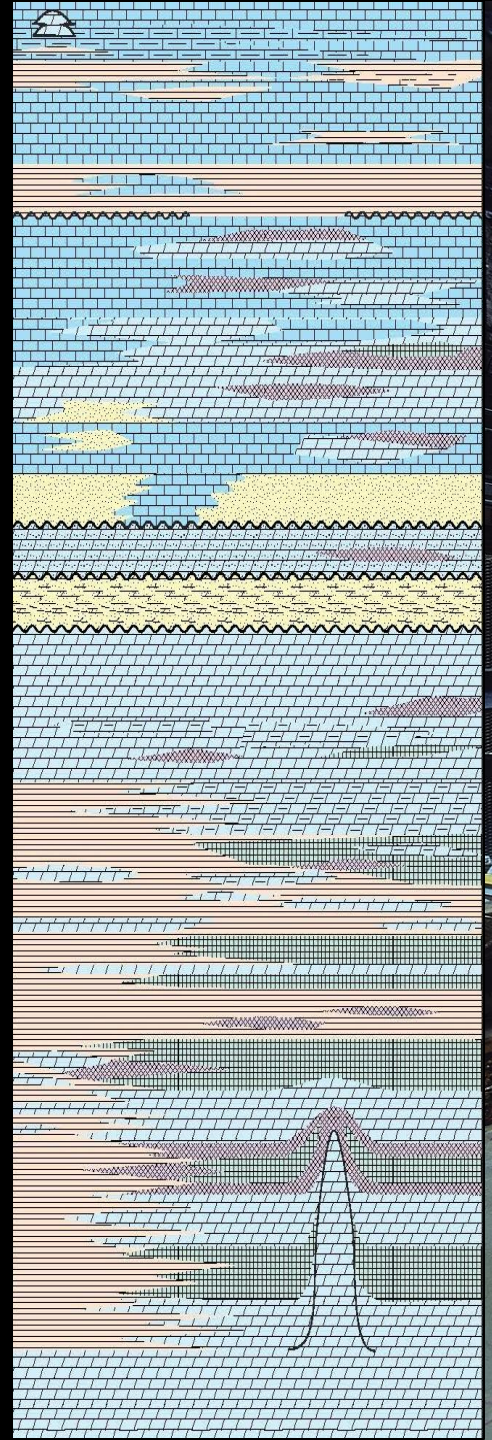
GEOLOGY IN TUNNELING

THE INFLUENCE OF GEOLOGY ON TUNNEL DESIGN AND CONSTRUCTION

Elizabeth Dwyre, PE, BC.GE | GeoVirginia 2025





Three Project Examples

For each project :

Project Description

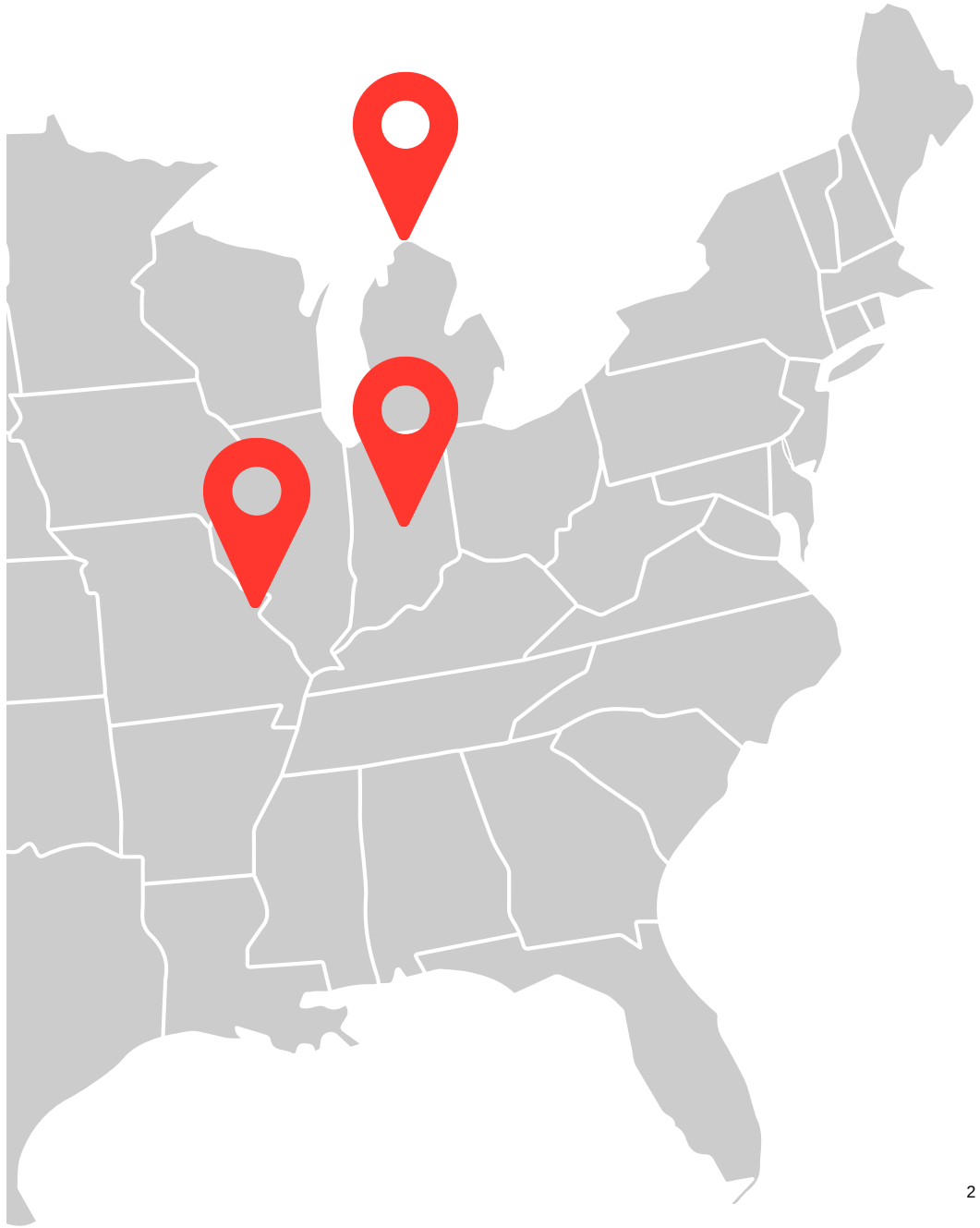
Geologic Setting

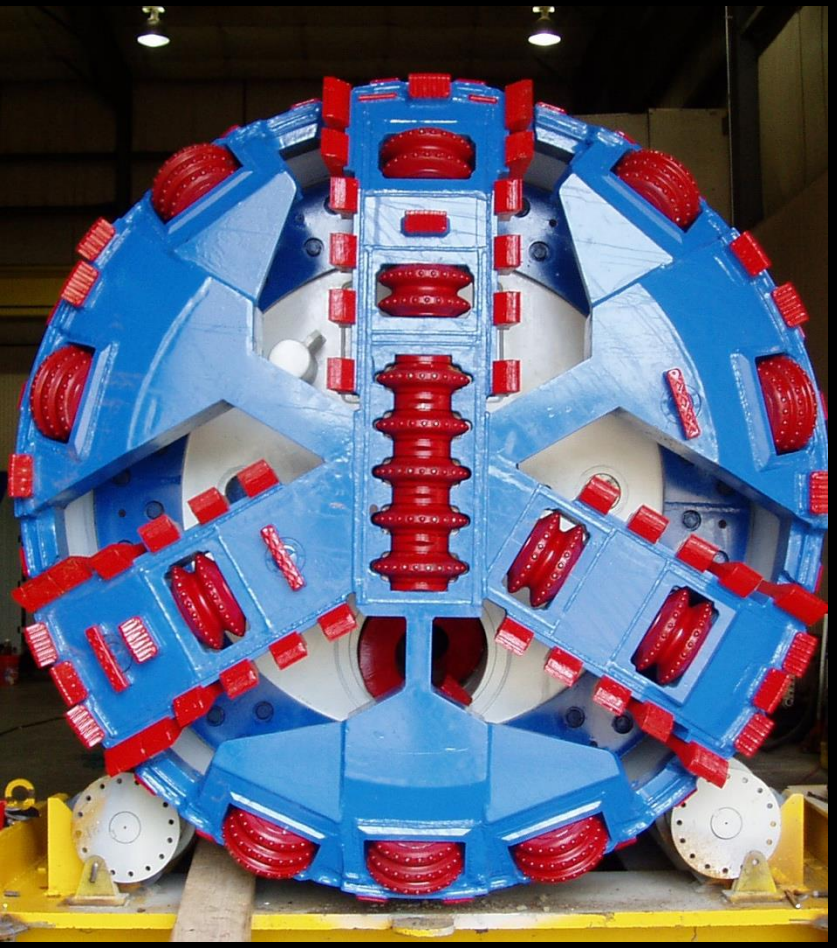
Past Projects

Influence of Geologic Conditions on Design

Experience in Construction

Success Factors for Managing Geologic Risk

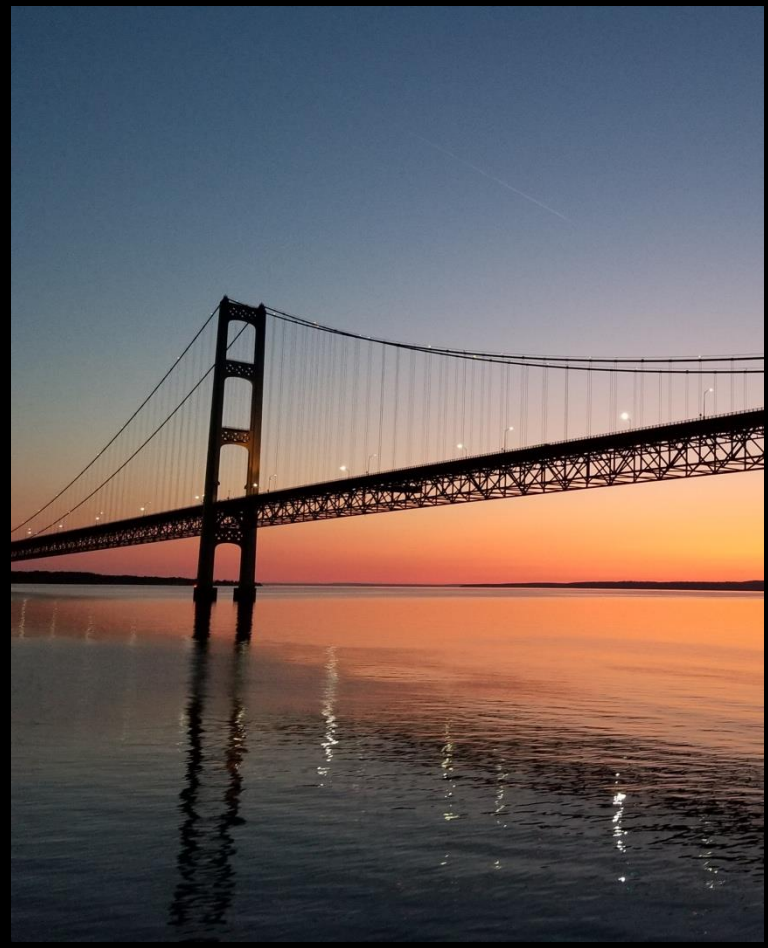




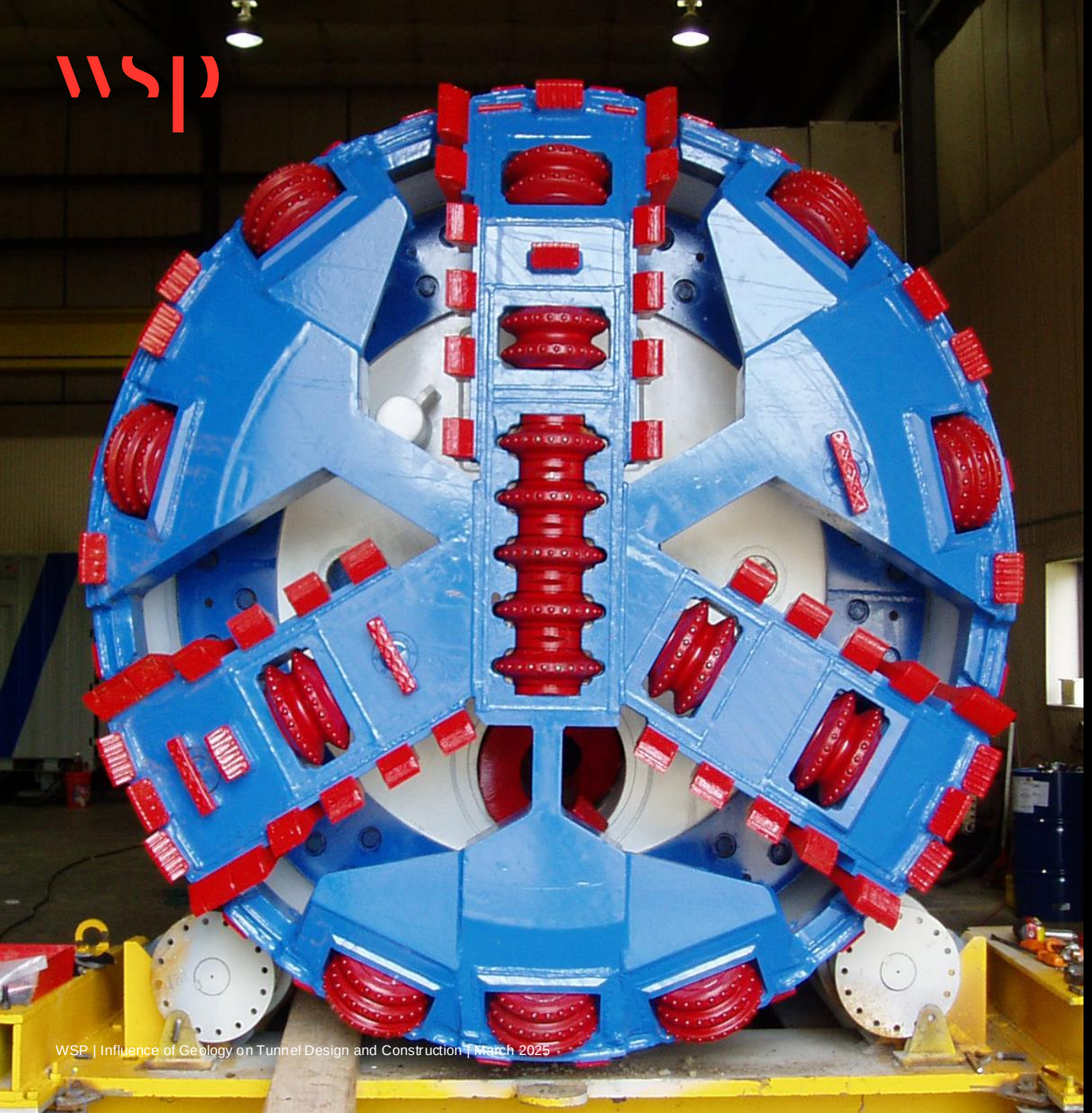
Central Energy Plant Utility Tunnel
Midfield Terminal Project
Indianapolis, IN



Lower Meramec Tunnel
Metropolitan St. Louis Sewer District
St. Louis, MO



Great Lakes Tunnel Project
Enbridge Energy, Inc.
Straits of Mackinac
Mackinac & Emmet Counties, MI



Central Energy Plant Utility Tunnel

Midfield Terminal Project
Indianapolis, IN
Indianapolis Airport Authority

1 mile utility corridor

2000 lf utilidor tunnel, 8.5 ft inside diameter

Conveys heating, cooling and 13 kV power from plant to terminal

Under an active runway and two taxiways

Earth Pressure Balance (EPB) Tunnel Boring Machine (TBM)

