Underground Mine Exploration and Void Mapping along Interstate 70 (MUS-70-15.31) and State Route 93 (MUS-SR 93-12.80) Muskingum County, Ohio

By:
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Terracon Consultants, Inc.

Terracon
Consulting Engineers and Scientists

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Geohazards 2014 – 14th Annual Technical Forum
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Focus

- Project Information and Investigation Methodology
  - Ohio DOT proactive approach
- Abandoned Mine Subsidence Challenge
  - The problems
- Geotechnical Underground Mine Exploration Investigations
  - Exploratory borings
  - Void imaging and mapping
- Void Volume Determination
- High Risk Areas Identification
- Conclusions and Recommendations

Ohio DOT Proactive Approach

Development of a comprehensive abandoned mine subsidence risk assessment and mitigation program for…

- ❑ Minimizing subsidence risk through cooperative team effort involving ODOT, Terracon, and ZAPATA
- ❑ Mapping known and unknown mines that exist beneath roadways
- ❑ Focusing exploratory borings and void mapping where mitigation efforts should be directed
- ❑ Determining void volume
- ❑ Identifying high risk areas which require mitigation

Why abandoned mine subsidence is so complex to solve

The Problem

Many unknown conditions…!

Subsurface
- Strata
- Geologic setting
- Mining depth

Mine workings
- Dry and/or flooded
- Stable
- Collapse / rubble / gob

Voids / openings
- Location & orientation
- Size
- Lateral extent

Mine records / maps
- Incomplete
- Incorrectly geo-referenced
- Nonexistent

Extraction rate
- 40% to 70%, or
- 80% to 100%

Time-dependent
- Integrity of coal
- Integrity of roof structure

The Solution

- Accurate risk assessment
- Cost-effective mitigation techniques

➢ Geotechnical Underground Mine Exploration Investigations

Proactive Approach

ODOT Two Projects
- MUS-70-15.31 (I-70)
- MUS-SR93-12.80 (SR-93)

Void Imaging

- Video camera
- Sonar & laser imaging

Focused Exploratory Borings Program

Total 70 Borings
Drill cutting logging

Geotechnical Engineering Solution
- Developed 2D and 3D images of the voids
- Determined current mine conditions
- Determined volumes of mapped voids
- Identified high risk areas that require mitigation

Site Location

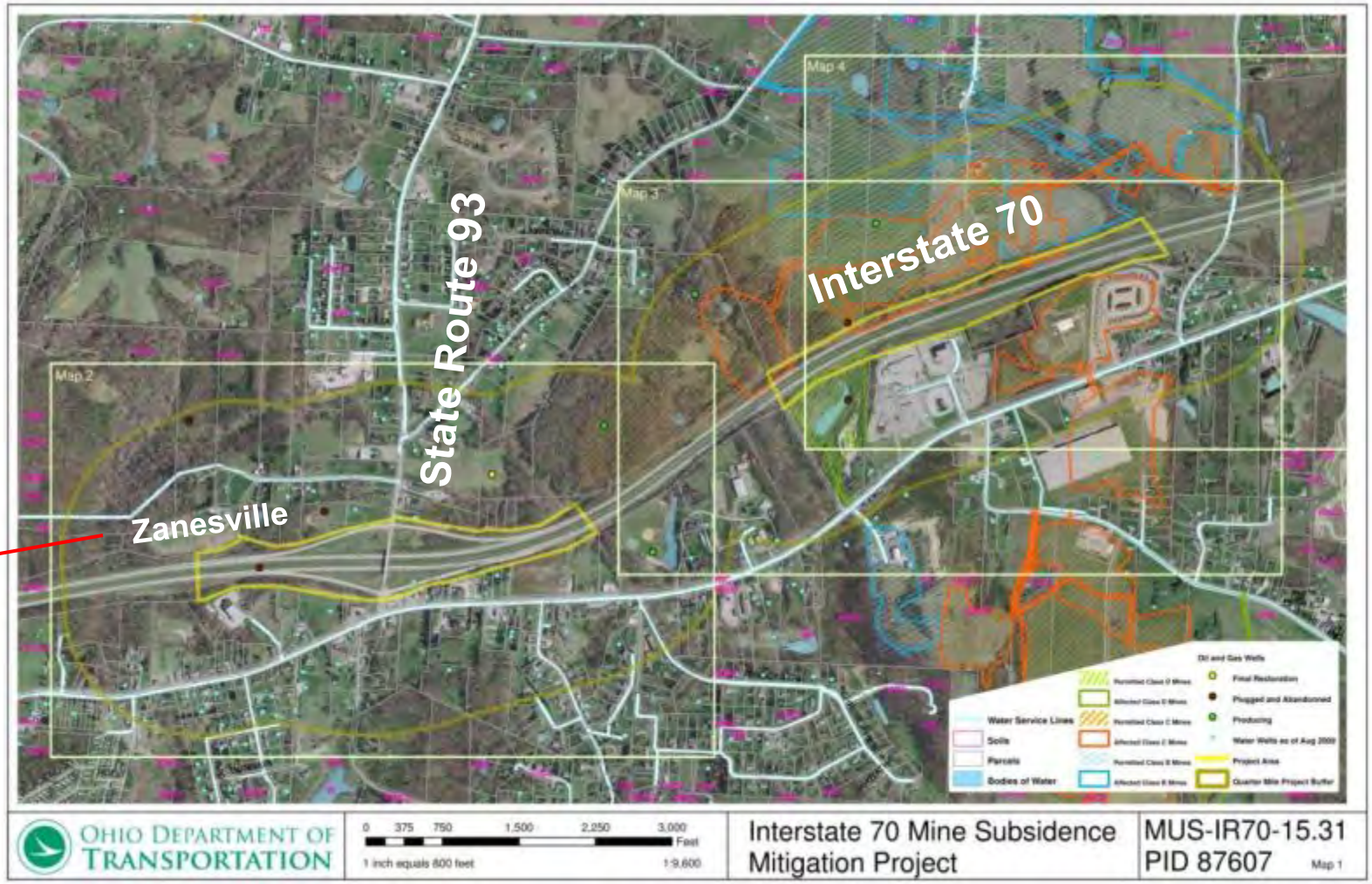
Along I-70 East of Zanesville, Ohio

I-70 between ~ MM 157 & 159

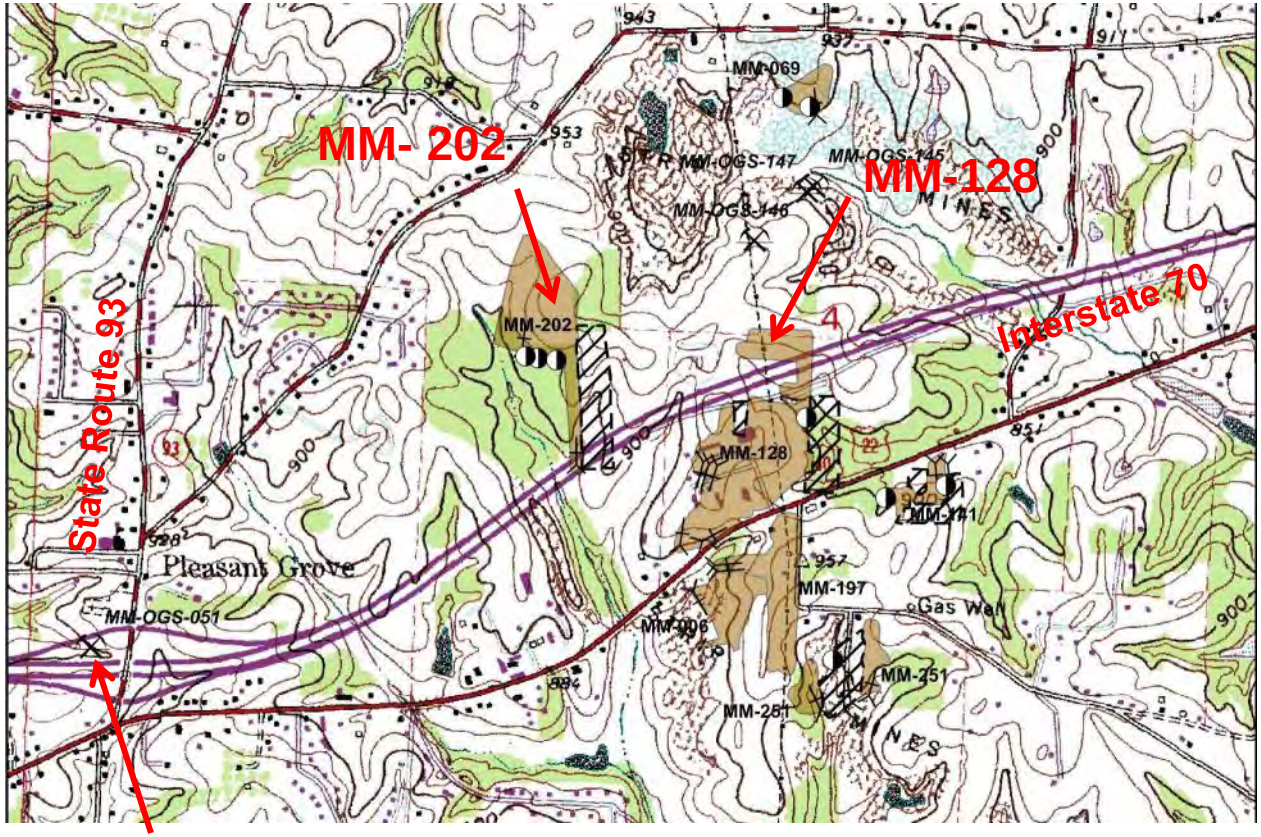
Exit 157 – I-70 & State Route 93

Site Location

Along I-70 East of Zanesville, Ohio



Abandoned Underground Mines - Washington Twp., Muskingum Co. Ohio



MM -202

- Forest Hill Mine
- Abandoned 1932
- Upper Freeport No. 7 coal

MM -128

- Greiner Mine
- Abandoned 1959
- Upper Freeport No. 7 coal; Mine El. ~ 887 ft

MM –OGS-051

- Handchy Mine
- Date ~1917 – Mined for local use
- Upper Freeport No. 7 coal; Mine EL. ~900 ft

MM-OGS-051

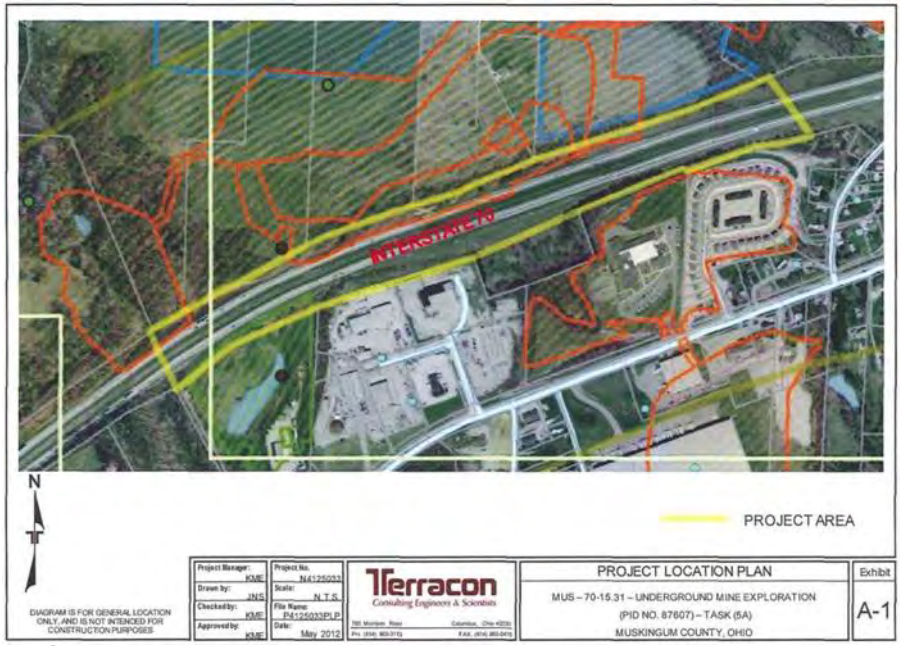
Projects Location Plans

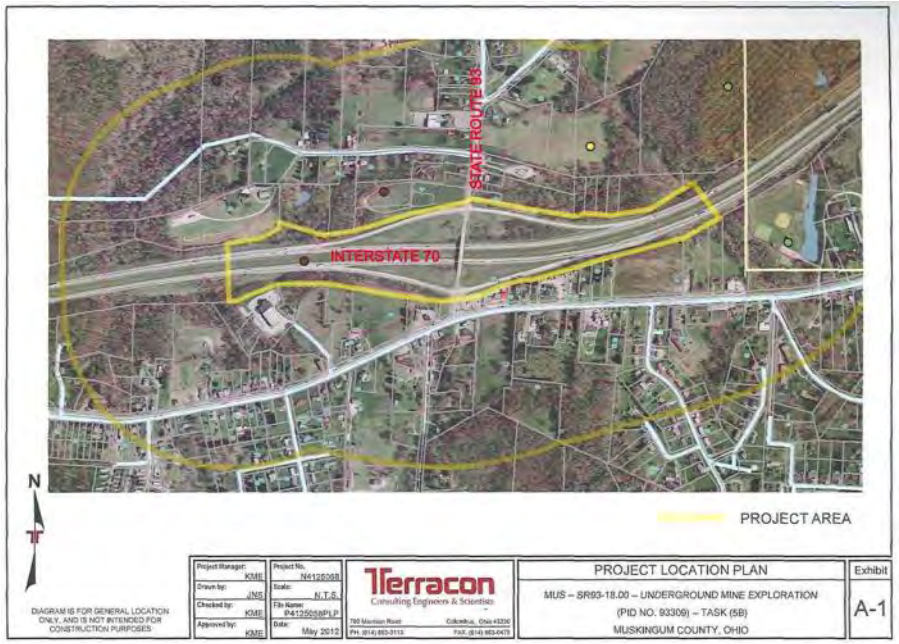
I-70 Project Site

- Mining method: Room-and-pillar extraction
- Coal seam thickness: ~ 5 ft
- Overburden thickness: 15 to 60 ft
- Lithology: Consisting of clay, sandstone, and shale

