DESIGN AND CONSTRUCTION OF THE HARLAN TUNNELS

Presenter Name John Stanton

Presenter Title Chief, Geology Section

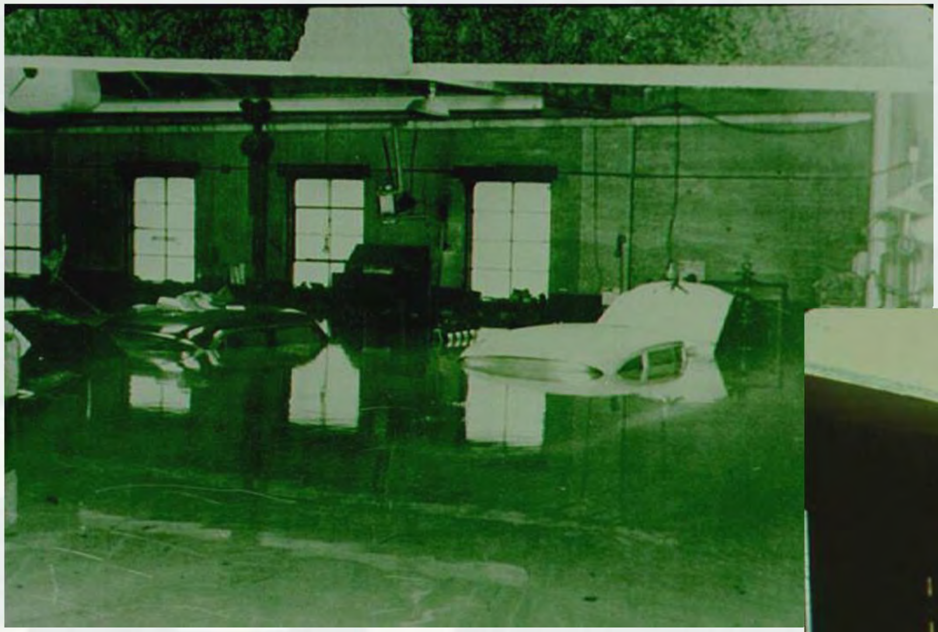
Duty Location Nashville, TN

Date of Presentation August 3, 2010

US Army Corps of Engineers
BUILDING STRONG®

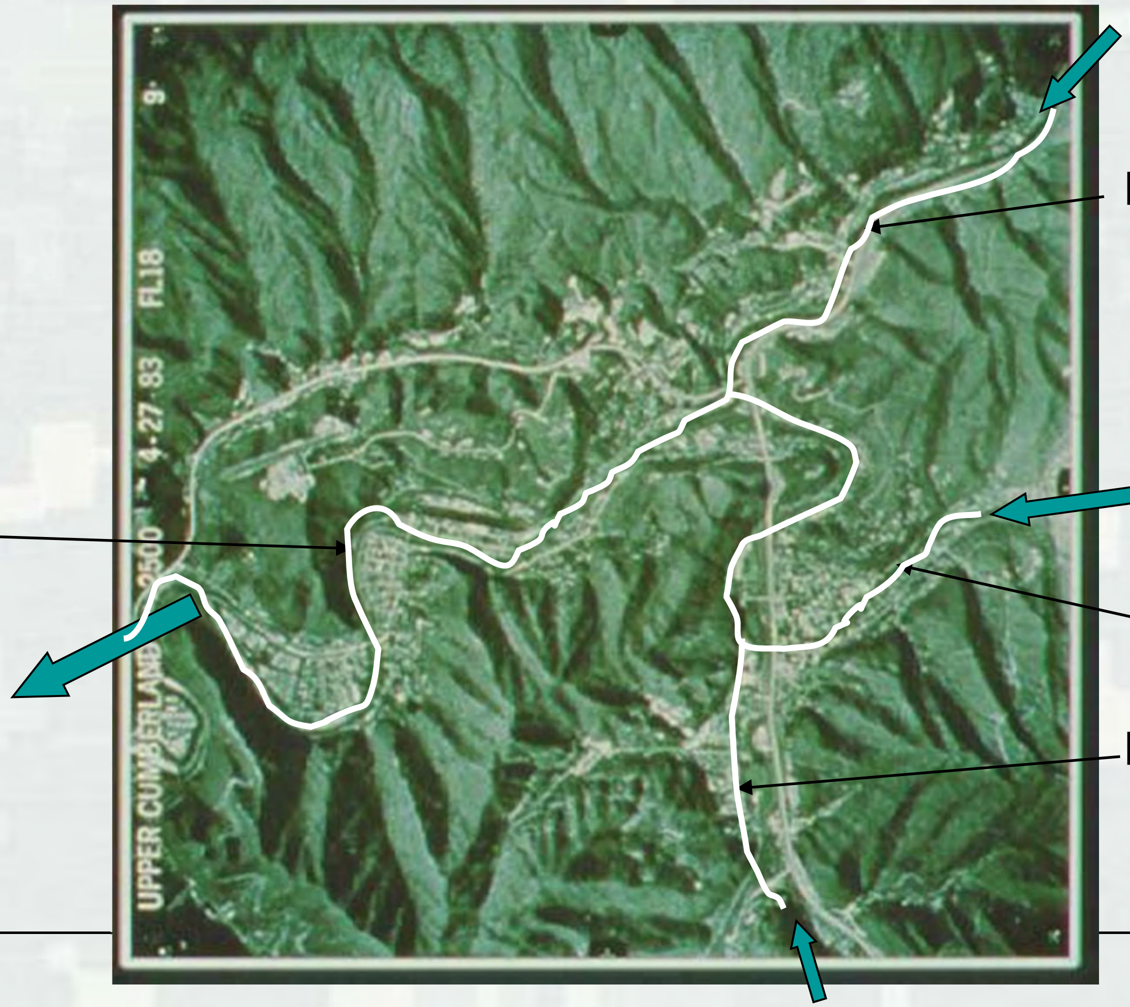
Project Location

The Problem



April 1977

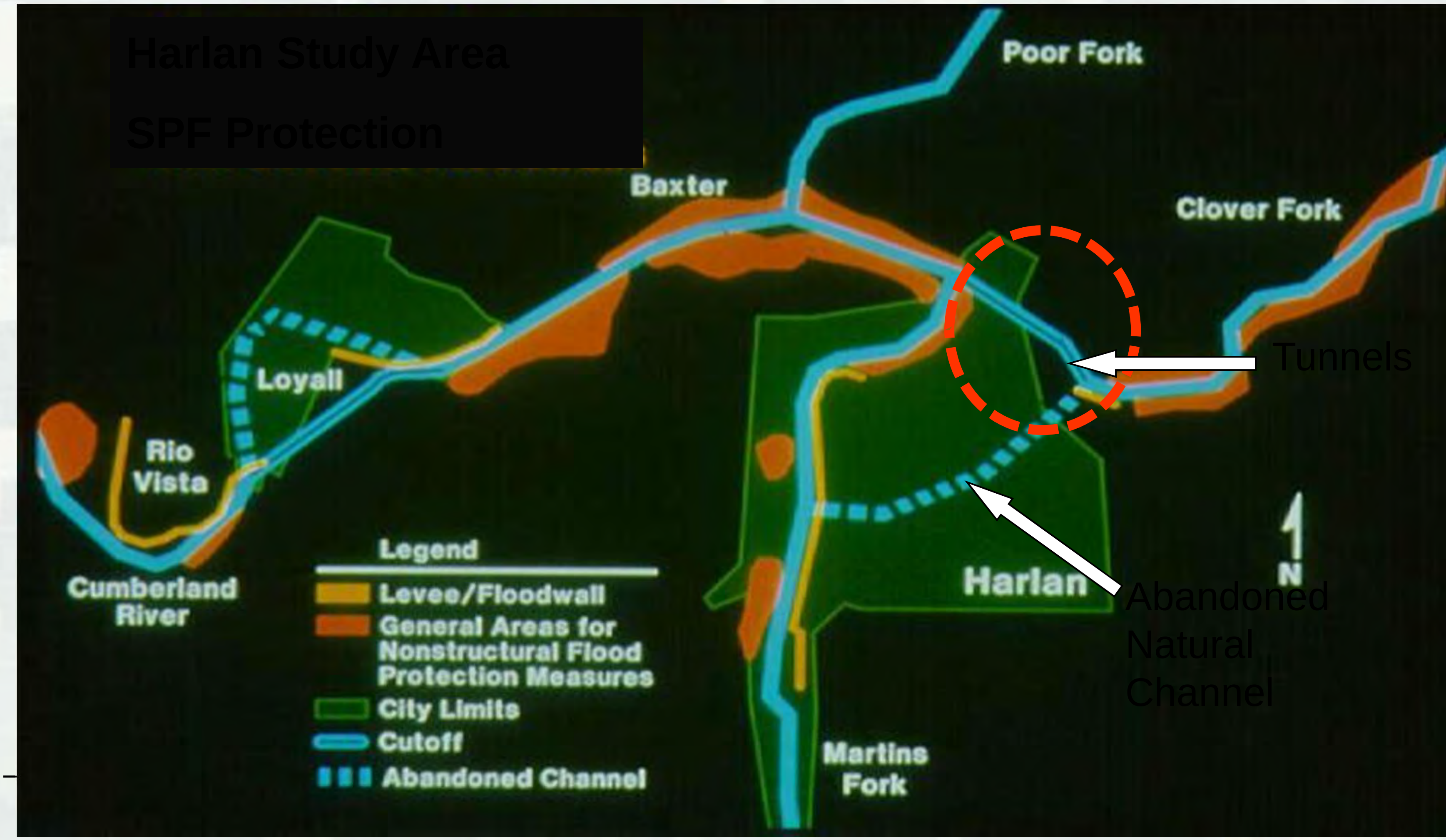
Why In Harlan?



The Recommended Plan

- Diversions
- Levees and floodwalls
- Pump stations and gravity outlets
- Non-structural

