



SHRP2 SOLUTIONS
TOOLS FOR THE ROAD AHEAD

Utility Locating Technologies (R01B) Training and Field Demonstrations

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Federal Highway Administration

American Association of State Highway and Transportation Officials
AASHTO

Discuss Todays Agenda (*changes*)

- **Classroom till Noon**
- **Lunch (*on your own*)**
- **Equipment Demos**
- **Field Data Review**

U.S. Department of Transportation
Federal Highway Administration

American Association of State Highway and Transportation Officials
AASHTO

Introduction: Utility Bundle Overview

SHRP2 – Strategic Highway Research Program

IAP – Implementation Assistance Program

- **Product Overview**
  - *3D Utility Location Data Repository* (R01A)
  - *Identifying and Managing Utility Conflicts* (R15B)
  - *Utility Locating Technologies* (R01B)

Round 6: *Proof of Concept* ($150K each agency)

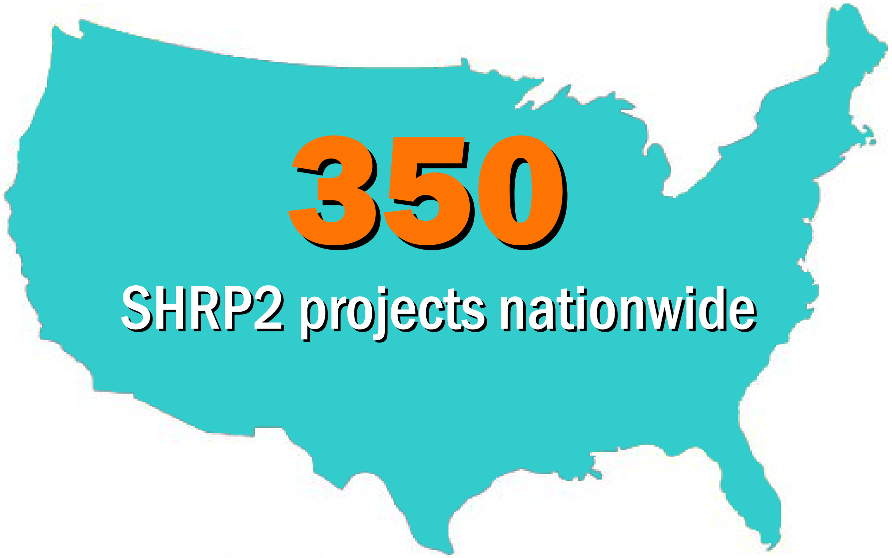
California, Ohio, Arkansas, Oregon, Virginia

Round 7: *Lead Adopter* ($100K each agency)

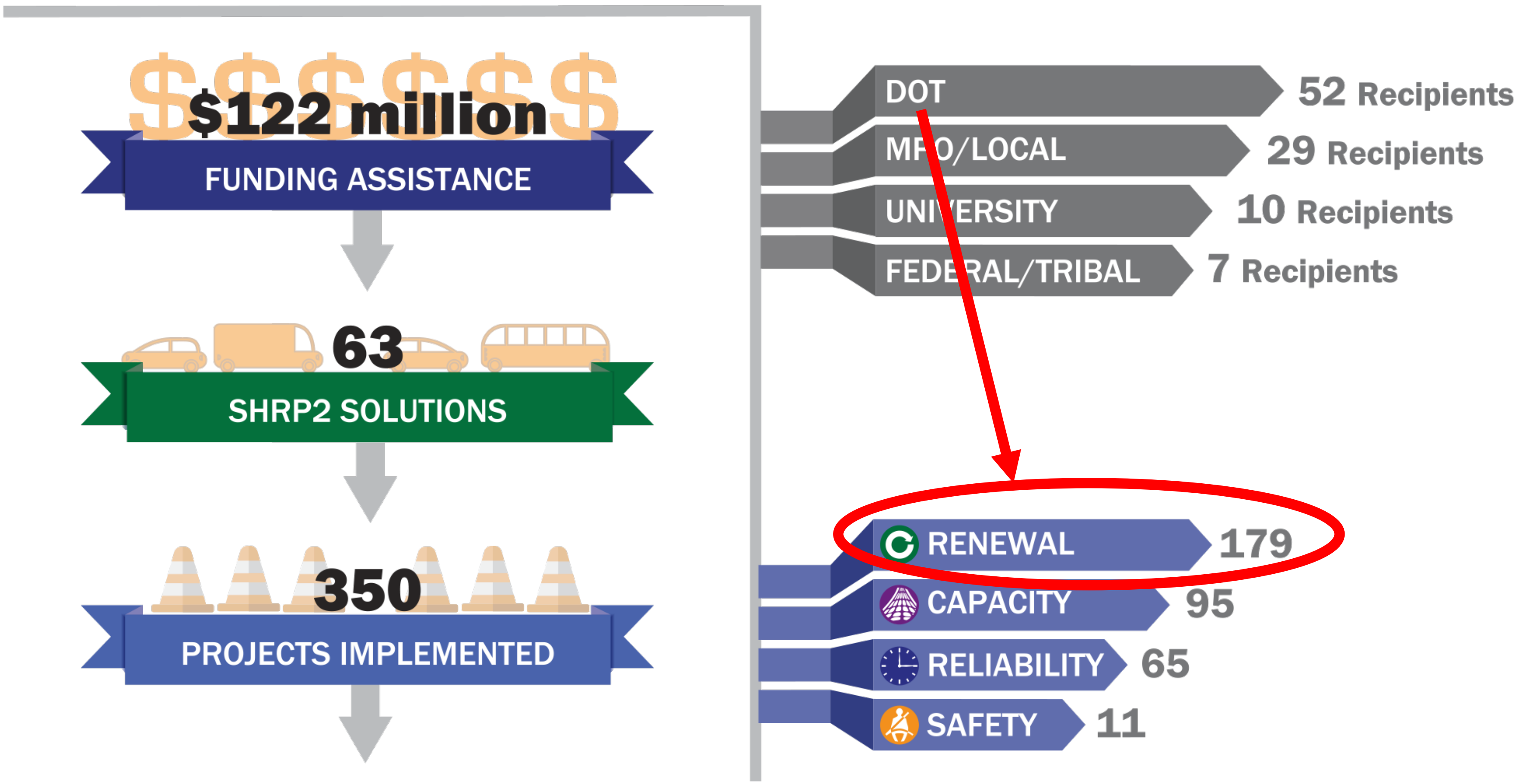
States California, Indiana, Montana

SHRP2 at a Glance

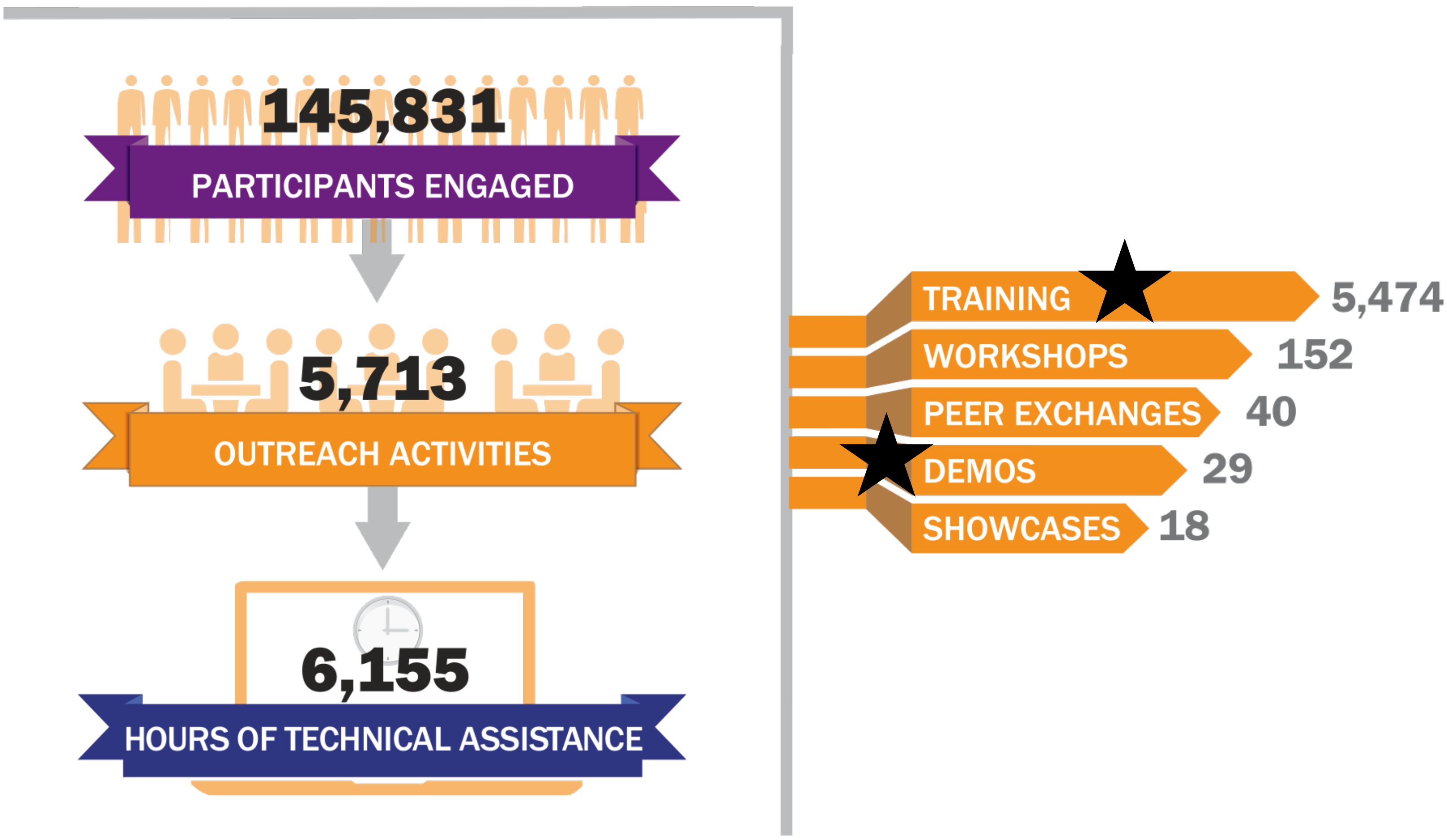
- **SHRP2 Solutions** –63 products
- **Solution Development** – processes, software, testing procedures, and specifications
- **Field Testing** – refined in the field
- **Implementation** – 350 transportation projects; adopt as standard practice
- **SHRP2 Education Connection** – connecting next-generation professionals with next-generation innovations



SHRP2 Implementation: Moving Us Forward



SHRP2 Implementation: Moving Us Forward

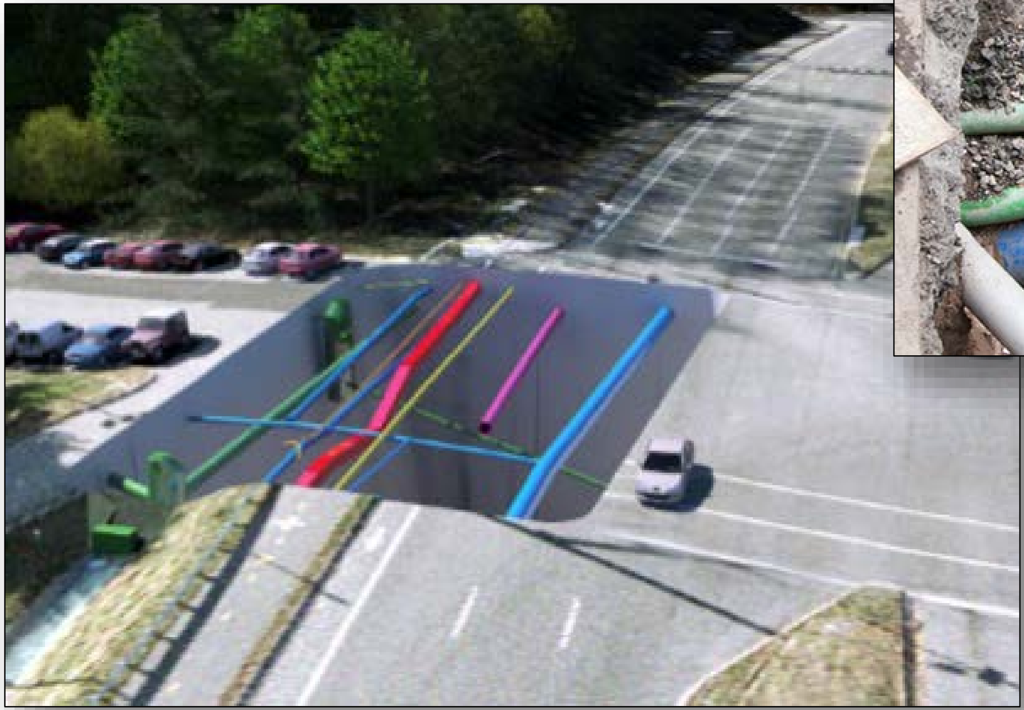


Why Using Advanced 3D Utility Location & Delineation is Important

Utility Bundle (R01A/R01B/R15B)

Challenge: Locating and Managing Utilities

Solution: Three Products



3D Utility Location Data Repository (R01A)

Moving from 2D to 3D utility management.

SME: Cesar Quiroga
Senior Research Engineer
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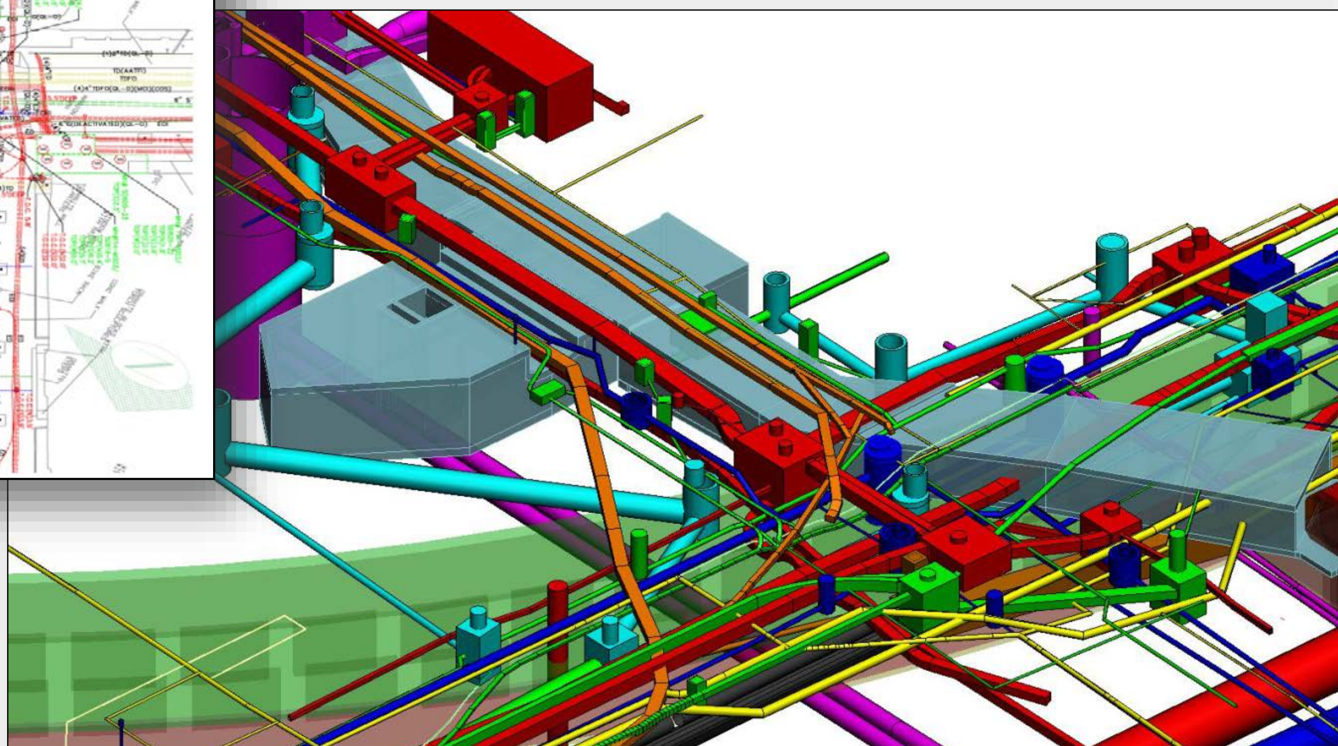
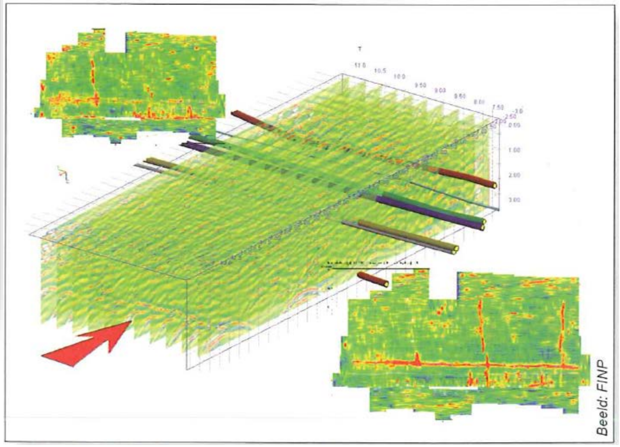
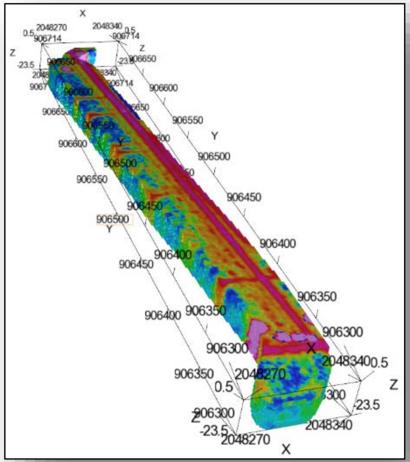
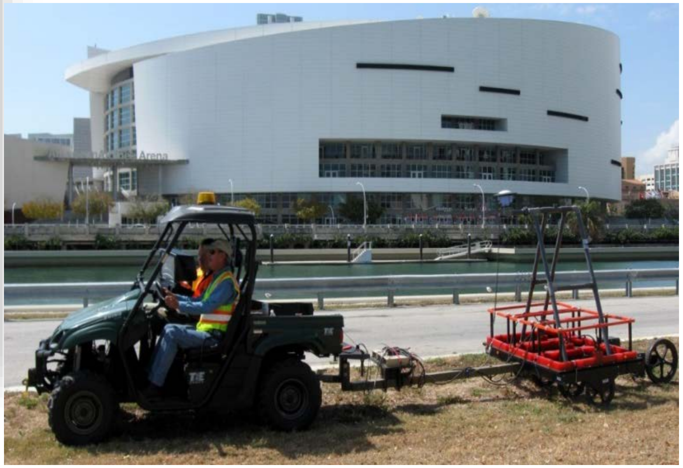


Utility Locating Technologies (R01B) – Today's Effort

MCGPR and TDEMI for 3D Utility Location







Identifying and Managing Utility Conflicts (R15B)

Managing Utility Conflicts Ahead of Construction

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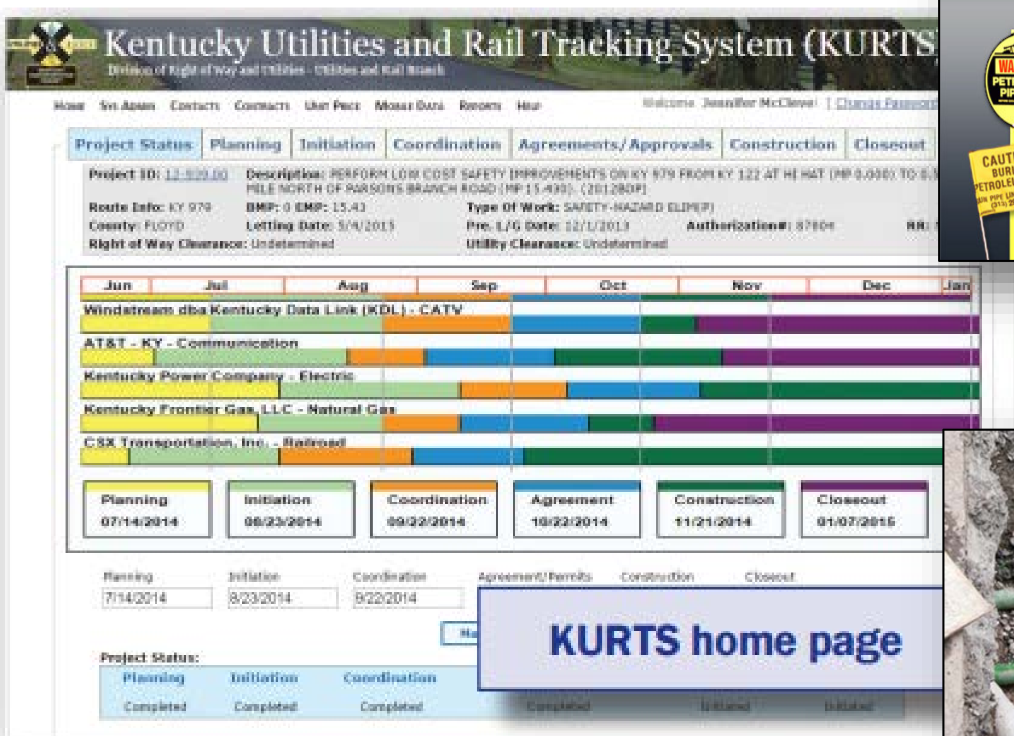


ASCE 38

ASCE Standard

Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data

QL-D

QL-C

QL-B

QL-A

2D Utility Mapping

- Utility location services: X, Y
- Test holes at specified locations: Z (X, Y if surveyed)
- American Society of Civil Engineers ASCE 38-02

  Standard Guideline:
  - Quality Level D: Review of existing records: X, Y
  - Quality Level C: Survey of visible appurtenances: X, Y
  - Quality Level B: Geophysical methods for underground utilities: X, Y
  - Quality Level A: Exposed utilities at specified locations: X, Y, Z
    - » Test holes
    - » Valves
    - » Manholes
    - » Vaults
    - » Building basement walls

Traditional 2D Multi-Sensor/ Technology Toolbox

GPR

RF Locators

Many types of systems:

- ✓ Radio-Frequency (RF)
- ✓ Electromagnetic Induction (EMI)
- ✓ Ground Penetrating Radar (GPR)
- ✓ Magnetometers (Mag)
- ✓ Acoustic sensors
- ✓ Inertial mapping inside pipes
- ✓ Use of sondes inside pipes

RTS & GPS Systems

V
A
C
-
E
X

POS-LOC

SHRP2 Technologies Developed

2 Technologies chosen for SHRP2 IAP to *SUPPLEMENT* the standard tool box for utility locating!

Advanced Geophysical Hardware

- Multi-Channel Ground Penetrating Radar (MCGPR)
- Time-Domain Electromagnetic Induction (TDEMI)

Advanced Software

- Software for processing, interpretation and visualization of MCGPR in 3D, and TDEMI data in 2D (plan-view)

Today's Training Outline

Advanced Geophysical Methods: MCGPR & TDEMI

- Basic Theory
- Limitations
- Complications
- Variations
- Applications
- Why is works for utility mapping
- When it won't work for utility mapping
- Requirements for effective use
- Final Products – What do you get out of the method?

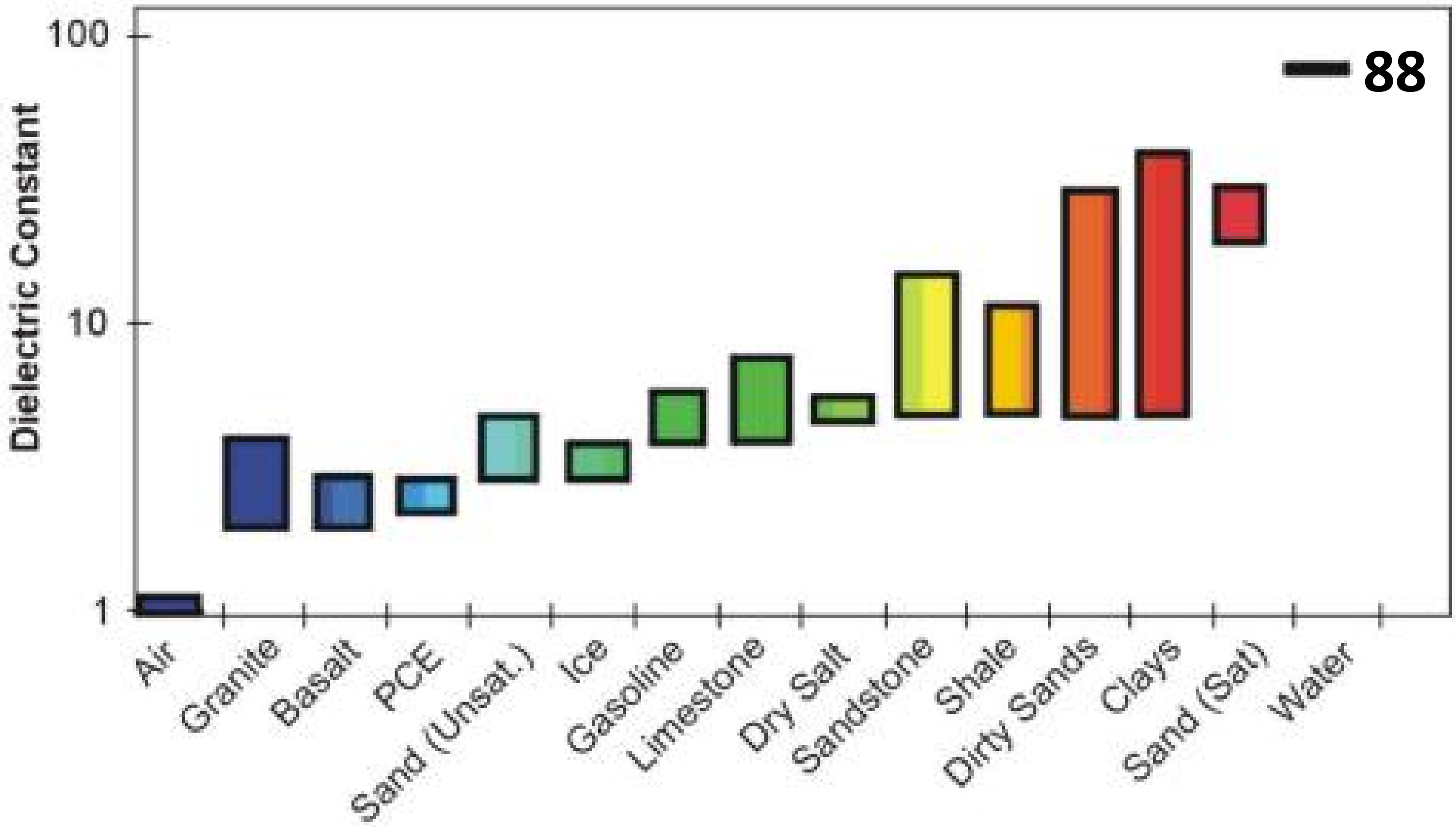
Same outline for both methods!

