

3D GPR Survey of the Coming Street Commons Property

A report to the Community Engagement Council at the College of Charleston

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Abstract

The purpose of this study was to collect 3D GPR data for the College of Charleston's Community Engagement Committee (motion carried on December 4, 2026, to request the study) to identify subsurface features that may indicate burials and evidence of past human occupation. A 3D ground penetrating radar (an 18-channel, 450-MHz Raptor system from Impulse Radar) survey was conducted, and 199 swaths with 18 channels (radargrams) per swath with an effective spacing of 8 cm were collected. Data were processed using proprietary software systems from Impulse Radar Condor and Earth Access, LLC to create depth slices and profile data for interpretation. Key anomalies include multiple features aligning with structures found on historical maps, modern utilities, broad pits, and multiple broad hyperbolic features of unknown origin. With respect to obvious grave shafts, the survey was inconclusive. However multiple features are recognized consistent with graveyards of the time. Management recommendations are beyond the purview of this investigation. No ground-truthing was performed.

Findings indicate the likely presence of graves in the northern section of the site on the west side of the parking lot; 19th Century foundations, cisterns or basements, wells, and buildings; and typical utility intrusions along the edge and in supply to younger infrastructure.

While features were clearly identified in some areas, that does not indicate an absence of former presence where later development may have disrupted subsurface conditions and where they are no longer visible with remote sensing methods.

1. Introduction

1.1. Purpose of Report and Nature of the Undertaking

The purpose of the study and this resulting report was identified as necessary through engagement with the Community Engagement Council (CEC) to conduct a GPR survey prior to hardscape removal and was based on professional advice from the SHPO office, the author, and other GPR practitioners prior to the contractor survey. While the contractor disagreed, the College of Charleston supported the CEC request to have the survey run prior to hardscape removal. This study has not included any direct subsurface work and includes only data collected in this GPR study and from a site drone survey conducted in mid-February 2026 to document conditions. The investigation is non-invasive.

1.2. Regulatory Framework

The Project 205/Coming Street Commons is subject to review by the South Carolina Department of Environmental Services, Bureau of Coastal Management (SCDES-BCM) through the Coastal Zone Consistency process (SCDES-BCM Ref. HQE-MAZM-0BJ2E), with cultural-resource review and consultation by the South Carolina Department of Archives and History, State Historic Preservation Office (SHPO Project No. 25-JS0212). Reference SCDES-BCM Ref # HQE-MAZM-0BJ2E and SHPO Project # 25-JS0212.

1.3. Project Description

The charge of this GPR survey was to collect a 3D GPR survey of the property on behalf of the College of Charleston's Community Engagement Council, providing the Council with a member-driven information that ensures easy, direct access to data and analytical outcomes. The initial charge also required presentation to that group and an explanation of the findings, the first of which was provided in March 2026, and the second presented May 7, 2026, to the CEC and university administration. During the initial process, the scope shifted from a survey and report to the CEC on the same relative scale of the 2024 assessment to this report to the South Carolina State Historical Preservation Office (SHPO). This report documents the process, procedures, methods, and presents that data to the administration at the College of Charleston.

The ground-penetrating radar (GPR) campaign covers an area bounded to the north by Vanderhorst Street and to the west by Coming Street and is known as the Coming Street Commons property at the College of Charleston (“the property”).

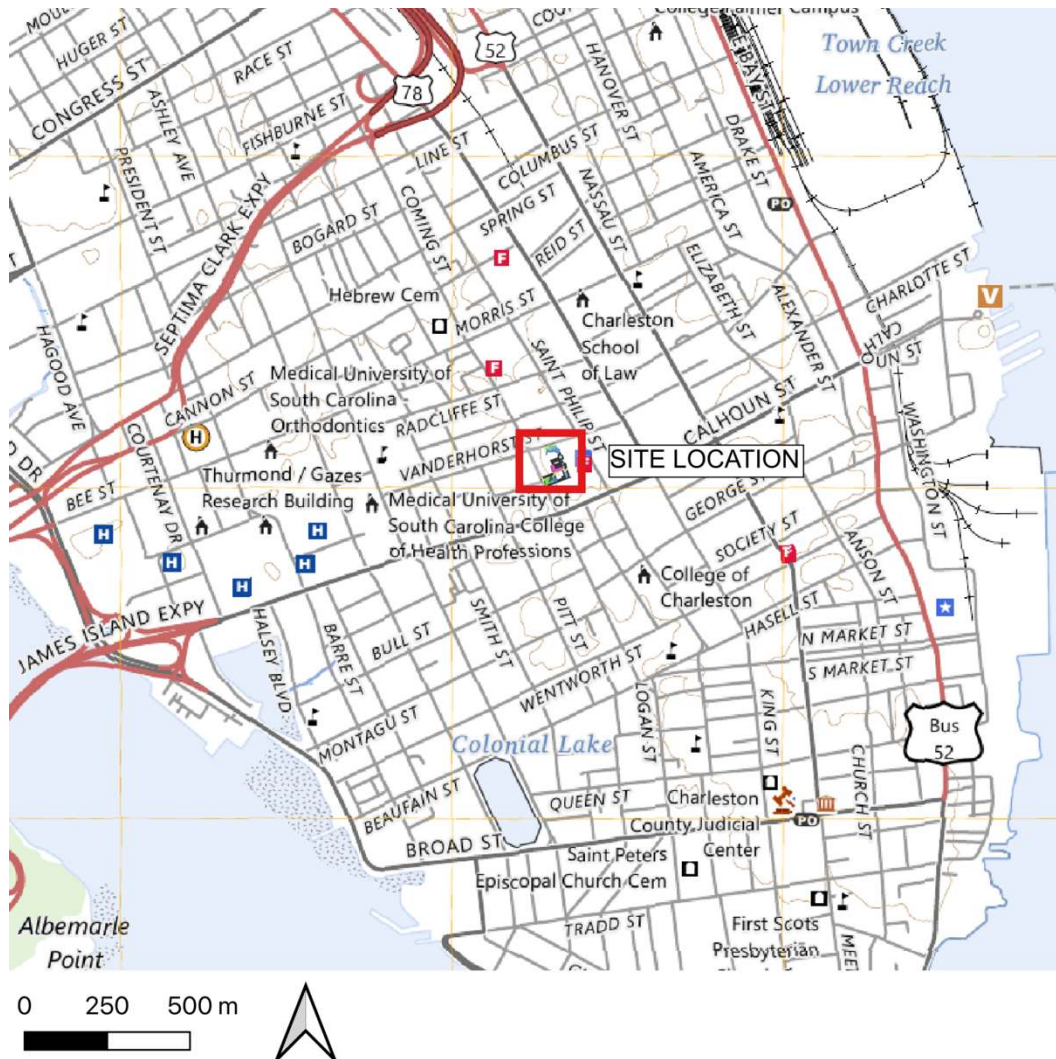


Figure 1. The project area is located on the Charleston Peninsula in the Central South Carolina coast between the Ashley River to the west, the Cooper River to the east, and Charleston Harbor to the southeast. The site is in the block bound by Vanderhorst St., Coming St., Calhoun St., and St. Phillips St. Source: USGS



Figure 2. Coming Street Commons property at the College of Charleston. The project area is outlined from Coming Street to the southwest and Vanderhorst St. to the north.

1.4. Project Personnel and Schedule

Personnel:

Dr. M. Scott Harris, PG, College of Charleston, Department of Geology and Environmental Geosciences and Archaeology Program (GPR data collection, Drone data collection, GPR data processing, Drone data processing, GPR data interpretation).

Field crew consisted of students and multiple members of the community, including:

- Khadija Boutdhich
- Katie Jones
- Bella Redding
- Caroline Housman
- Nicholas Marroguin Monrique
- Sarah Seymore
- Four Community Engagement Council members
- Two members of the press

Field data were collected on February 13 and February 14, 2026.

1.5. Project Documentation

Field notes, raw GPR data files, processed GPR data files, raw drone imagery, processed orthophoto mosaics, and coordinate files are either within this document or with Facilities Management at the College of Charleston.

2. Environmental Setting

2.1. Physiographic and Geologic Context

The site lies within the Lower Coastal Plain physiographic province, in the central core of the Charleston peninsula. The geology is predominantly the Wando Formation, and it is adjacent to former tidal creeks that have now been backfilled to create the urban landscape of downtown Charleston. The considerable urban debris above sands and muds of the area, combined with the high capillary fringe associated with the water table (~8' below the land surface during the survey), have created a heterogeneous subsurface where GPR performance is good to poor.

2.2. Soils and GPR Suitability

The heterogeneous soils of this portion of the Lower Coastal Plain are highly variable, differing from block to block at a much finer scale than is feasible through NRCS soil associations and standard geological mapping. To follow detailed data would be folly. In general, these soils attenuate the signal quickly due to their moisture content. Dielectric permittivity is generally around 12.5, with a typical RDP range of 10- 15 for ϵ_r (relative dielectric permittivity), which is high for this site given hyperbolic velocity calculations. See Appendix A-1 for the USDA report for the area.

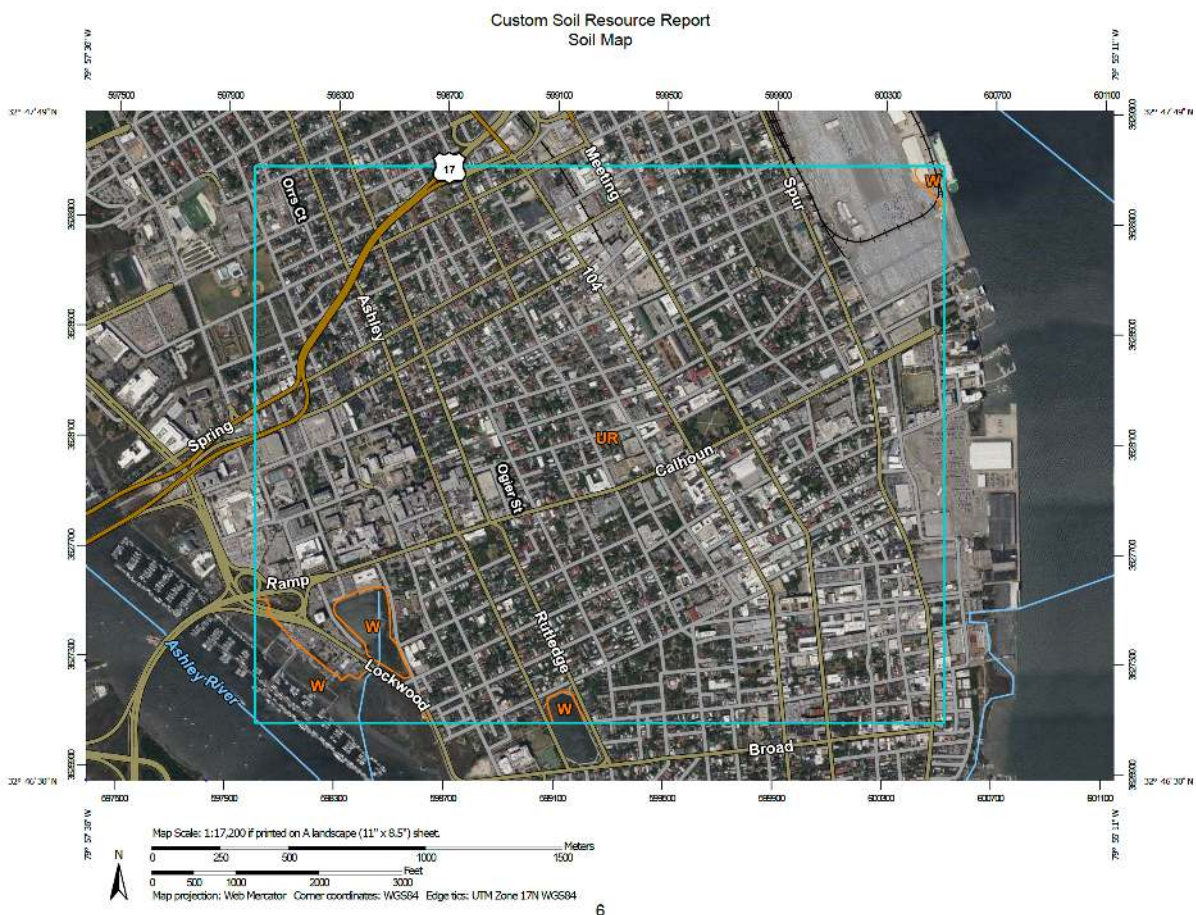


Figure 3. Soil map of the study area. The only two soil types are "Urban" and "Water" given the nature of the area. See Appendix A-1 for the full USDA report of the area.

2.3. Known Disturbances and Limiting Factors

During colonial times, the site was originally shown on the region's 1750s maps as a point with tidal creeks and marshes to the southwest, northwest, and west. Purchased by the City of Charleston in 1793 and designated as a cemetery in 1794, the burial ground continued operations until 1807, when it was considered full. From 1817 to 1825, the area was subdivided, and both brick and wooden structures were built on the site¹. These most likely included foundations, shallow cellars, cisterns, wells, and privies, which could possibly have penetrated grave shafts and burials in the area. Since that time, those houses have been removed, and the current site has been leveled, with a YWCA placed in the middle of the southern half of the former cemetery. The site now consists of paved and

¹ Carpini and Brummitt, *Historic Research and Geophysical Assessment 106 Coming Street and 99 St Philip Street Charleston, South Carolina S&ME Project No. 24130280*.

gravel lots, a wall separating the northern and southern portions of the site, and the YWCA at the time of survey. Utilities are identifiable on the edges of the property, and the YWCA has water, electric, and sewer connected.



Figure 4. Site on January 30, two weeks prior to survey. Looking south-southeast from Vanderhorst Street parking lot. (photo by M. Scott Harris)



Figure 5. January 30, 2026, image looking approximately west just south of Vanderhorst Street. (photo by M. Scott Harris)



Figure 6. View of the site February 4, 2026, looking south-southwest from the north side of the YWCA (brick structure to left) with the School of Natural and Environmental Sciences across Coming Street in the distance. (photo by M. Scott Harris)

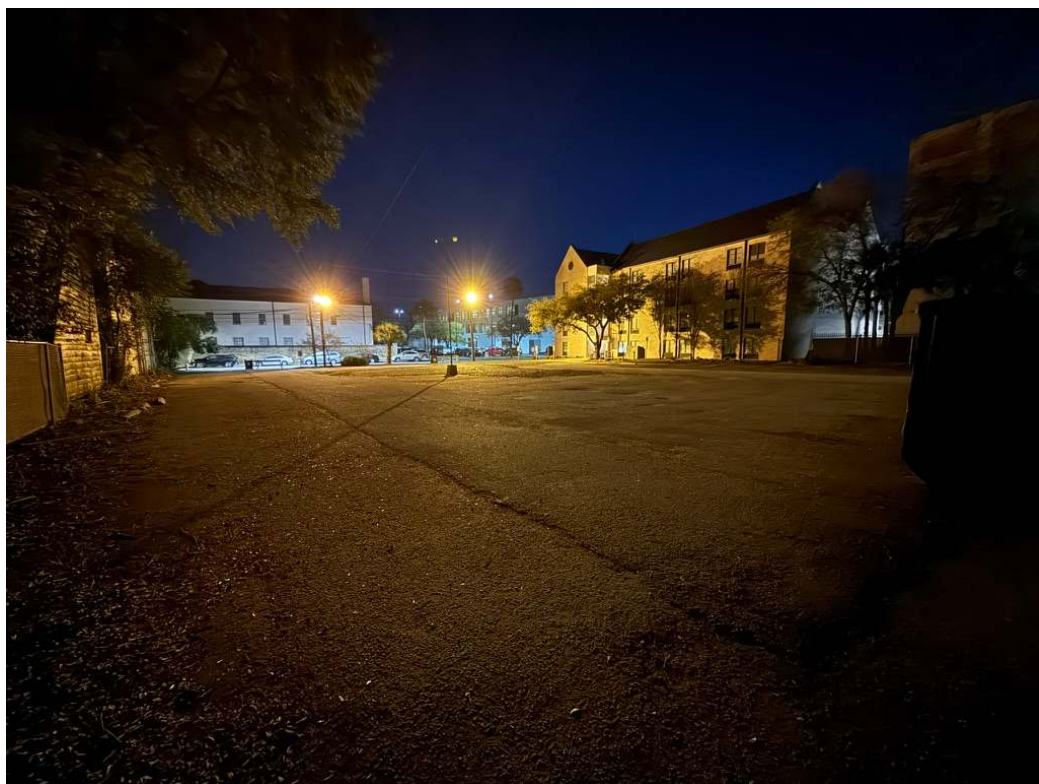


Figure 7. Public Safety at the College of Charleston had all lots and surfaces cleared of vehicles for the survey on February 14, 2026. Vanderhorst Street is visible to the north in front of the white building. (photo by M. Scott Harris)

3. Cultural Context and Previous Investigations

The cultural context is outside the scope of this document and has been presented elsewhere regarding the property².

4. Research Design

4.1. Research Questions and Objectives

Ground-penetrating radar (GPR) and drone work are used to characterize near-surface and surface conditions at the time of the survey. The goal is to detect, characterize, and identify, without disturbance, depth to sterile ground, grave-related features, and superposed infrastructure, including building construction and utilities, and other culturally related features, and to distinguish burial-related anomalies from later structural, depositional, and utility disturbances.

² Tulla et al., *Public Burial Ground (1790s-1807). Coming, Vanderhorst & Calhoun Streets, Charleston, South Carolina*.

4.2. Justification for Multi-Method Remote Sensing Approach

GPR was requested by the Community Engagement Council and thus was the chosen method. The 18-channel system was chosen to obtain a comprehensive, accurate 3D evaluation of the subsurface. The drone provides surface context and good relative spatial control, while the GPR provides a clear subsurface image when conditions are appropriate for proper radar propagation. Complex surface conditions, moist soils, increased mud content, and other factors may limit potential across varied areas of the site.

4.3. Expected Targets and Anomaly Signatures

Expected targets include original surfaces prior to any backfill adjacent to historic creeks, grave shafts, cisterns, wells, foundations, trenches, utilities, and other soil disturbance practices over the last three hundred years.