Cellular concrete backfill

Utility Corridor Alignment



Critical Infrastructure



Alignment & Profile Criteria

≥ 1.5 tunnel dia. Cover at Aircraft Pavement

≥ 1 tunnel dia Cover at RSA, TSA

≥ 2’ Separation Below Twin Culverts

0.3% Slope Provided for Positive Drainage

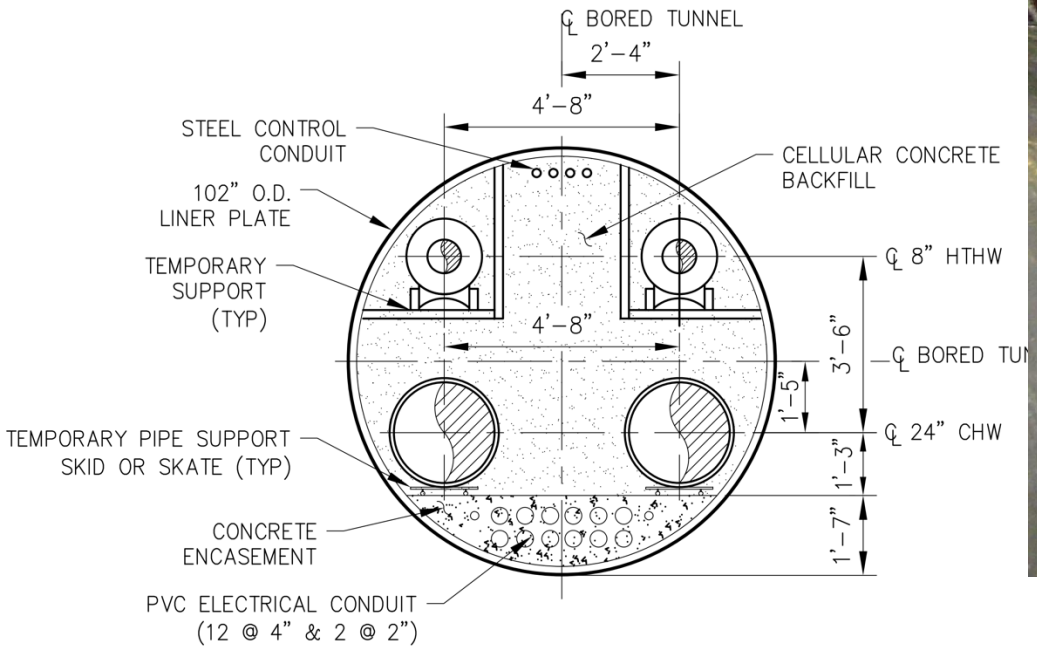


Gasketed Steel liner plate



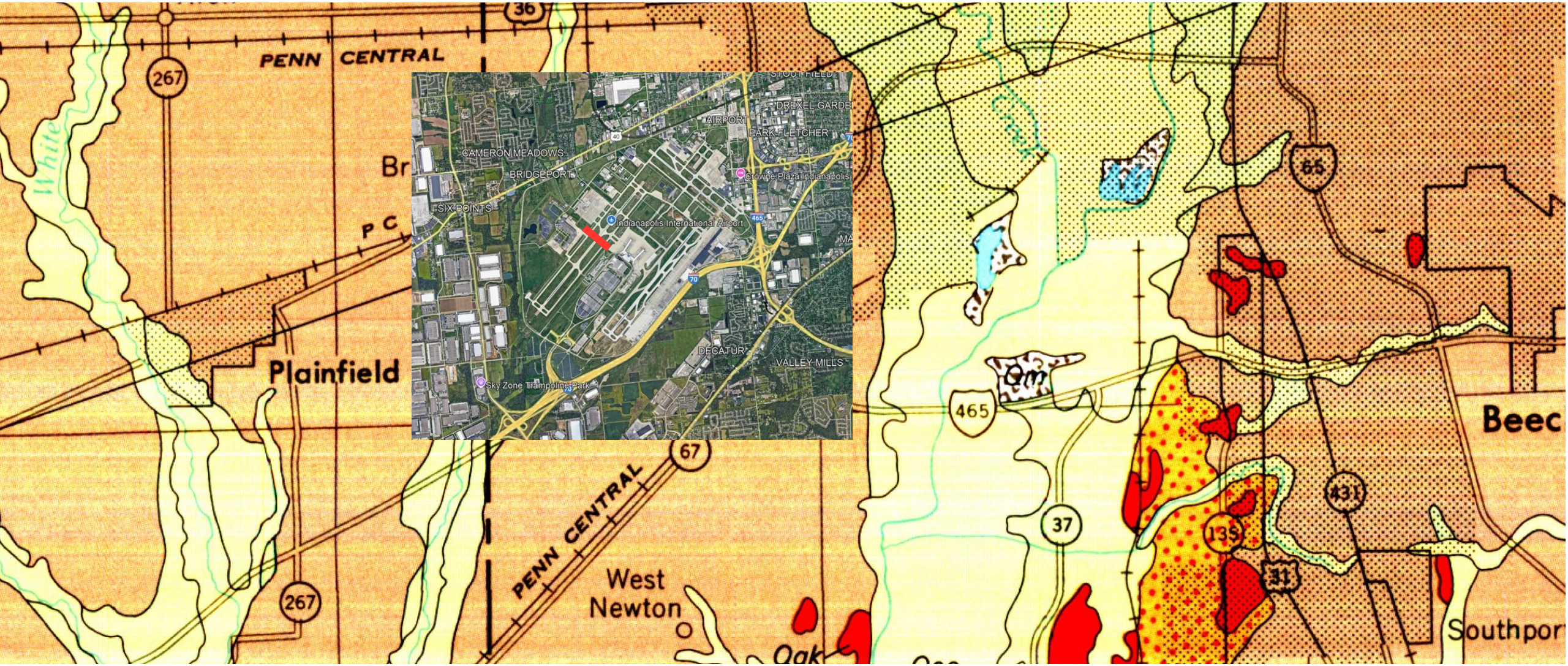


Utility installation

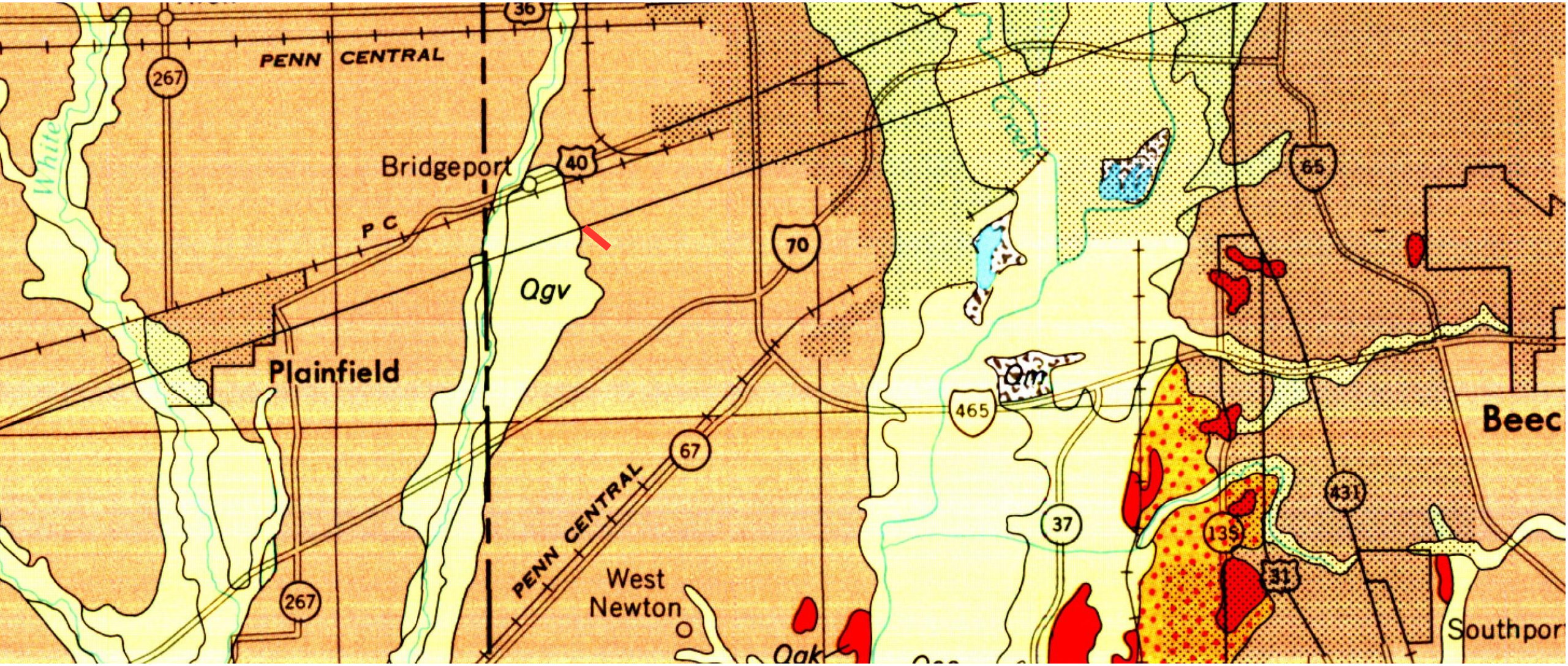




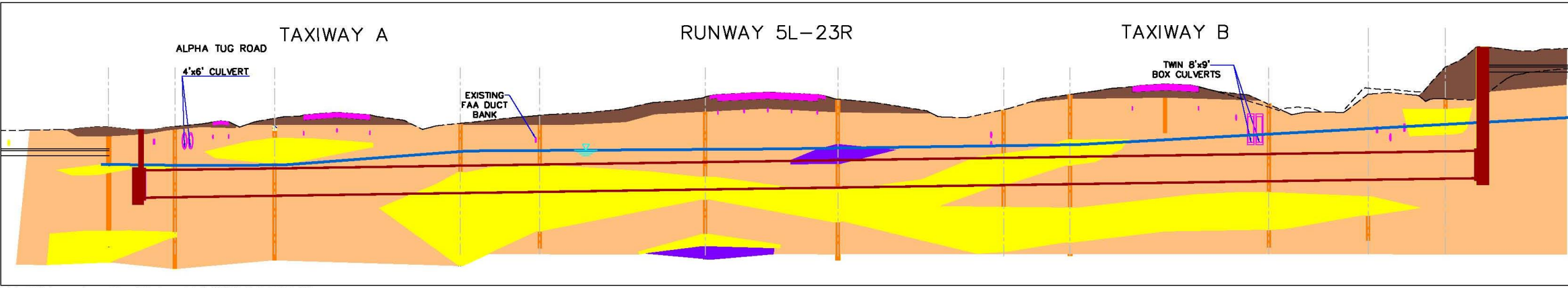
Geologic Setting



Geologic Setting



Subsurface Profile



IAA_32_tunnel_profile_V8.dgn 11/3/2006 3:57:53 PM

Info from Past Projects

Midfield Terminal Drilled Shafts – local large boulders



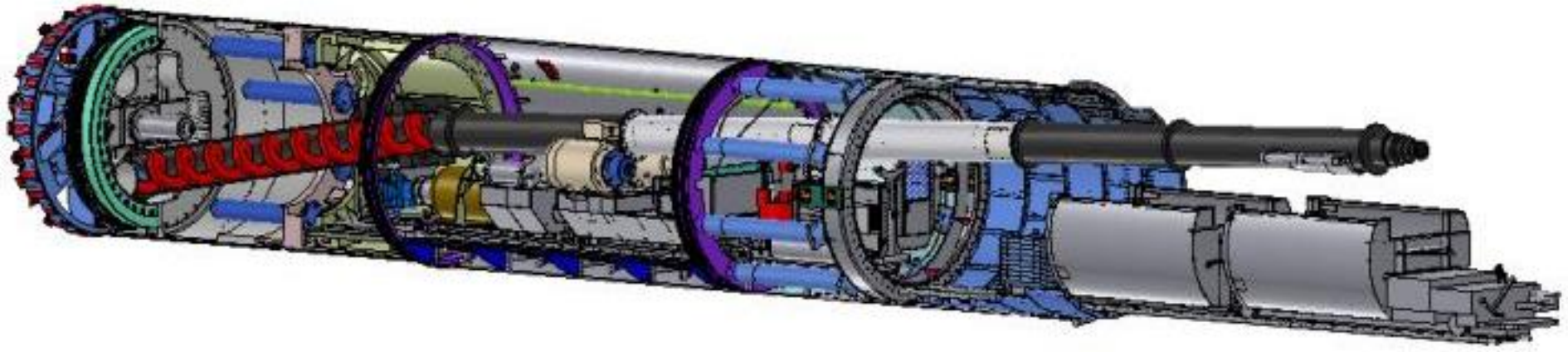
I-70 Relocation – Hard Cobbles and Boulders



Risk – Running Sands cause settlement

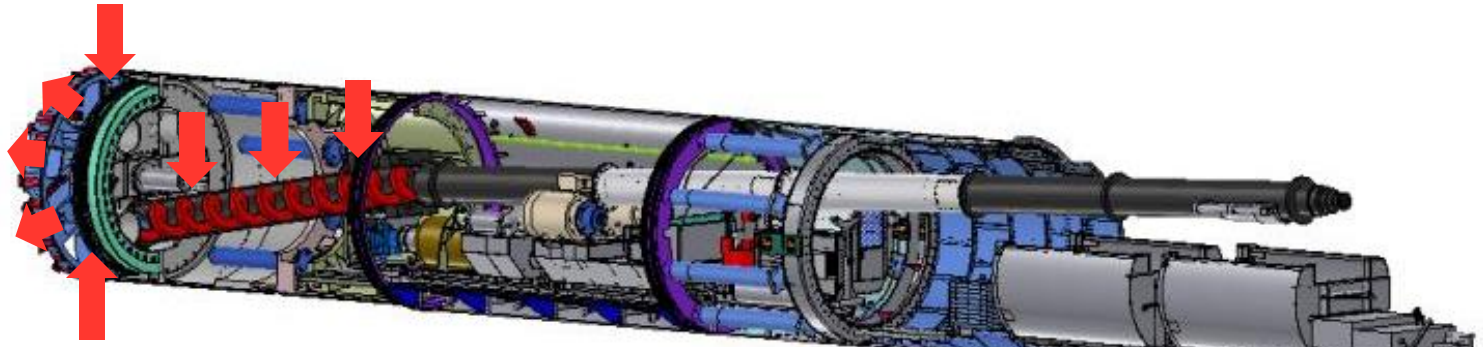
Mitigation: Pressurized Face Tunneling: Earth Pressure Balance (EPB) Tunnel Boring Machine (TBM

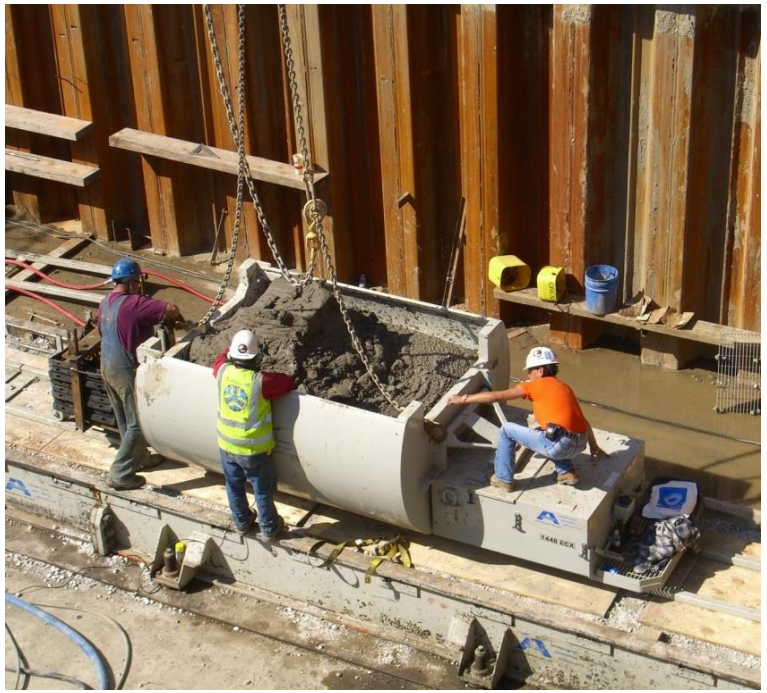






Soil Conditioning





Risk – Obstructions prevent TBM advance

Mitigations: Appropriate cutting tool selection – Linear cutter tests at CSM

Pegmatite
UCS = 14,200 psi
Cerchar = 5.0



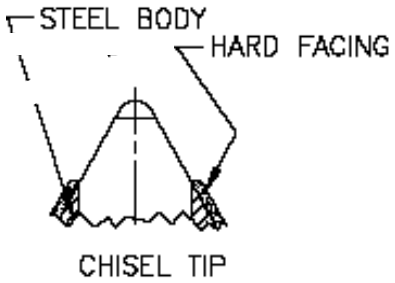


Mafic
UCS = 39,500 psi
Cerchar = 4.8





Double Disc Cutter After Testing







Two photos of the original dual disc cutter with chisel carbide inserts after linear cutter test

Selected EPB Shield







Risk: Annular voids cause settlement

Mitigation: Rapid setting pressurized annular grout

Annulus grouting equipment

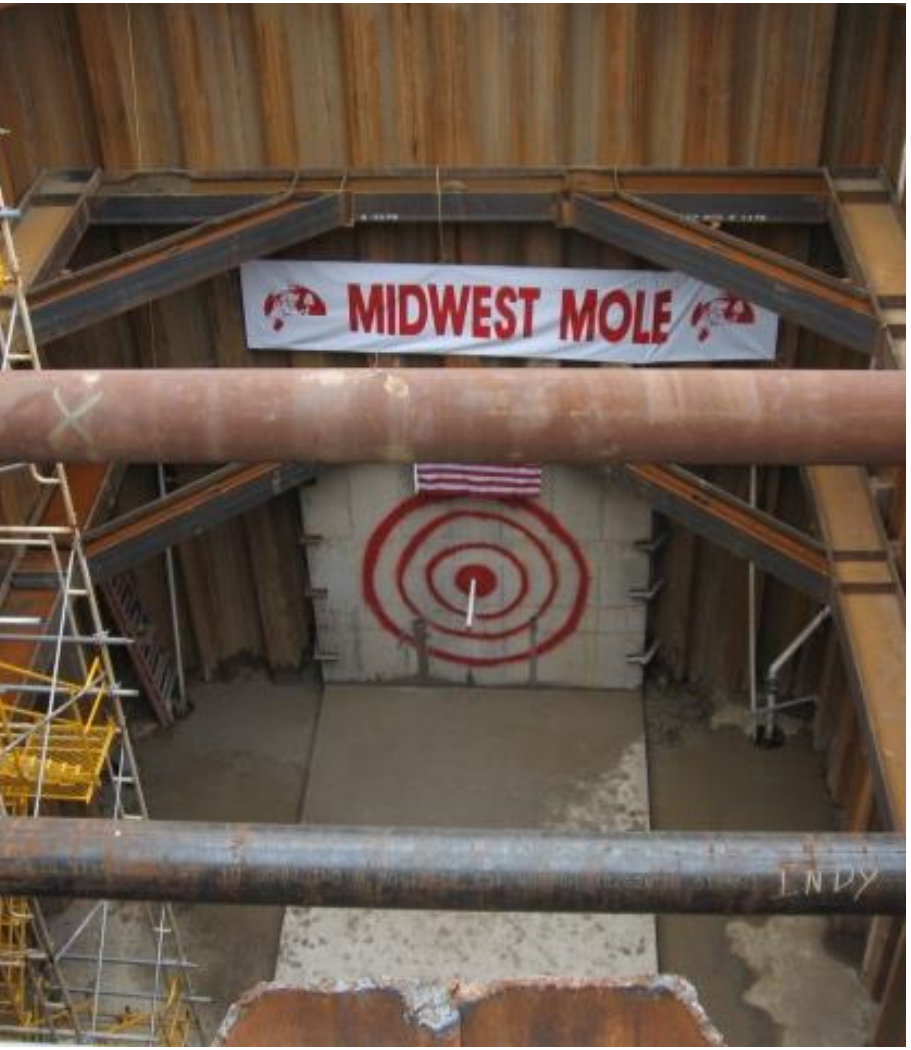


Grouting



Check of grout ports




MIDWEST MOLE





Owner	Indianapolis International Airport
Thermal Energy Operations	BHMM Energy Services CitizensThermalEnergy Steam and Chilled Water
General Contractor	BOWEN Engineering Corporation CONTRACTORS · ENGINEERS
Tunnel Subcontractor	MIDWEST MOLE, INC.
Design Engineer:	WSP