Start with Multi-Channel Ground Penetrating Radar

Basic GPR Theory

- Uses electromagnetic energy normally in the 10 MHz to 1500 MHz frequency range
  - Lower frequencies (*longer wavelengths*) image deeper but with lower resolution than higher frequencies (*shorter wavelengths*)
- Any change in the ***dielectric constant*** value (*next slid*e) will generate a reflection. The polarity of the reflected wave is effected by whether the reflecting material is more or less conductive than the surrounding material
- Reflected energy is measured at the GPR receiver

GPR – The Dielectric Constant



This is <u>the</u> <u>material property</u> that governs how well GPR signals transmit through or reflect off of layers / objects

www.cflhd.org/resources/agm/

Theory
Conductivity vs. Dielectric

Conductivity/Resistivity

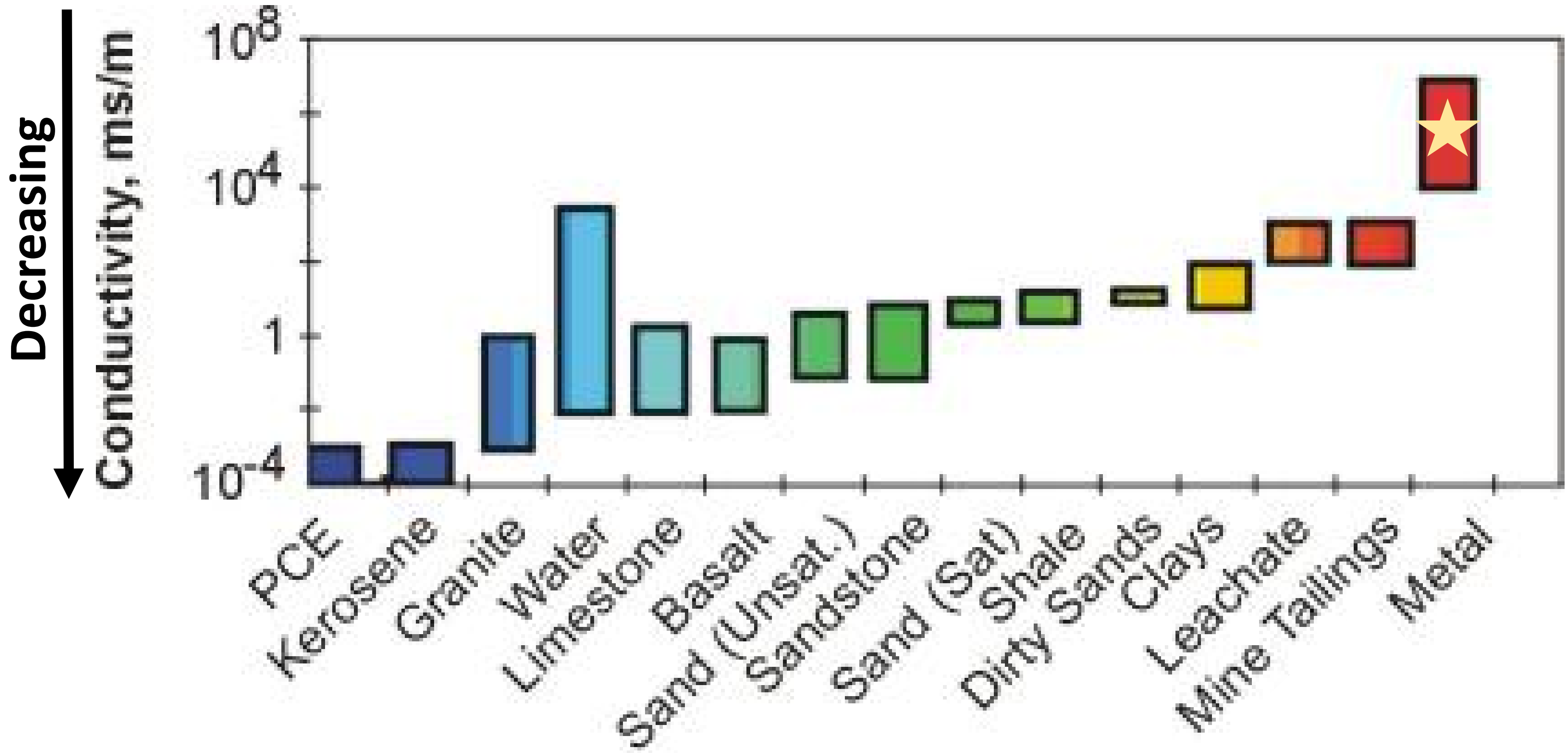
- GPR does not measure or sense soil '***conductivity***'
- Higher soil conductivity conditions adversely affect signal penetration and clarity.
- Material conductivity values of .01 ***mSiemens/meter*** can make GPR a poor choice

Dielectric Constant

- Dielectric is the ability of a material to act like a capacitor
- GPR senses changes in dielectric properties within the survey area
- No absolute dielectric values are determined; only relative changes within the survey area

GPR Signal Penetration vs. Material Conductivity

**You will see this graphic again when we discuss TDEMI*



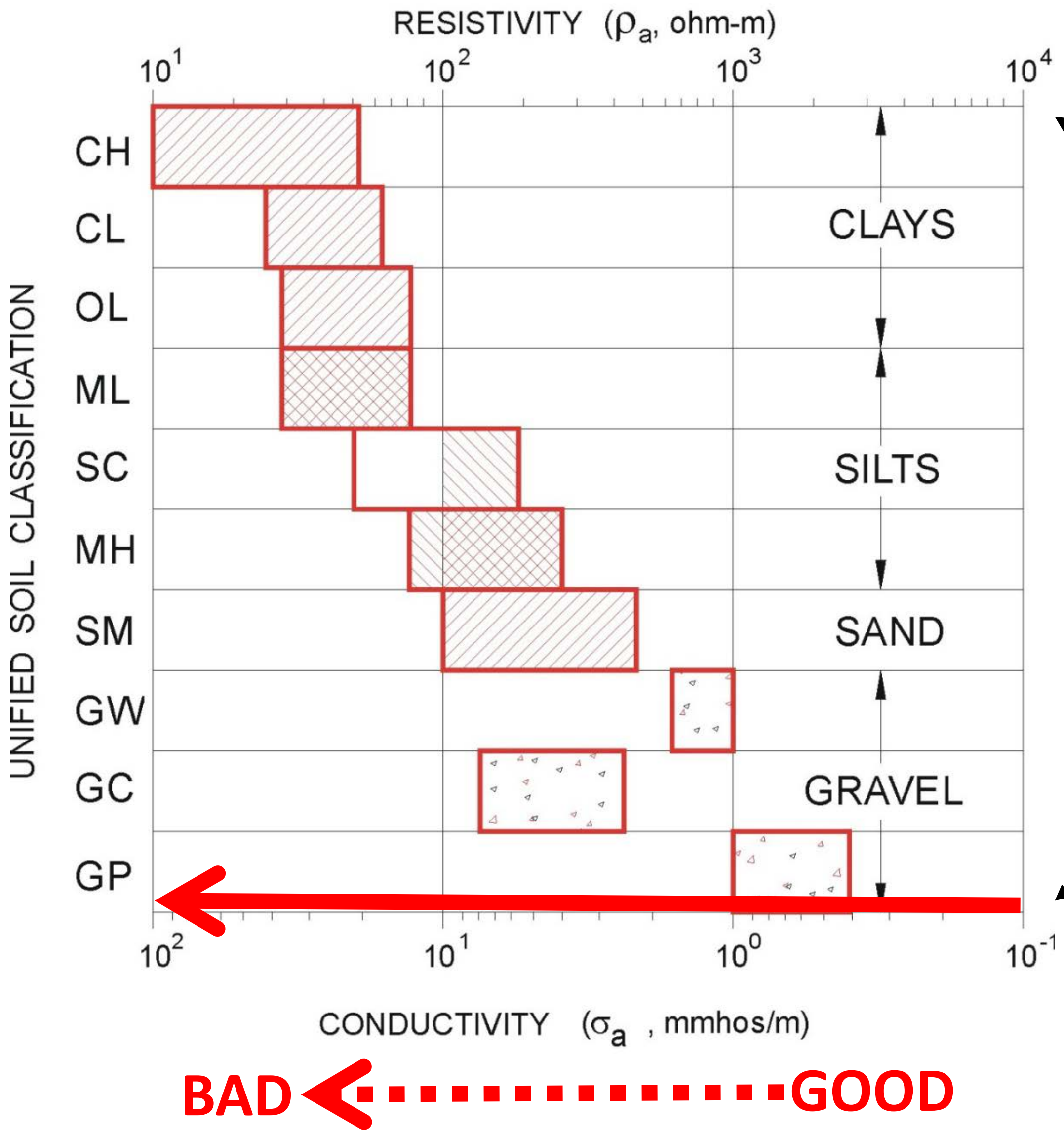
GPR Signal Penetration in Various Materials

Good Radar Media	Poor Radar Media
Dry Salt	Salt water
Snow	Metals
Ice and fresh water	CLAY
Peat	CLAY RICH SOILS
Wet or dry sand	Conductive minerals
Dry rocks	
Concrete and pavement	

Works

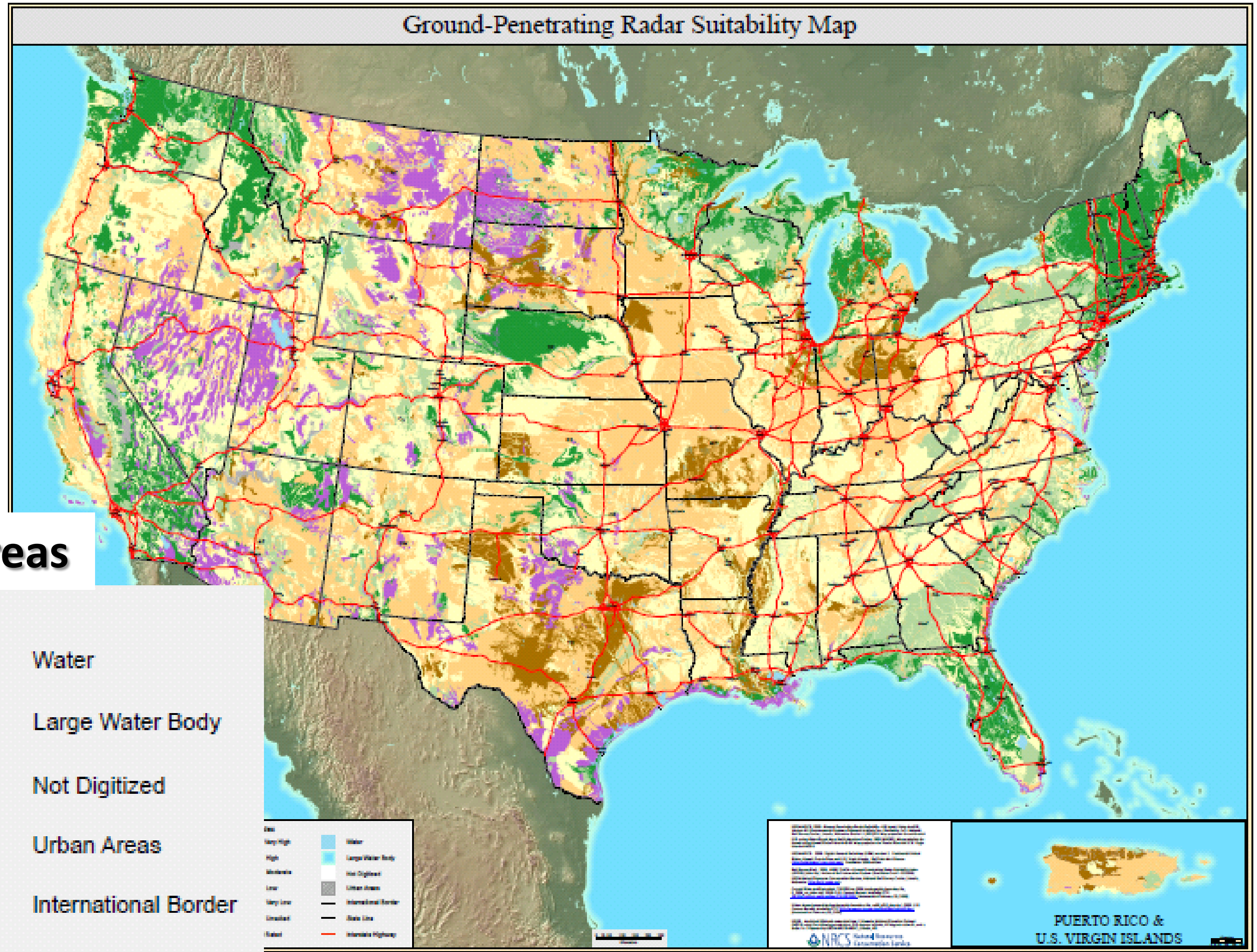
Doesn't Work

GPR – Conductivity in Soils

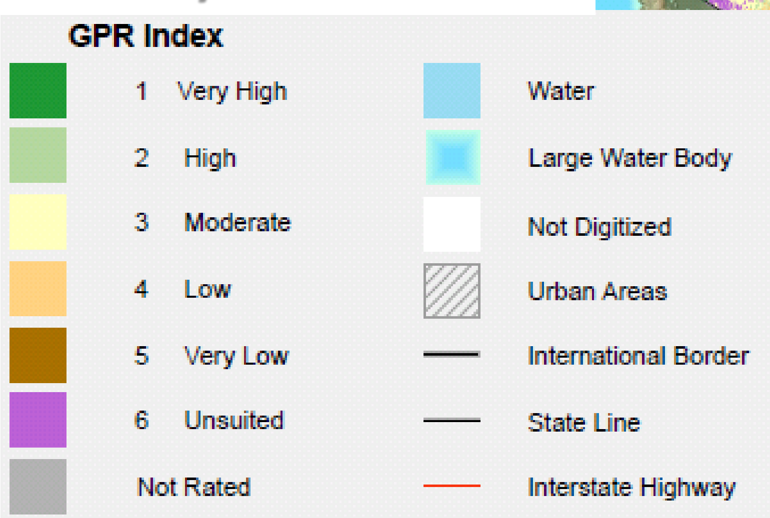


Conductivity is the inverse of Resistivity

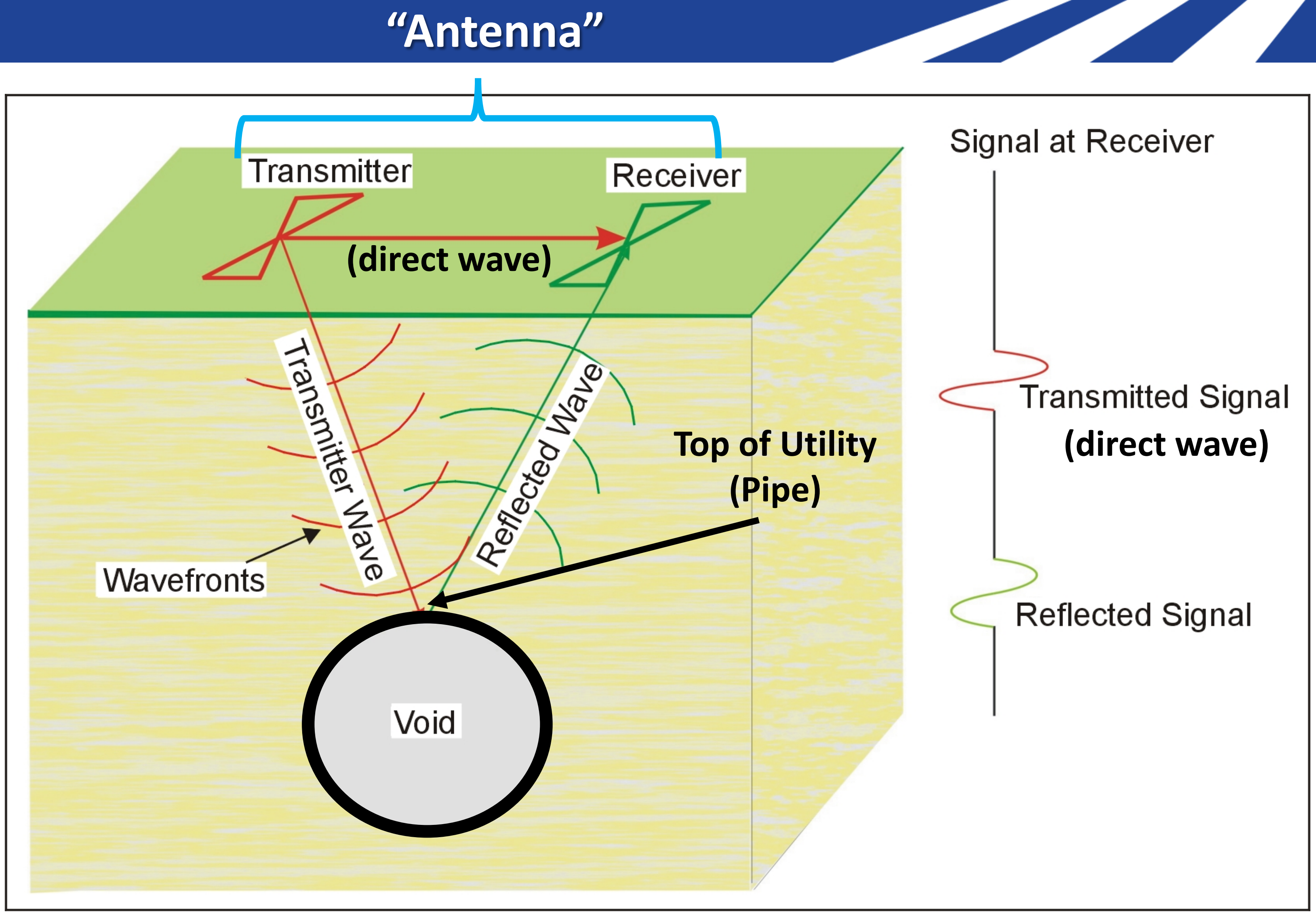
Basic GPR Concepts
Soil Suitability Map of the US



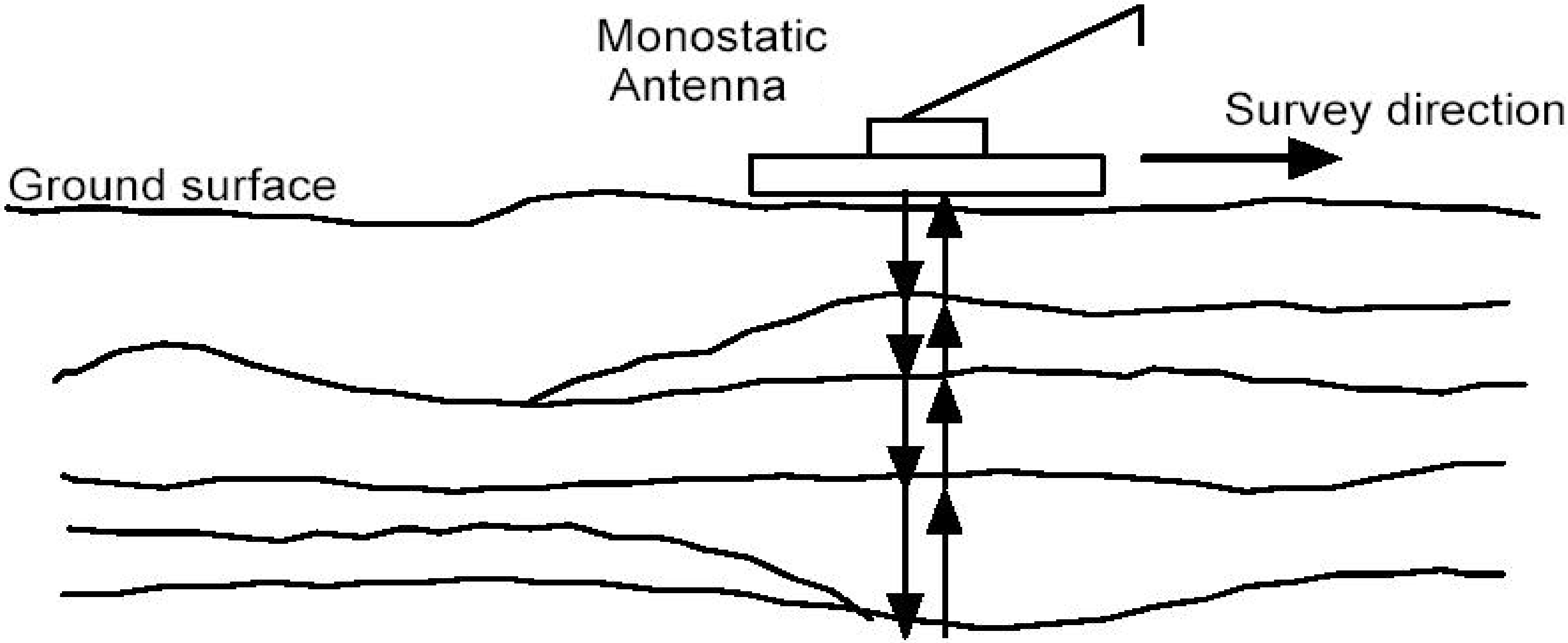
Suitability of GPR in Areas



GPR – Reflected Signals



GPR Antenna Size/Frequency & Depth/Resolution

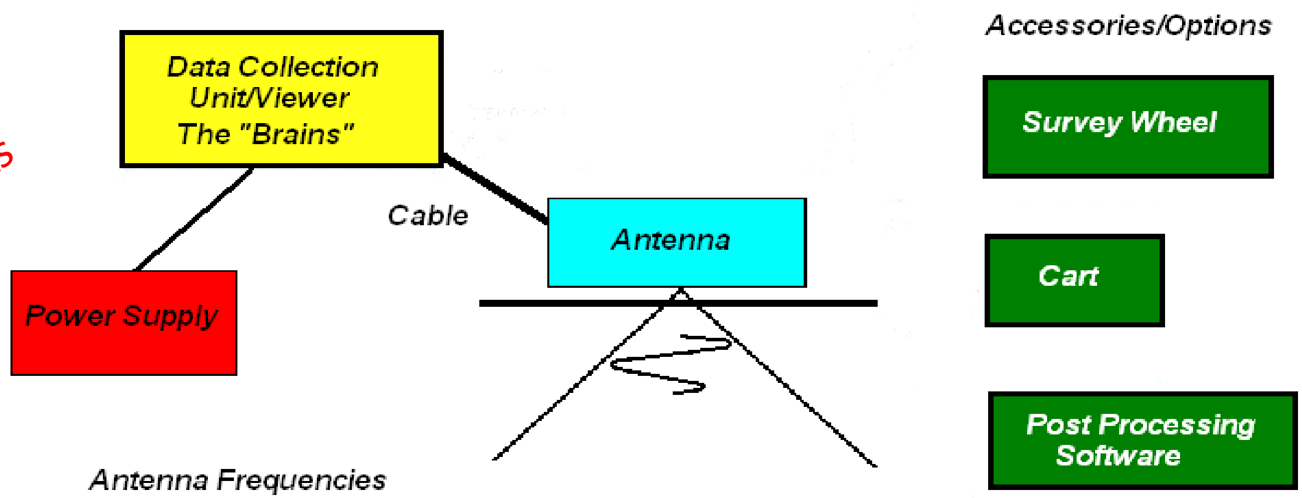


Antenna Size		Frequency		Depth of Penetration		Resolution
Small	=	High	=	Shallow	=	High
Big	=	Low	=	Deep	=	Low

Basic Concepts
Types of GPR Antennas

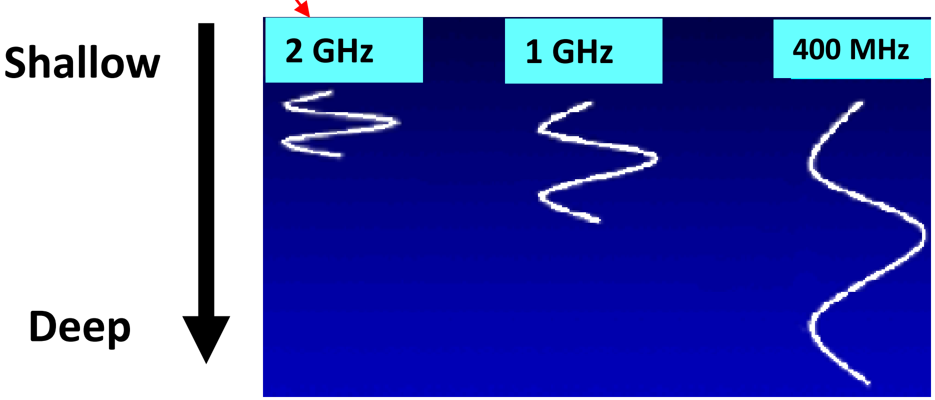
Note the lack of GPS (need)

**Mapping rebar and PST's*



Note Error in your books

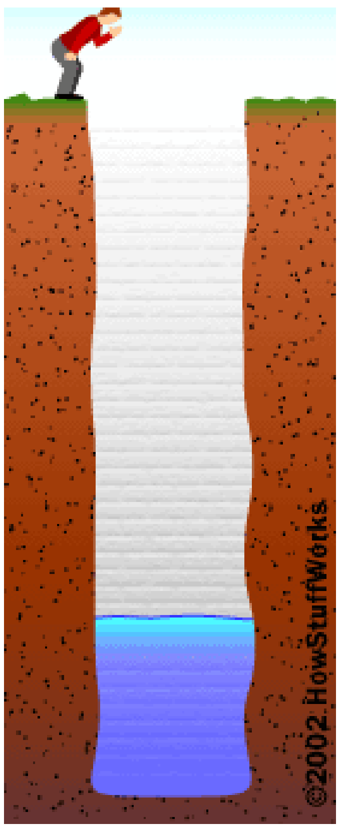
Antenna Frequencies

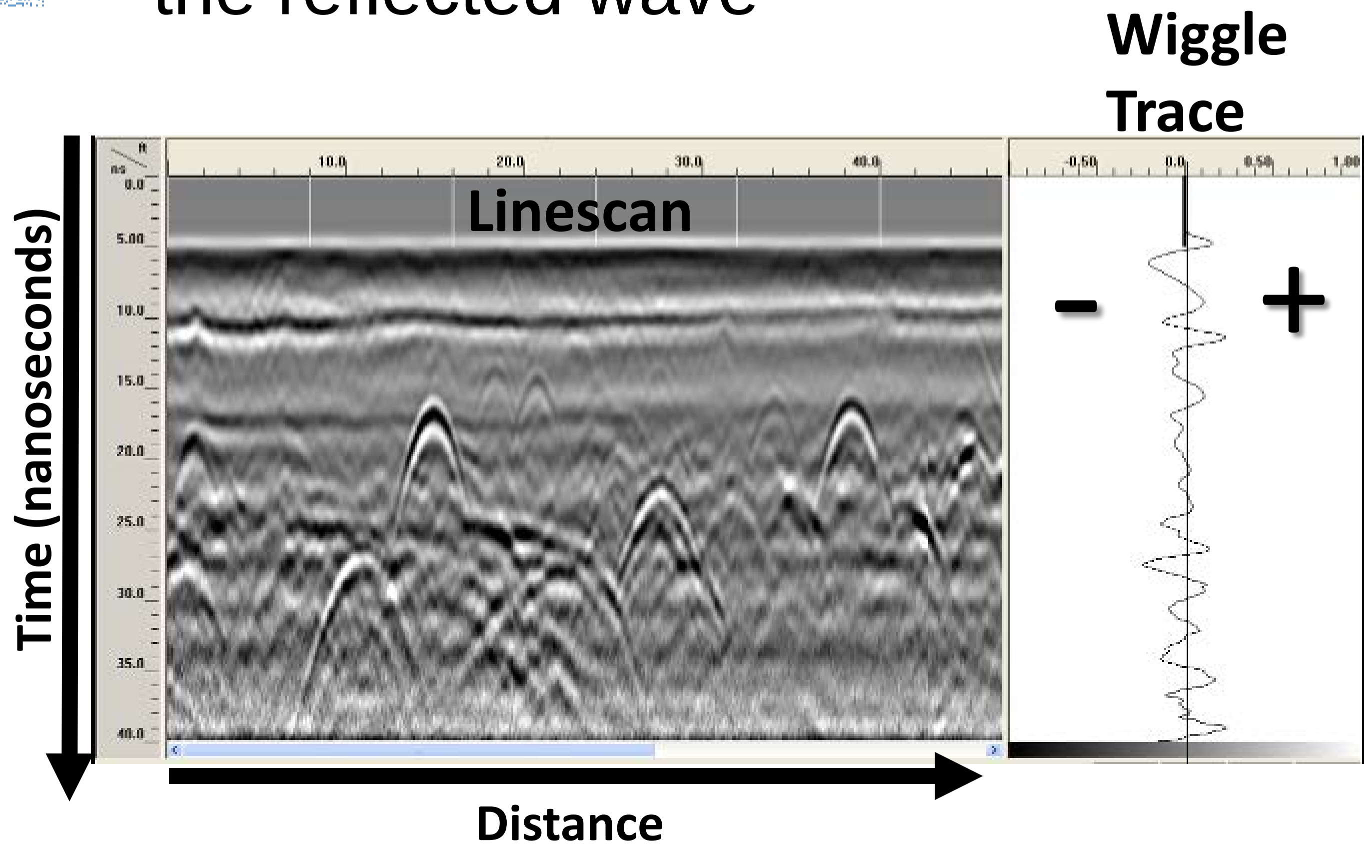


Visualization **of the concept of 'frequency' for a GPR wave**

Basic Concepts – A Series of *Cartoons* to Demonstrate How GPR Works

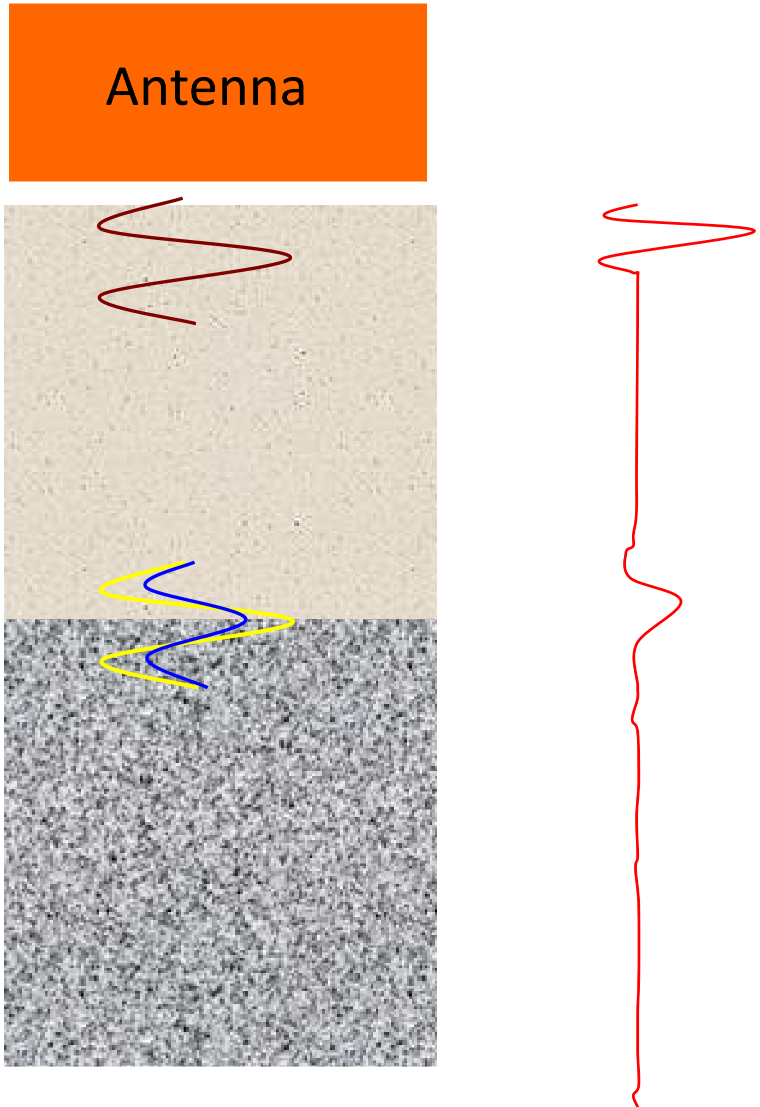
We record the two-way travel **time**, and the **amplitude** of the reflected wave





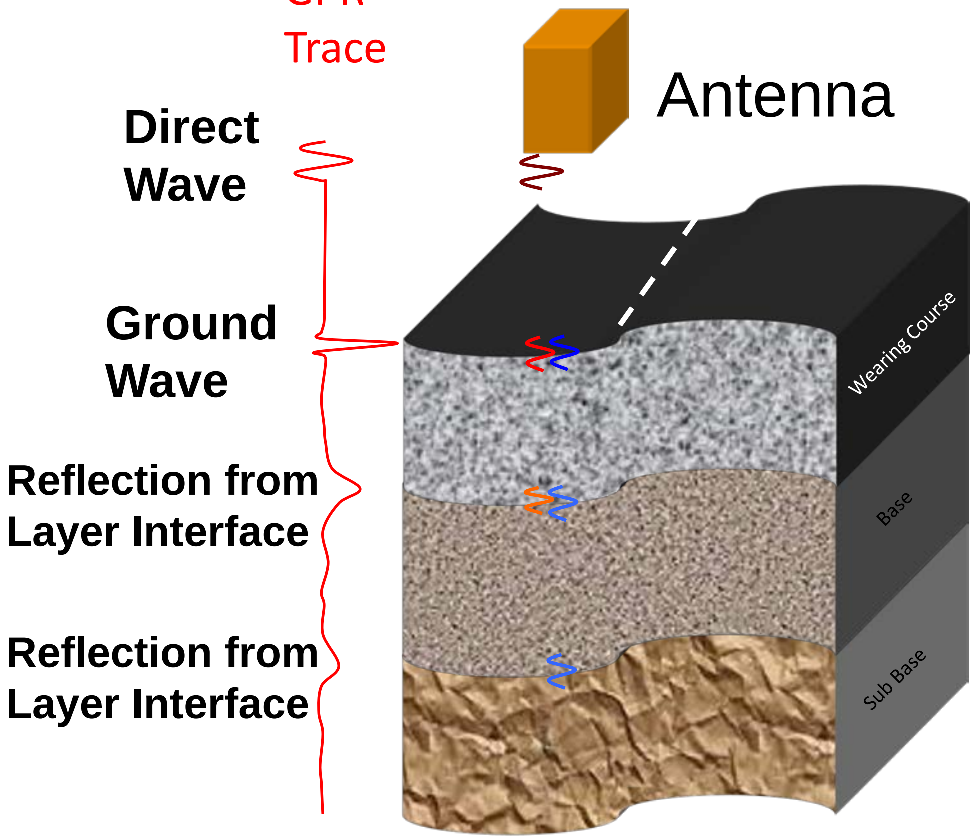
Courtesy: Geophysical Survey Systems, Inc.