5. Field Methods

5.1. Ground Penetrating Radar

An ImpulseRadar Raptor-45 with 18 channels on a vehicle mount gathered 8-cm spaced radargrams. The GPS antenna was mounted forward of the system to reduce interference with the GPR. Positioning was with an Emlid Reach RS4 in concert with real-time corrections through the South Carolina Virtual Reference System.



Figure 8. The Talon GPR is mounted to the rear of the vehicle. The GPS is centered over the cab. (photo by M. Scott Harris)

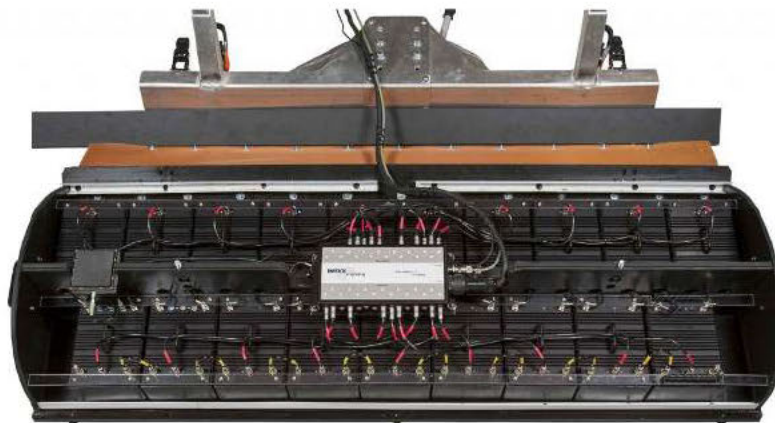


Figure 9. Inside the Raptor GPR system showing antenna configuration resulting in 8-cm spaced radargrams (image from ImpulseRadar).

5.2. Drone Survey and Processing

An area map and digital surface model were created from an aerial grid survey collected with a DJI Mavic 3. Parallel flight lines were generated in DroneDeploy, transferred to the drone, and the flight path was run to collect photographs. Photos were collected with 80% front overlap and 75% side overlap for 3D capture at 40 m above ground level. Although the area is generally flat, terrain awareness settings were used to maintain 40-m AGL flight.

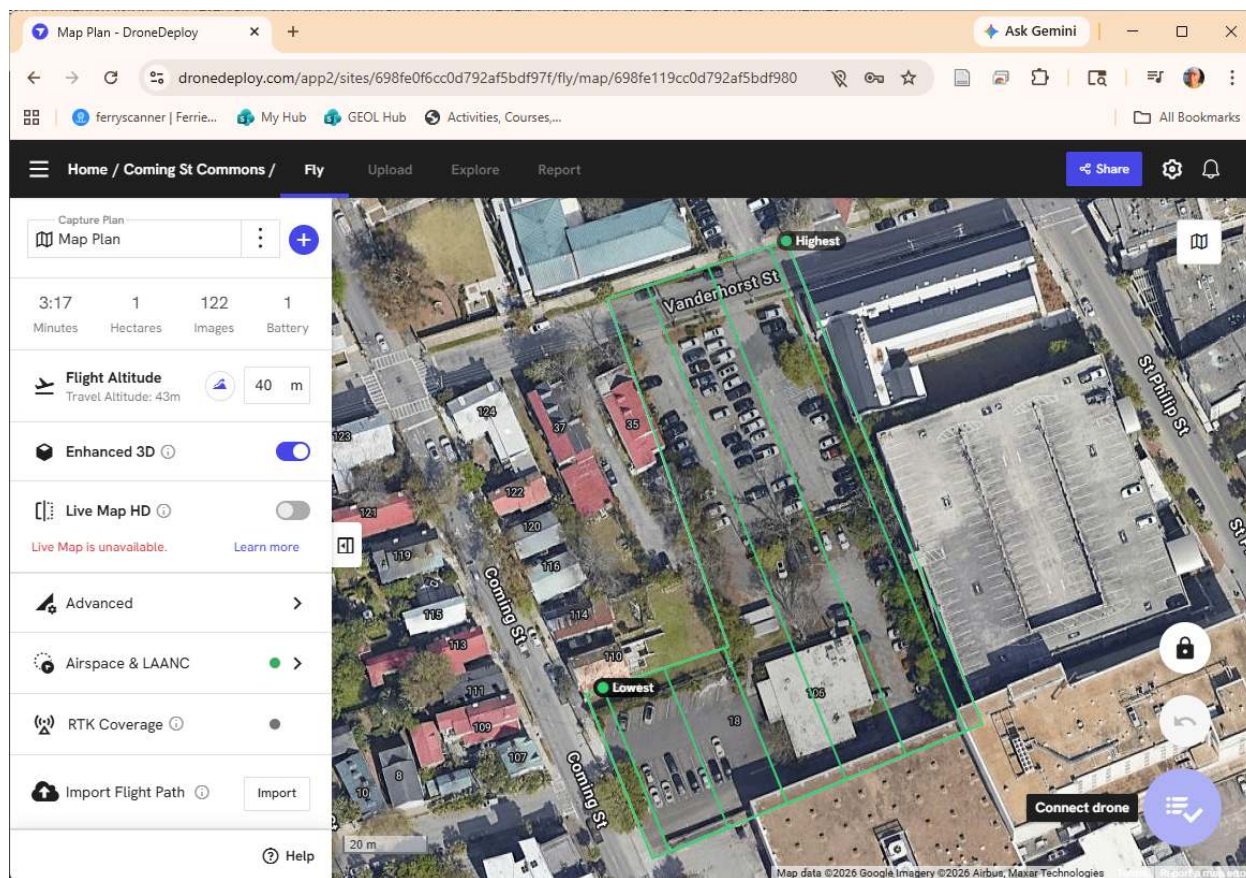


Figure 10. Planned flight lines for aerial mapping survey. Drone Deploy flightline generator.

5.3. GPR Data Processing

See section 6.3 to 6.13.

5.4. GPR Instrumentation

An ImpulseRadar Raptor 18-channel 450MHz system was used with an Emlid RS4 real-time kinematic global navigation satellite system (RTK-GNSS) attached via cell phone to NTRIP corrections provided through the South Carolina Virtual Reference System (VRS).

5.5. GPR Acquisition Parameters

Please see Section 6.3 through 6.13. The 3D data collected during the survey used a perpendicular-broadside co-polarized configuration.

5.6. GPR Survey Grid and Geospatial Control

Due to the system's true 3D nature, swaths were collected to fully cover the area. The GeoTIFF output slices were collected in WGS84-UTM Zone 17 N, and the accuracy was tied to the RTK-GNSS through the South Carolina VRS. Most positioning was better than 2 cm in xyz, with some outliers adjacent to the taller buildings.

5.7. GPR Transect Layout and Spacing

GPR data were collected along swaths (Figure 11), with 0.084-m-spaced lines across the entire AOI where accessible. Data were not collected at concrete car stops or where other objects (walls, vegetation, etc.) prevented access.

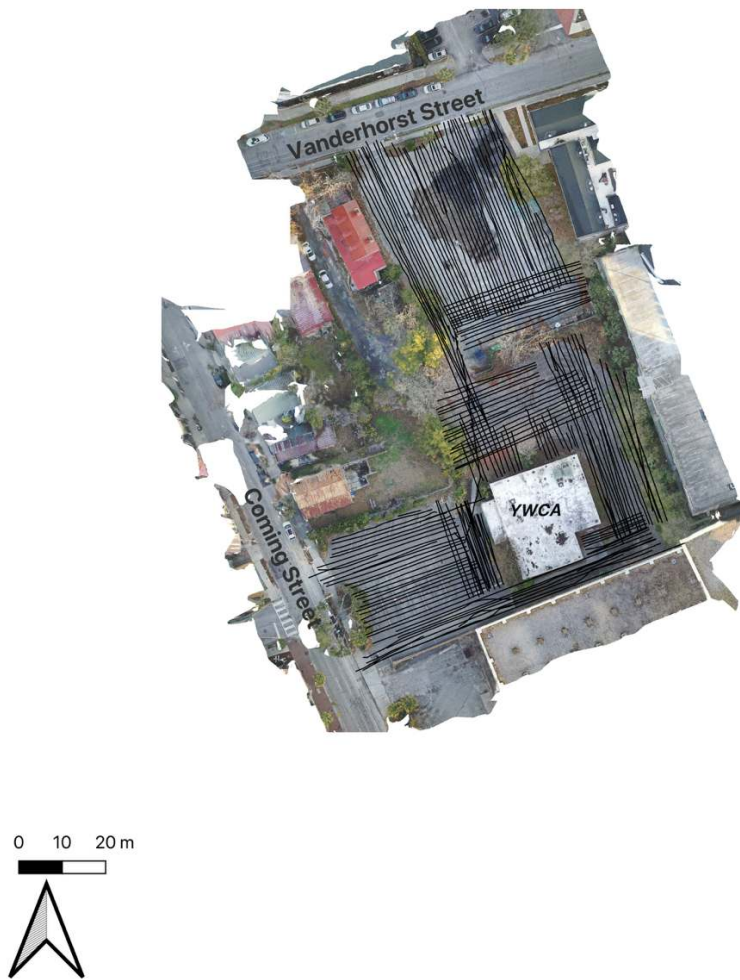


Figure 11. GPR tracklines in black over drone orthophotograph. Each line represents the center line for the 18 channels of the survey. Nine channels are on either side of the line.

5.8. Environmental Conditions During Acquisition

The survey was conducted on Friday, February 13, 2026, and Saturday, February 14, 2026, with morning temperatures around 40°F locally and highs in the mid-50s. The dry, cool conditions with still air to light north winds caused local ground-level frost on the grass (Figure 12). The drone flight took place on the morning of February 14, starting at 7:25 AM and concluding with the last photograph at 7:33 AM.



Figure 12. Light frost on the grass at the site on February 14, 2026, 7:42:50AM local time. (photo by M. Scott Harris)

5.9. Constraints on Fieldwork

Surveyed areas were only in the accessible lots at the time of survey. The area under the YWCA, the wall separating the Vanderhorst Street lot and the YWCA area (and associated scaffolding and dumpster), areas with construction materials, and areas with heavy vegetation were not surveyed, nor were areas where the concrete car stops were located.

6. Data Processing and Analysis Methods

6.1. Drone Photogrammetric Processing

Data were processed using Bentley Systems³ iTwin Modeler and Engine with standard settings.

Reconstruction - Orthophoto/DSM_1 ⓘ

Completed 2.5D, Regular planar grid (grid size 15 meters), 83 tile(s), extra precision

Overview Spatial Framework Geometry Constraints Reference Model **Processing Settings**

Preset type: Custom ▾

Selection of matching pairs	For structured aerial dataset ▾	
Photos used for geometry	Exclude thermal imagery ▾	
Geometric precision	Extra ▾	Extra precision, larger file size (tolerance of 0.5 pixel in input photos)
Hole-filling	Fill all holes except at tile boundaries ▾	
Color correction mode	Automatic (machine learning) ▾	Apply the color correction computed during Aerotriangulation.
Geometry resolution limit (meters)	0	Clamp resolution of geometry if finer than the specified limit

Figure 13. Settings for creation of the orthophoto and digital surface model in iTwin Capture Modeler Master by Bentley Systems.

6.2. GPR Software and Workflow

After data collection, data were loaded into ViewR (ImpulseRadar), and navigation was verified and corrected as needed. The data were then opened in Condor processing software⁴. The processing steps included:

1. Import data into ViewR
 - a. Verify and Quality Control (QC) the entire dataset and individual swaths
 - b. QC positioning data

³ Bentley Systems, "iTwin Capture - Using April Tags as Control Points - Communities."

⁴ ImpulseRadar, "Raptor-User-Manual-Ver.-1.00."

- c. Apply GPS offsets from Raptor position
 - d. Fix GPS
 - e. Export to Condor software format
- 2. Load raw data exported from ViewR into Condor software
 - a. Dewow (time window width 41 samples; filter width 8 samples)
 - b. DC Removal
 - c. Bandpass Filtering
 - i. Low cut: 100 MHz
 - ii. Low pass: 180 MHz
 - iii. High pass: 720 MHz
 - iv. High cut: 900 MHz
 - d. Time-zero adjustment
 - i. Threshold: 3000
 - ii. Correct for antenna separation
 - iii. Adjustment velocity: 15 cm/ns (not the migration velocity)
 - iv. Fixed time zero: yes
 - e. Geometry Binding:
 - i. Minimum positioning step: 0.05 m
 - ii. Interpolation distance interval: 0.042 m
- 3. Preprocess
 - a. Muting of high- and low-amplitude: Ratio = 3
 - b. Amplitude Correction: AGC with 19 ns centered operator length
 - c. Antenna Ringdown Removal: 501 traces
- 4. Interpolated with Max gap of 0.2m, interpolated every 2 slices, and used topmost swath for overlaps
- 5. Migration with velocity of 8.6 cm/ns and several bounding velocities (most data were viewed unmigrated for identification of hyperbolae)
- 6. After preprocessing within Condor, data were then imported into the Earth Access GPR software described below. Here, visuals could be more easily characterized based on return contrast.

Due to low contrast differentiation in Condor software, Dr. Harris partnered with Earth Access, LLC, to develop visualization software for these types of data, both profile by profile and through slices. The software primarily varies contrast through multiple color ramps to identify subtle features without heavy reprocessing or rebuilding of 3D voxels or cubes.

The products in this report and the appendices are derived primarily from the Earth Access, LLC gpr-tools, as well as some from the Condor software. For the full analysis and settings during GPR processing, see sections 6.3 thorough 6.13.

6.3. GPR Processing Steps Applied

The workflow for the GPR processing includes the steps in Table 1. Two recipe steps are intentionally not in the history: first break (computes the t0 picks consumed by time_zero; mutates no data) and envelope (enabled: false). Pipeline mode: classic (full gain $t^{2.5}$ baked in).

Table 1. GPR processing order, operation, and parameters.

#	Operation	Parameters	From recipe step	Physical effect
1	remove_dc	pre_t0_samples: 50	dc_shift	Subtract DC bias from 50 pre-t0 samples
2	correct_time_zero	mode: per_trace, smoothing: median_5, median_shift: 40, max_shift: 40	time_zero	Align first break to t=0, per trace
3	dewow	type: runmed, window_samples: 41	dewow	Running-median low-freq removal (window forced odd 40→41)
4	normalize_direct_wave	method: peak, window_ns: [0, 10.0]	normalize_direct_wave	Normalize each trace to direct-wave peak (0–10 ns)
5	bandpass	low: 112.5 MHz, high: 1125 MHz, order: 4, zero_phase: true	bandpass	Zero-phase Butterworth band-pass
6	power_t_gain	n: 2.5	gain (tpow $\alpha=2.5$)	Time-power gain $t^{2.5}$ (depth compensation)
7	remove_background	mode: moving, method: median, window: 75	background_remove	Moving-median (75 traces) background removal

6.4. Time-Zero Correction and Dewow

See Table 1.

6.5. Bandpass Filtering

See Table 1.

6.6. Gain Application

See Table 1.

6.7. Predictive Deconvolution

Not applied.

6.8. Migration

Not applied.

6.9. Topographic Correction

Due to the flat nature of the site, no topographic correction was applied.

6.10. Velocity Estimation and Depth Conversion

Velocity estimation through hyperbolic matching was conducted at spots with a buried utility adjacent to the YWCA.

6.11. Amplitude Slice Map Generation

Six survey-wide gridded depth-slice cubes (one per aggregation × interpolation), plus a shared YAML sidecar and a per-profile provenance JSON. Built 2026-05-24 from all 197 processed profiles by build_atlas (Stolt migration → per-slice aggregation → gridded interpolation).

Files (each ~0.95–1.02 GB, zlib-4 compressed): slices_rms_nn.nc, slices_rms_idw.nc, slices_rms_linear.nc, slices_envelope_nn.nc, slices_envelope_idw.nc, slices_envelope_linear.nc — total 4,480,518,506 bytes.

Table 2. Atlas (cube and slices) dimensions for all six cubes generated.

Dimension	Size	Notes
depth	125	Number of time/depth slices
y	2610	Northing grid rows ($2610 \times 0.05 \text{ m} \approx 130.5 \text{ m}$)
x	1746	Easting grid columns ($1746 \times 0.05 \text{ m} \approx 87.3 \text{ m}$)

Table 3. Cube data variables and pyramid levels for on-screen viewing.

Variable	Dims	Type	Notes
slice_amplitude	(depth, y, x)	float32, zlib-4	Gridded slice amplitude
slice_amplitude_ov2	(depth, 1305, 873)	float32, zlib-4	½-resolution overview (pyramid)
slice_amplitude_ov4	(depth, 653, 437)	float32, zlib-4	¼-resolution overview (pyramid)

Table 4. Data cube coordinate variables.

Coordinate	Dims	Units	Description
slice_center_ns	(depth)	ns	Slice window centre (TWT)
slice_top_ns	(depth)	ns	Window top (TWT)
slice_bottom_ns	(depth)	ns	Window bottom (TWT)
slice_center_m	(depth)	m	Centre depth = center_ns × v/2
slice_top_m	(depth)	m	Top depth
slice_bottom_m	(depth)	m	Bottom depth
easting	(x)	m	UTM easting of grid columns
northing	(y)	m	UTM northing of grid rows

Table 5. Global attributes per cube. Aggregations generated with RMS or Envelope, and interpolation was nearest neighbor, IDW, or linear. RMS IDW is considered best for this survey. All slices are in the appendices.

Attribute	Value	Notes
aggregation_method	rms or envelope	Per file
interpolation_method	nn, idw, or linear	Per file
velocity_m_per_ns	0.086	Migration / depth-conversion velocity
thickness_ns	0.6977	Slice window width
step_ns	0.6395	Spacing between slice centres
range_start_ns	0.0	Earliest slice TWT
range_stop_ns	80.0	Latest slice TWT
max_distance_m	0.5	Max interpolation search distance
grid_resolution_m	0.05	Grid pixel size
n_source_profiles	197	Input profiles
gpr_tools_version	0.6.0	

Attribute	Value	Notes
created_utc	2026-05-24T05:39:42Z	Build timestamp

Depth coverage: 0–80 ns at $v = 0.086$ m/ns $\rightarrow$ one-way depth **0 to ≈ 3.44 m**, across 125 slices ≈ 27.5 mm increments.

