Geophysics for Everyone

Electromagnetic

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Fugro Airborne Surveys

Summary at the start

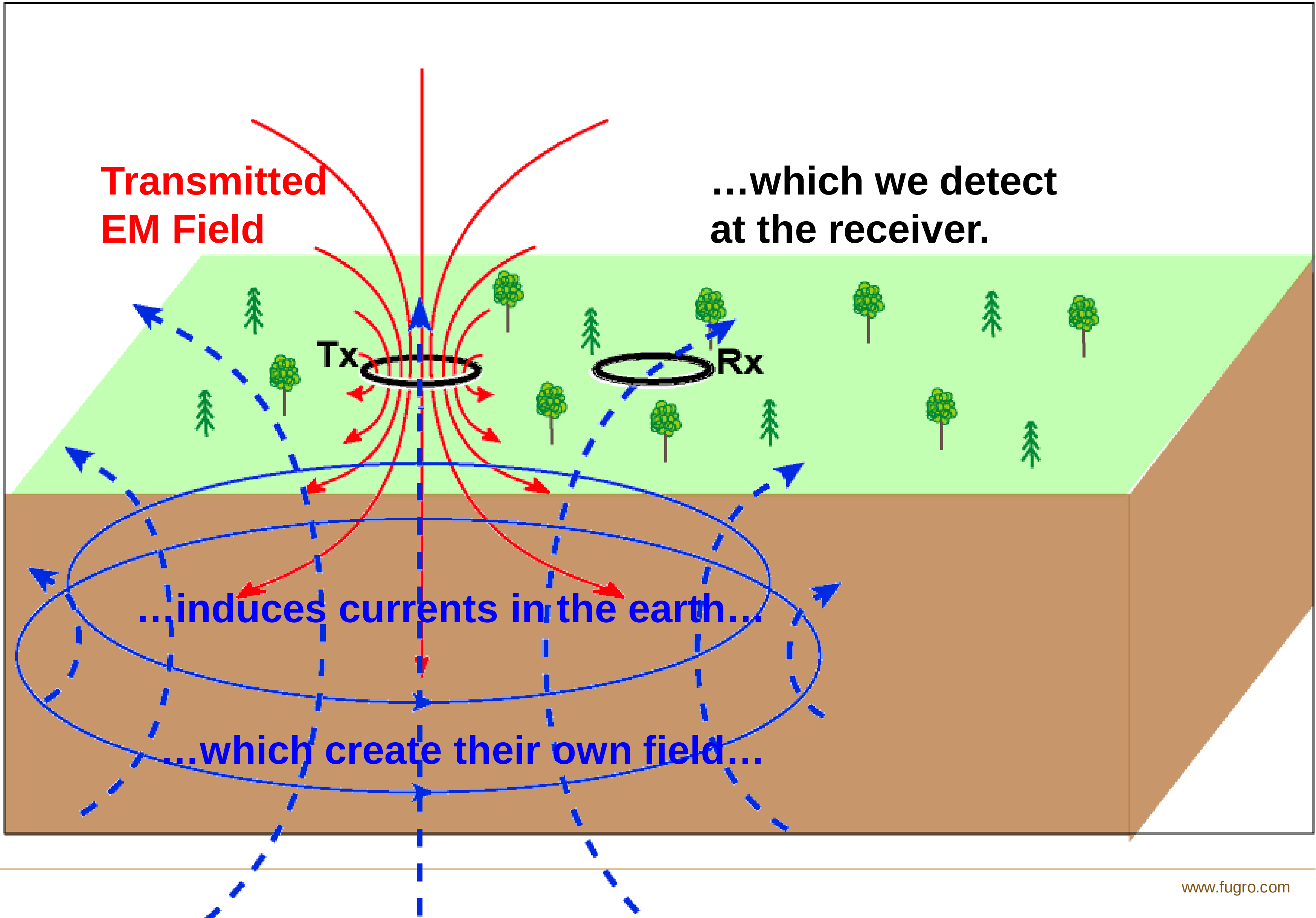
•Electromagnetic (EM) is used to detect electrically conductive deposits and alteration, and to map geology by changes in electrical resistivity.

•Resistivity is controlled by mineralogy (sulphides, oxides, clay minerals) and by porosity, saturation and salinity.

