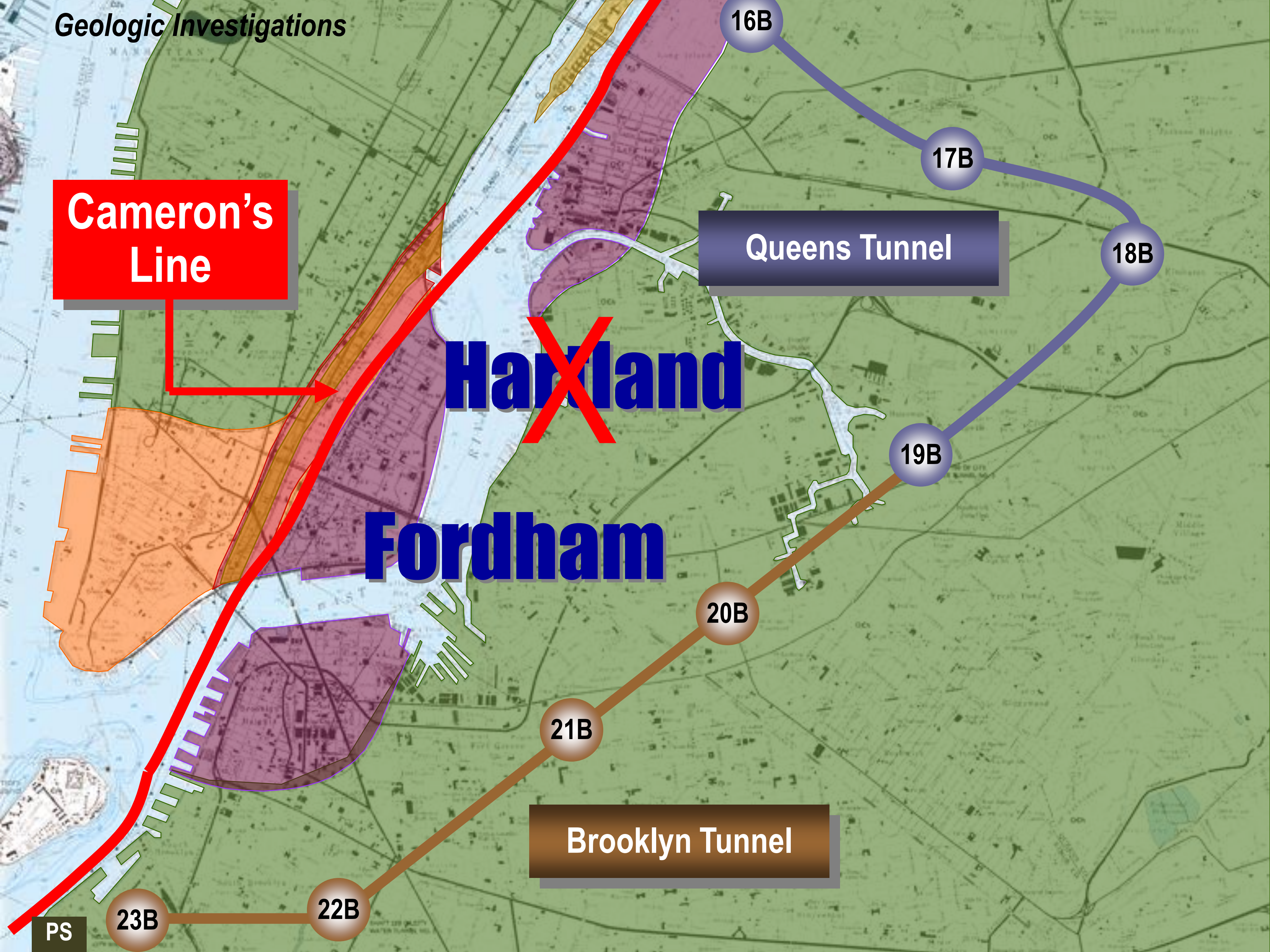
Anticipated vs. Actual Penetration Rate



Excessive Fines

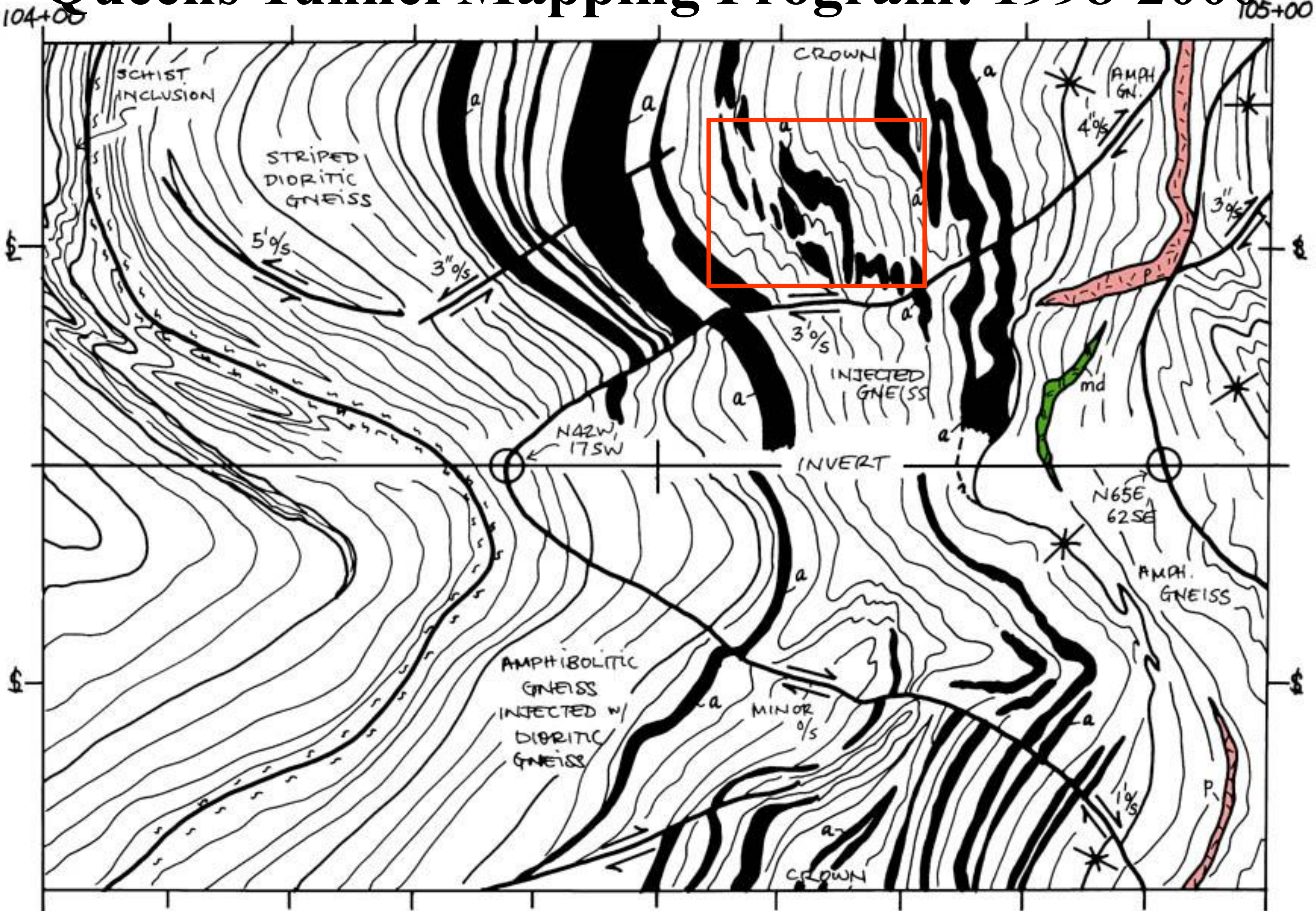
Blocky Ground





Geologic Investigations
Cameron's Line
Hartland
Fordham
Queens Tunnel
Brooklyn Tunnel
16B
17B
18B
19B
20B
21B
22B
23B
PS