6.12. Companion atlas — slice_atlas_metadata.yaml

Written alongside the cubes (schema slice_atlas_version: 2, status: complete). Full contents:

```

slice_atlas_version: 2

status: complete

epsg: 32617

gpr_tools_version: 0.6.0

created_utc: '2026-05-24T05:39:42.078340+00:00'

generation_parameters:
  velocity_m_per_ns: 0.086
  thickness_ns: 0.6977
  step_ns: 0.6395
  range_start_ns: 0.0
  range_stop_ns: 80.0
  max_distance_m: 0.5
  grid_resolution_m: 0.05
  n_slices: 125

n_source_profiles: 197 (with 18 profiles per the 197 swaths)

source_profiles: [cofc csc_S001_001_processed.nc, ... 197 entries ...]

methods_generated:
- {aggregation: envelope, interpolation: idw}
- {aggregation: envelope, interpolation: linear}
- {aggregation: envelope, interpolation: nn}
- {aggregation: rms, interpolation: idw}
- {aggregation: rms, interpolation: linear}
- {aggregation: rms, interpolation: nn}

files_written: [slices_rms_nn.nc, slices_rms_idw.nc, slices_rms_linear.nc,
                slices_envelope_nn.nc, slices_envelope_idw.nc, slices_envelope_linear.nc]

total_disk_bytes: 4480518506

param_hash: 06e8eb0995a197aecf20b7a9e32d363754bf7679cc132edf8c6cb587502bf877

pyramid:
  min_dim: 1024

```

```
base_shape: [2610, 1746]

levels:
- {factor: 2, shape: [1305, 873]}
- {factor: 4, shape: [653, 437]}
```

Interpolation parameters (defaults for this build): IDW $p = 2.0$, $k = 12$; NN and linear have no extra parameters; kriging was not generated. param_hash is the SHA-256 of the canonical generation parameters — identical inputs reproduce it.

This atlas was written by an older code path (slice_atlas_version: 2), so it does not carry the per-profile source_provenance or enhancement_preset blocks the current code adds (v4). Each source profile's processing history still lives in its own .nc (Stage 1).

6.13. Deferred display enhancement

Once the 3D cube atlas was created, real-time viewing provided multiple contrast sliders to enhance the slice view in specific areas of the data. This new method provided by Earth Access, LLC, afforded better viewing and contrast enhancement than a standard Hilbert transform.

A view-time enhancement applied for interpretation/display; This view is **not baked** into the stored slice_amplitude or profile amplitude values: (see file: processed02/enhancement_presets.json)

```
{"__active__": {"name": "imported from blank_starting_point",
"gain": {"type": "tpow", "alpha": 2.0},
"envelope": {"enabled": false, "method": "hilbert"},
"gpr_tools_version": "0.6.0", "created_utc": "2026-06-16T18:26:45Z",
"notes": "Interpretation gain:  $t^{2.0}$  (source  $t^{2.5}$  minus baseline  $t^{0.5}$ ); Envelope: off"}}
```

6.14. Integration of Drone and GPR Datasets

All GNSS-gathered data were coordinated and organized into EPSG: 32617 (see <https://epsg.io/32617>) for the standard. As stated earlier, no topographic conversion was needed for the site.

6.15. Anomaly Identification and Classification Scheme

Please see sections 6.17 through 6.20 for the detailed classification schema and descriptions of each type. Anomalies were identified using both radargram and slice data. Anomalies identified on the radargram were digitized and projected onto slice data where

they were subsequently outlined in XY coordinates. While many features crossed multiple radargrams and penetrated multiple slices, cubes were not fully digitized.

6.16. Purpose and Inputs

Every anomaly reported here carries a stable identifier, an interpretation class, a confidence tier, and a geophysical signature. The **anomaly register** is the record of those assignments and of how each was decided; it holds **177 anomalies** grouped from the survey's digitized features.

- Feature database: Condor Export_002_features.geojson — 229 digitized features
- Slice atlas measured against: processed02_slices (param_hash 06e8eb0995a1...)
- Cube: envelope_nn; velocity 0.086 m/ns
- Register generated: 2026-07-28T15:01:56.509866+00:00
- Register file last written: 2026-07-28T15:24:22.156693+00:00
- Produced with gpr-tools v0.6.0

6.17. Interpretation Classes

Class is **derived from the feature's kind, never entered per-feature**, so two features of the same kind can never be classed differently. A kind with no entry in the map falls back to UNK.

Class	Meaning
AR	archaeological
UT	utility
NAT	natural
UNK	unknown

The kind → class map in force for this survey comes from this survey's own vocabulary.yaml classes: block:

Table 6. Class and associated kind of feature.

Class	Kind
AR	aligned features
AR	cistern(?)
AR	foundation
AR	grave, possible
AR	grave_perimeter
AR	grave_shaft_wall

Class	Kind
AR	hearth, possible
AR	likely_grave
AR	possible_grave
AR	structural_foundation
AR	structure
AR	wall
AR	well
AR	wide, shallow pit
UT	utility
UT	utility_marker
UT	utility_trench
NAT	boundary, soil anomaly
NAT	rock_or_clast
NAT	root_or_organic
NAT	soil_horizon
UNK	broad_hyperbola
UNK	echo front
UNK	feature_uncertain
UNK	hyperbola_apex
UNK	reference_marker
UNK	reflector_ambiguous
UNK	reflector_continuous
UNK	unclassified
UNK	unknown, needs verification

6.18. Signature Vocabulary

The signature records the *geophysical expression* of an anomaly, independently of what it is interpreted to be. It is a controlled vocabulary:

Table 7. Definition of the various signatures identified in the GPR radargram and the associated number of anomalies.

Signature	Definition	Anomalies
hyperbola	point-source diffraction; a discrete buried object	5
planar_break	a laterally continuous reflector offset or truncation	47
amplitude_high	locally elevated reflection strength against its own depth slice	59
attenuation	locally suppressed amplitude — absorption or scattering loss	0

Signature	Definition	Anomalies
<code>chaotic_scatter</code>	incoherent high-frequency scatter; disturbed or heterogeneous fill	1
<code>geometry_only</code>	digitized on geometry alone; no diagnostic waveform character	74

6.19. Confidence Tiers

Tiers are assigned by declared rule, not by judgement, using the parameter values this register was produced with:

- **Tier 1** — amplitude percentile ≥ 90.0 **and** (≥ 2 swaths **or** ≥ 3 persistent slices).
- **Tier 2** — a clear signature on a single observation (`geometry_only` does not count as clear) **or** ≥ 2 persistent slices.
- **Tier 3** — everything else.

Tier is evidence strength, not archaeological importance. A Tier 3 possible grave is not a lesser find than a Tier 1 utility; it is a find with less geophysical corroboration. The tier column must not be read as a ranking of significance.

This survey makes the point concretely: of the 24 anomalies interpreted as possible graves, 6 at Tier 2, 18 at Tier 3. Graves are typically low-contrast features — a backfilled shaft in similar soil returns little amplitude — so they score low on rules built around amplitude and persistence while remaining the most archaeologically significant anomalies in the survey.

6.20. Grouping and Identifier Assignment

Identifiers take the form CSC-{CLASS}-{NNN} (e.g. CSC-AR-001). **IDs are write-once and are never renumbered:** a re-run of the register keeps every existing ID and continues numbering from the highest in use, so an ID cited in this report will still mean the same anomaly after the next revision.

One anomaly may group several digitized features (the same thing seen on two swaths or outlined twice). Grouping is automatic but deliberately conservative — proximity and depth overlap alone never merge two features. Members must *also* satisfy a shape gate: intersecting footprints, both compact (elongation < 5), or similar shapes (elongation ratio ≤ 3). This keeps a compact cistern from fusing with a long linear that happens to pass nearby. Rejected near-merges are logged, and the review CSV's group column is the manual escape hatch for a merge or split the rule gets wrong.

- Footprint buffers: point 0.25 m radius, polyline 0.15 m half-width
- Grouping radius: 1.0 m between member centroids

- Velocity-pick attach radius: 1.0 m
- Swath counting: n_swaths is the number of **distinct** S### swaths across an anomaly's member features (a union, not the maximum over members). Features digitized on a profile parse the swath from the profile name; features digitized on the slice atlas count the distinct swath tracklines passing within the line buffer of the rasterized footprint.

7. Results

7.1. Drone Survey Results

The drone survey was conducted before shadows were cast across the site on the morning of February 14, 2026. The flight collected 166 aerial photographs in a regular parallel line spacing. A grid was established and 166 photographs collected for the survey. State the resulting orthophoto resolution (GSD), DSM cell size, vertical and horizontal accuracy as derived from the April Tag ground control points (GCPs; residuals on control), and any visible surface features identified (depressions, mounds, plot boundaries, grave markers, vegetation patterning).

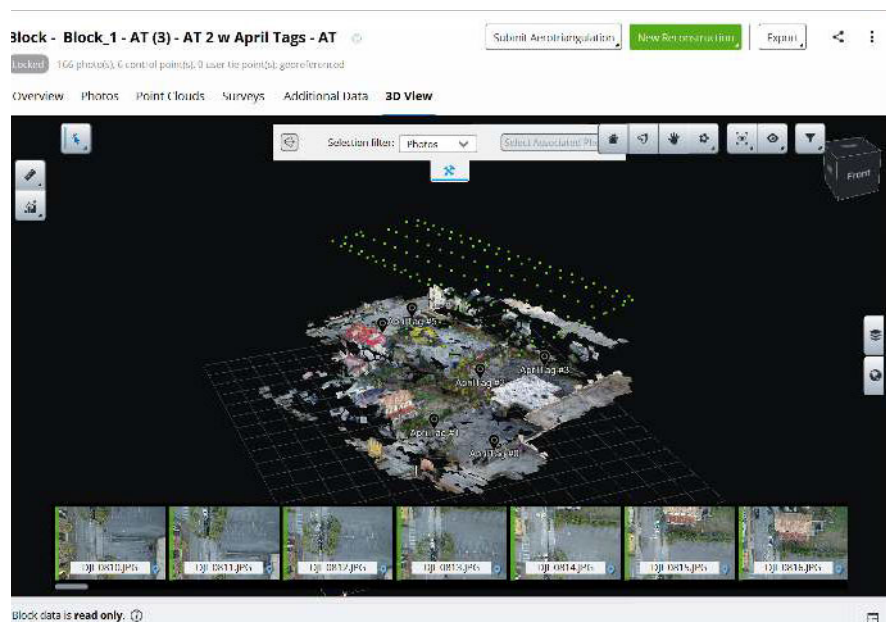


Figure 14. Drone mapping image showing photo locations (Green dots) above the recreated digital surface model (DSM) for the AOI.

The Acquisition report and the Quality report are provided in Appendix 1 and Appendix 2. respectively. The georeferenced orthophotograph created as a result has 1-cm resolution.

7.2. Surface Features Identified from Photogrammetric Data

No surface features were identified in the photogrammetric data that are not clearly discernible on the ground.



Figure 15. Georeferenced orthophoto mosaic of the AOI. Image has 1-cm pixel size.

7.3. GPR Survey Coverage Overview

The survey resulted in 197 usable swaths (full width of the mounted system), or 3,852 radargrams (individual profiles used to create the 3D), with ~8-cm spacing over the entire accessible area, yielding full, true 3D imaging with the 450 MHz system. GPS offsets from the antenna included 6.08 m forward and 2.03 m vertical for the GPS position. Data processing history has been placed in sections 6.2 to 6.13 for the primary data interpretation dataset. Areas of overlap between swaths reduce the effective number while maintaining the 8-cm spacing across the entire area. The survey covers ~5,280

square meters (~56,600 square feet or ~1.30 acres), and 5.85 km of swath lines were collected, resulting in an overall length of ~105.3 km of profile data.

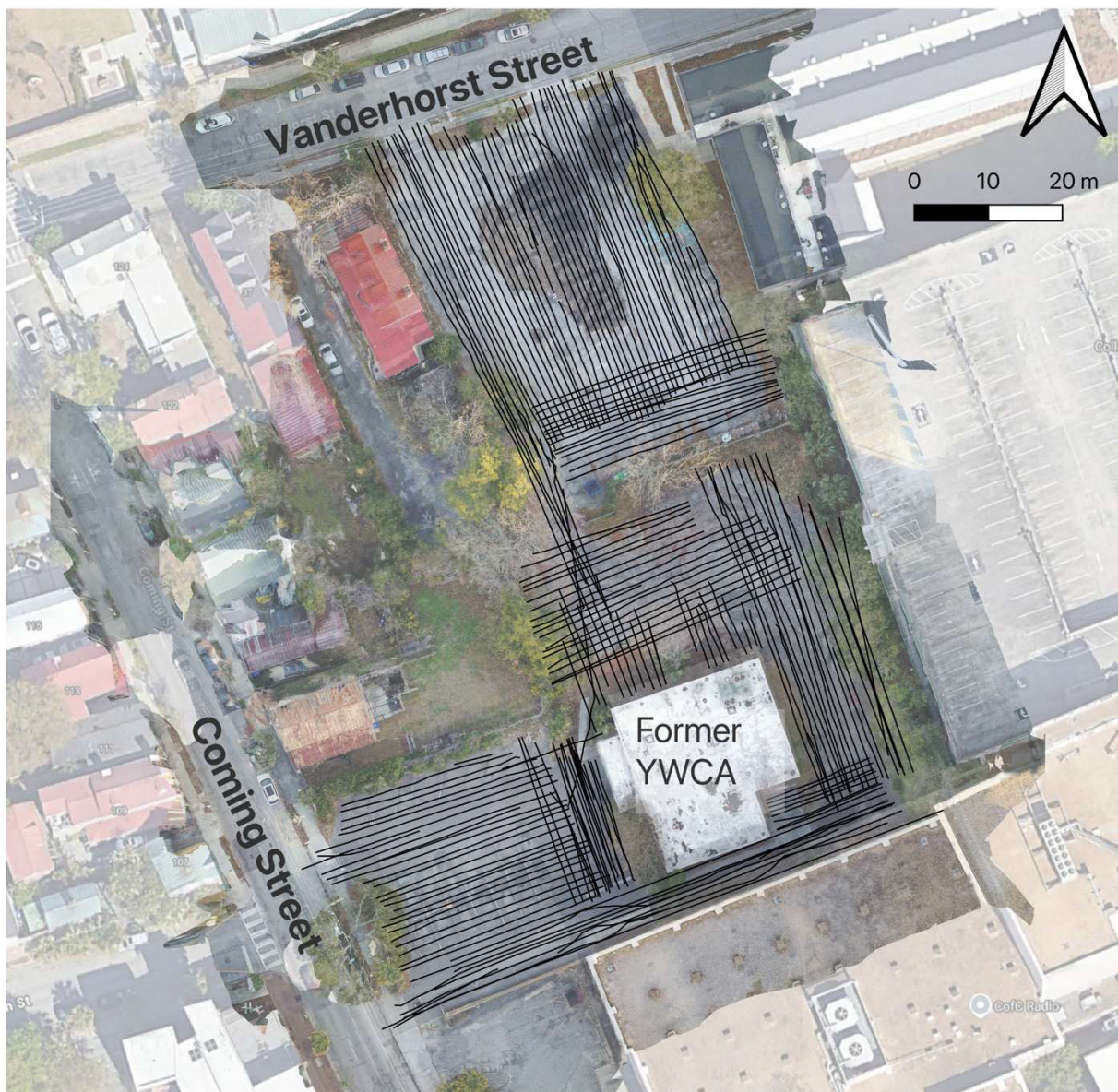


Figure 16. GPR trackline location map. Each of the 197 swaths on this map represents 18 profiles.

7.4. GPR Anomaly Inventory

The project was initiated to determine whether remote sensing could identify potential grave sites from prior site use. In the process of identifying potential grave sites, the larger features have also been identified using the criteria set out in Section 6.7. A summary of identified anomalies is presented here.

7.5. Results

Class	Tier 1	Tier 2	Tier 3	Unassigned	Total
AR	20	31	27	0	78
UT	7	27	1	0	35
NAT	0	0	2	0	2
UNK	16	12	34	0	62
Total	43	70	64	0	177

Figure 17. Total anomalies by Class and Tier digitized for the project. Many more anomalies exist than those identified here.

177 anomalies span 0.12–2.58 m below surface.

8 anomalies carry an analyst departure from the automatic proposal. They are listed in full in Appendix G; in summary:

- 8 — echo front = laterally continuous reflection front, not a conduit; elongation alone insufficient for UT (CSC-UNK-043, CSC-UNK-044, CSC-UNK-046, CSC-UNK-048, CSC-UNK-049, CSC-UNK-050, CSC-UNK-052, CSC-UNK-053)

4 velocity pick(s) provide velocity control for this survey.

- 608b911b-be69-451f-a1dc-9105603ba5e4 — attached to CSC-AR-034; CSC-AR-034 no longer matches any feature in the database (see §6.7.7 Caveats and Limitations) — the pick still documents velocity at that location
- 34649e81-fdaa-4a2c-a79f-4267ea947ad6 — attached to no anomaly (apex at 15.4 ns on cofc csc_S163_148_processed.nc); it documents velocity at that location without corroborating a particular anomaly
- ee30950e-06d5-4b9f-86d0-c6b1c3f12052 — attached to no anomaly (apex at 17.8 ns on cofc csc_S163_148_processed.nc); it documents velocity at that location without corroborating a particular anomaly
- 3fba4efb-f4bf-4f93-b447-f1105f06c622 — attached to no anomaly (apex at 4.9 ns on cofc csc_S163_148_processed.nc); it documents velocity at that location without corroborating a particular anomaly

7.6. Caveats and Limitations

17 digitized features carry no anomaly ID. They were digitized after the last register run and so appear in Appendices E and F, drawn and unlabeled, but have no row in the register and are not counted in any table above: 7 × grave, possible (polygon); 5 × grave_perimeter (polyline); 2 × unclassified (point); 3 × unclassified (polyline). Re-running classify-features would register them; existing IDs would not be renumbered.

1 register IDs no longer match any feature in the database — the features were deleted or re-identified after the register was written: CSC-AR-034.