The Project Layout



Aerial View Along Tunnel Alignment

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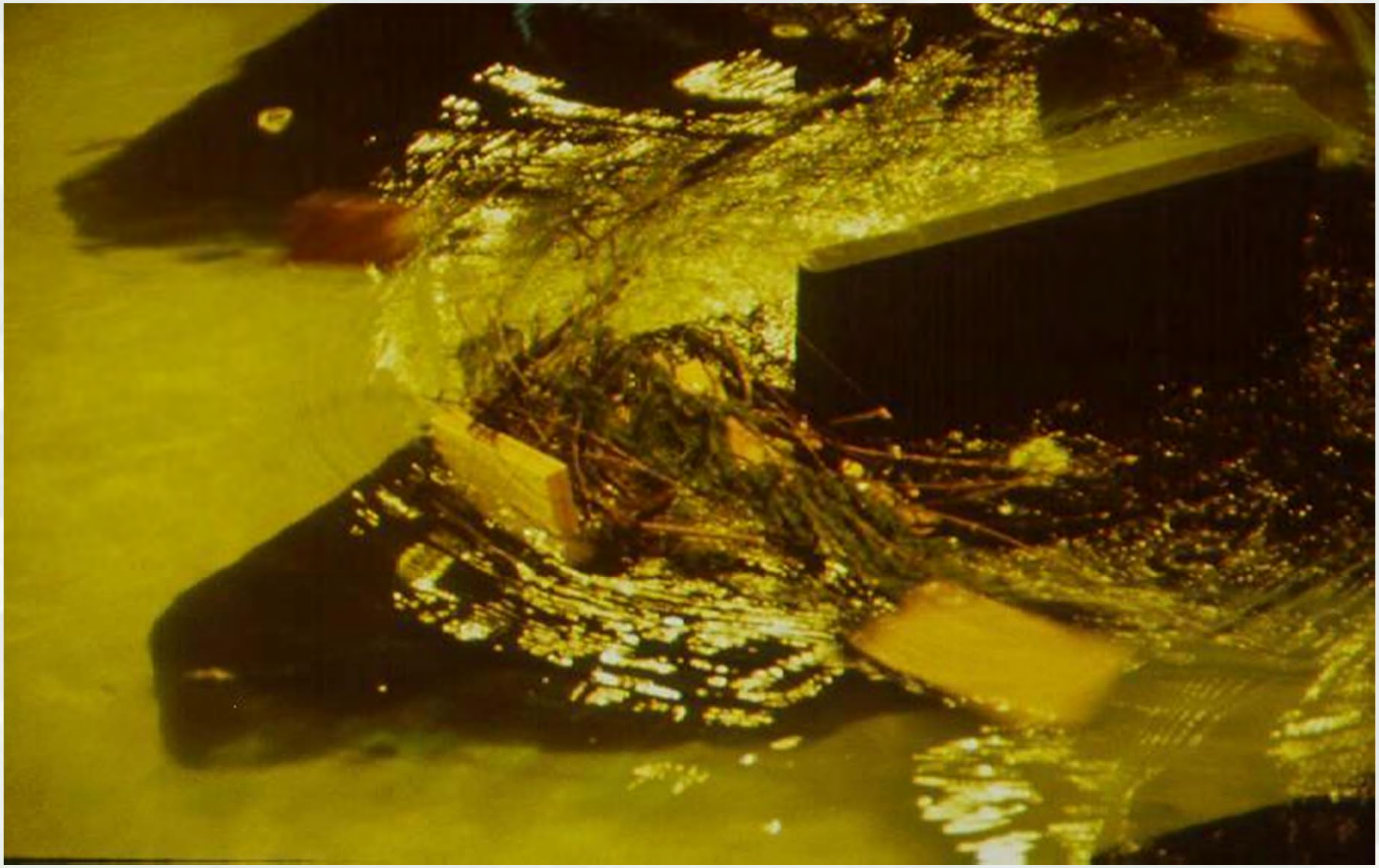
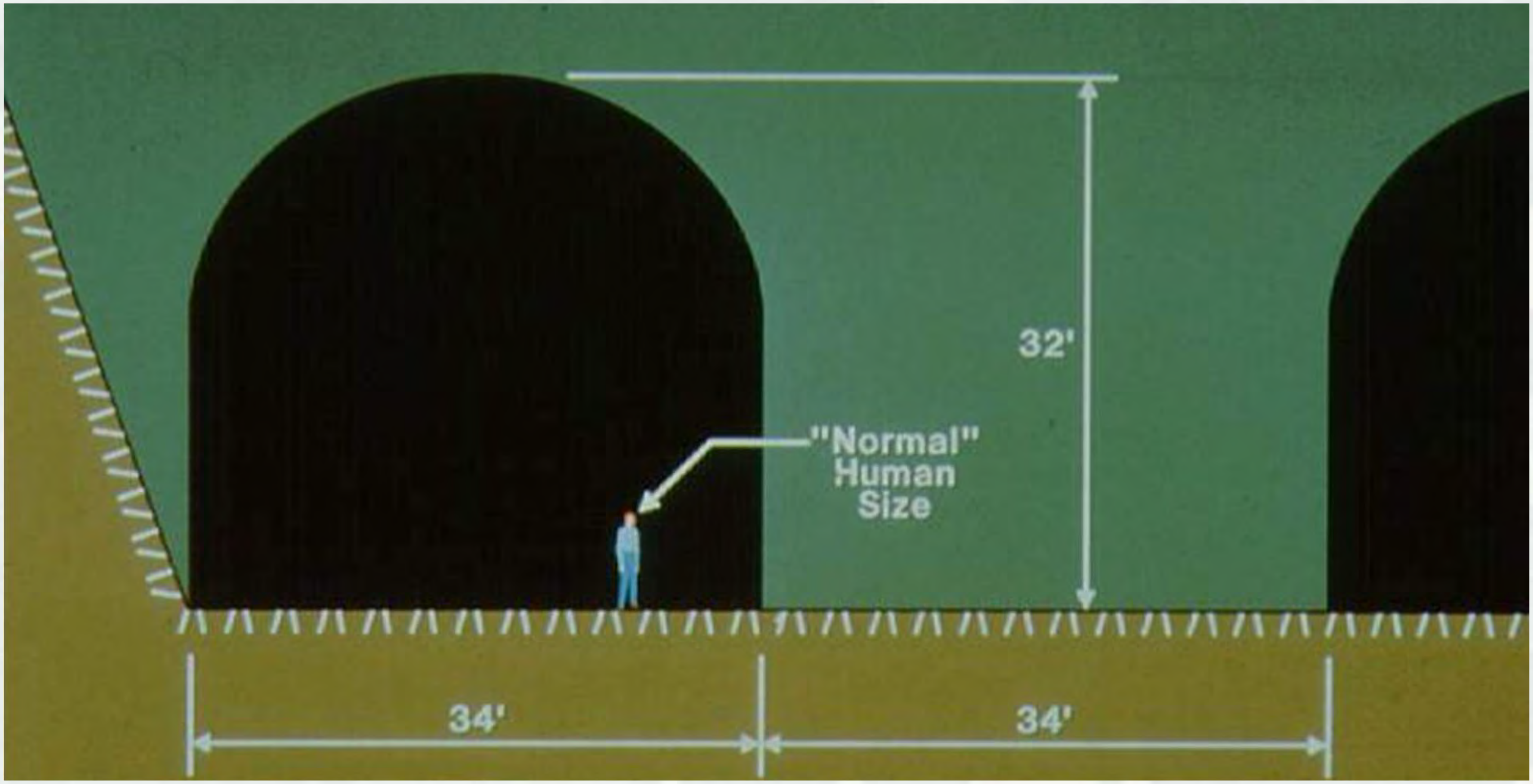
Feasibility of Tunnels

Physical Model, Waterways Experiment Station - Flow Test

Modeling the Intake With Debris.

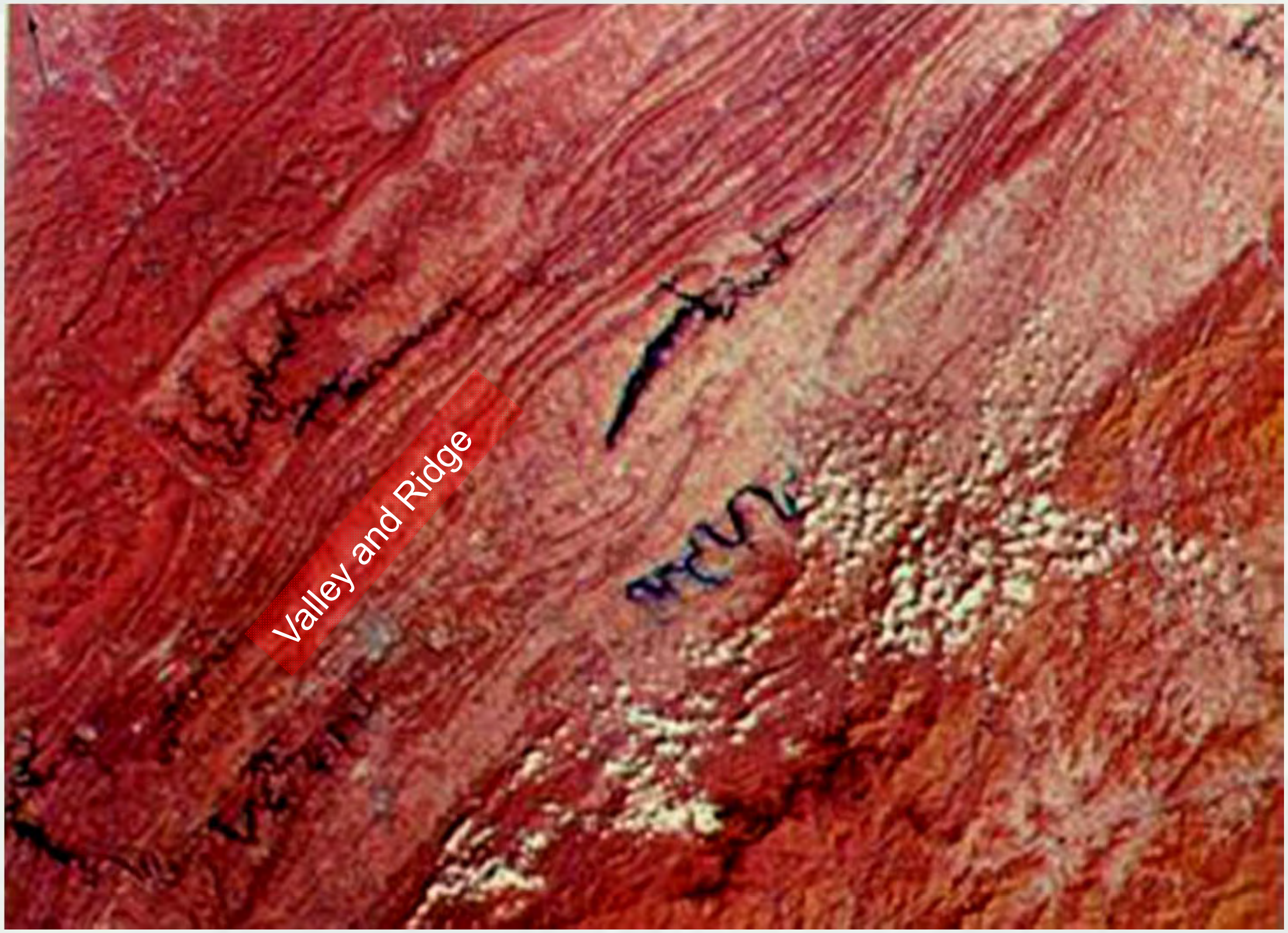


The Tunnels Relative to Human Size.



Geology of the Project

★Approximate Location of Harlan



Landsat View, South of the Project

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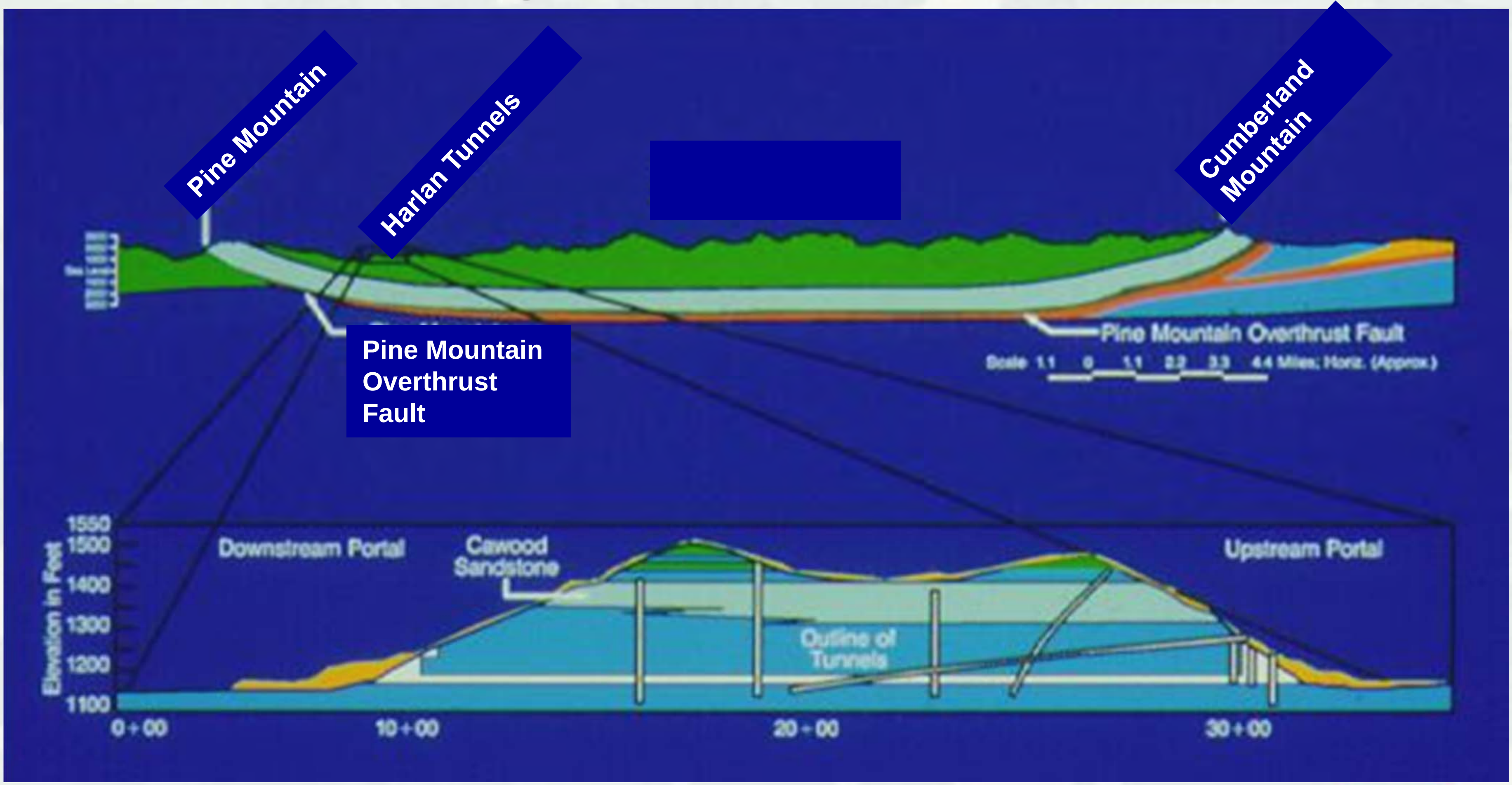
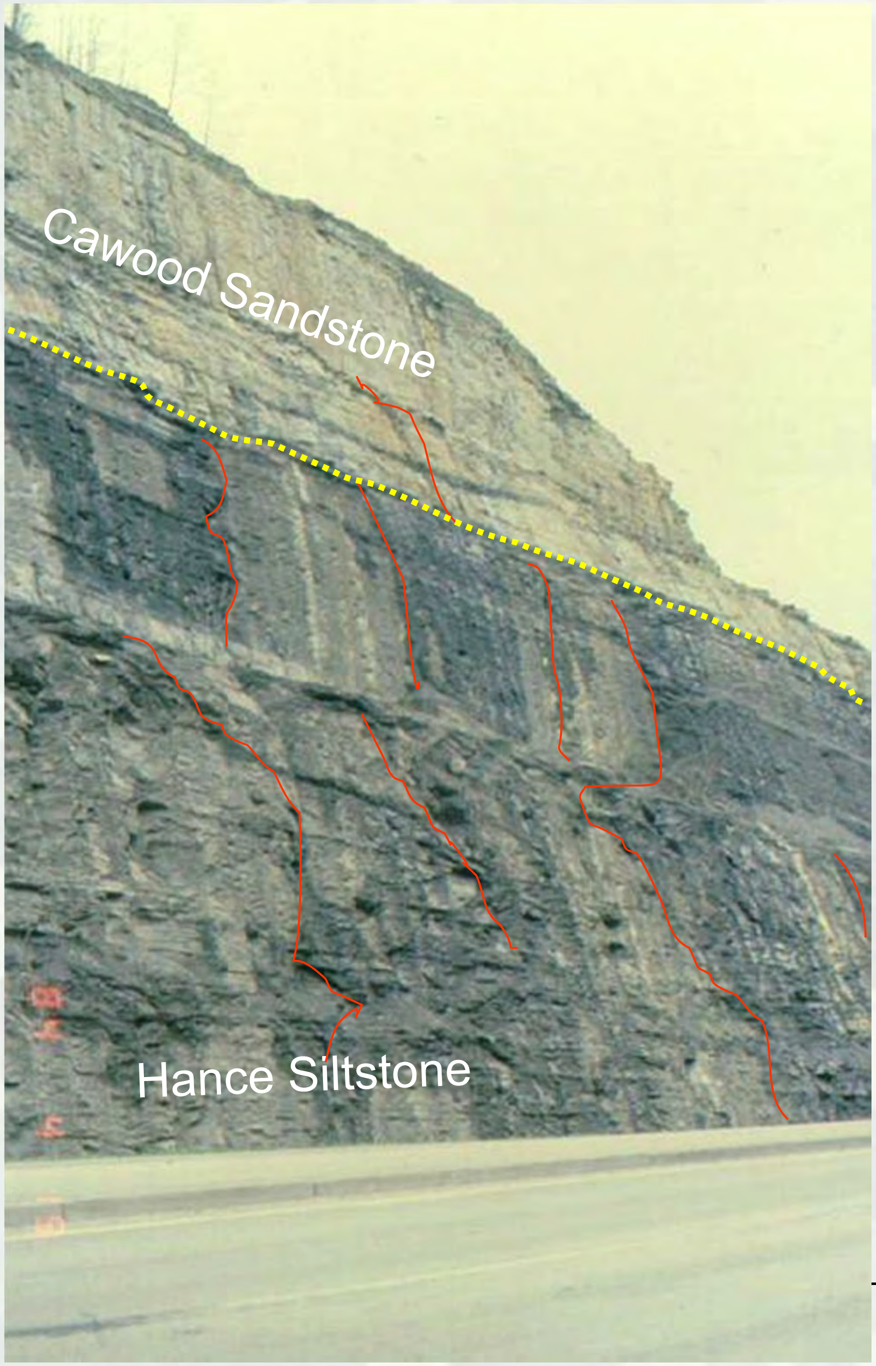
Geologic Cross-section