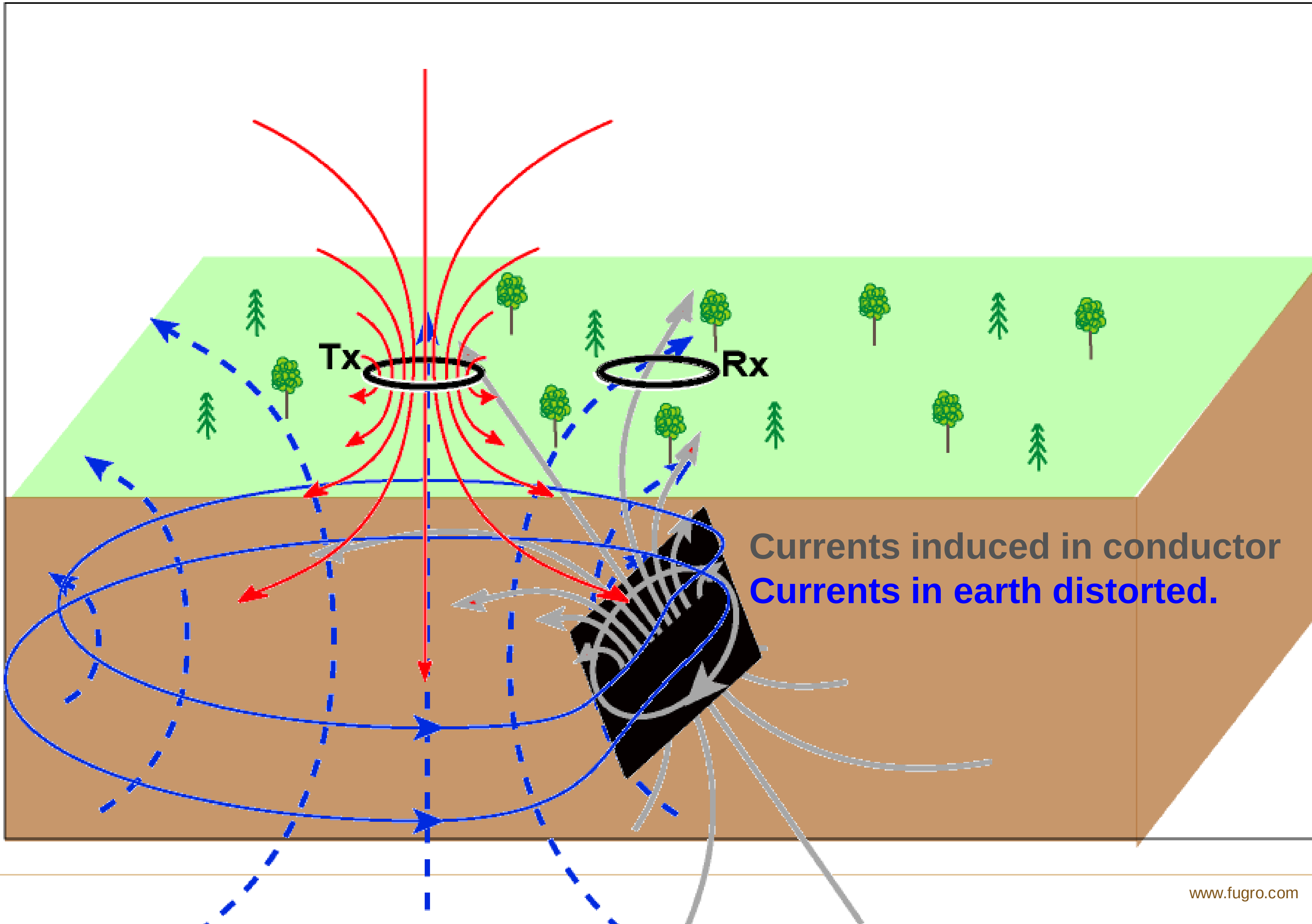
•Explorers need to understand the electrical nature of the target, the host geology, and over-lying geology (e.g. overburden).

•There is a HUGE range of EM systems to choose from!