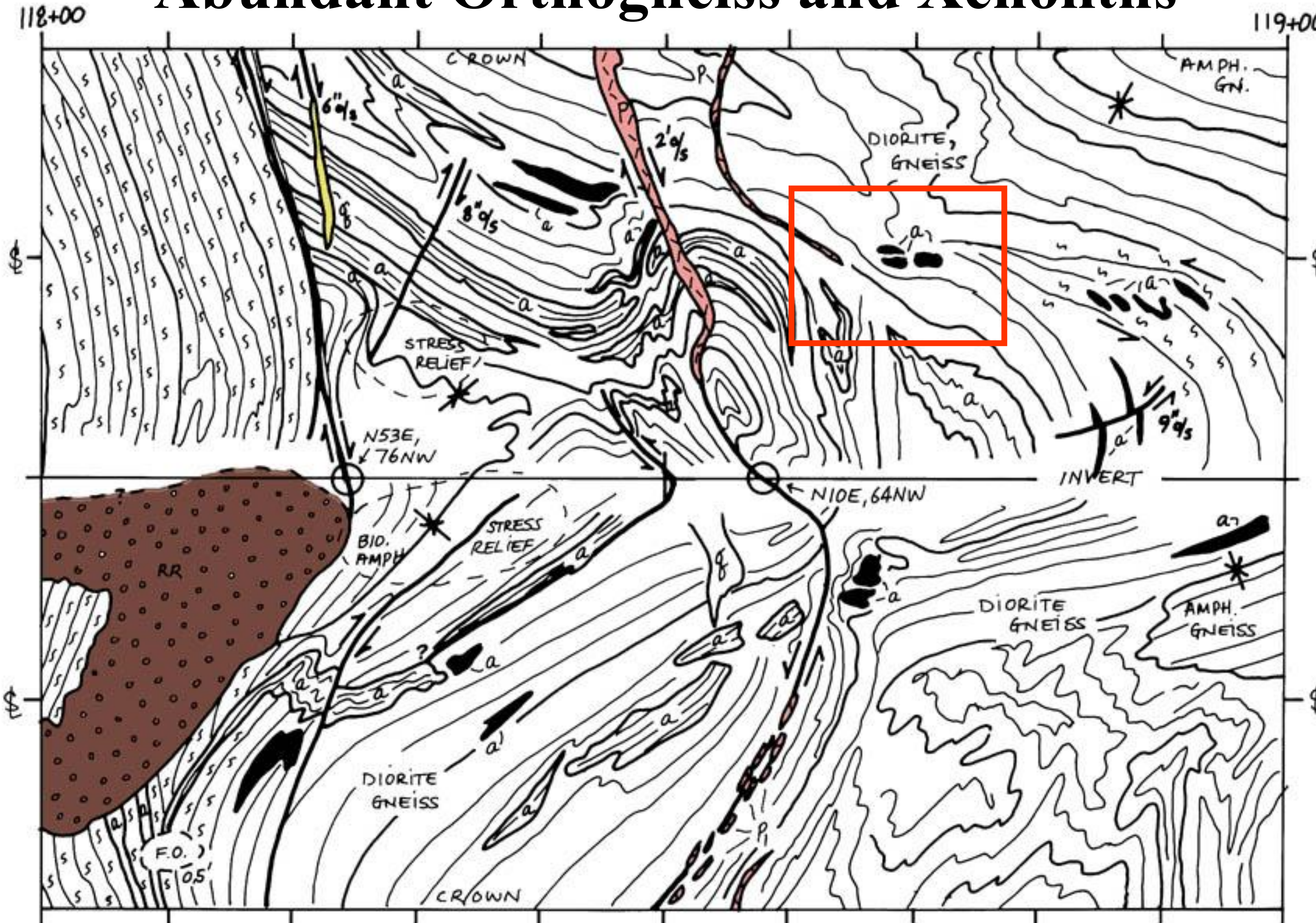
Queens Tunnel Mapping Program: 1998-2000