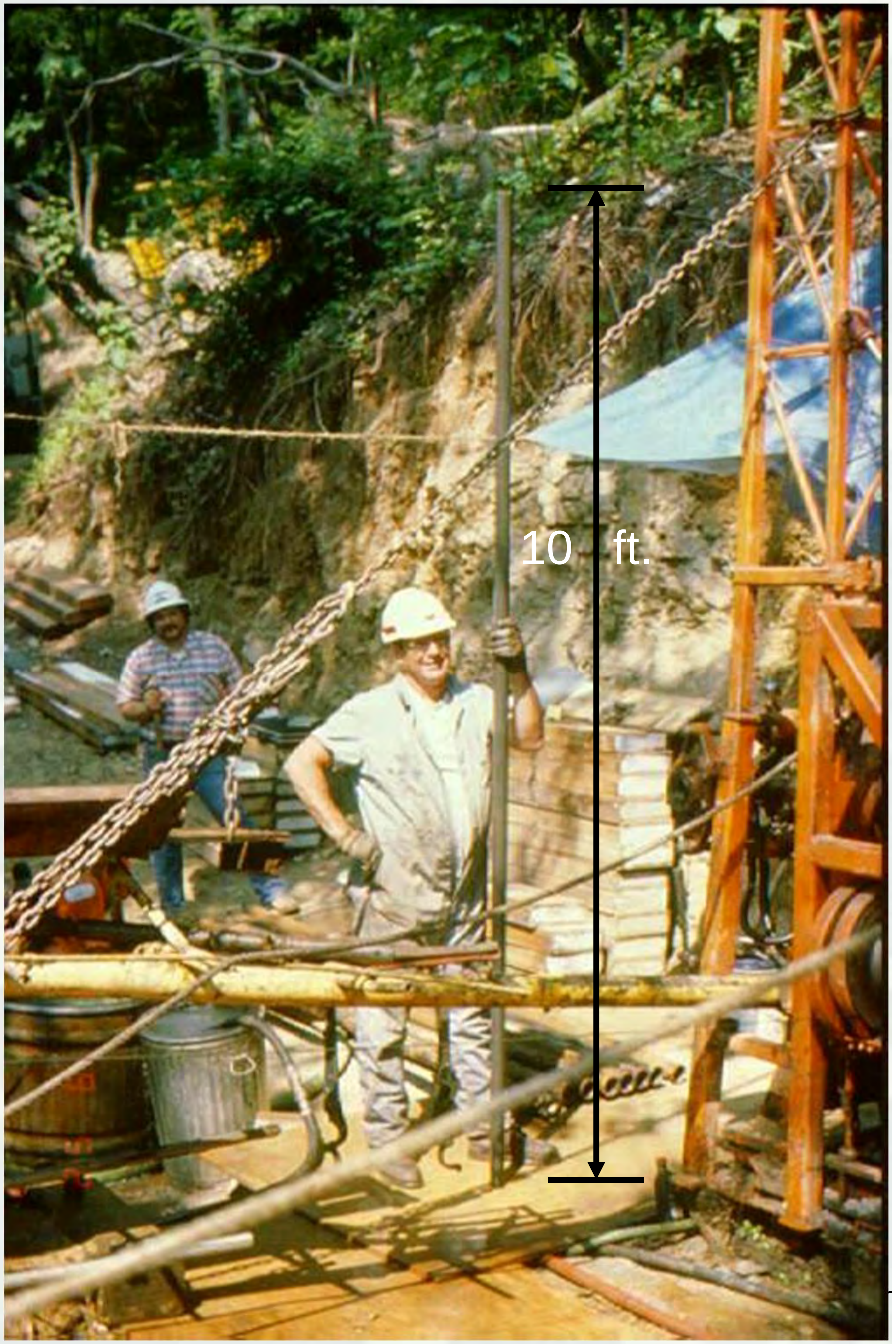


Typical Section Exposed on Road Cut at Highway 421.

A good location for gathering strikes and dips.

The Exploration Program

Single Shot Camera Borehole Survey System.



Core Recovery From the Horizontal Drilling

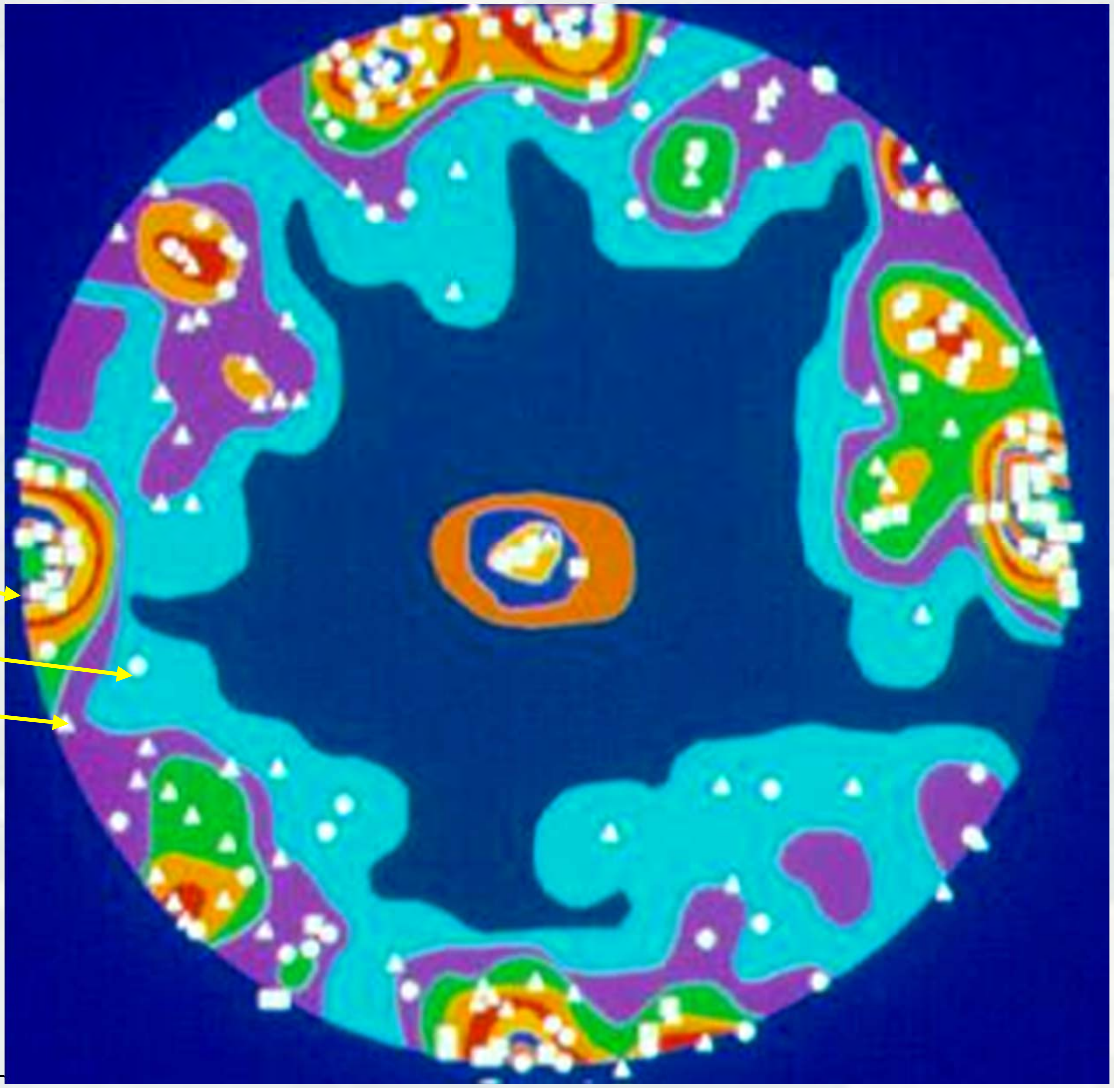
70% recovered as 10 ft. unbroken cores.

Videotaping the Holes

Polar Plot of Discontinuities

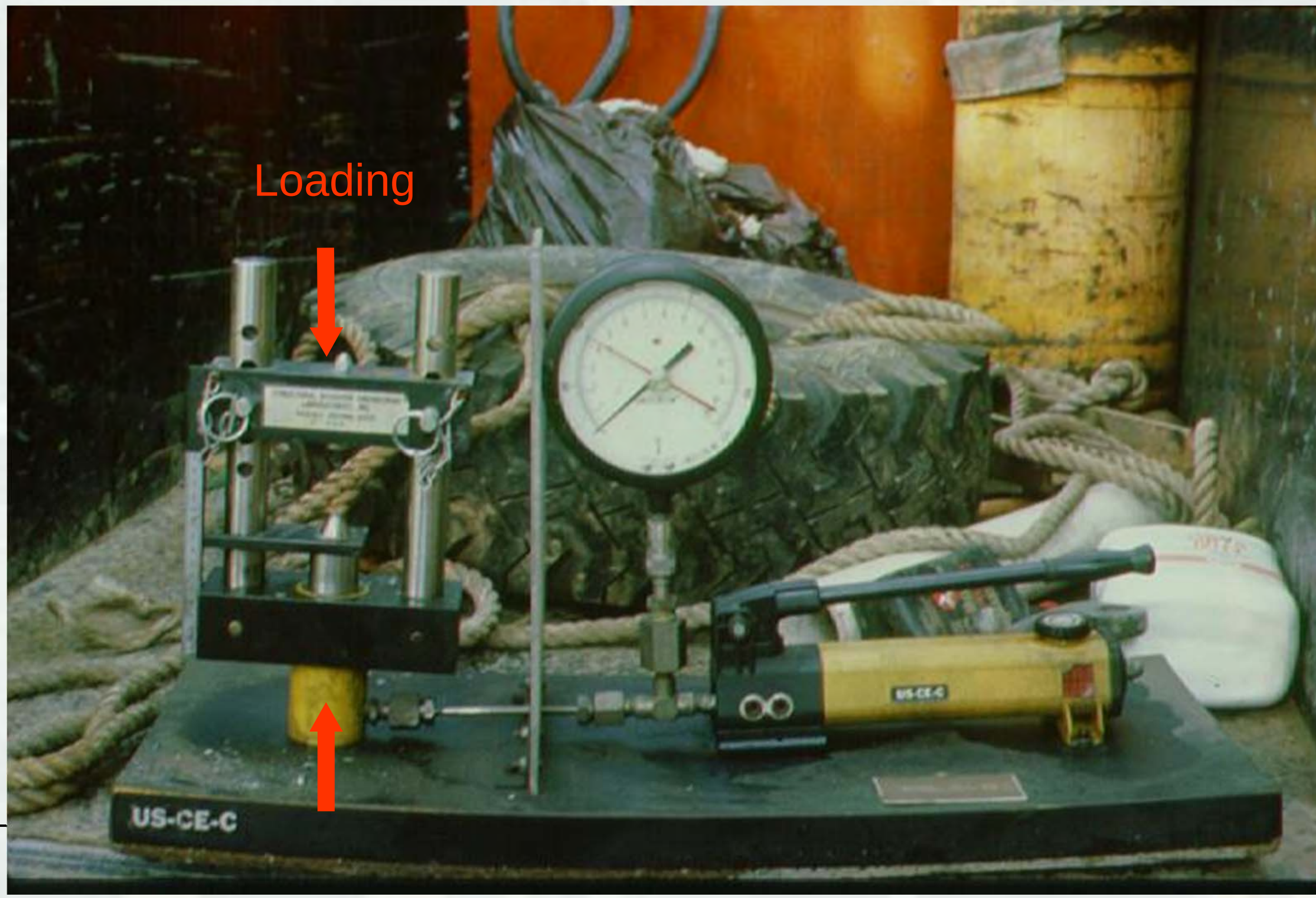
Different symbols for different data sources such as angle holes, televiewer, or surface mapping.