- An anomaly whose footprint intersects no swath track line scored with `n_swaths = 0`, which caps it below Tier 1 by rule regardless of how strong its amplitude response is.
- The amplitude percentile is **relative to the anomaly's own depth slice**, not an absolute threshold. Under a deferred-gain pipeline where gain is applied on the interpretation layer, no absolute amplitude calibration is available, so a percentile compares an anomaly against its own depth's background and nothing else.
- `velocity_pick` features are excluded from the register by design: they are instrument evidence (velocity control), not anomalies. 4 such features were excluded here. (Excluded kinds: `velocity_pick`.)
- Depths are derived from the atlas velocity of 0.086 m/ns applied to the digitized two-way travel time; they are not independently surveyed. Depth precision is bounded by the slice geometry — 0.6977 ns thick windows stepped every 0.6395 ns (≈ 0.03 m thick, 0.03 m step) — so a depth is a window, not a horizon.

7.7. Representative Radargrams

All data are presented in the appendices. The following radargrams are representative of the entire dataset and show the typical reflector patterns for most identified anomalies. The processed radargrams (Appendix B volume 1 through 8) and the processed radargrams with identified anomalies (Appendix E volume 1 through 8) are provided.

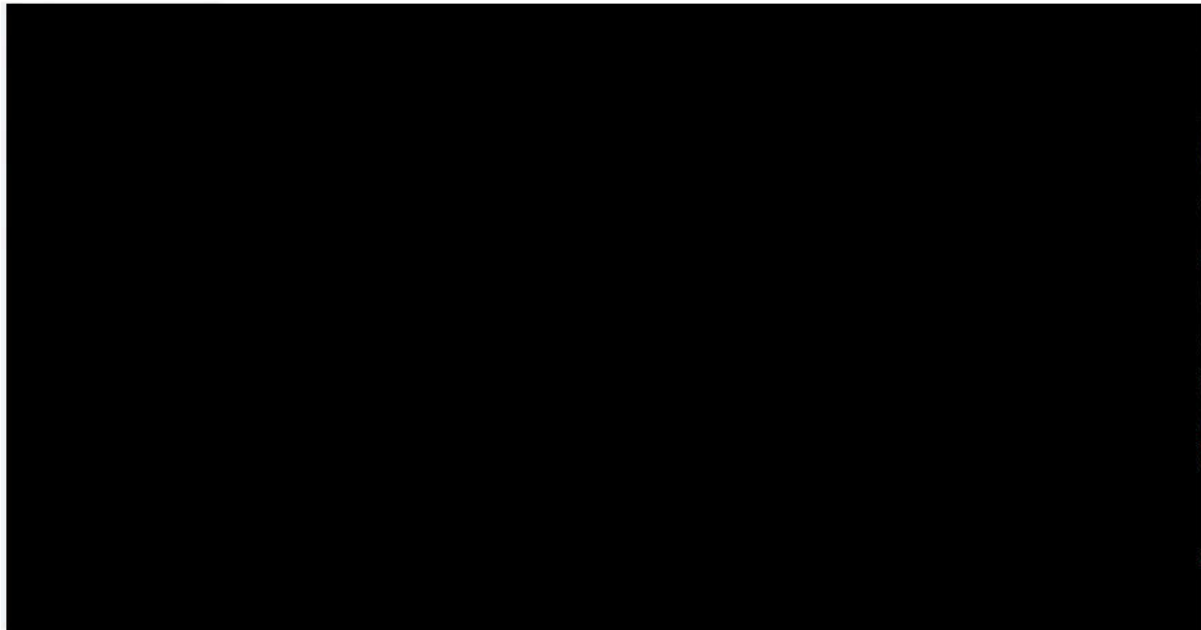


Figure 18. [REDACTED] Some anomalies are identified in the image. The most prominent are the utilities at approximately 50 and 100 traces down the line; the large rectangular structure between ~475 and 550 is rectangular in plan view (see slice image) and identified as a cistern or basement. Smaller anomalies between 300 and 400 traces and between 600 and 675 traces are subtle but consistent across multiple swaths and channels and

are interpreted as grave shafts based on slice dimensions (see Figure XX). The horizontal dashed line is at ~12 ns and the vertical trace is at 385 traces from the start of the line.

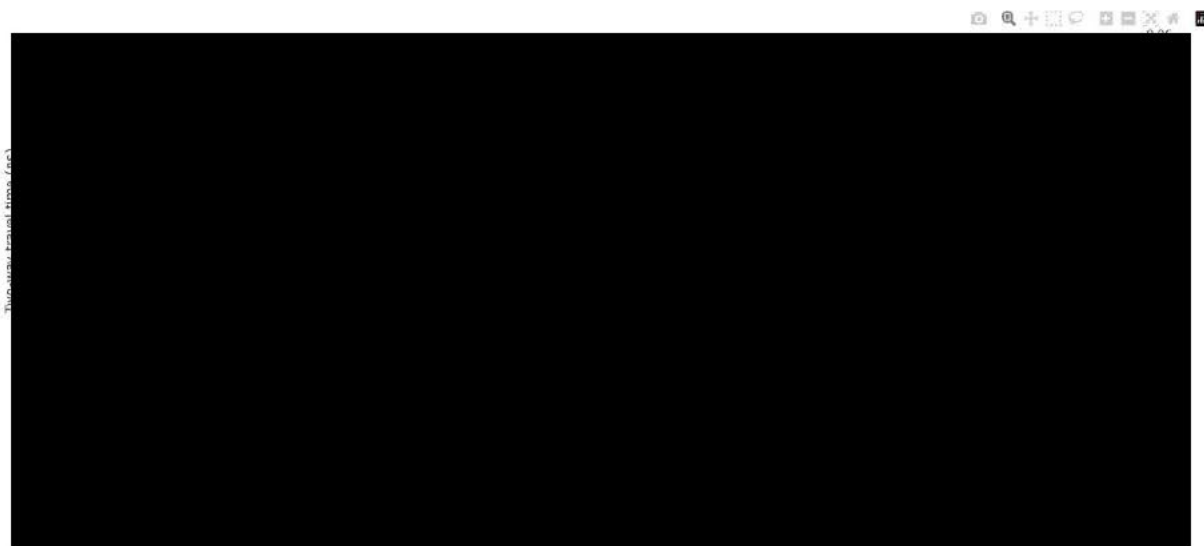


Figure 19. Zoom from Figure 16 showing hyperbolic features identified as potential grave shafts on either side of the interpreted cistern. Only excavation can be used to properly identify these features.

7.8. Amplitude Slice Maps

All slices are presented in the appendices. The following slice maps are representative of the entire dataset and show the typical patterns for most identified anomalies. The slice maps (Appendix C) and the slice maps with identified anomalies and features (Appendix F) are provided.

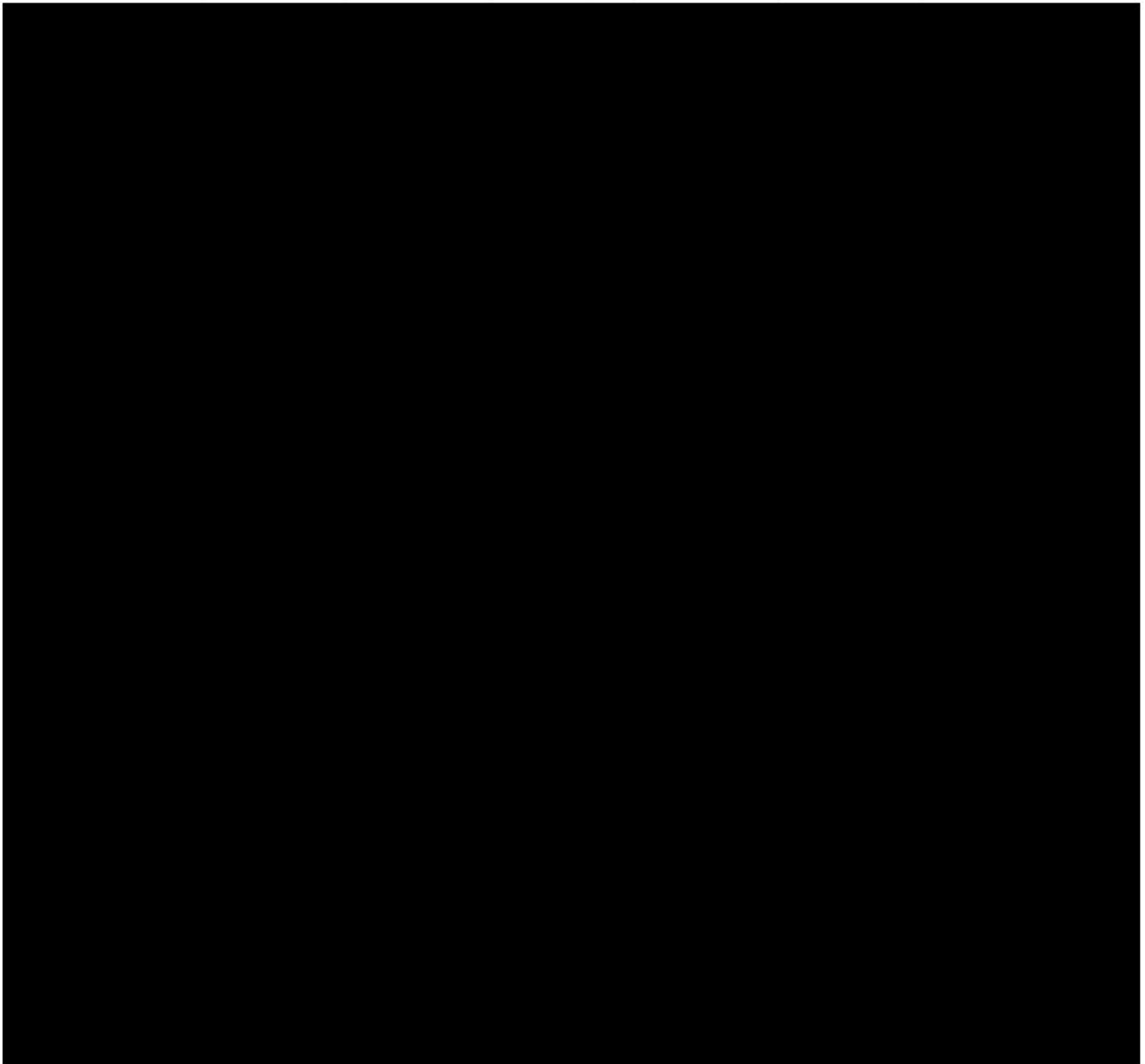


Figure 20. Amplitude slice at 11.86 ns center (window 11.51-12.21 ns TWTT; ~ 0.51 m). North is up.

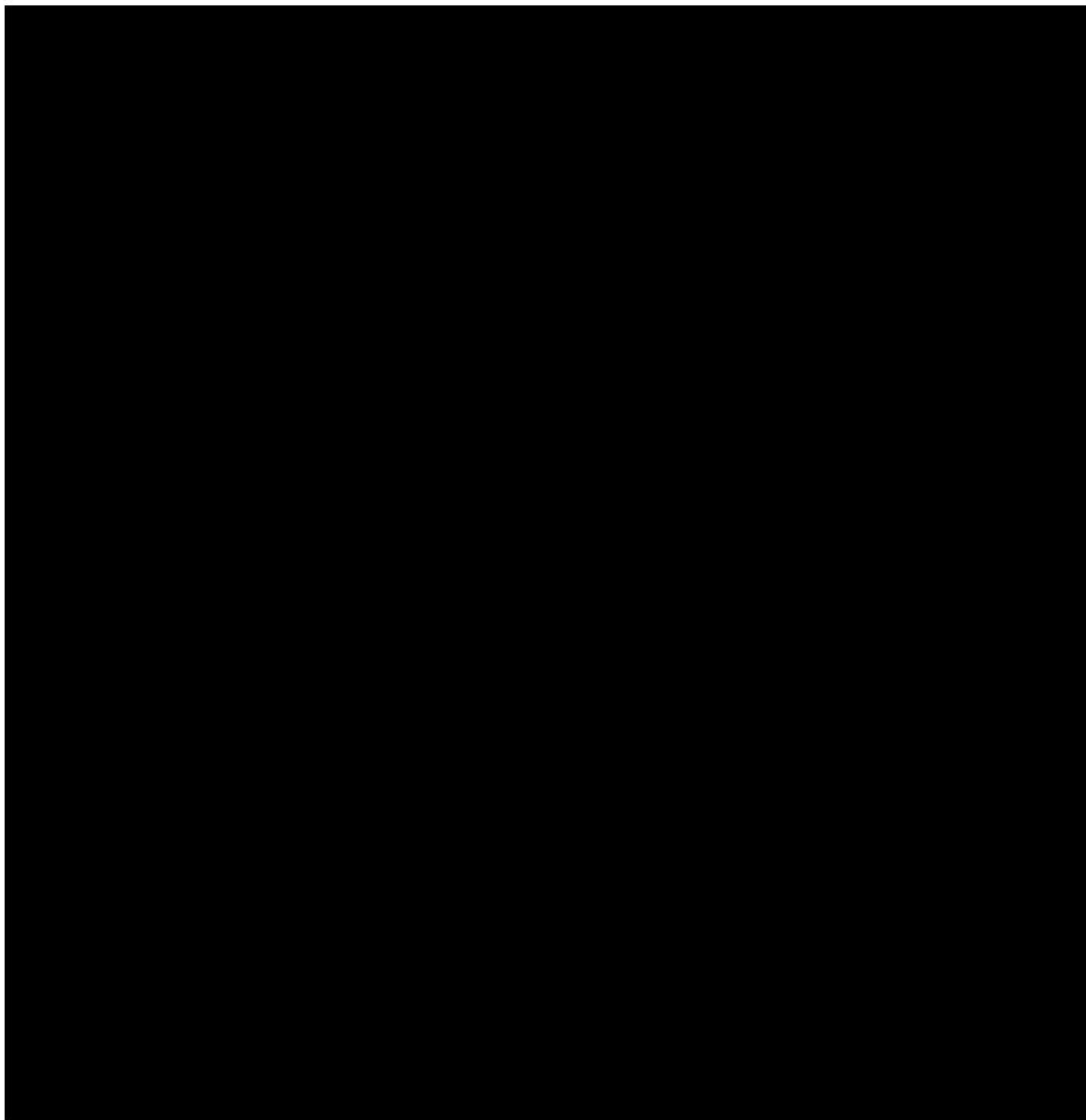


Figure 21. GPR slice at ~12 ns (0.51 m). North is up.

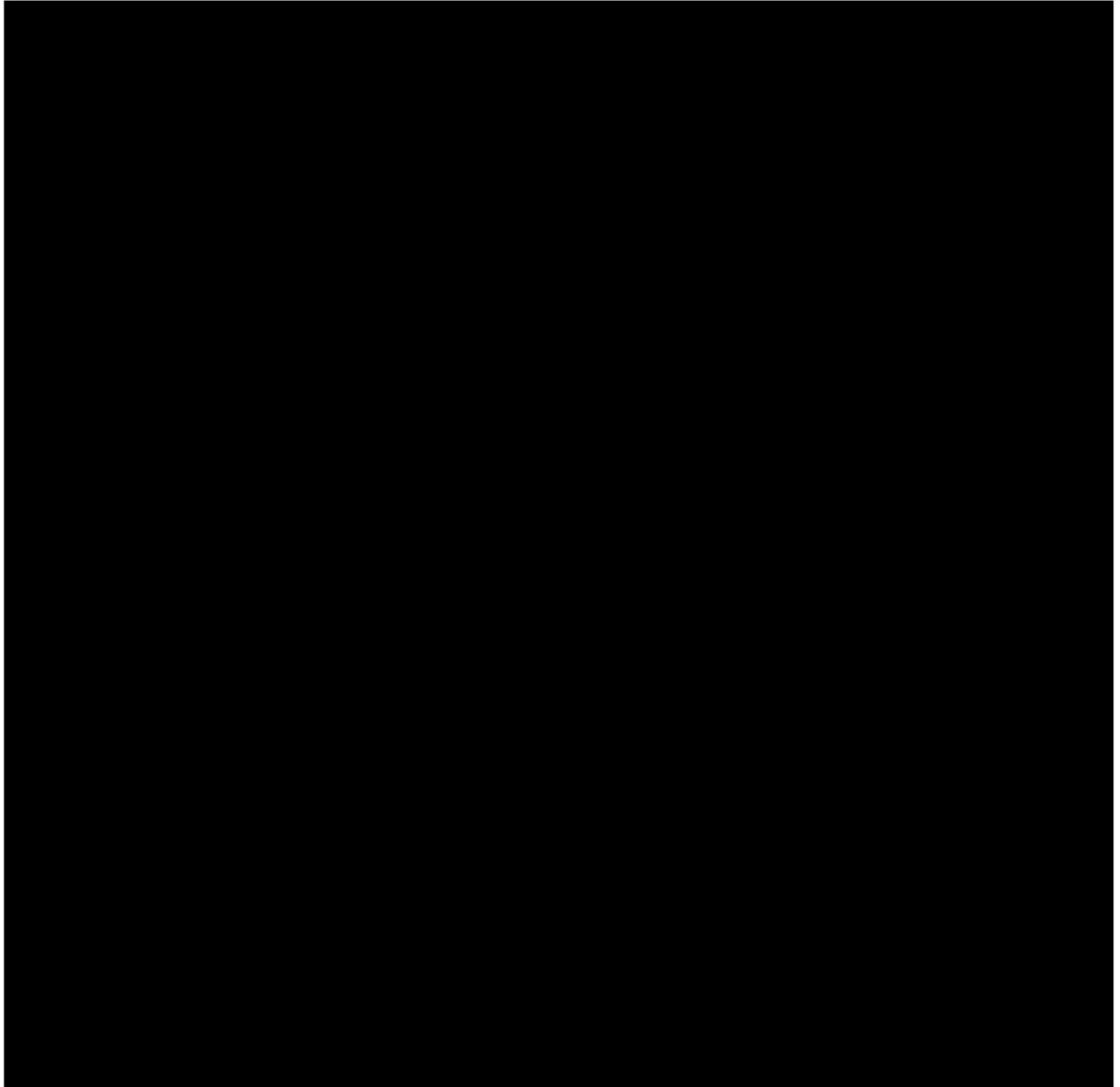


Figure 22. GPR slice at ~12 ns (0.51 m) showing some anomalies. North is up. Likely grave shafts are identified by the small rectilinear features approximately 2m x 1m in the image.