- Scale 1 in. = 10 ft


104+60
104+65

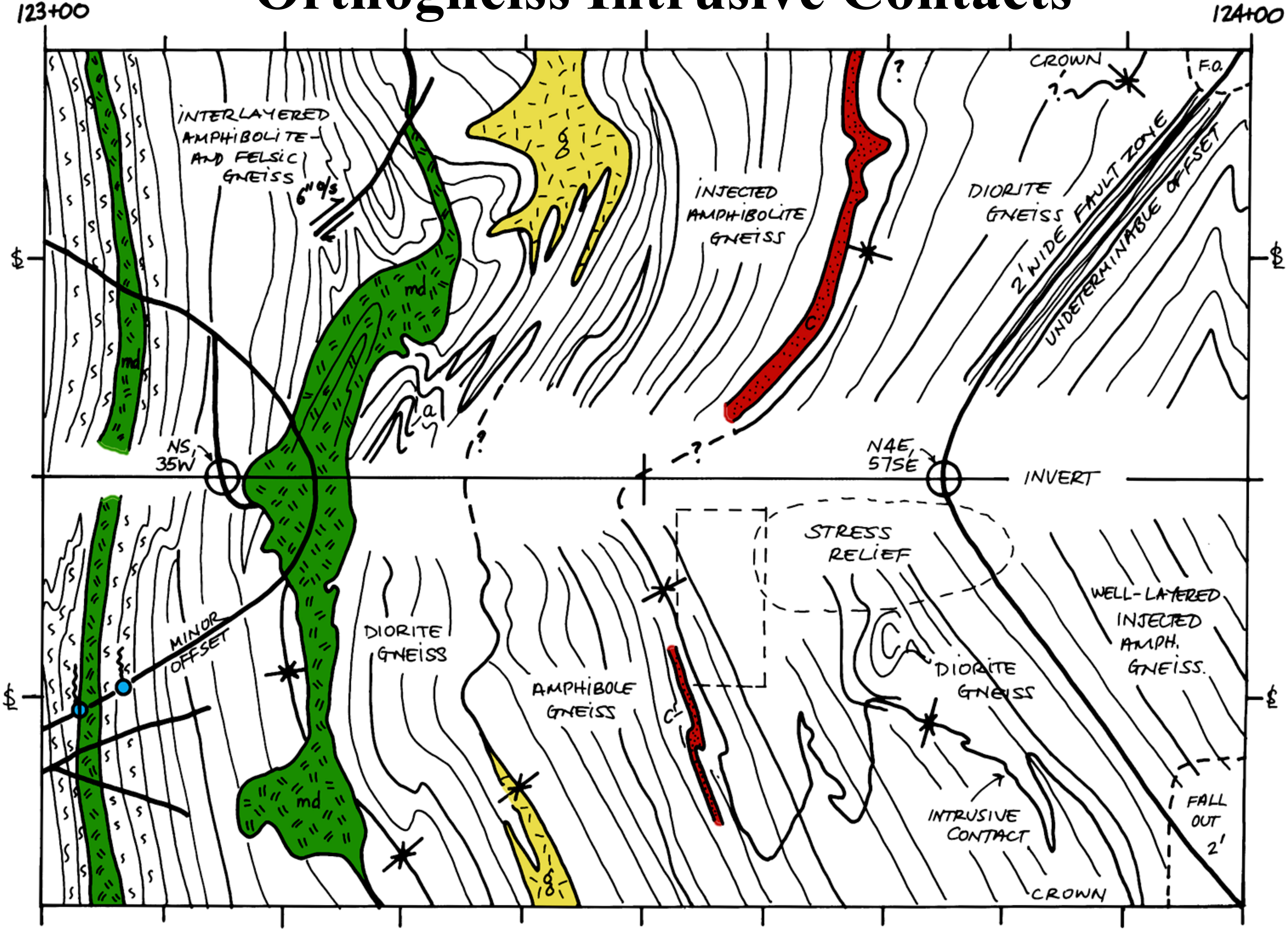
Abundant Orthogneiss and Xenoliths



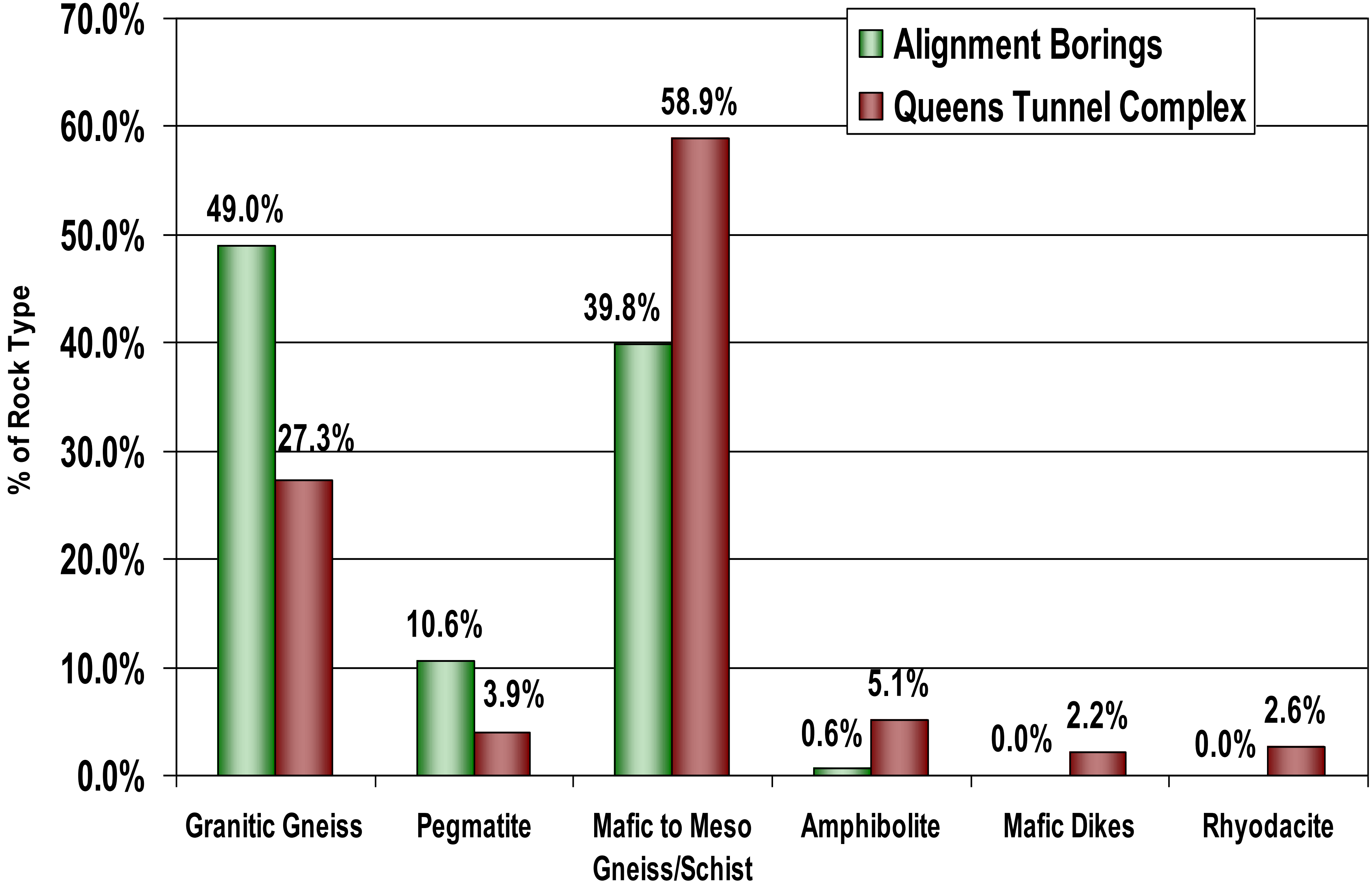
- Scale 1 in. = 10 ft

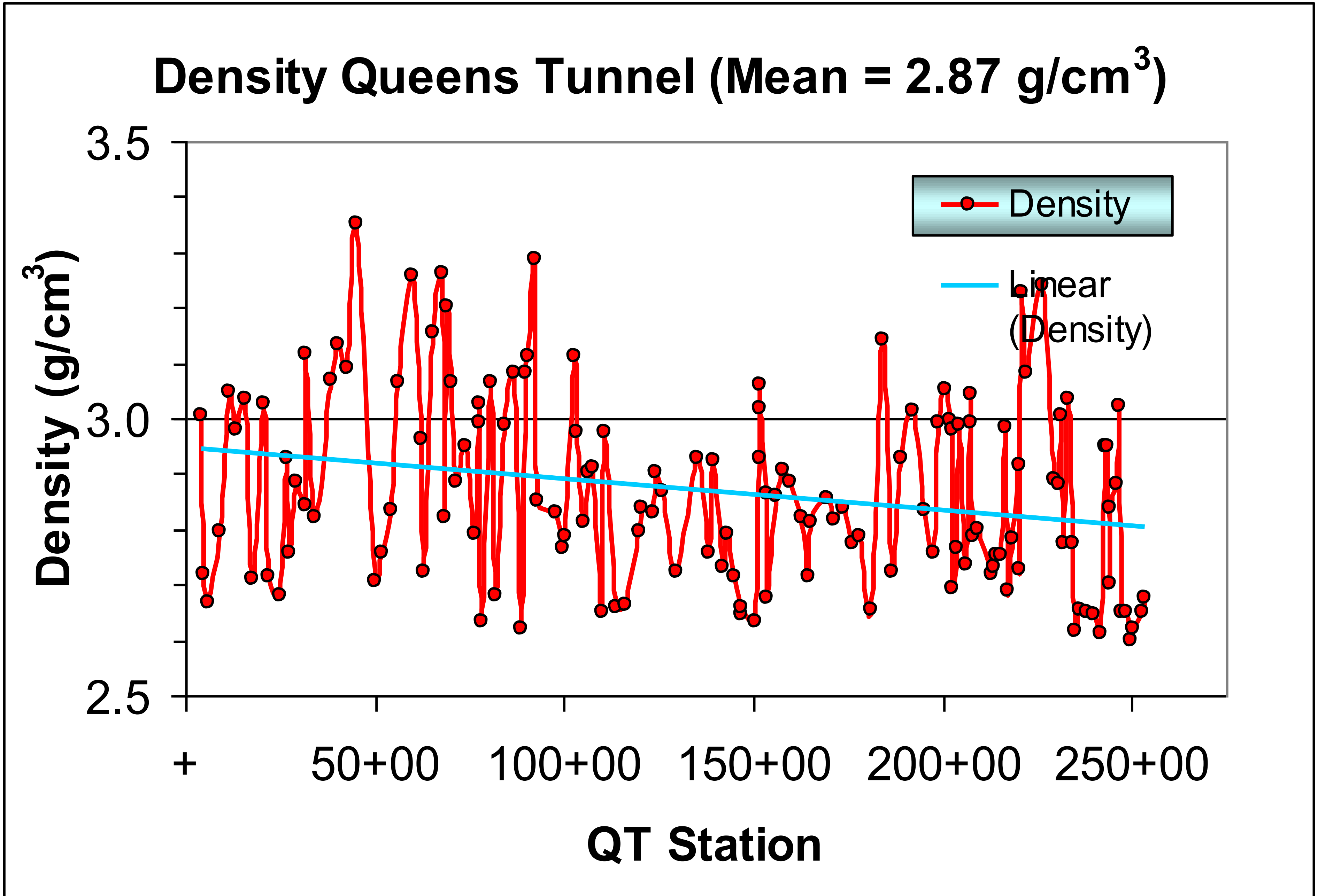

ADJ
118
118+70
118+

Orthogneiss Intrusive Contacts



Comparative Lithologic Analysis





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

Density Analysis

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

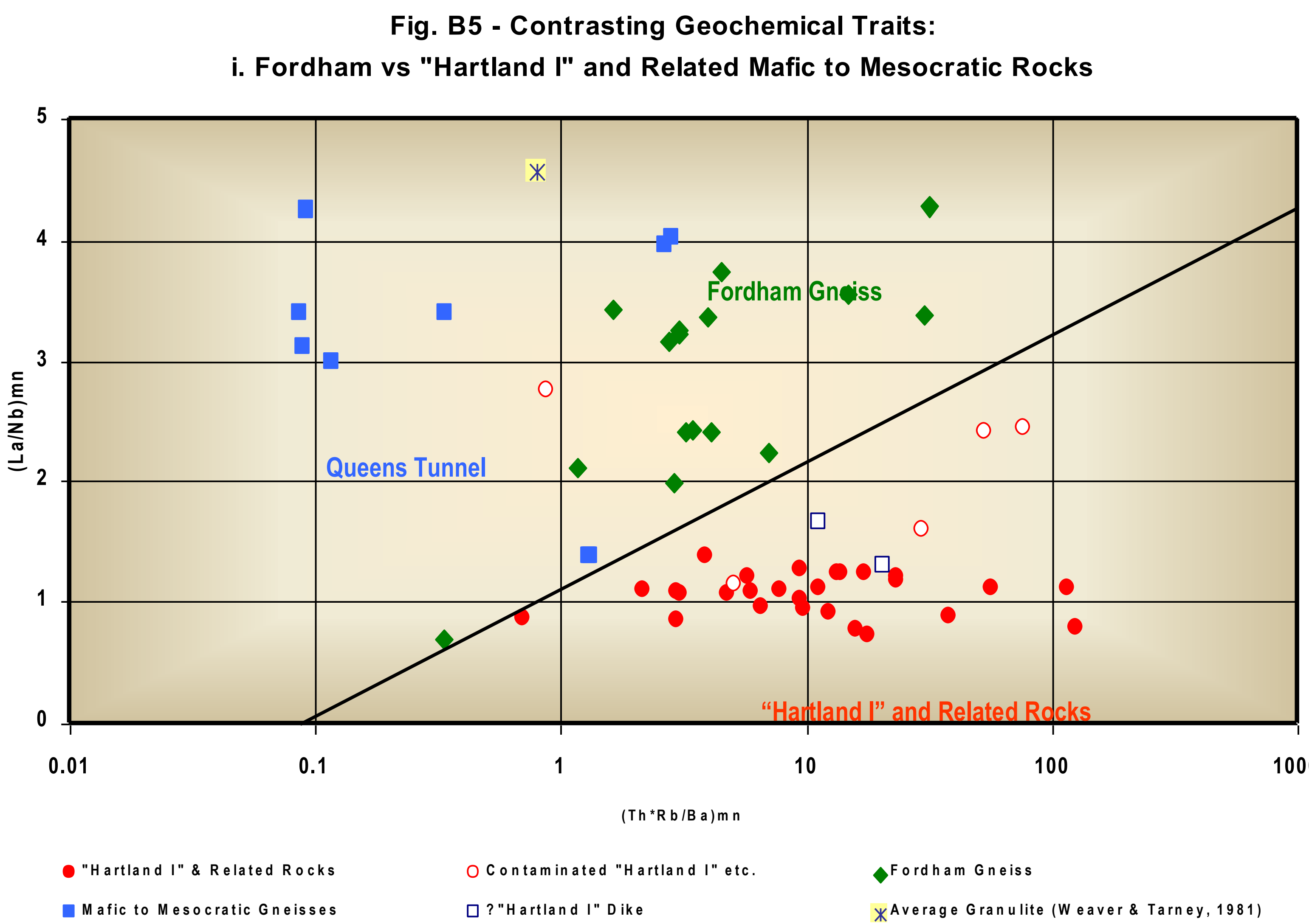
QT Mean = 2.87 (Dioritic Rock Mass)

From: Clark (1966, p. 20)