North

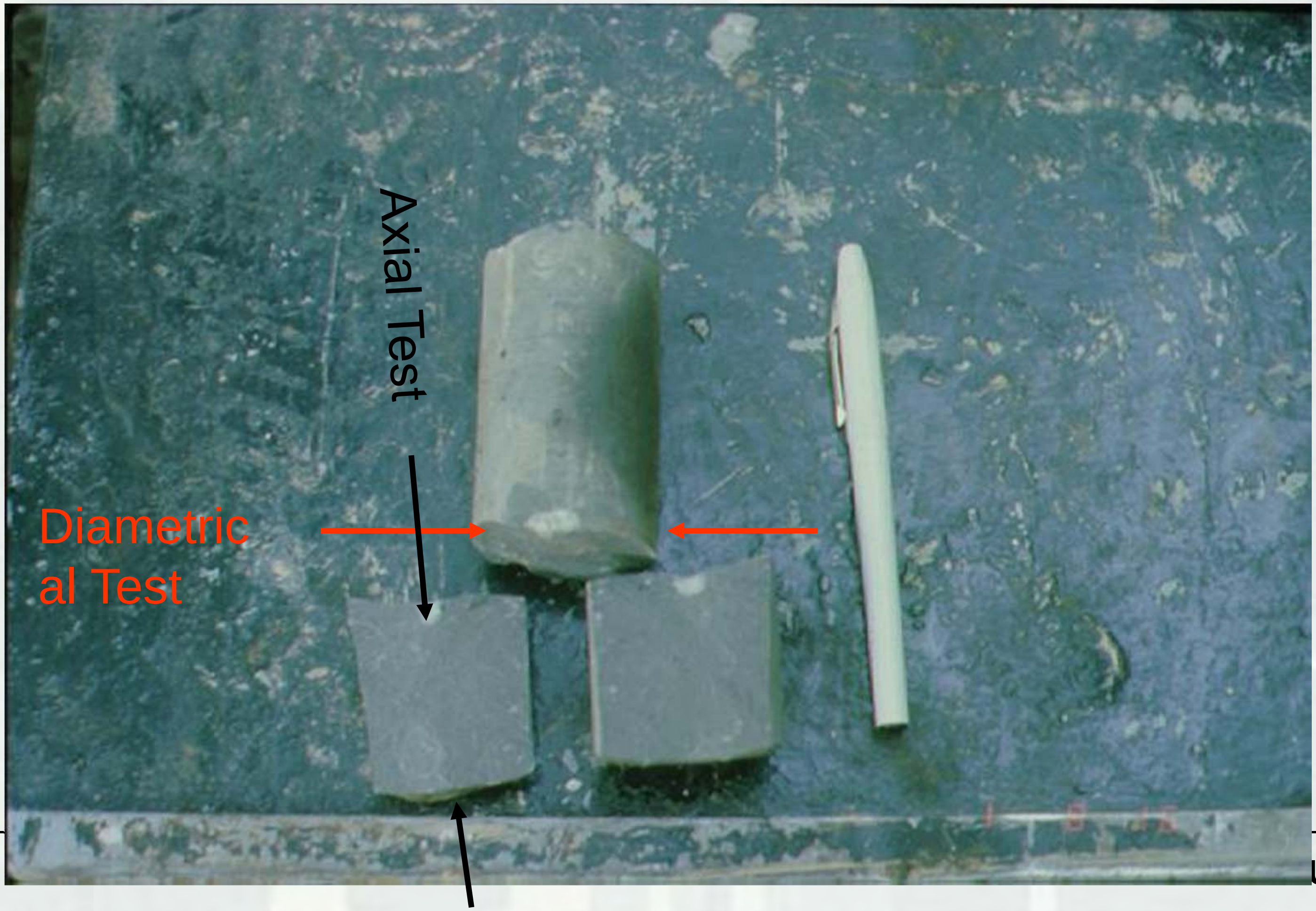


South

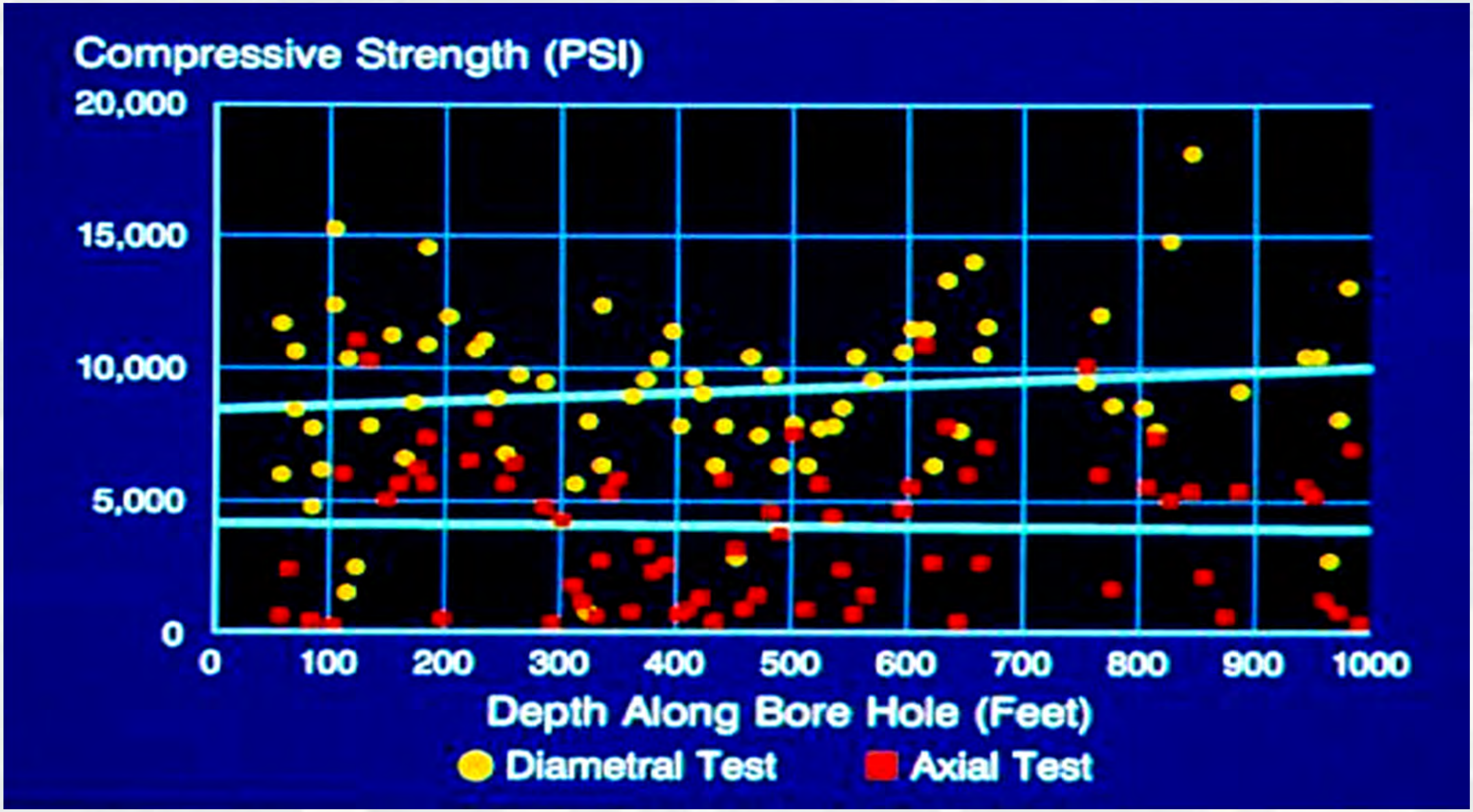
Point Load Testing Apparatus



Typical Sample After Testing



Point Load Test Data For Hole CH-1



Other Field Testing.

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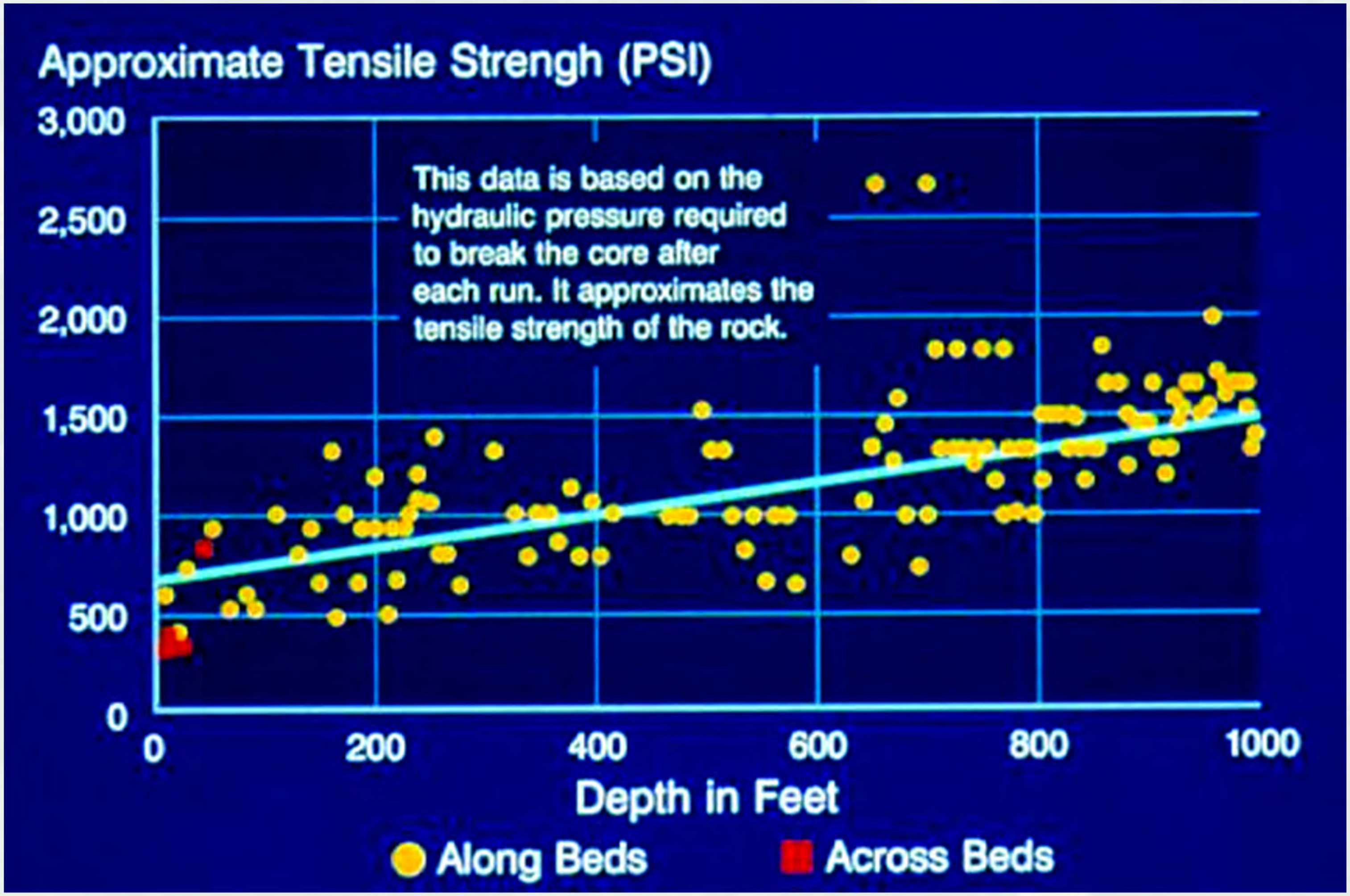
Pull Break Tensile Test



Cross-hole Seismic Velocity Profiling

Why Do the Profiling?

Ripping can be cheaper but is it feasible?