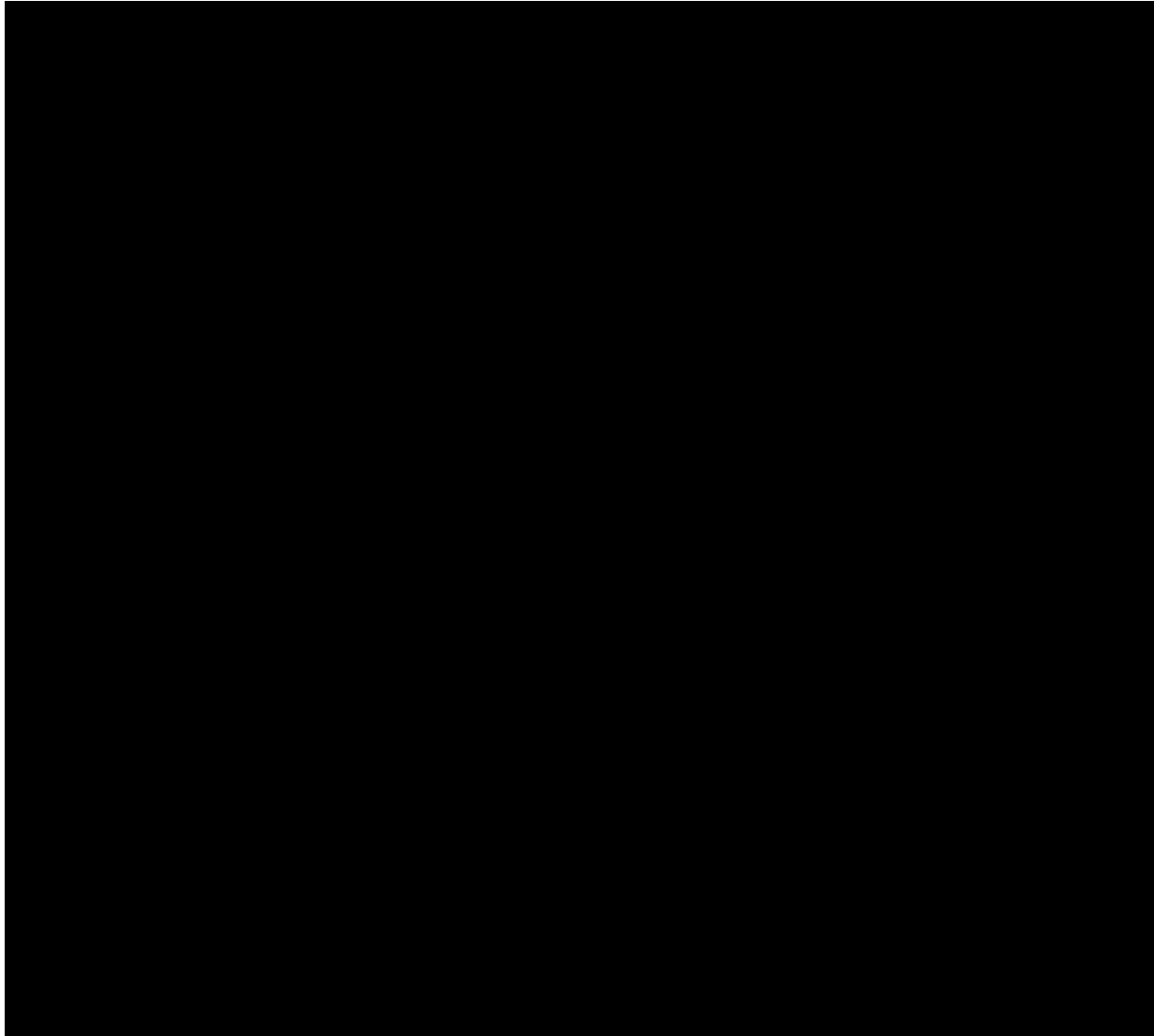


Figure 23. GPR amplitude slice centered on 13.14 ns (~0.57 cm). Swath lines included show features cross multiple swaths; each swath has nine profiles to either side. North is up.

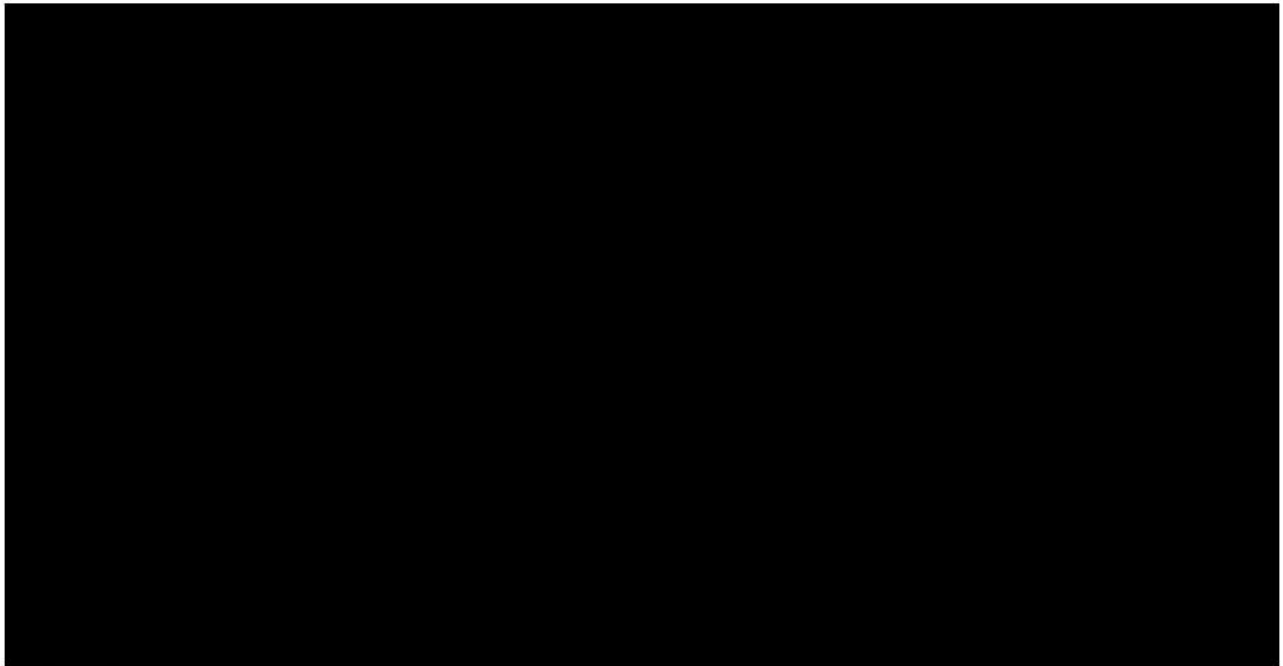


Figure 24. Slice 25 (centered on 16.34 ns; ~0.70 m). Log color stretch 0.0000 to 0.008 to highlight mid-range and lower on envelope idw aggregation for the slice atlas.

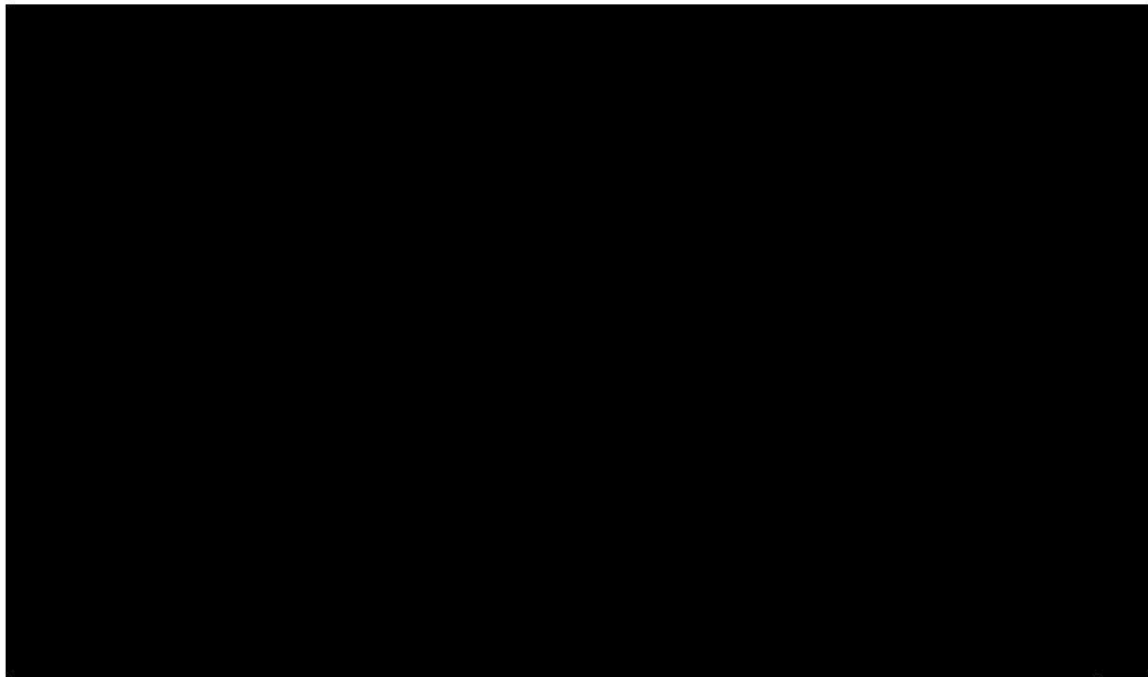


Figure 25. Slice 25 (centered on 16.34 ns; ~0.70 m). Log color stretch 0.0000 to 0.008 to highlight mid-range and lower on envelope idw aggregation for the slice atlas. Rectangular features show strong alignment NNW to SSE with an approximate E-W orientation.

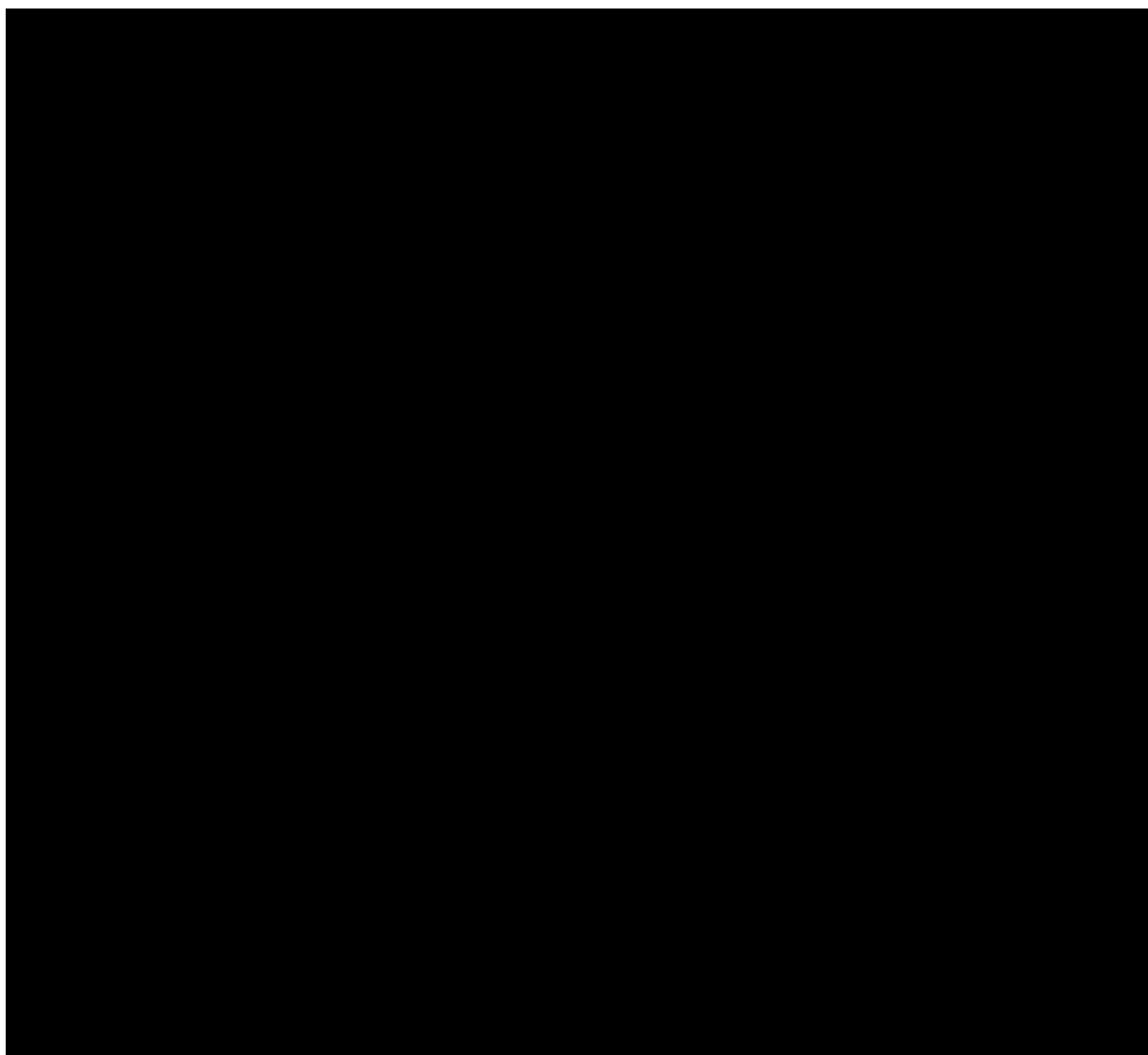


Figure 26. GPR amplitude slice centered on 13.14 ns (~0.57 cm). Swath lines included show features cross multiple swaths; each swath has nine profiles to either side. The most distinct possible grave features are outlined along with building structures, wells, and utilities. North is up.

See the appendices for the full stack of features.

7.9. Ground-Truthing Results

None performed. Ground-truthing is recommended to determine the source and significance of identified anomalies and to inform appropriate treatment of the site. Should archaeological or human remains be encountered, subsequent actions, including consultation with any appropriate parties, should proceed in accordance with applicable laws and established protocols.

7.10.Site-Level Description

The site contains multiple underground utilities, structures, and possible grave shafts. In general, the structures are 15 to 20 m in length and 4 to 11 m in width. Some appear to be complete foundations, while others are deeper with partial footprint piers on which the building stood.

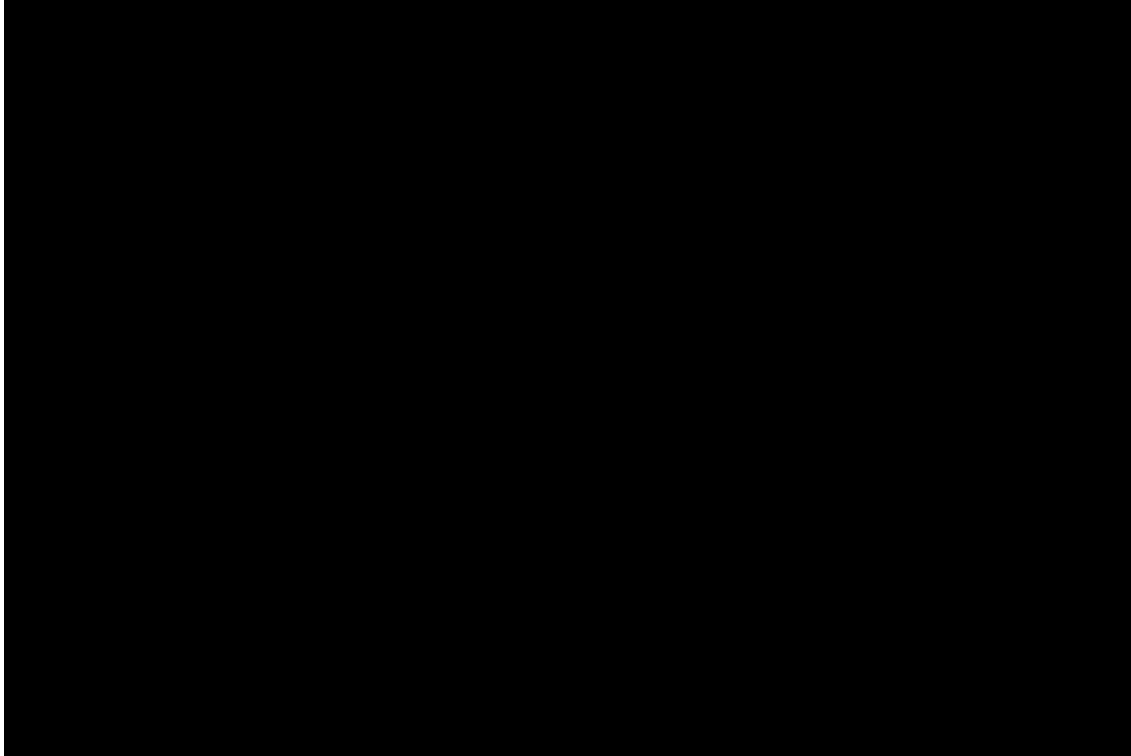


Figure 27. Overview of GPR for the entire site for time slice 28 centered on 18.25 ns (~78.5-cm depth).