Lower Meramec Tunnel

Metropolitan St. Louis Sewer District
St. Louis, MO

6.8 miles

78 to 286 ft bgs

Sanitary sewer conveyance

6 drop structures

8 ft ID pipe-in-tunnel

11-ft minimum excavated diameter

Main Beam Tunnel Boring Machine (TBM)

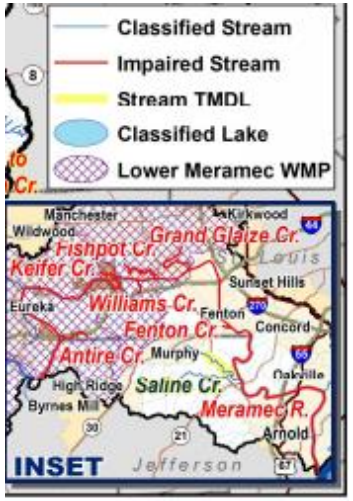
Lower Meramec Tunnel

Project Purpose:

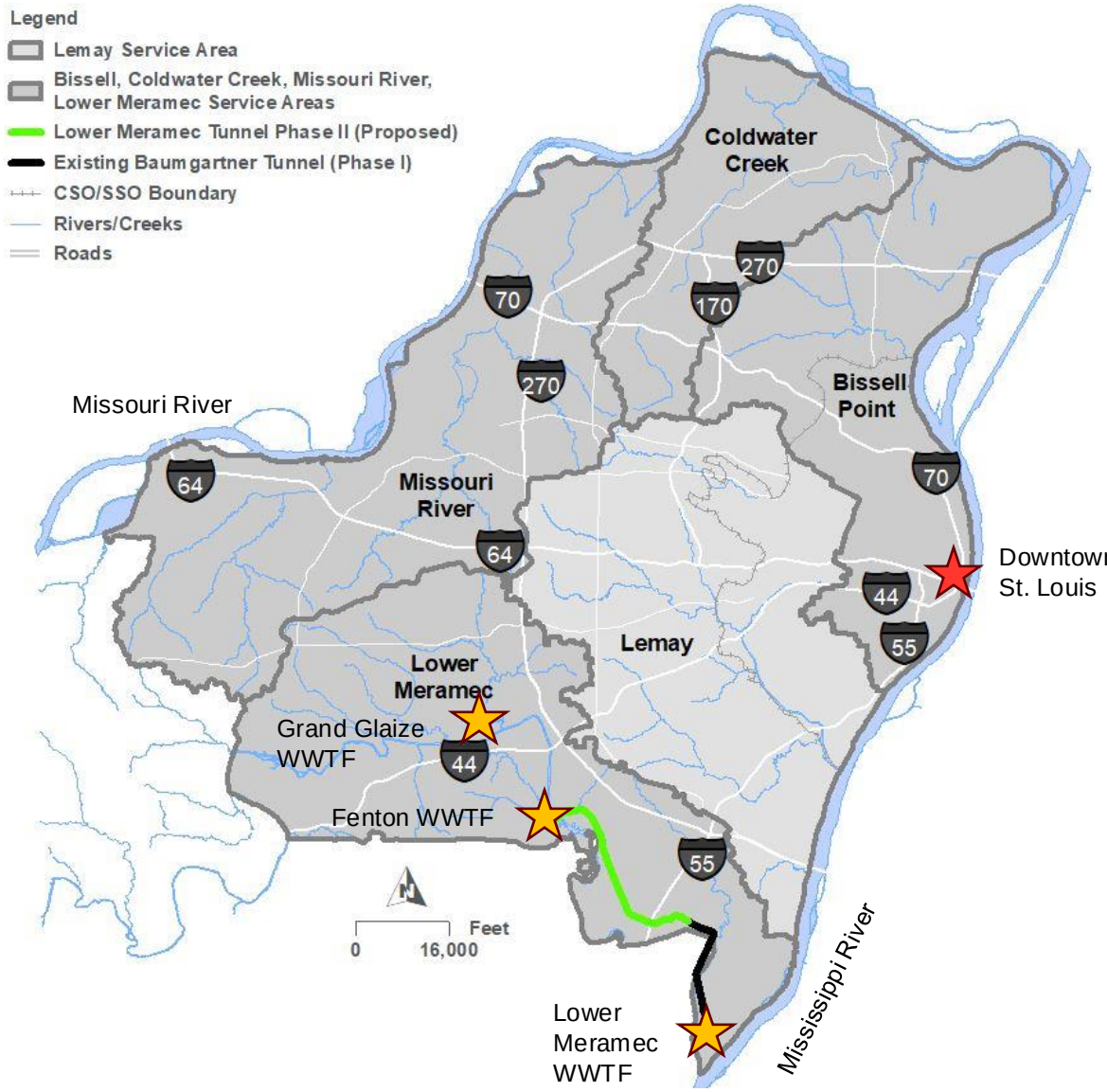
Convey wastewater from the location of the existing Fenton WWTF to the LMT WWTF

Elimination of the flood-prone Fenton WWTF and improve water quality in the Meramec River

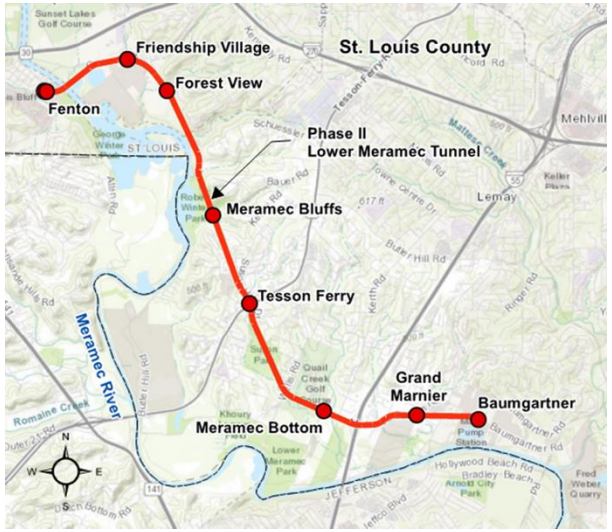


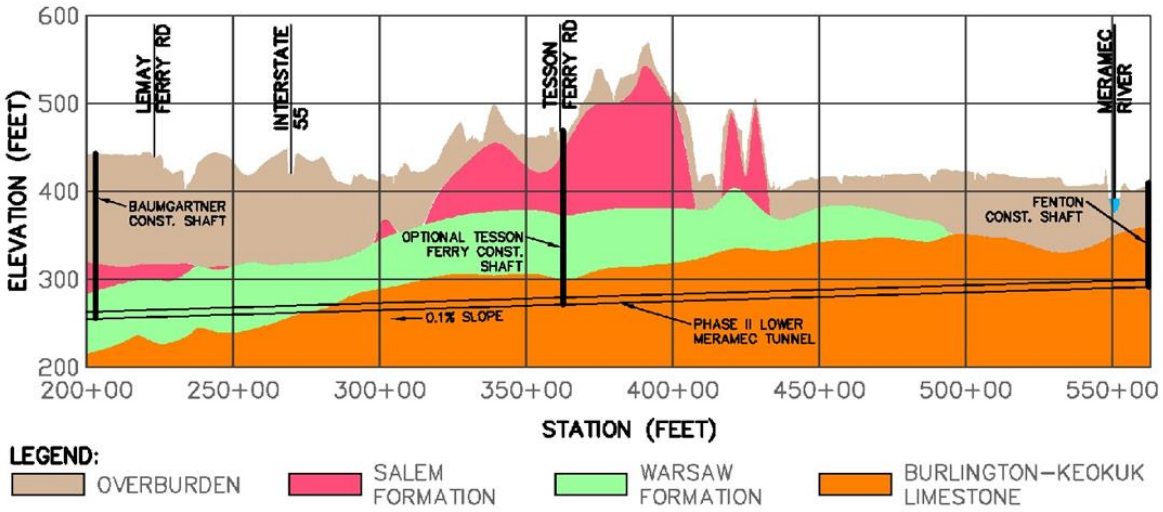


Metropolitan St. Louis Sewer District (MSD)

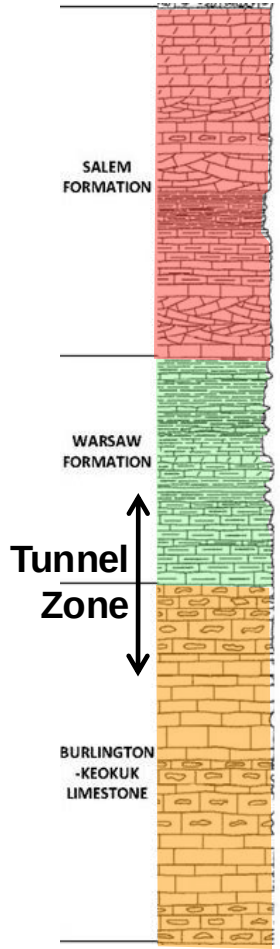


Alignment and Geologic Setting

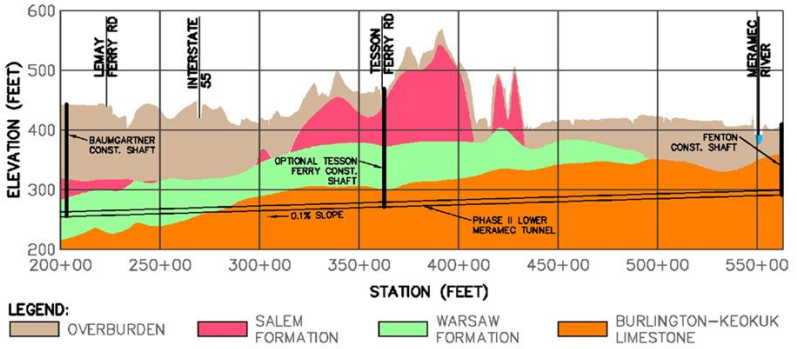




75 borings: 25% 75%
of the tunnel zone



Geologic Strata



Salem Formation

Gray to brown **limestone and dolomite**

Calcarenitic, fine to coarse-grained, occasionally cross bedded with thin to massive bedding and oolitic in places. Contains **scattered light gray chert**.

Slightly weathered to unweathered.

Areas of moderately to highly weathered rock expected near the bedrock-soil interface.

The contact with the underlying Warsaw Formation is gradational.

Warsaw Formation

Upper: Dark gray, fissile **shale.**

Lower: Calcareous shale and **gray limestone**; finely to coarsely-crystalline, occasionally dolomitic and contains geodes and **scattered** light gray to white **chert** nodules and stringers.

Slightly weathered to unweathered

Areas of moderately weathered rock expected near the bedrock-soil interface.

The contact with the under underlying Burlington-Keokuk Limestone is gradational.

Burlington-Keokuk Formation

White to blueish gray **limestone**

Medium to coarsely-crystalline, medium to thick bedded, fossiliferous and **chert bearing.** Light gray nodules and layers; **chert content >50% in some layers** (Thompson, 1986).

Slightly weathered to unweathered

Areas of moderately weathered rock expected near the bedrock-soil interface **and at depth**.

Past Project Experience: Baumgartner Tunnel (Phase I)

Constructed from 2004 to 2007

Construction Cost: $55.8M

Length: 20,200 feet

Depth: 160 to 180 feet

8 feet ID, 12.5 feet Exc. Dia.

5 Drop Structures, Lift Station Shaft & Screen Structure Shaft

- **Geologic knowledge gained from Baumgartner project**
  - Water-bearing zones within the rock formations;
  - The presence of hydrogen sulfide and methane gas; and
  - Abrasive chert.

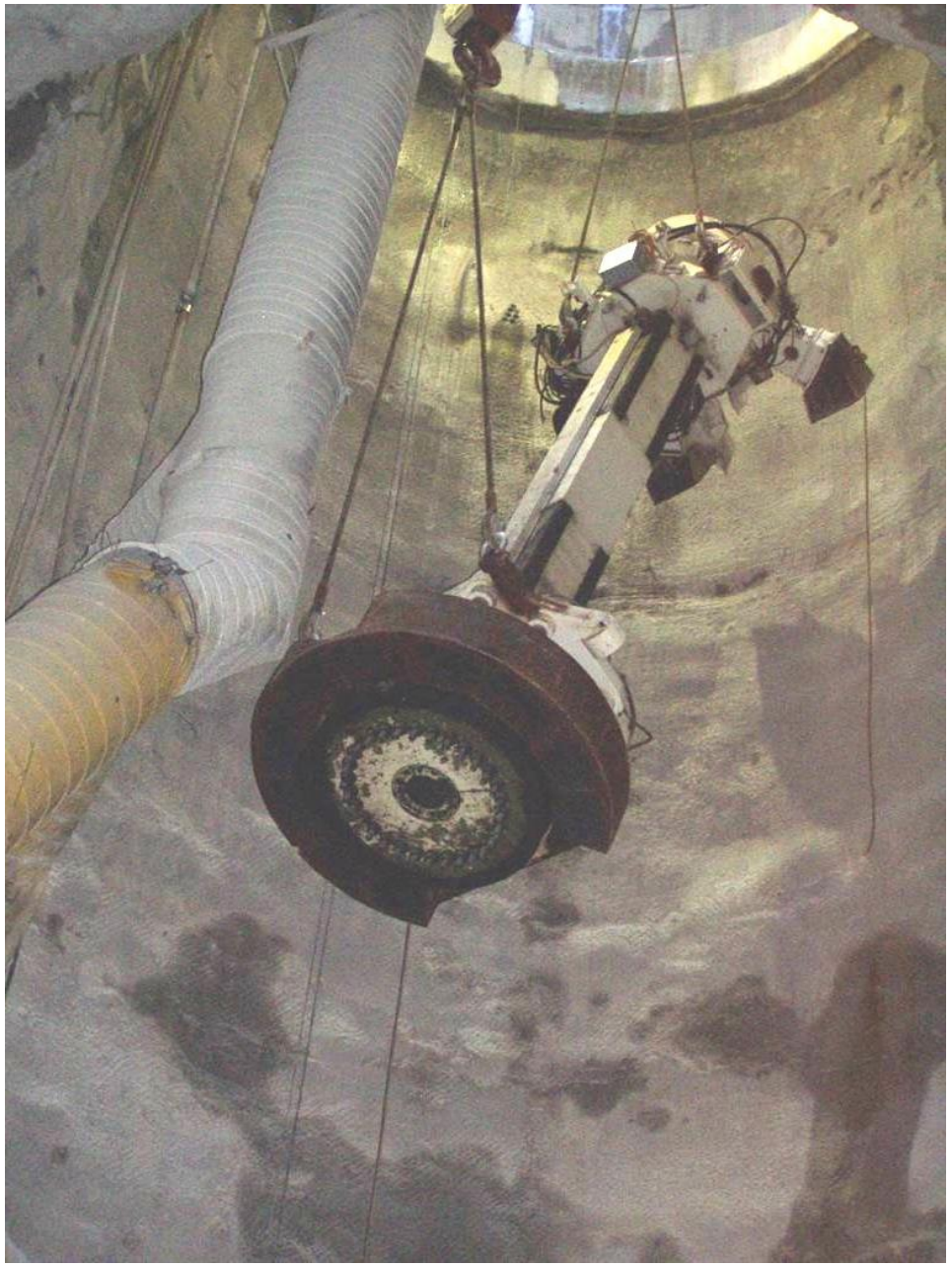
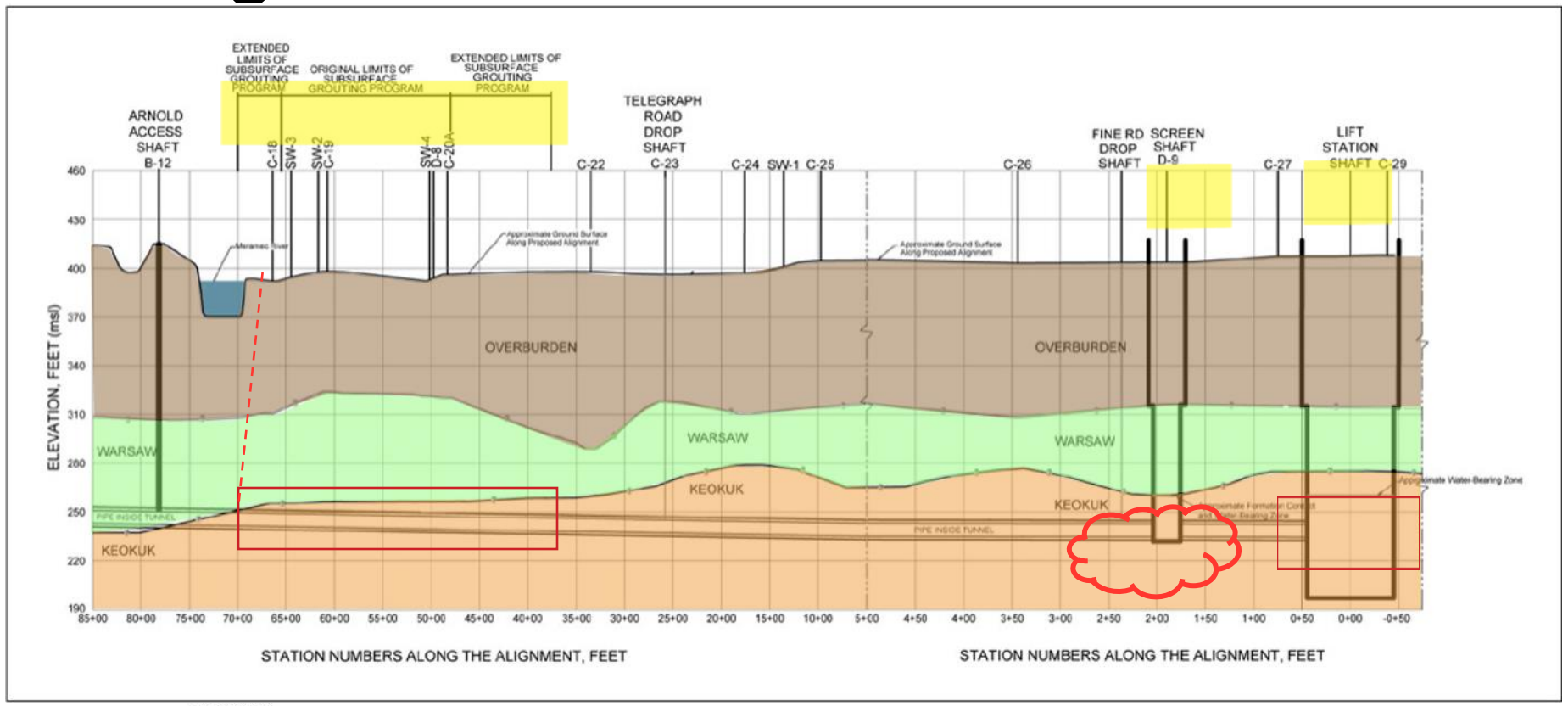