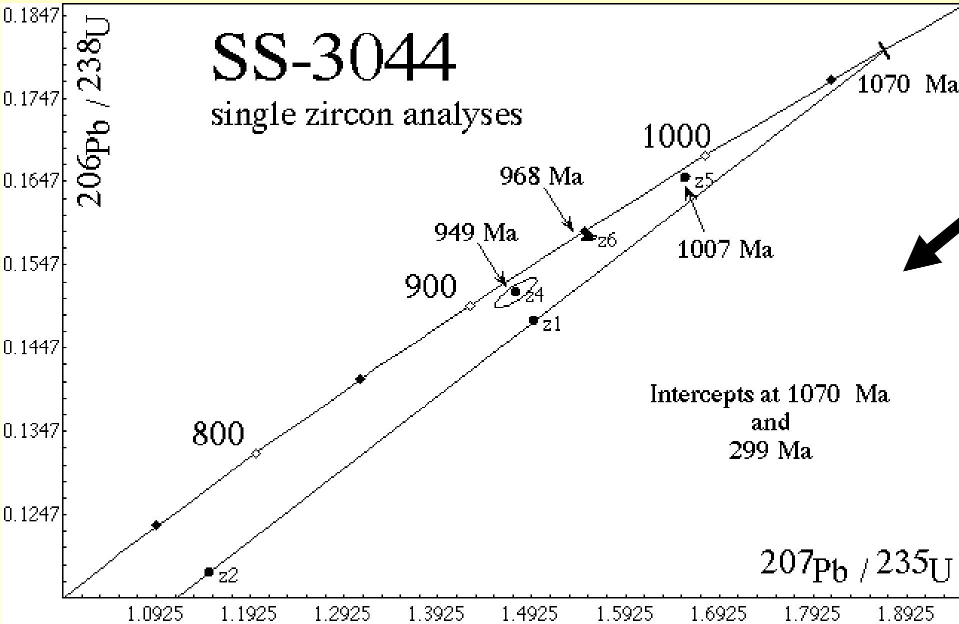

Unexpected High Garnet Content
Increased density and abrasivity of rock mass

Brocks' Geochemical Investigations

- Major elements, trace elements, rare earth elements (REE)