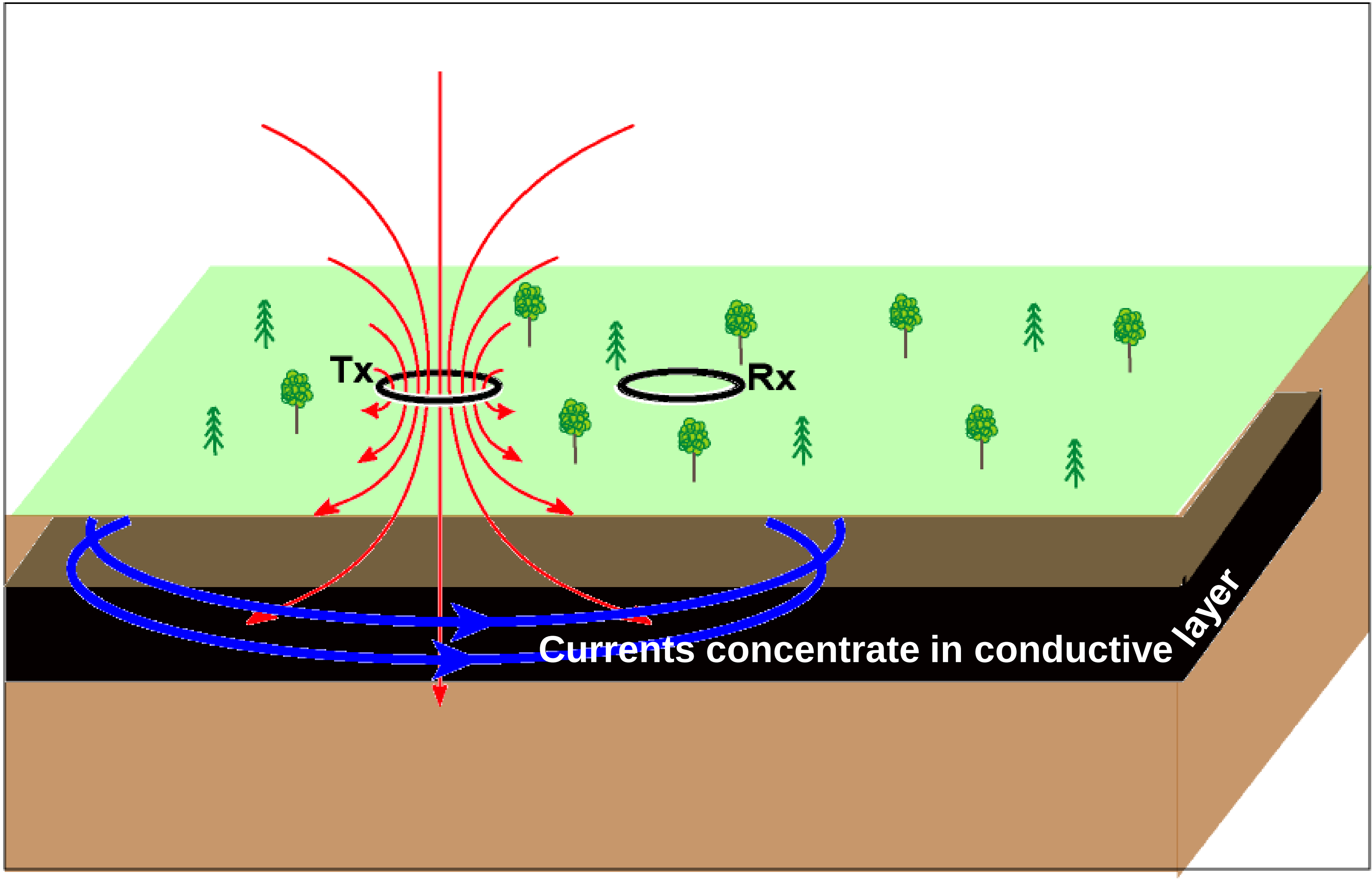
Basic EM Principles



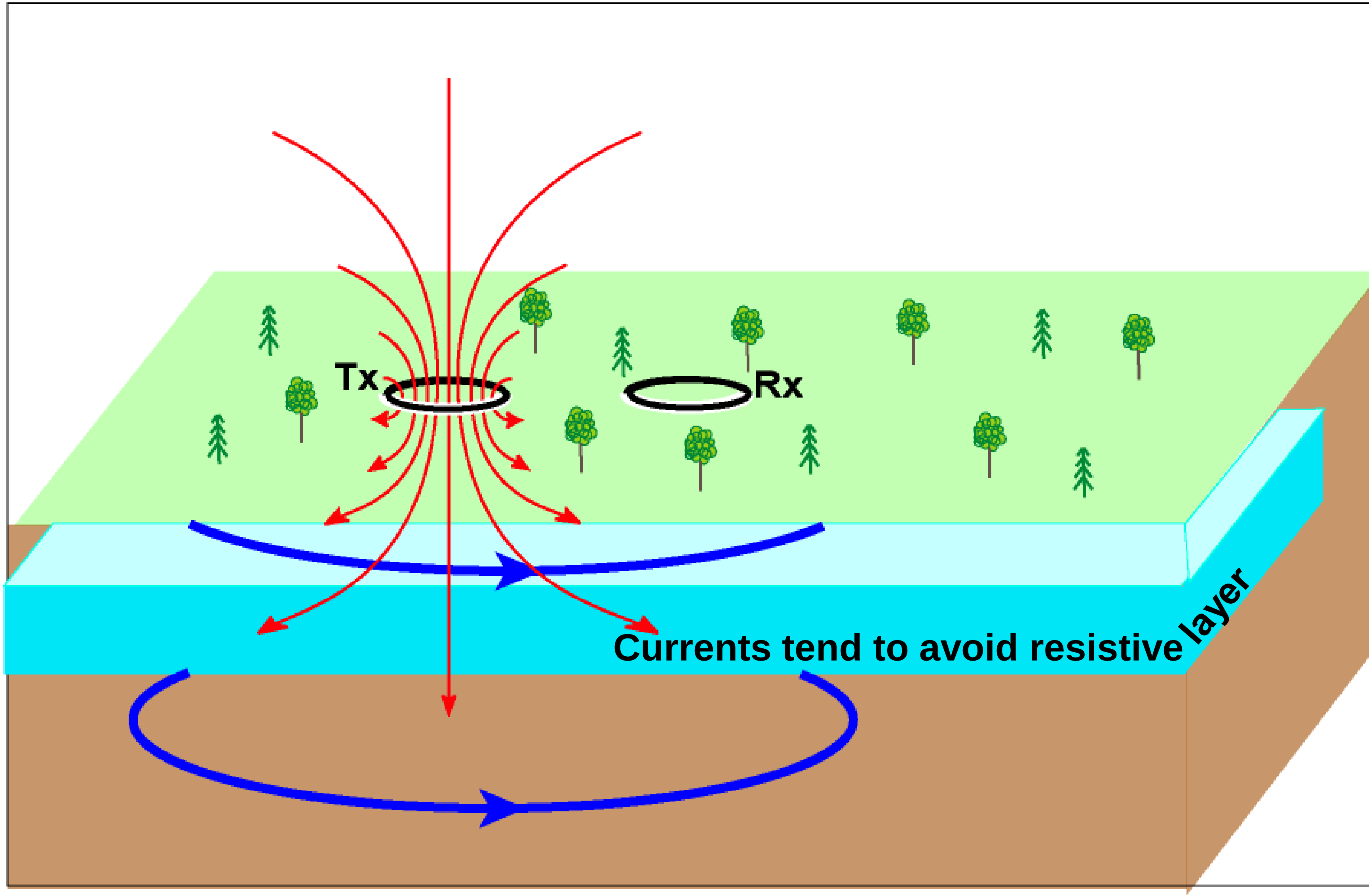
Basic EM Principles