SR-93 Project Site

- Mining method: Room-and-pillar extraction
- Coal seam thickness: ~ 4.5 ft
- Overburden thickness: 15 to 37 ft
- Lithology: Consisting of clay, sandy silt, sandstone, and shale



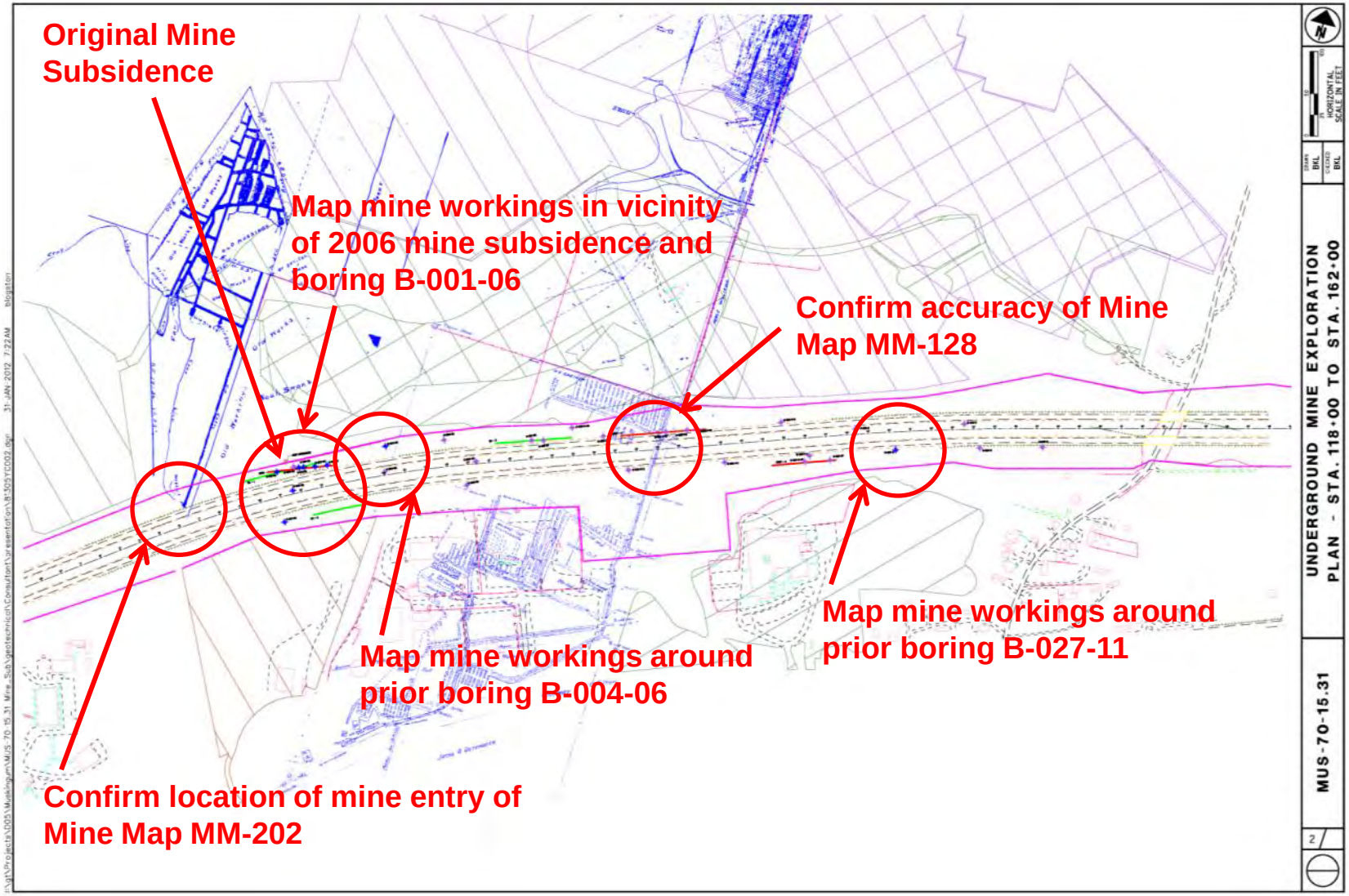


I-70 Project Objectives

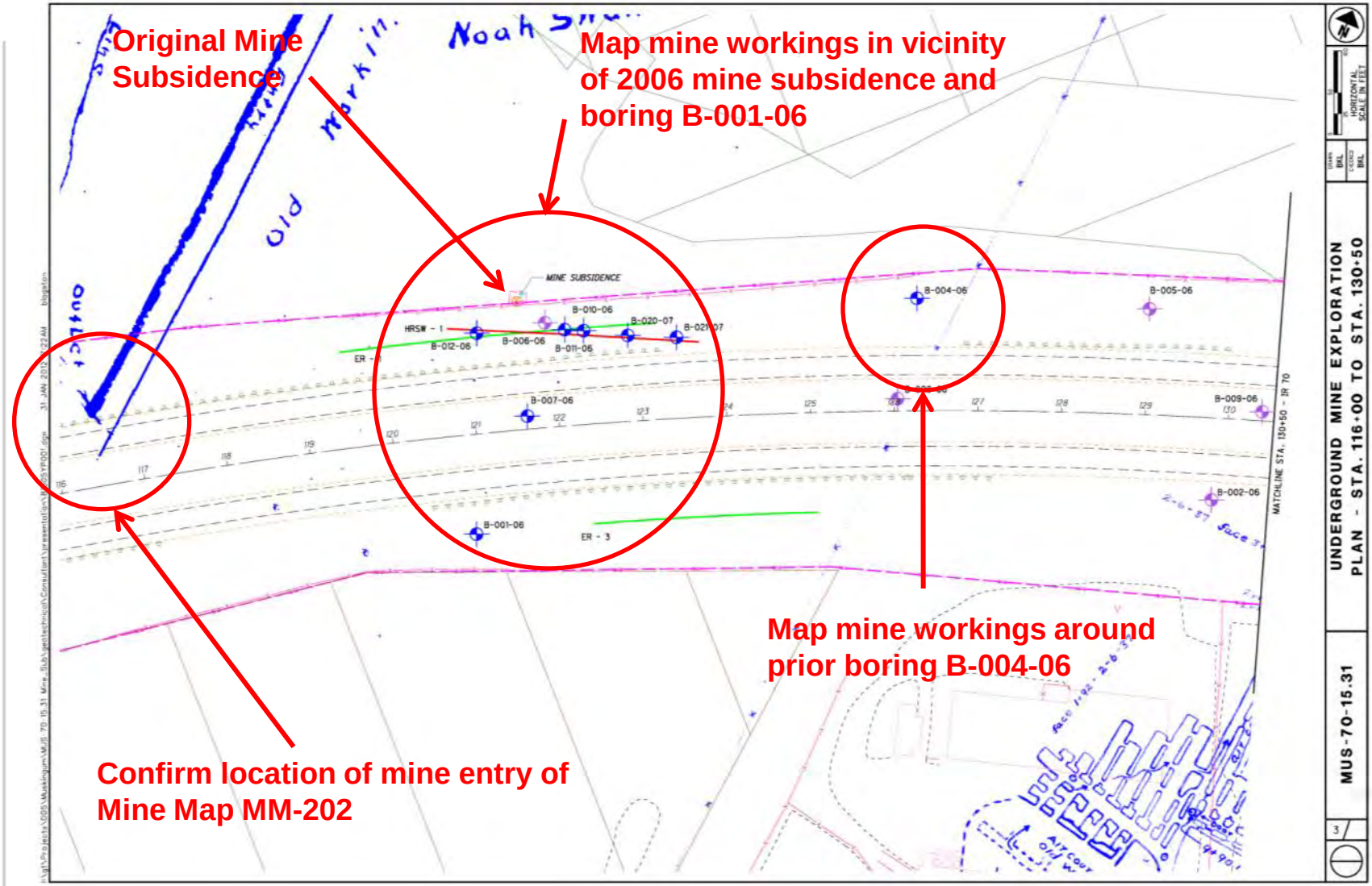
- MUS-70-15.31 Project: ~ 3,800 feet long through area of historic underground and surface coal mining
  - Ohio DOT first observed ground subsidence at the R/W fence left of Sta. 122+00 in 2006
  - Ohio DOT conducted literature search and performed multiple prior phases of drilling and geophysical surveys

- Objectives of Exploration: Use Down-the-Borehole Laser and Sonar Void Imaging and Mapping to:
  - Confirm the accuracy of Mine Map MM-128
  - Map the mine workings around prior borings B-027-11 and B-004-06
  - Confirm the location of the mine entry of Mine Map MM-202
  - Map Mine workings in the vicinity of original subsidence and prior boring B-001-06