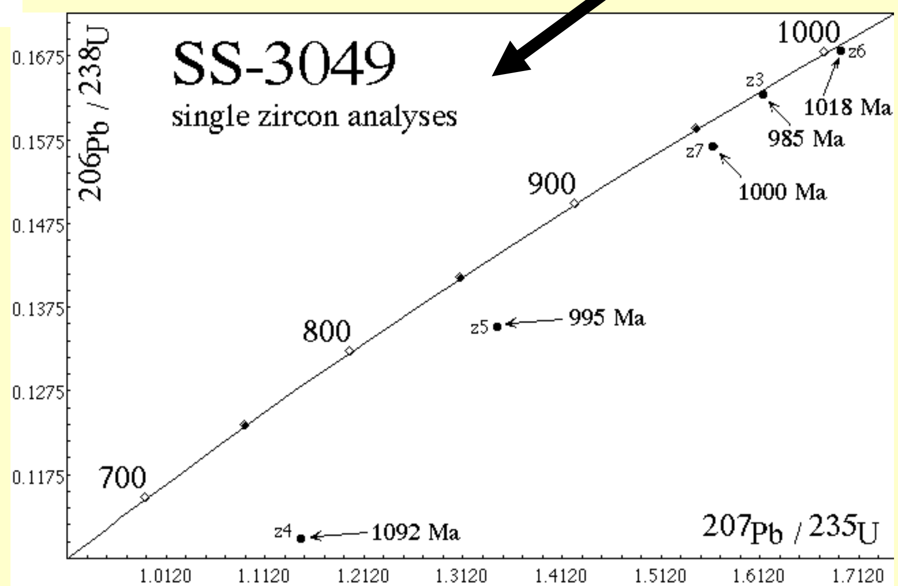


1.0 Ga U/Pb Geochronologic Analysis

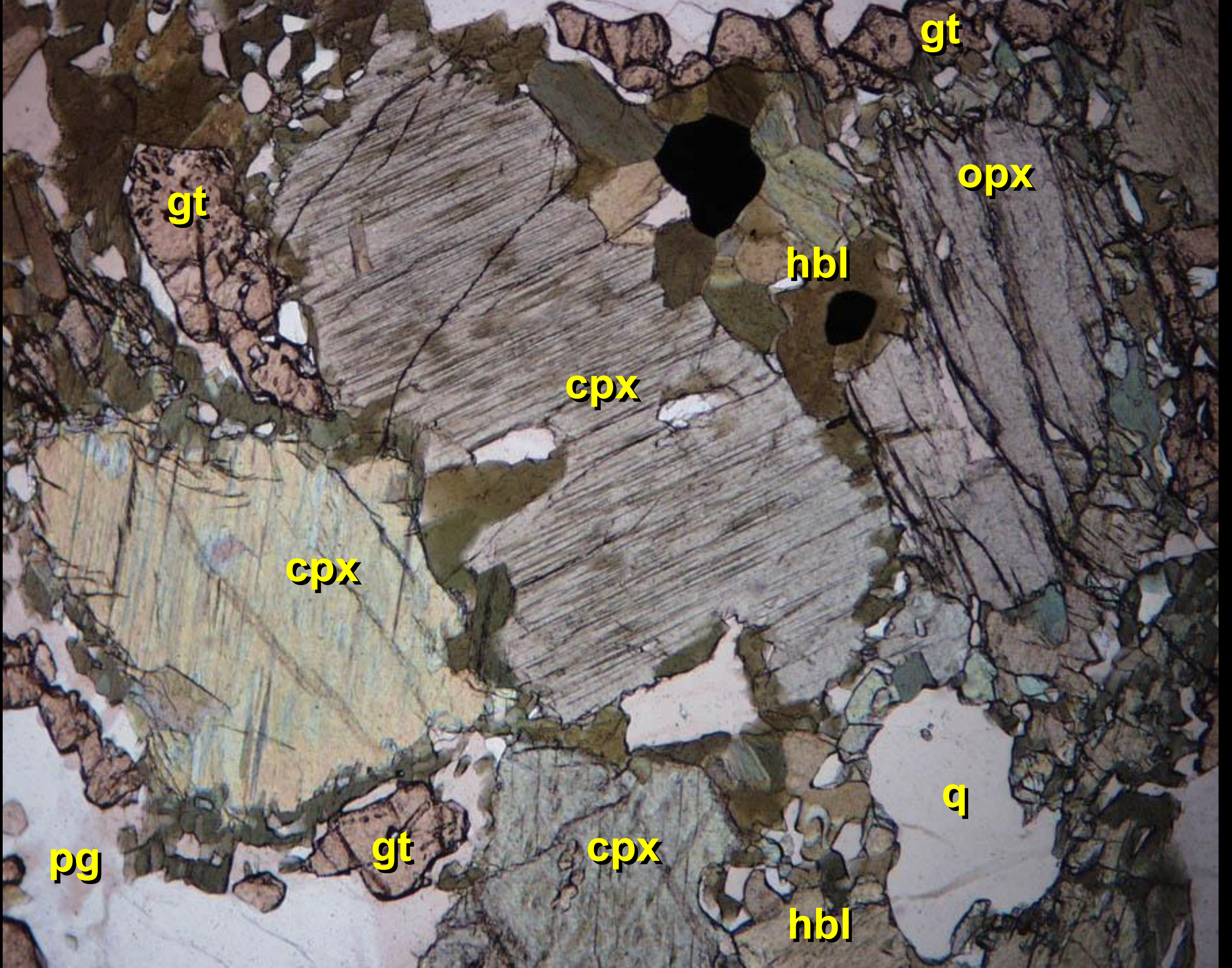


Station 9+45

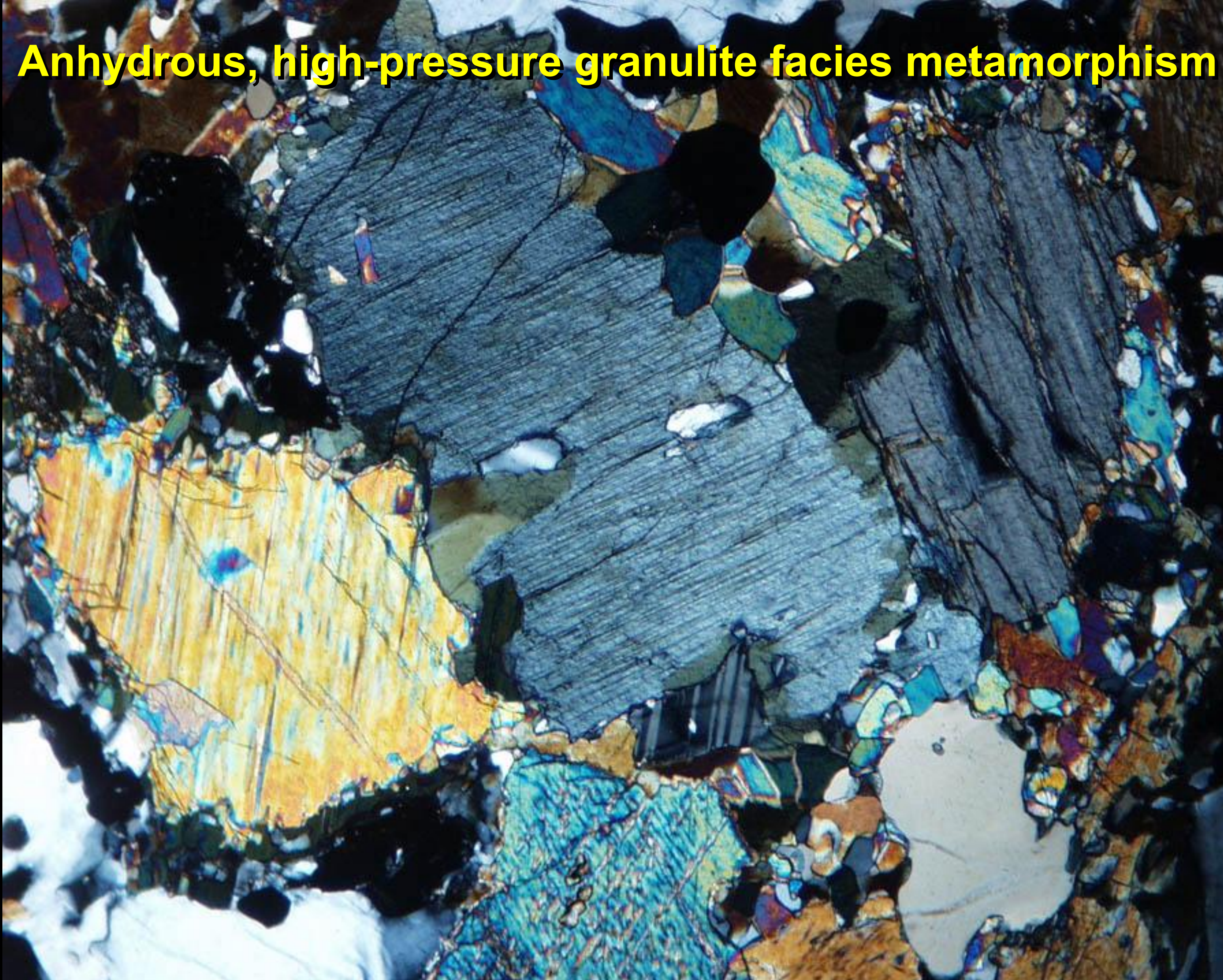
Station 68+15

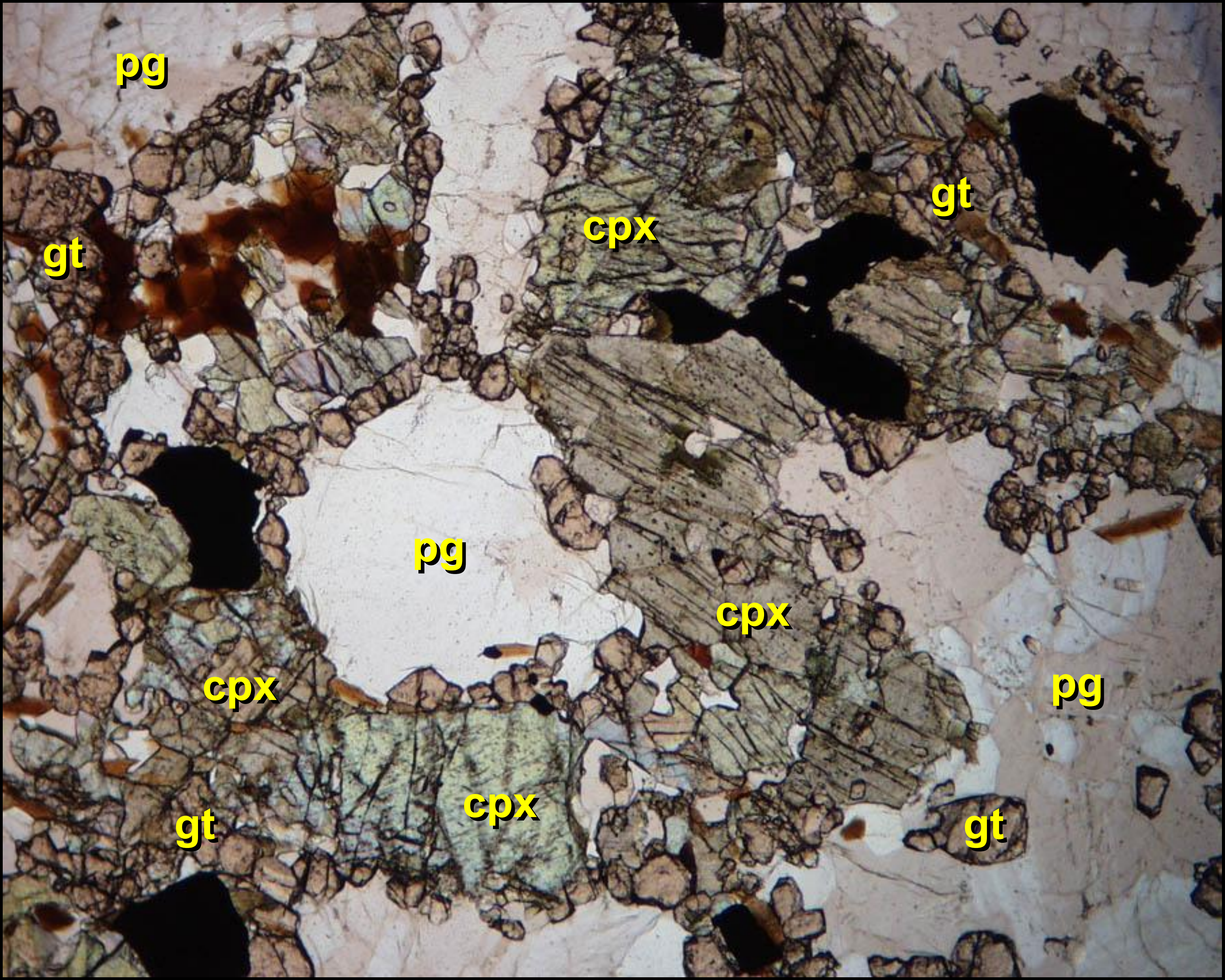


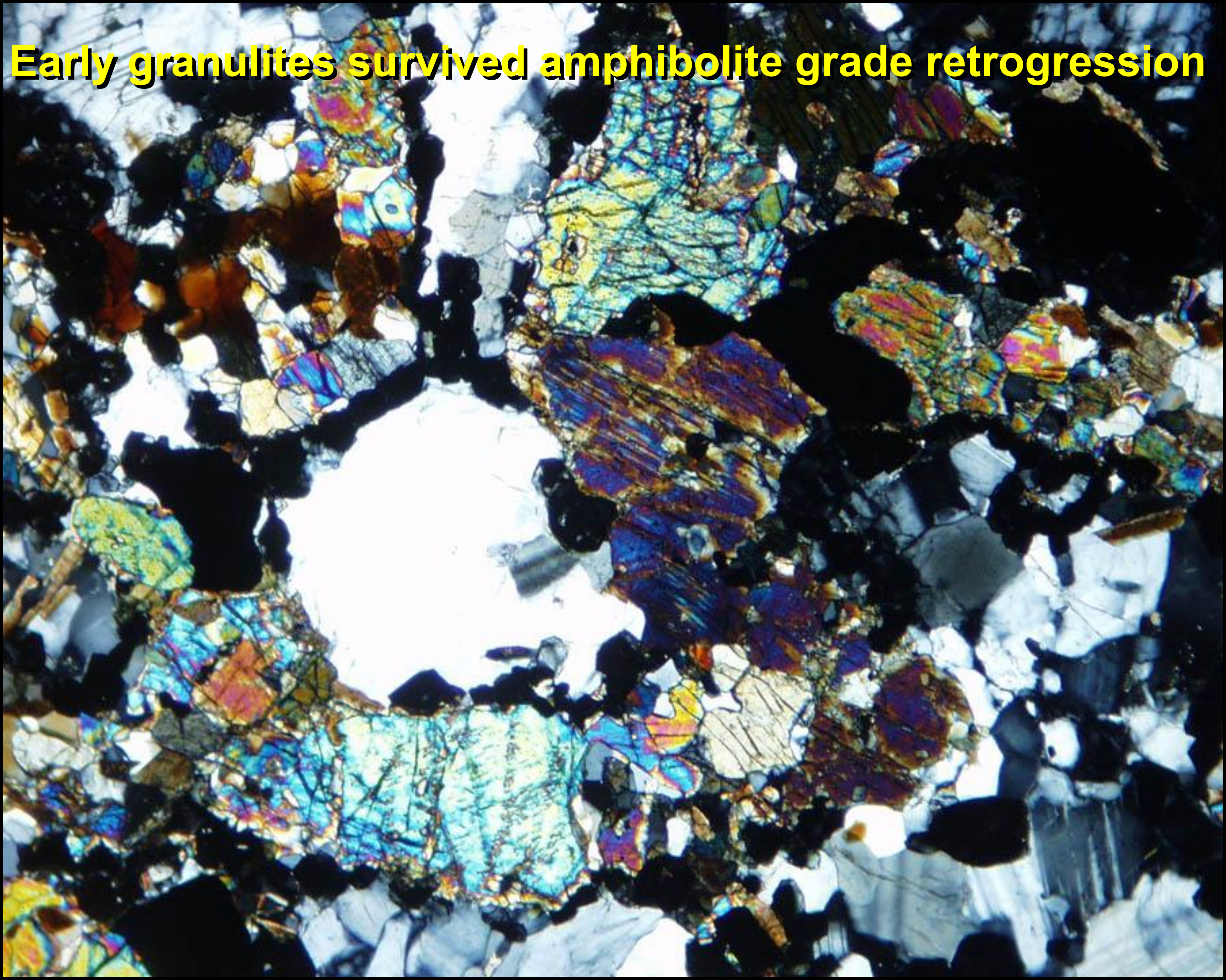
Age dating verified Fordham vs. Hartland