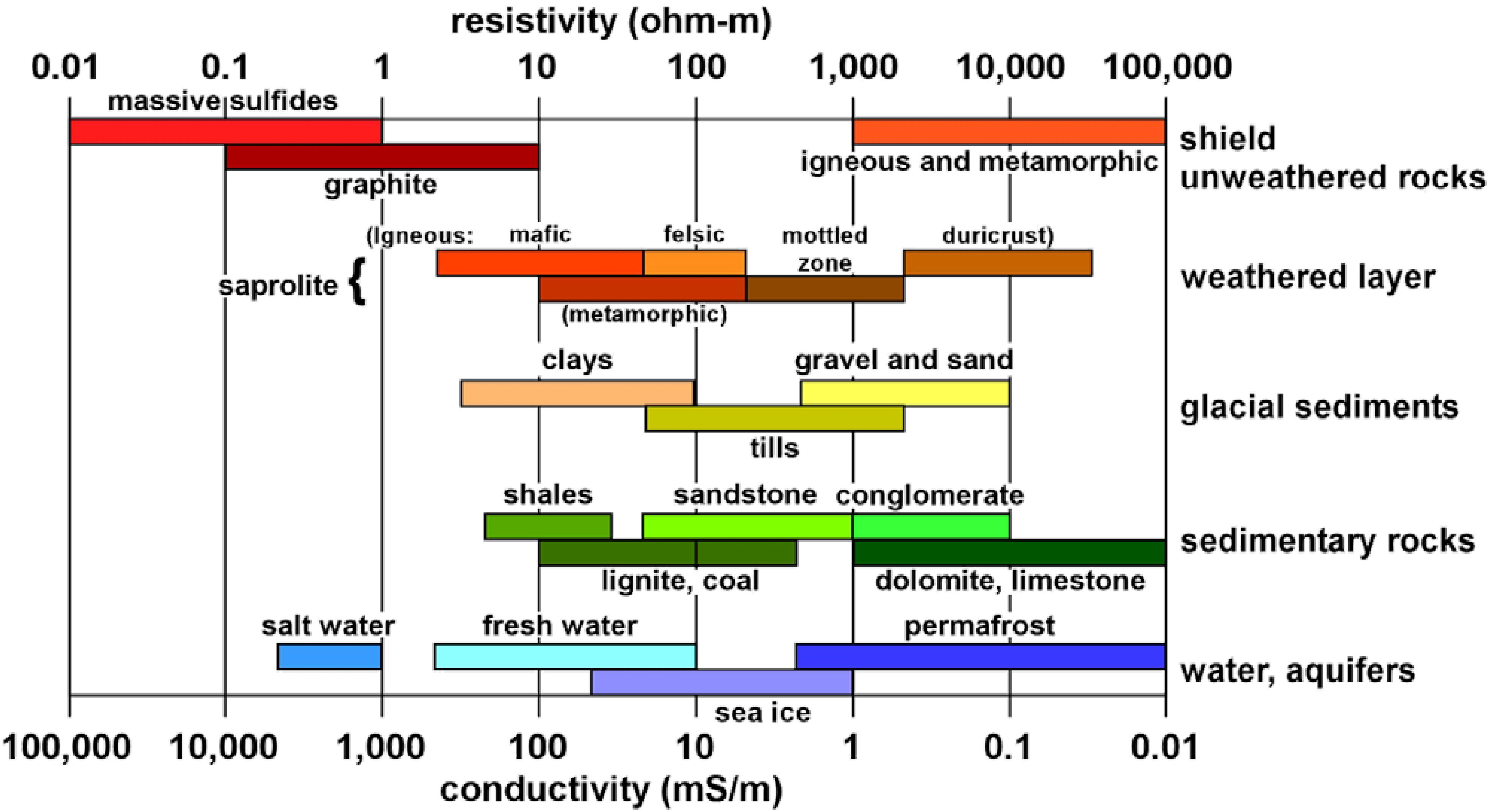
Basic EM Principles



Basic EM Principles



Resistivity of Common Rocks



(from Palacky, 1988)