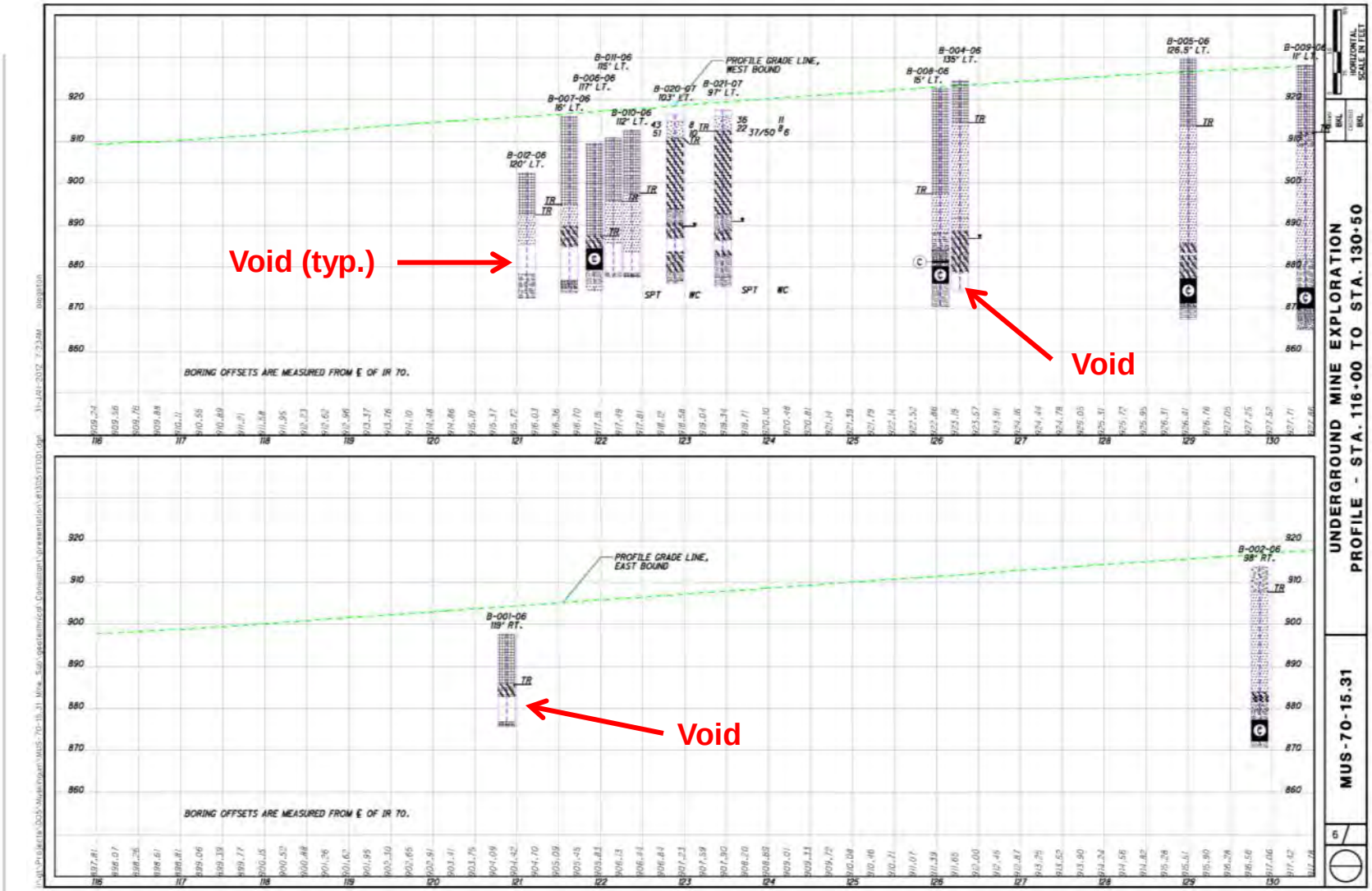
I-70 Project Objectives



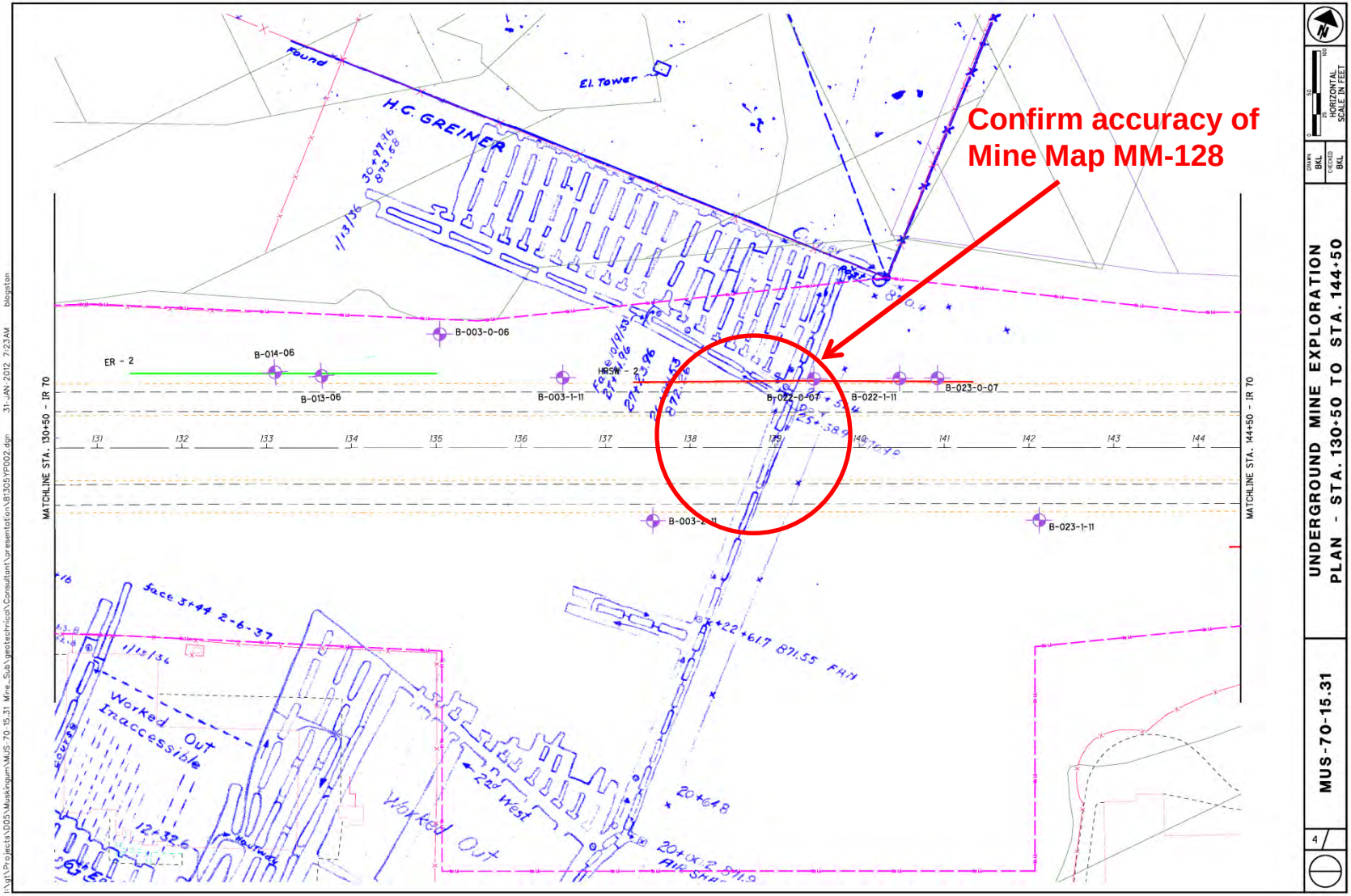
I-70 Project Objectives – Sta. 116+00 to 130+50



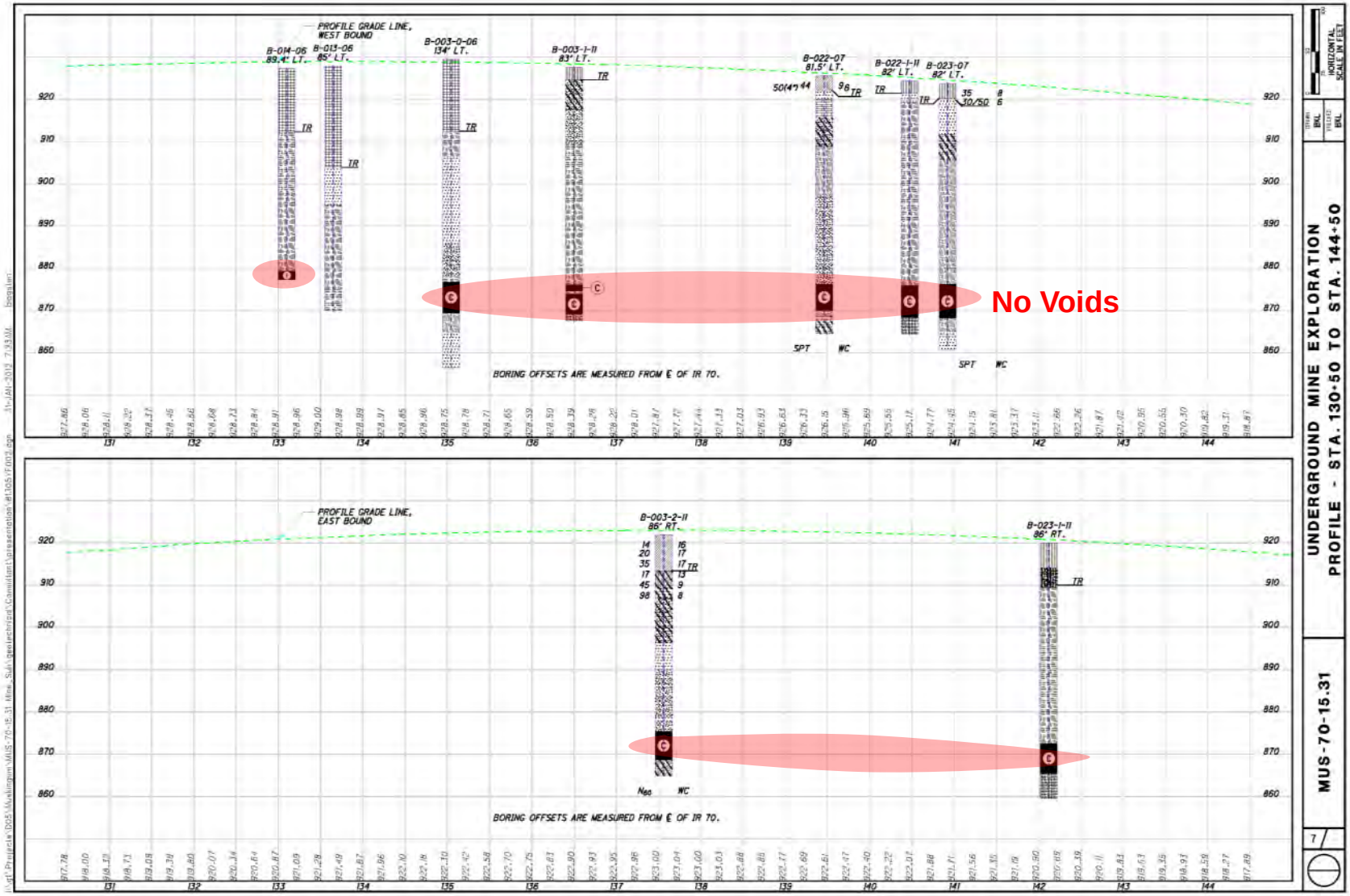
Prior Borings – Sta. 116+00 to 130+50



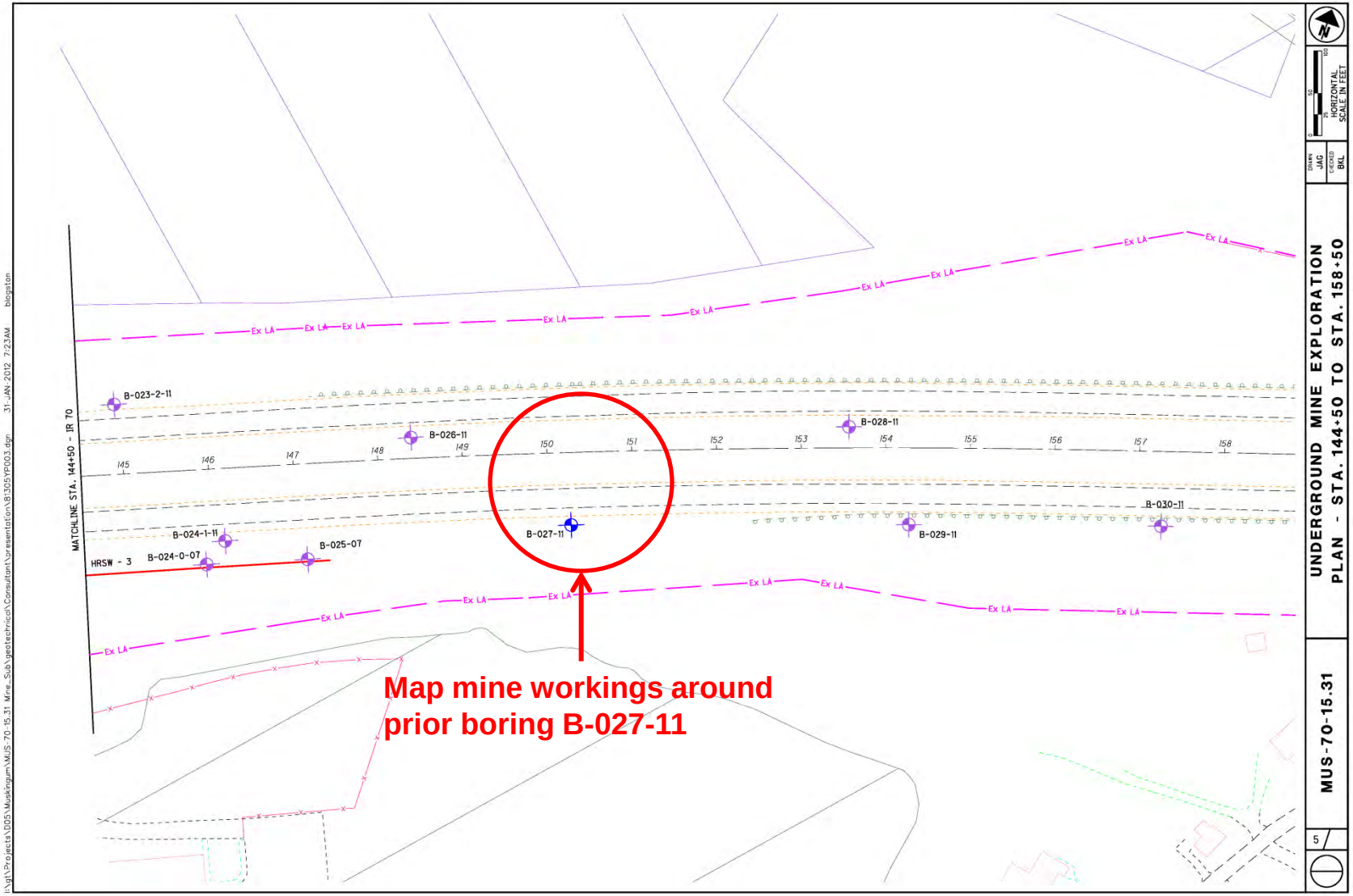
I-70 Project Objectives – Sta.130+50 to 144+50