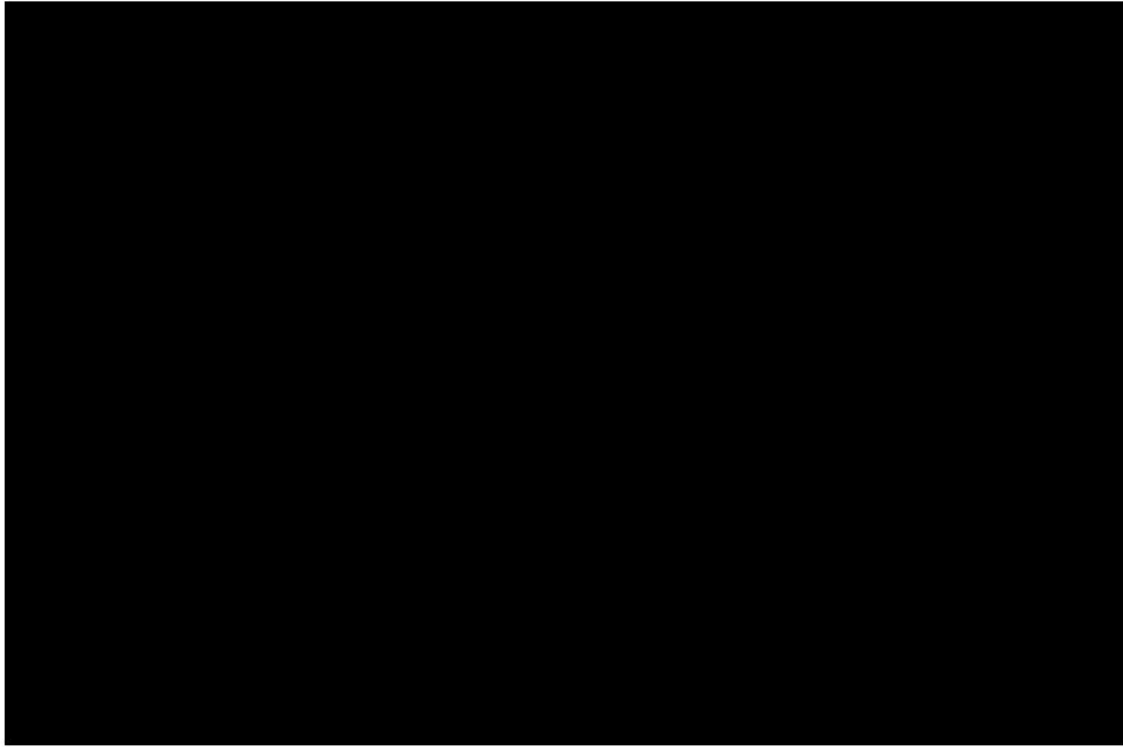


Figure 28. North section of the site showing multiple anomalies commonly associated with foundations, piers, hearth, cisterns or basements, wells, utilities, and possible grave shafts. Zoom into slice 28.

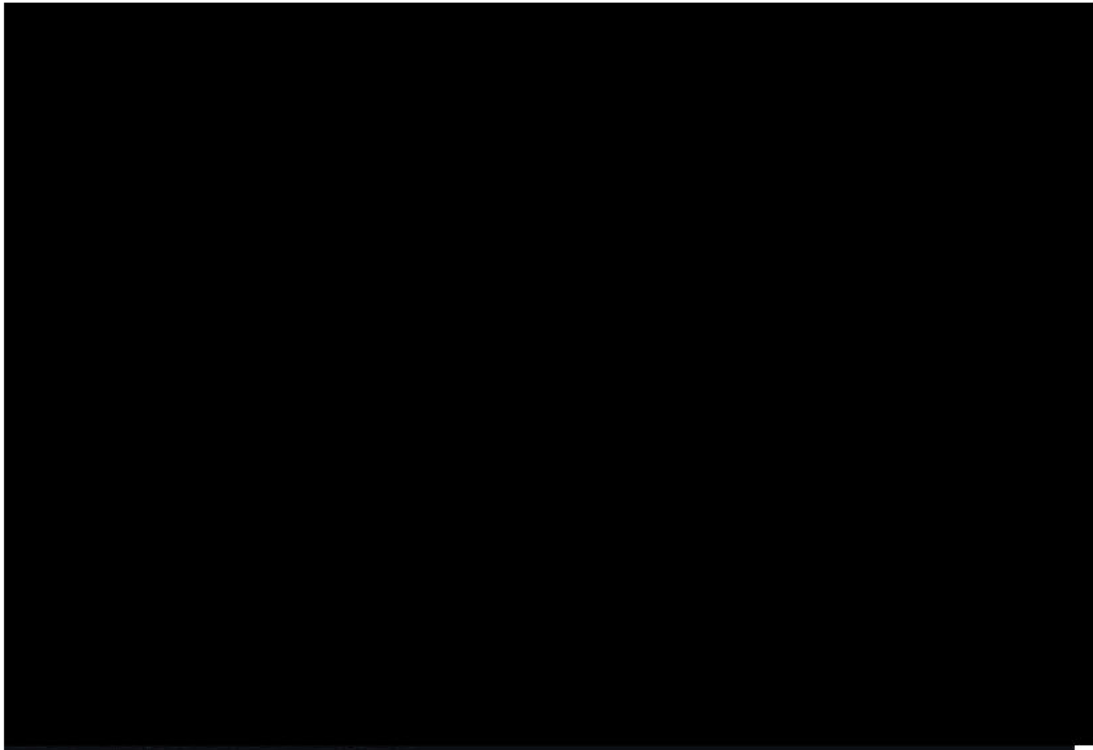


Figure 29. South section with Coming Street to the left. Slice 28.

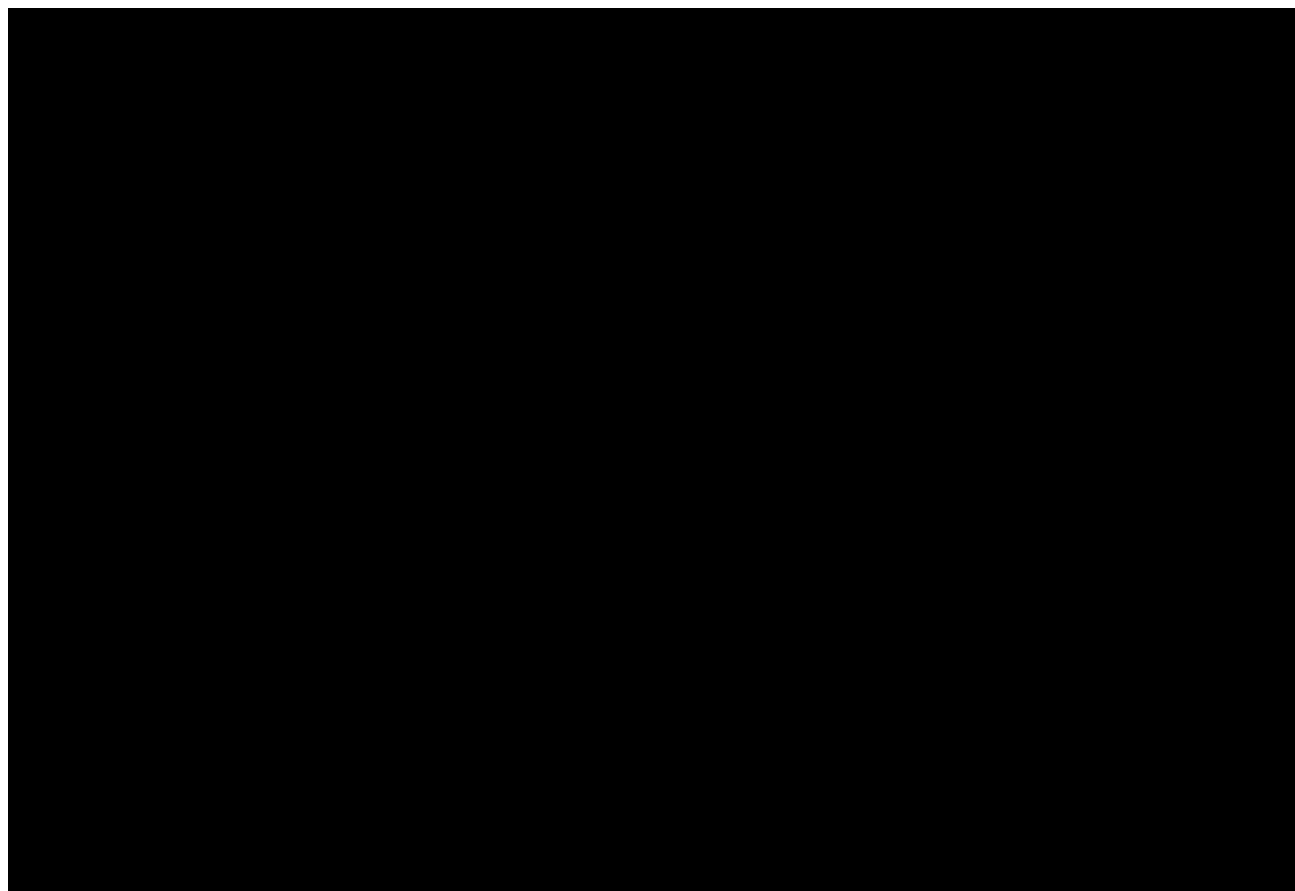


Figure 30. Same image as previous with center on 10.58 ns (~0.45 m). Slice 15, higher in the section (10.6 ns; ~0.45 m).

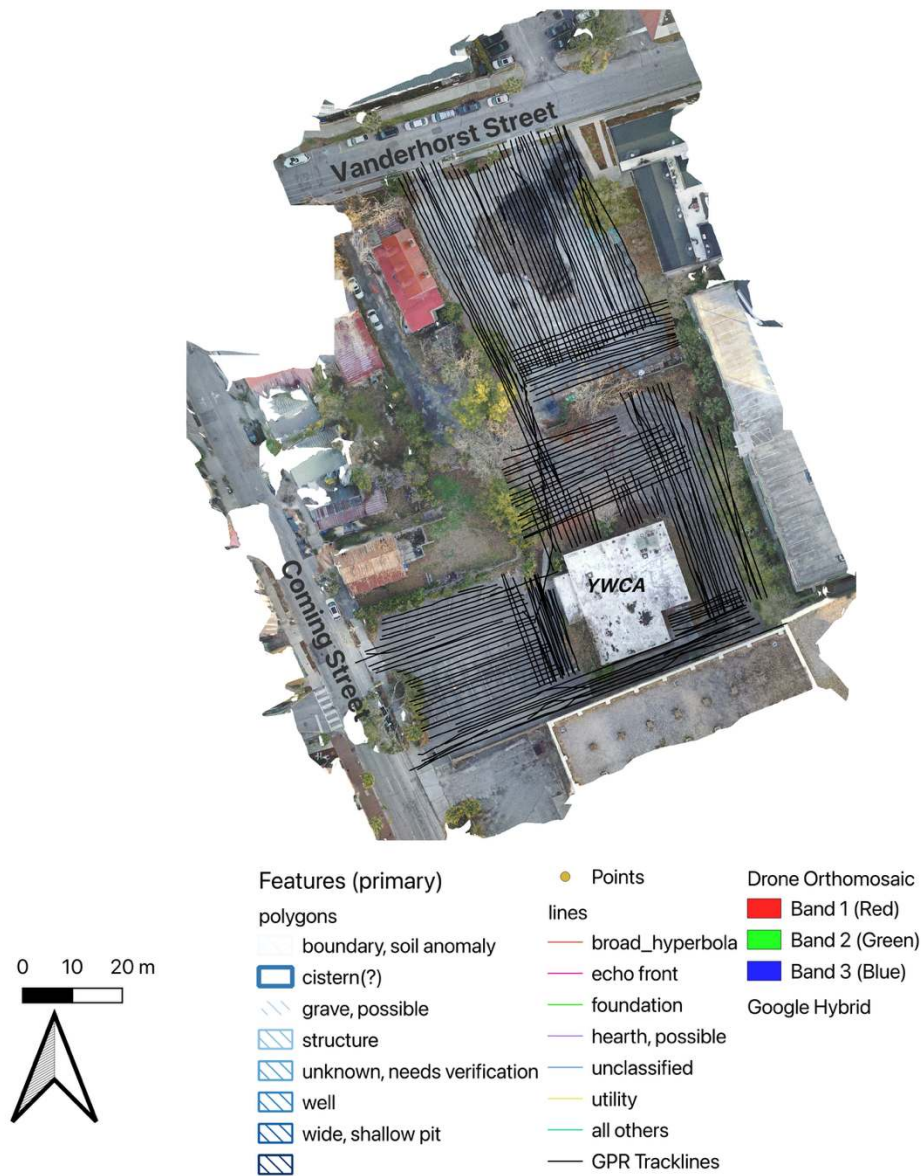


Figure 31. GPR trackline locations over the orthomosaic.

Velocity Calculation

The velocity for the dataset was estimated to be 0.0806 m/ns (meters per nanosecond; 8.06cm/ns) based on matching a hyperbolic reflection from a utility line (Figure 8).

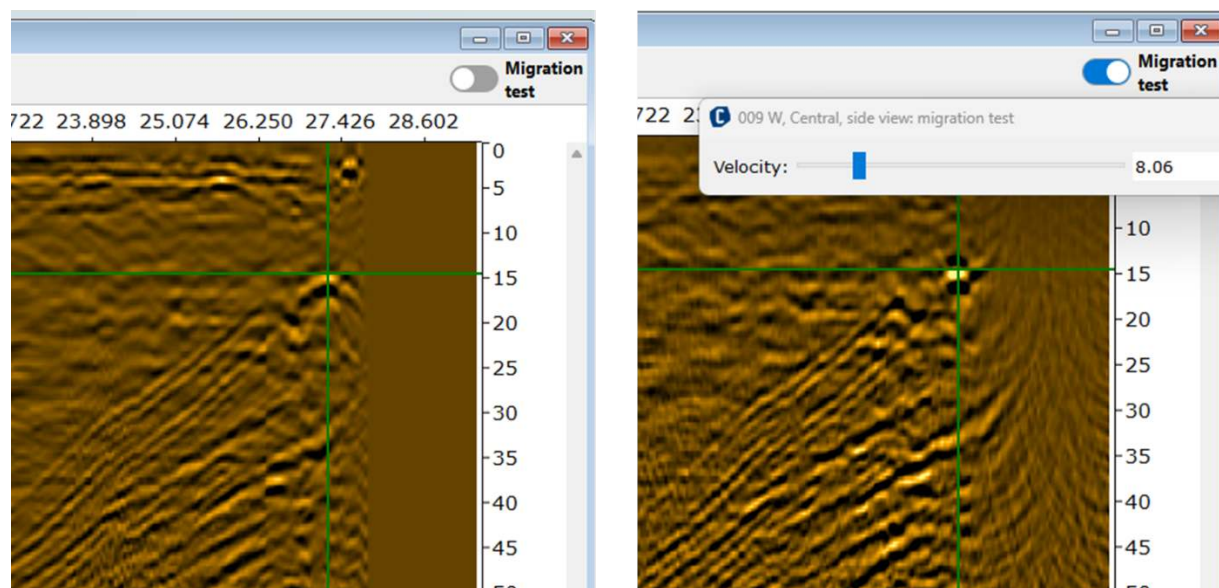


Figure 32. In the left image, a hyperbola is seen at the intersection of the green lines where an underground utility is located. When the correct velocity is applied during migration, the hyperbola collapses to a point feature (as seen in the right image). This hyperbola yielded a velocity of 8.06 cm/ns, while the others yielded higher values due to the site's geology. A velocity of 8.60 cm/ns was used throughout this report.

7.11.Feature Identification

Features were identified with multiple passes through the dataset due to the varied subsurface responses to different features. In some cases, features were identified based on the presence of hyperbolic reflectors, while others were viewed in migrated data to assess the overall shape (such as a cistern or basement).

Because excavations have not been conducted, some features are generally identified, but many remain unknown. All identification is speculative until excavated.

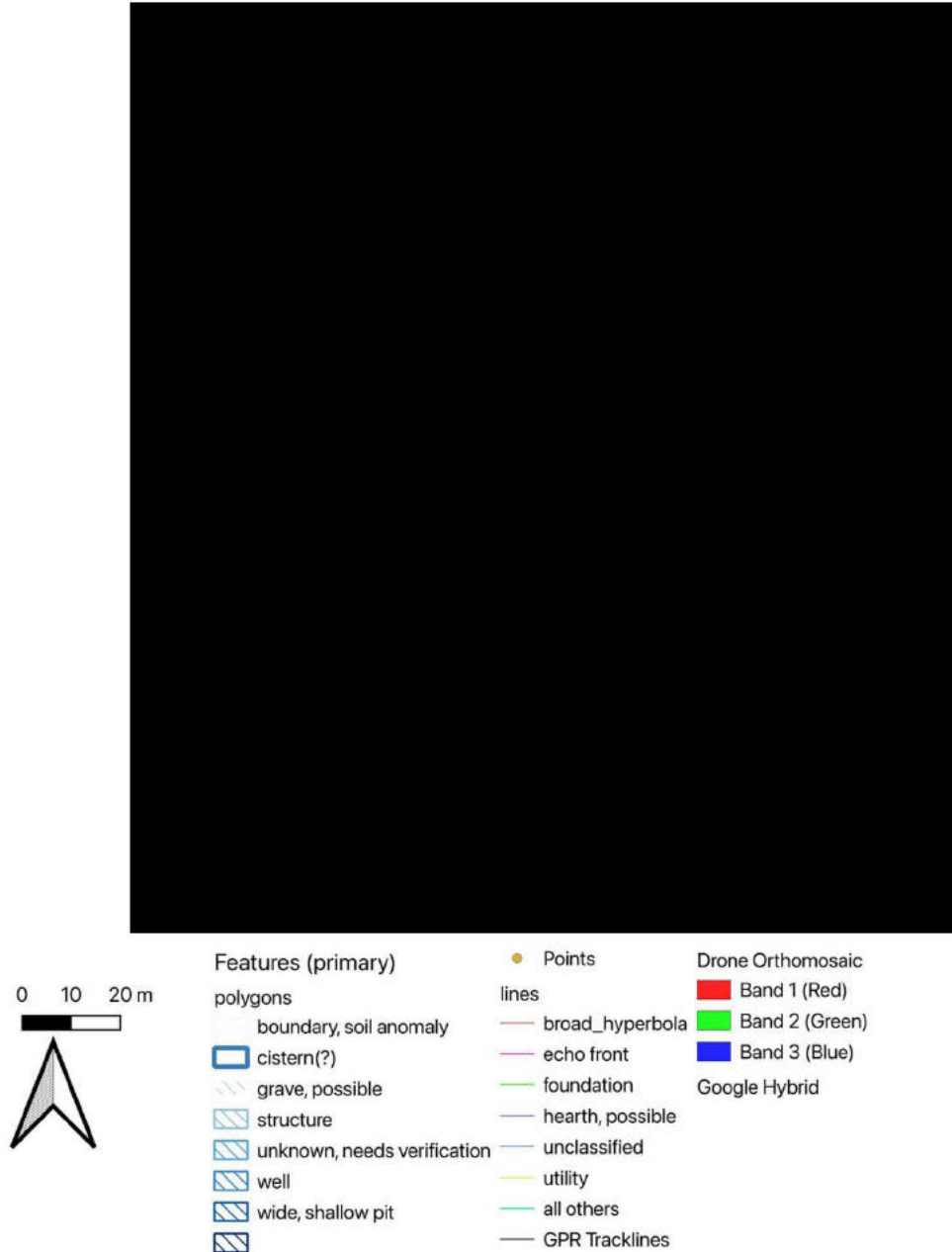


Figure 33. Location of various GPR anomalies (features) found in the GPR. Not all features have been itemized.