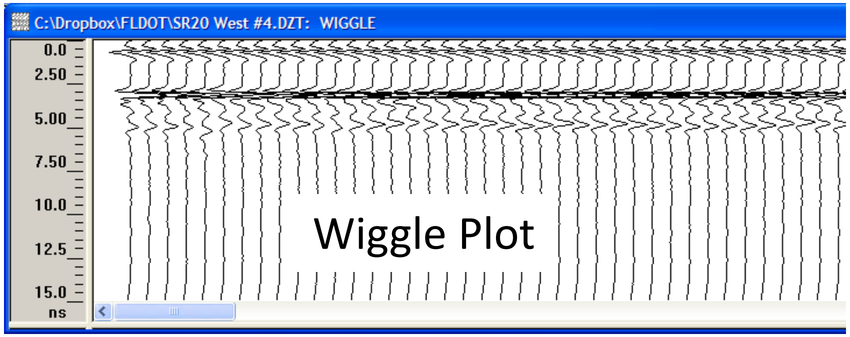
Basic Concepts
Recorded Reflections

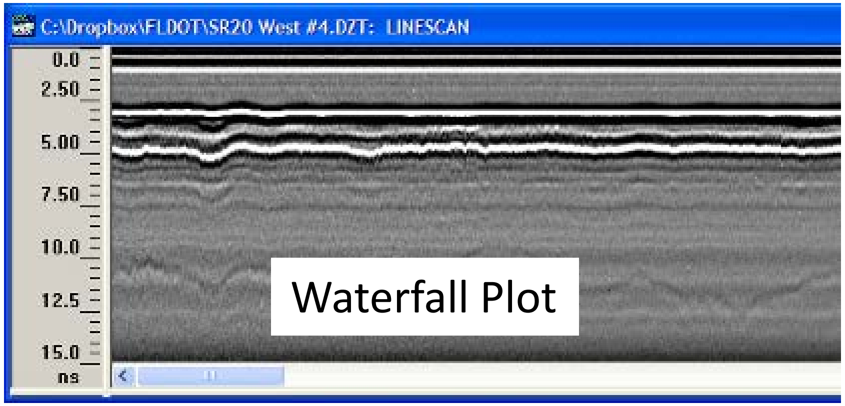


Basic Concepts – Reflections from Multiple Layers

Courtesy: Geophysical Survey Systems, Inc.







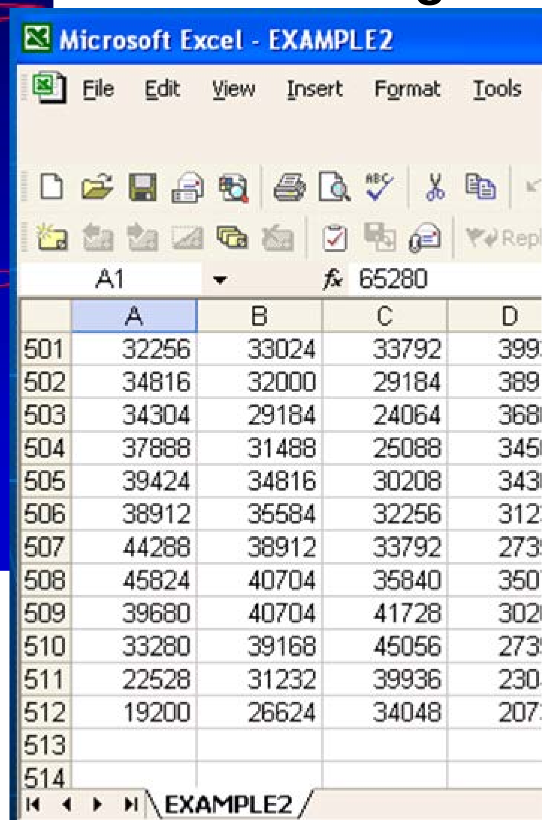
Reflections are produced when the GPR pulse encounters a material with different dielectric constant – for this Model:

Dielectric Constant: Air = 1 Asphalt = 3-5 Concrete = 6-8

Basic Concepts

Electromagnetic Reflection Theory

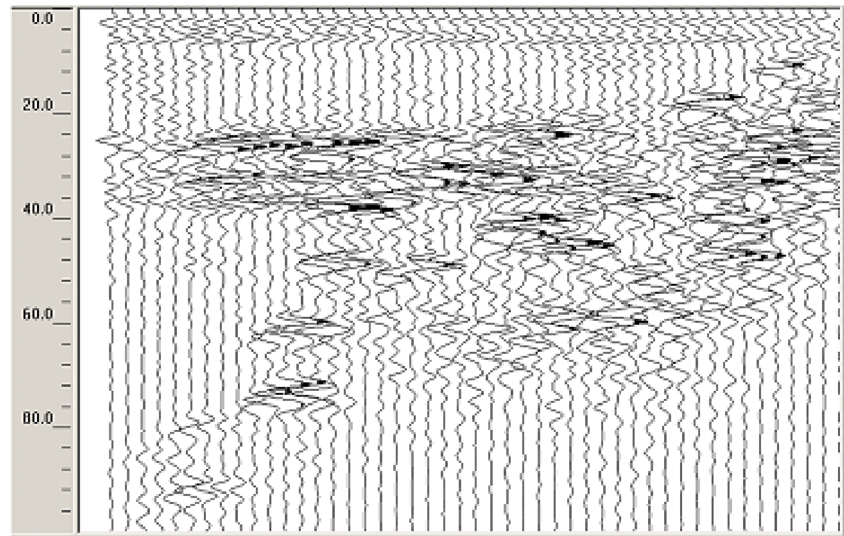
Traces are Digitized



	A	B	C	D
501	32256	33024	33792	399
502	34816	32000	29184	389
503	34304	29184	24064	368
504	37888	31488	25088	345
505	39424	34816	30208	343
506	38912	35584	32256	312
507	44288	38912	33792	273
508	45824	40704	35840	350
509	39680	40704	41728	302
510	33280	39168	45056	273
511	22528	31232	39936	230
512	19200	26624	34048	207
513				
514				

Measurements of Times and Amplitudes

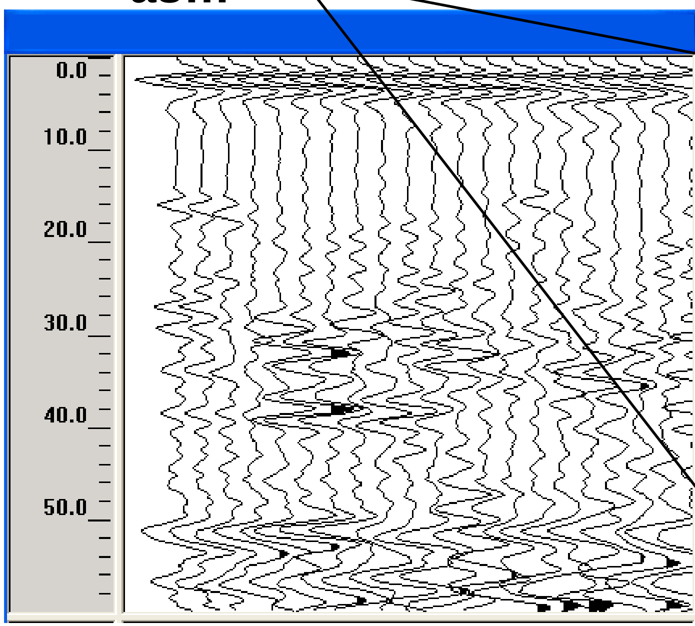
Scans of reflected pulses shown side by side

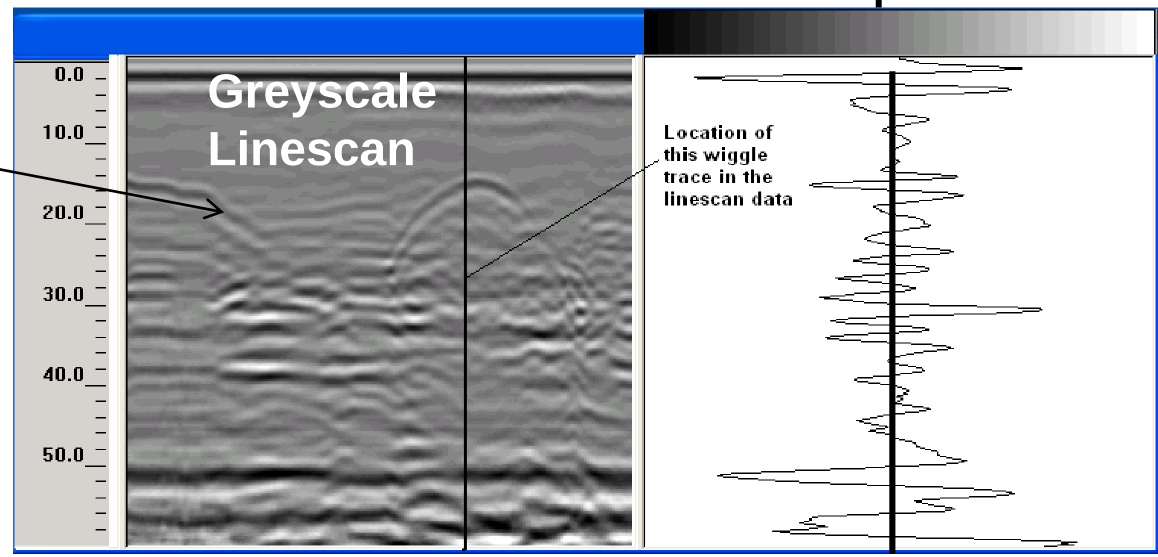


From here – the next slide shows how GPR data are presented from this '*wiggle trace*' plot to a '*waterfall*' plot

Basic Concepts
Wiggle Trace to Linescan Data

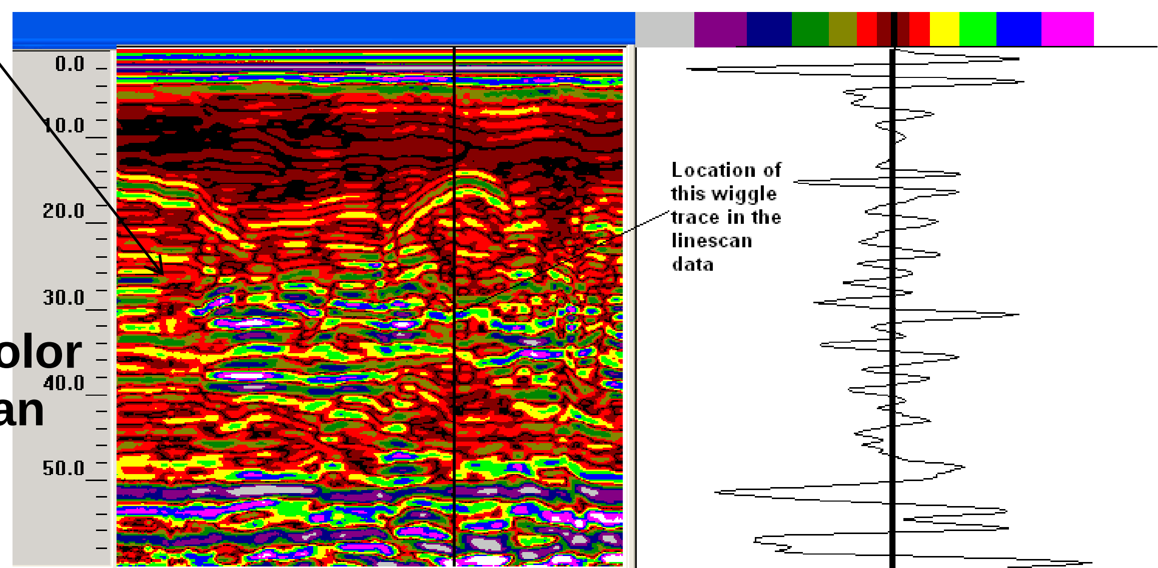
Same Wiggle Trace Data Displayed as…





Amplitudes are assigned colors (greyscale or multi colors) to create a ***linescan GPR*** **'profile' or 'section'**.

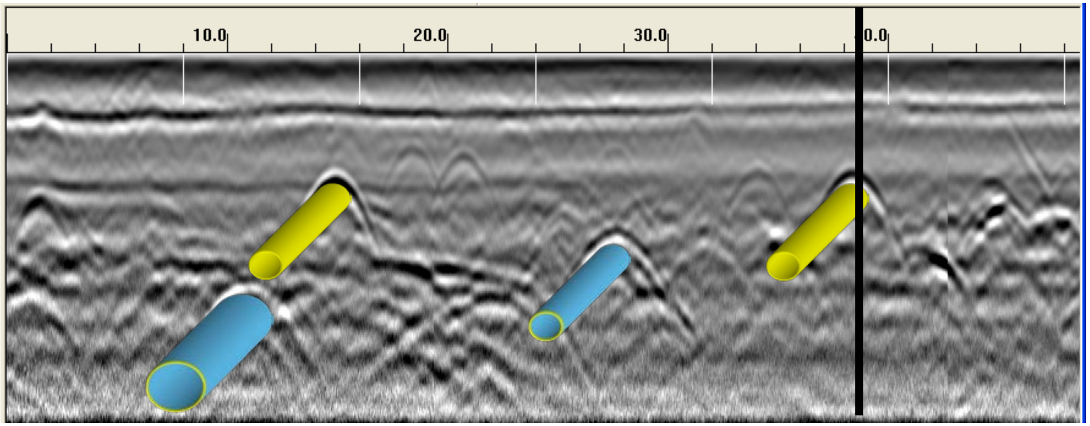
Multi-color Linescan



Basic Concepts

Creating a 2D Linescan Data & Interactive Re-Locating

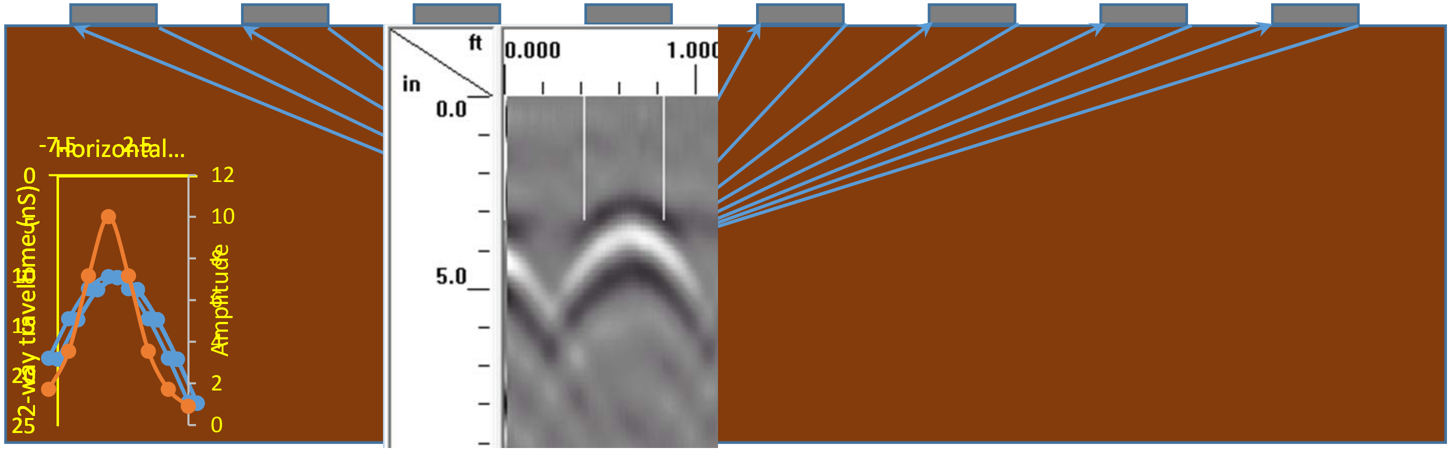
Antenna



Courtesy: Geophysical Survey Systems, Inc.

*Single antenna system

Development of the GPR
Hyperbola



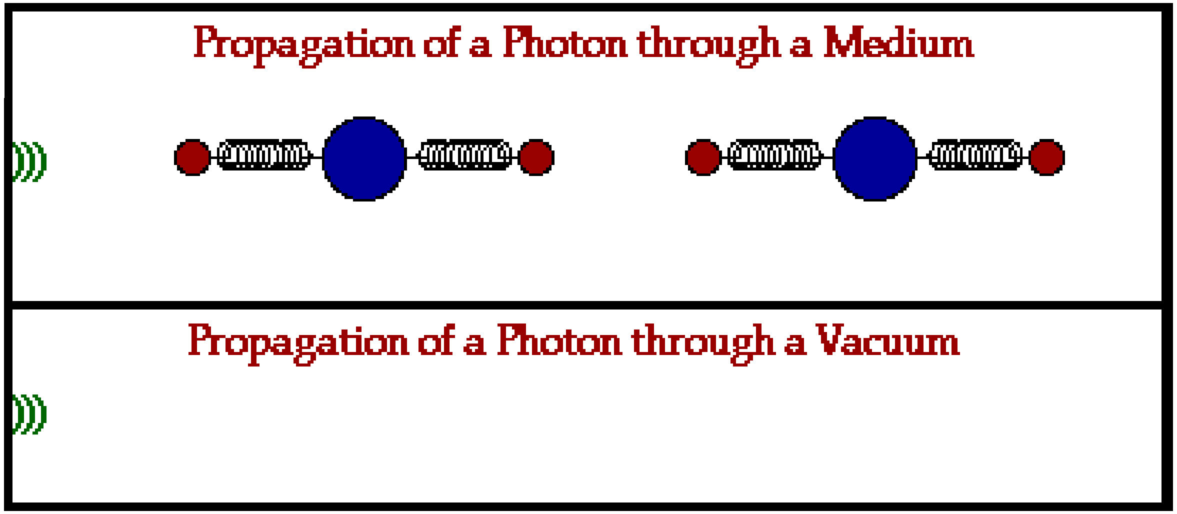
Basic GPR Theory

$$v = f\lambda = \frac{c}{\sqrt{K}}$$

Speed of Light

Dielectric Constrant

$v = velocity$
$f = frequency$
$\lambda = wavelegth$

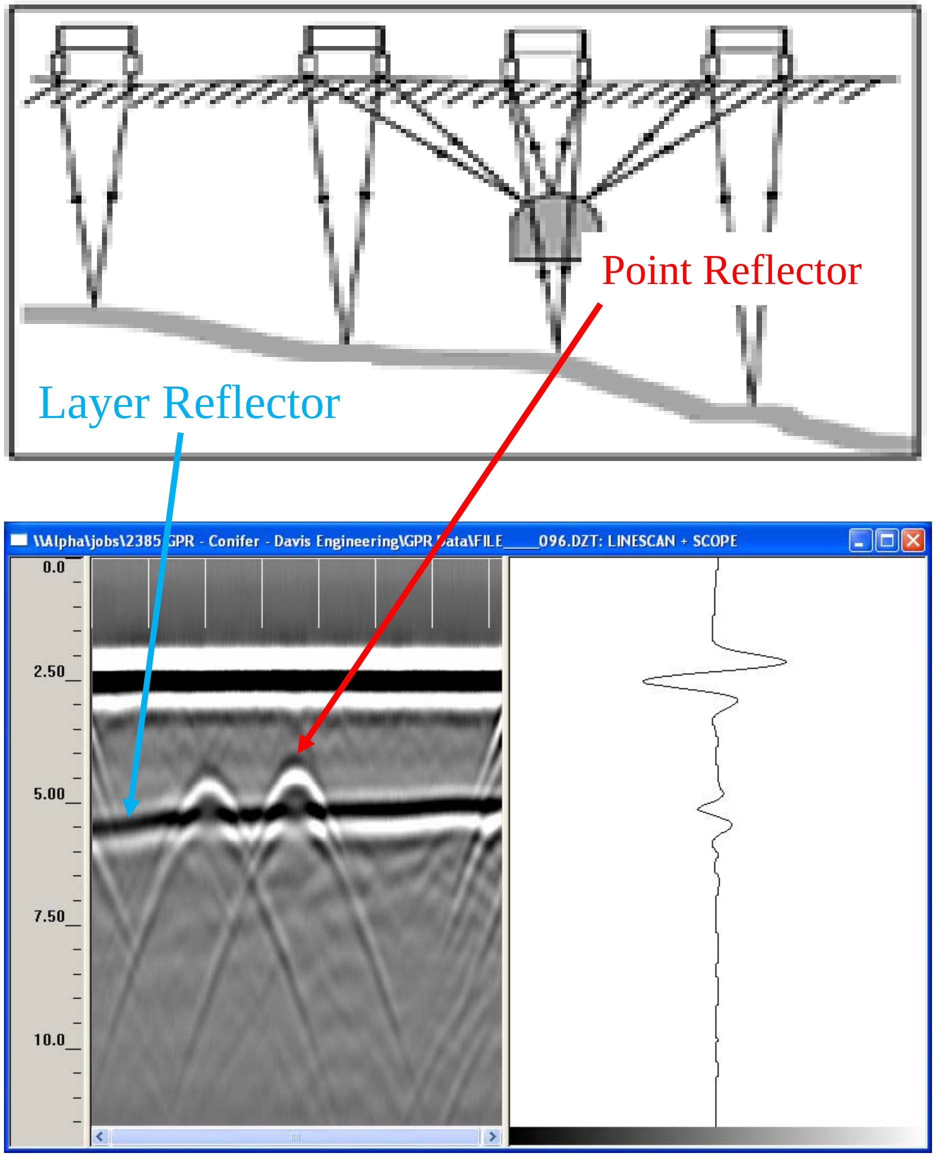


Basic GPR Theory

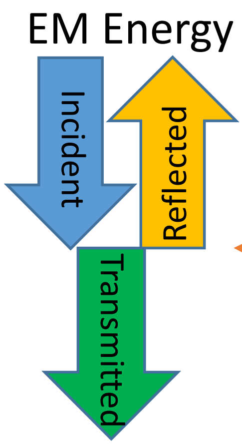
- The scans are then typically plotted as ***waterfall plots*** of all of the individual data traces collected
- The lightness or darkness (or color) of each point in the plot shows the **amplitude and polarity** of the data at a given time in each trace

Typical Material GPR Velocities

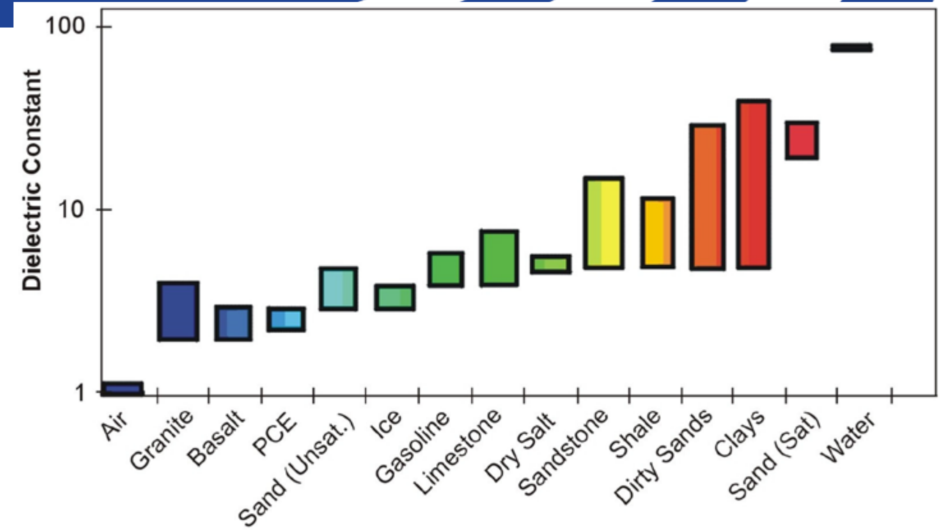
- Air = 2 ns/ft
- Water = 18 ns/ft
- Dry Concrete = 4.5 ns/ft
- Asphalt = 4.5 ns/ft
- Dry Sand = 4 ns/ft
- Dry Clay = 4 ns/ft
- Wet sand = 7.5 ns/ft
- Wet Clay = 10.5 ns/ft

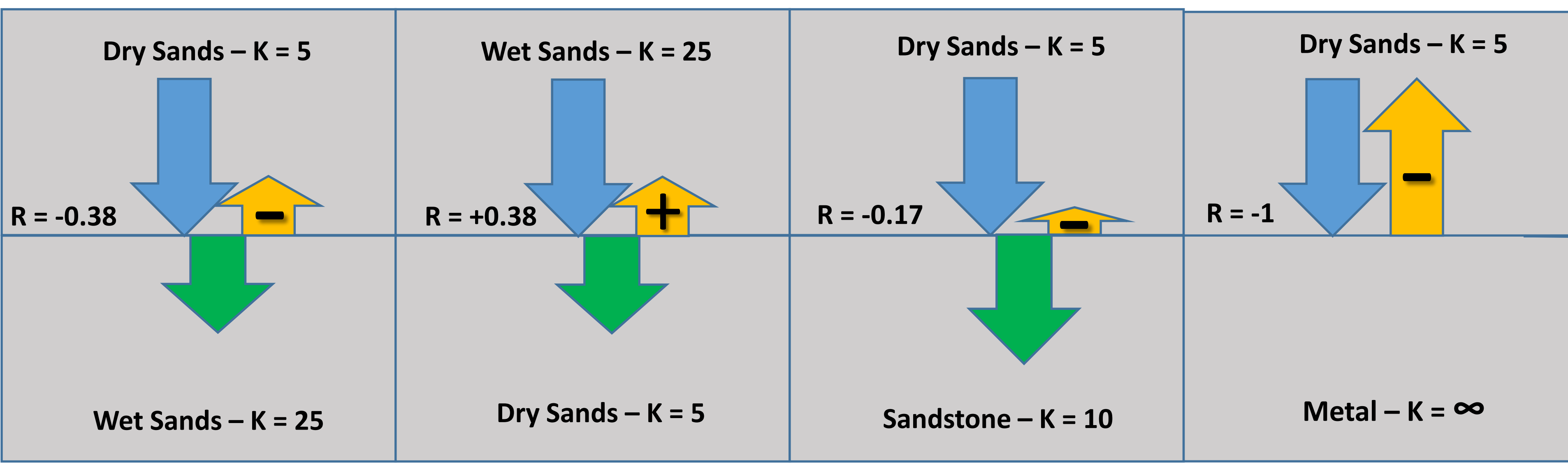


Basic GPR Theory – Wave Transmission



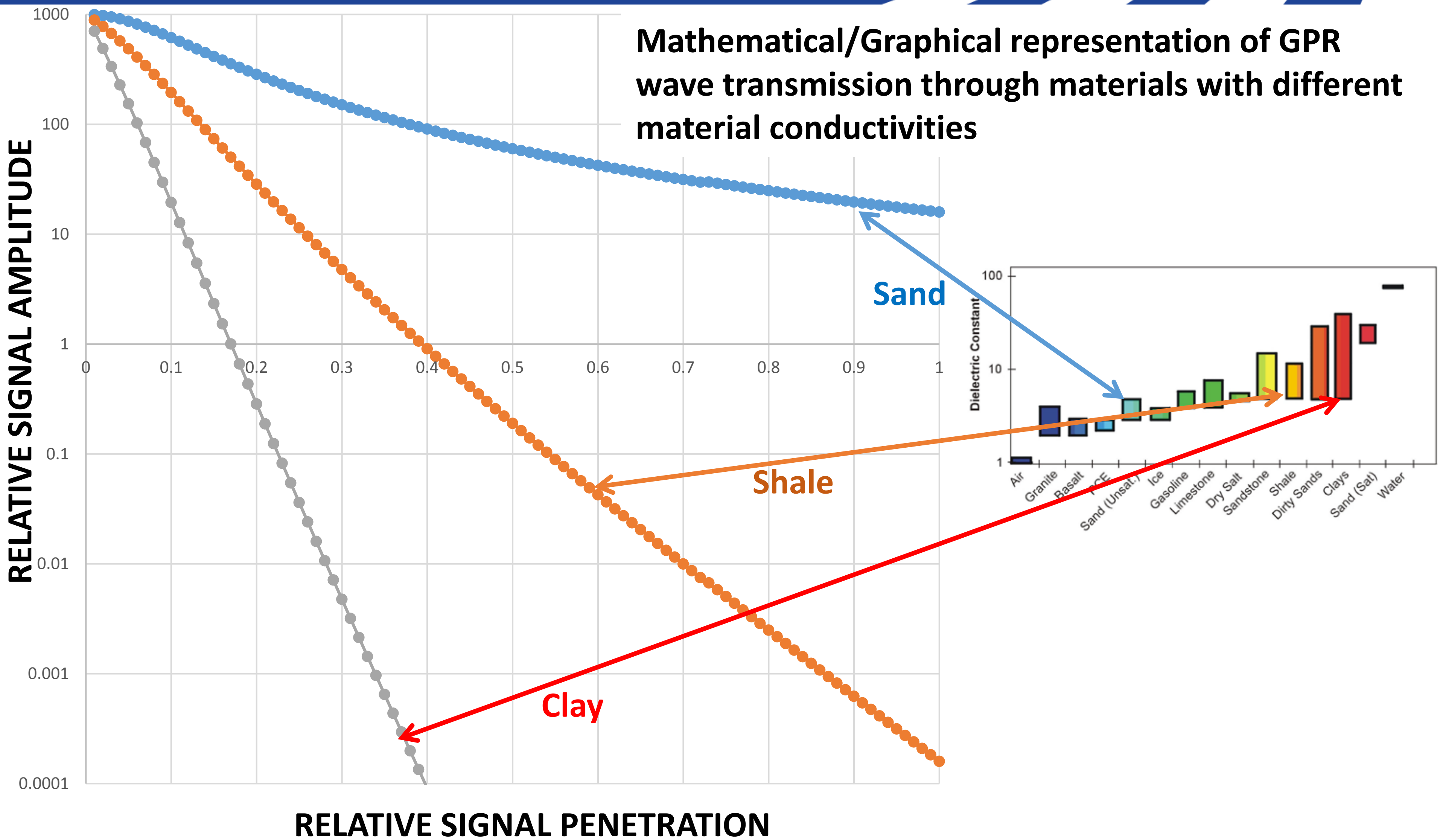
$$R = \frac{\sqrt{K_1} - \sqrt{K_2}}{\sqrt{K_1} + \sqrt{K_2}}$$