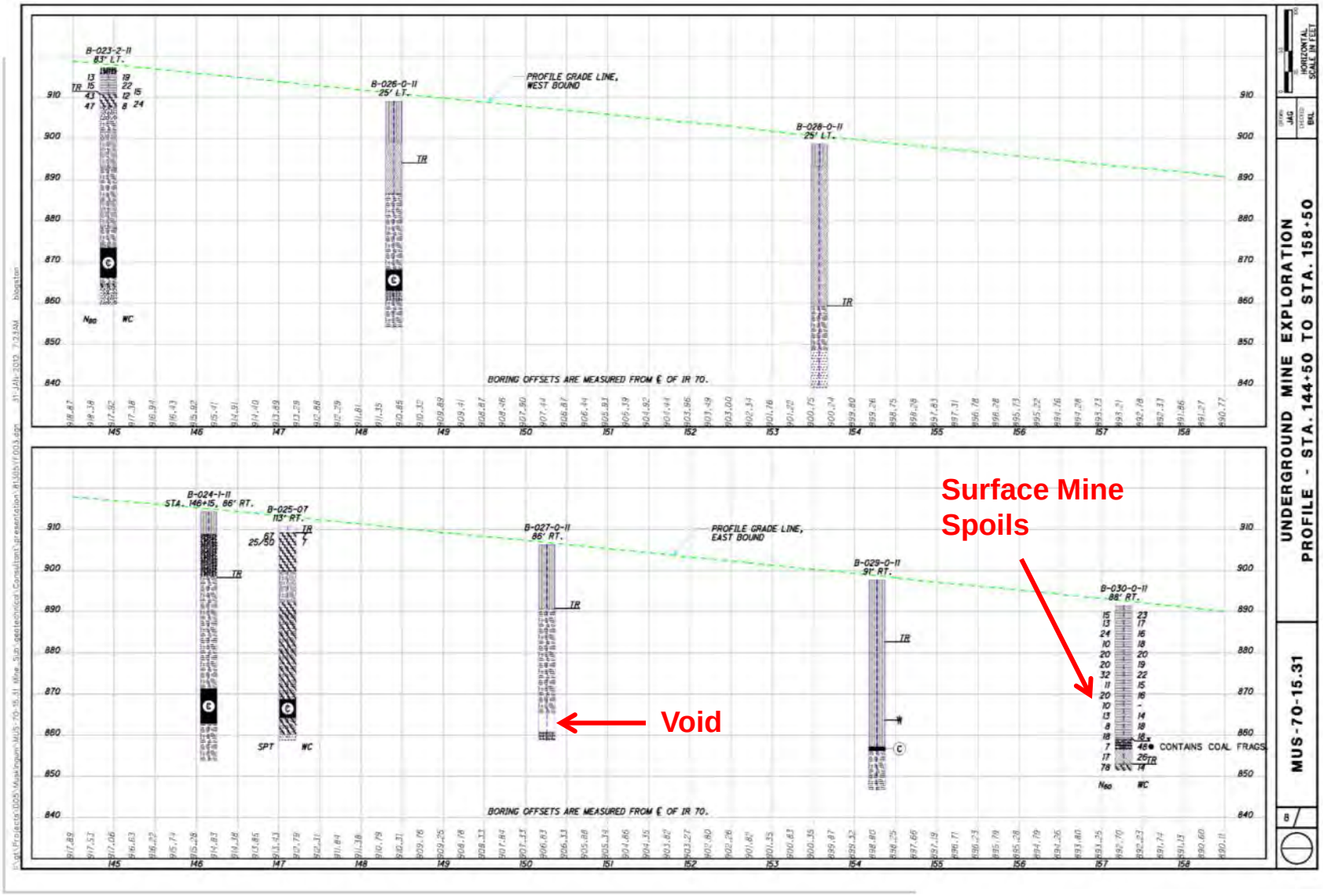
Prior Borings – Sta. 130+50 to 144+50



I-70 Project Objectives – Sta. 144+50 to 158+50



Prior Borings – Sta. 144+50 to 158+50

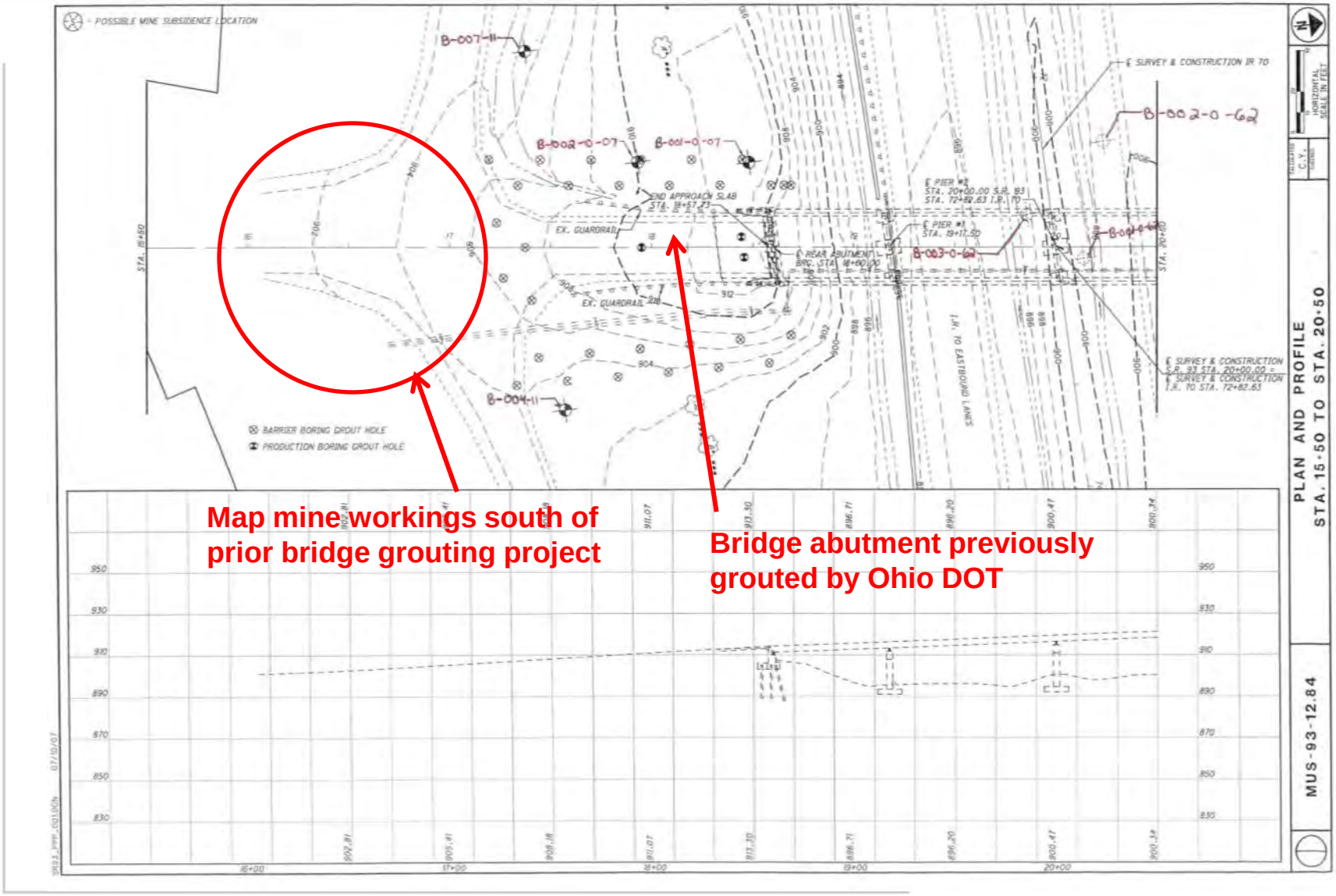


SR-93 Project Objectives

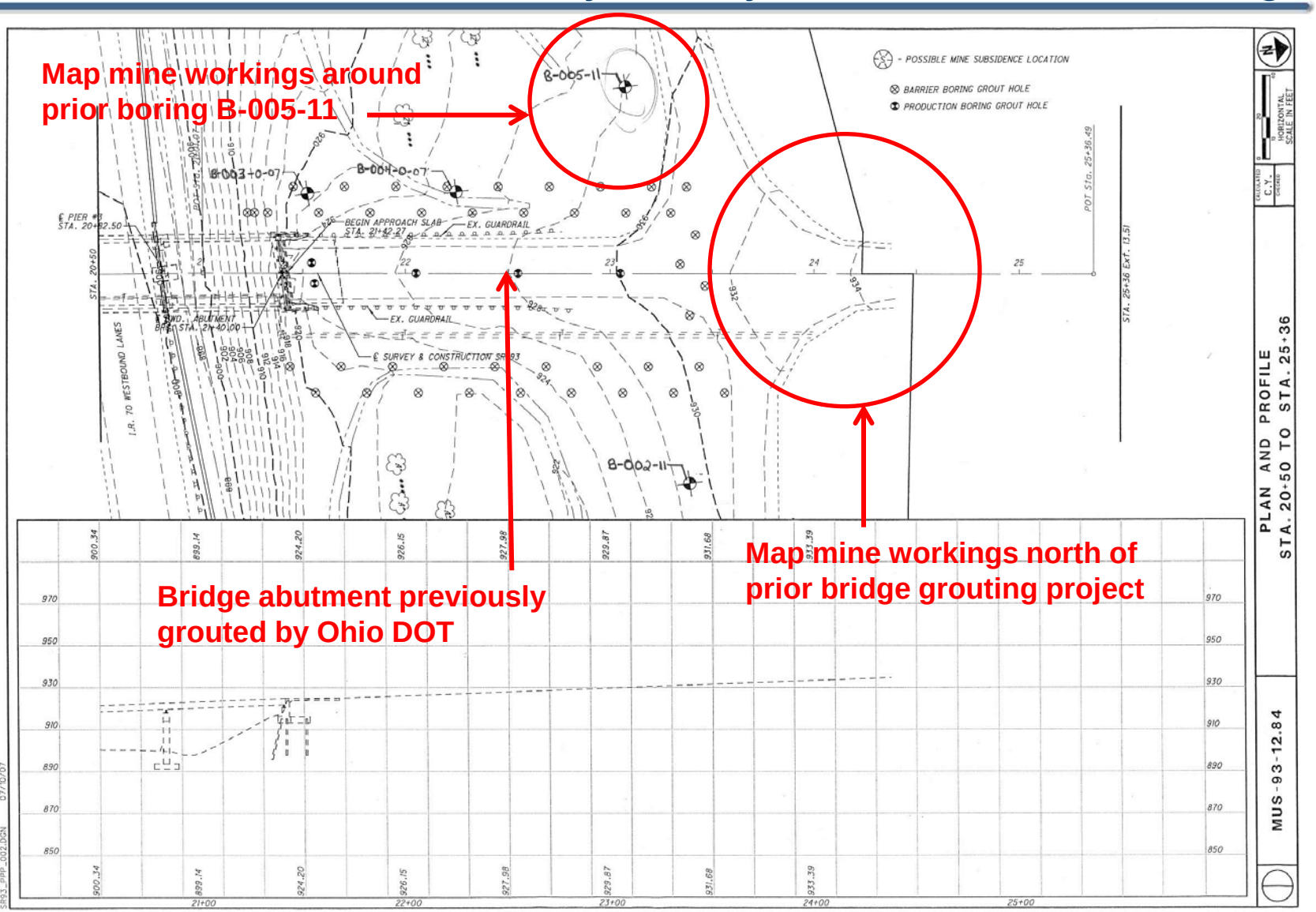
- MUS-SR 93-12.80 Project: Interchange of SR-93 and I-70 area of historic underground and surface coal mining
  - Ohio DOT conducted a literature review of original construction plans, results of drilling and prior grouting of SR 93 bridge, and their exploratory borings
  - Construction diaries indicated that some mine remediation work was performed during original construction; however records were vague relative to where on the ramps remediation can be considered complete and where further exploration was needed

- Objectives of Exploration:
  - Use Down-the-Borehole Laser and Sonar systems to map the mine workings north and south of the prior bridge grouting project; and mine workings encountered in boring B-005-11
  - Perform geotechnical test borings along the ramps and SR 93 to:
    - o check for the presence of mine workings; and
    - o perform laser and sonar void mapping, if mine workings encountered

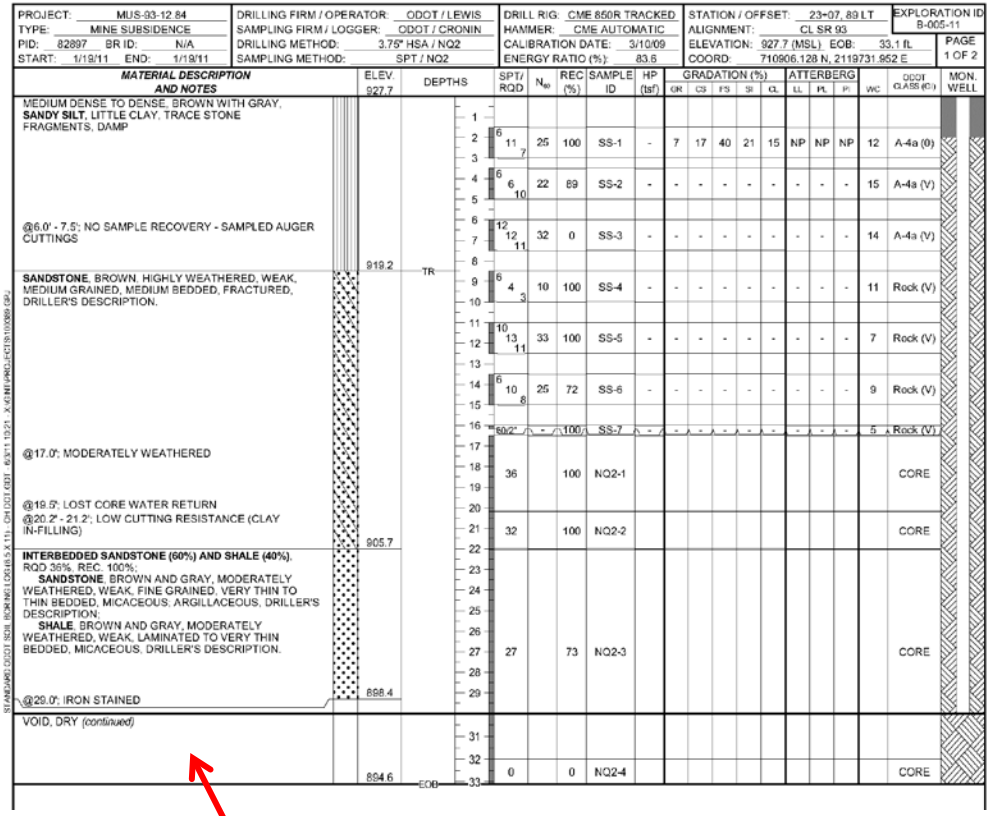
SR 93 Project Objectives – South of Bridge



SR 93 Project Objectives – North of Bridge



Prior SR 93 Boring – B-005-11



PROJECT: MUS-93-12.84	DRILLING FIRM / OPERATOR: ODOT / LEWIS	DRILL RIG: CME 850R TRACKED	STATION / OFFSET: 23+07, 89 LT	EXPLORATION ID B-005-11
TYPE: MINE SUBSIDENCE	SAMPLING FIRM / LOGGER: ODOT / CRONIN	HAMMER: CME AUTOMATIC	ALIGNMENT: CL SR 93	
PID: 82897 BR ID: N/A	DRILLING METHOD: 3.75" HSA / NQ2	CALIBRATION DATE: 3/10/09	ELEVATION: 927.7 (MSL) EOB: 33.1 ft.	PAGE 1 OF 2
START: 1/19/11 END: 1/19/11	SAMPLING METHOD: SPT / NQ2	ENERGY RATIO (%): 83.6	COORD: 710906.128 N, 2119731.952 E	