Image Credit: As-Built Construction Photos (MSD)

Baumgartner Tunnel



Reference:
Abkemeier and Groves, 2011

Baumgartner Shaft

LMT Investigation: Inspection of Baumgarter Shaft

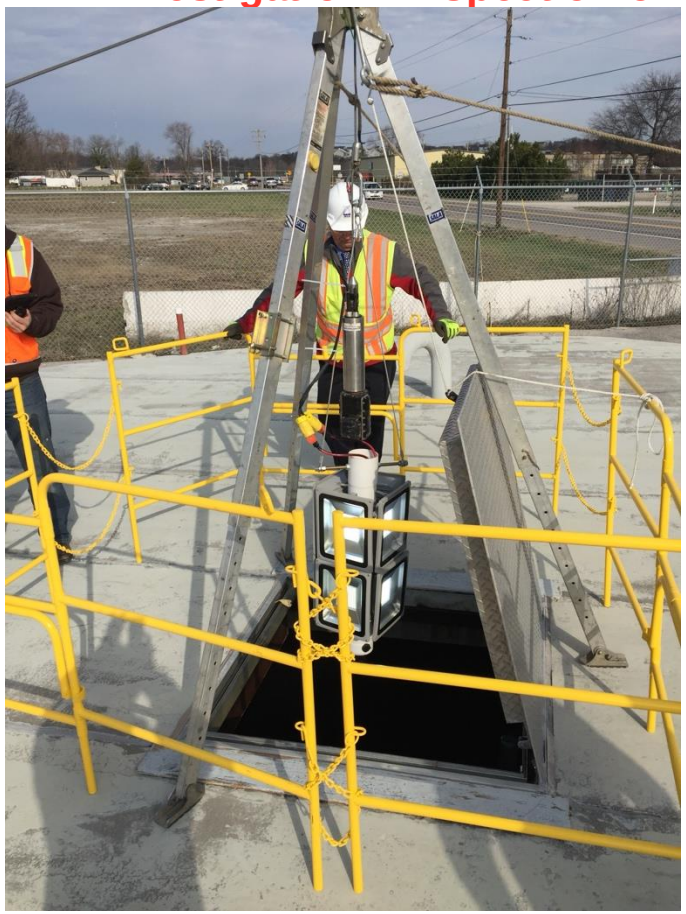
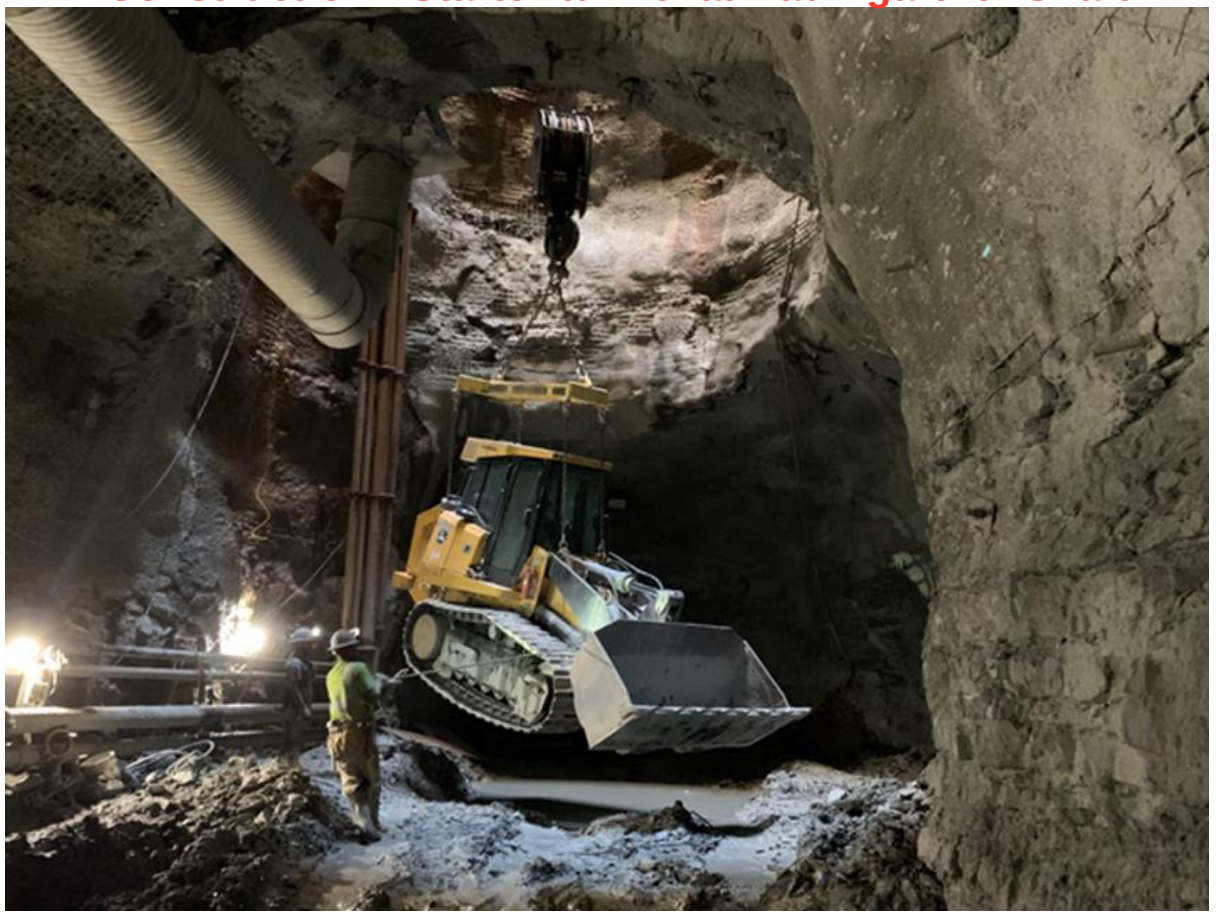


Image Credit: Baumgartner CCTV Inspection Report (Trekk, 2018)

LMT Construction: Starter tunnel at Baumgartner Shaft



Groundwater Inflow

493 packer tests in 56 borings

75% k<1x10^{-5} cm/sec

A few moderate to high k values, up to 10^{-3} cm/sec

- near W/B-K transitional contact zone
- at Meramec River crossing

2 long-term constant discharge aquifer tests

Inflow estimate based on:

Heuer (1995, 2005)
Raymer (2005, 2015)

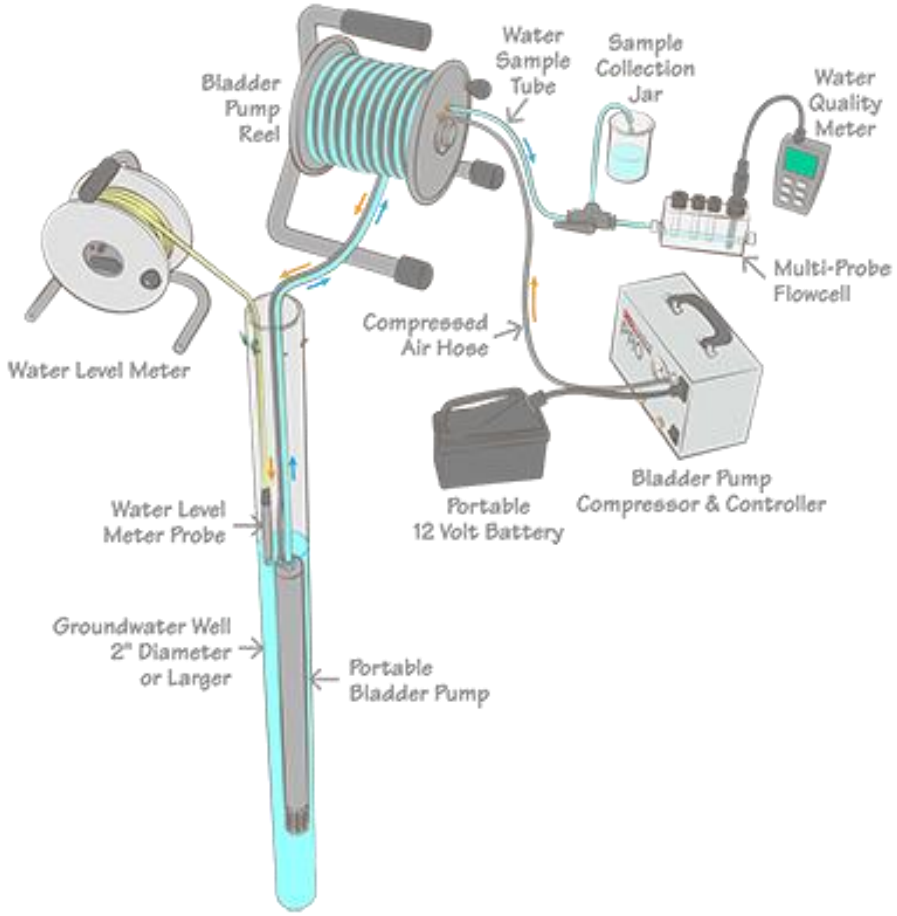
GBR Baseline: 1,110 gpm

Specified mandatory pre-excavation probing in select locations



Aquifer Testing at Meramec Bottom Drop Structure

Presence of Gases



Groundwater Sampling



GBR baselined as Potentially Gassy.

Requires active ventilation and air quality monitoring during construction

Analytic results for dissolved gases in groundwater:

Methane (CH_4):	15 µg/L to 114 µg/L
Hydrogen Sulfide (H_2S):	66 µg/L to 3,230 µg/L

Abrasive Chert

Visual observations in core

½ - 14 inch thick

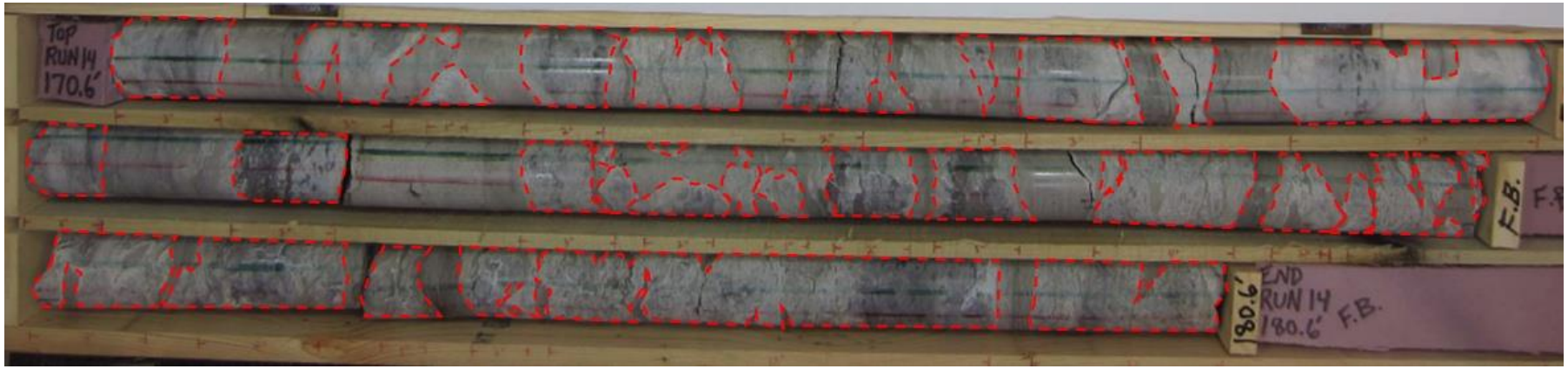
0-65%

Lab testing

15% solution HCL acid bath

X-ray diffraction on remaining material to identify quartz & chert

Visual Chert Content (%)	Range of Values				
	Number of Core Runs	10th Percentile (%)	Median (%)	90th Percentile (%)	Max (%)
Warsaw Formation	256	0	0	7	25
Burlington-Keokuk Limestone	473	20	32	45	65



Estimates of cutter consumption rates:

(Bruland, 1998 and Nilsen & Ozdemir, 1993)

Warsaw:
235 to 380 yd3/cutter

Burlington-Keokuk:
225 to 243 yd3/cutter

Construction Shafts

Baumgartner Launch Shaft (Existing)