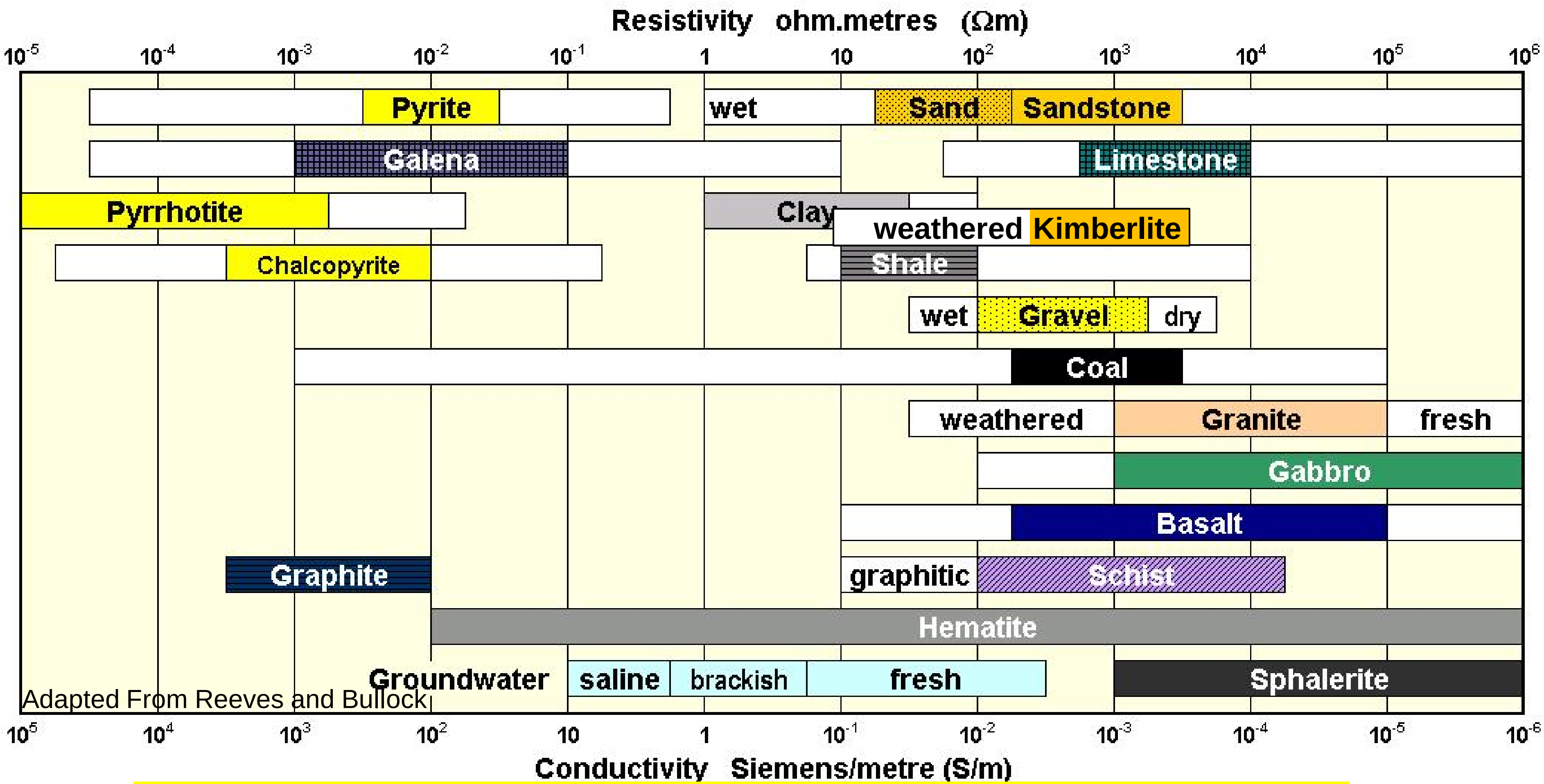
Conductivity = 1/Resistivity

Conductivity Resistivity

CLAY

ALTERATION

SILICA. $CaCO_3$



VMS IOCG Porphyry Iron Fmn

NiCu SaskU MVT Sed Repl. Vein

Controls on Resistivity

Mineralogy

- **conductivity of the minerals**
- **connections: do they form a conductive pathway?**
- **volume: thick, weakly conductive zones look like thin, strong conductive zones**
  (consider sensitivity footprint of system)

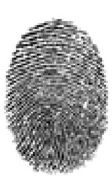
Water content

- **porosity / fracturing** (pathways)
- **saturation**
- **salinity**

Alteration

- **Chlorite, sericite decrease resistivity**
- **Silicification, carbonate increases resistivity**

Conductivity depends as much on form and bulk as on conductivity of the mineral.



Worth repeating:
thick, weakly conductive formations look like thin, strongly conductive ones!

The Question Geophysicists Hate

HOW DEEP CAN IT SEE?
(It depends….)

Depends on Penetration:

- **Conductivity of ground**
- **Time or Frequency**
- **Strength of transmitter**
- **Sensitivity and noise in receiver**

Depends on Detection:
(All of the above, and..)