Basic GPR Theory

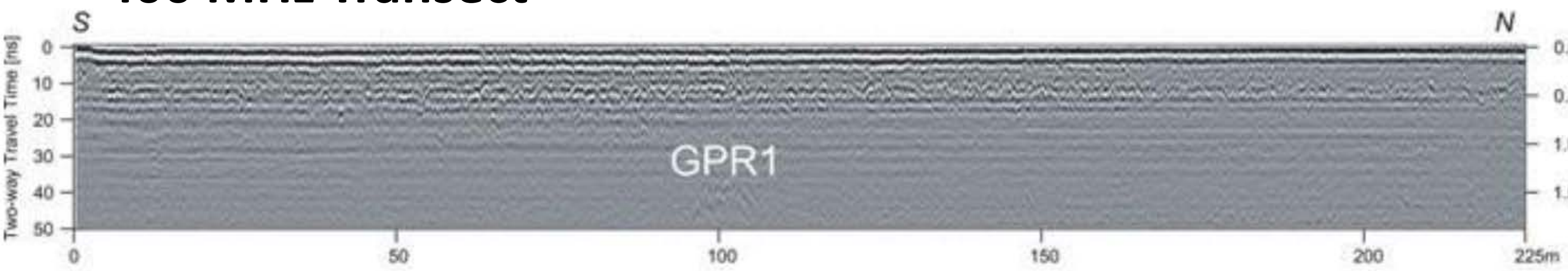
Mathematical/Graphical representation of GPR wave transmission through materials with different material conductivities



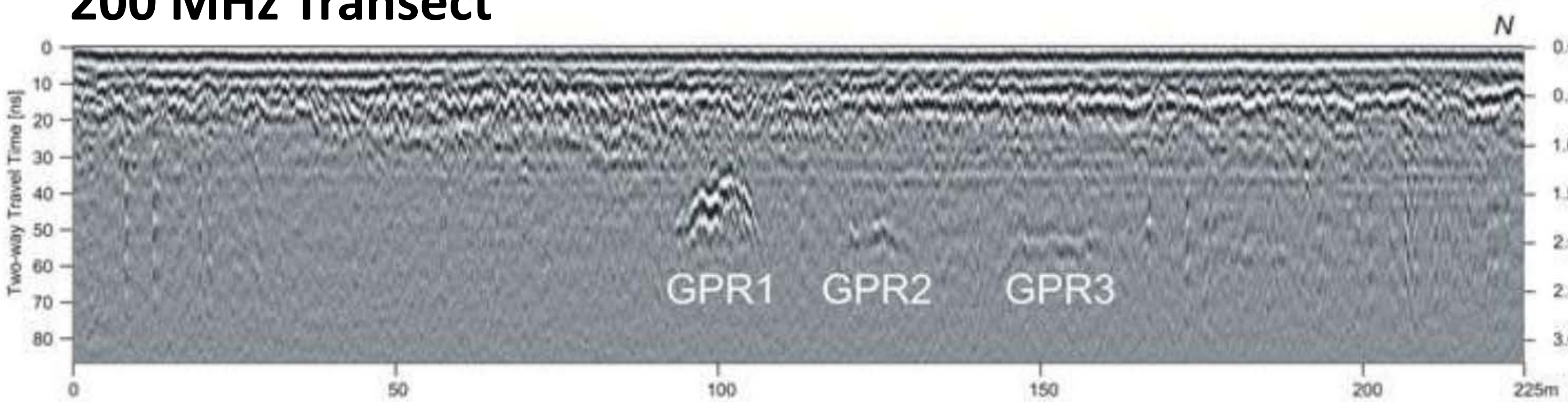
Frequency vs. Resolution of Anomalies

<u>Same transect</u> – two different GPR frequency antennas

400 MHz Transect

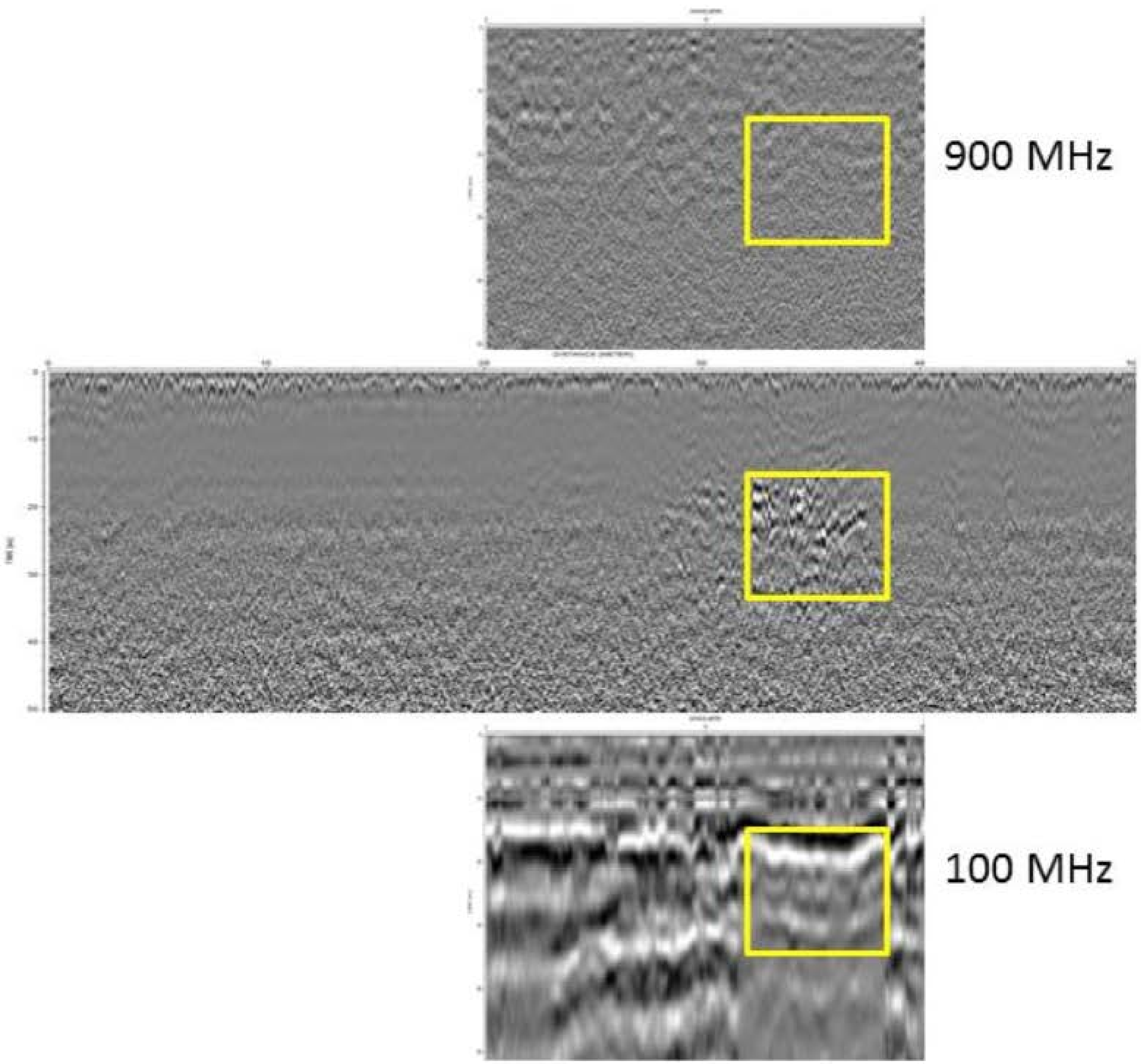


200 MHz Transect



Frequency vs. Resolution of Anomalies

Same transect – three different frequency antennas



900 MHz

400 MHz

100 MHz

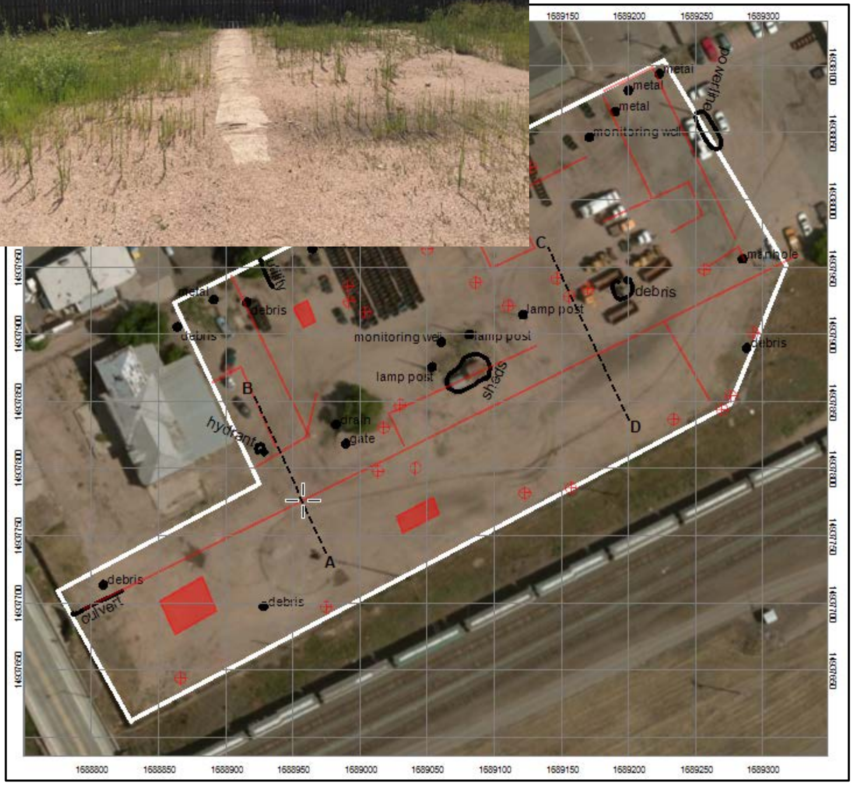
***Same time scales**

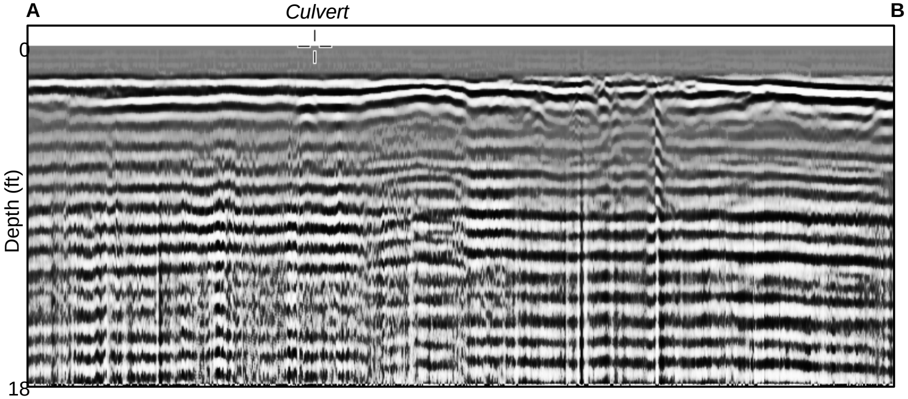
Lower Frequency 'sees' Deeper

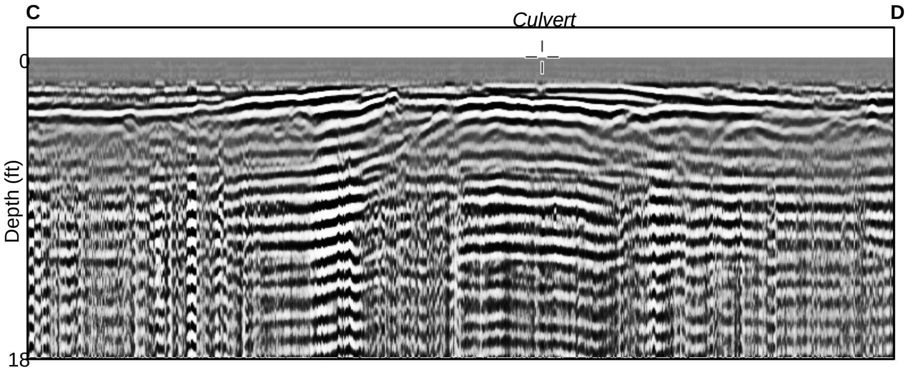
What Makes GPR Complex

- **Will a feature cause a reflection?**
  - Depends on:
    - Dielectric constant of feature
    - Dielectric constant of material feature is in or next to
    - Signal strength at feature (is your signal strong enough to go from surface, to feature, and back?). Depends on initial signal strength and absorption/attenuation of material between the surface and the feature of interest.
- **Data requires expert interpretation**
  - Is a reflection caused by a utility, rock, void?
  - Near surface or even surficial features will create “echoes” downward in time. Important to note the earliest time (or shallowest depth) that the feature is present
  - Interpretation is, to a large part, subjective. Two experts can come to different conclusions
- **Often GPR will simply not work due to geologic conditions**
  - It is very important to understand why and when this will be the case
  - Requires background research or knowledge of the site
- **Even single sensor and single frequency system generate large data sets. Advanced systems generate huge data sets that require special software and organization to make the most of.**

Example
Where GPR Does Not Work

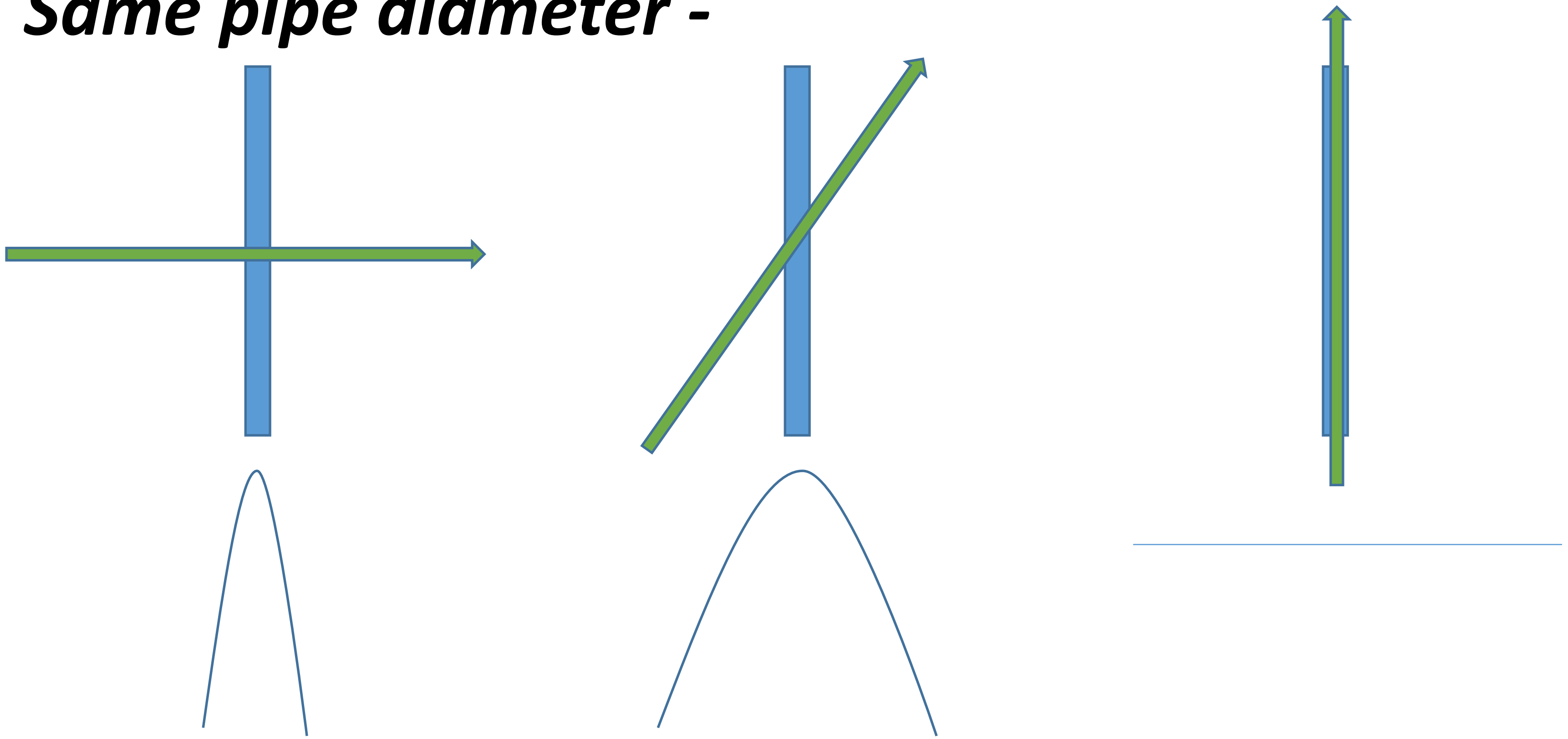






Effect of Scan Direction vs. Utility Orientation

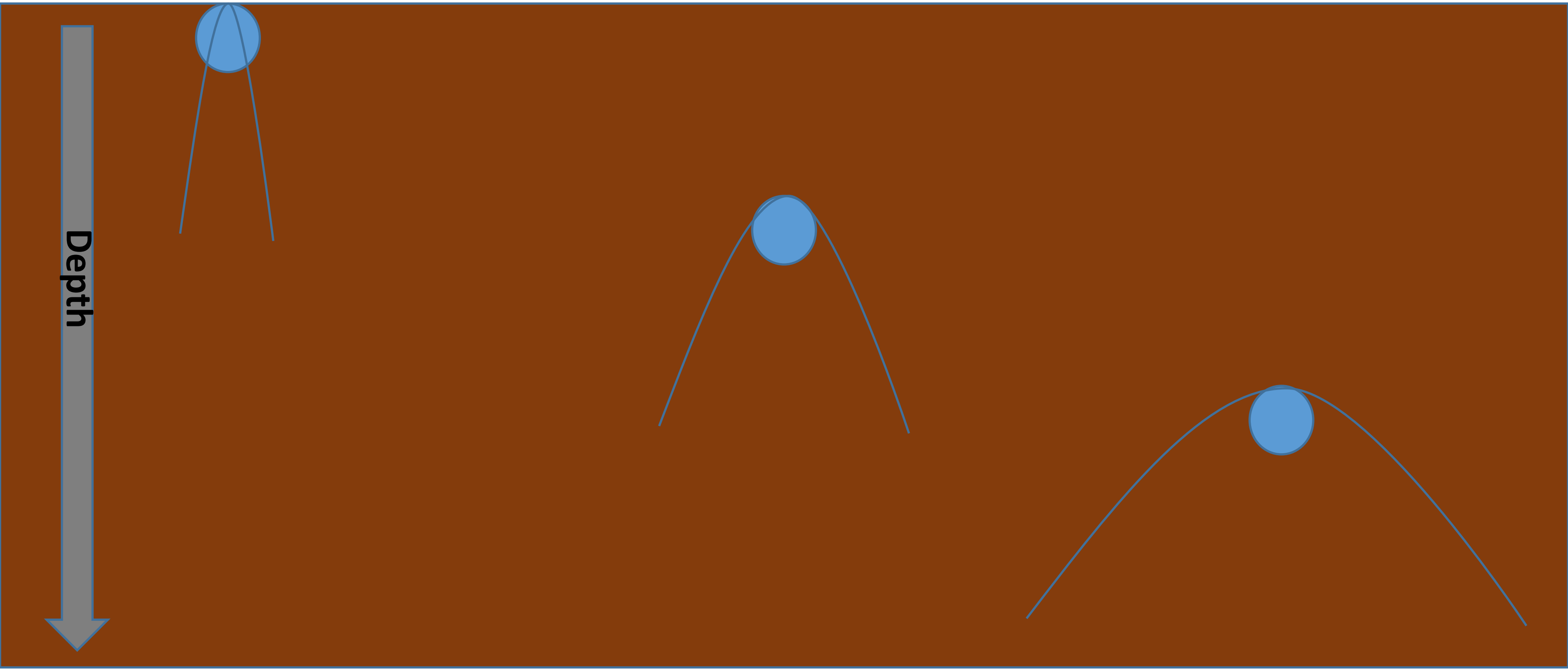
Same pipe diameter -



***Single Antenna System**

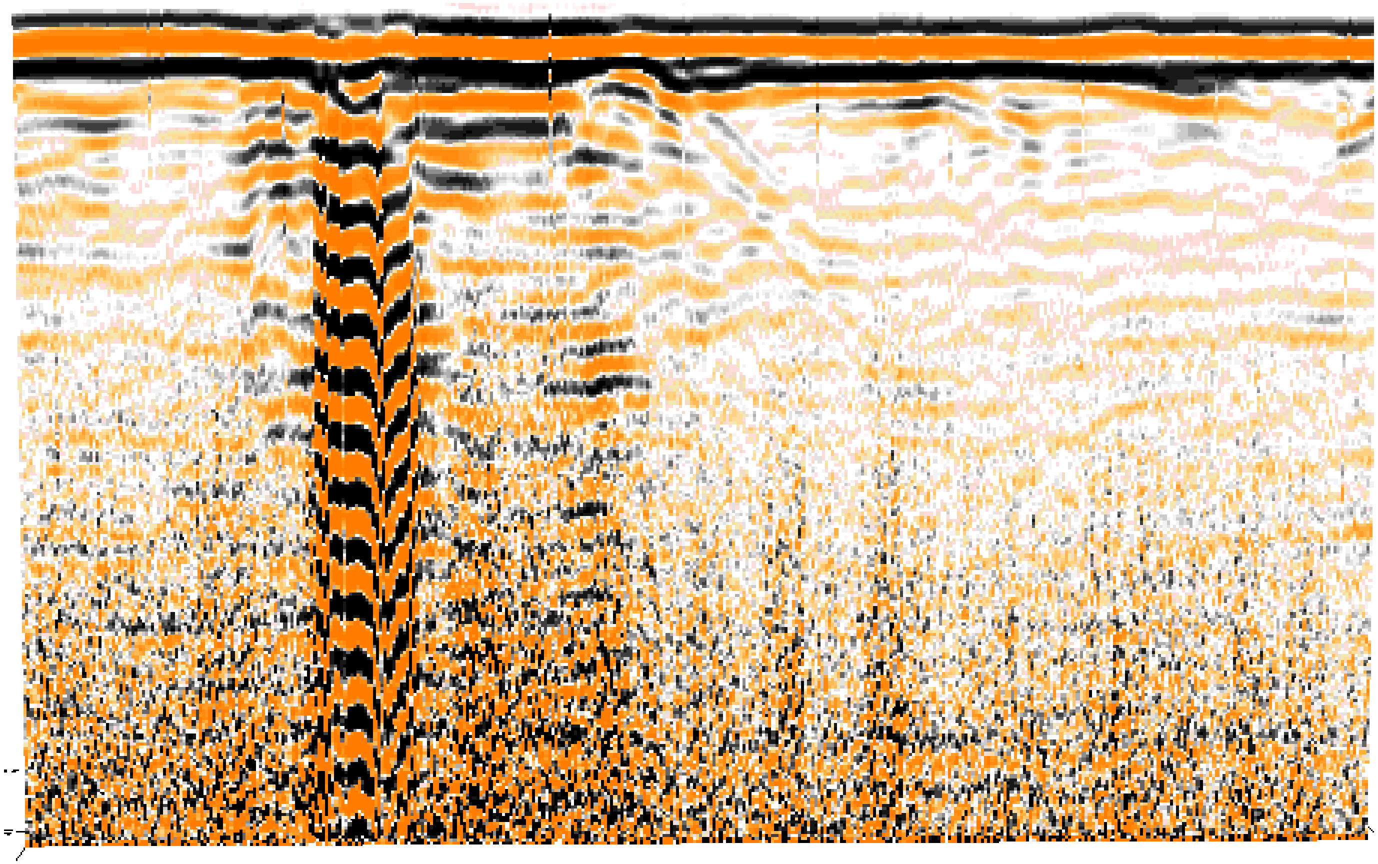
Effect of Burial Depth on Hyperbola Shape

Same pipe diameter -



GPR Signal "Ringing" Response from Surface Metal

For example – a manhole cover!



Direct Air Signal and Ground Reflections

- **Direct Air Signal** is the direct reading of the transmitter (**Tx**) signal in the receiver (**Rx**)
- **Ground Reflection** is a very large, horizontal reflector that is the signal reflecting from the ground surface
- Both show up in the beginning of records, but can “echo” down to later times
- Both can be reduced by using a horizontal filter

External Noise Sources

- Radio Signals
- Police RADAR guns
- Cell Phones
- Hand Held Radios
- And more…

How to Understand Radargrams

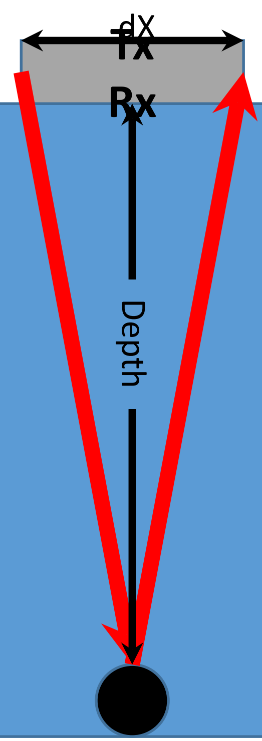
- **The results from GPR surveys are often complicated to understand**
- **The Y axis is often time, not depth**
  - This is because the response as a function of time is what is actually measured
  - Can be converted to depth if a velocity is assumed
- **Often responses from multiple features overlap**
  - Responses from shallow features can cause echoes going down in time (or depth) that can complicate interpretations of deeper features
- **Uneven terrain can cause the instrument to bounce, causing false anomalies**

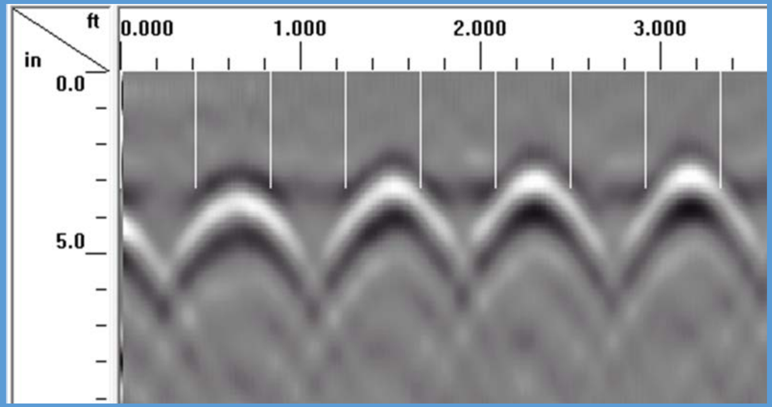
Converting ‘Time to Depth’

How to estimate/calculate material velocity?