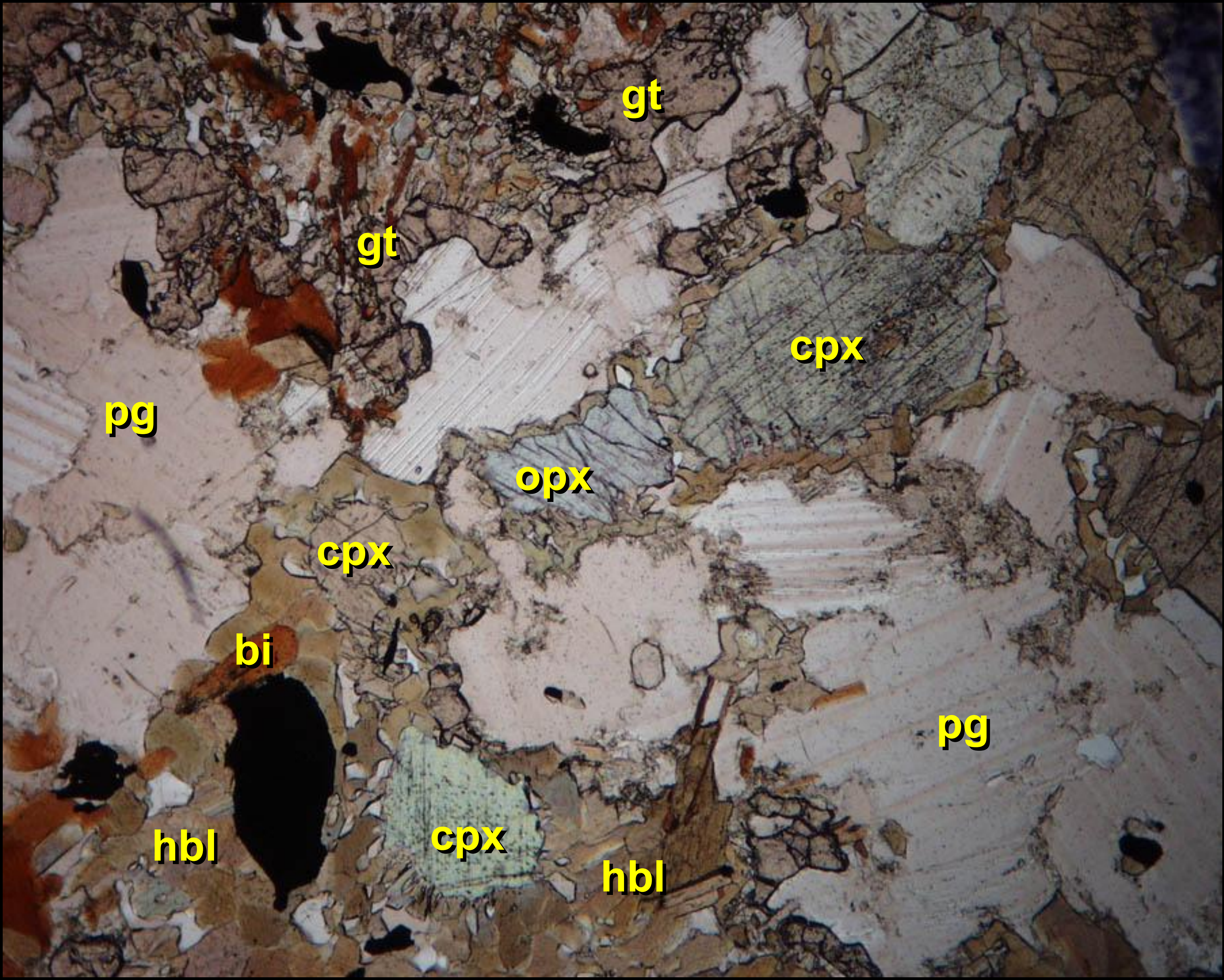

gt
gt
opx
hbl
cpx
cpx
q
pg
gt
cpx
hbl

Anhydrous, high-pressure granulite facies metamorphism



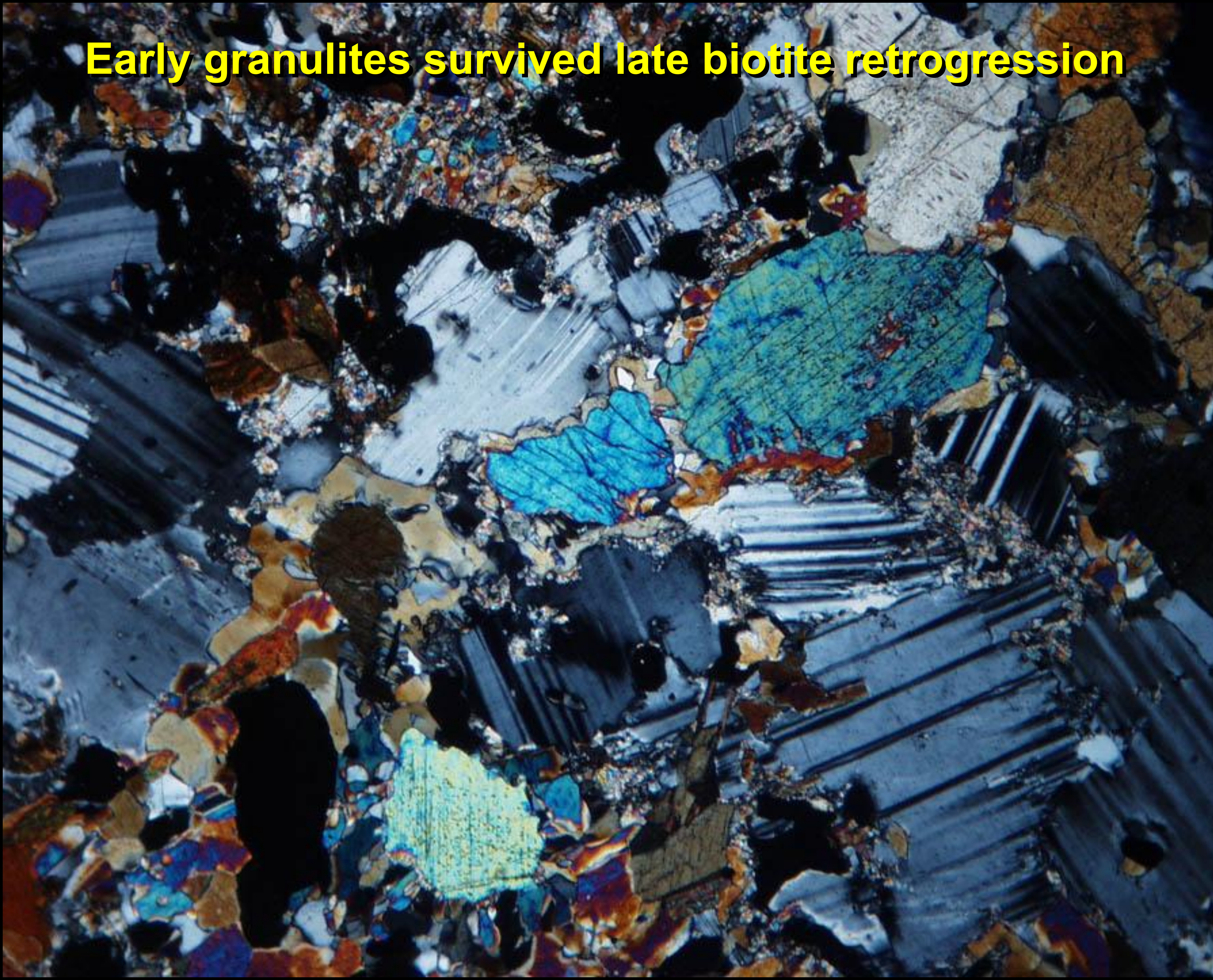

pg
gt
cpx
gt
pg
cpx
cpx
pg
cpx
gt
gt


Early granulites survived amphibolite grade retrogression

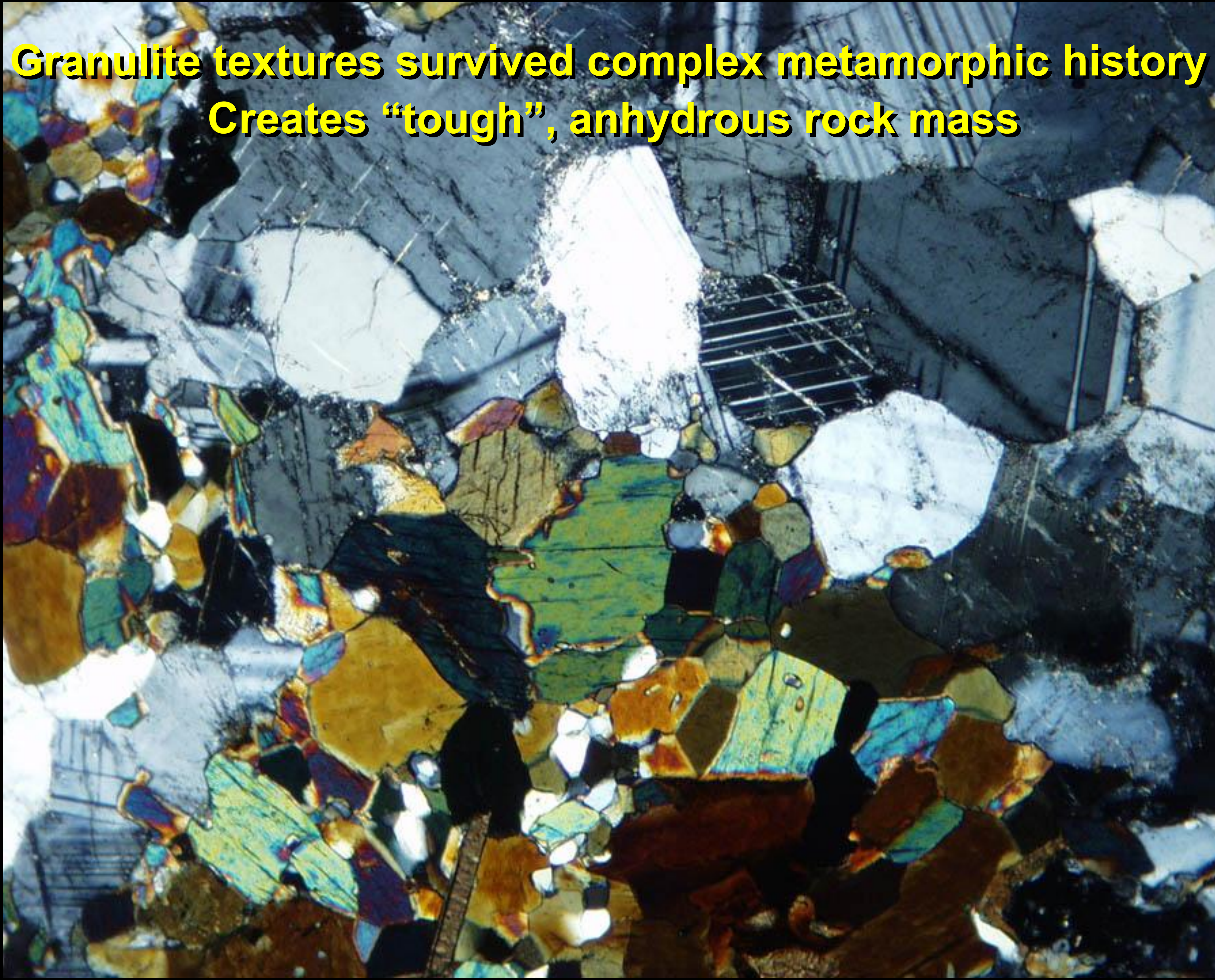


gt
gt
cpx
pg
opx
cpx
bi
pg
hbl
cpx
hbl

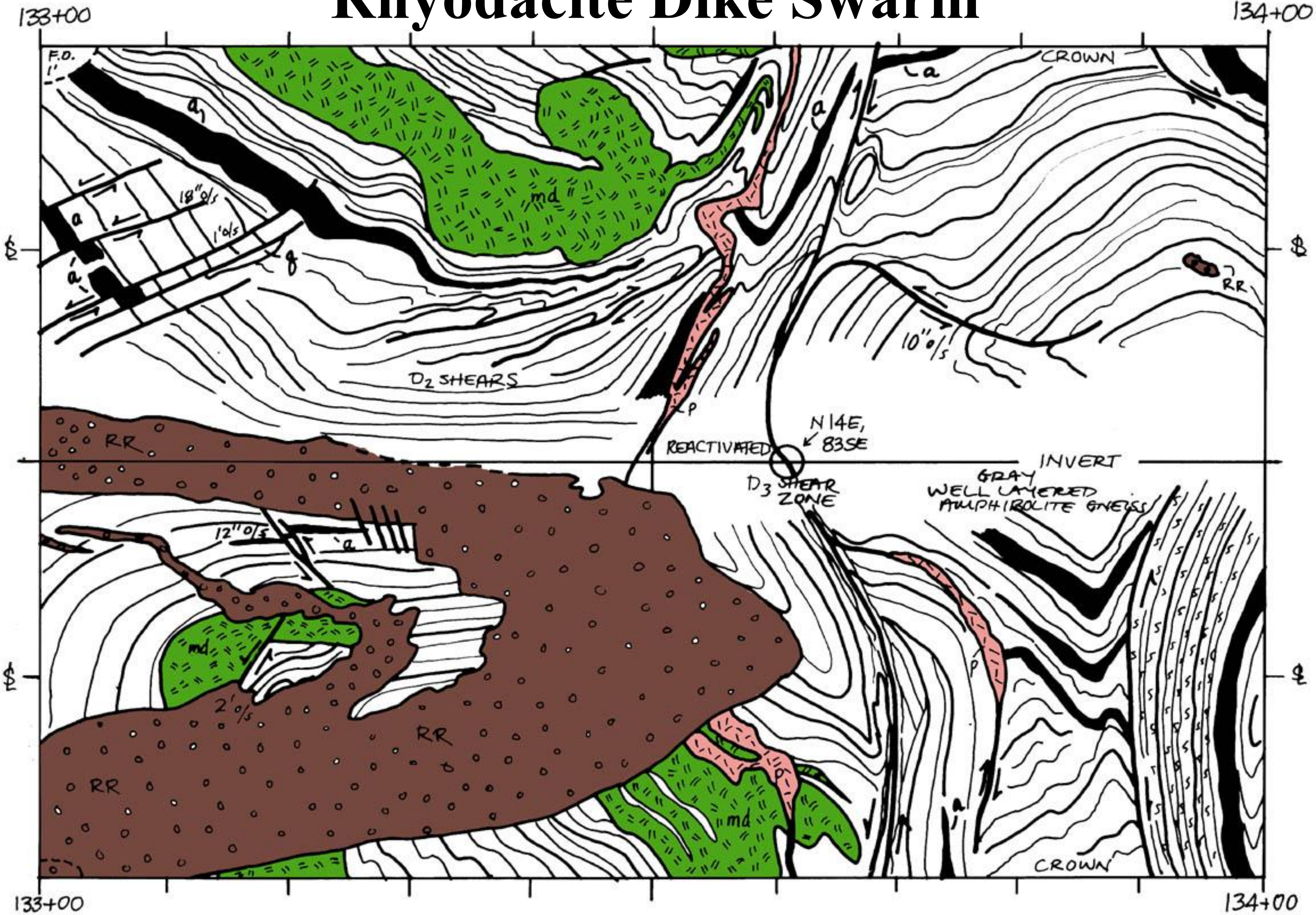
Early granulites survived late biotite retrogression



Granulite textures survived complex metamorphic history
Creates “tough”, anhydrous rock mass

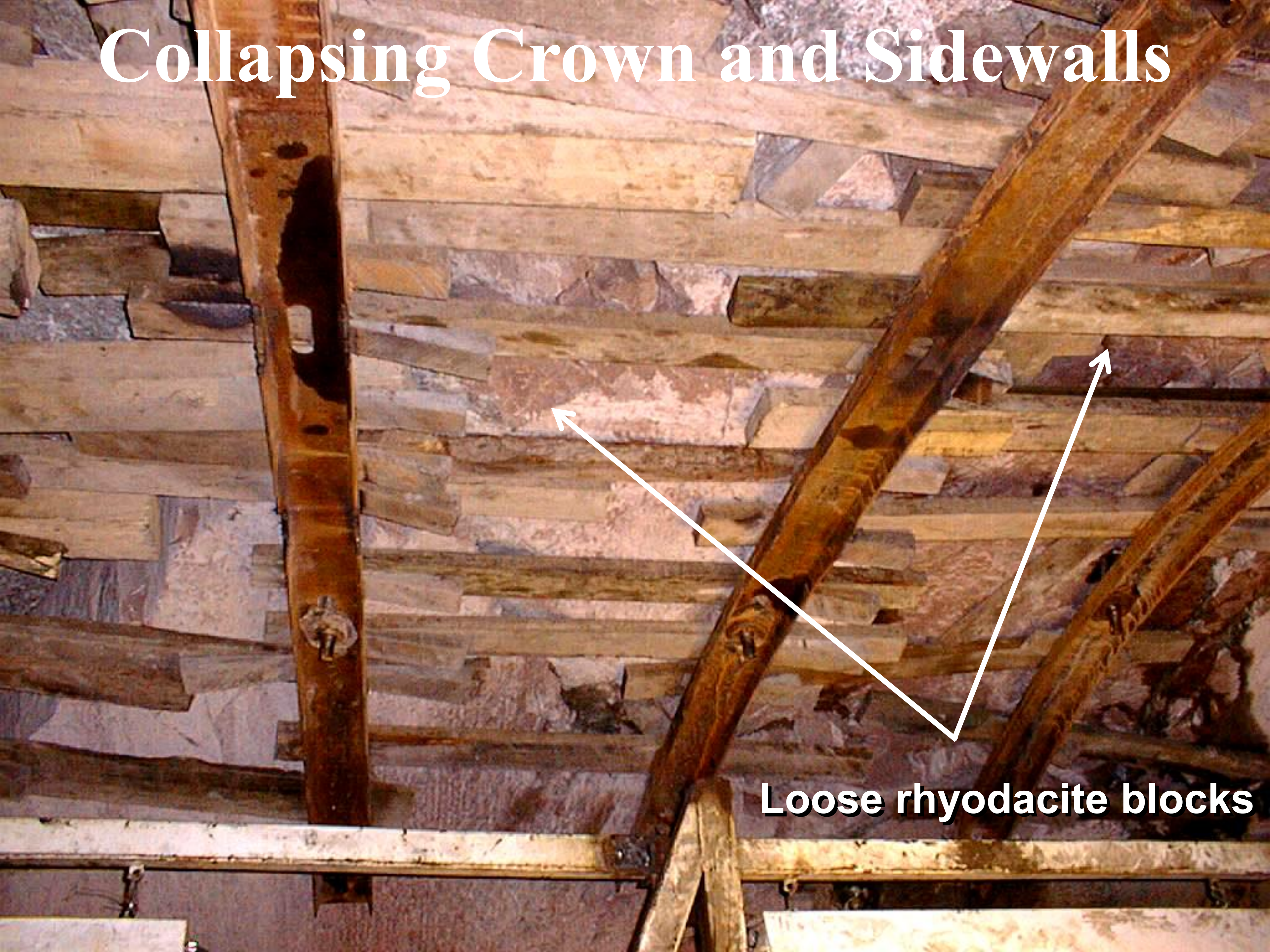


Rhyodacite Dike Swarm




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


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


Collapsing Crown and Sidewalls
Loose rhyodacite blocks

Summary – QT Low Penetration

- **Queens Tunnel: Fordham, not Hartland**
  - Weakly foliated near-isotropic orthogneiss rock mass
  - Tougher, much older deep-seated granulite terrane
  - More highly metamorphosed and structurally complex than the Hartland
  - Decreased TBM penetration rate the result of tougher Fordham rock
- **Collapsing face, crown, and sidewalls forced installation of additional support because of:**
  - Massive ground cut by >300 fractured (faulted) zones
  - Rhyodacite cooling fracture pattern and contact effects
  - Broad zones of subhorizontal fabrics and shear zones

HERRENKNECHT TBM ADVERTISEMENT

Rock Does Not Equal Rock

At Herrenknecht, maximum tunnelling performance and the greatest possible safety are the ultimate goals for the development of tunnelling machines. Expert analysis of the geological conditions result in a "tailored hard rock machine".