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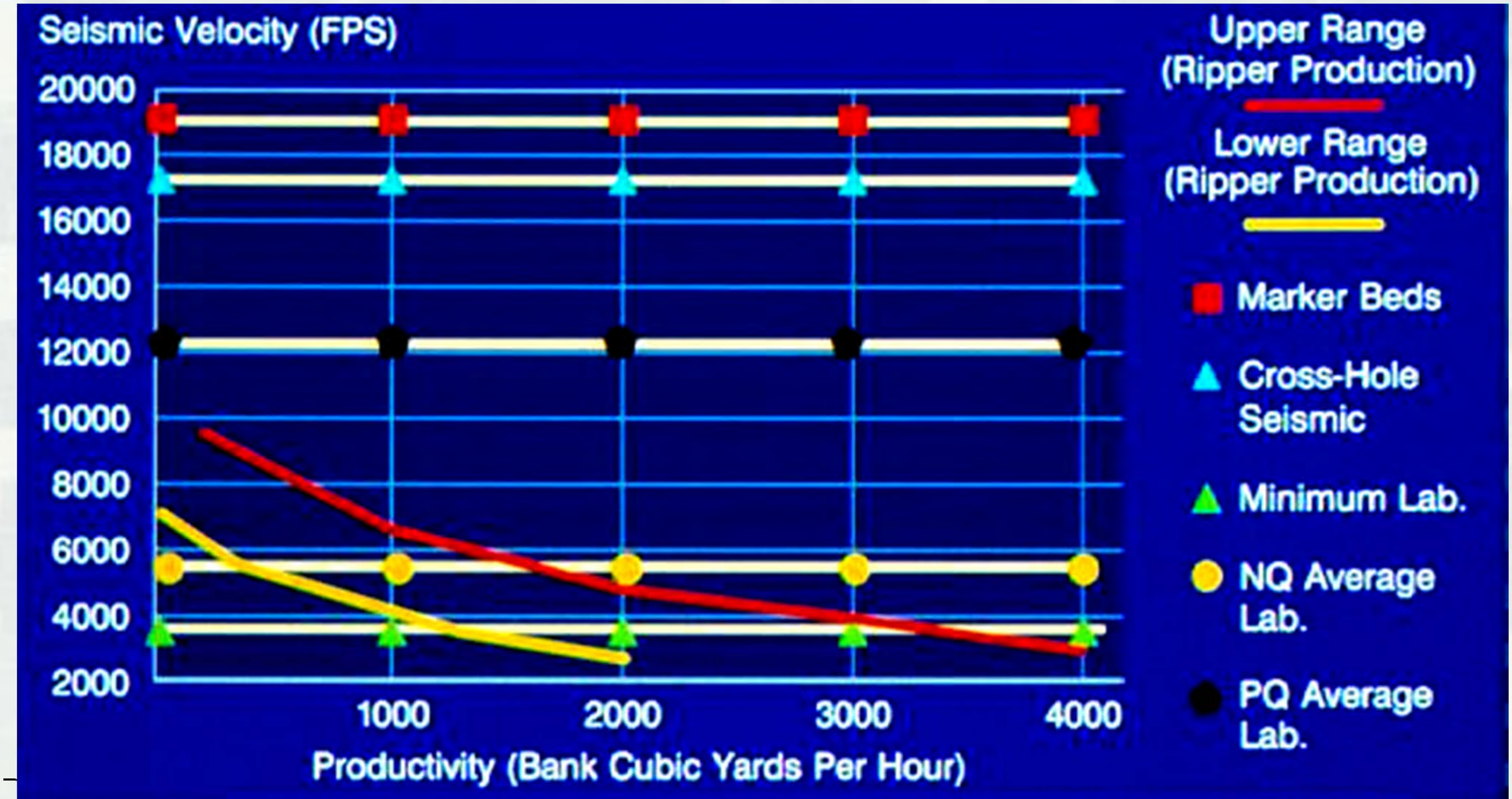
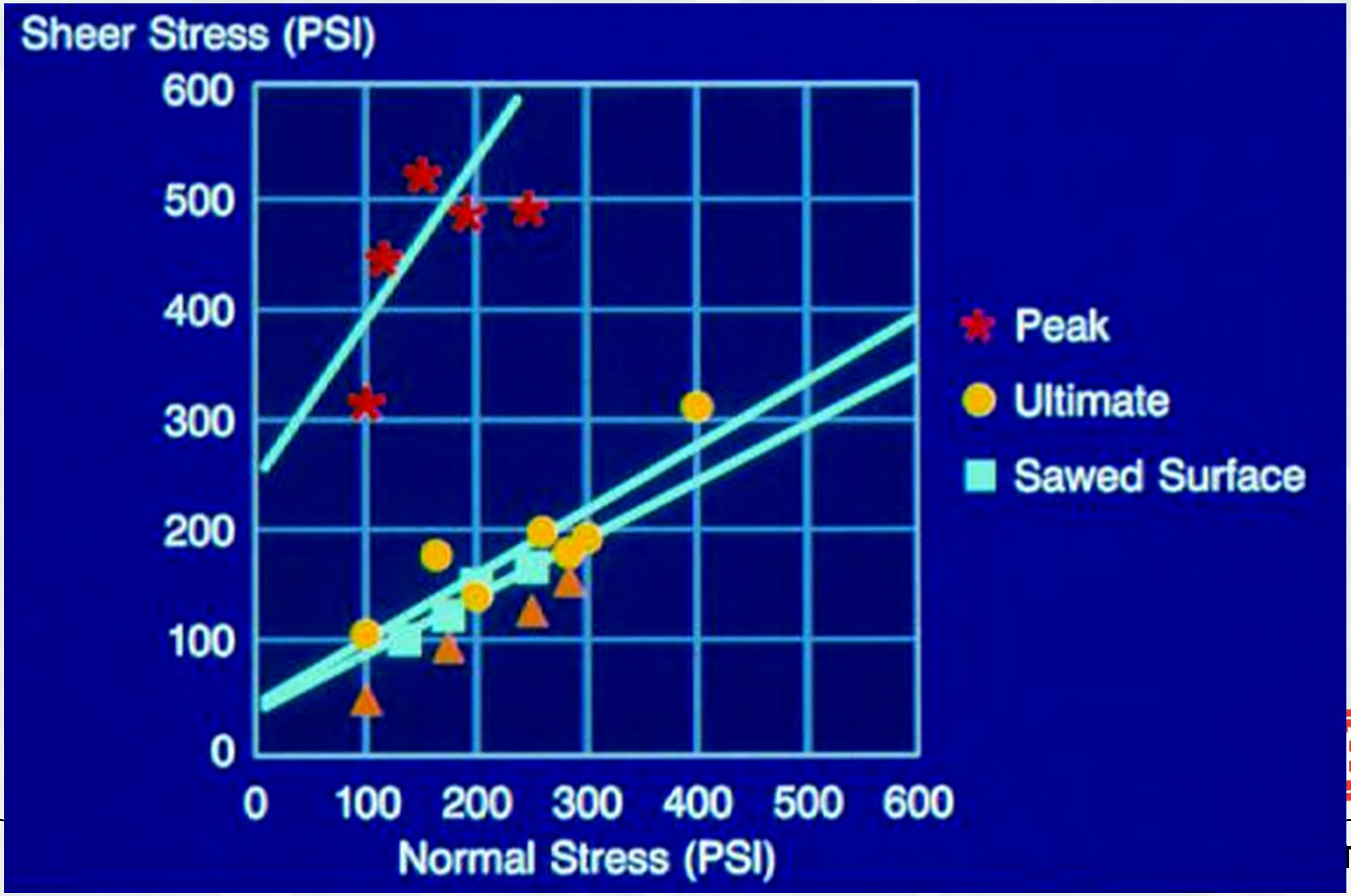
Estimating Ripping Production Vs. Seismic Velocity of the Rock Mass



Direct Shear Test Averages



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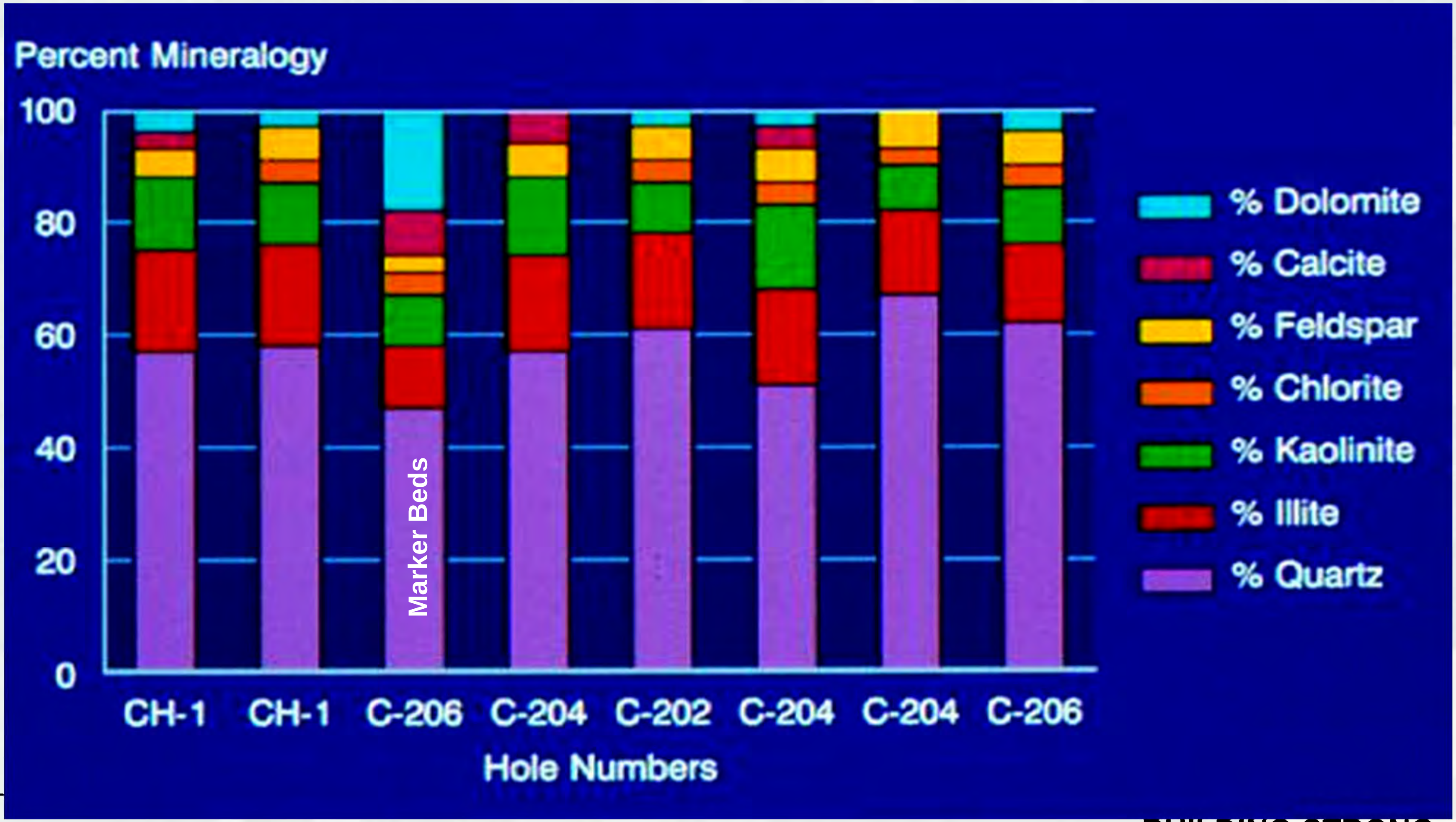
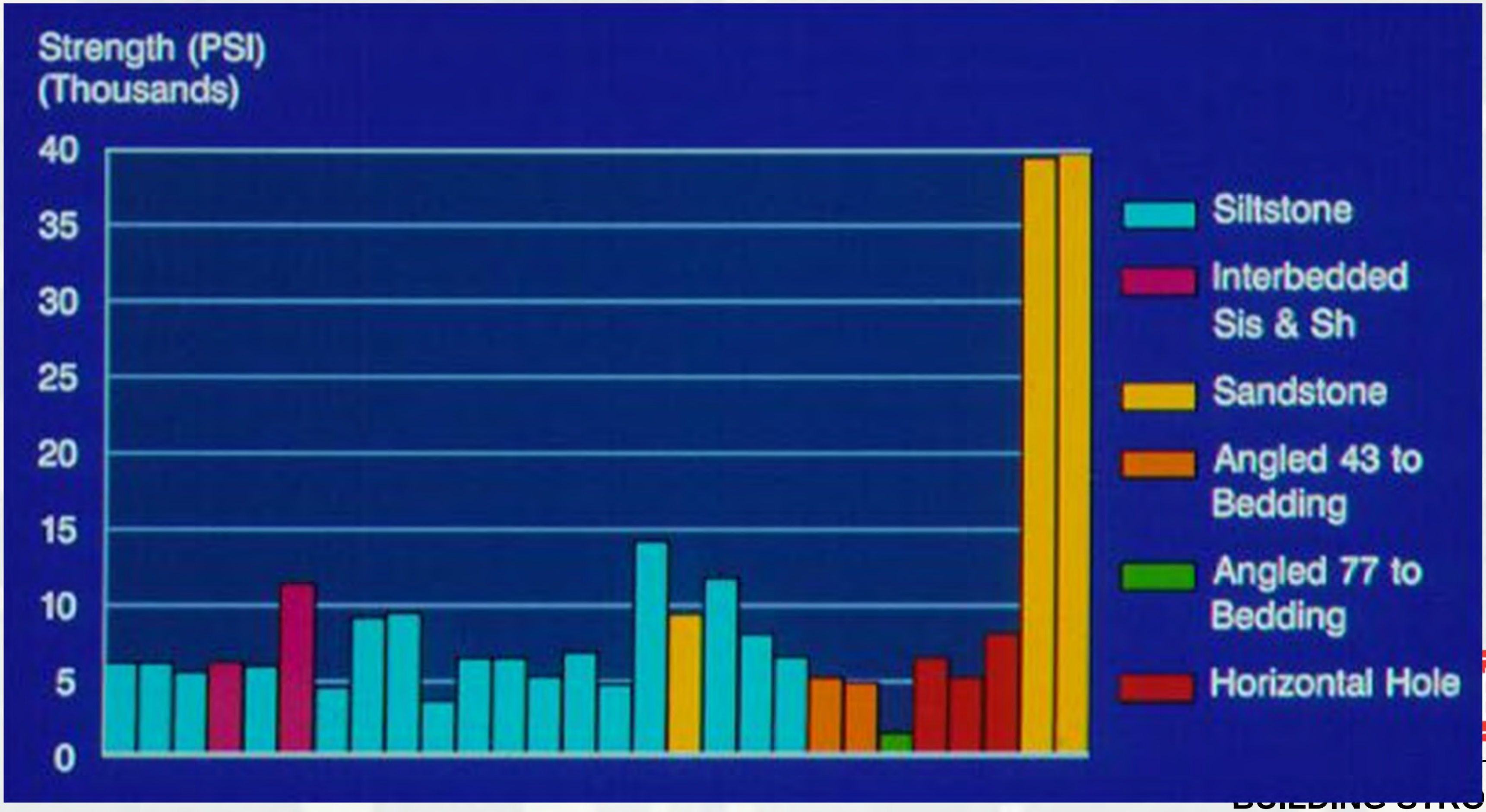
X-ray Diffraction Data