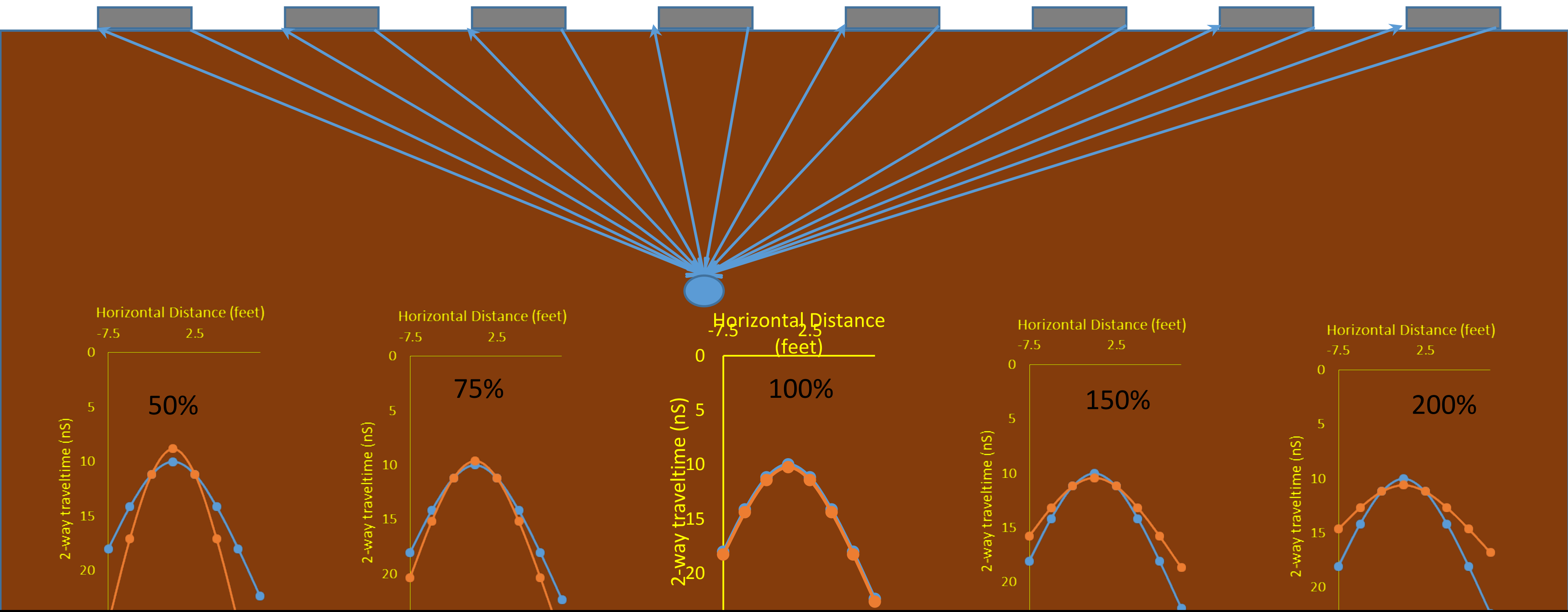
$$Dist = 2\sqrt{\left(\frac{dX}{2}\right)^2 + (Depth)^2} \approx 2(Depth)$$

$$Depth \approx \frac{time * Velocity}{2}$$





Average Velocity by Hyperbola Fitting



Note: Only works if the source of the hyperbola is a point source or linear source that is perpendicular to direction of movement

Migration: Digital Signal Processing

- Once you have a material velocity calculated, hyperbolas can be "*reduced*" to a smaller anomalies at their actual location/position

***Collapses the Hyperbola at the position of the reflector**

Effects of Surface Features

- **Not all features seen on a radargram are from the subsurface**
  - Nearby objects such as buildings, lamp-posts and the like can cause reflections if antenna are not ‘shielded’
  - These can be identified by estimating the velocity as shown above
    - If the velocity is the same as the speed of light in air ($3x10^8$ m/s) it should be considered suspect or an above ground feature
    - EM waves travel slower in solid / earth materials (soil, rock, roadway etc…) than in air
    - Remember, these will be broader anomalies to go along with the higher velocity values
    - Buildings and other extended features will cause broad flat anomalies
      - If approaching a building, anomaly could look linear
    - Light posts, trees etc. will generate hyperbolic anomalies

Utilities Detection and Mapping

Utilities detection and mapping

Real Time Detection → **Single Antenna Systems**

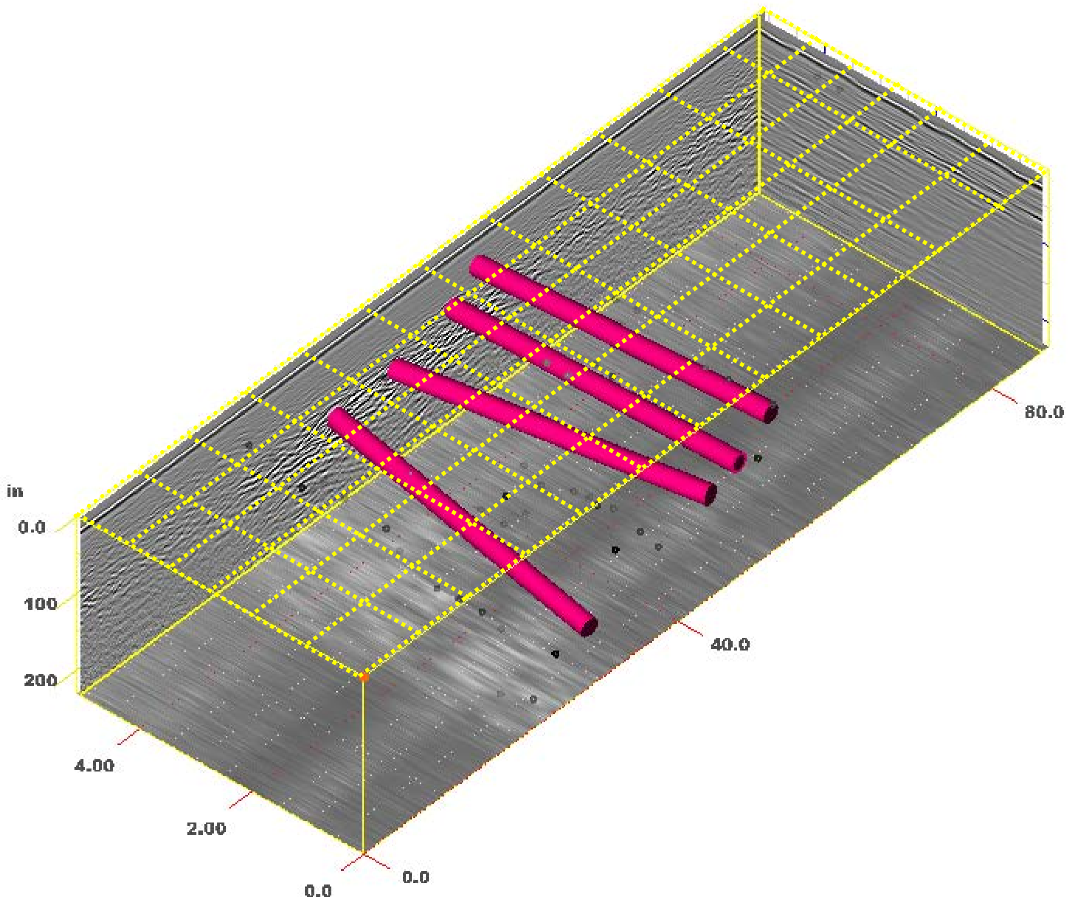
Detection and Mapping → **Multi-Channel Systems**

Mapping for Trencher → **Multi-Frequency Systems**

Advanced system for extensive **3D** utilities mapping → **STREAM-EM MCGPR**

TODAY

Basic Concepts – Building a 3D Data Set (*Cube*)



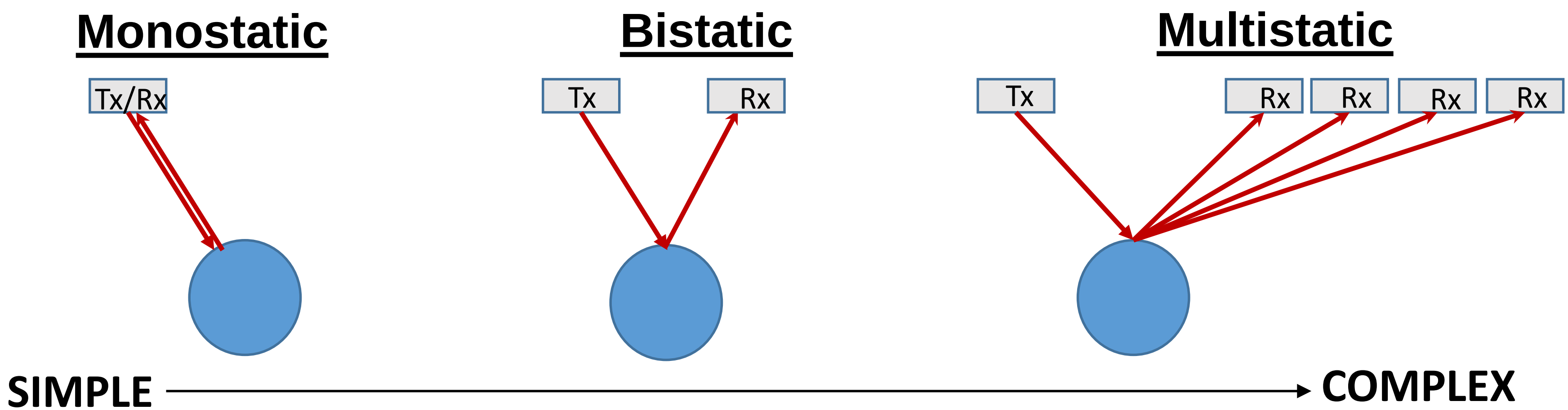
Advanced Multi-channel GPR - MCGPR

IDS Stream-EM System

3D Radar System

Monostatic, Bistatic vs. Multi-channel GPR

- **Monostatic** GPR uses the same antenna for transmission and reception
- **Bistatic** GPR use separated antenna for transmission and reception
- **Multistatic** / multi-channel systems use multiple receivers and on transmitter



Advantages/Disadvantages of Monostatic/Bistatic/Multistatic

Monostatic GPR

Advantages

- Single antenna is simpler to deploy
- Simple position determination
- No relative sensor motion issues

Disadvantages

- Limited aperture
- Requires Tx/Rx switch

Bistatic/Multistatic

Advantages

- Larger aperture
- Multiple angles of illumination
- Possible clutter rejection
- Tomography possible

Disadvantages

- Requires very acc
- Accurate relative Tx/Rx positions
- Requires accurate time sync
- Relative motion between Tx and Rx corrupts signal
- Direct signal must be removed

IDS STREAM-EM: Modularity and Array Architectures

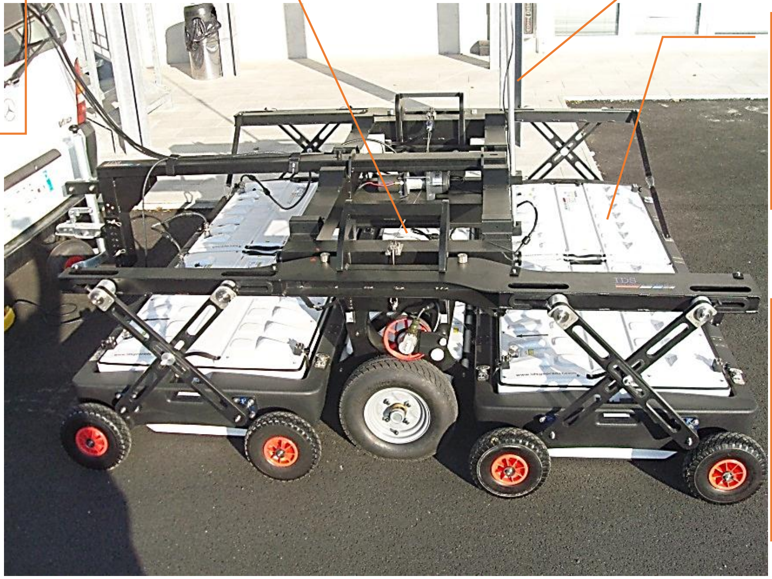
4 dual frequency 200-600 MHz antennas (DCL array) for the detection of shallow and deep junctions (HH polarization)

MF Hi-Mod: the DCL array can be extracted from the Stream-EM to be used in the MF Hi-Mod configuration for mapping sidewalks and areas with difficult accessibility.

GPS or Total Station

1x200 MHz DML array for detecting main pipes along the road (6 cm transversal sampling; VV polarization)

Stream X: the DML array can be extracted from the Stream-EM to be used in the Stream-X configuration for archeology or environment surveys.



Modular composition: easily reassembled

Stream EM

Stream X

Hi-Mod

IDS Systems (we will see today)

Stream EM

SYSTEM SPECIFICATIONS	
OVERALL WEIGHT (PC NOT INCLUDED)	228kg (500 lbs)
RECOMMENDED LAPTOP	Panasonic CF-31 Tough-Book or similar
MAX. ACQUISTION SPEED (@ STD. SCAN INTERVAL)	15 kph (9mph)
POWER CONSUMPTION	72 W
POSITIONING	Survey wheel and/or GPS or total station
NUMBER OF CONTROL UNITS	3 synchronized DAD MCH FW
SCAN RATE PER CHANNEL: (@512 SAMPLES/SCAN)	87 scans/sec
SCAN INTERVAL	17 scans/m @ 200 MHz 33 scans/m @ 600 MHz
POWER SUPPLY	SLA Battery 12VDC 100 Ah
ANTENNA SPECIFICATIONS	
ENVIRONMENTAL	IP65
ANTENNA FOOTPRINT	1.84 m Width
NUMBER OF CHANNELS	38
ANTENNAS CENTRAL FREQUENCIES	200MHz (34 channels) and 600 MHz (4 channels)
ANTENNA POLARIZATION	Horizontal (HH) and Vertical (VV)
ANTENNA SPACING	6 cm
CERTIFICATION	EC, FCC, IC

Stream X

SYSTEM SPECIFICATIONS	
RECOMMENDED LAPTOP	Panasonic CF-19 or CF-31 Tough-Book
MAX. ACQUISTION SPEED (@ STD. SCAN INTERVAL)	36 kph (22 mph)
POWER CONSUMPTION	28 W - 200 MHz version
POSITIONING	Doppler radar and/or GPS or total station
NUMBER OF CONTROL UNIT	1 DAD MCH @ 200 MHz 4 DAD MCH @ 600 MHz
SCAN RATE PER CHANNEL: (@512 SAMPLES/SCAN)	87 scans/sec
SCAN INTERVAL	8 scans/m
POWER SUPPLY	SLA Battery 12VDC 12 Ah + electric crane battery
ANTENNA SPECIFICATIONS	
IP GRADE	IP65
SCAN WIDTH	1.80 m Width
NUMBER OF CHANNELS	15 / 44
ANTENNA CENTER FREQUENCIES	200MHz or 600MHz
POLARIZATION	VV
ANTENNA SPACING	12cm / 4cm
CERTIFICATION	EC, FCC, IC

Hi-Mod

SYSTEM SPECIFICATIONS	
OVERALL WEIGHT (PC NOT INCLUDED)	31 kg (68 lbs) @ 1 antenna 58 kg (128 lbs) @ 4 antennas
RECOMMENDED LAPTOP	Panasonic CF-19 Tough-Book
MAX. ACQUISTION SPEED (@ STD. SCAN INTERVAL)	9 kph (5.6 mph)
POWER CONSUMPTION	13.3 W @ 1 antenna 26.6 W @ 4 antennas
POSITIONING	Magnetic wheel and/or GPS or total station
NUMBER OF CONTROL UNIT	1 DAD MCH FW
SCAN RATE: (@512 SAMPLES/ SCAN)	from 741 scan/sec. to 181 scan/ sec.
SCAN INTERVAL	42 scans/m
POWER SUPPLY	SLA Battery 12VDC 12 AH
ANTENNA SPECIFICATIONS	
ENVIRONMENTAL	IP65
ANTENNA FOOTPRINT	38x43 cm (single antenna)
NUMBER OF HARDWARE CHANNELS	from 2 to 8
ANTENNA CENTER FREQUENCIES	200 MHz / 600 MHz or 400 MHz / 900 MHz
ANTENNA POLARIZATION	HH
ANTENNA SPACING	50 cm
CERTIFICATION	EC, FCC, IC

STREAM-EM: Main Benefits

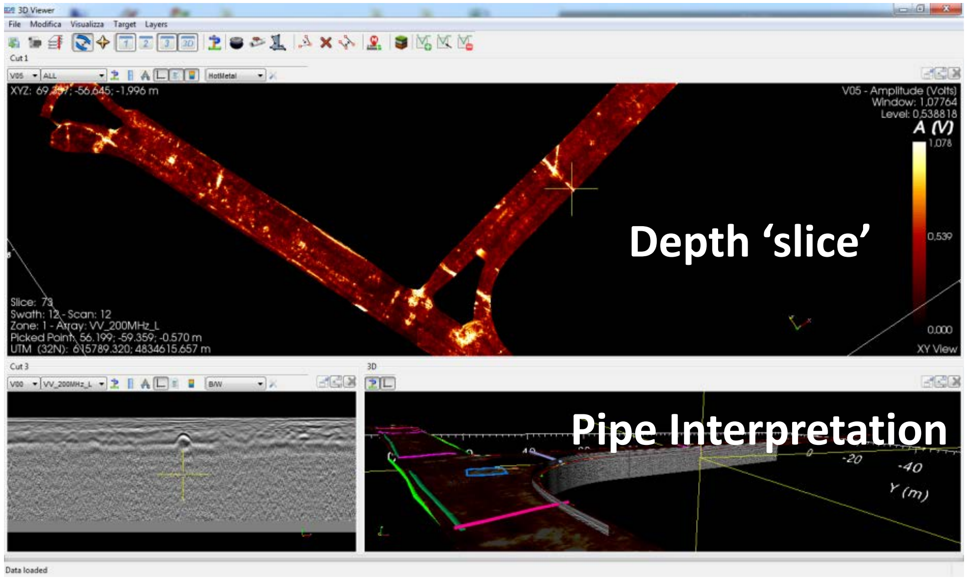
- GPR solution towed by a vehicle (speed > 10mph).
- Data collection in longitudinal direction (without the need of moving the array in the transversal directions) but detection of utilities and connections.
- High productivity
- High modular structure
- High detection capability
- Avoid blocking the road traffic
- Exploit the same advanced processing feature of RIS MF Hi-Mod
- Possibility of different kind of towing frames

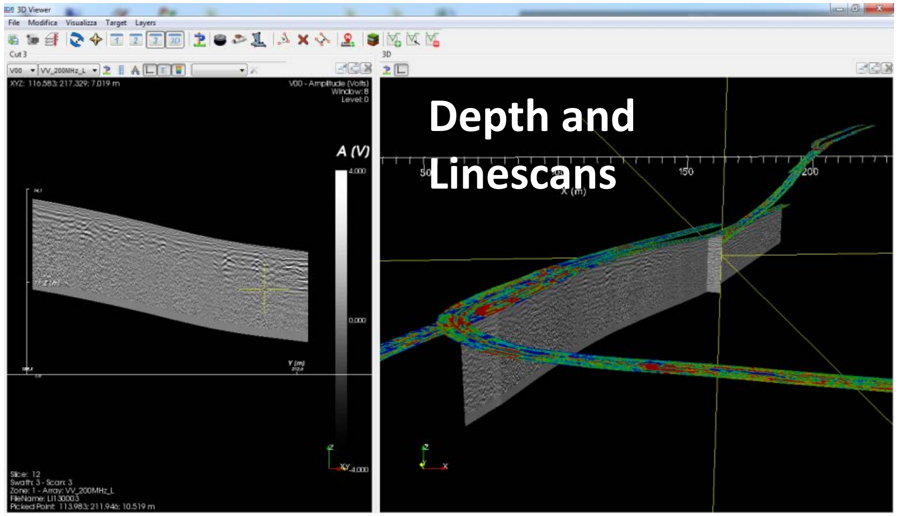
Stream EM System: complete configuration including 3 array of antennas

GRED HD 3D Processing Software

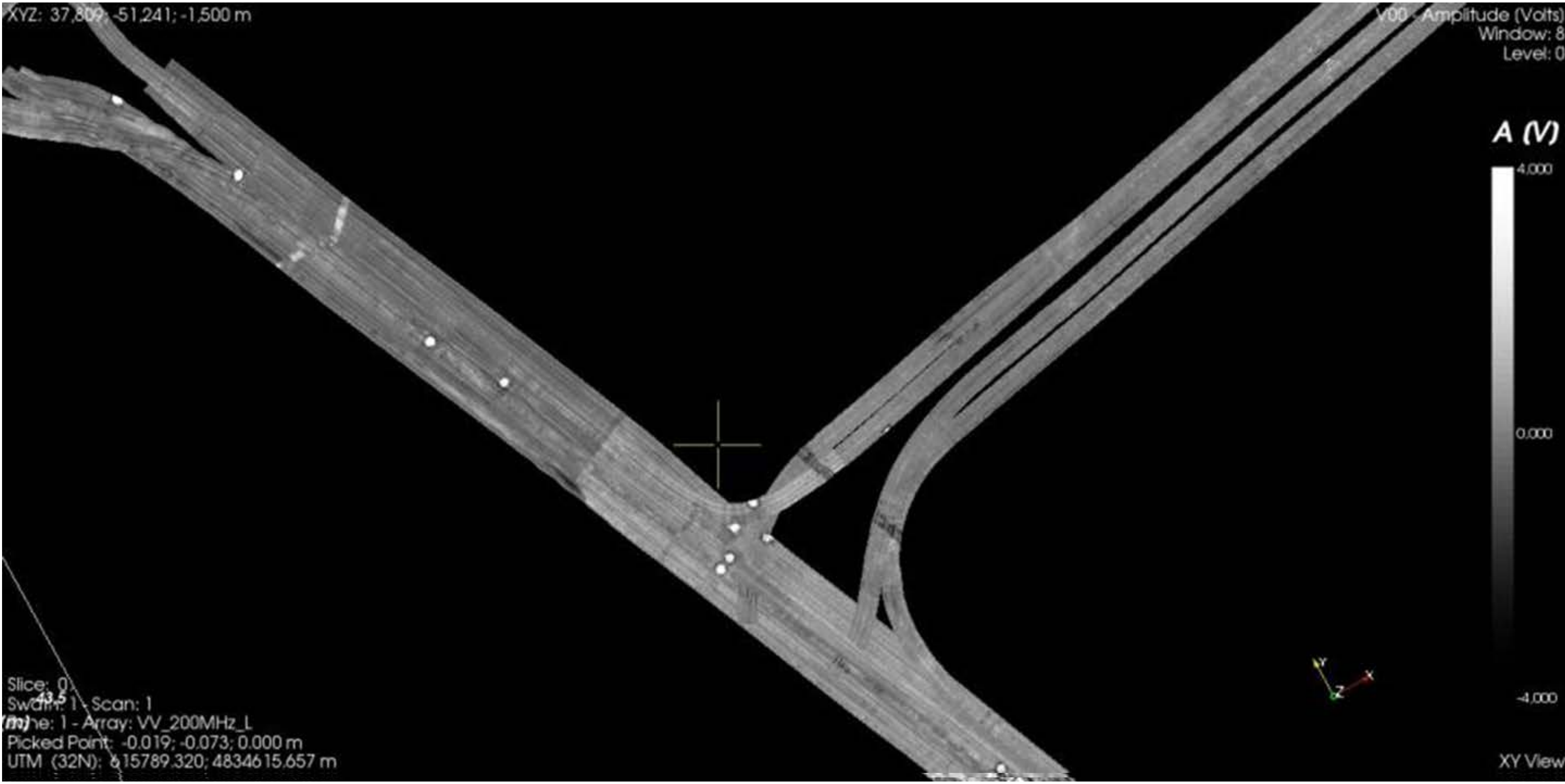
The **GRED HD** software comes with a 3D graphic interface, and advanced software features making it an advanced and complete tool for post processing Ground Penetrating Radar data. The software is able to show:

- Tomography (time slices),
- Radar scans parallel to the acquisition direction,
- Virtual Radar scans orthogonal to the acquisition direction
- 3D view.





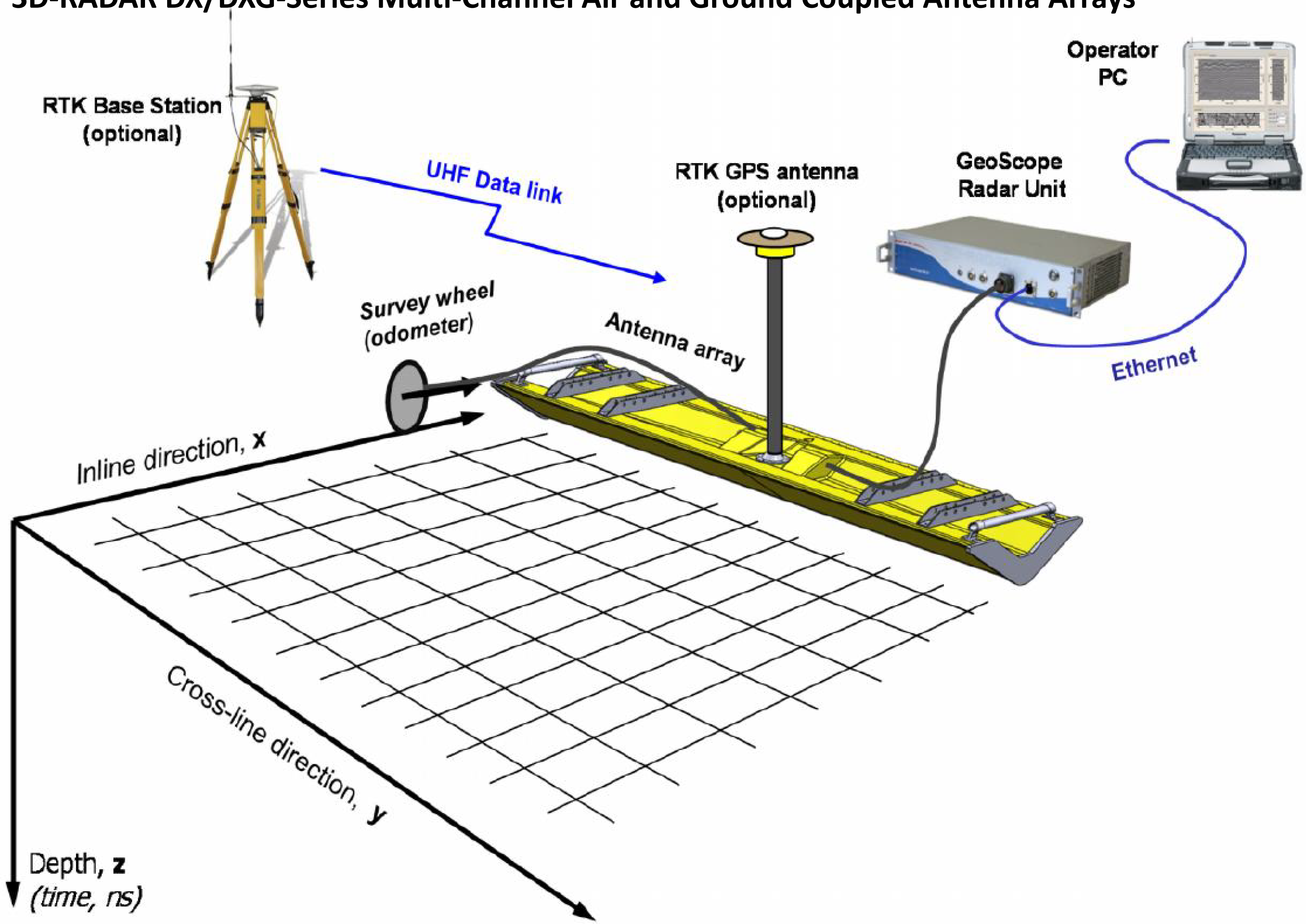
GPR Results
Depth Slicing 3D Volume



3D Radar Theory Of Operation

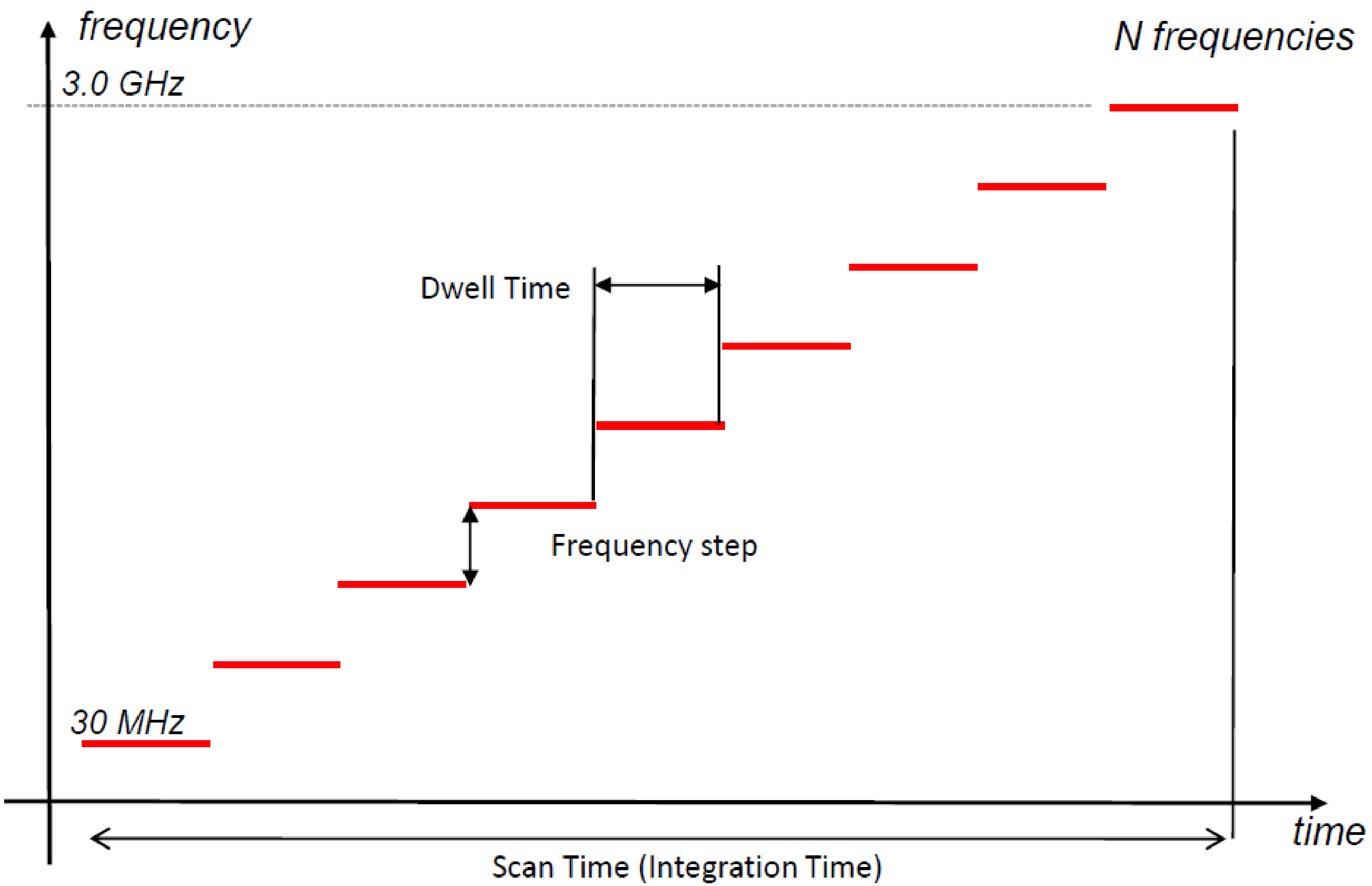
Principle of Operation

3D-RADAR DX/DXG-Series Multi-Channel Air and Ground Coupled Antenna Arrays



3D Radar Theory Of Operation

Step-frequency waveform



3D RADAR Specs

DXG-Series multi-channel antenna arrays

- 200 MHz - 3.0 GHz frequency range
- All elements have uniform size and frequency response
- Simultaneous recording on two receiver antennas
- 2.95 inch (7.5cm) antenna spacing
- Multi-offset and automatic CMP-recording
- Built-in GPS for time stamp and coarse positioning