MATERIAL DESCRIPTION AND NOTES	ELEV. 927.7	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SR	CL	LL	PL	PI	WC	ODOT CLASS (GI)	MON. WELL
MEDIUM DENSE TO DENSE, BROWN WITH GRAY, **SANDY SILT**, LITTLE CLAY, TRACE STONE FRAGMENTS, DAMP		1																
		2–3	6 11 7	25	100	SS-1	-	7	17	40	21	15	NP	NP	NP	12	A-4a (0)	
		4–5	6 6 10	22	89	SS-2	-	-	-	-	-	-	-	-	-	15	A-4a (V)	
@6.0' - 7.5'; NO SAMPLE RECOVERY - SAMPLED AUGER CUTTINGS		6–7	12 12 11	32	0	SS-3	-	-	-	-	-	-	-	-	-	14	A-4a (V)	
	919.2	8																
SANDSTONE, BROWN, HIGHLY WEATHERED, WEAK, MEDIUM GRAINED, MEDIUM BEDDED, FRACTURED, DRILLER'S DESCRIPTION.		TR 9–10	6 4 3	10	100	SS-4	-	-	-	-	-	-	-	-	-	11	Rock (V)	
		11–12	10 13 11	33	100	SS-5	-	-	-	-	-	-	-	-	-	7	Rock (V)	
		14–15	6 10 8	25	72	SS-6	-	-	-	-	-	-	-	-	-	9	Rock (V)	
		16	50/2"	-	100	SS-7	-	-	-	-	-	-	-	-	-	5	Rock (V)	
@17.0'; MODERATELY WEATHERED		17–18	36		100	NQ2-1											CORE	
@19.5'; LOST CORE WATER RETURN @20.2' - 21.2'; LOW CUTTING RESISTANCE (CLAY IN-FILLING)		20–21	32		100	NQ2-2											CORE	
	905.7	22																
INTERBEDDED SANDSTONE (60%) AND SHALE (40%), RQD 36%, REC. 100%; **SANDSTONE**, BROWN AND GRAY, MODERATELY WEATHERED, WEAK, FINE GRAINED, VERY THIN TO THIN BEDDED, MICACEOUS; ARGILLACEOUS, DRILLER'S DESCRIPTION; **SHALE**, BROWN AND GRAY, MODERATELY WEATHERED, WEAK, LAMINATED TO VERY THIN BEDDED, MICACEOUS, DRILLER'S DESCRIPTION.		23–29	27		73	NQ2-3											CORE	
@29.0'; IRON STAINED	898.4																	
VOID, DRY *(continued)*		31–32																
	894.6	EOB 33	0		0	NQ2-4											CORE	

Void

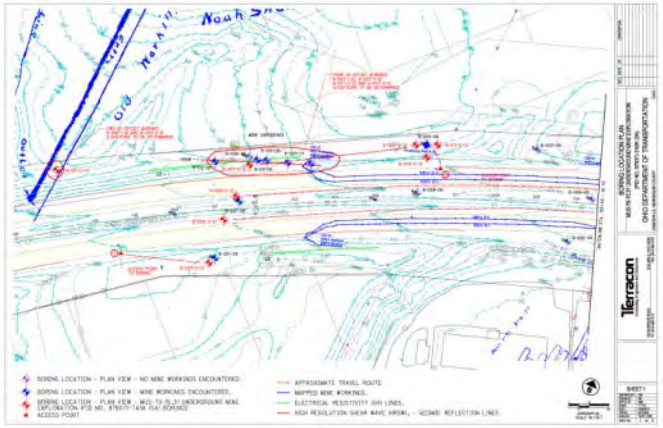
Boring B-005-11 location

Project Team

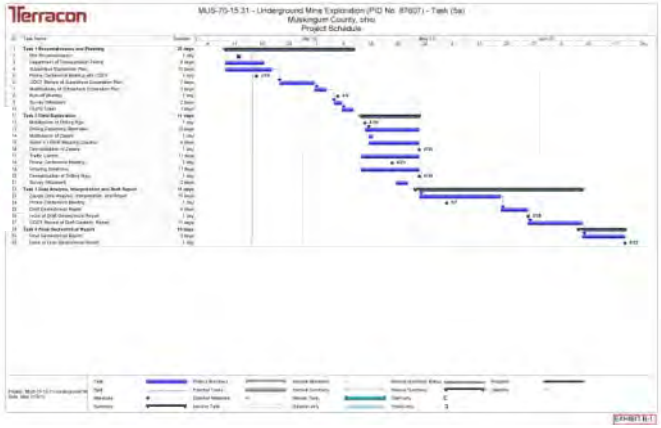
- Client: ODOT District 5 – Nikunj Kadakia, P.E. – Transportation Engineer
  Brian Logston, P.E. – Geotechnical Engineer
- Terracon Consultants, Inc. – Kevin Ernst, P.E. – Project Manager
  Jennifer Sorg, P.E. – Project Engineer
  - Project Management and Planning
  - Field Coordination and Borehole Logging
  - Drilling Services – Geotechnical Test Borings
  - Report Preparation
- ZAPATA Incorporated – Kanaan Hanna – Mining Engineer
  Jim Pfeiffer - Geophysicist
  - Down-the-Borehole Laser and Sonar and Scanning
  - Data Reduction and Analysis, Void Mapping, Volume Calculations, Report
- Woolpert Consultants, Inc. – Steve Newell, P.S. – Project Surveyor
- Beckley Drilling and Blasting, Inc. – Drilling Services
  - Drilling 6-inch diameter boreholes for Down-the-Borehole Scanning
- Area Wide Protection – Traffic Control

❑ Exploration Plan

- ➢ Boring Locations
- ➢ Drilling and Sampling Methods
- ➢ Casing Installation
- ➢ Down-the-borehole scanning
- ➢ Boring sealing
- ➢ Traffic Controls
- ➢ Field Coordination and Communications
- ➢ Schedule
- ➢ Safety



Safety

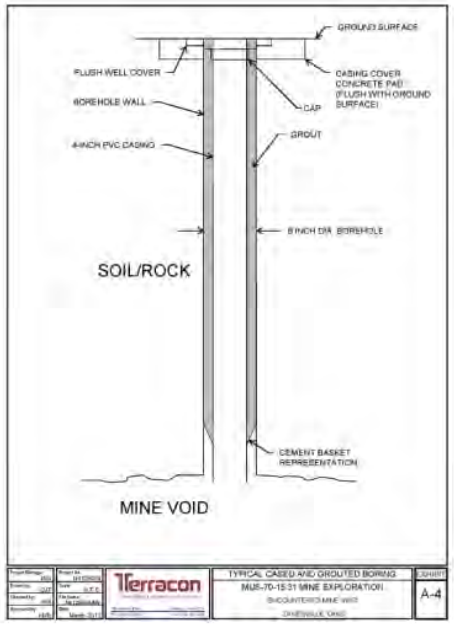


❑ Boreholes

- Beckley provided Atlas Copco L6 Drilling Rig
- 6-inch diameter borehole
- Down-the-Hole Percussion Hammer
- Rapid Advancement of Borehole
- Air drilling

❑ Casing

- 4-in diameter casing
- Casing grouted
- Flush mounted protective cover
- Allows for future grouting /observation



Laser, Sonar, and Video Camera Tools

Tethered Robotic Downhole Systems
Void Mapping & Imaging
"Real Time Visualization"

Downhole Sonar Void Scanning / Mapping (Water-filled void)

- Imagenex Digital Multi-frequency Profiling
- One-axis scanning: horizontal plane (360-degree scan)
- Scans: multiple 2-D plans create 3-D model
- Distance measurements: 300 ft
- Accuracy: ± 1 degree

Downhole Laser Void Scanning / Imaging (Air-filled void)

- MDL: C-ALS
- Scans: 3-D or 2-D horizontal and vertical slices
- Equipped with video camera (~20 ft)
- Distance measurements: 500 ft
- Accuracy ± 0.5 degree

Downhole Video Camera Void Imaging (Air-filled or water-filled void)

- Images: Vertical and horizontal control
- Video recording capabilities
- Distance measurements ~ 25 ft

Focused Underground Exploratory Borings

I-70

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Underground Exploratory Boring Field Activities Using Atlas Copco Roc L6H Down Hole Hammer
MUS-70-15.31 Underground Mine Exploration
(PID No. 87607) - Task (5A)
Ohio Department of Transportation
Zanesville, Muskingum County, Ohio

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
00299	June, 2012	HJV	KH	As Shown	1

SR-93

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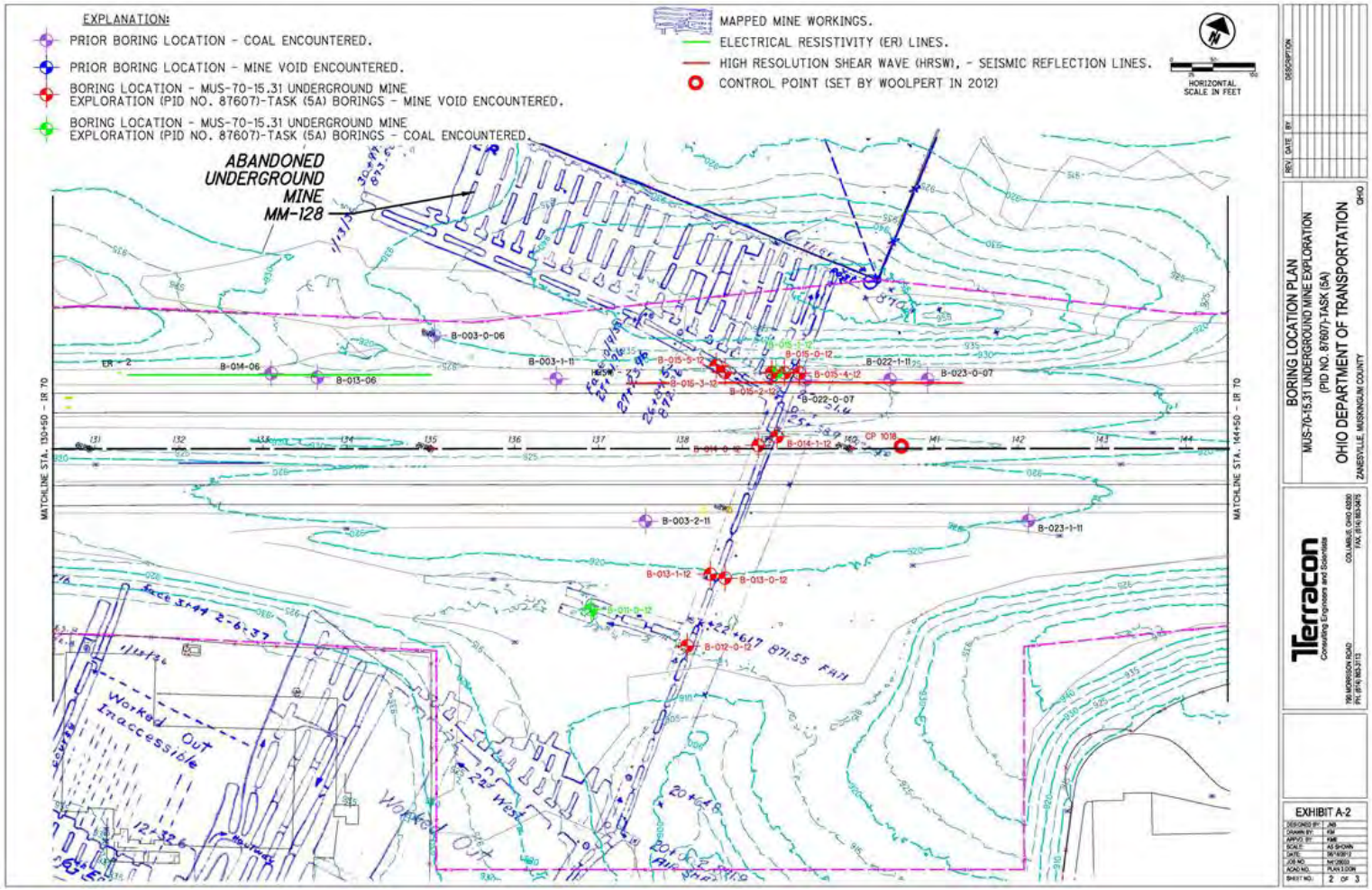
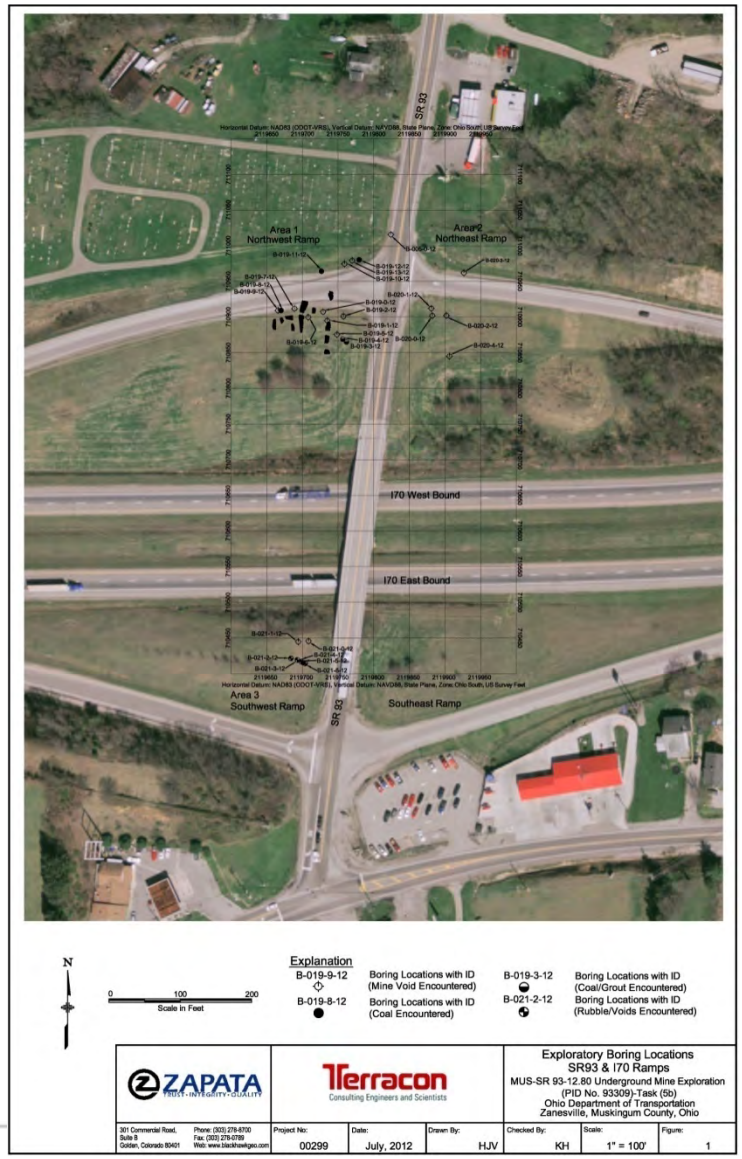
Underground Exploratory Boring Field Activities Using Atlas Copco Roc L6H Downhole Hammer
MUS-SR 93-12.80 Underground Mine Exploration
(PID No. 93309) - Task (5b)
Ohio Department of Transportation
Zanesville, Muskingum County, Ohio