Unconfined Compressive Strength.



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Rock Mass Classification System Analysis RMR System (CSIR)

	High Value	Low Value
1. Rock U_c Strength (10,557 psi - 5,412 psi)	6	3
2. RQD Rating (95 - 100)	20	20
3. Joint Spacing (1 Ft. - 10 Ft.)	30	20
4. Joint Roughness (Very Rough - Slightly Rough)	25	20
5. Groundwater (Dry - Moist)	10	7
6. Adjustment for Joint Orientation (Bedding)	-10	-10
Rock Mass Rating	82	61
Rock Classification	Very Good	Good

Rock Mass Classification System Analysis
Q System (NGI)

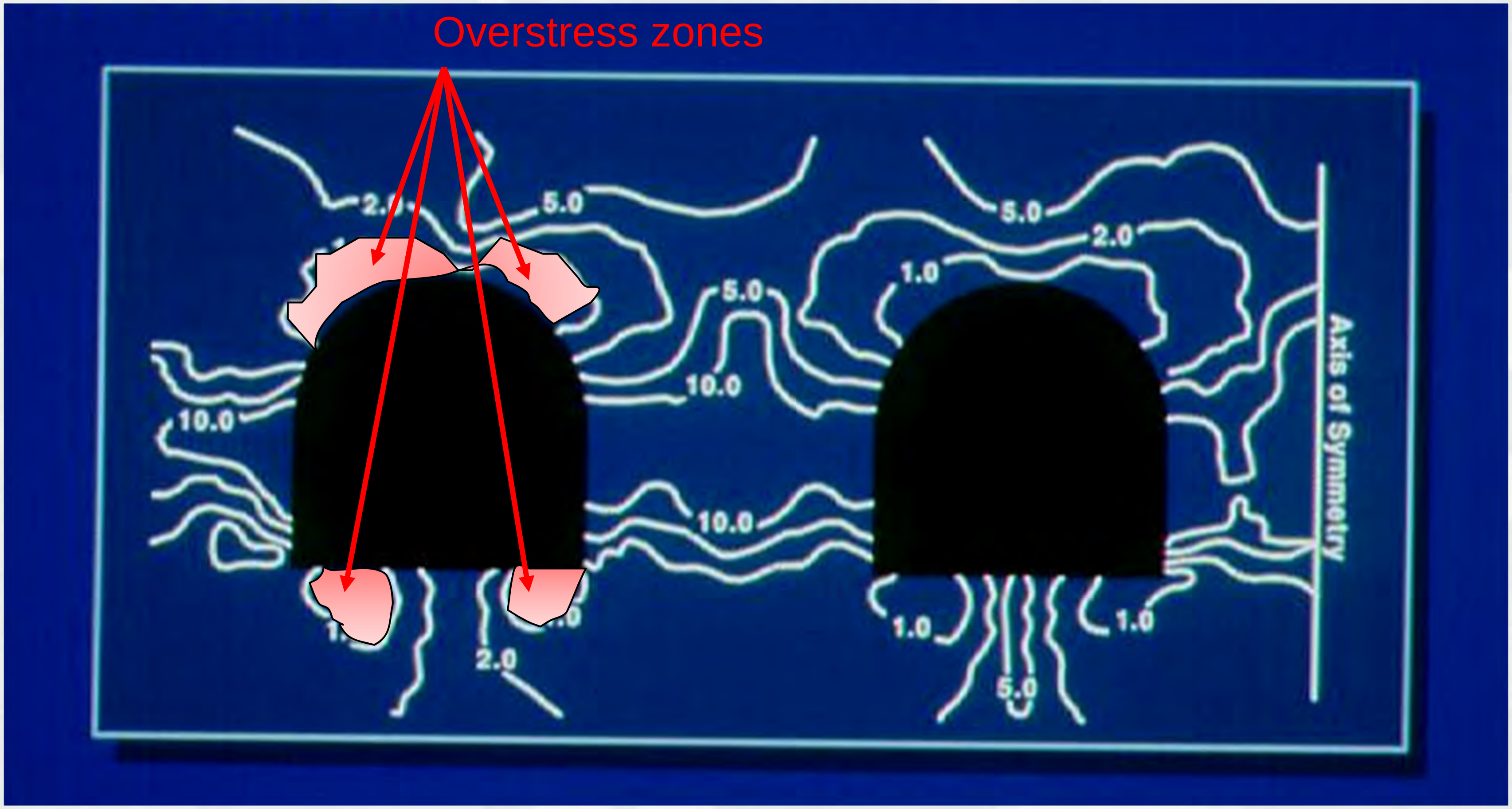
			High Value	Low Value
1.	RQD	Range From Borings	100	95
2.	J_n	Joint # (Massive to One Joint Set)	2.0	0.5
3.	J_r	Joint Roughness (Smooth to undulating)	4.0	3.0
4.	J_a	Joint Alteration (Unaltered)	1.0	1.0
5.	J_w	Joint Water (Dry to Minor Inflows)	1.0	1.0
6.	SRF	Stress Reduction Factor (Low to Medium)	2.5	1.0

$Q = RQD/J_n * J_r / J_a * J_w/SRF$

Maximum Q = 100/0.5 * 4/1 * 1/1 = 800 . . . . Extremely Good Quality Rock

Minimum Q = 95/2 * 3/1 * 1/2.5 = 57. . . . . Very Good Quality Rock

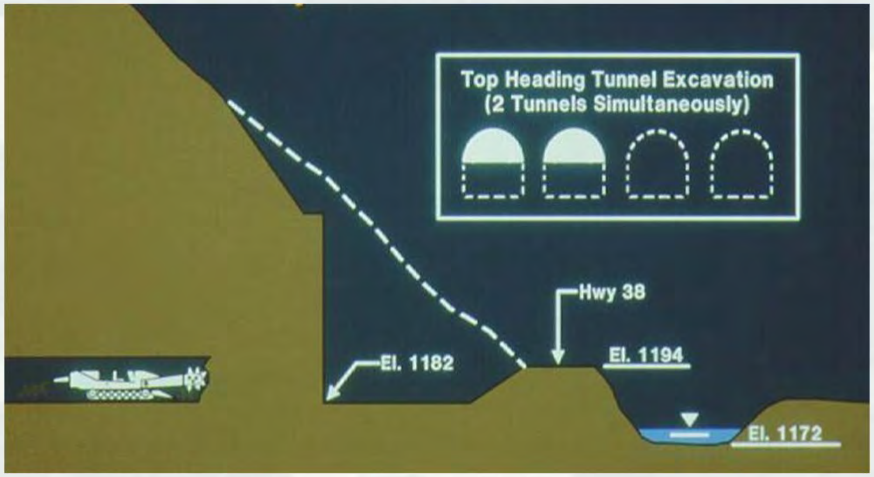
Boundary Element Analysis



Tunneling Methods

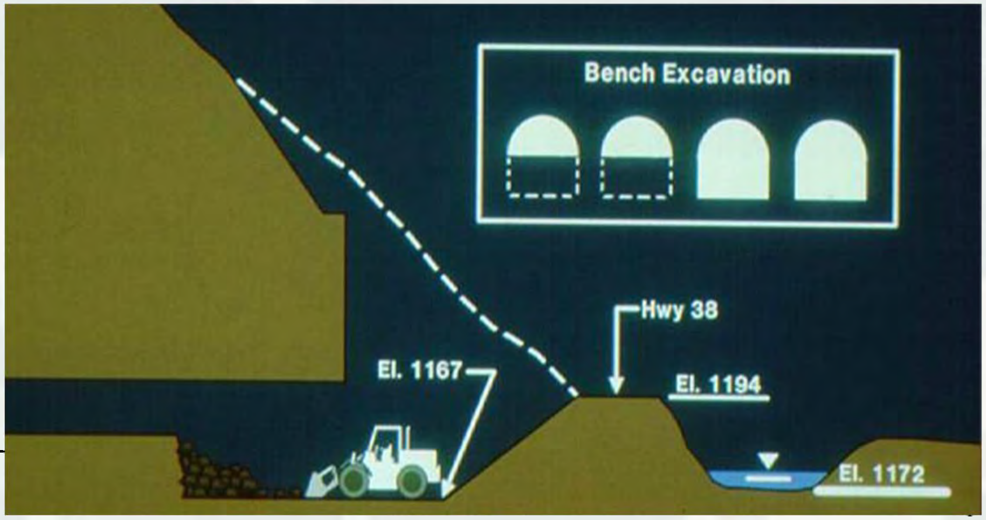
- **Drill and blast** - most commonly used flexible. Disruptive to rock mass.
- **Tunnel boring machines** - For long tunnels most economical. Least flexible. Least disruptive to rock mass.
- **Road headers** - limited rock strength. Most flexible. Not disruptive to rock mass.

Tunnel Excavation Plan

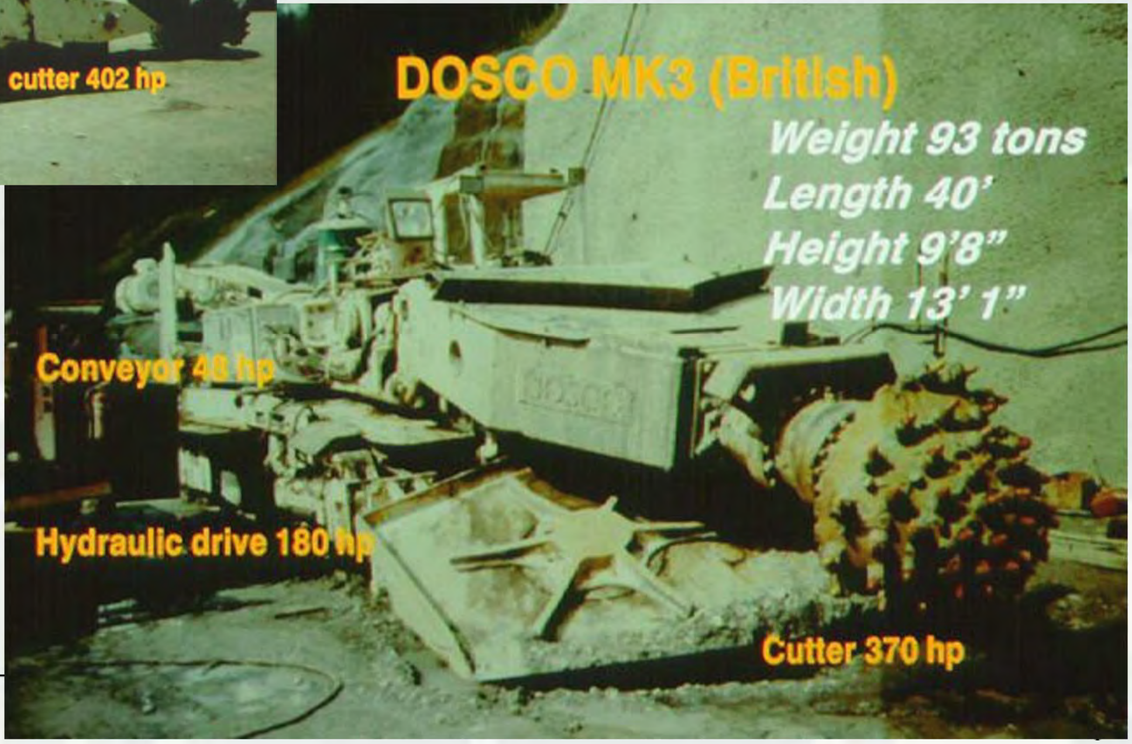


Phase I Top Heading by Road Header.