- **Size of target**
- **Conductivity of target**
- **Geometry (system and target)**
- **Geological Noise**

Conductive Minerals

Conductive	**Metal Sulphides (Fe, Cu, Pb, Ni, Mo)** (<u>not</u> Zn, Sb)
↓	**Metal Oxides(Fe, Mn)**
Resistive	**Carbonates**
↓	
Very Resistive	**Silicates**

Note: It is really hard to get resistivity information on minerals.

Conductors in Exploration

Targets:

Sulphides (Fe, Cu, Pb, Ni, Mo) (<u>not</u> Zn, Sb)

Best: massive mineralization

OK: veins

Maybe: disseminated (only if >10-20%)

Metal Oxides (mag,hem,lim)

•depends on form

Kimberlite

Alteration zones

Geological Noise:

Graphite (often massive, extensive**)**

Clay Minerals – sediments or alteration products

shears, fractures, alteration horizons (porosity and minerals**)**

Lakes, swamps, overburden (sub-crop troughs**)**

Resistivity of Rocks

	Graphitic
Conductive	Clay-rich sedimentary
↓	Carbonates
Resistive	Sandstone (+/-water)
↓	Metasediment (un altered)
Very Resistive	Metavolcanic
	Igneous (un altered*)

* mafic and ultramafic rocks alter much faster – sometimes years.

EM Mapping in Exploration

Most igneous, crystalline rocks too resistive to separate

Distinguish sedimentary from crystalline

Maybe meta-sediments

Mapping sedimentary types

Requires sensitivity to high resistivity range, good calibration

Geological Noise:
Overburden thickness and type
Alluvial cover

Evaluating the EM Target

Before flying EM – need confidence that it will work.

- **How conductive (or resistive) wrt host geology?**
  - **Conductive targets <u>much</u> easier to detect than resistive –**
    (even with same contrast**)**
  - **Host geology conductivity varies also**
- **Is it big enough to detect?**

Best: previous geophysical measurements
OK: Measured rock properties
…Sigh: estimate or model from geological description

Evaluating the EM Target

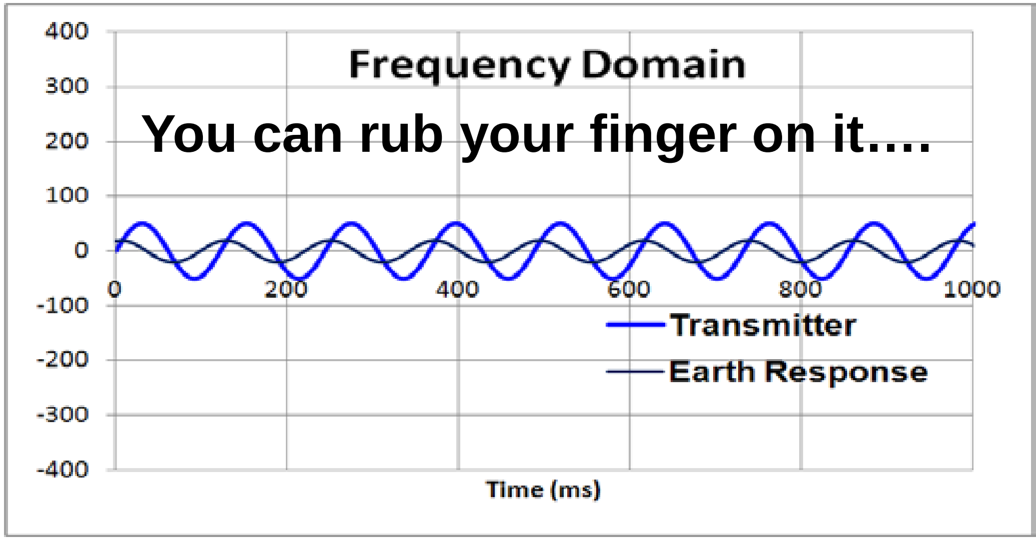
What we need to know:

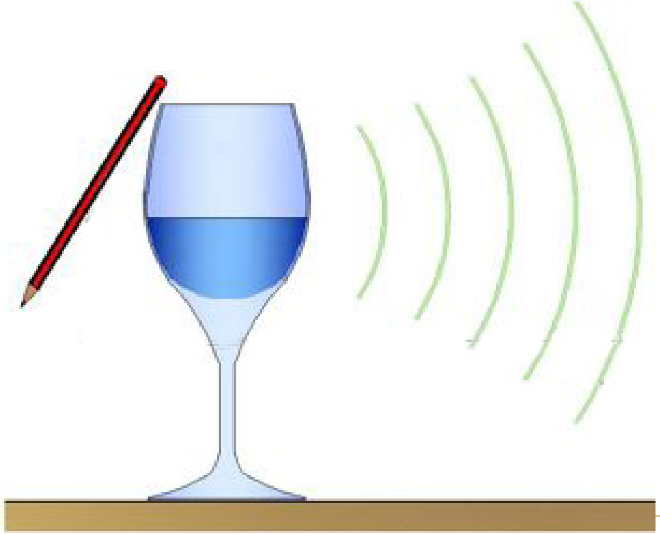
- **Host rock type**
- **Overburden type and thickness and variability**
  - **till, alluvium, calcrete, saprolite**
- **Target size: economic interest**
- **Depth range of (economic) interest**
- **Target mineralogy**
  - **alteration halo – type, intensity and size**
  - **TOTAL SULPHIDES!**