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
00299	July, 2012	HJV	KH	As Shown	2

Example: I-70 Boring Location Plan



Example: SR-93 Boring Location Plan



Void Mapping: Sonar and Laser Systems

I-70

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Web: www.blackhawkgeo.com

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Consulting Engineers and Scientists

Void Mapping Field Activities
Using Video Camera, Sonar, and Laser Systems
MUS-70-15.31 Underground Mine Exploration
(PID No. 87607) - Task (5A)
Ohio Department of Transportation
Zanesville, Muskingum County, Ohio

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
00299	June, 2012	HJV	KH	As Shown	2

SR-93

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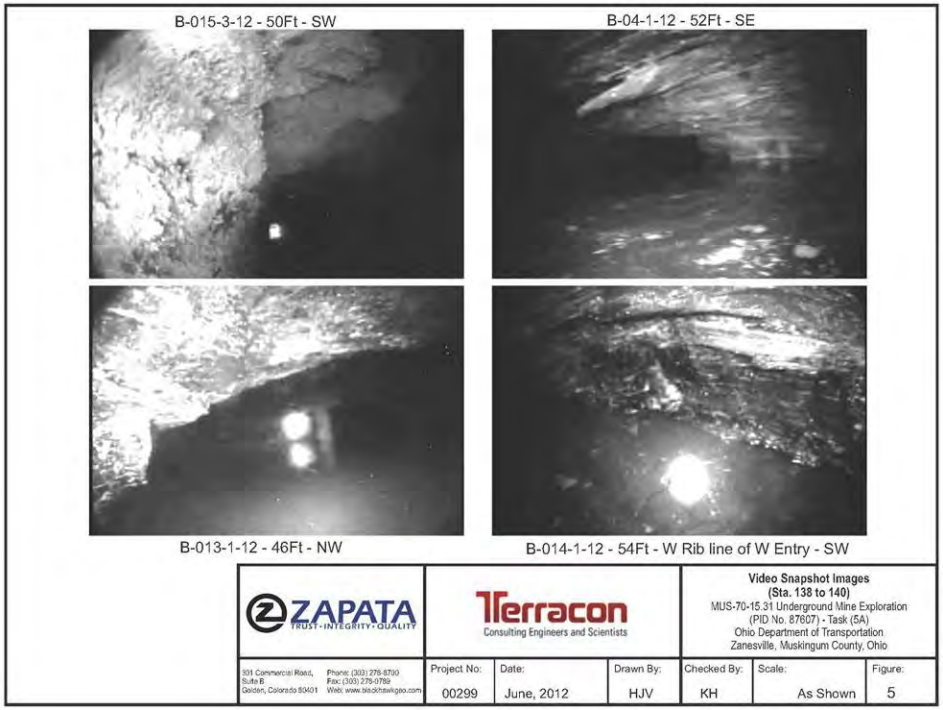
Consulting Engineers and Scientists

Void Mapping Field Activities
Using Sonar and laser Systems
MUS-SR 93-12.80 Underground Mine Exploration
(PID No. 93309) - Task (5b)
Ohio Department of Transportation
Zanesville, Muskingum County, Ohio

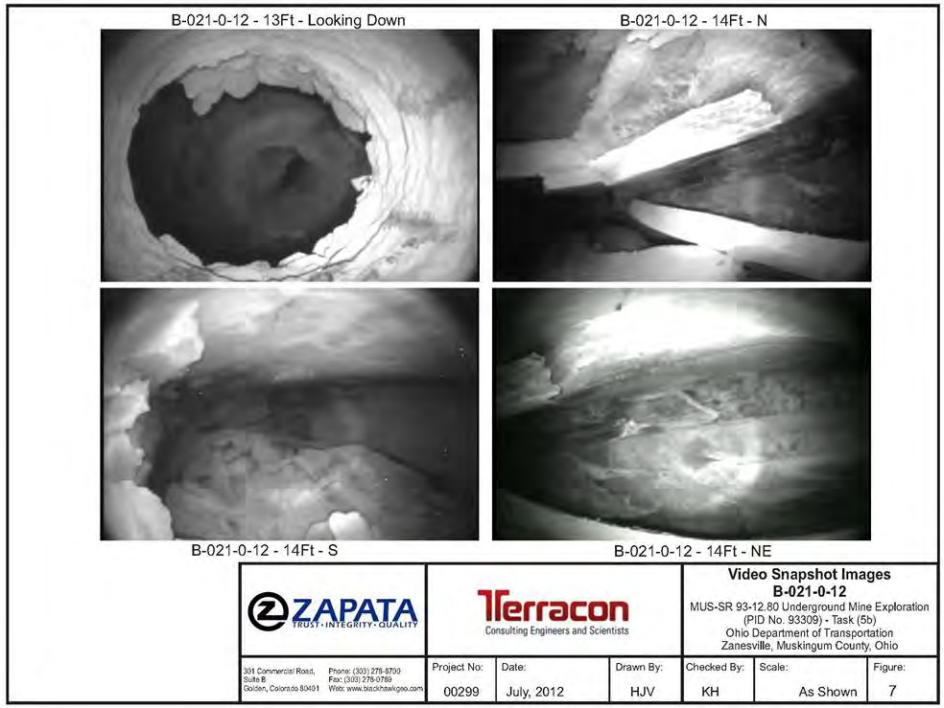
Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
00299	July, 2012	HJV	KH	As Shown	3

Video Snapshot Images

I-70

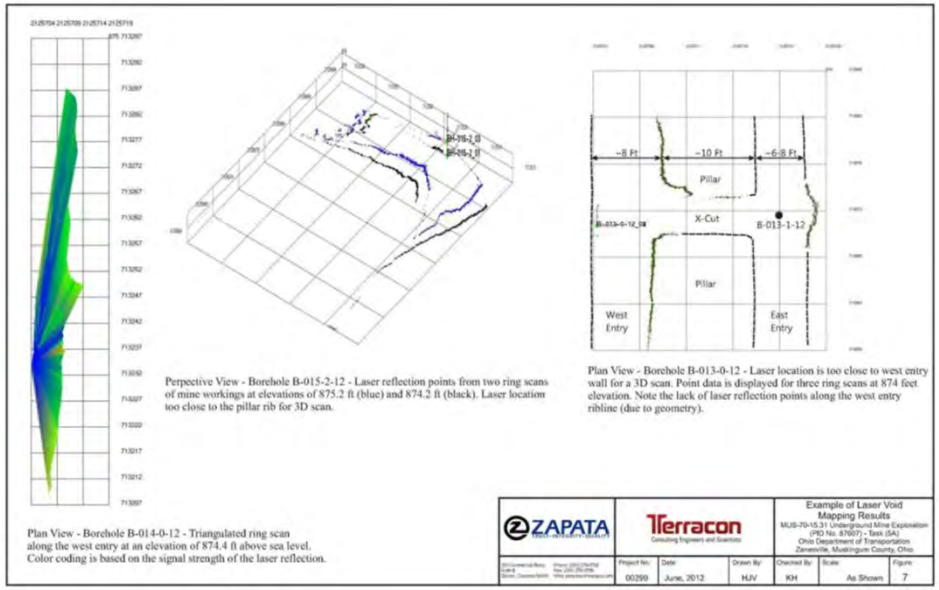


SR-93

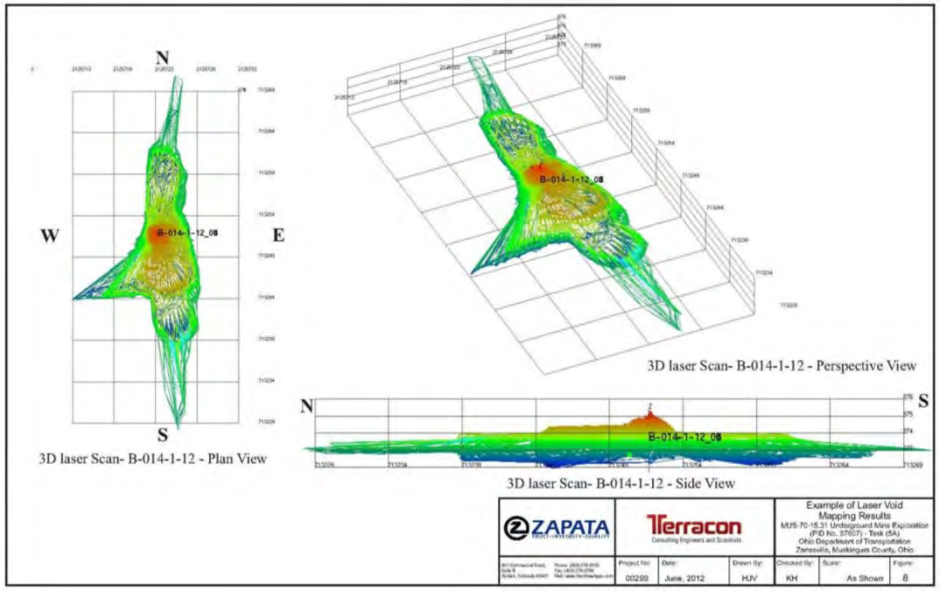


Examples: I-70 Laser Void Mapping Results

2D Laser scans in various boreholes
B-014-0 plan, B-015-2 perspective, and B-013-0 plan views



3D Laser scans in borehole B-014-1
Plan, perspective, and side views

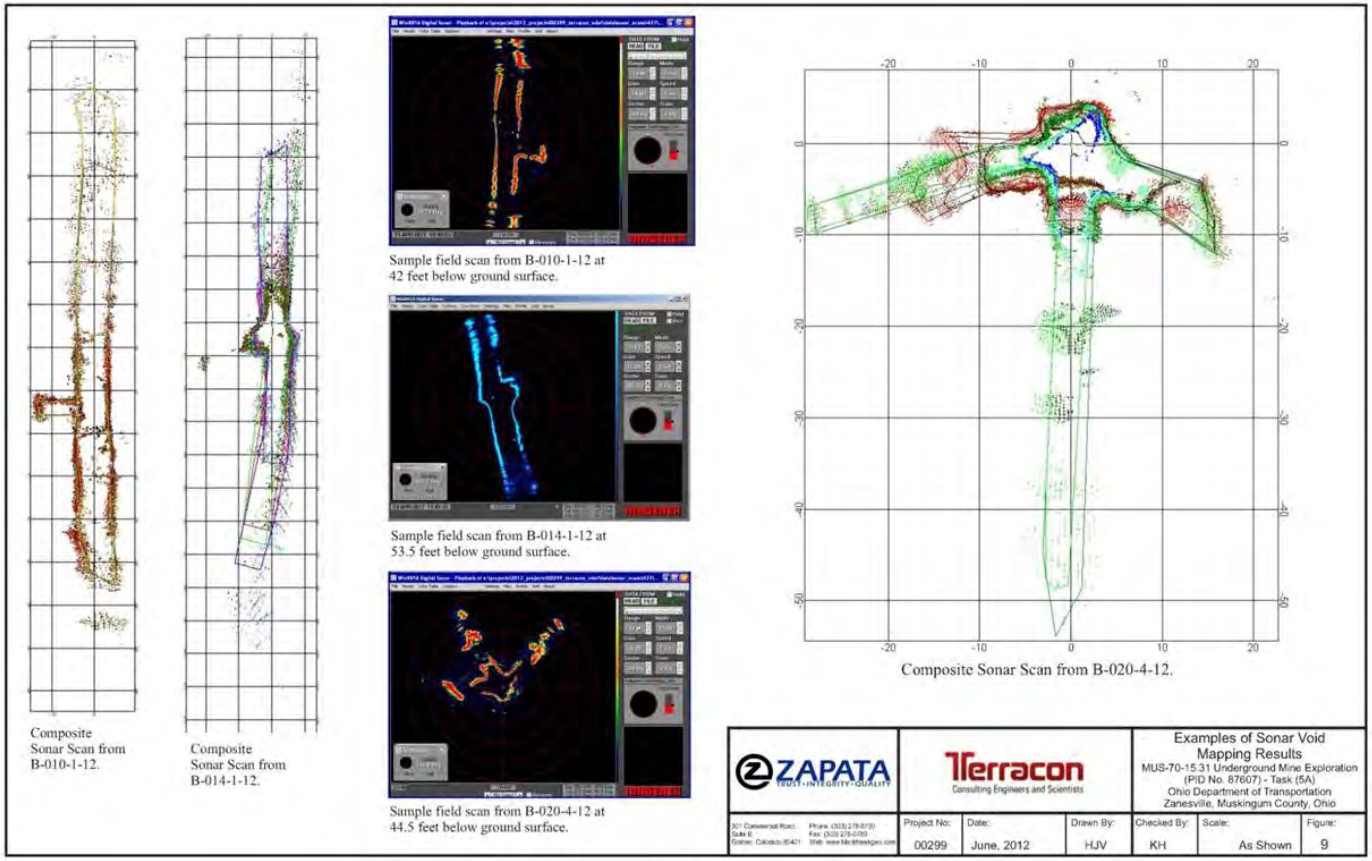


Examples: I-70 Sonar Void Mapping Results

Composite scans
B-010-1 & B-014-1

Real time scans
Various boreholes

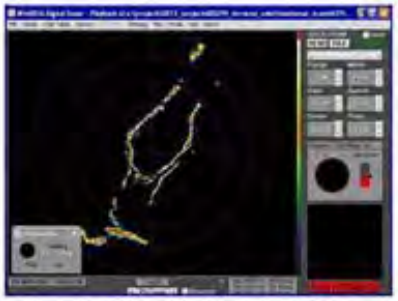
Composite scans
B-020-4



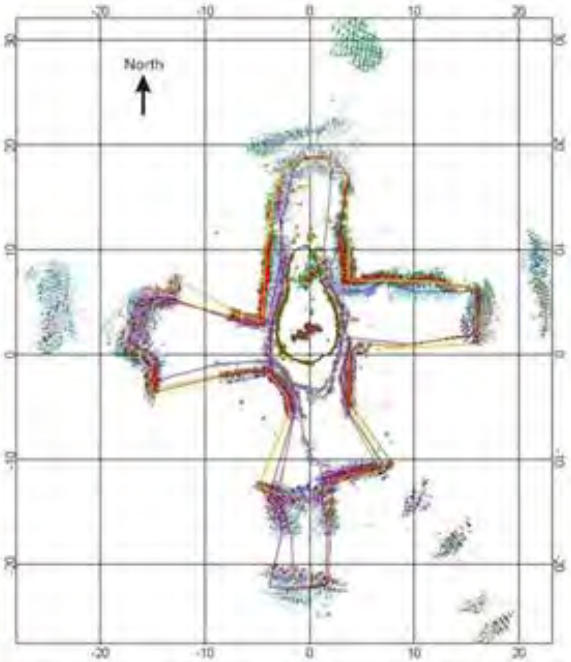
Examples: I-70 Sonar Void Mapping Results