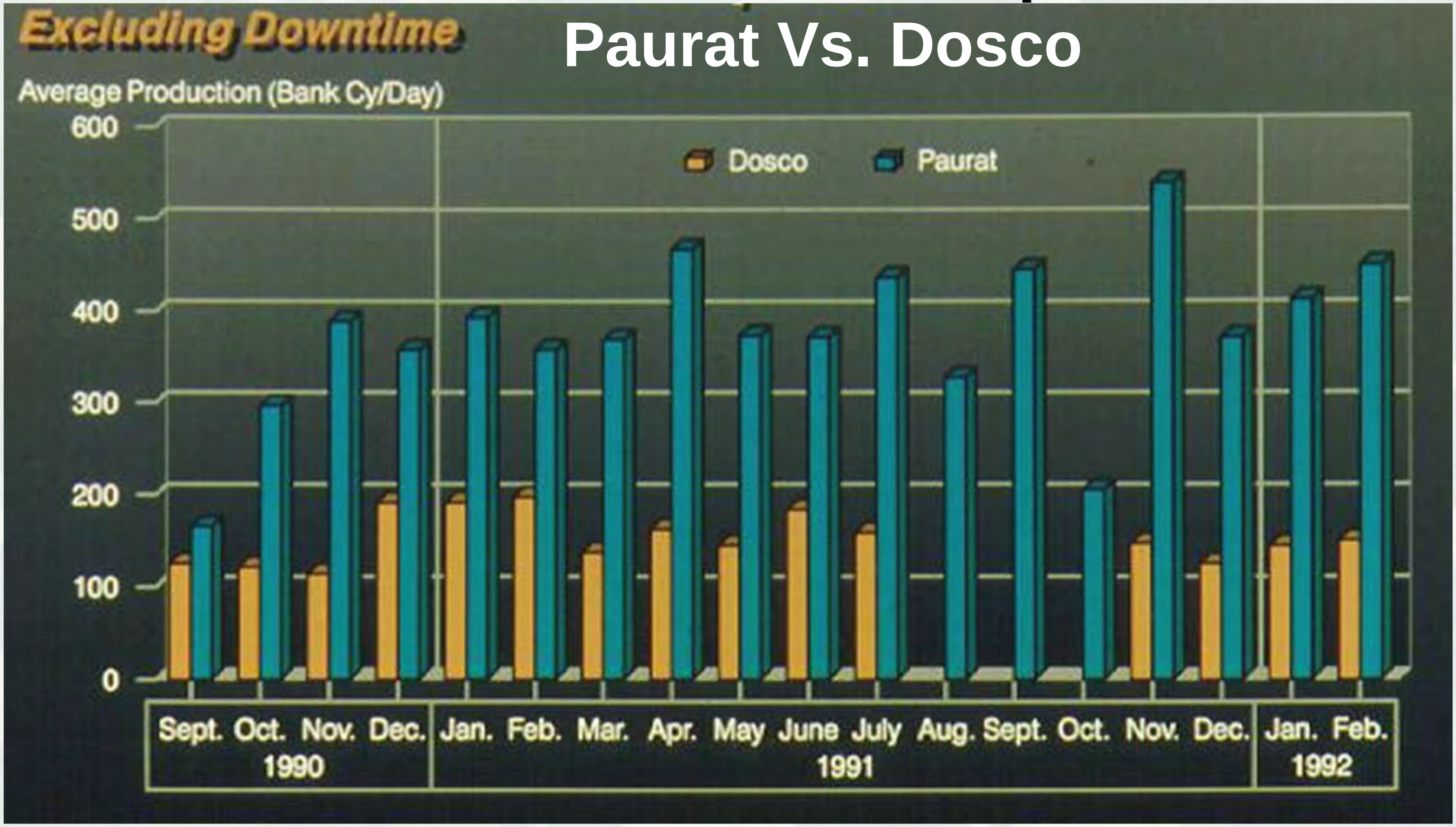
Phase II Bench by drill and blast with wall trimming by Road Header.



Two Heavy Duty Machines

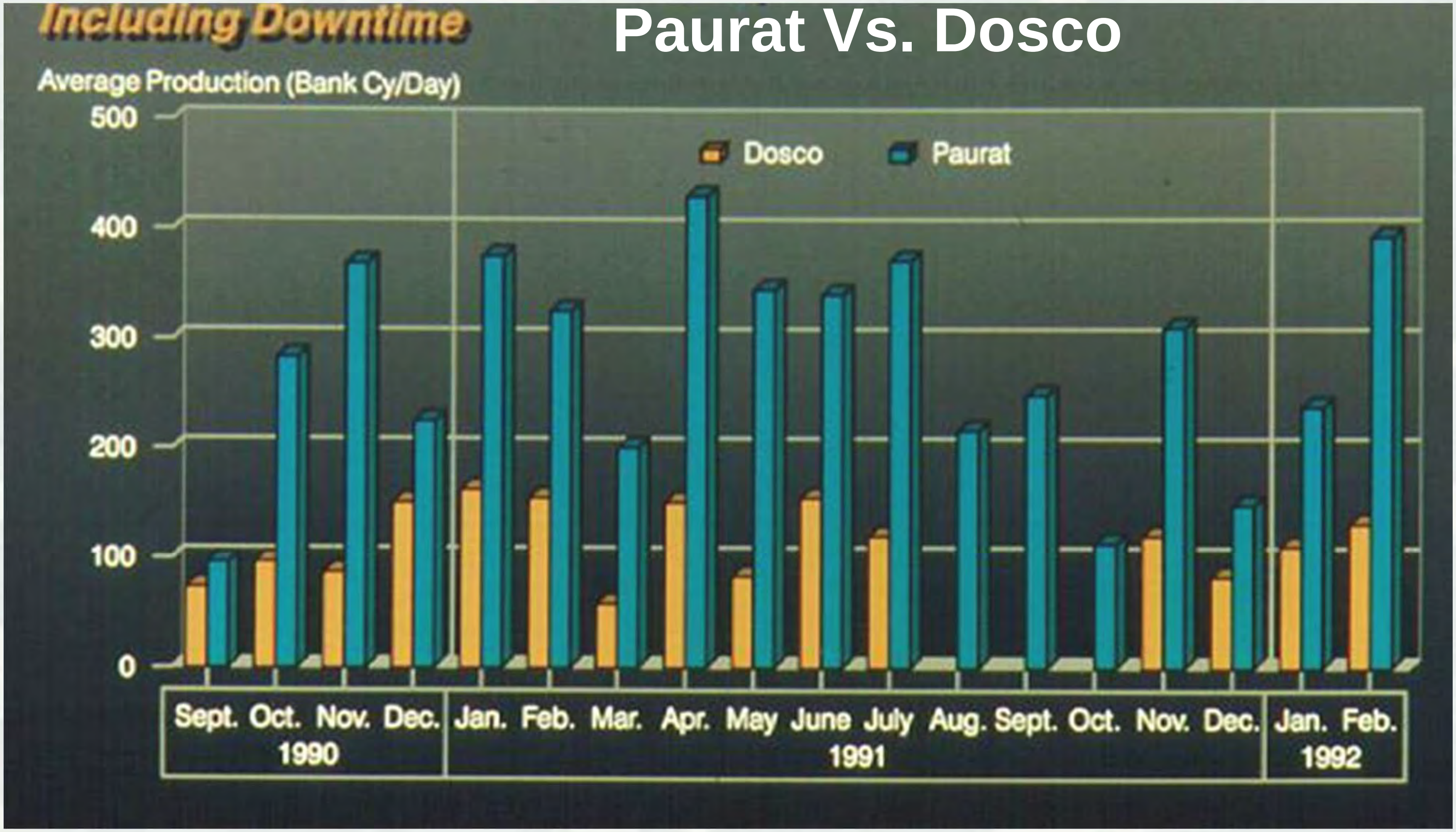


Production Comparison



Downtime/repairs

Production Comparison



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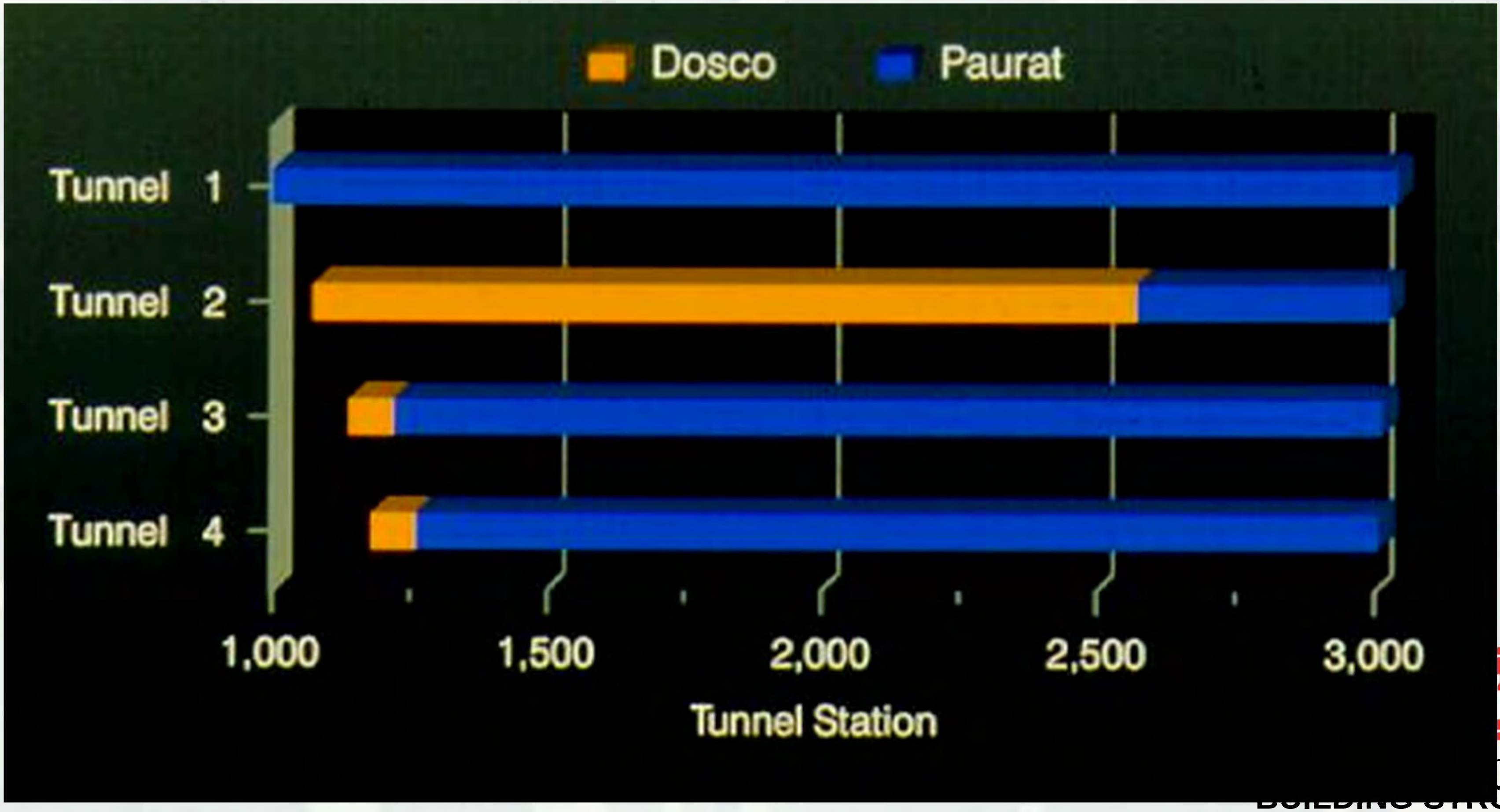
Top Heading Excavation Paurat Vs. Dosco