Fenton Retrieval Shaft



Key WSP Project Team Members

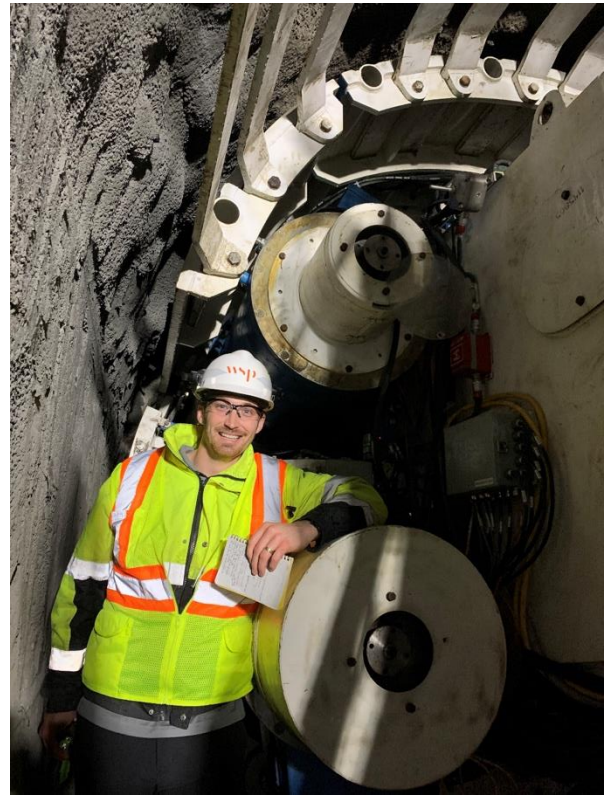
Everett Litton, PE – Project Manager



Xiaomin You, PhD, PE – DPM

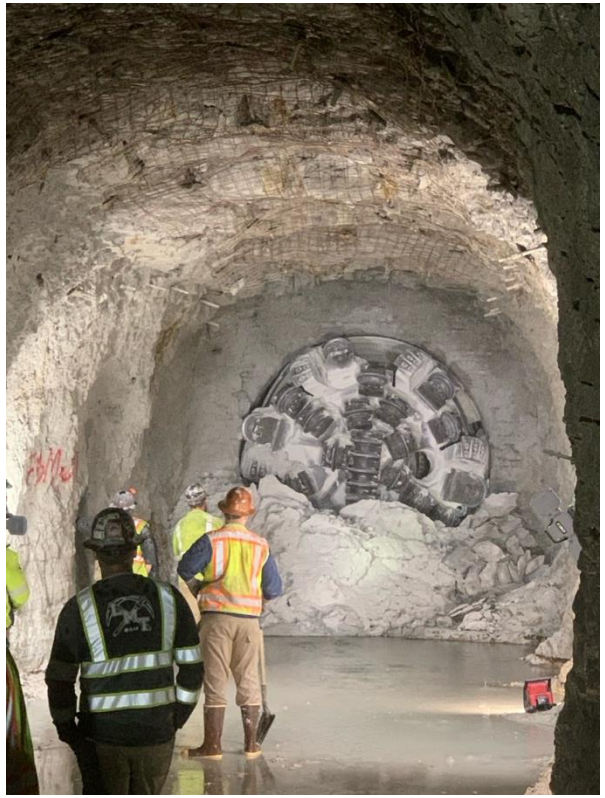


Luke Ducey, Field Geologist



Approaching in-service date November 2025

Hole-through October 2024

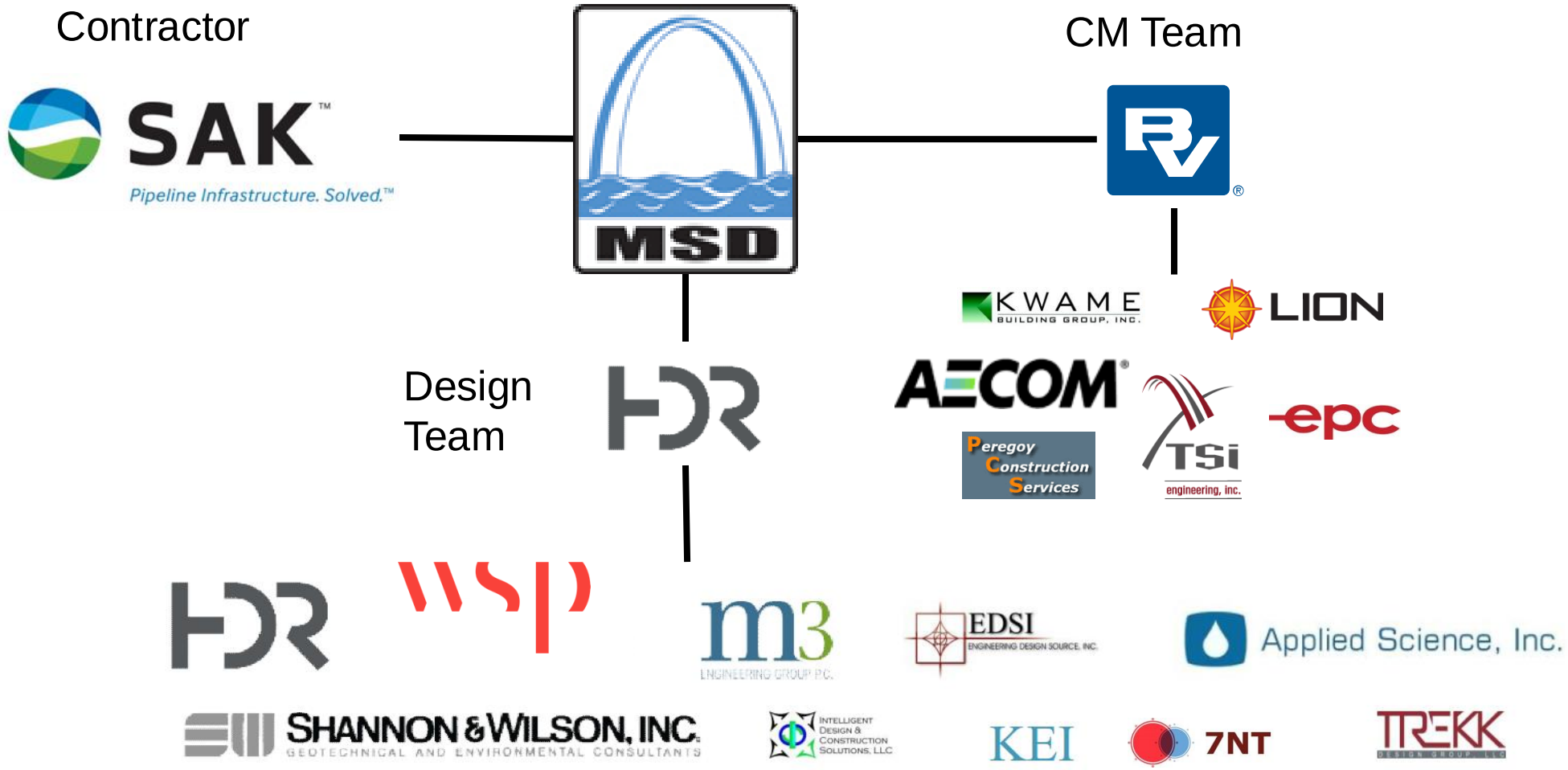


TBM Retrieval



March 2025 Hobas Pipe Installation




Contractor
SAK
Pipeline Infrastructure. Solved.™
MSD
CM Team
RV
KWAME BUILDING GROUP, INC.
LION
AECOM
Peregoy Construction Services
TSi engineering, inc.
epc
Design Team
HDR
HDR
wsp
m3 ENGINEERING GROUP P.C.
EDSI ENGINEERING DESIGN SOURCE, INC.
Applied Science, Inc.
SHANNON & WILSON, INC. GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS
INTELLIGENT DESIGN & CONSTRUCTION SOLUTIONS, LLC
KEI
7NT
TREKK



Great Lakes Tunnel Project

Enbridge Energy, Inc.
Straits of Mackinac
Mackinac & Emmet Counties, MI

3.9 miles long, 21 ft inside diameter tunnel

- Will house a 30-inch petroleum pipeline
- Replacing two existing parallel 20-inch pipelines

To be constructed by

- Pressurized face Tunnel Boring Machine (TBM)
- Precast Concrete Tunnel Lining

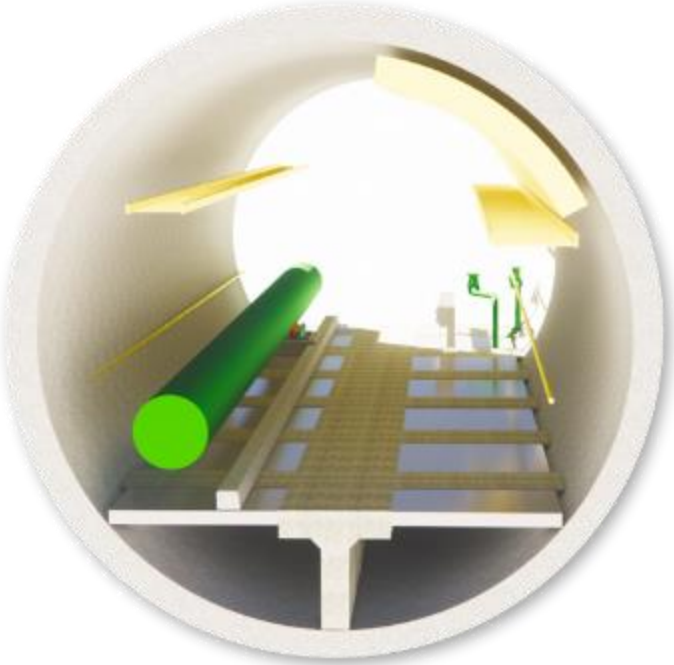
Pipeline in Tunnel

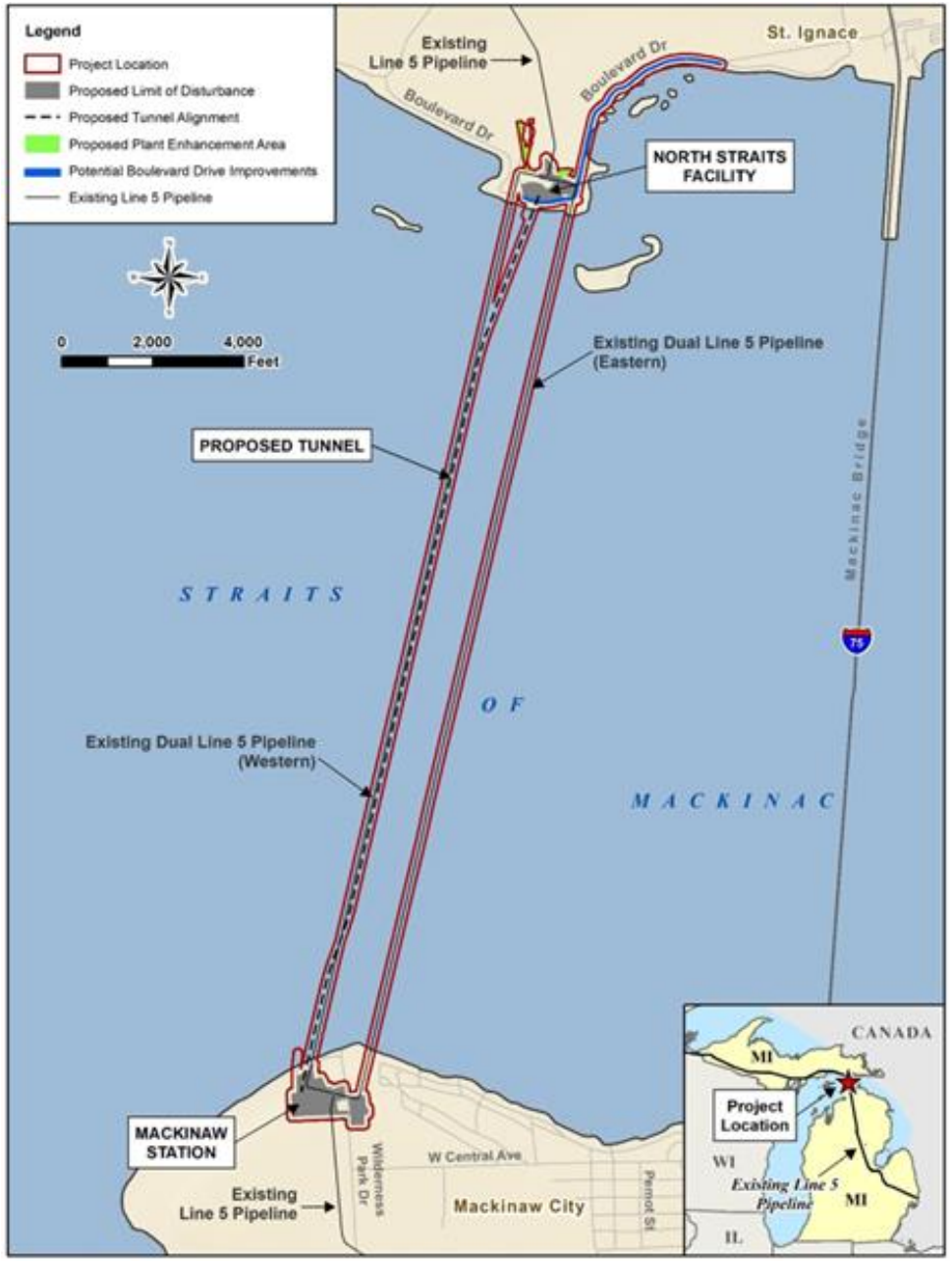
Existing Pipeline



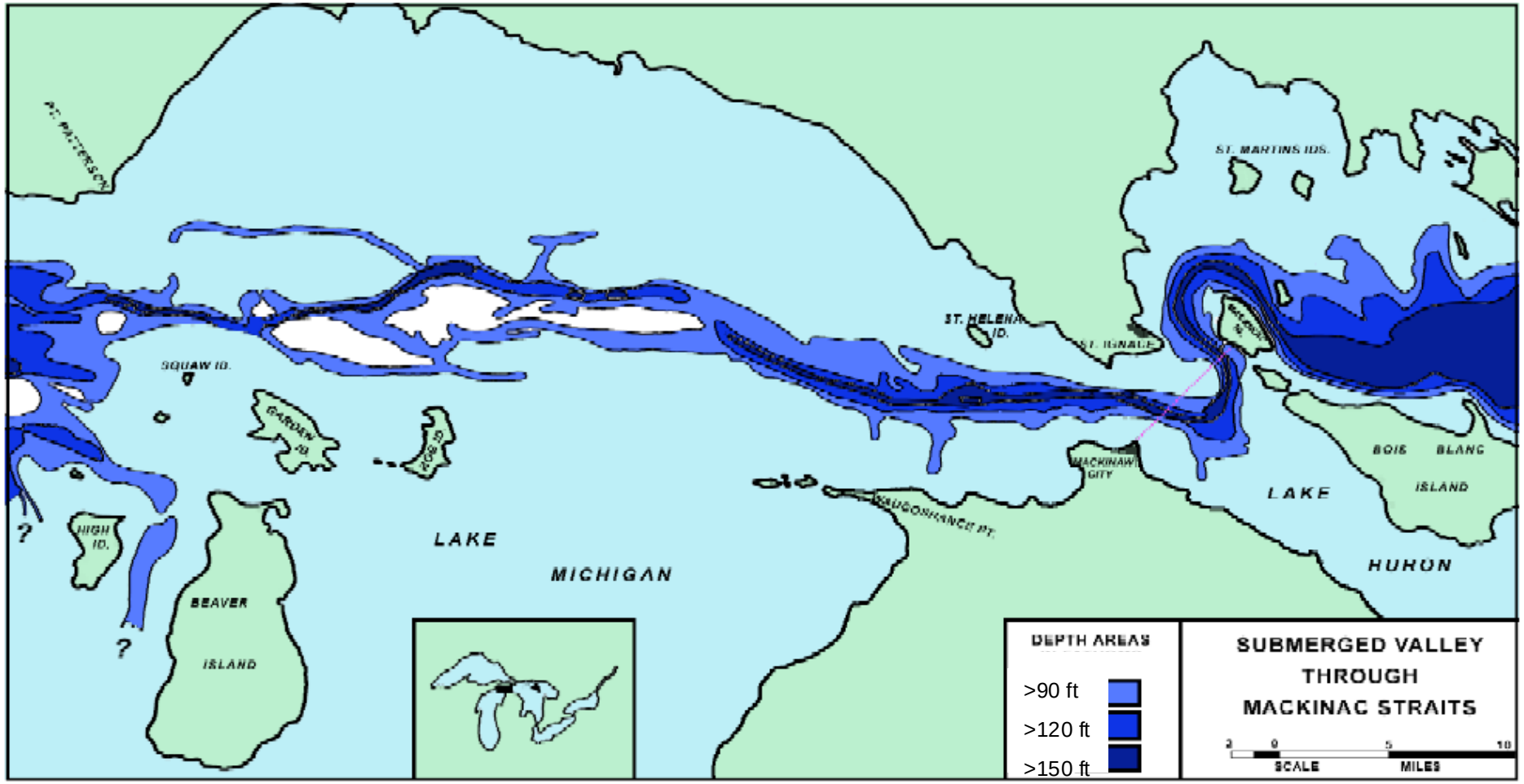
Screw anchor and 20” pipeline on lakebed

Proposed Pipeline in Tunnel

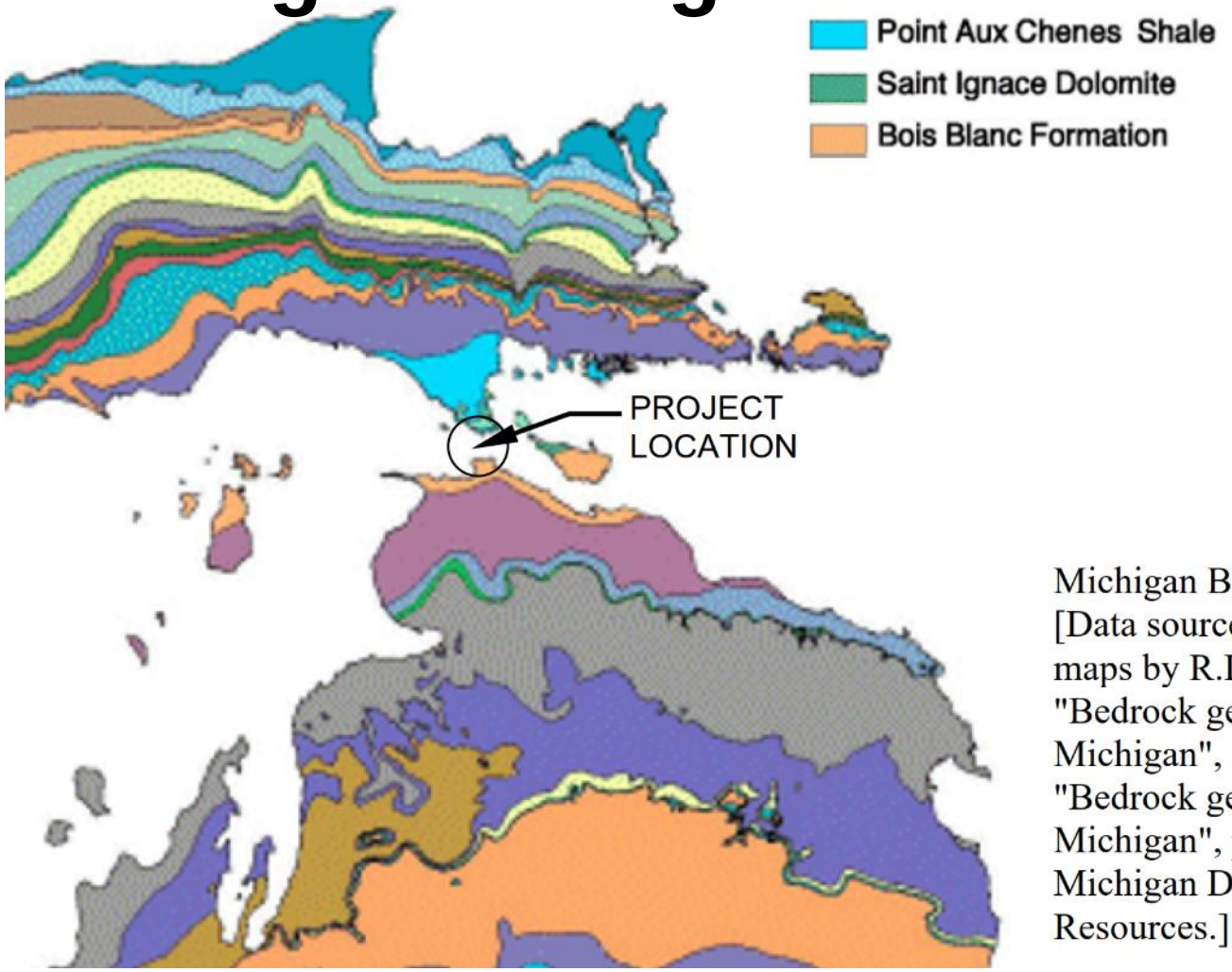


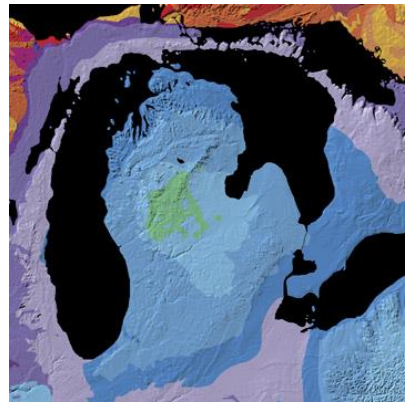


Submerged River Channel (After Stanley, 1938; in 2007 Field Guide to Mackinac Island, AIPG)