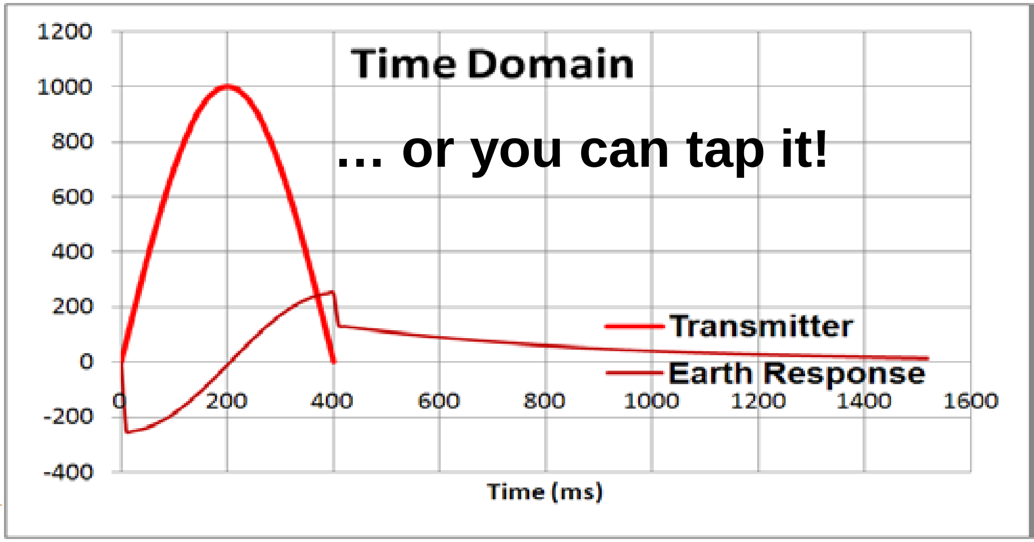
The anomaly is caused by the total sulphides (not just the economic sulphides)!

Time Domain and Frequency Domain

How do you check the tone of a wine glass?