Utilities

Utilities are present primarily adjacent to roads and penetrating the site from Coming Street towards the building, angling to the corner and paralleling the NW side of the building.

Structures

Multiple foundations and structures are present in the near subsurface, from ground level down to more than 2.0m depth (Figure XX – isolate the structures and show those)

Backfill and excavations

Several areas appear to be broad, shallowly disturbed regions. These are interpreted as areas that have been leveled with backfill and appear to be related to the leveling of the project area in previous decades or centuries.

Potential grave areas

High-contrast in mid- to low-response (low decibel) revealed ~24 features that have an orientation mainly E-W, [REDACTED]. In profile (Figure XX), there are clear hyperbolae, and continuity across the 8-cm spaced lines shows continuity. This also occurs across swaths, validating continuity over multiple GPR passes. However, identification of these features does not mean that graves are present, or that other graves are present but not identified.

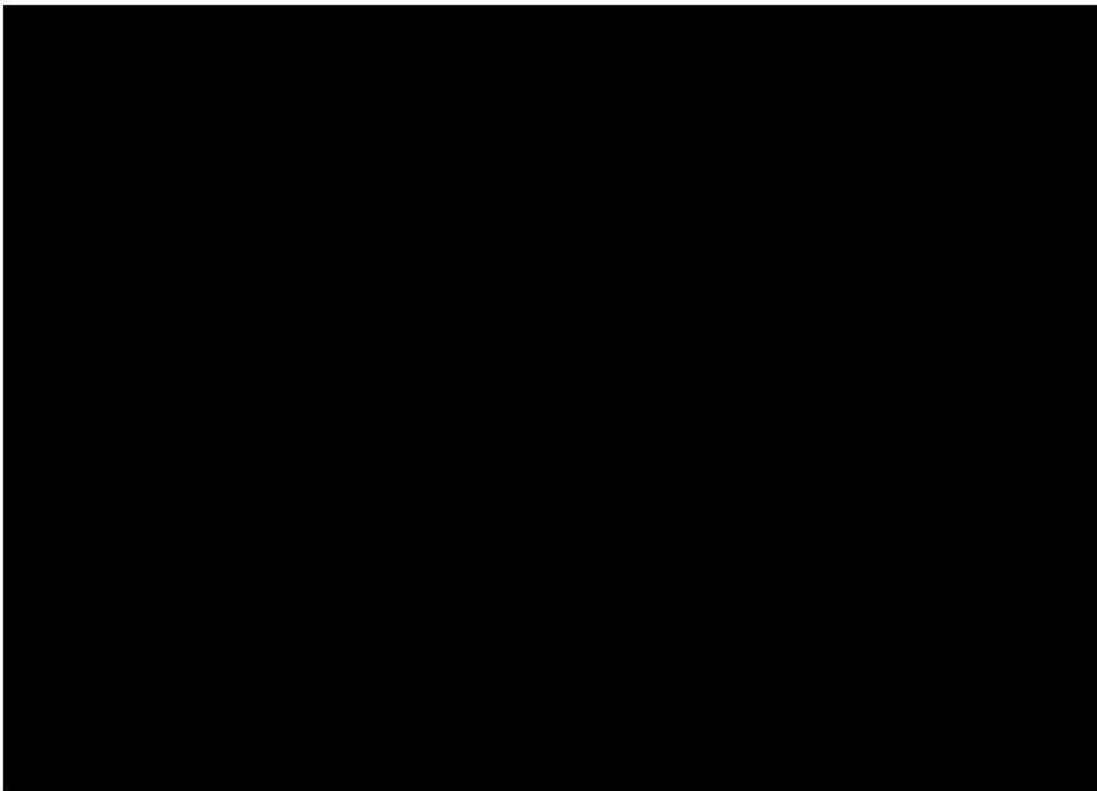


Figure 34. Profile across a presumed cistern (yellow box with green sides) and base of several presumed grave shafts (blue line and dot, to right). Five-meter scale at bottom. Depth based on velocity of 8.06 cm/ns.

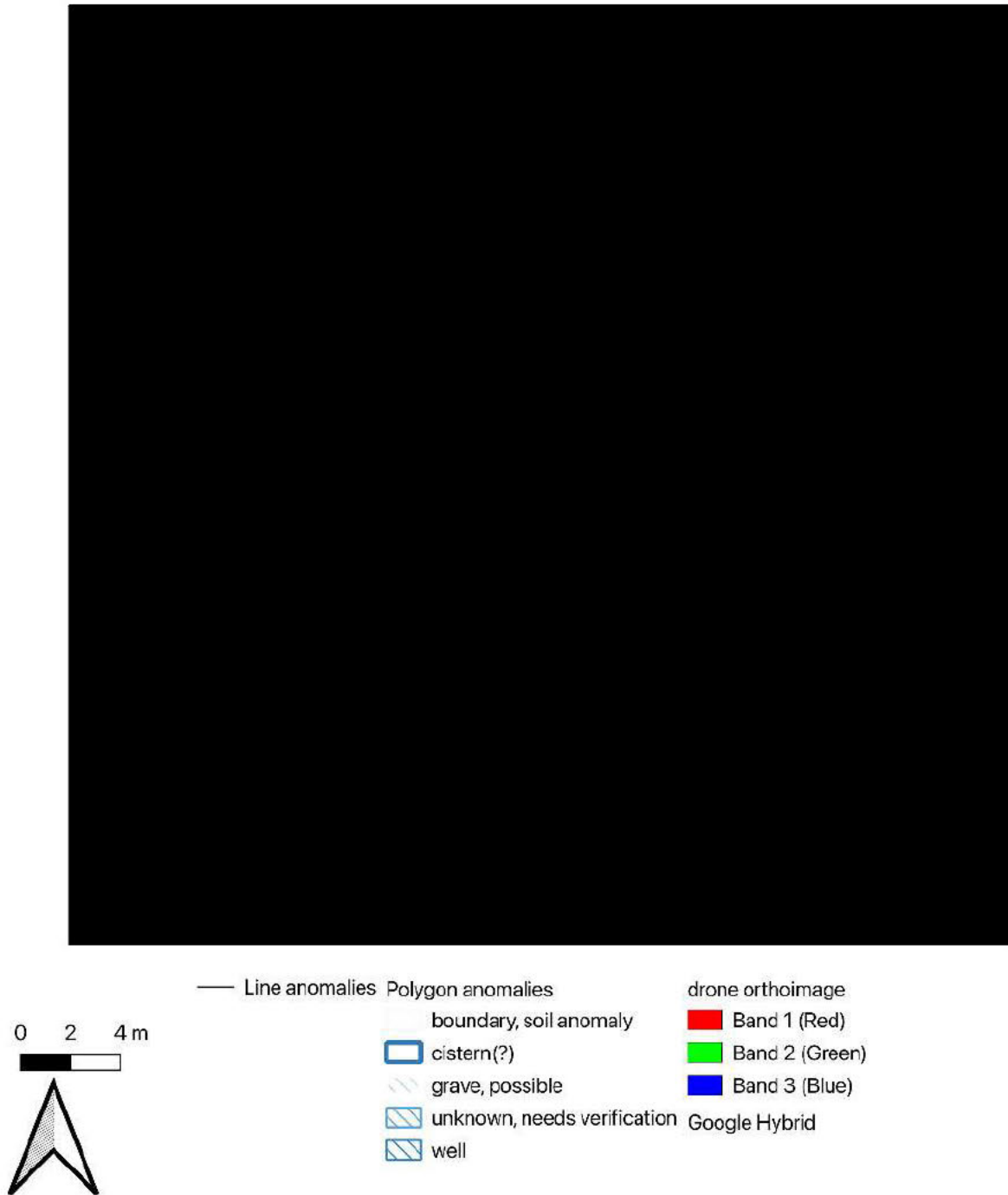


Figure 35. Zoom to area identified as containing areas of potential graves in white. Other features include cisterns and wells, and an area of abundant subsurface disturbance to the northeast.

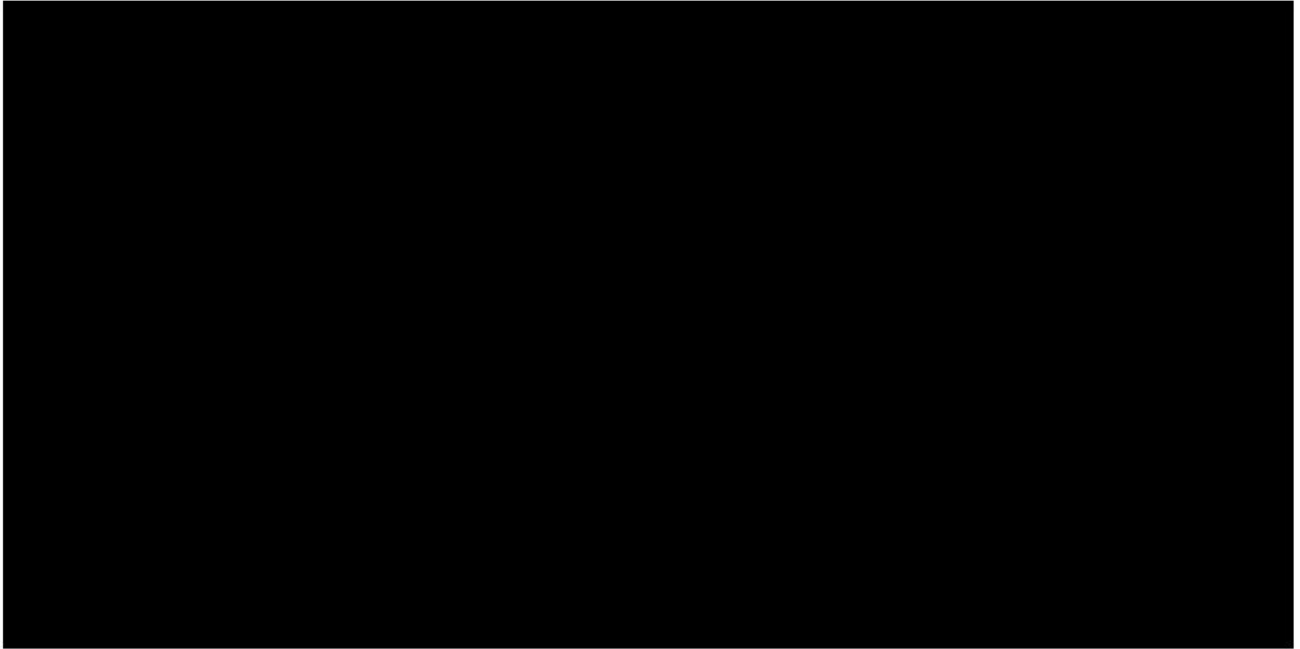


Figure 36. GPR slice centered on 10.58 ns (window of 10.23-10.93 ns TWTT, or approximately 44.0-47.0 cm). Dark areas are high subsurface reflectivity.

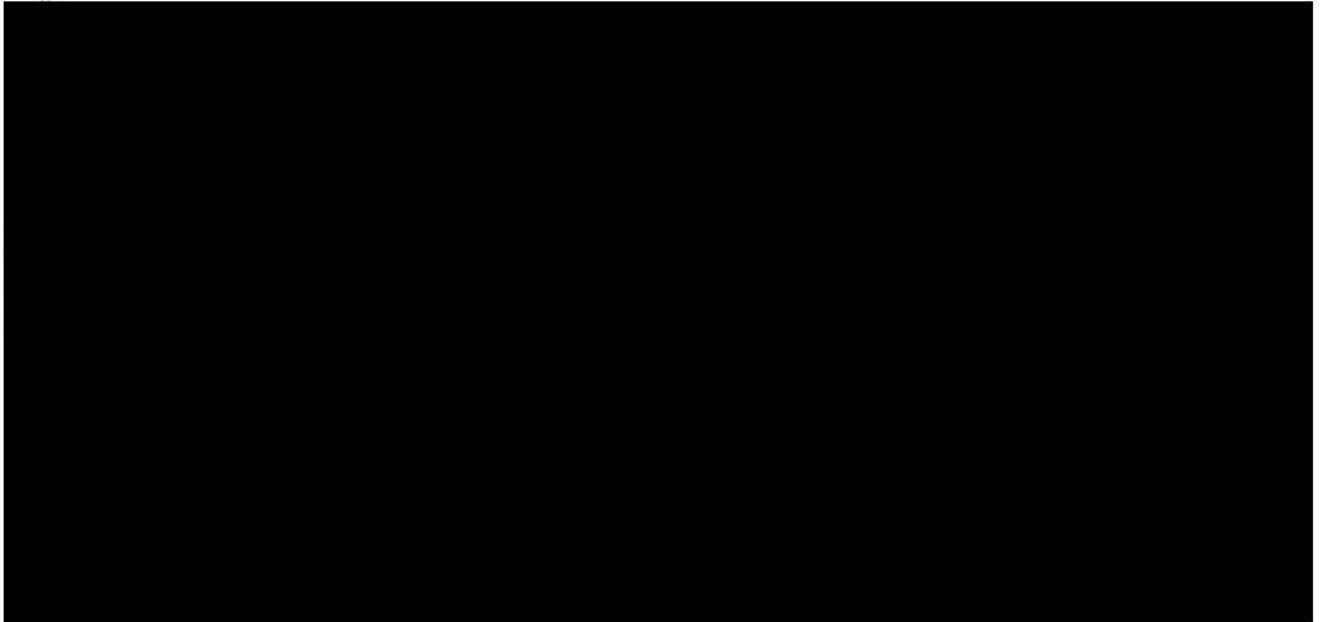


Figure 37. GPR slice centered on 10.58 ns with tracklines (roughly parallel lines NNW to SSE), outlined cisterns, well (dark blue), and potential grave sites (light blue).

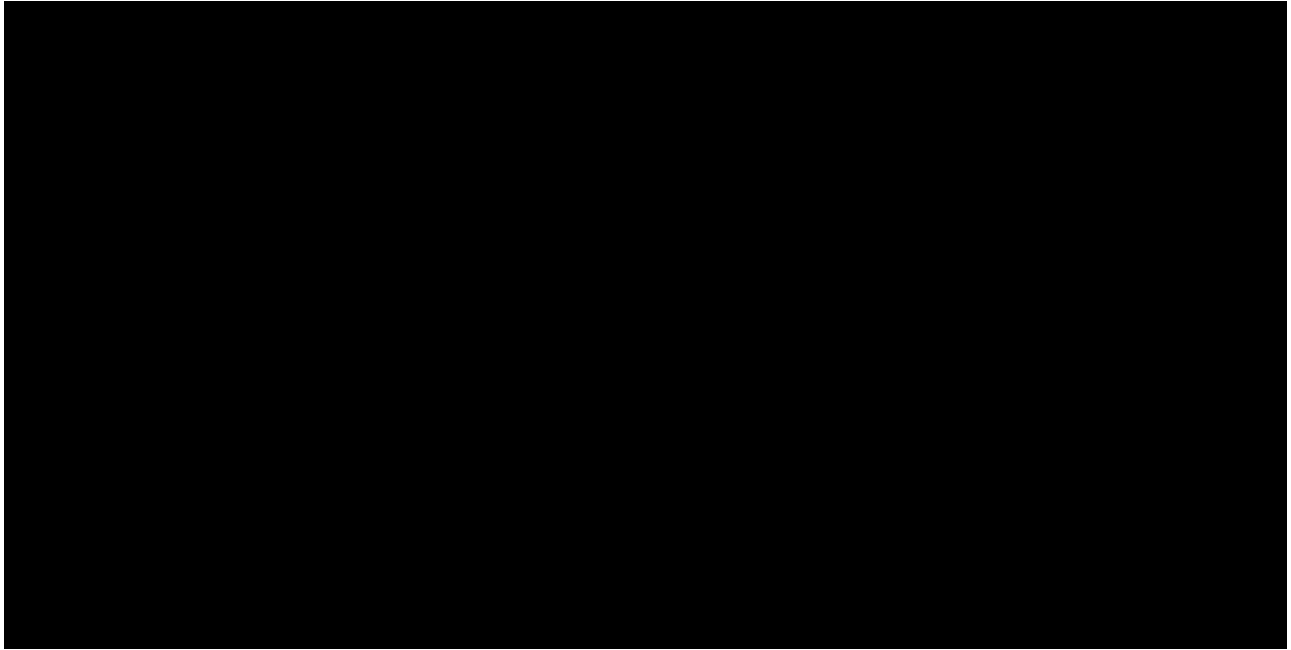


Figure 38. Same as previous image without tracklines and only features.

8. Interpretation

8.1. Anomaly Interpretation

Given the well-documented history of the site, interpretation is based on anomalies, GPR returns, feature orientation, feature locations in modern and historical contexts, and continuity of features across multiple GPR profiles and swaths.

The long linear features adjacent to roadways and penetrating the site towards the former YWCA and light pole are clearly utilities. Some have clearly defined trench boundaries, but those appear to be the more modern or larger-diameter pipes or electrical lines adjacent to Coming Street or Vanderhorst Street.

Rectangular, aligned, large structures are interpreted as the location of former homes, including brick foundations, chimney supports (hearth areas), and cisterns (or possible basement areas). Circular, deeply penetrating features of <2-m diameter (generally ~1.2 m) are interpreted as wells.



8.2. Integration of Surface and Subsurface Evidence

In general, the area has been a cleared parking lot the last 50 of its roughly 230-year history, and no surficial expression of subsurface features is clear in most areas. It is interesting that one circular structure to the west side of the property has a surface expression of degraded asphalt in the same circular pattern (structural failure of asphalt over compressible soils).