Borehole B-004-1: Real time and composite scans at depths from 14.5 to 16.5 ft bgs

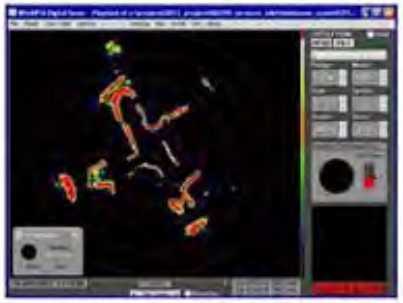
Screen capture from the field of sonar scan at 14.5 ft below ground surface. Top of image is at an azimuth of 46.6 degrees, referenced from magnetic north.



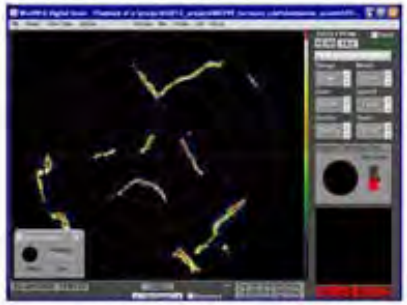
Screen capture from the field of sonar scan at 15 ft below ground surface. Top of image is at an azimuth of 331.2 degrees, referenced from magnetic north.



Composite sonar scans for B-004-1-12 after rotating to true north. Colored lines are interpreted void extent for each horizontal sonar scan.



Screen capture from the field of sonar scan at 15.5 ft below ground surface. Top of image is at an azimuth of 38.6 degrees, referenced from magnetic north.



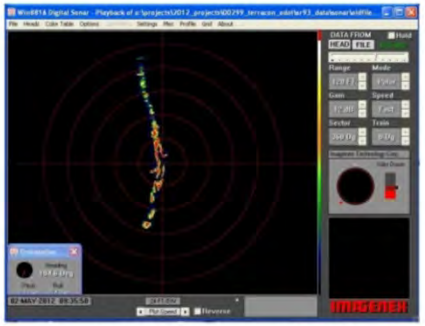
Screen capture from the field of sonar scan at 16.5 ft below ground surface. Top of image is at an azimuth of 35.9 degrees, referenced from magnetic north.

ZAPATA | Terracon Consulting Engineers and Scientists | Example of Sonar Void Mapping Results
MUS-70-15.31 Underground Mine Exploration (PID No. 87607) - Task (5A)
Ohio Department of Transportation
Zanesville, Muskingum County, Ohio

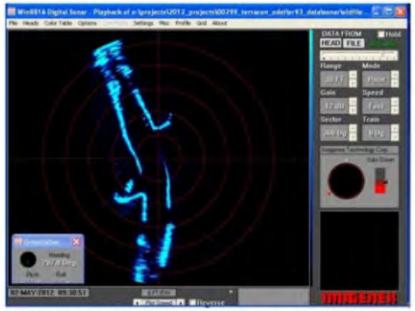
Project No.	Date	Drawn By	Checked By	Scale	Figure
00299	June, 2012	HJV	KH	As Shown	10

Examples: SR-93 Sonar Void Mapping Results

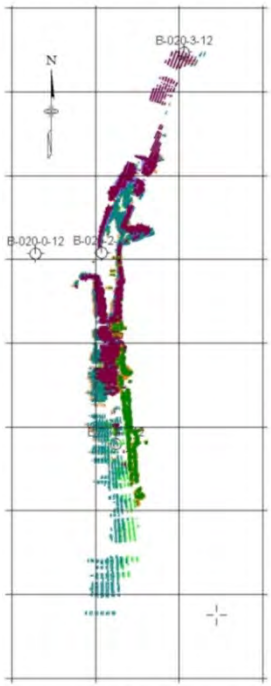
Borehole B-020-2: Real time and composite scans at depths from 33.5 to 35.5 ft bgs



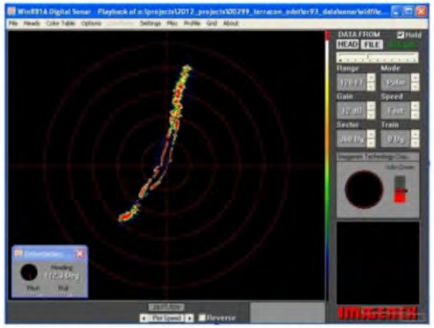
Screen capture from the field of sonar scan at 33.5 ft below ground surface. Top of image is at an azimuth of 194.6 degrees, referenced from magnetic north.



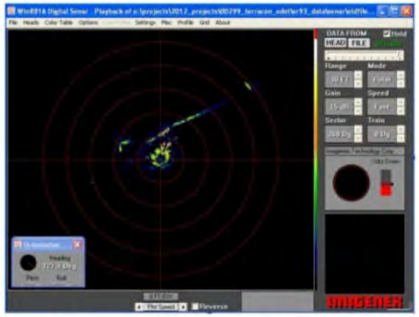
Screen capture from the field of sonar scan at 33.5 ft below ground surface. Top of image is at an azimuth of 207.8 degrees, referenced from magnetic north.



Composite sonar scans for B-020-2-12 after rotating to true north.



Screen capture from the field of sonar scan at 34.5 ft below ground surface. Top of image is at an azimuth of 172.3 degrees, referenced from magnetic north.

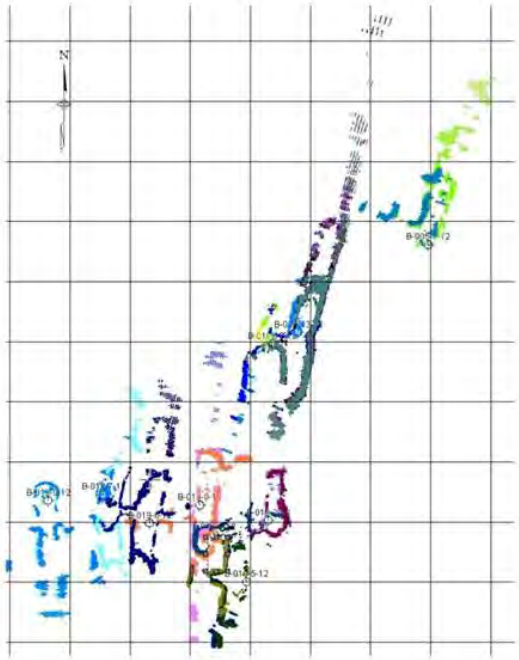


Screen capture from the field of sonar scan at 35.5 ft below ground surface. Top of image is at an azimuth of 127.1 degrees, referenced from magnetic north.

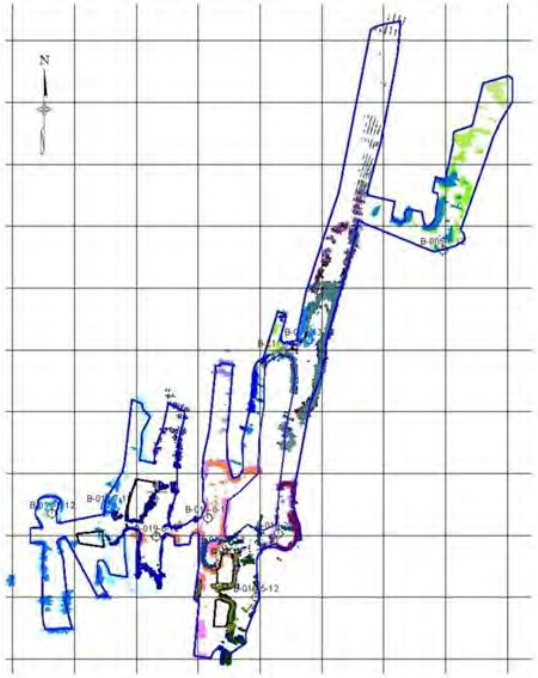
ZAPATA TRUST·INTEGRITY·QUALITY	Terracon Consulting Engineers and Scientists	Example of Sonar Void Mapping Results Northeast Ramp of SR 93 MUS-SR 93-12.80 Underground Mine Exploration (PID No. 93309) - Task (5b) Ohio Department of Transportation Zanesville, Muskingum County, Ohio				
301 Commercial Road, Suite B Golden, Colorado 80401	Phone: (303) 279-9700 Fax: (303) 279-0799 Web: www.zapatahawkgeo.com	Project No: 00299	Date: July, 2012	Drawn By: HJV	Checked By: KH	Scale: As Shown	Figure: 10

Examples: SR-93 Sonar Void Mapping Results

Composite scans in various boreholes showing the maximum extents of voids outlined in *blue*, and pillars outlined in *black* (Grid squares are 25 ft)



Composite sonar scans from multiple wells, selected to outline the maximum extent of mine workings on the northwest side of SR93. Grid squares are 25 feet on a side.



Interpreted composite sonar scans, northwest side of SR93 Maximum extents are outlined in blue, internal pillars are outlined in black. Grid squares are 25 feet on a side.

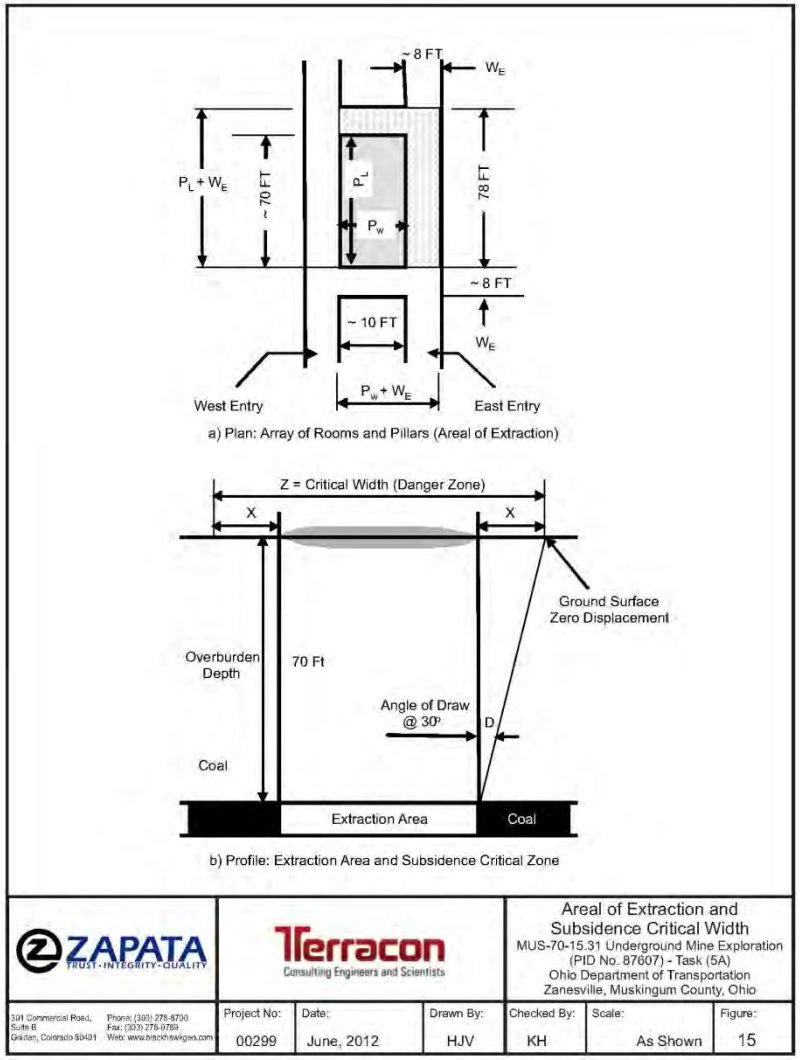
ZAPATA TRUST · INTEGRITY · QUALITY	Terracon Consulting Engineers and Scientists	Example of Sonar Mine Void Interpretation Northwest Ramp of SR 93 MUS-SR 93-12.80 Uncerground Mine Exploration (PID No. 93309) - Task (5b) Ohio Department of Transportation Zanesville, Muskingum County, Ohio			
334 Commercial Road, Suite B Golden, Colorado 80401 Phone: (303) 279-6700 Fax: (303) 279-0769 Web: www.zapatatechnologies.com	Project No: 00299	Date: July, 2012	Drawn By: HJV	Checked By: KH	Scale: As Shown	Figure: 9