3D-Radar Examiner

Designed to handle huge datasets

- No data reduction
- Post processing performed on full dataset

Drastically reduced processing time

- Data available for analysis almost immediately after the survey

Intuitive GUI

- Easy extraction of meaningful data

High positioning accuracy

- State-of-the-art GPS outliers filtering

Easy to use annotation function

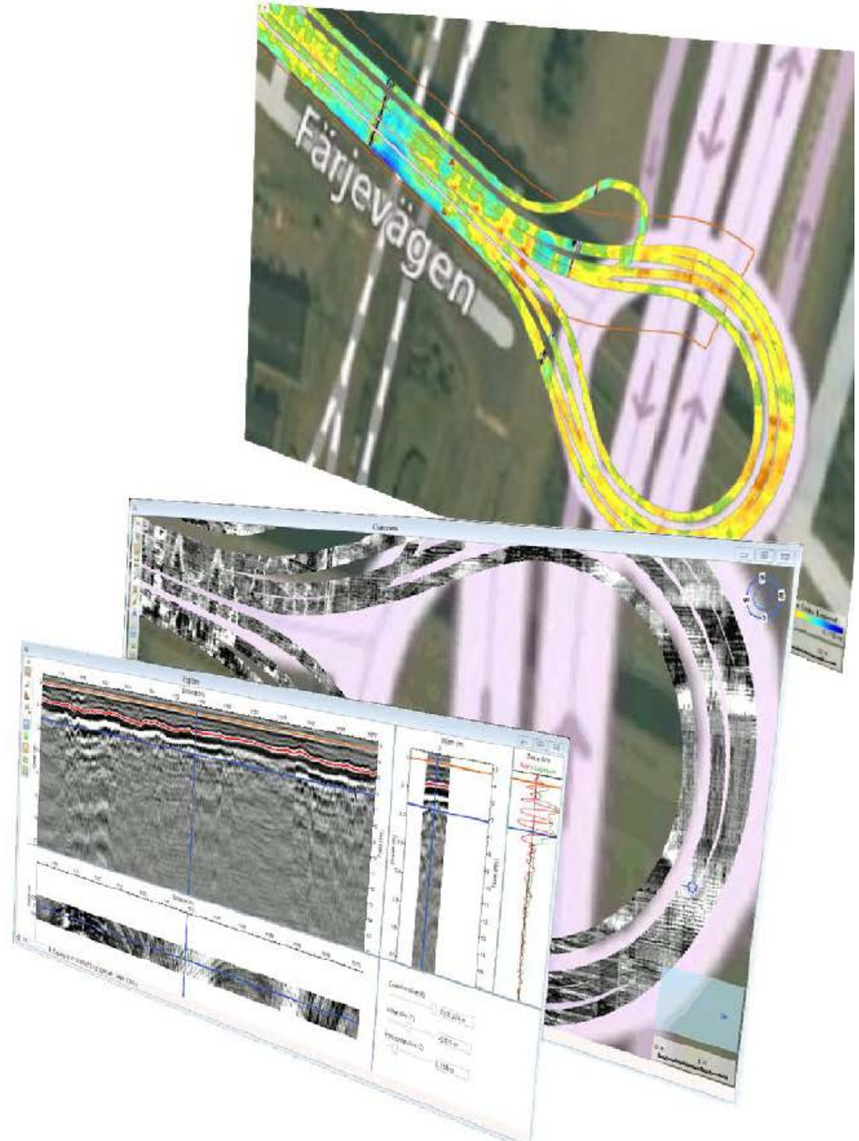
- Annotations exported with subsurface images

Import/Export of geo-referenced maps and images

- AutoCAD, Google Earth, Video

Fully documented SW development kit

- Integration of specific algorithms



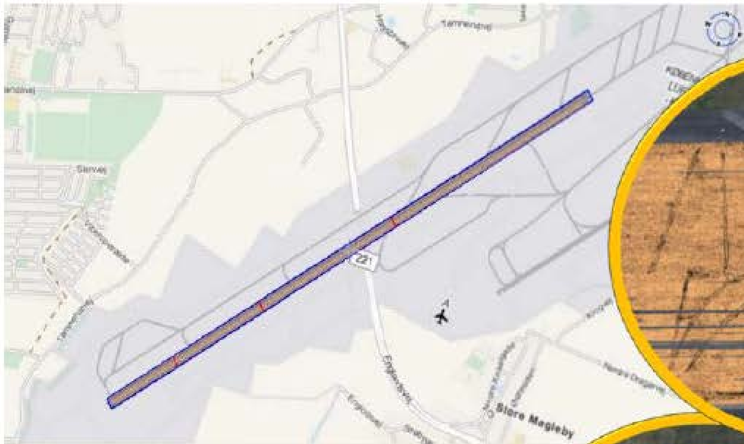
Airport Runway Inspection

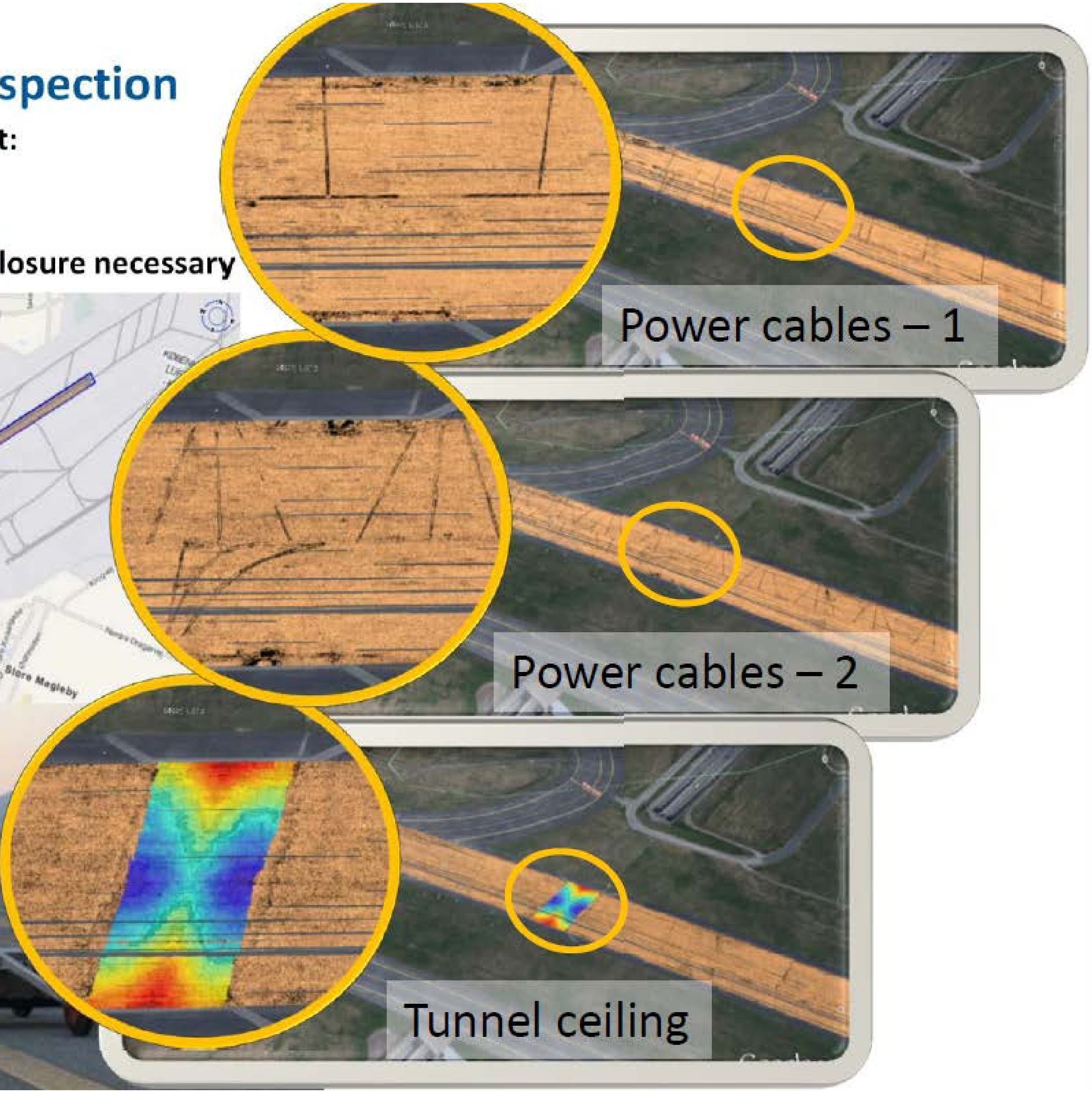
Copenhagen Kastrup airport:

Area covered: 3 km x 60 m

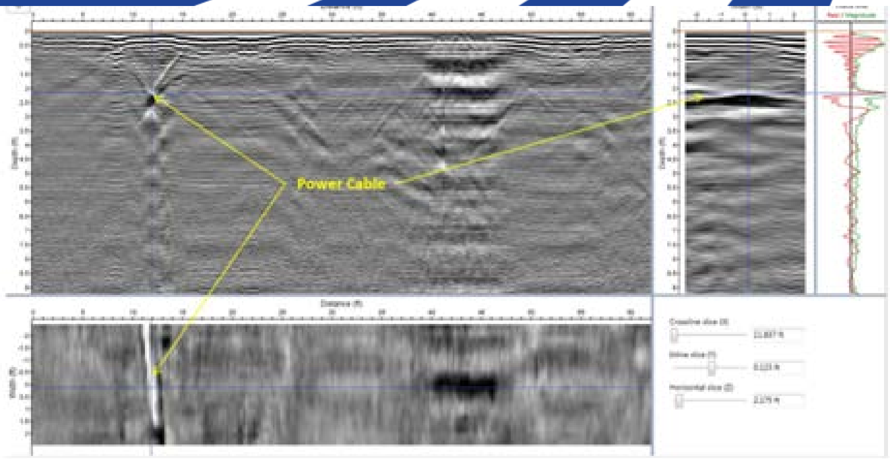
Survey duration: 5 h 20 min

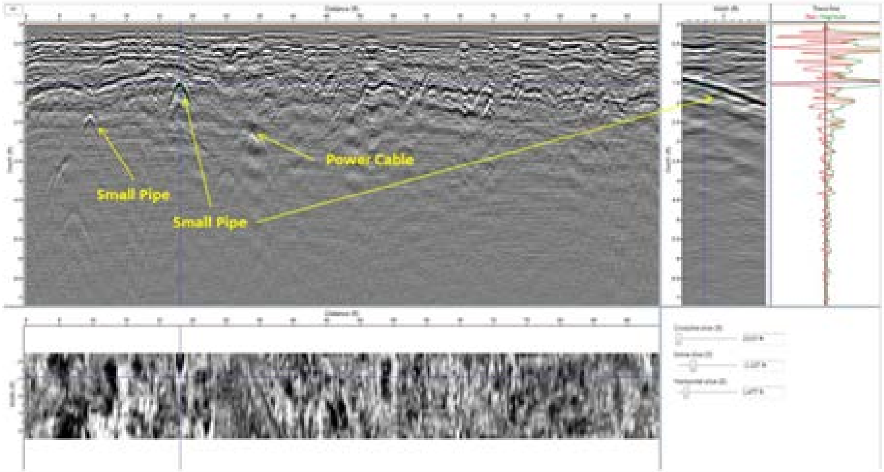
No closure necessary

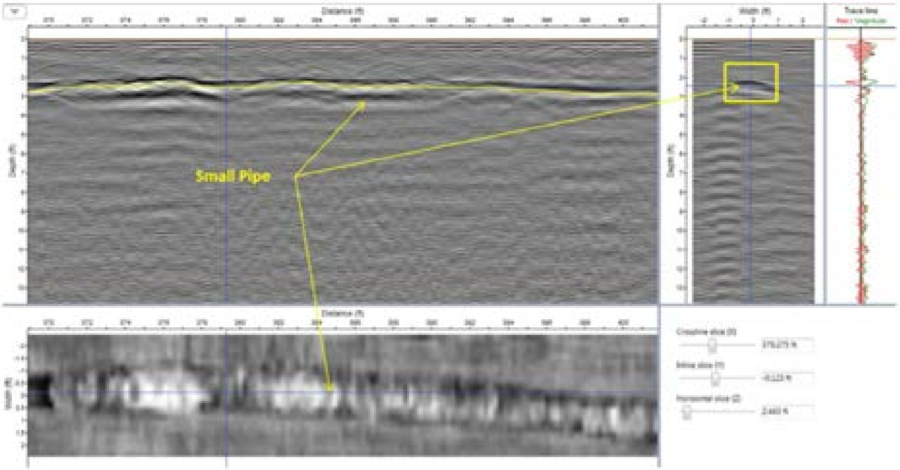




3D Radar Example datasets



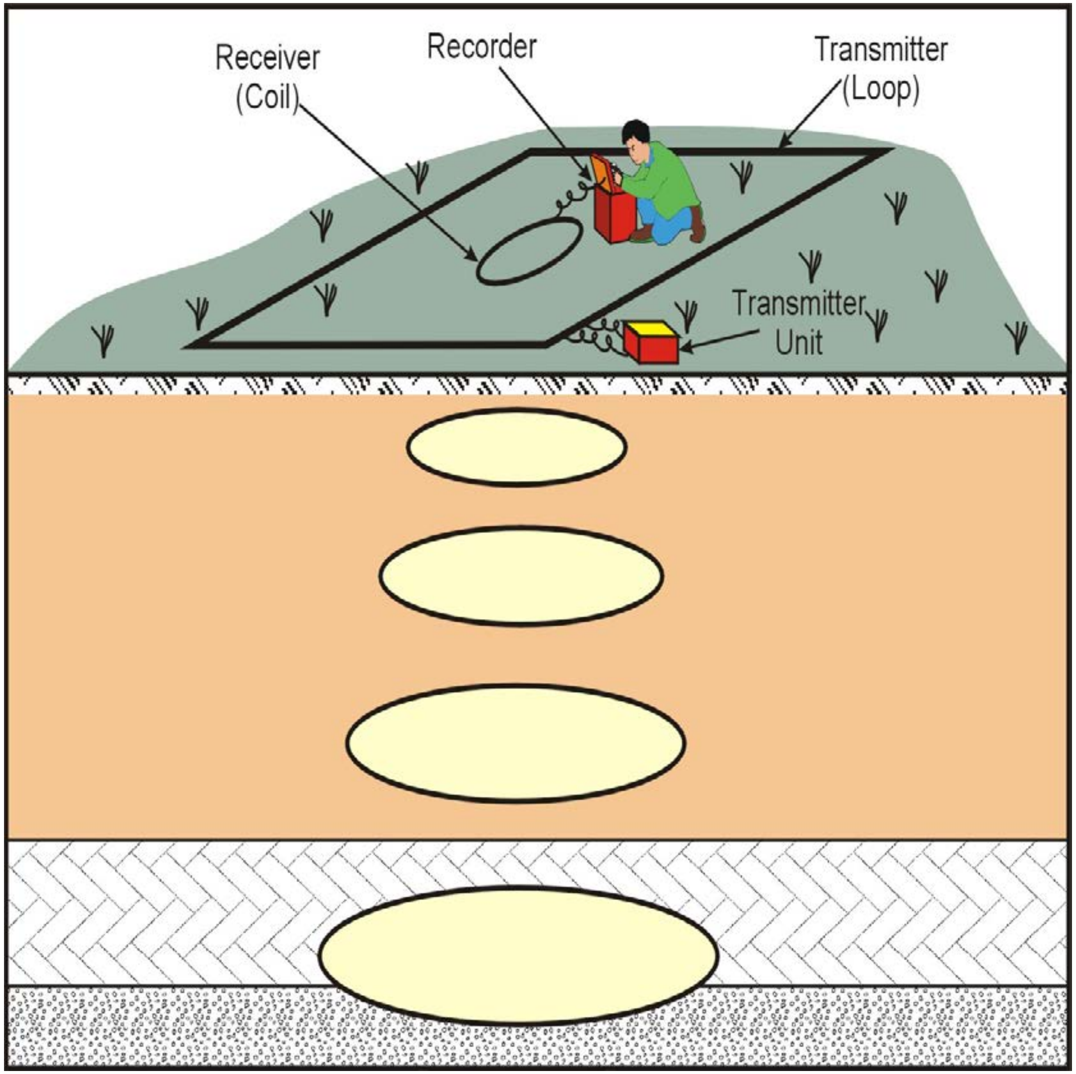




Next Section: Time-Domain Electromagnetic Induction

QUESTIONS ON GPR?

SHRP2 TDEMI



Receiver
(Coil)
Recorder
Transmitter
(Loop)
Transmitter
Unit

TDEMI - Applications

- Unexploded Ordnance (UXO) detection
- Utility locating & imaging
- Identify **metallic objects**
  (*ferrous or non-ferrous)
- Geologic mapping (1D or 2D)
- Environmental problems (UST, wells, etc.)

TDEMI - Method

- Current is transmitted though the transmitter loop (Tx) in a time varying manner with on and off cycles
  - Most commonly a square wave
  - Normally cycle frequency 60hz or higher
- Receiver loops (Rx) record data after the transmitter is turned off
  - The goal is to measure the current induced in metallic objects such as utilities, not the primary field created directly by the transmitter current
  - Typically, measurements are made over windows of time after transmitter turnoff.
    - Referred to as ***"time-gates"***

Faraday's Law

$$\boxed{\nabla \mathrm{x} \mathbf{E}} = \boxed{\frac{-\partial \boldsymbol{B}(t)}{\partial t}}$$

The Curl of Electric Field
A measure of the rotation of the vector electric field

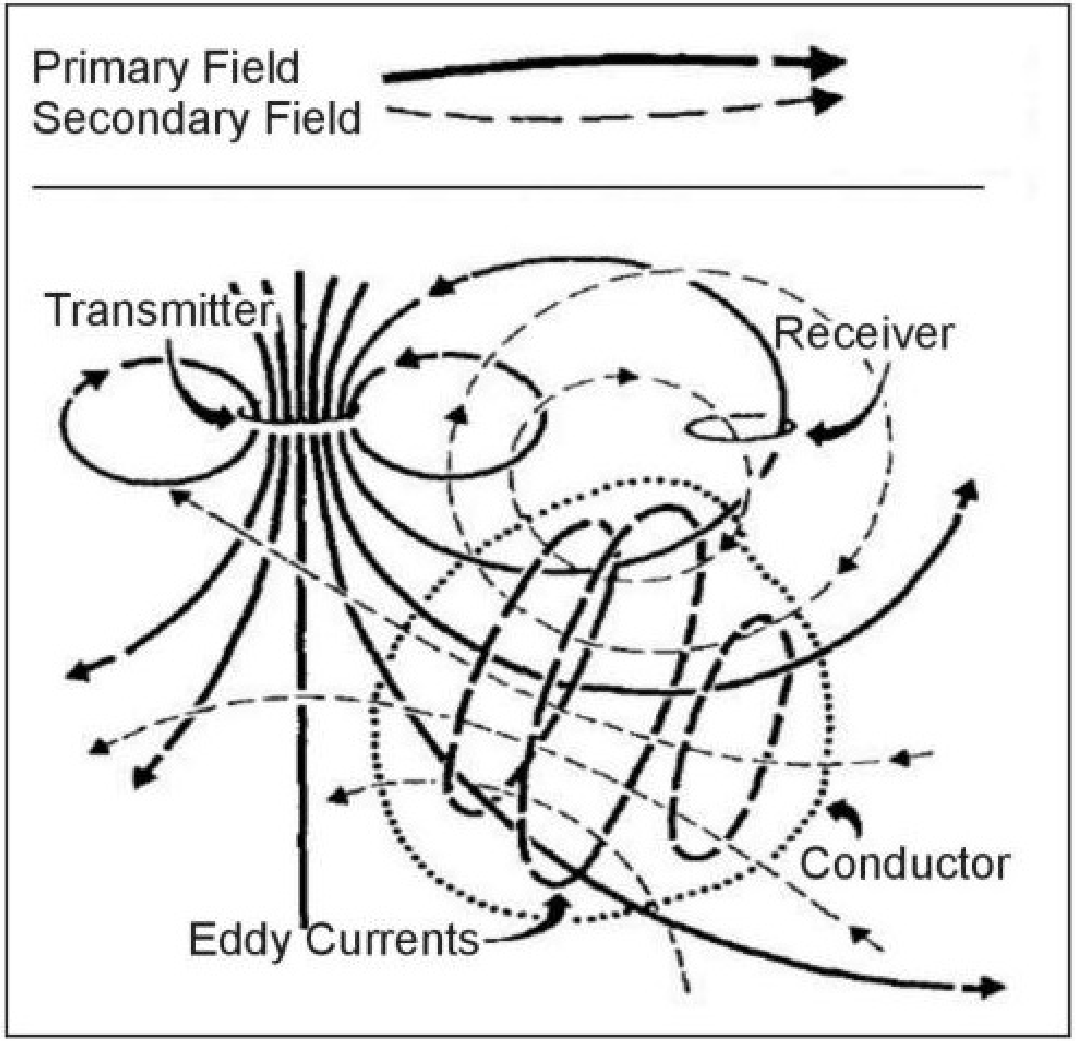
The partial derivative of the magnetic field with respect to time
Measures how the magnetic field changes with time

What does this mean?

- A magnetic field that is changing in time will generated a rotating electric field
- A rotating electric field will generate a time varying magnetic field
- Which, in turn produces a current in a TDEMI receiver loop

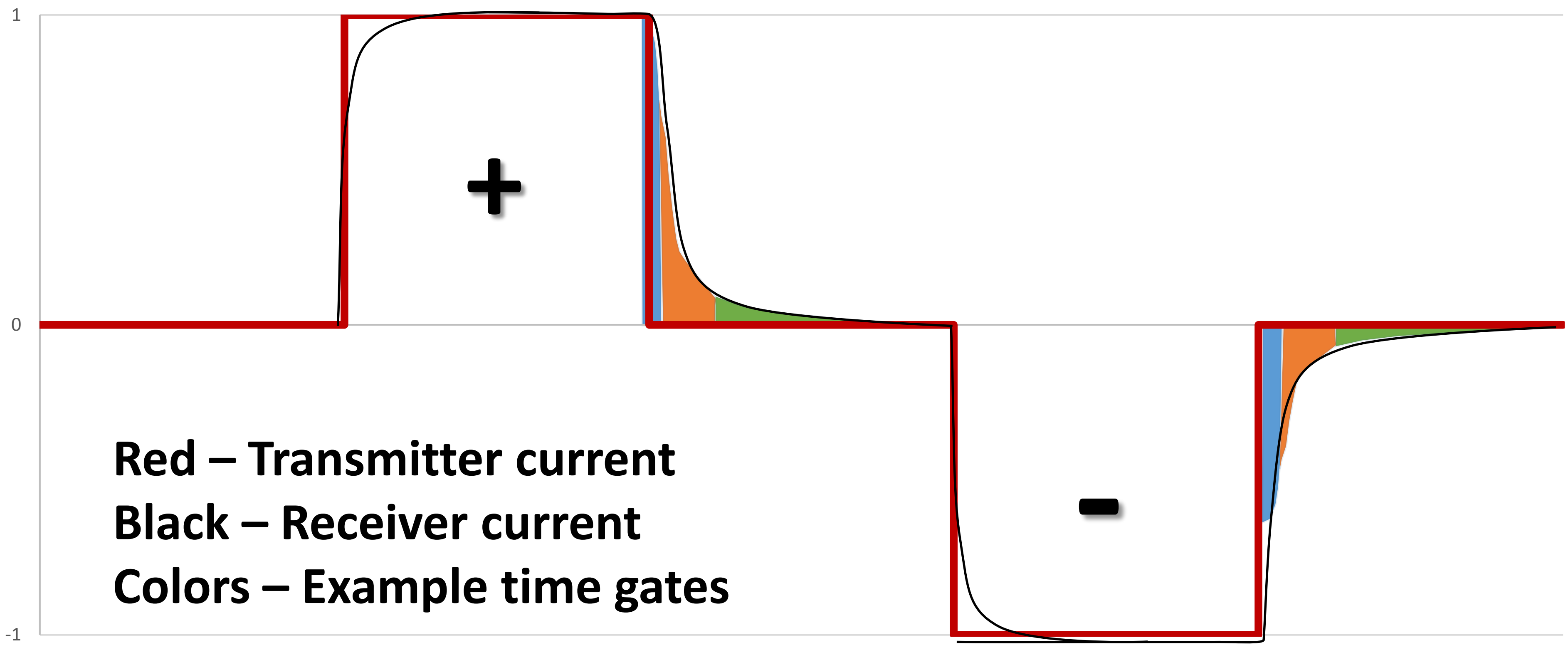
TDEMI – Basic Theory

- The EM field in the earth



EMI in a Metal/Utility Object

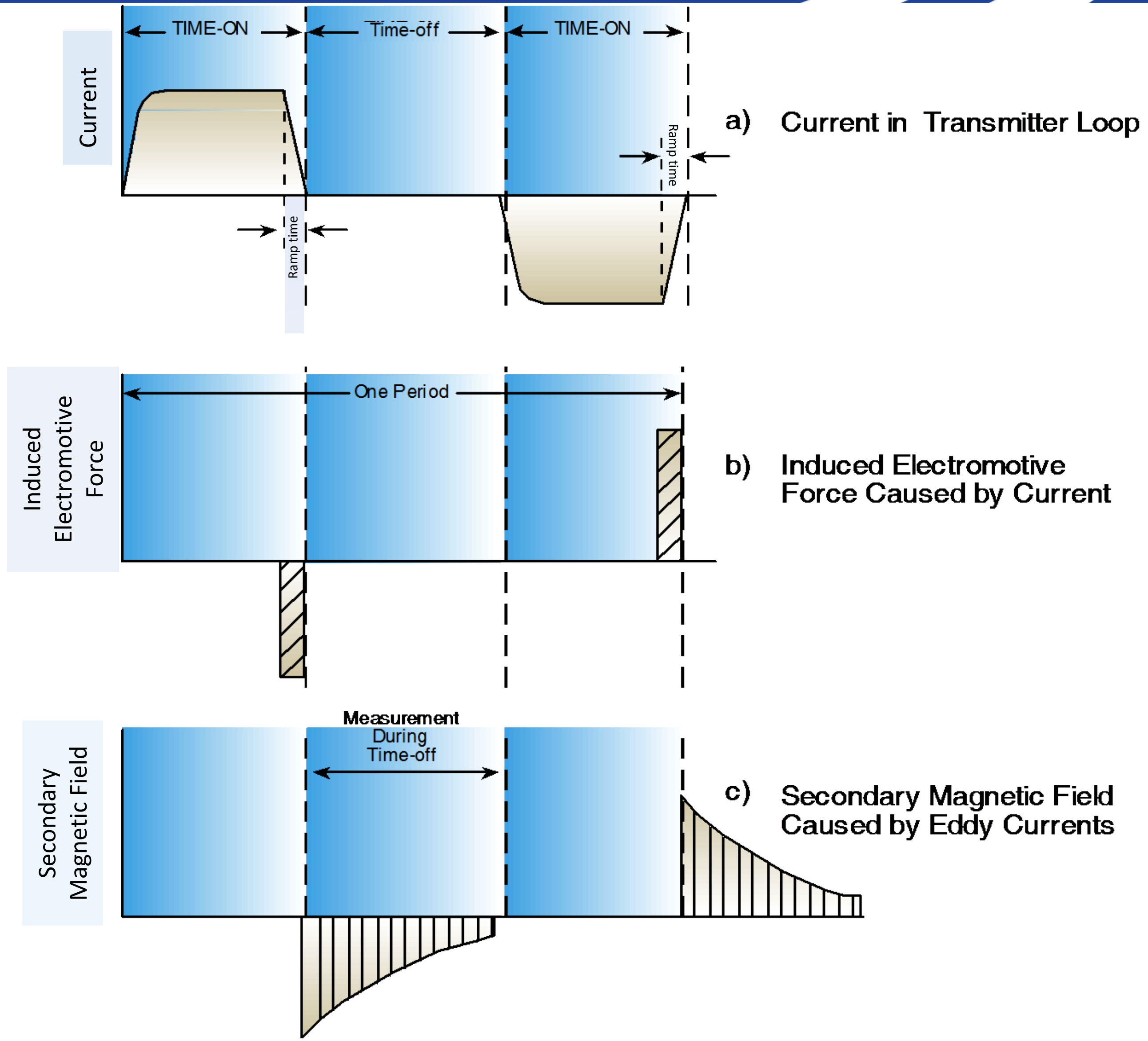
Transmitter Waveform – Receiver Record Time



***NOTE THE TIME SCALE (60 per second)**

Number of pulses per second is termed the "Duty Cycle"

TDEMI Theory



Data Collection Parameters

- Data collection parameters can vary significantly between systems and applications.
  - Tx frequency – number of times per second that the Tx turns on and off
    - Lower frequencies allow for longer recording after turn-off, and potentially deeper investigations
    - Higher frequencies allow for more stacking or higher sample rates
      - Stacking response from multiple Tx turn-offs increases signal to noise at the expense of sample rate
  - Number and size of time gates
    - More time gates allow for better discrimination of targets, but fewer allow for larger signal to noise ratios due to longer time periods being added together

Data Collection Parameters – Effective Sample Rate

Tx Frequency	Stacking	Effective Sample Rate (per sec)	Down-line sample distance at 5 mph (inches)
270	1	270	0.3
270	10	27	3.3
270	100	2.7	32.6
270	500	0.54	163.0
120	1	120	0.7
120	10	12	7.3
120	100	1.2	73.3
120	500	0.24	366.7
60	1	60	1.5
60	10	6	14.7
60	100	0.6	146.7
60	500	0.12	733.3
30	1	30	2.9
30	10	3	29.3
30	100	0.3	293.3
30	500	0.06	1466.7
15	1	15	5.9
15	10	1.5	58.7
15	100	0.15	586.7
15	500	0.03	2933.3

TDEMI Applications

- TDEMI is very flexible and can be used for everything from metal detection to geology mapping
- For Geology mapping, larger Tx and Rx loops are used, and transmitter turn-off is very controlled and measured. The important information is not just signal amplitude, but where the amplitude is in time after transmitter shut-off (which time gates)
- For metal mapping, smaller Tx and Rx loops are used, often with many turns in the wire.