8.3. Limitations and Sources of Uncertainty

The highly variable soil conditions across the site create several lines of uncertainty in depth due to velocity interpretations. While internally consistent, the drone imagery was shifted to align with the GPR's higher-precision position by using the best April tag in the set. Areas closest to buildings, behind the former YWCA at the AT&T and Bell buildings, experienced GPS coverage failures, and positions are estimated, most likely within better than 10 cm.

The higher-frequency GPR (450 MHz) provided much greater detail than is generally available from lower-frequency systems but also uncovered many more anomalies that are often missed by them. This increase in profile density also created much more data than the typical system (3546 profiles in total), allowing for better slice observation and much denser profile-to-profile analysis. Thus, time slices were the primary observation method for identifying coherent anomalies across the site. The new software provided by Earth Access, LLC, enabled much easier visualization and contrast adjustment during digitization, which is not fully captured in this document.

9. Drone Survey, Quality Report Rectified to April Tag 2

See Appendix A-2.

```
gdalwarp -s_srs "+proj=ortho +lat_0=32.78605 +lon_0=-79.93944 +x_0=0  
+y_0=0 +datum=WGS84 +units=m +no_defs" -t_srs EPSG:32617 -r bilinear -  
progress -co COMPRESS=LZW -co PREDICTOR=2 -co TILED=YES -co  
BIGTIFF=IF_NEEDED "/Users/coastalplain/Library/CloudStorage/OneDrive-  
CollegeofCharleston/Projects/2026_ComingStCommons/DroneData/CSC_20260214/P  
roductions/Production_1 (2)/Production_1_ortho_merge.tif"  
"/Users/coastalplain/Library/CloudStorage/OneDrive-  
CollegeofCharleston/Projects/2026_ComingStCommons/DroneData/CSC_20260214/P  
roductions/Production_1 (2)/Production_1_ortho_merge_UTM.tif"
```

10. GPR Acquisition and Processing Parameters

10.1. Processing and Metadata Reference

Coming Street Commons GPR Survey — Condor Export_002

Full metadata inventory: raw ImpulseRadar Raptor / Condor files → processed profile NetCDF cubes → survey-wide slice atlas.

Instrument: **ImpulseRadar Raptor**, 18-channel array, 450 MHz. Processing package: gpr_tools v0.6.0. CRS: **UTM Zone 17N / WGS 84 (EPSG:32617)**. Survey acquired 2026-02-13 and 2026-02-14.

Values are read directly from the files. Acquisition parameters and the processing chain are constant across all 197 profiles; per-profile array sizes (sample and trace counts) vary with line length. Concrete values are from the representative profile `cofc_csc_S001_001` unless noted.

Table 8. Provenance is distributed across four record types; in decreasing order of how much processing history each contains the following records.

Record	Location	What it documents
processing_history attribute	each processed02/*.nc	Ground truth — every filter applied, in order, with resolved parameters + timestamps
processing_recipe.yaml attribute	each processed02/*.nc	Intended recipe spec (all steps incl. disabled)
slice_atlas_metadata.yaml	processed02_slices/	Slice/atlas generation parameters + source list + hashes
Raw .iph header	each raw profile	Acquisition parameters only — records no filtering

10.2. Stage 0 — Raw Condor export files (per profile)

Each profile is a set of companion files sharing a basename, e.g. `cofc_csc_S001_001.*`. Naming: `cofc_csc_S###_###` where `S###` is the survey line ID and `###` the sequential export index. 197 profiles total used for the survey.

10.3. .iph — acquisition header (plain text, KEY:value)

Table 9. Full contents of `cofc_csc_S001_001.iph` (header file). Derived: sample interval 0.1953125 ns; raw time window $512 \times 0.1953125 = 100.0$ ns; antenna center frequency 450 MHz (not stored in the Condor header — supplied by the reader as the Raptor standard).

Field	Value (S001_001)	Meaning / mapping
HEADER VERSION	1	Condor header schema version
DATA VERSION	16	Condor data schema version
DATE	2026-02-13	Acquisition date
TIME	14:31:48	Acquisition start time (local)
SAMPLES	512	Samples per trace → <code>n_samples</code>
FREQUENCY	5120.000000	Sampling frequency (MHz) → <code>sample_interval_ns</code> = $1000/5120 = 0.1953125$ ns
TRIG SOURCE	wheel	Wheel-encoder trigger (uniform trace spacing)
TIME INTERVAL	0.050000	Seconds between triggers (time mode)
DISTANCE INTERVAL	0.038637	Metres between traces → <code>trace_interval_m</code>
ANTENNA SEPARATION	0.250	Tx–Rx separation, m
NUMBER_OF_CH	18	Channel count → <code>n_channels</code>
CH_X_OFFSETS	–0.714 ... +0.714 (18 vals)	Per-channel cross-track offset from array centre, m (0.084 m spacing)
CH_Y_OFFSETS	0.000 × 18	Per-channel along-track offset, m
POSITION POLE HEIGHT	0.000	GNSS pole height, m

10.4. .ipr — raw trace binary

Table 10. Raw trace binary in the raw data file (.ipr).

Property	Value
Data type	16-bit signed integer, little-endian (<i2)
File header	None — trace data starts at byte 0
Layout	Channels interleaved within each position: (<code>n_positions</code> , <code>n_channels</code> =18, <code>n_samples</code> =512)
Size identity	<code>filesize</code> = <code>n_positions</code> × 18 × 512 × 2 bytes (exact)
Amplitude units	raw counts

10.5. .pos / .time / .status / folder-level files

.pos — positioning. Header UNITS:m, then rows trace_no easting northing elevation in UTM metres. Sparse (GPS fixes less frequent than triggers), 1-indexed, interpolated to every trace. First row (S001_001): 1 599282.363733 3628023.668277 3.669.

.time — trigger timestamps. Rows trace_no date time with millisecond precision (e.g. 1 2026-02-13 19:31:45:000). One row per trace.

.status — instrument status log. Two columns trace_index status_code (sparse; code 4 throughout S001_001).

Table 11. Files maintained for this survey.

Folder-level file	Contents
utmzone.info	VERSION:1 / UTMZONE:17N → EPSG:32617 (17N → 32600+17)
Condor Export_002_features.geojson	Digitized interpretation features (GeoJSON)
vocabulary.yaml, view_settings.json, velocity_picks.json, enhancement_presets.json, ObjectFeatureDefinitions.cnf	App / interpretation state (not part of the raw→processed data path)

11. Stage 1 — Processed profile cubes (processed02/*_processed.nc)

One NetCDF-4 file per profile, named {raw_stem}_processed.nc (e.g. c0fc_csc_S001_001_processed.nc). CF-1.11 conventions. 197 files, ~0.4–60 MB each depending on the length and subsequent number of traces.

11.1.Dimensions (S001_001)

Table 12. The atlas dimensions for the profile cubes.

Dimension	Size	Notes
channel	18	All array channels retained (3-D cube)
sample	434	After time-zero cropping + trim to per-channel minimum (raw was 512)
trace	494	Along-track positions for this line

sample and trace sizes vary per profile; channel is always 18.

11.2.Data variable

Table 13. The only data variable is amplitude of type float32.

Variable	Dims	Type	Attributes
amplitude	(channel, sample, trace)	float32	long_name = "GPR amplitude"; units = "counts"

11.3.Coordinates (15)

Table 14. Variables associated with the coordinates for each trace.

Coordinate	Dims	Units	Description
time_ns	(sample)	ns	Two-way travel time
trace_index	(trace)	—	Trace index
channel	(channel)	—	Channel index (0–17)
channel_label	(channel)	—	A01 ... A18
ch_x_offset_m	(channel)	m	Cross-track offset from array centre
easting_ch	(channel, trace)	m	Per-channel UTM easting
northing_ch	(channel, trace)	m	Per-channel UTM northing
lat_ch	(channel, trace)	°N	Per-channel latitude
lon_ch	(channel, trace)	°E	Per-channel longitude

Coordinate	Dims	Units	Description
easting	(trace)	m	Array-centre UTM easting
northing	(trace)	m	Array-centre UTM northing
lat	(trace)	°N	Array-centre latitude
lon	(trace)	°E	Array-centre longitude
elevation	(trace)	m	Ground elevation
distance_m	(trace)	m	Cumulative distance along track

An optional time_zero_ns (trace) coordinate — physical TWT at corrected sample 0 — is written when time-zero correction records it; not present on this file.

11.4.Global attributes (20)

Table 15. Global attributes for the individual radargram/profile.

Attribute	Value (S001_001)	Notes
Conventions	CF-1.11	
gpr_tools_version	0.6.0	Package version that wrote the file
vendor	ImpulseRadar	
instrument	Raptor (Condor export)	
antenna_freq_mhz	450.0	Antenna centre frequency
centre_frequency_MHz	450.0	CF-style duplicate
sample_interval_ns	0.1953125	dt
n_samples	512	Original acquisition count (array sample dim is 434 after crop)
n_traces	494	Matches trace dim
n_channels	18	Real channel count
channels	1	From recipe 'channels' field (recipe metadata, not physical count)
data_units	amplitude_counts	
source_path	.../Condor Export_002/cofc csc_S001_001.ipr	Raw file this derives from
source_format	condor_ipr	
read_at_utc	2026-05-23T19:17:58Z	When raw data was read
velocity_m_per_ns	0.1	Velocity stamped by recipe (atlas used 0.086 — see caveats)
survey_date	(empty)	From recipe survey_day (unset)

Attribute	Value (S001_001)	Notes
epsg	32617	CRS
processing_recipe_yaml	(full YAML — below)	Intended recipe spec
processing_history	(JSON list — below)	Operations applied

11.5. Embedded recipe (processing_recipe_yaml, verbatim)

The recipe for the batch data processing applied to each profile.

```
recipe:
  name: blank_starting_point
  survey_day: ''
  instrument: ''
  channels: 1
  velocity_m_per_ns: 0.1
  notes: Steps were enabled and applied as the processing history or chain in next table.

steps:
- name: first_break
  params: {method: aic, refine: zero_crossing, consolidate: median,
           smoothing_window: 5, window_samples: 20, threshold: 0.05,
           search_window_ns: [0, 25.0]}
- name: dc_shift
  params: {pre_t0_samples: 50}
- name: time_zero
  params: {mode: per_trace, smoothing: median_5}
- name: dewow
  params: {type: runmed, window_samples: 40}
- name: normalize_direct_wave
  params: {method: peak, window_ns: [0, 10.0]}
- name: bandpass
  params: {low_hz: 112500000.0, high_hz: 1125000000.0, order: 4, zero_phase: true}
- name: gain
  params: {type: tpow, alpha: 2.5}
- name: background_remove
  params: {method: median, window_traces: 75}
- name: envelope
  params: {method: hilbert}
```

```

enabled: false

output:

  format: netcdf

  subfolder: processed

  filename_pattern: '{stem}_processed.nc'

  embed_recipe: true

  embed_history: true

```

The recipe's notes: All steps disabled is stale — the steps were enabled and applied, as processing_history (below) confirms. Trust processing_history.

11.6. Applied processing chain (processing_history, in order)

Each entry stores {operation, params, timestamp_utc, gpr_tools_version}. Operations as recorded:

Table 16. Applied processing chain applied to each profile.

#	Operation	Parameters	From recipe step	Physical effect
1	remove_dc	pre_t0_samples: 50	dc_shift	Subtract DC bias from 50 pre-t0 samples
2	correct_time_zero	mode: per_trace, smoothing: median_5, median_shift: 40, max_shift: 40	time_zero	Align first break to t=0, per trace
3	dewow	type: runmed, window_samples: 41	dewow	Running-median low-freq removal (window forced odd 40→41)
4	normalize_direct_wave	method: peak, window_ns: [0, 10.0]	normalize_direct_wave	Normalize each trace to direct-wave peak (0–10 ns)
5	bandpass	low: 112.5 MHz, high: 1125 MHz, order: 4, zero_phase: true	bandpass	Zero-phase Butterworth band-pass
6	power_t_gain	n: 2.5	gain (tpow $\alpha=2.5$)	Time-power gain $t^{2.5}$ (depth compensation)
7	remove_background	mode: moving, method: median, window: 75	background_remove	Moving-median (75 traces) background removal

Two recipe steps are intentionally not in the history: first_break (computes the t0 picks consumed by time_zero; mutates no data) and envelope (enabled: false). Pipeline mode: **classic** (full gain $t^{2.5}$ baked in). Recipe-step → recorded-operation renaming: dc_shift→remove_dc, time_zero→correct_time_zero, gain→power_t_gain, background_remove→remove_background.

12. Stage 2 — Slice atlas cubes (processed02_slices/slices_*.nc)

Six survey-wide gridded depth-slice cubes (one per aggregation × interpolation), plus a shared YAML sidecar and a per-profile provenance JSON. Built 2026-05-24 from all 197 processed profiles by build_atlas (Stolt migration → per-slice aggregation → gridded interpolation).

Files (each ~0.95–1.02 GB, zlib-4 compressed): slices_rms_nn.nc, slices_rms_idw.nc, slices_rms_linear.nc, slices_envelope_nn.nc, slices_envelope_idw.nc, slices_envelope_linear.nc — total **4,480,518,506 bytes**.

12.1. Dimensions (all six cubes)

Table 17. Established dimensions of the created cubes used to create the slices.

Dimension	Size	Notes
depth	125	Number of time/depth slices
y	2610	Northing grid rows (2610 × 0.05 m ≈ 130.5 m)
x	1746	Easting grid columns (1746 × 0.05 m ≈ 87.3 m)

12.2. Data variables

Table 18. The atlas cubes were processed into full scale, 1/2 scale, and 1/4 scale for visualization at different zoom rates. The pyramid structure allowed for easier viewing during processing.

Variable	Dims	Type	Notes
slice_amplitude	(depth, y, x)	float32, zlib-4	Gridded slice amplitude
slice_amplitude_ov2	(depth, 1305, 873)	float32, zlib-4	½-resolution overview (pyramid)
slice_amplitude_ov4	(depth, 653, 437)	float32, zlib-4	¼-resolution overview (pyramid)

12.3. Coordinates

Table 19. Coordinate variables applied to each slice atlas cube.

Coordinate	Dims	Units	Description
slice_center_ns	(depth)	ns	Slice window centre (TWT)
slice_top_ns	(depth)	ns	Window top (TWT)
slice_bottom_ns	(depth)	ns	Window bottom (TWT)
slice_center_m	(depth)	m	Centre depth = center_ns × v/2

Coordinate	Dims	Units	Description
slice_top_m	(depth)	m	Top depth
slice_bottom_m	(depth)	m	Bottom depth
easting	(x)	m	UTM easting of grid columns
northing	(y)	m	UTM northing of grid rows

12.4. Global attributes (per cube)

Table 20. The global variables for each slice atlas cube.

Attribute	Value	Notes
aggregation_method	rms or envelope	Per file
interpolation_method	nn, idw, or linear	Per file
velocity_m_per_ns	0.086	Migration / depth-conversion velocity
thickness_ns	0.6977	Slice window width
step_ns	0.6395	Spacing between slice centres
range_start_ns	0.0	Earliest slice TWT
range_stop_ns	80.0	Latest slice TWT
max_distance_m	0.5	Max interpolation search distance
grid_resolution_m	0.05	Grid pixel size
n_source_profiles	197	Input profiles
gpr_tools_version	0.6.0	
created_utc	2026-05-24T05:39:42Z	Build timestamp

Depth coverage: 0–80 ns at $v = 0.086 \text{ m/ns}$ → one-way depth **0 to $\approx 3.44 \text{ m}$** , across 125 slices $\approx 27.5 \text{ mm}$ increments.

12.5. Companion sidecar — slice_atlas_metadata.yaml

Written alongside the cubes (schema slice_atlas_version: 2, status: complete). Full contents:

```

slice_atlas_version: 2
status: complete
epsg: 32617
gpr_tools_version: 0.6.0
created_utc: '2026-05-24T05:39:42.078340+00:00'
generation_parameters:
  velocity_m_per_ns: 0.086
  thickness_ns: 0.6977

```

```

step_ns: 0.6395
range_start_ns: 0.0
range_stop_ns: 80.0
max_distance_m: 0.5
grid_resolution_m: 0.05
n_slices: 125
n_source_profiles: 197
source_profiles: [cofc csc_S001_001_processed.nc, ... 197 entries ...]
methods_generated:
- {aggregation: envelope, interpolation: idw}
- {aggregation: envelope, interpolation: linear}
- {aggregation: envelope, interpolation: nn}
- {aggregation: rms, interpolation: idw}
- {aggregation: rms, interpolation: linear}
- {aggregation: rms, interpolation: nn}
files_written: [slices_rms_nn.nc, slices_rms_idw.nc, slices_rms_linear.nc,
                slices_envelope_nn.nc, slices_envelope_idw.nc, slices_envelope_linear.nc]
total_disk_bytes: 4480518506
param_hash: 06e8eb0995a197aecf20b7a9e32d363754bf7679cc132edf8c6cb587502bf877
pyramid:
  min_dim: 1024
  base_shape: [2610, 1746]
  levels:
    - {factor: 2, shape: [1305, 873]}
    - {factor: 4, shape: [653, 437]}

```

Interpolation parameters (defaults for this build): IDW $p = 2.0$, $k = 12$; NN and linear have no extra parameters; kriging was not generated. param_hash is the SHA-256 of the canonical generation parameters — identical inputs reproduce it.

This atlas was written by an older code path (slice_atlas_version: 2), so it does not carry the per-profile source_provenance or enhancement_preset blocks the current code adds (v4). Each source profile's processing history still lives in its own .nc (Stage 1).

12.6.Deferred display enhancement -- processed02/enhancement_presets.json

A view-time enhancement applied for interpretation/display; **not baked** into the stored slice_amplitude or profile amplitude values:

```
{ "__active__": {"name": "imported from blank_starting_point",  
  "gain": {"type": "tpow", "alpha": 2.0},  
  "envelope": {"enabled": false, "method": "hilbert"},  
  "gpr_tools_version": "0.6.0", "created_utc": "2026-06-16T18:26:45Z",  
  "notes": "Interpretation gain:  $t^{2.0}$  (source  $t^{2.5}$  minus baseline  $t^{0.5}$ ); Envelope: off"}}
```

These variables varied for viewing slice data to better visualize different contrasts within the slice data.