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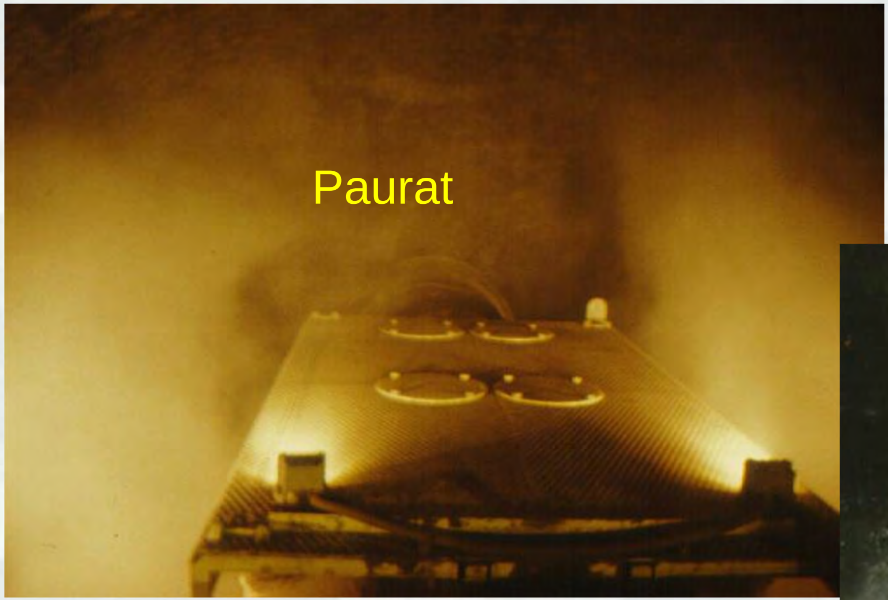
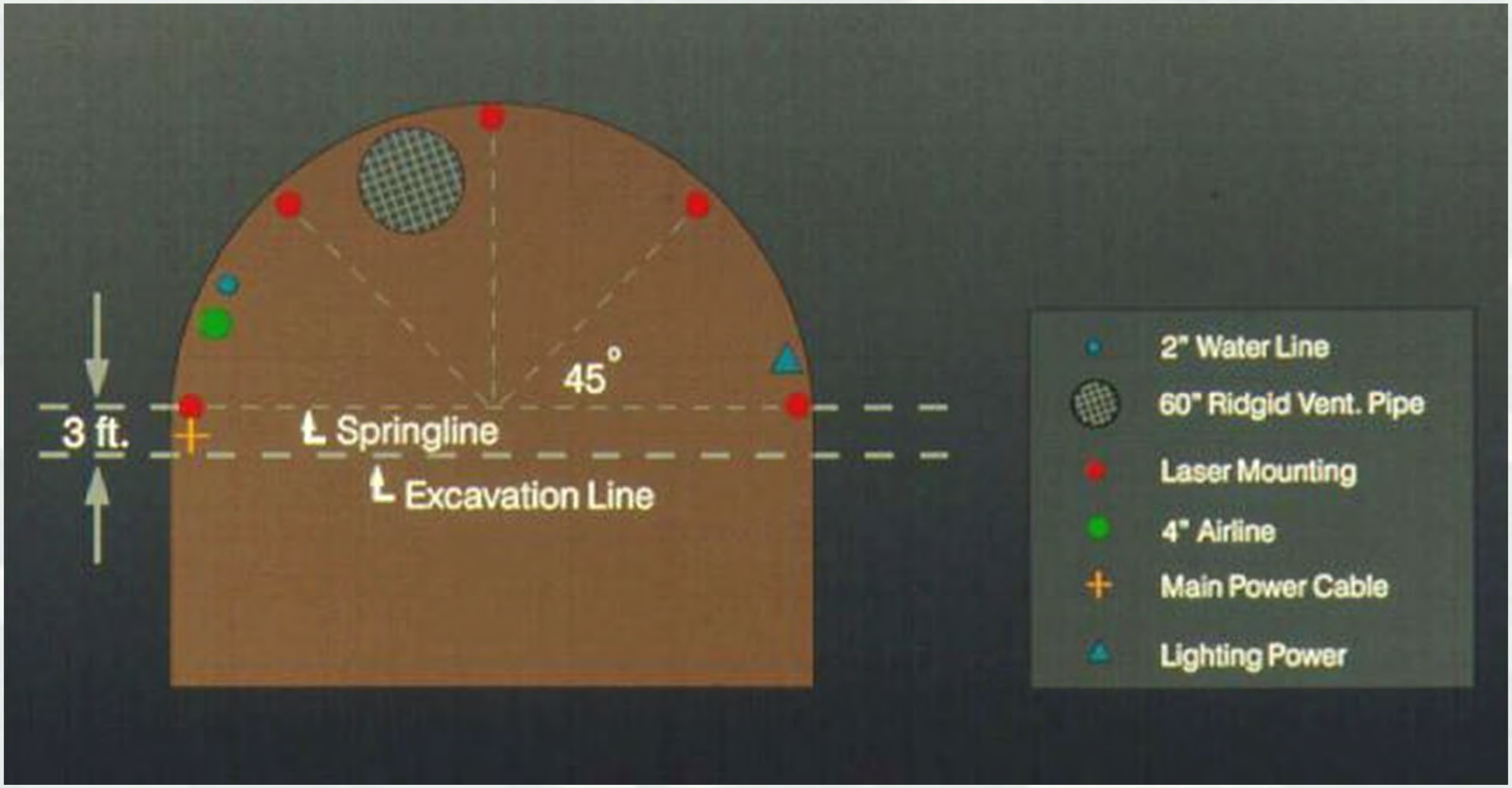
Road Headers at Work



Blasting the Bench

Tunnel Utility Layout



Ventilation System Design
Silicosis Is a Concern!

Air Requirements:

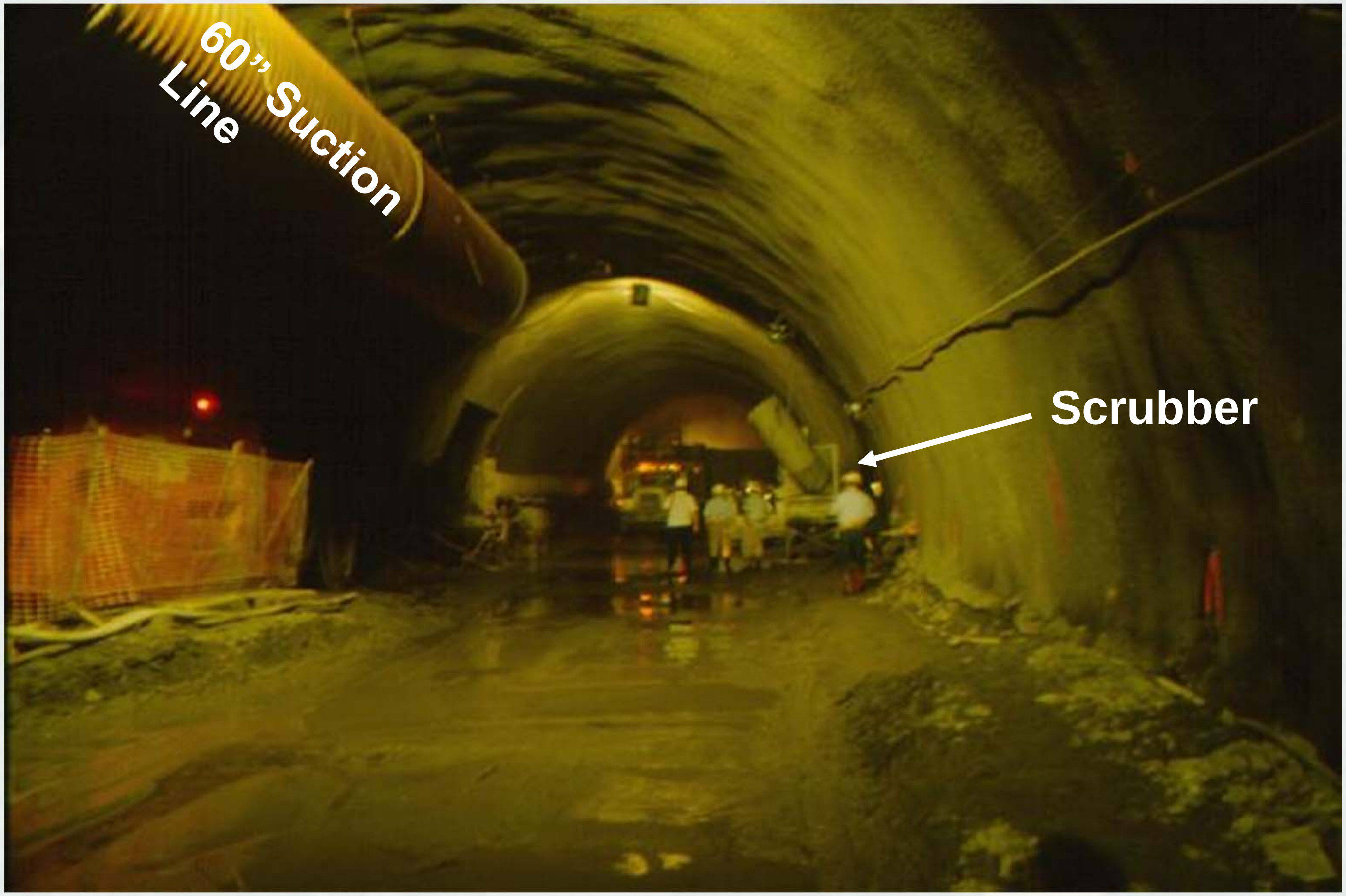
Diesel Engines:	900 H.P. total x 100 C.F.M./H.P.	=	90,000 C.F.M.
Personnel:	15 Men x 200 C.F.M./Man	=	3,000 C.F.M.
Total Required:			93,000 C.F.M.

System Used = 100,000 C.F.M. → Air Velocity in top heading = 200 FPM

Fan System

Jet Air Fan Model R–4200–B w/ 200 H.P., 1,800 RPM Motor

At the Heading



Scrubber

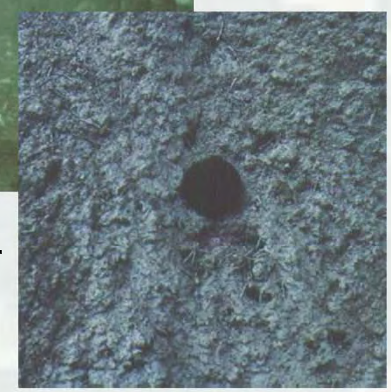
Alignment With Lasers

Support of the Roof…..
Rock Bolts

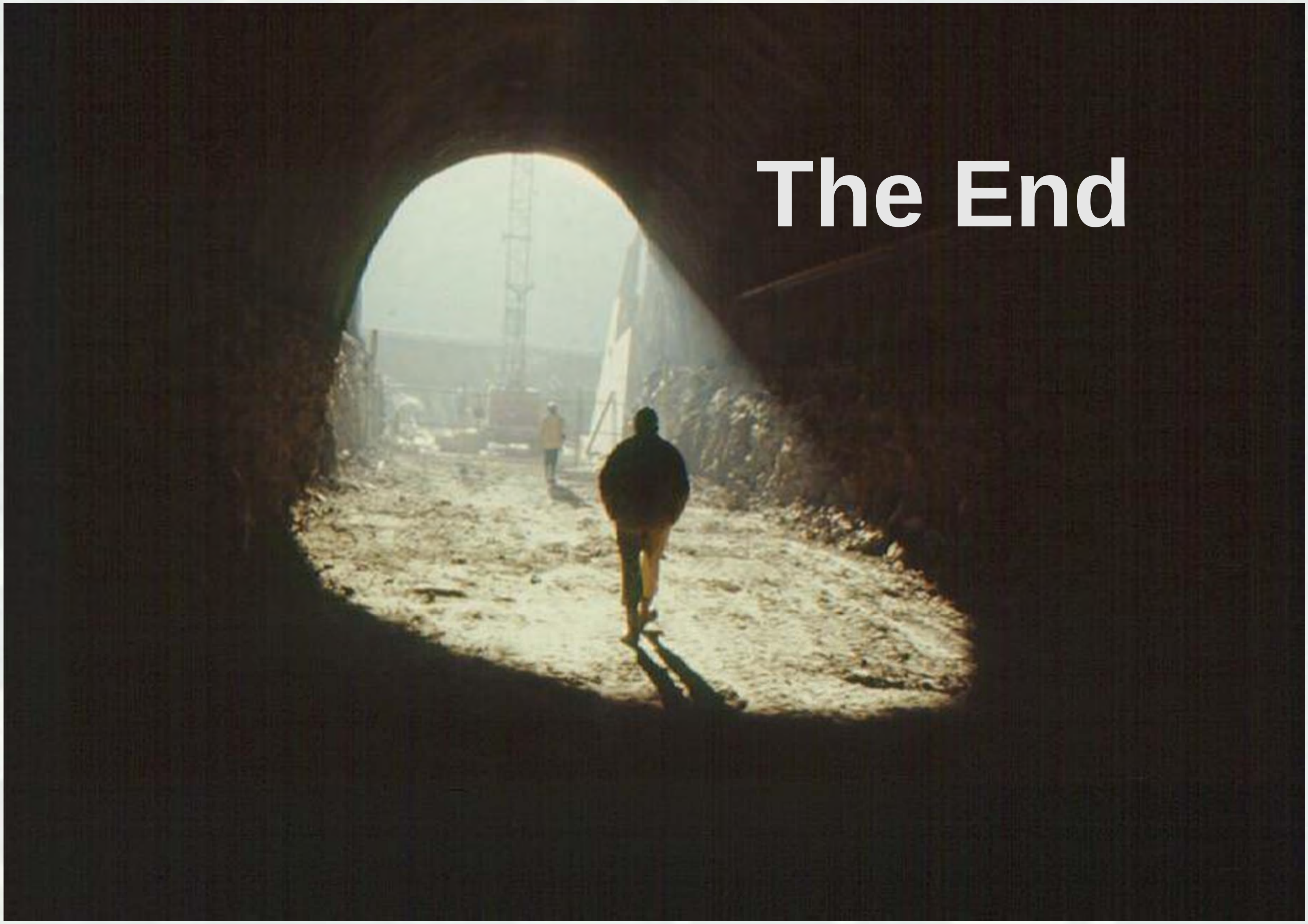
10’ long 1” ∅ steel bolts on 5 foot centers.

Support of the Roof…….
Shotcrete.

4” minimum of steel fiber reinforced shotcrete



The Upstream Portal


The End