TDEMI – Other Applications

- UXO
- Buried Tanks, barrels, utilities, cars (yes, we have found buried cars)
- Geologic targets
  - Faults
  - Gravel deposits
  - Clay layers
- Groundwater
  - Contamination plumes
  - Water quality (salinity)
  - Aquifer thickness, extents

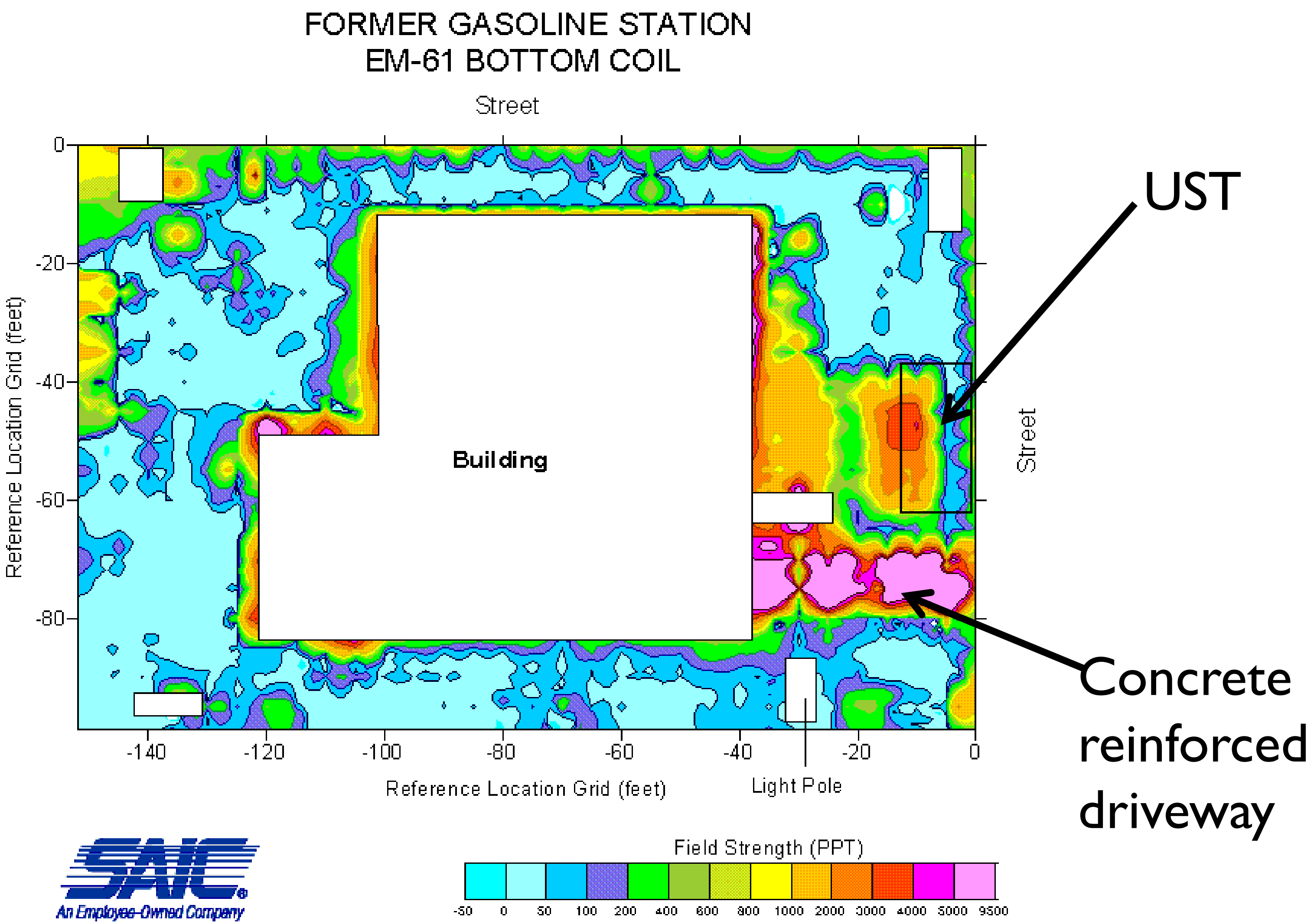
TDEMI “Metal-Detecting” Instrument

Geonics EM-61MK2
(with GPS)

TDEMI "Metal-Detecting" Instrument

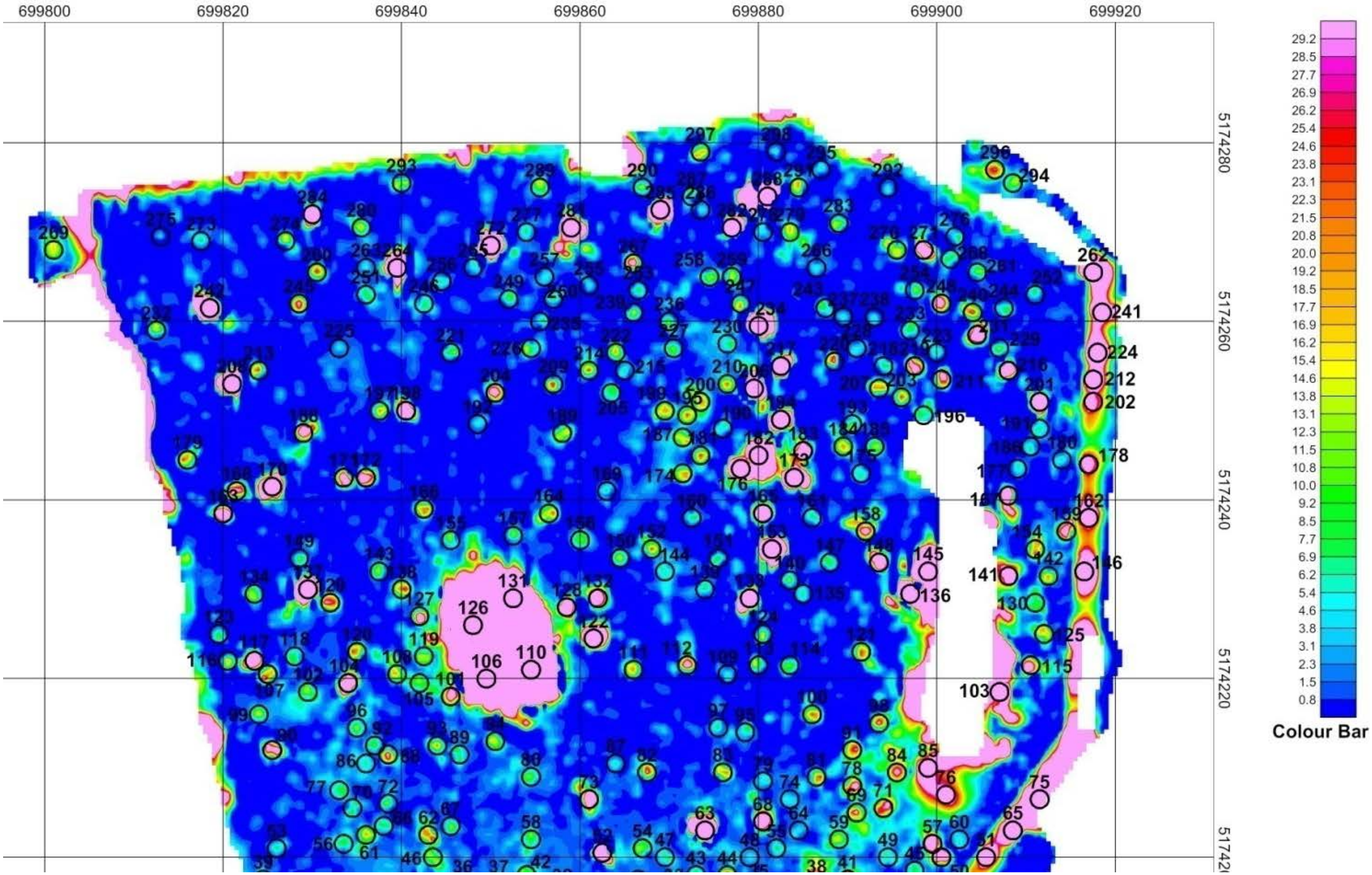
Zonge's Dynamic Nano-TEM
(with GPS)

TDEMI - Environmental (UST)

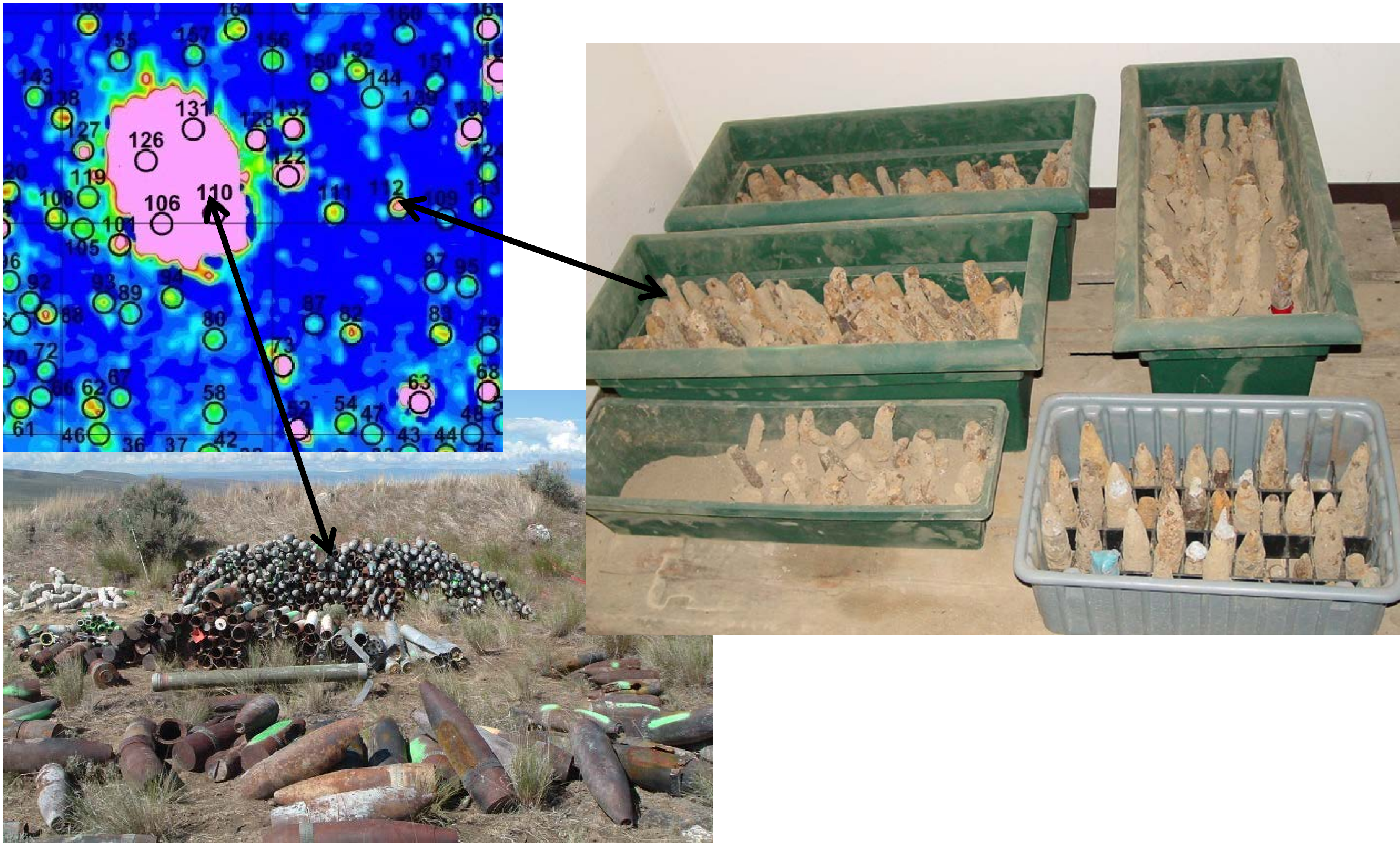


SAIC An Employee-Owned Company

TDEMI – Environmental (UXO)

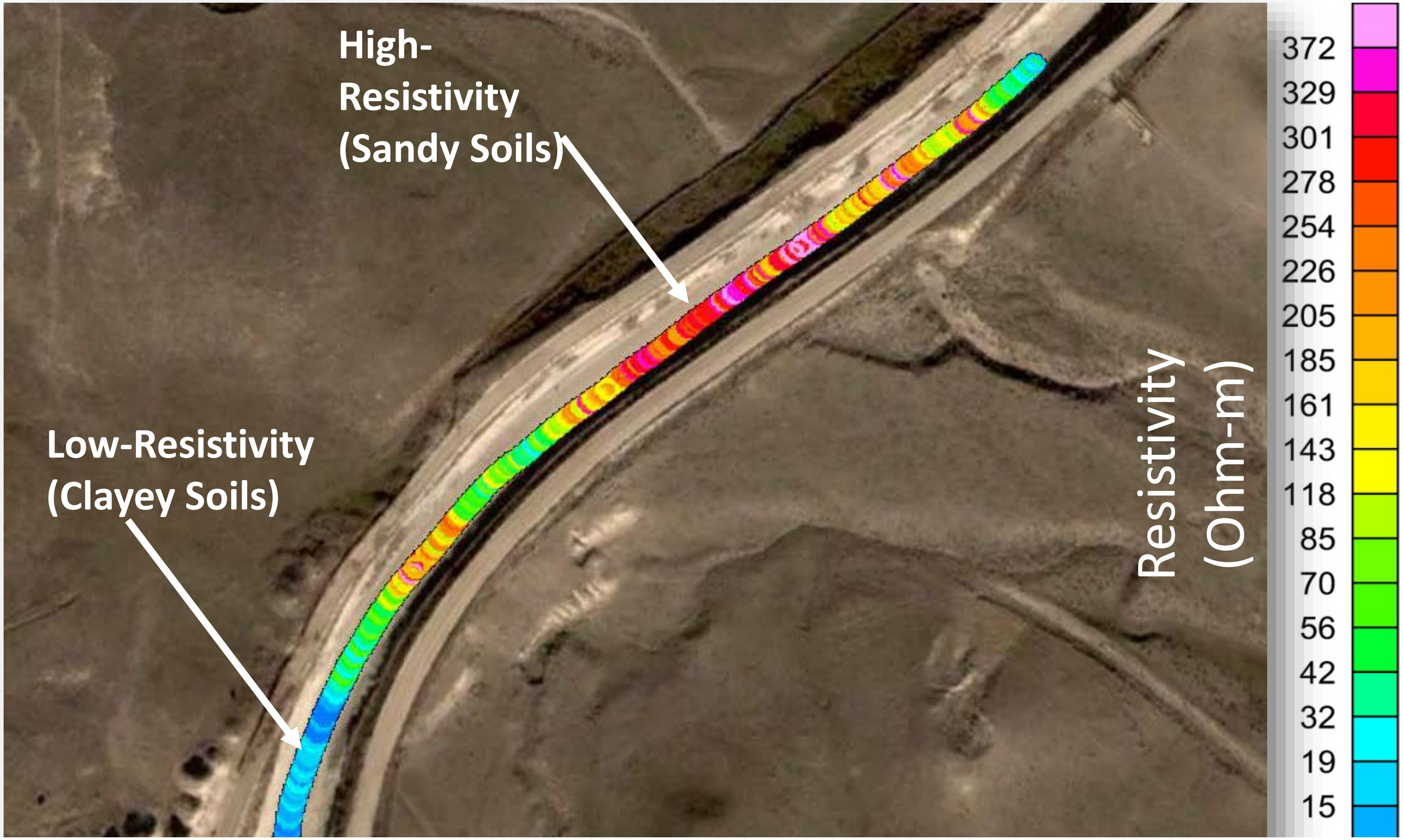


UXO – Unexploded Ordnance
"Dig Results"



TDEMI – Engineering (sand/gravel mapping)

TDEMI – Engineering (sand/gravel mapping)

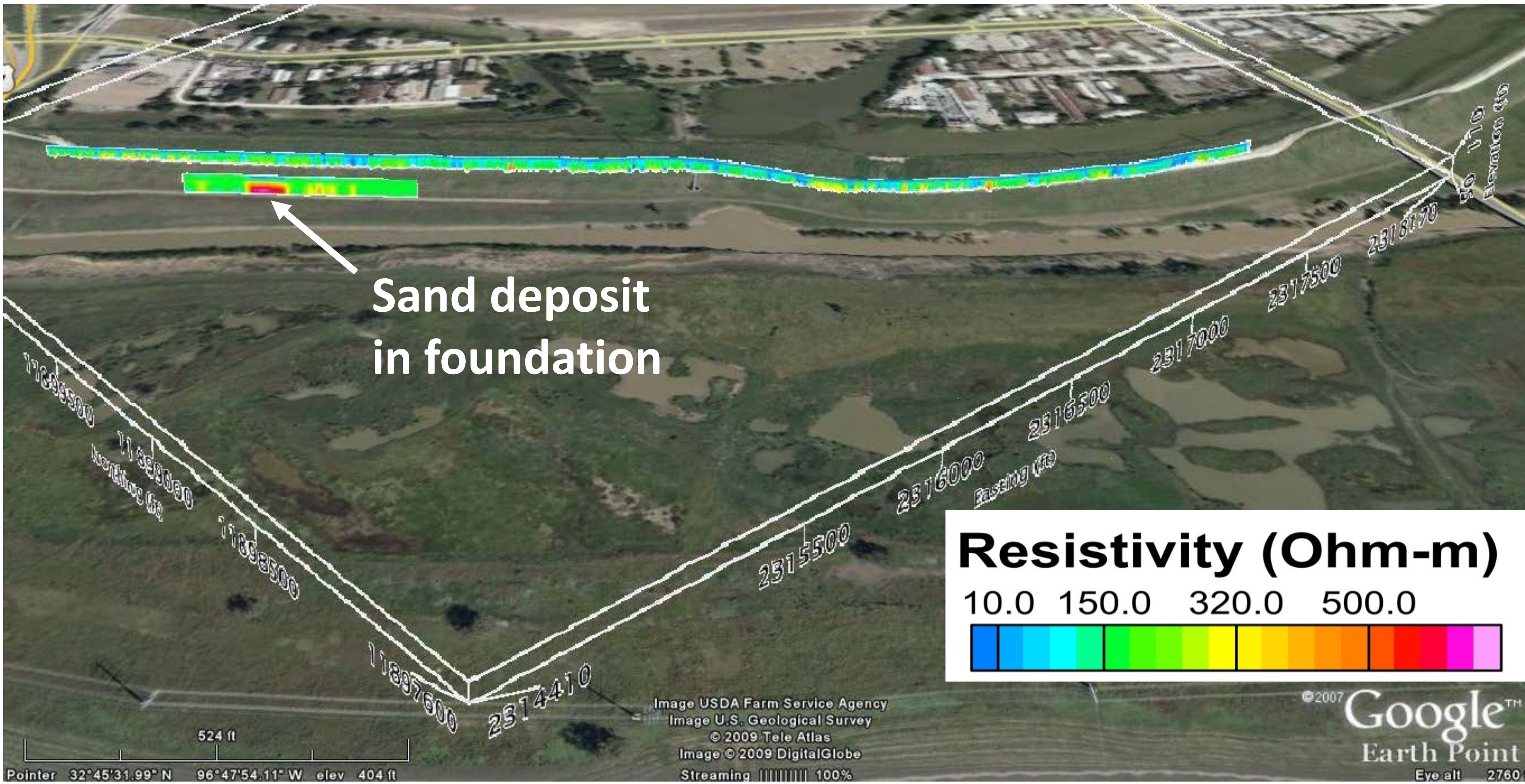


Inverted resistivities sliced at a depth of 10 feet b.g.s.

Able to distribute plan and profile results easily for viewing in ***Google Earth***

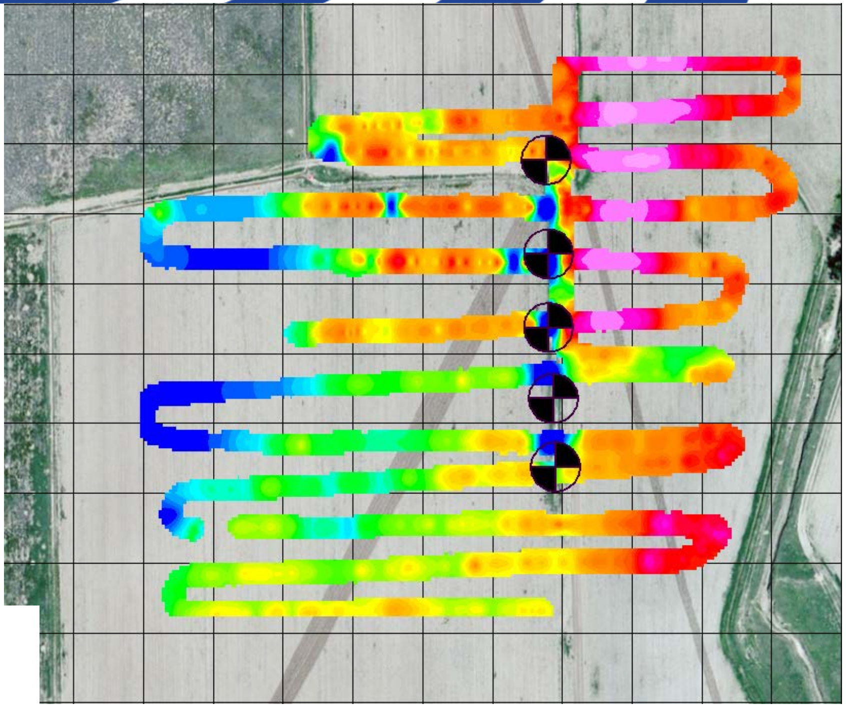
TDEMI – Engineering (Levee Inspection)

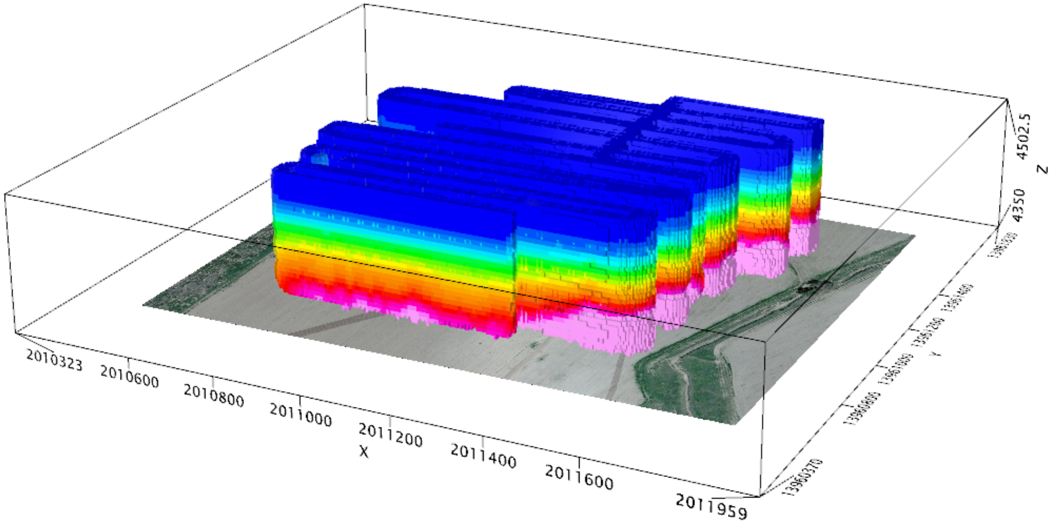
TDEMI – Engineering (Levee Inspection)



TDEMI for Geologic Mapping

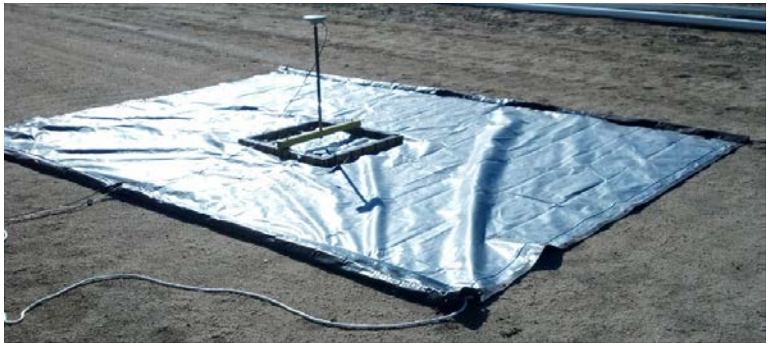
Off Topic – TDEMI on another scale: Geologic mapping for clay/gravel and groundwater applications





Wrap-up '*Other*' TDEMI Applications

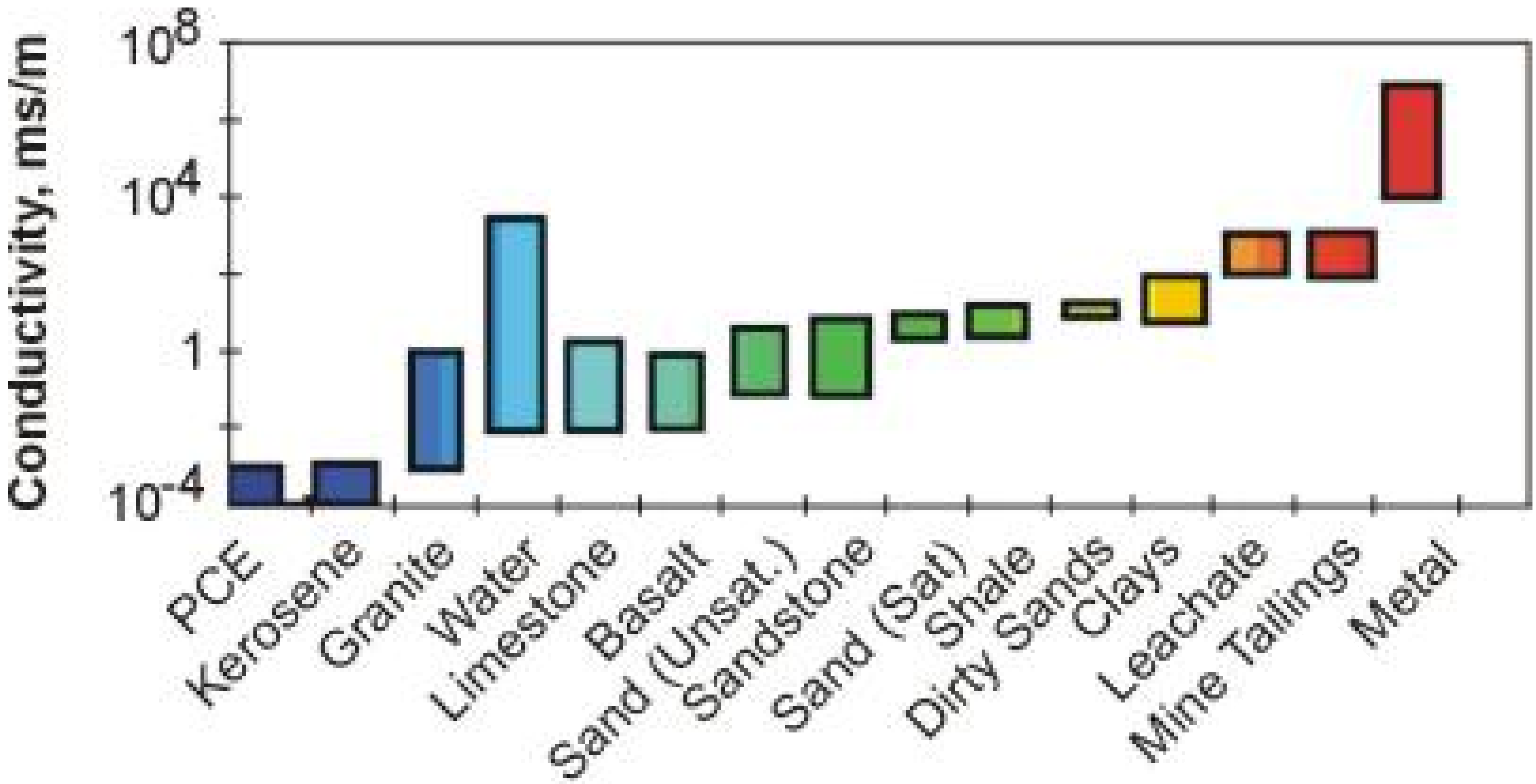
- Is used on scales measured in inches and miles – mineral exploration
- Loops as large a mile on side or as small as a centimeter
- Can be installed on carts, hand carried, laid out on the ground or be installed on helicopters or airplanes



When Does TDEMI Work Well for Utilities?