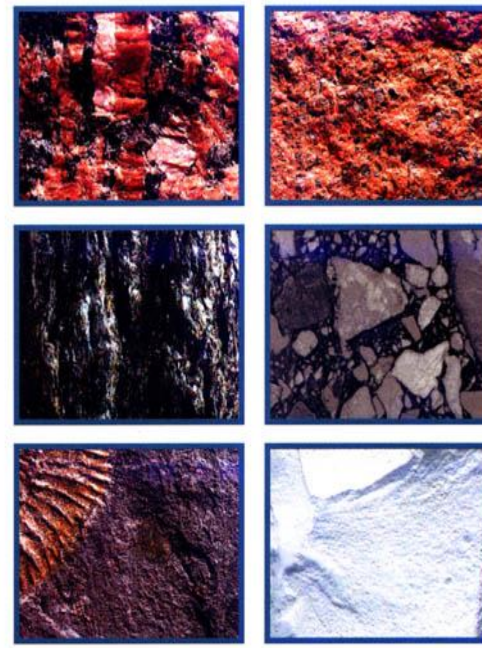
Whether it is solid rock, abrasive rock or rock under high pressure, weathered transition zones with high ground water pressure or caverns, the variety of the geological conditions in a planned tunnel route is virtually unlimited. At Herrenknecht, the geological analysis of the ground conditions is always taken into consideration in the machine design. Cutters and cutterhead are ideally adapted to the varying degrees of hardness and abrasion in sedimentary, metamorphic or igneous rock.

All Experts On One Team

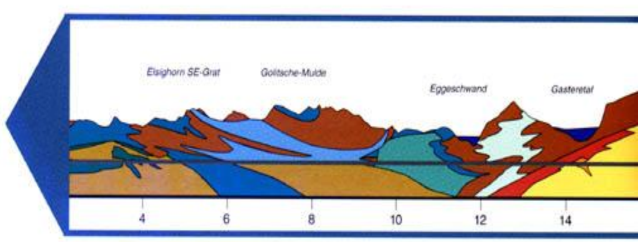
The excavation process in hard rock takes place in the peak state of the shear and compression resistance as well as tensile strengths of the rock. At the same time, the best possible tunnelling performance has to be achieved. At Herrenknecht, a team of internal specialists from the disciplines of rock mechanics, mechanical engineering and process technology find the optimum project solution for developing the machine design.

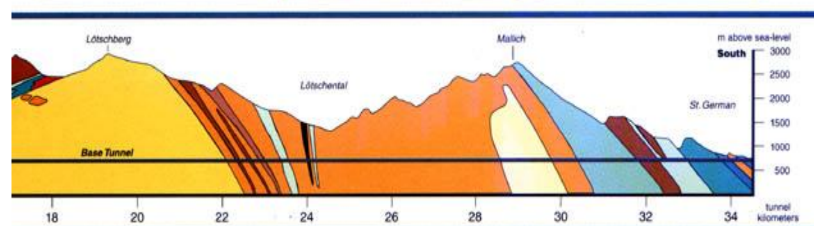
Geology

Mechanical rock excavation is confronted by rock with varying degrees of hardness, e.g. with extremely hard gneiss (top left) and granite (top right), medium hard mica schist (center left), breccia (center right) and claystone (bottom left) as well as limestone (bottom right).



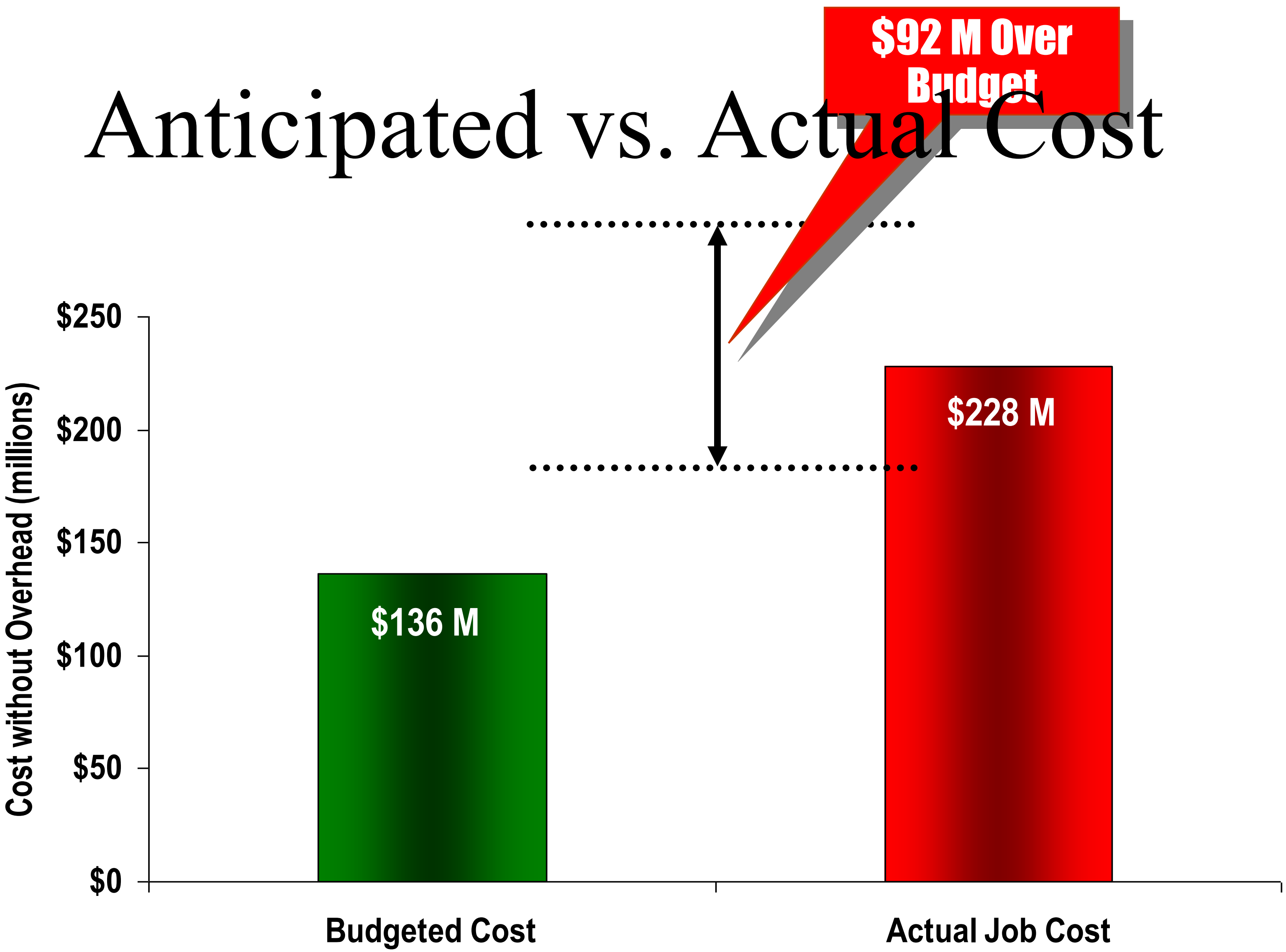
The formation of each mountain range is unique. Lötschberg in Switzerland consists of a wide variety of rock formations along the tunnel route. Herrenknecht supplied two single gripper machines (Ø 9.43 m), which enable mechanical rock stabilization as close as 4.2 m behind the cutterhead.



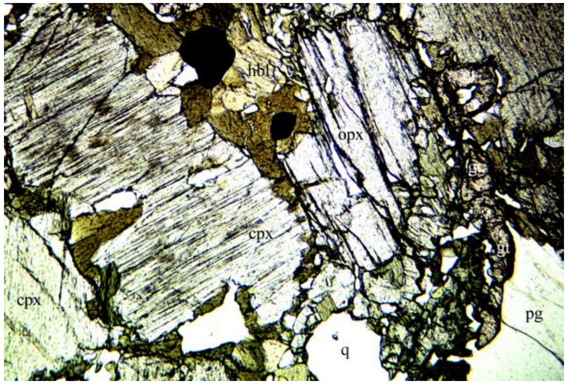


Extra Slides

Anticipated vs. Actual Cost



- **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	53-39no	M some Ex	M Exsol	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 siev	tr
Q119	026+65	45	2.93	m 10	m15	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	trms
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/ver	10c vermi
068+10	068+10	5:50		M		M	55	m	M	m gn		*m vermic with plag*	
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

Petrographic Data Sheet