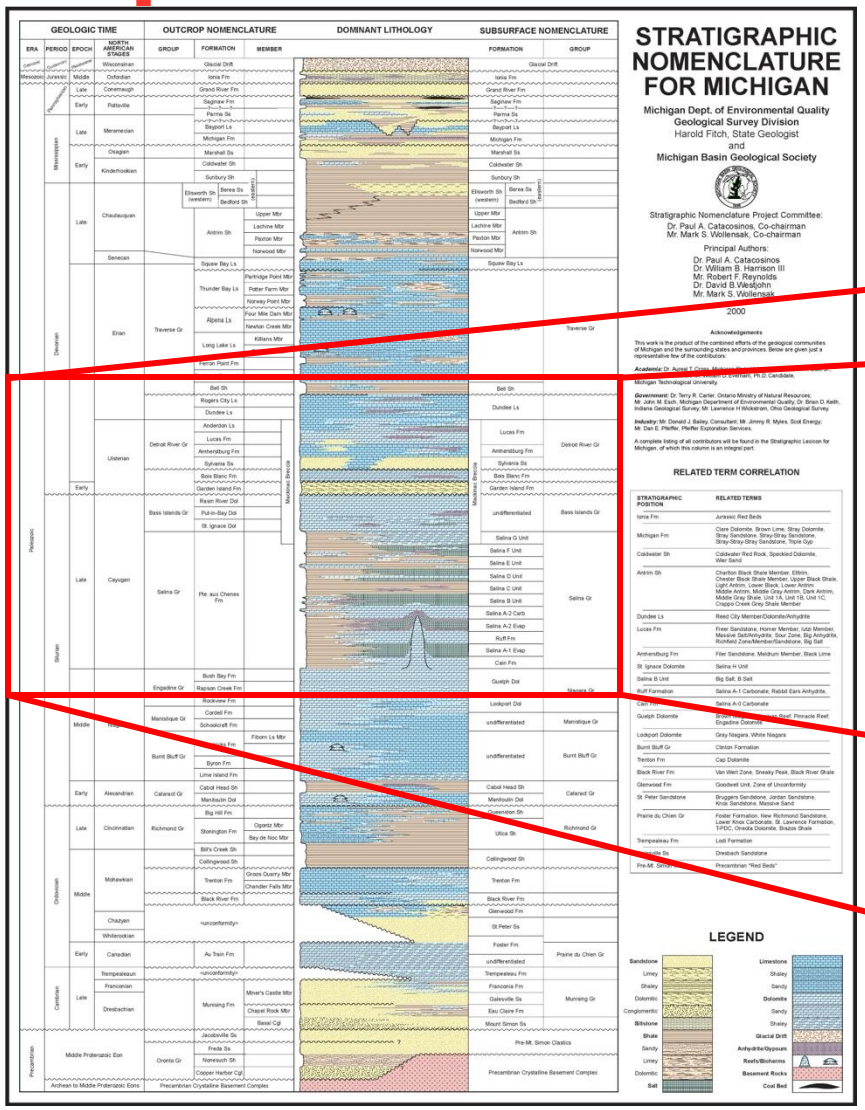
Regional Geologic Setting

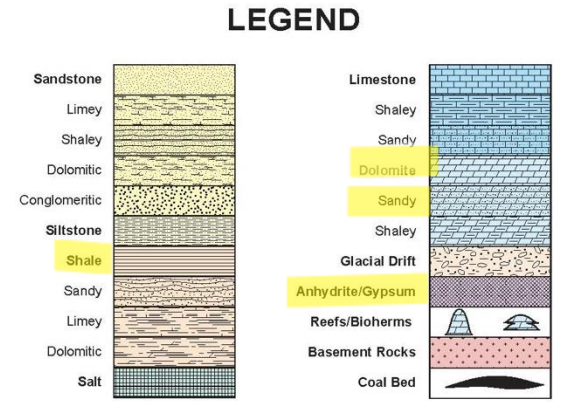


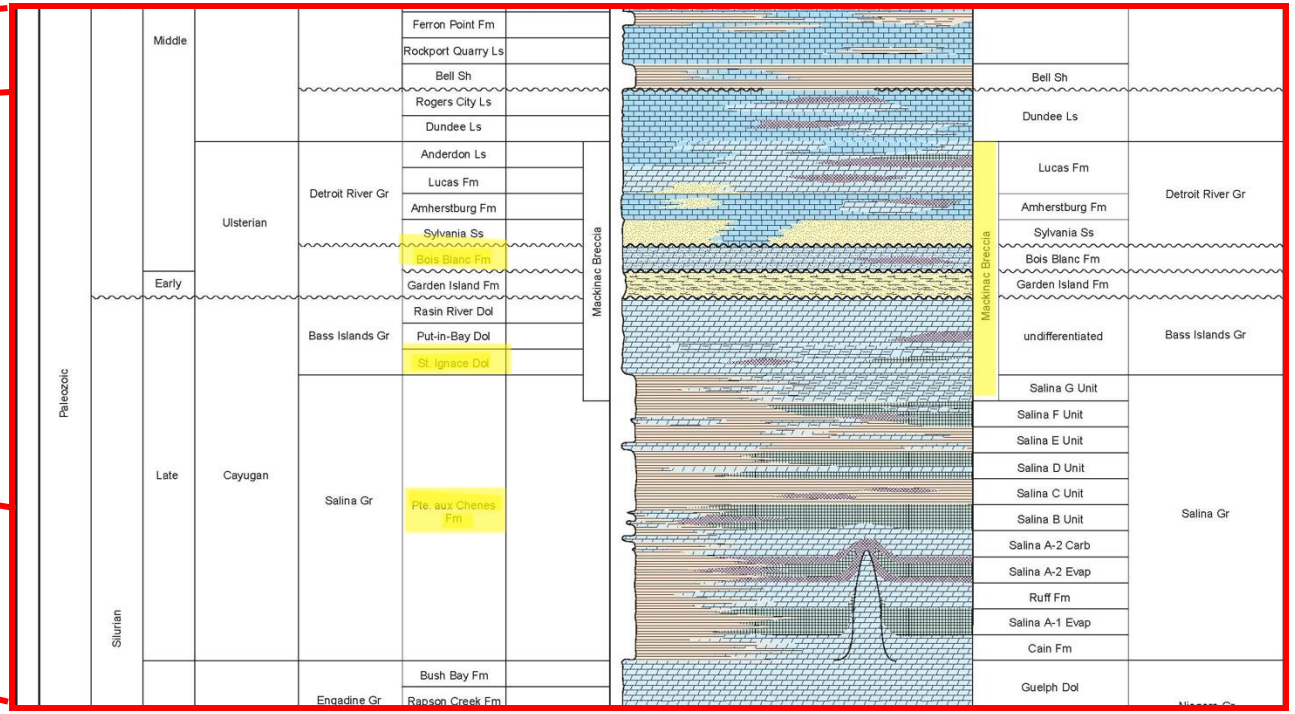


https://commons.wikimedia.org/w/index.php?curid=2246197

Michigan Bedrock Geology
[Data sources are the 1:500,000 maps by R.L. Milstein, 1987, "Bedrock geology of southern Michigan", and R.C. Reed, "Bedrock geology of southern Michigan", published by the Michigan Department of Natural Resources.]







Stratigraphic Nomenclature for Michigan,
Michigan DEQ Geological Survey Division & Michigan Basin Geological Society, Catcosinos et al, 2000

Formation of the Mackinac Breccia

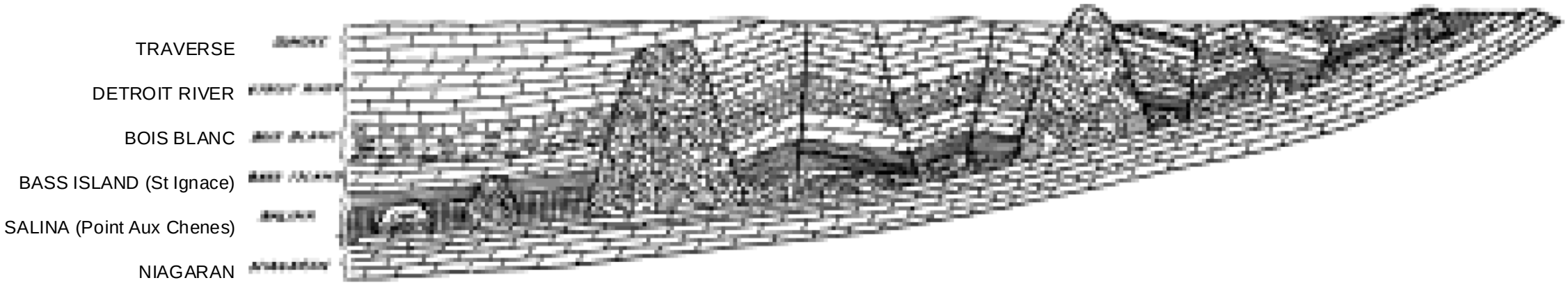


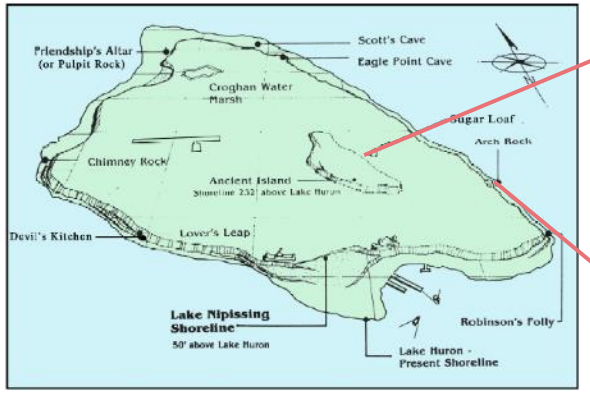
Figure 3. Hypothetical cross section of the Mackinac Straits Region showing collapsed formations above the Niagara limestone, breccia chimneys, and breccia stacks.

Michigan Geological Survey, PU44 Geological Series 37 Mackinac Breccia

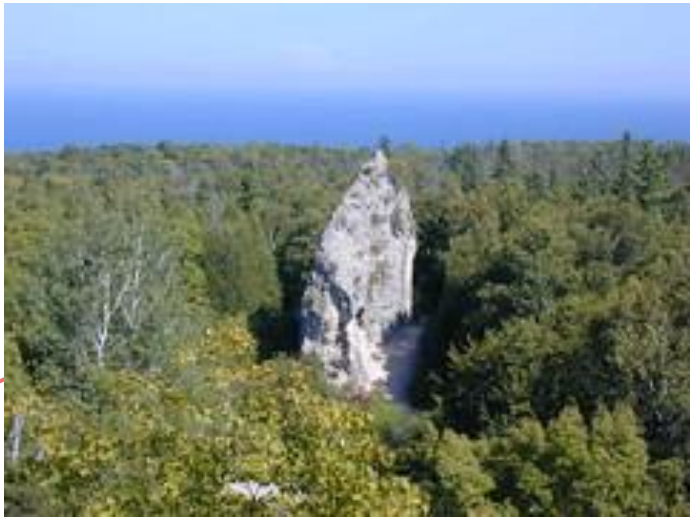
Mackinac Breccia



St. Anthony's Rock
St. Ignace, MI



Mackinac Island
(Porter & Nelhibel, 1984, in 2007 AIPG Field Guide)

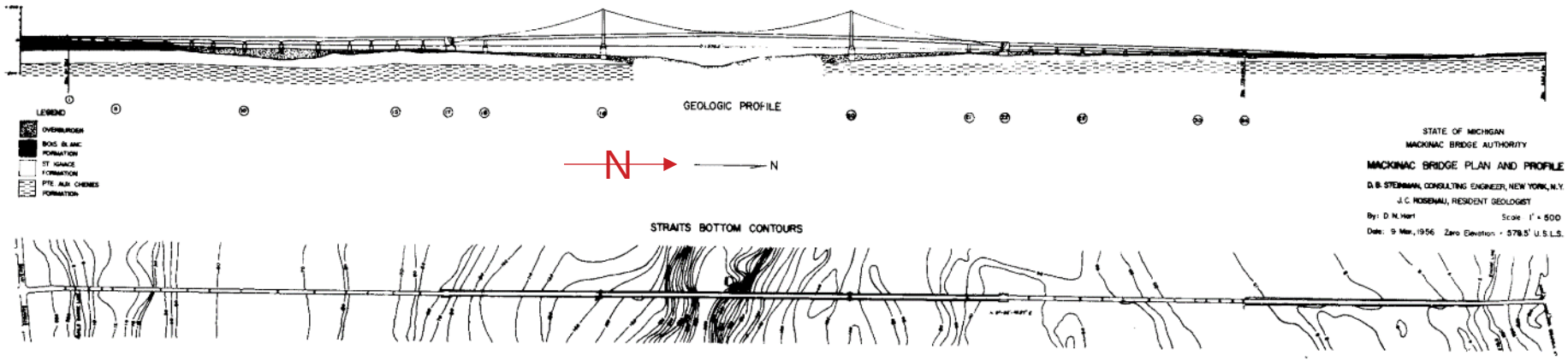


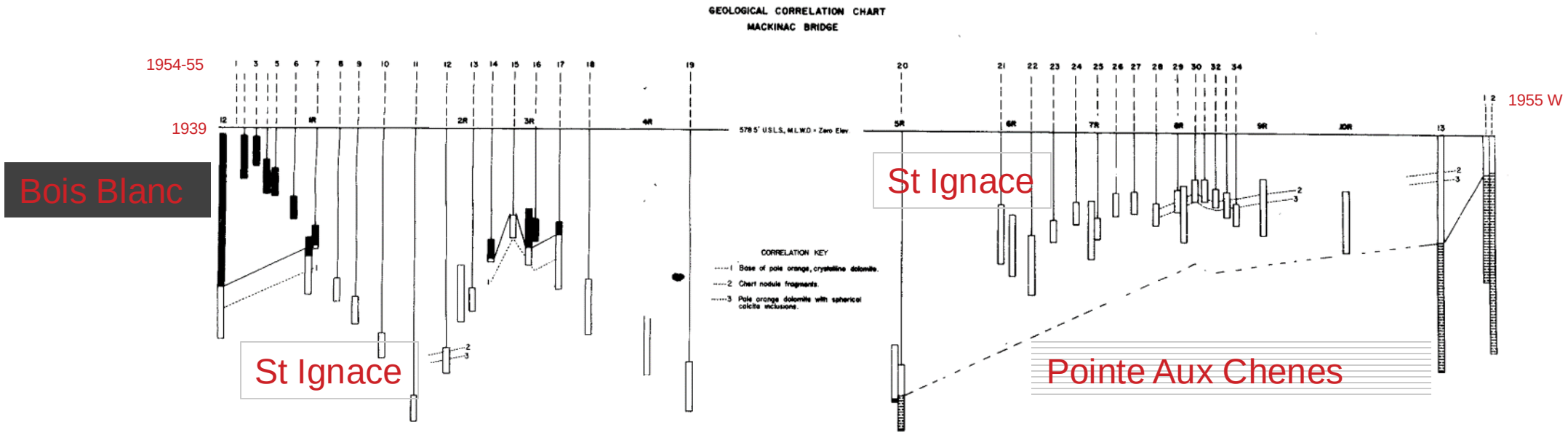
Sugar Loaf



Arch Rock

Historical Data: Mackinac Bridge

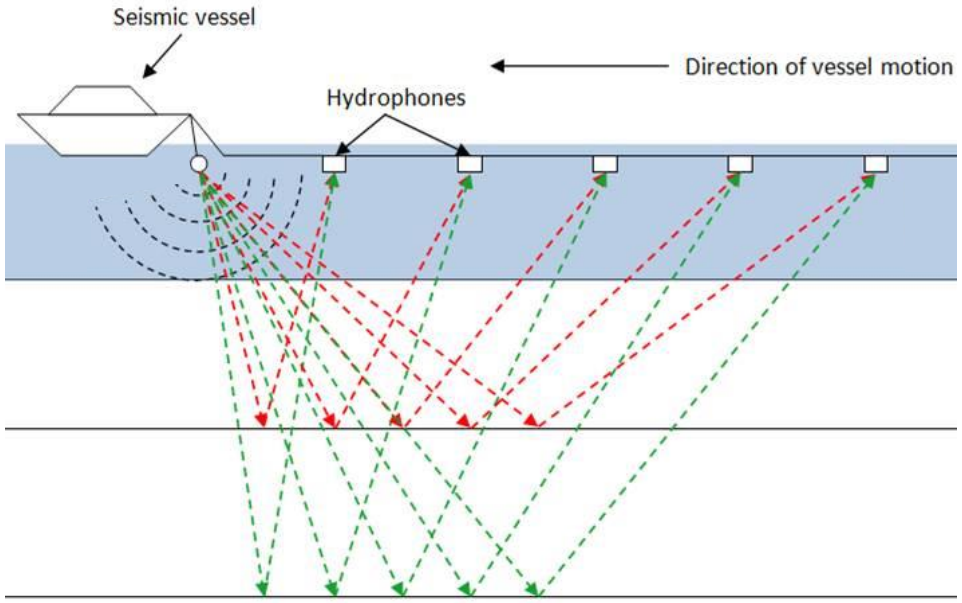


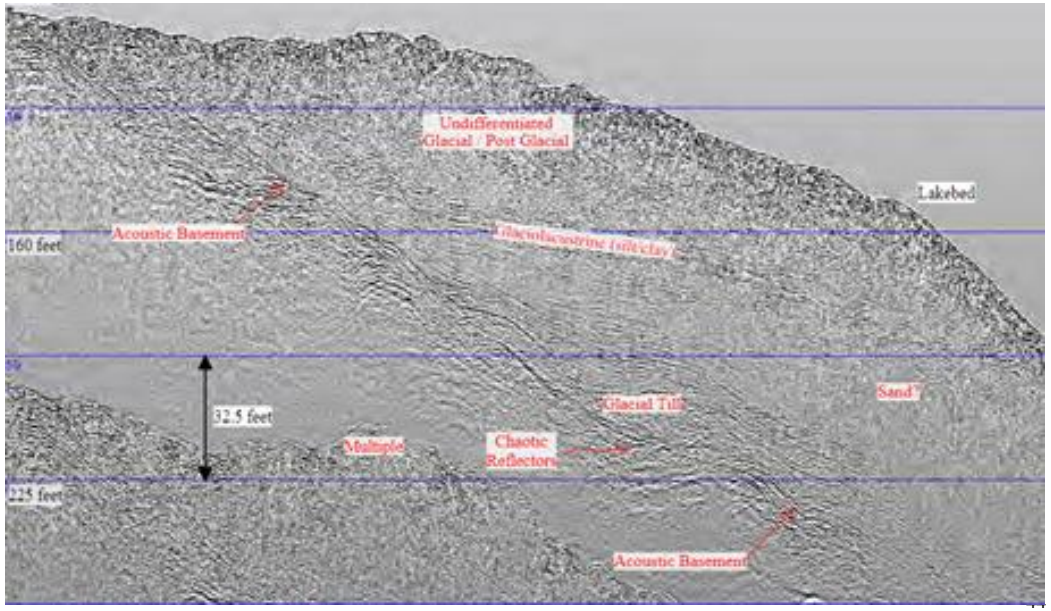


Marine Seismic Reflection/Refraction Survey (2018)



Geophysical data is interpreted to characterize the subsurface geologic conditions and geologic structure.