- When the target utility is metal (***ferrous & non-ferrous***)
- When utility is within the top 5-10 feet (*or so*)
- In any (*or at least most*) geologic settings

Range of Conductivity in Various Earth Materials

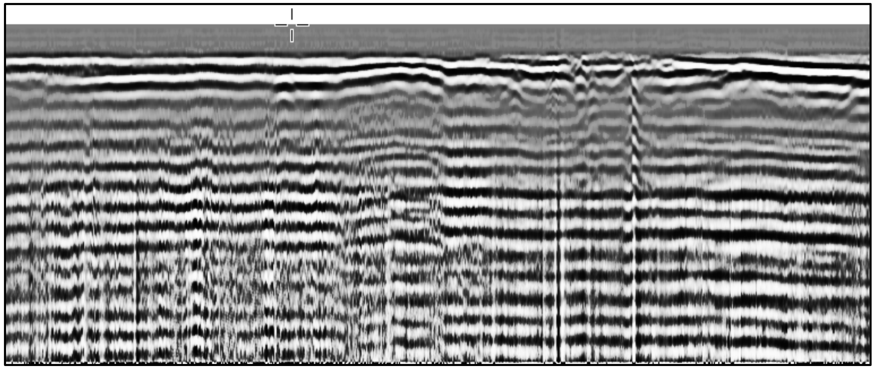


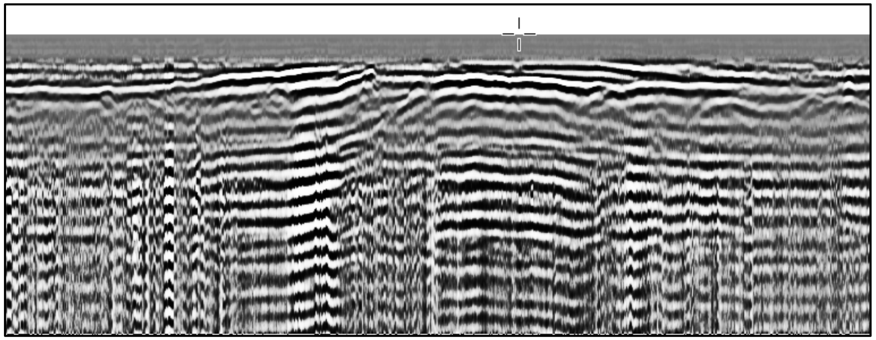
WHY DOES TDEMI WORK? → Material Contrasts!

An Example Where GPR Does Not Work

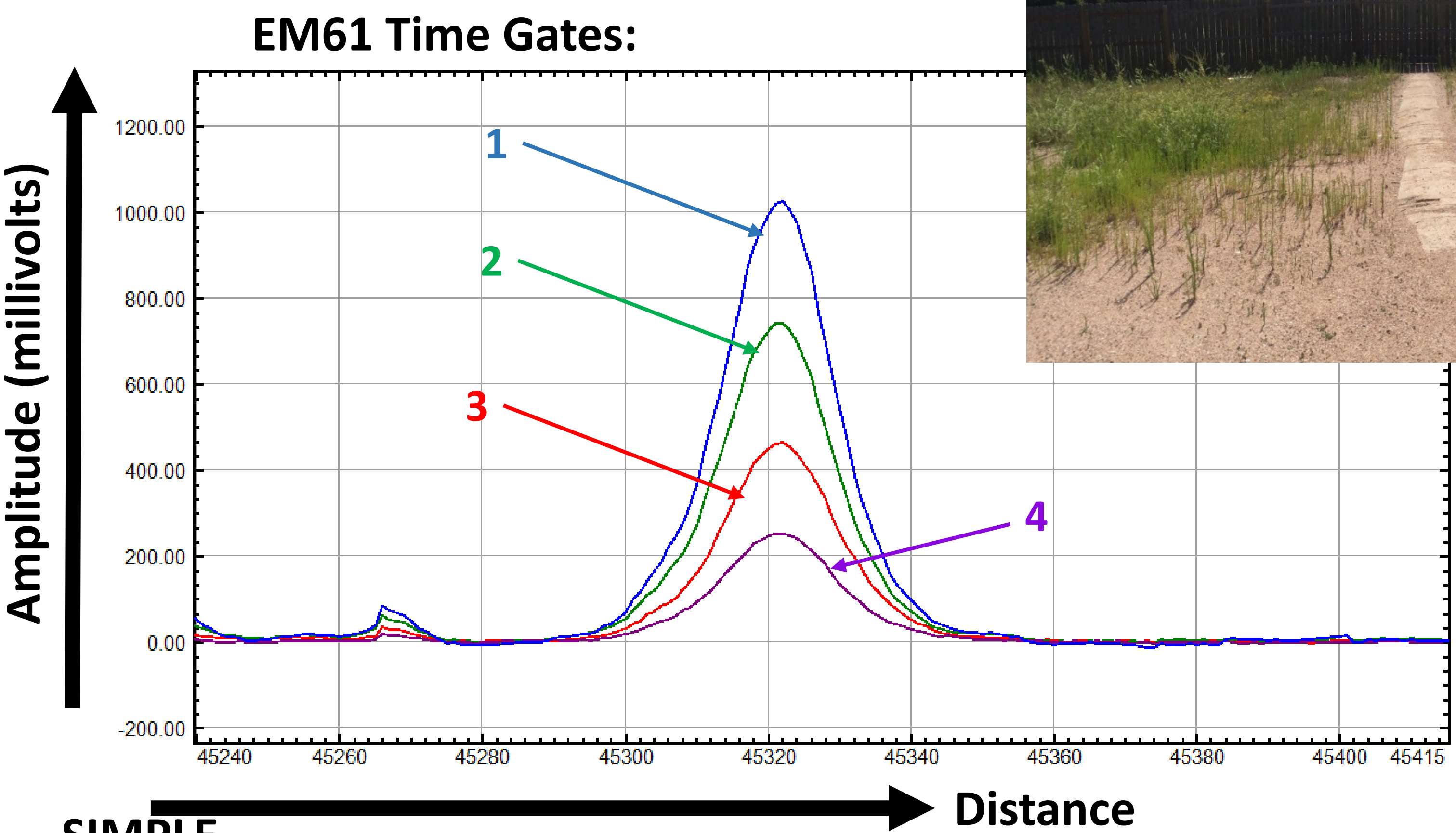
- When the survey area has too much metallic items at the surface.
  - For example, TDEMI will not work along a guard rail, near cars or through reinforced concrete
- When utility is non-metallic, such as:
  - Fiber optic cables without tracer wires
  - PVC, clay or non-reinforced cement pipes
  - Utilities that are too deep
- When depth to the utility is required (TDEMI only maps the lateral location, not depth).

An Example Where GPR Does Not Work



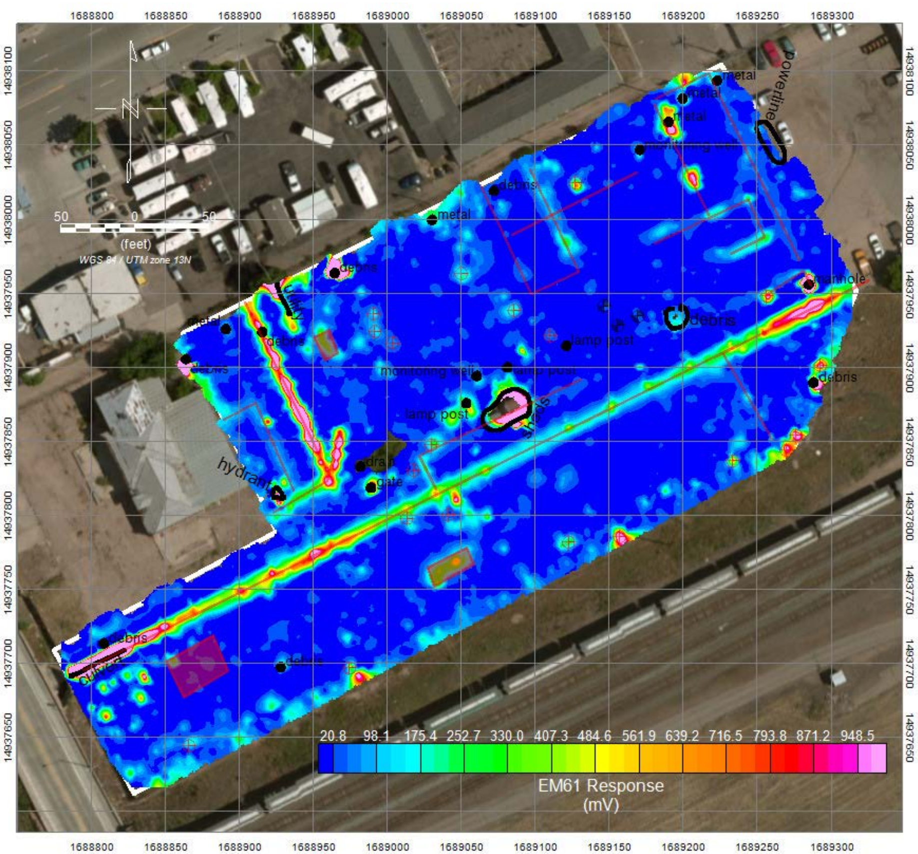


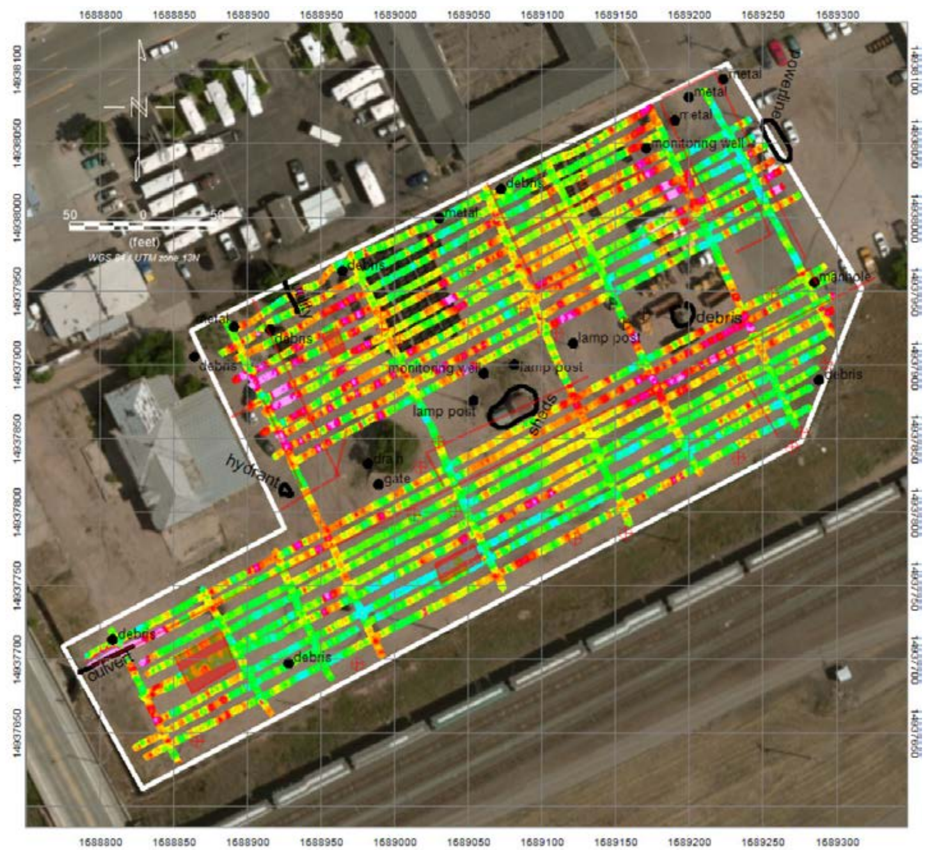
When is TDEMI better than GPR?



SIMPLE

TDEMI an GPR over the same site





TDEMI system used for the outdoor demo: Geonics EM61-MK2

Specifications

MEASURED QUANTITIES
Four time gates of secondary response in mV

EM SOURCE
Air-cored coil, 1 x 0.5 m size

CURRENT WAVEFORM
Unipolar rectangular current with 25% duty cycle

EM SENSORS
1. Main: Air-cored coil, 1 x 0.5 m in size, coincident with EM source
2. Focusing: Air-cored coil, 1 x 0.5 m in size, 30 cm above main coil

DYNAMIC RANGE
18 bits

OUTPUT MONITORS
Color active matrix TFT-LCD 240x360 pixels, and audio tone

DATA STORAGE
512 MB internal disk; SD and CF slots,user accessible

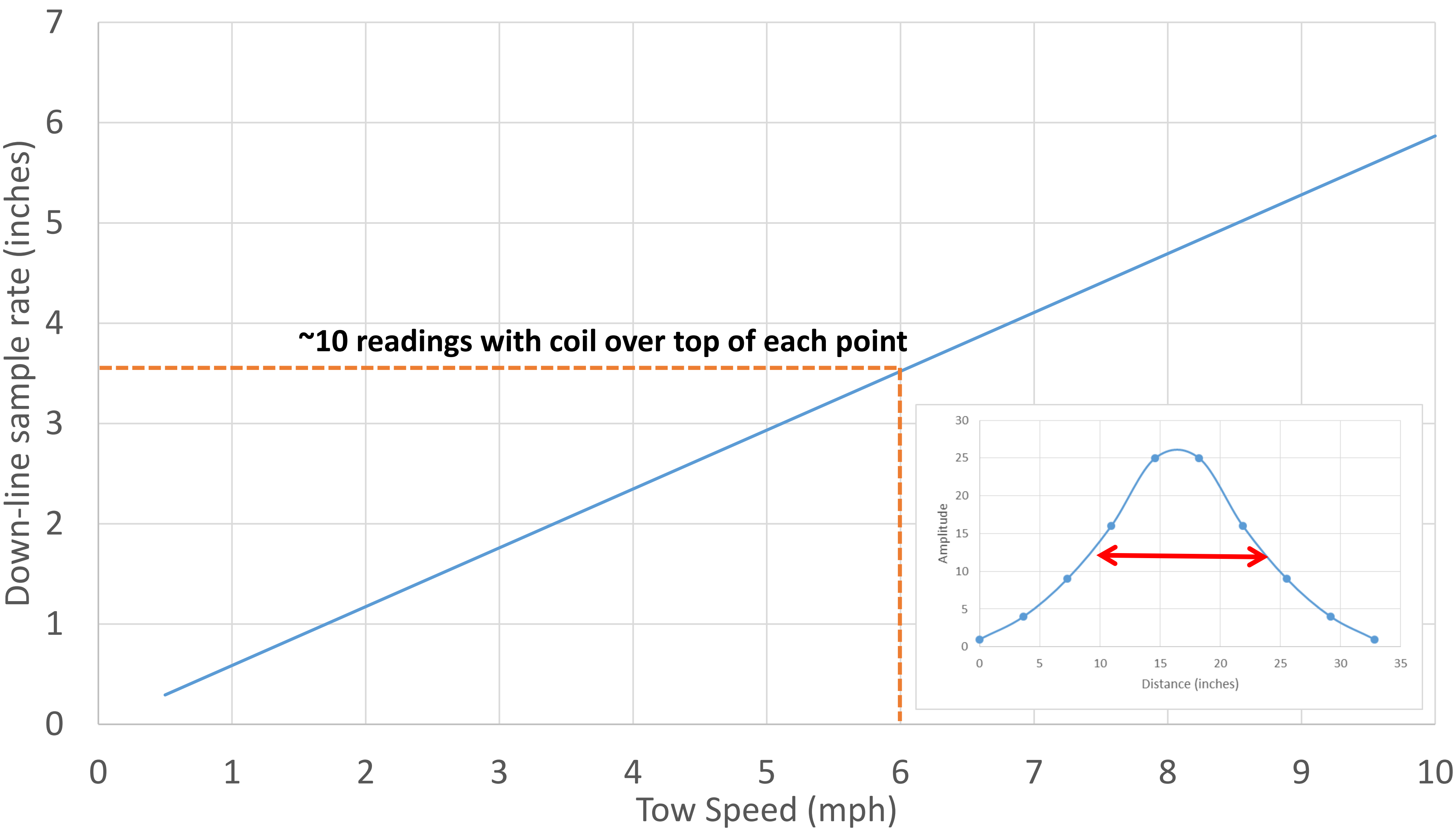
DATA OUTPUT
RS232 - serial port, Bluetooth

POWER SOURCE
12 V rechargeable battery for 4 h continuous operation

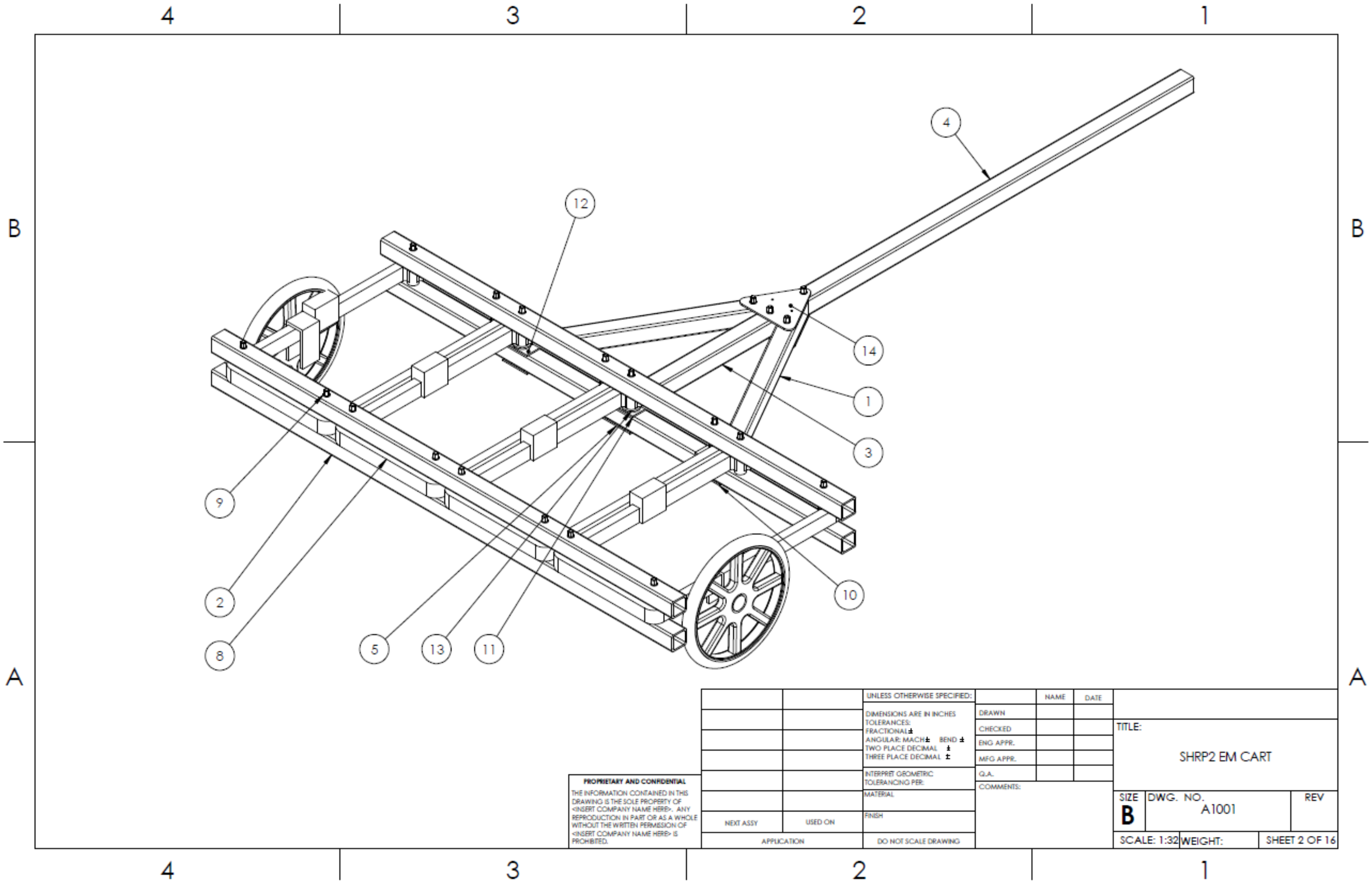
OPERATING TEMPERATURE
-30°C to +60°C

OPERATING WEIGHTS & DIMENSIONS
41 kg trailer mode;
100 x 50 x 5 cm (bootom),
100 x 50 x 2 cm (top)

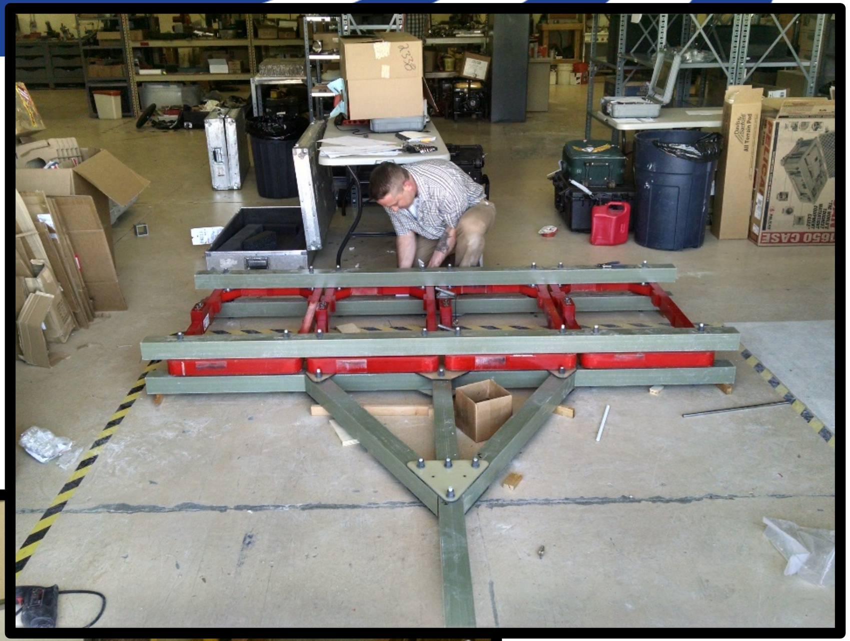
Geonics EM61 – Sample Rate and Maximum Speed (mph)

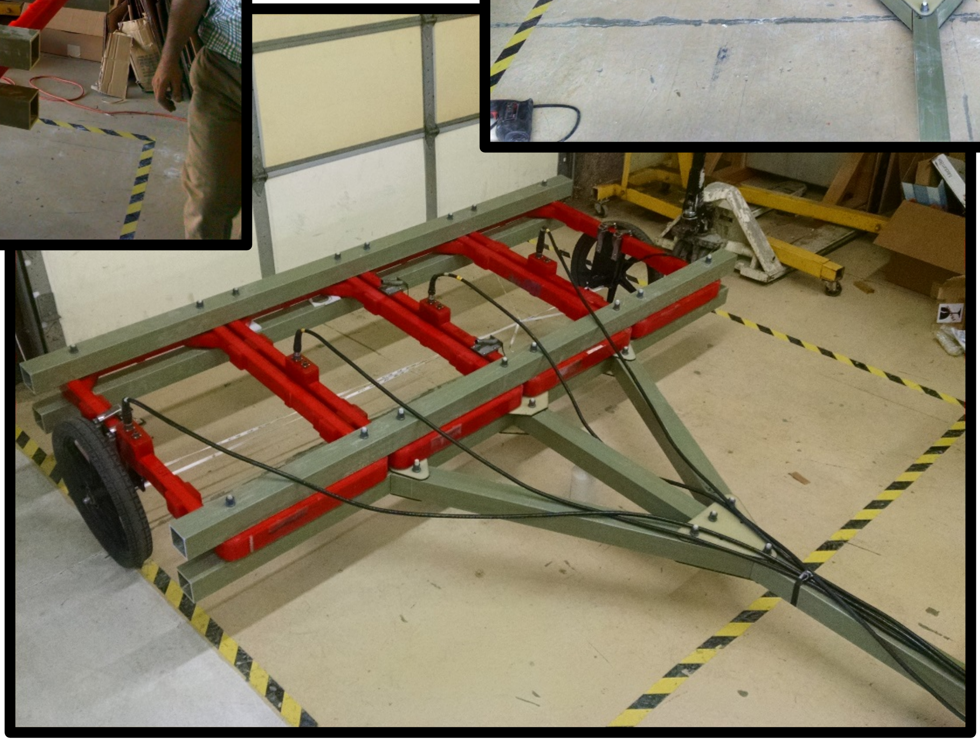


TDEMI Conceptual Cart Design (*for Demonstration)

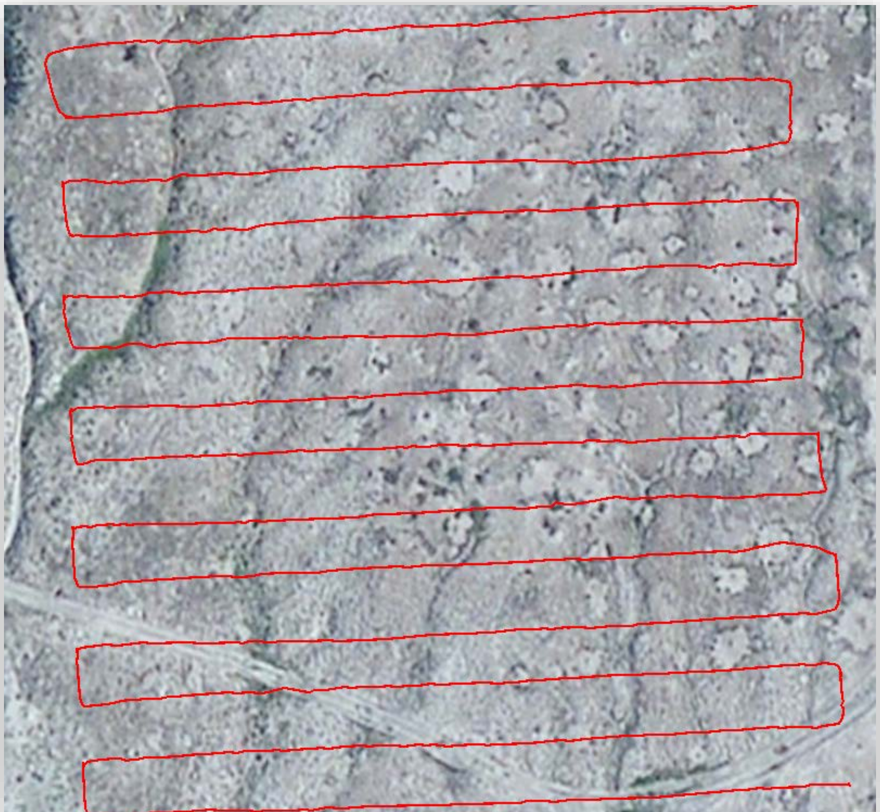


TDEMI Actual Cart for Demo

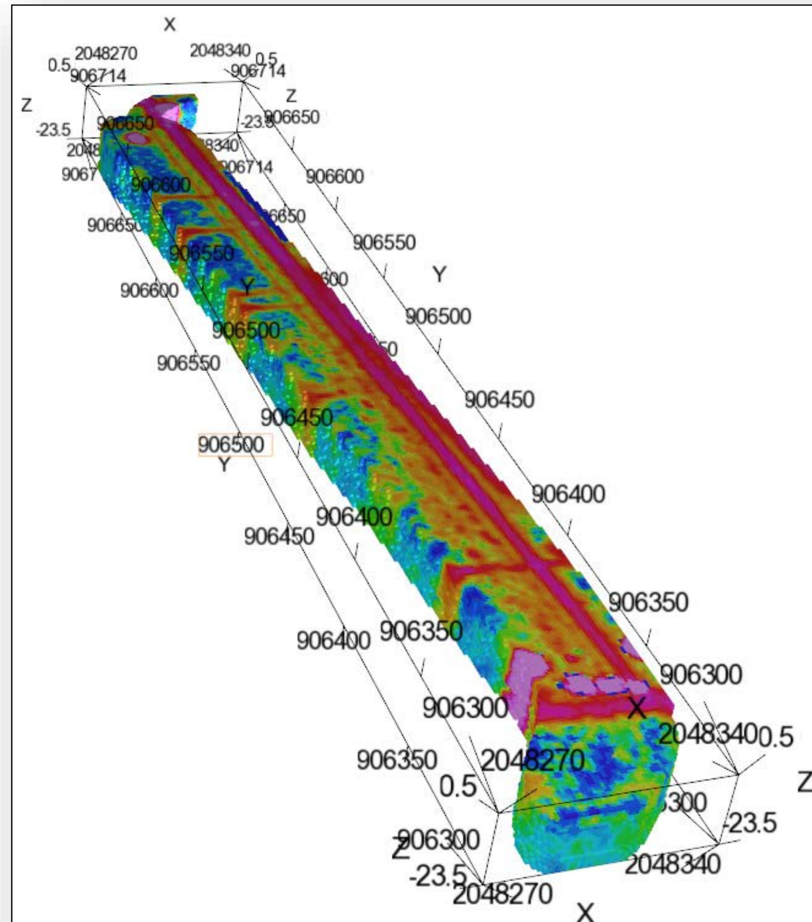




TDEMI Output - Time for Field Demonstration



TDEMI Line Path Map



SHRP2 R01B DEMO's

Time for Lunch

Then MCGPR and TDEMI Field Demonstrations

QUESTIONS ON TDEMI?

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GoSHRP2 website

www.fhwa.dot.gov/goSHRP2

– Product details
– Information about SHRP2 implementation phases

SHRP2 Utility Bundle website
http://shrp2.transportation.org/Pages/UtilityRelatedProducts.aspx
Implementation Information for AASHTO members