➢ Void Volume Determination

Void Volume Determination Considering Two Scenarios:

- ❑ Void volumes based on the laser and sonar void mapping, and
- ❑ Void volumes based on the current mine conditions (post-mining):
  - ❑ Average *mined* coal seam thickness/void height ~ 4.5 ft
  - ❑ Average *current* void heights ~ 2.5 to 3.5 ft
  - ❑ Percentage of the coal extracted ~ 65 – 75%
- ❑ Criteria used to determine the width of the "Danger Zone" of the area to be mitigated depends on:
  - ❑ Subsidence angle of draw "D" = 30 degree
  - ❑ Overburden depth = 15 – 60 ft
  - ❑ Width of extraction/mined-out area, and
  - ❑ Void height and void ground conditions

Areal of Extraction and Subsidence Critical Width Determination



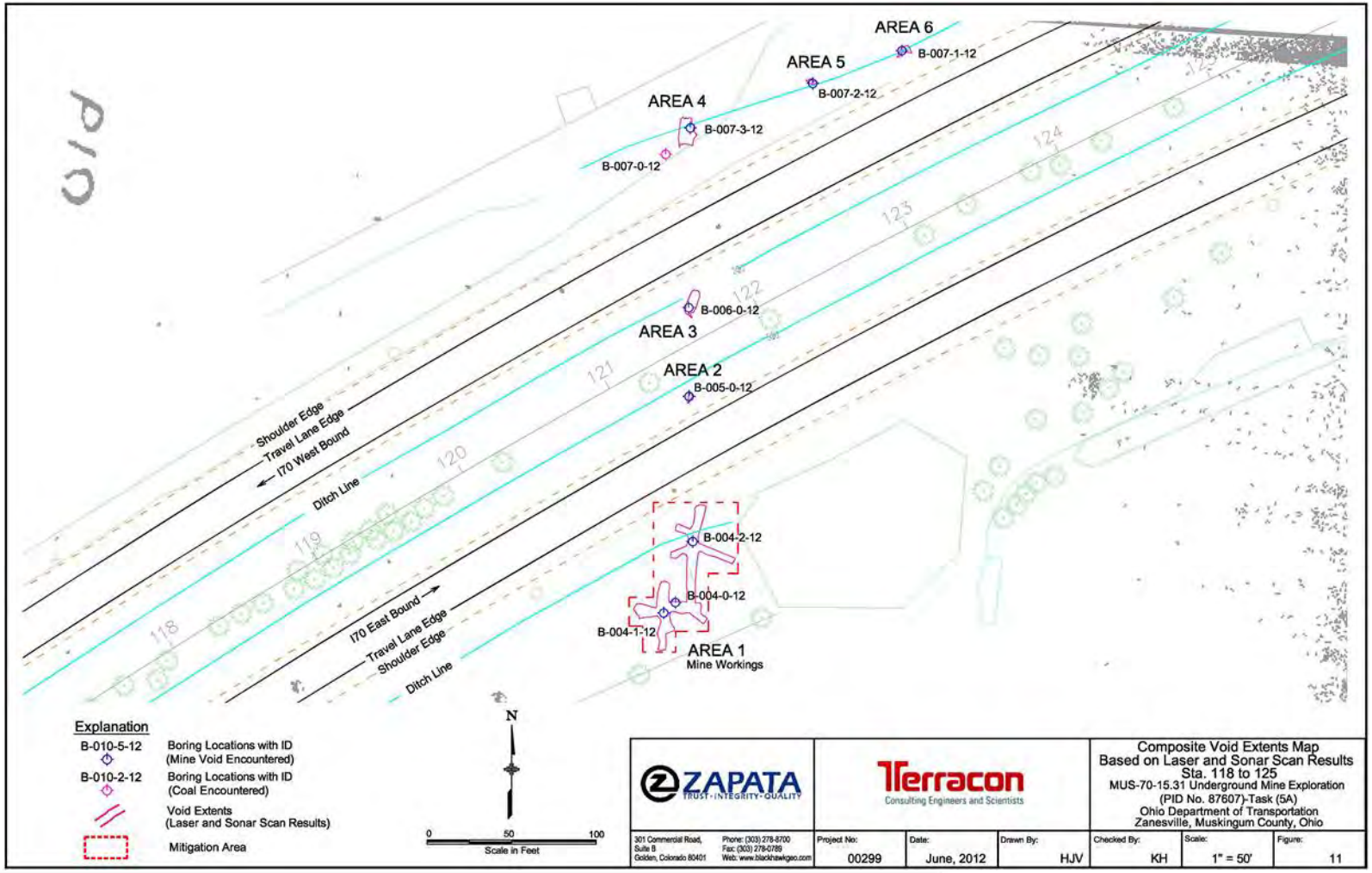
Void Volumes Determination for I-70 and SR-93

(Mapped void volume from the laser and sonar, and current void volume)

I-70 STA. 120 to 155	
Laser and Sonar Mapped Void Volume (Yd^3)	Current Void Volume (Post-Mining) Total void volume of Areas 1-11 to be mitigated (Yd^3)
778	2,461
SR-93	
744	2,733

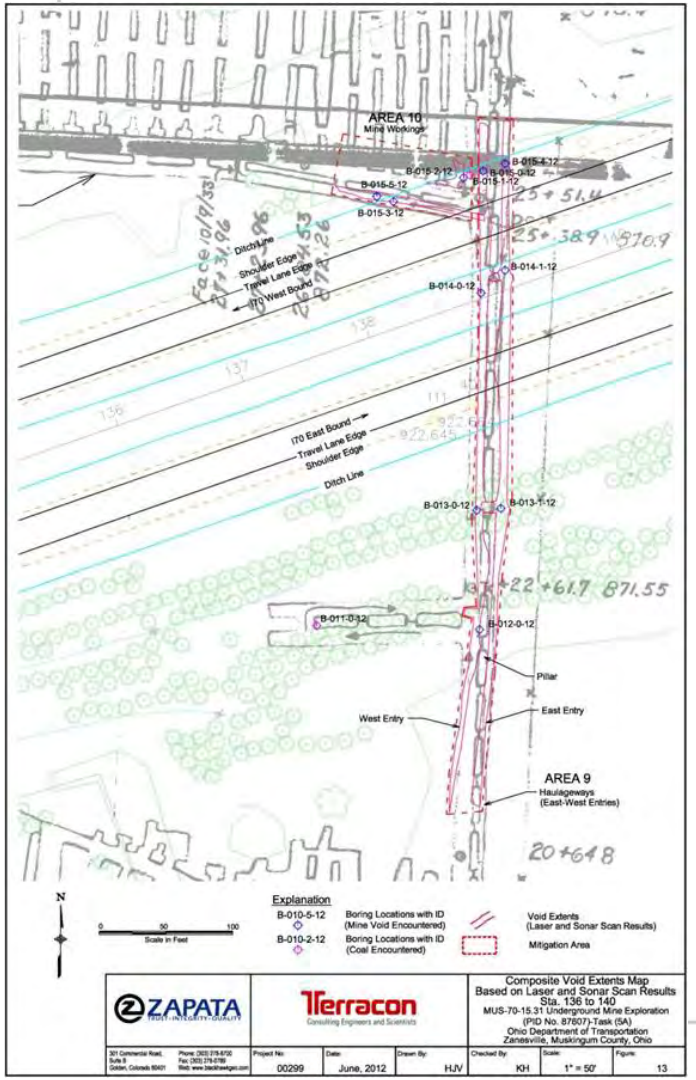
➢ Boundary Limits of the Areas to be Mitigated

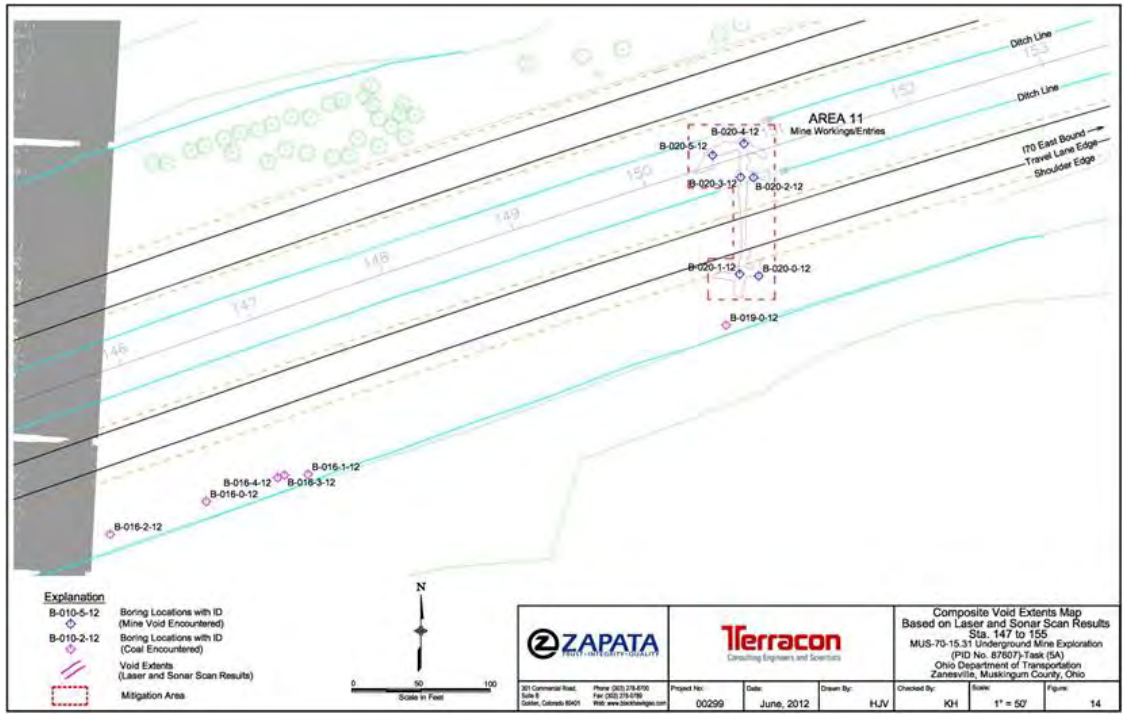
Examples: I-70 Areas 1 to 6 to be Mitigated



➢ Boundary Limits of the Areas to be Mitigated

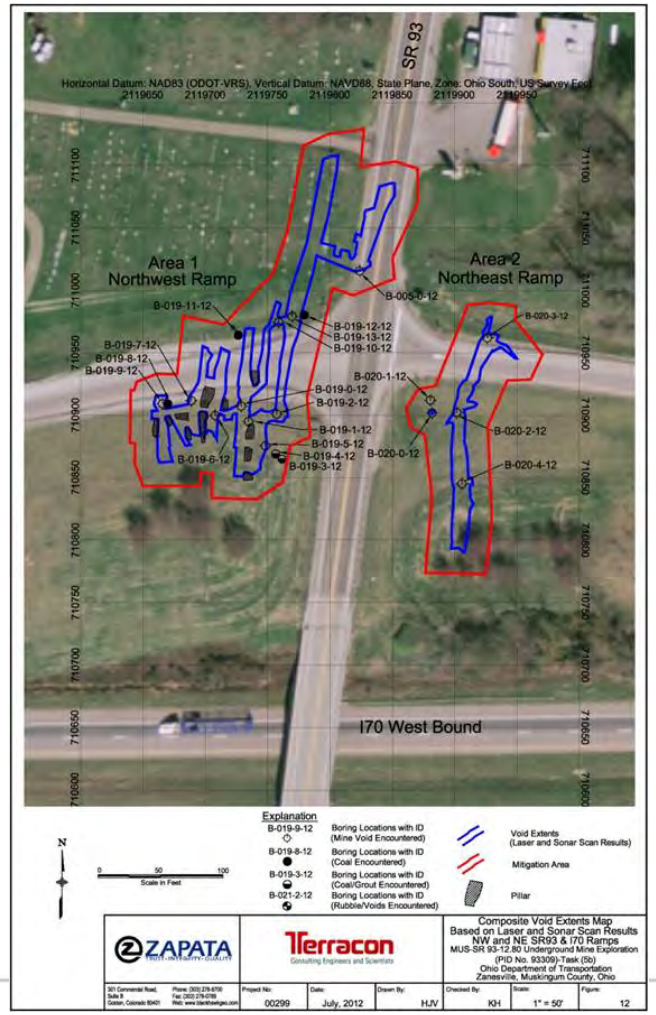
Examples: I-70 Areas 9 and 11 to be Mitigated





➢ Boundary Limits of the Areas to be Mitigated

Examples: SR-93 Areas 1, 2, and 3 to be Mitigated



Conclusions

- Underground exploration and void mapping confirmed the presence of :
  - Mine workings of the *known* historical mine maps
  - Mine workings where historical mine mapping *is not* available
- Subsurface void mapping further delineated the geometry of entries and production sections
- The total void volume presented is for the mitigation areas identified by this study
- The proactive approach employed by ODOT is in contrast to traditional drilling techniques typically employed for subsidence risk assessment and reclamation
- The focused exploratory boring and mine void mapping demonstrated the:
  - Capability ---Viability---and Economic Feasibility of this proactive approach

Recommendations

- Additional subsurface exploration and void mapping to provide for further delineation of unmapped mine workings in both areas, and could be taken as:
  - A pre-design activity, or
  - Incorporated into the stabilization program
- Any additional exploratory drilling program could be implemented as part of the construction phase as an *expedient* and *cost-effective* measure to:
  - Simultaneously identify and remediate abandoned mine workings, resulting in…
  - A focused effort on remediation rather than ongoing studies

Thanks

Terracon
Consulting Engineers and Scientists

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