2019 Boring Locations



Onshore, Nearshore, & Deepwater Borings

South Shore





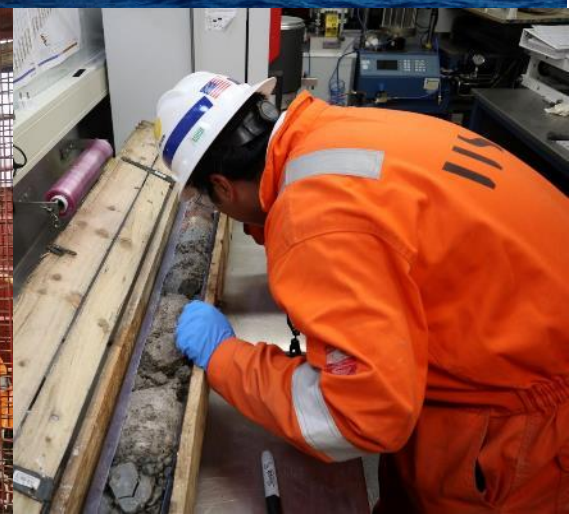
Jack-up Barge



Dynamically-positioned Drill Ship





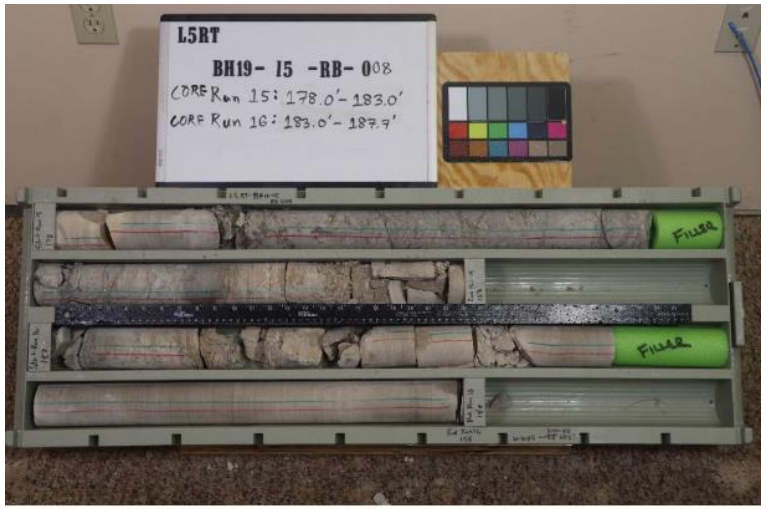


Rock Core Examples from Each Formation



BH19-09-RB-001 (Wet)

Bois Blanc



BH19-15-RB-008 (Wet)

St Ignace



BH19-17-RB-016 (Wet)

Pointe Aux Chenes

Field and Laboratory Testing

Field

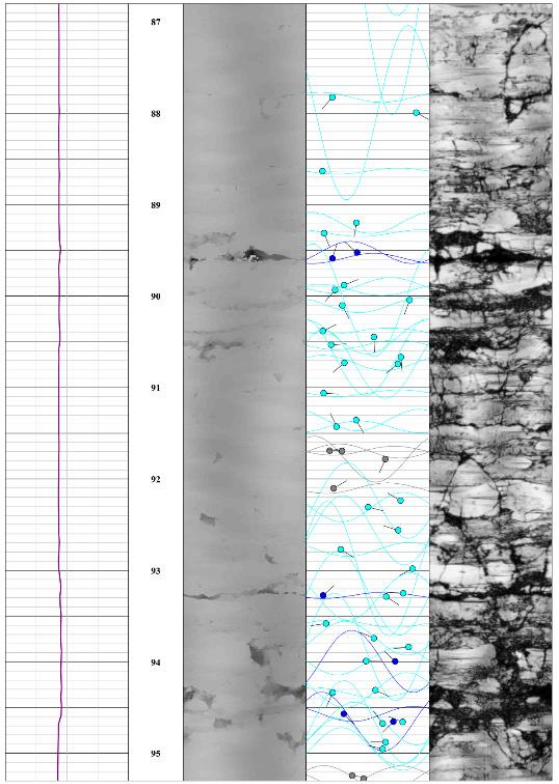
In-Situ Testing

- Downhole seismic
- Acoustic & Optical televiewer
- Natural gamma & Borehole caliper
- Electrical potential, Resistivity
- Temperature, Fluid conductivity
- Pressuremeter

Groundwater/Hydraulic conductivity

- Packer tests
- Observation wells
- Slug tests
- Aquifer Test (pump test)
- Water sampling for dissolved gases

Acoustic Televiewer



Laboratory

Soil

- Classification tests

Rock

- CERCHAR Abrasivity Index
- Direct Tensile Strength
- Unit Weight
- X-Ray Diffraction
- Point Load Index
- Punch Penetration
- Slake Durability
- Splitting (Brazilian) Tensile Strength
- Triaxial Compression w/Elastic Moduli, Unconfined Compression
- Mohs Hardness
- Pulse Velocity
- Drillability (abrasion,
- brittleness, drillability)
- Soil Abrasivity testing

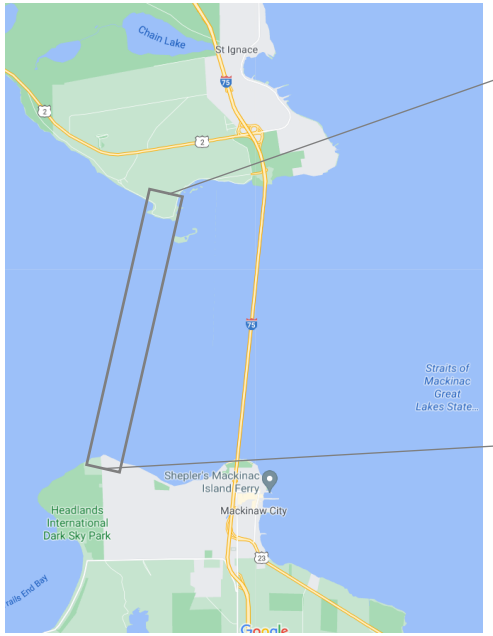
Rock Strength

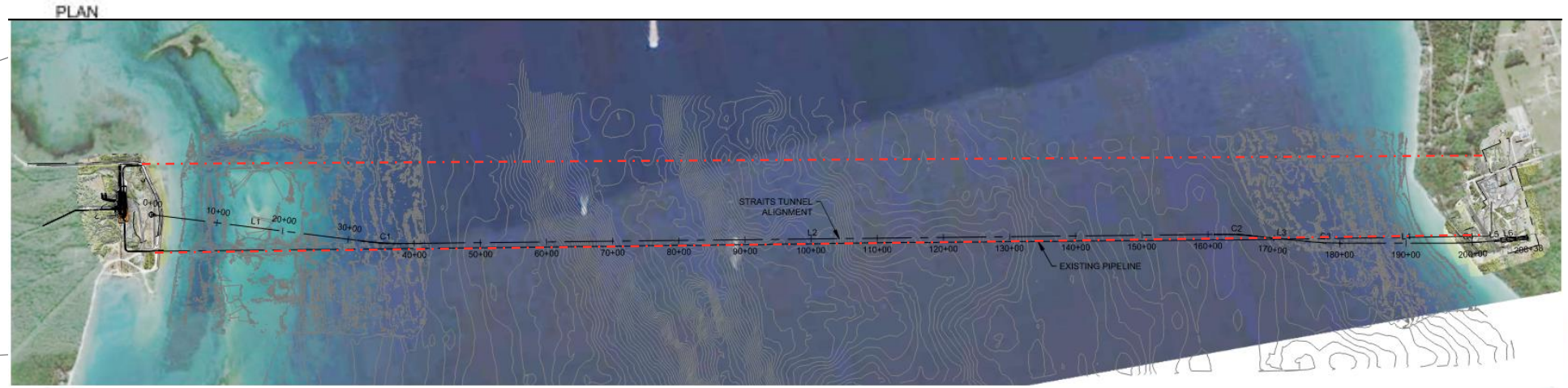


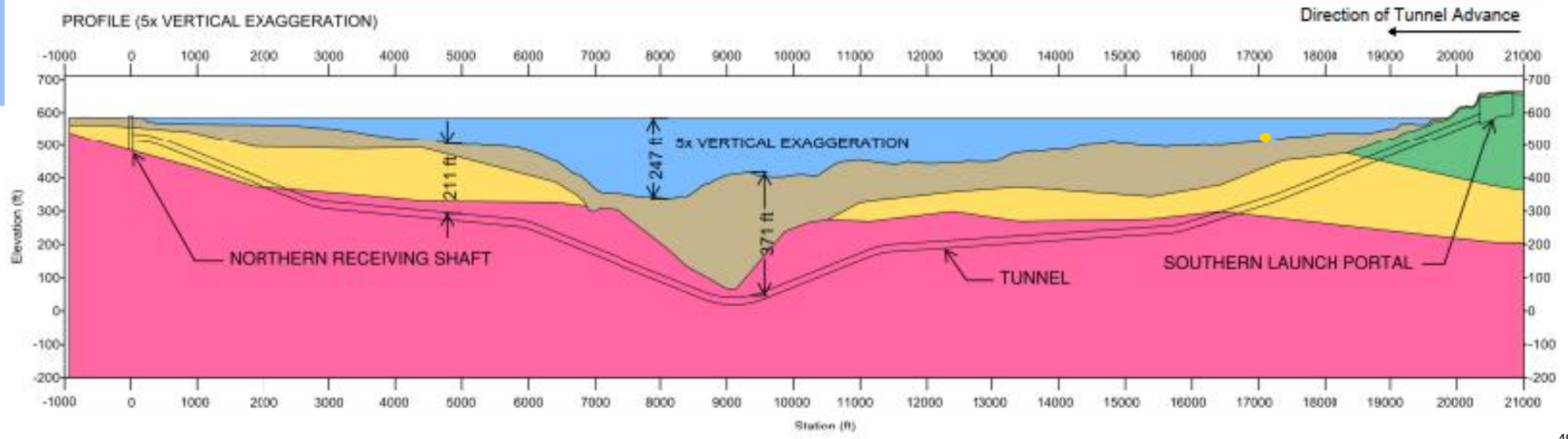




Tunnel Plan and Profile







Subsurface Risk Considerations

Low Likelihood Conditions

- Deeper-than-expected buried valley
- Open voids (karst)
- Toxic/combustible gases

Not anticipated – but if they occur can be managed with some adaptations during tunneling

Known Rock and Water Conditions

- Variable fracture frequency and hydraulic conductivity
- Claystones in Point Aux Chenes - zones of weak rock, slaking, & squeezing
- Rock parameters: expected tool wear
  - Maintenance interventions at high water pressures

Managed with the specified TBM and construction methods

Geologic understanding and subsurface data provides a sufficient basis for GBR, tunnel design and state-of-the-practice TBM specifications

Mackinaw Station Portal & North Straits Shaft

Launch



Retrieval



Influence of Ground Conditions on TBM Requirements

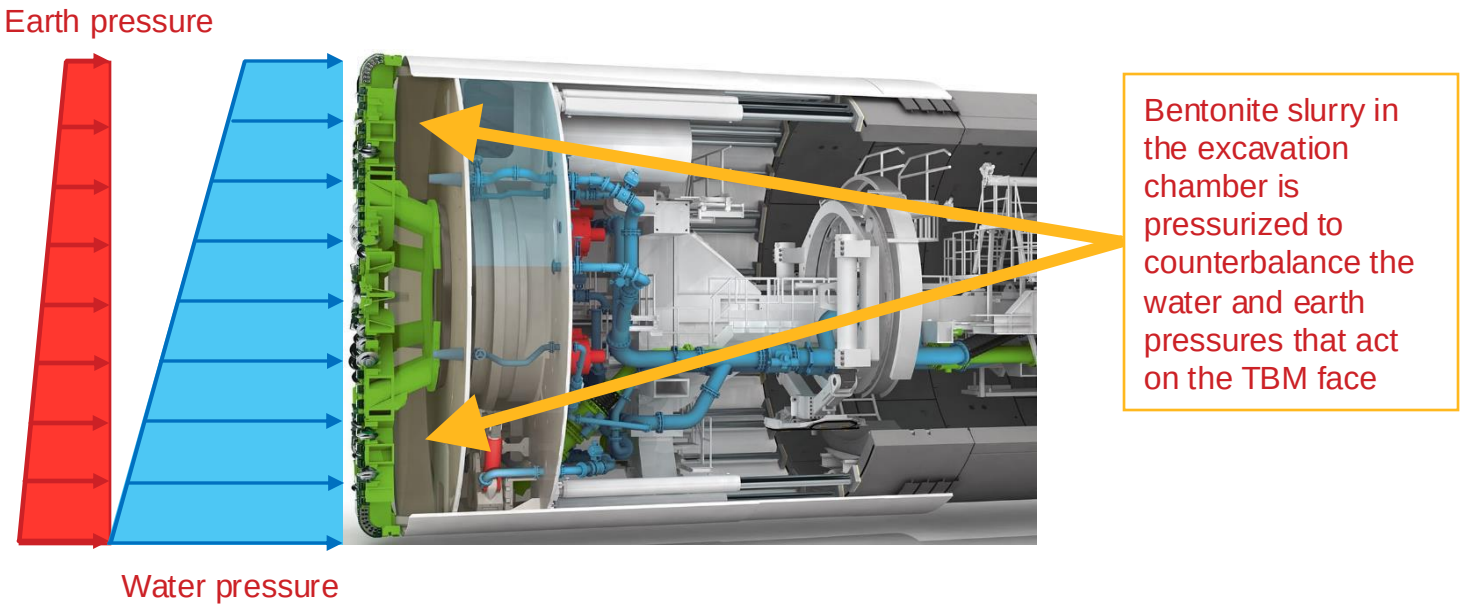
Pressurized face – slurry shield

Intervention frequency and methods

Diameter for construction & spaceproofing

Squeezing

Pressurized Face TBM



TBM Illustration: Herrenknecht Mixshield

Influence of Ground Conditions on TBM Requirements

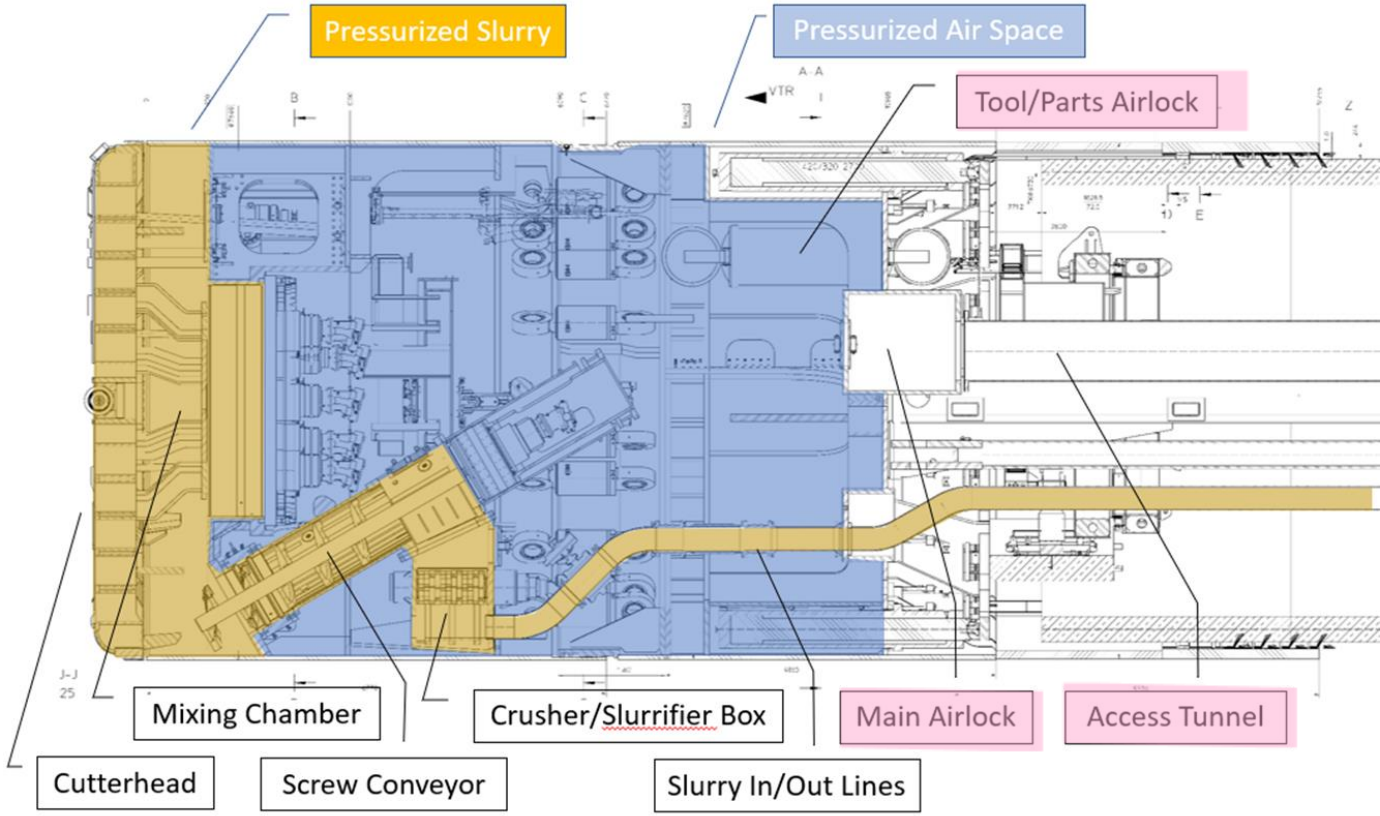
Pressurized face – slurry shield

Intervention frequency and methods

Diameter for construction

Squeezing





Influence of Ground Conditions on TBM Requirements

Pressurized face – slurry shield

Intervention frequency and methods

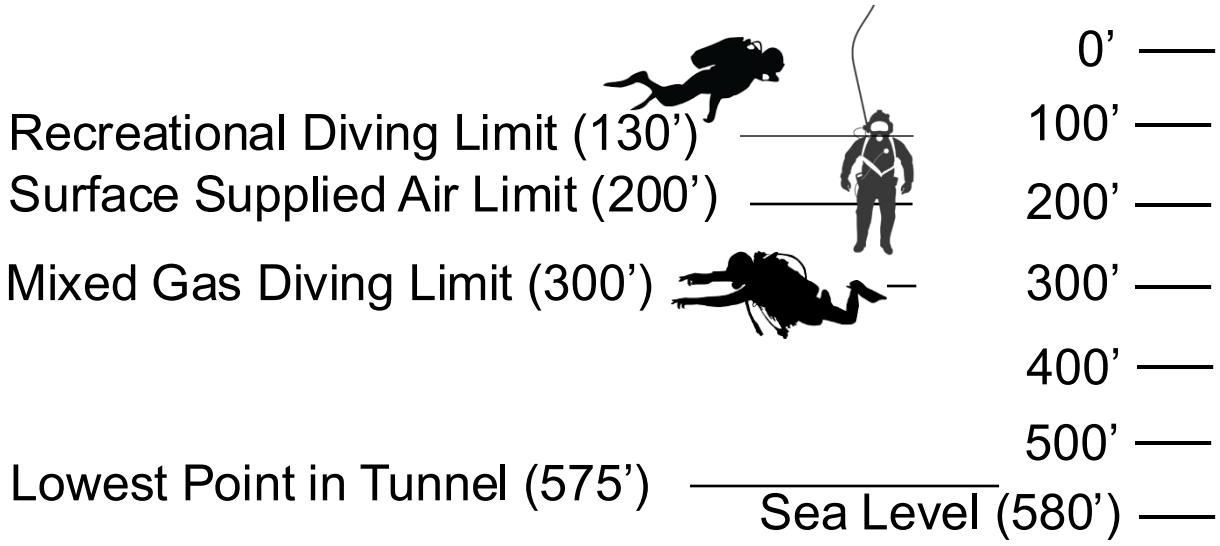
Diameter for construction

Squeezing

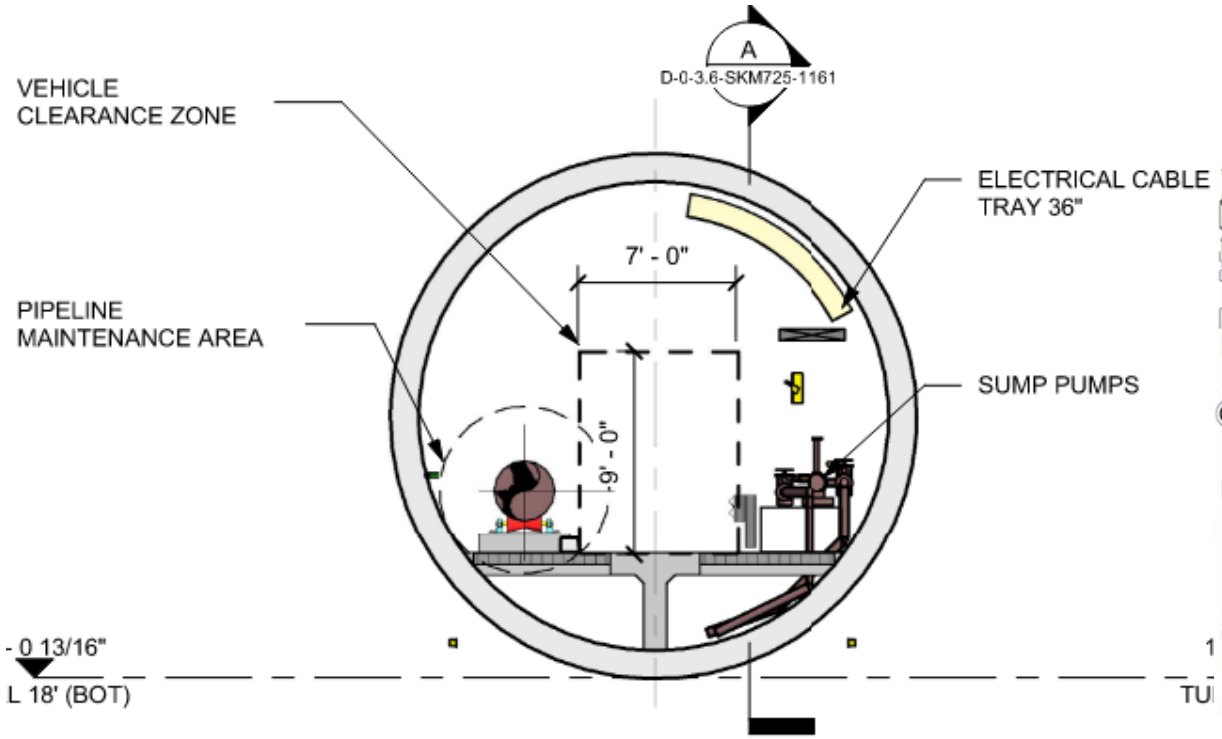


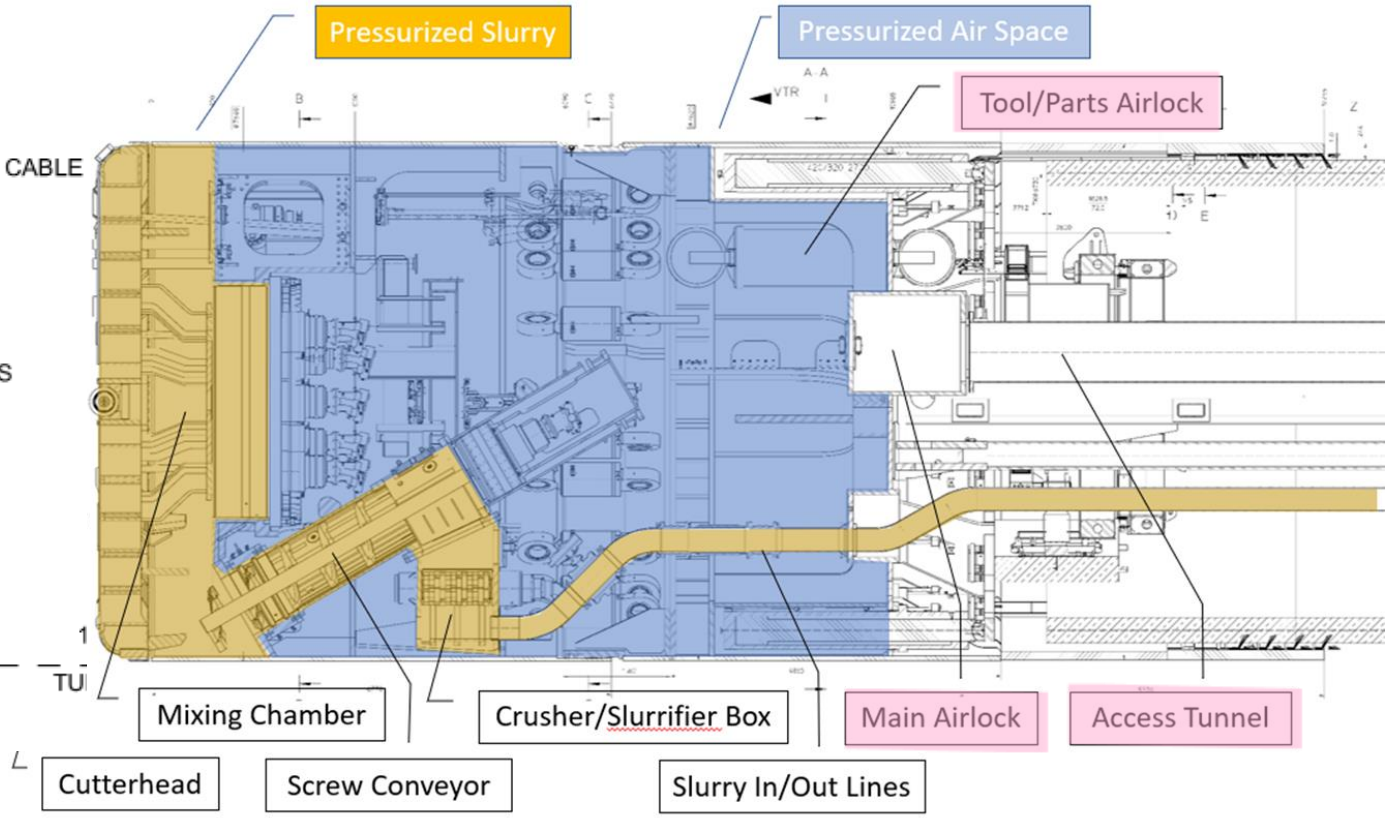
Why is Hyperbaric Intervention Needed?

- Brecciated (broken) rock is permeable, exposing the tunnel to full water pressure
- Frequency and time required for maintenance activities at the cutterhead
- Safety of workers performing maintenance activities



Influence of Ground Conditions on TBM Requirements





Influence of Ground Conditions on TBM Requirements

Pressurized face – slurry shield

Intervention frequency and methods

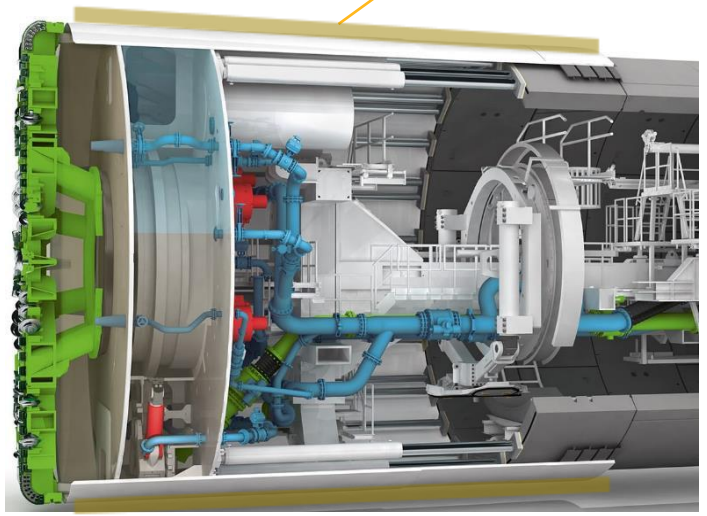
Diameter for construction & spaceproofing

Squeezing: Ground convergence resulting in the ground coming in contact with the TBM. Potential:

- at greater depth where ground loads are high **and**
- rock mass strength of the Point Aux Chenes is locally low.

Squeezing mitigation

Shield gap injection system injects a high viscosity, low shear strength filler around the TBM shield



Avoid TBM stoppage or limit duration

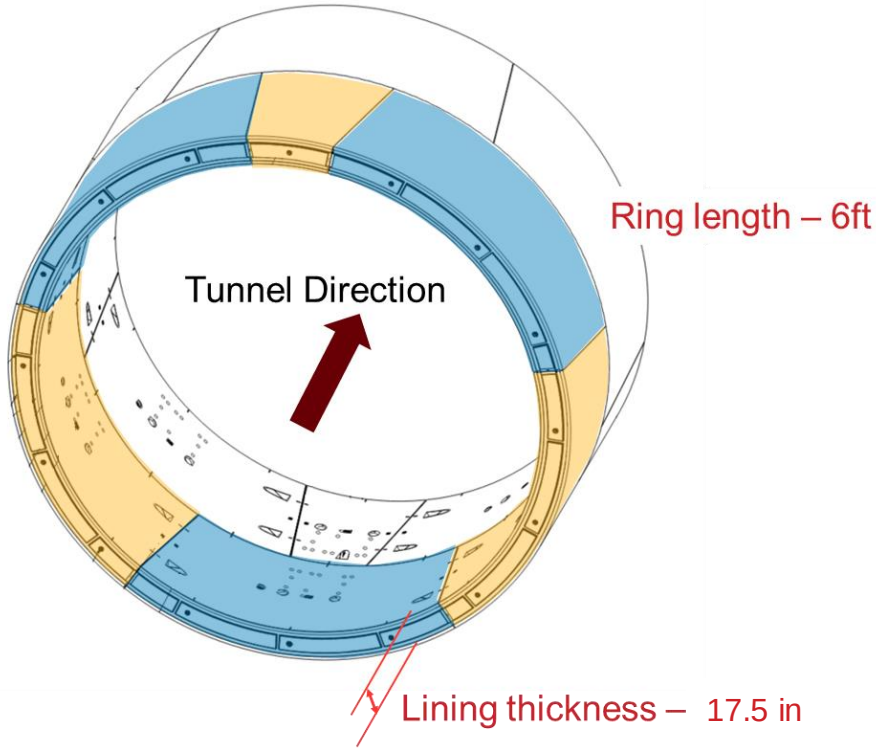
Influence of Ground Conditions on Precast Concrete Tunnel Lining Design

Design Loads & Reinforcing

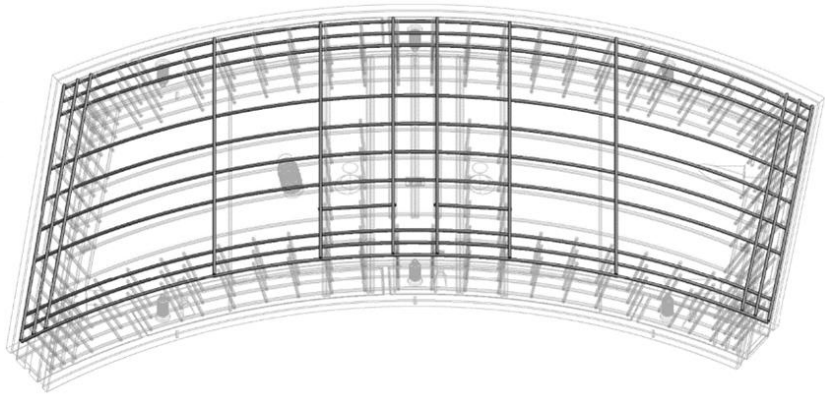
Key segments

Design Life

Leakage Criteria



Typical Welded Wire Reinforcement



Influence of Ground Conditions on Precast Concrete Tunnel Lining Design

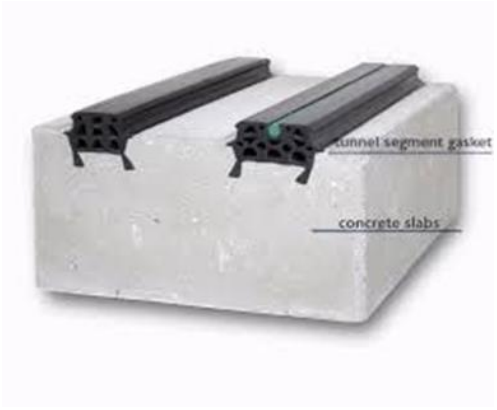
Installation – Key segments

Design Loads - Reinforcing

Design Life

Leakage Criteria

Double gaskets



Typical PCTL segments



Tunnel Leakage Criteria

Max. overall infiltration

- 7000 gal/day
- 0.7 gpm/1000 lf tunnel

Local criteria:

- 0.25 gallon per day for 10 sq. ft of tunnel lining area, and no more than 1 drip per minute at any location.
- No drips over the pipeline or where they have the potential to cause damage to equipment/utils
- No water ingress which causes entry of soil particles into the tunnel.

Great Lakes Tunnel Project

ENBRIDGE

Permitting

Stantec

Owners Engineer

WSP

Designer

ARUP

Contractor

MACKINAC STRAITS PARTNERS

CBNA

BARNARD

Success Factors for Managing Geologic Risk

- Recognize geologic risks with potential to impact design and construction
- Seek information from past projects
- Obtain early contractor involvement
- Provide contractual mechanisms to manage geologic risk



THANK YOU

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