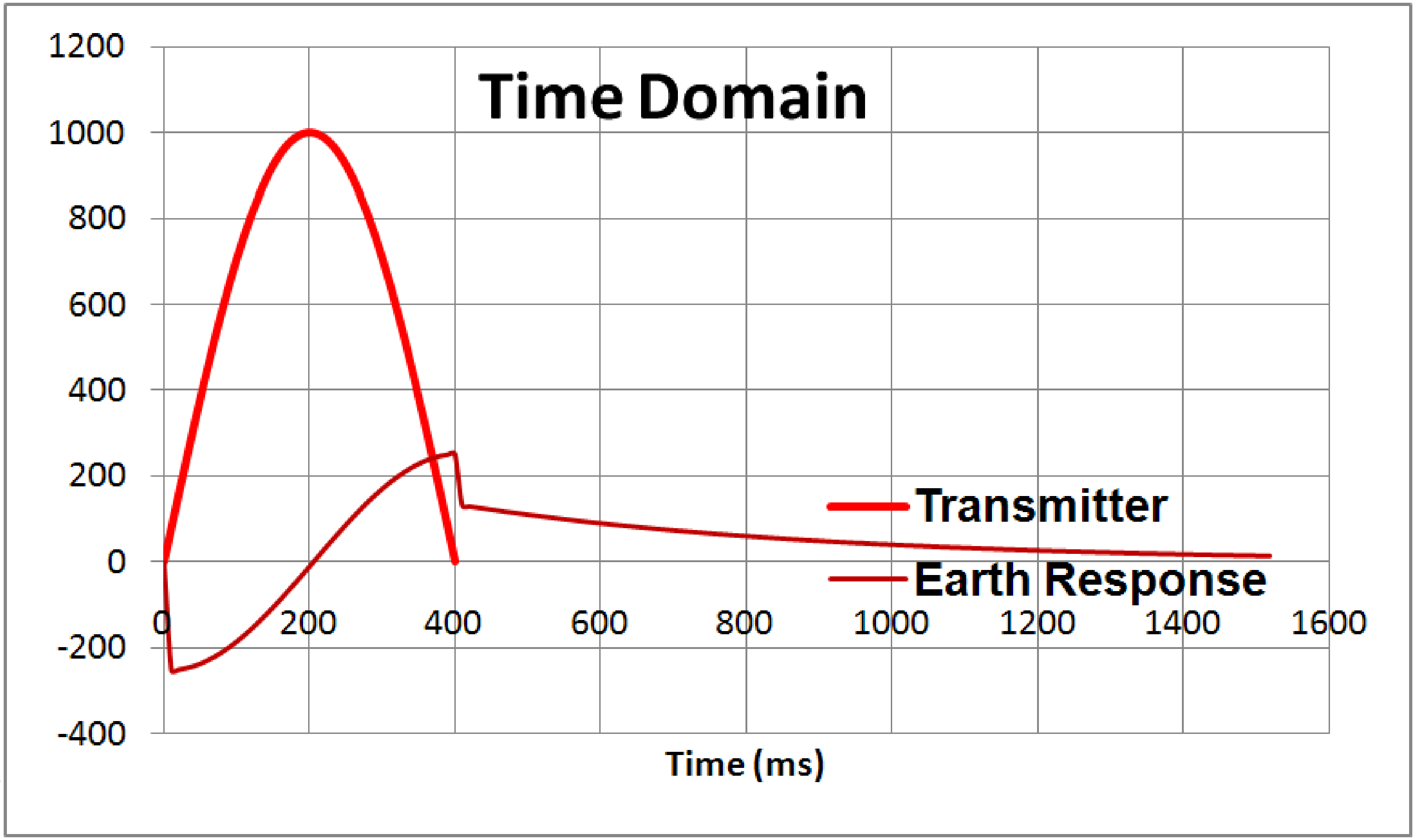




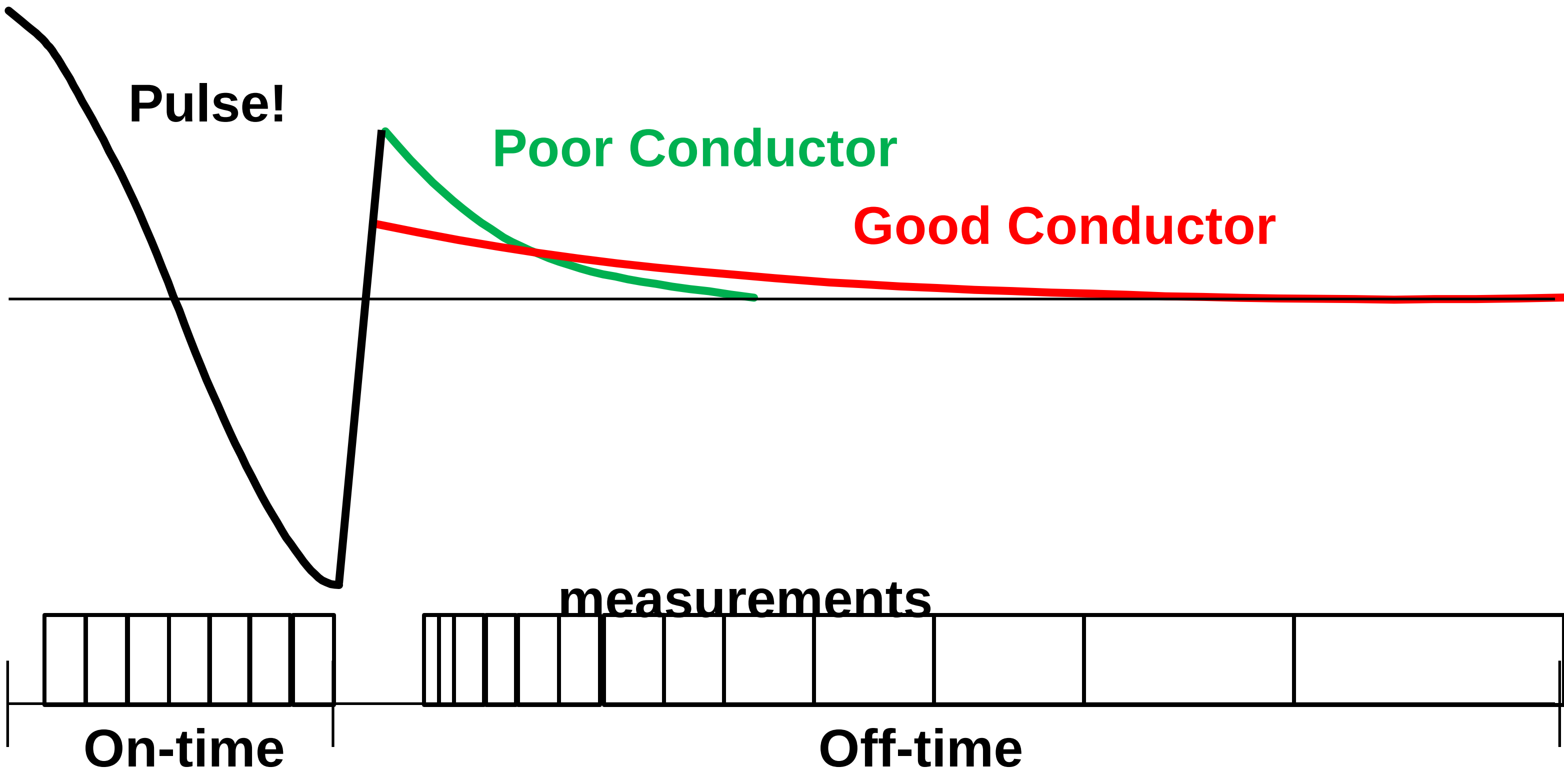


Time Domain

Time Domain:
High power pulse of energy
Earth continues to respond after pulse (off-time)
Data measured as many time channels (samples) during and after pulse.

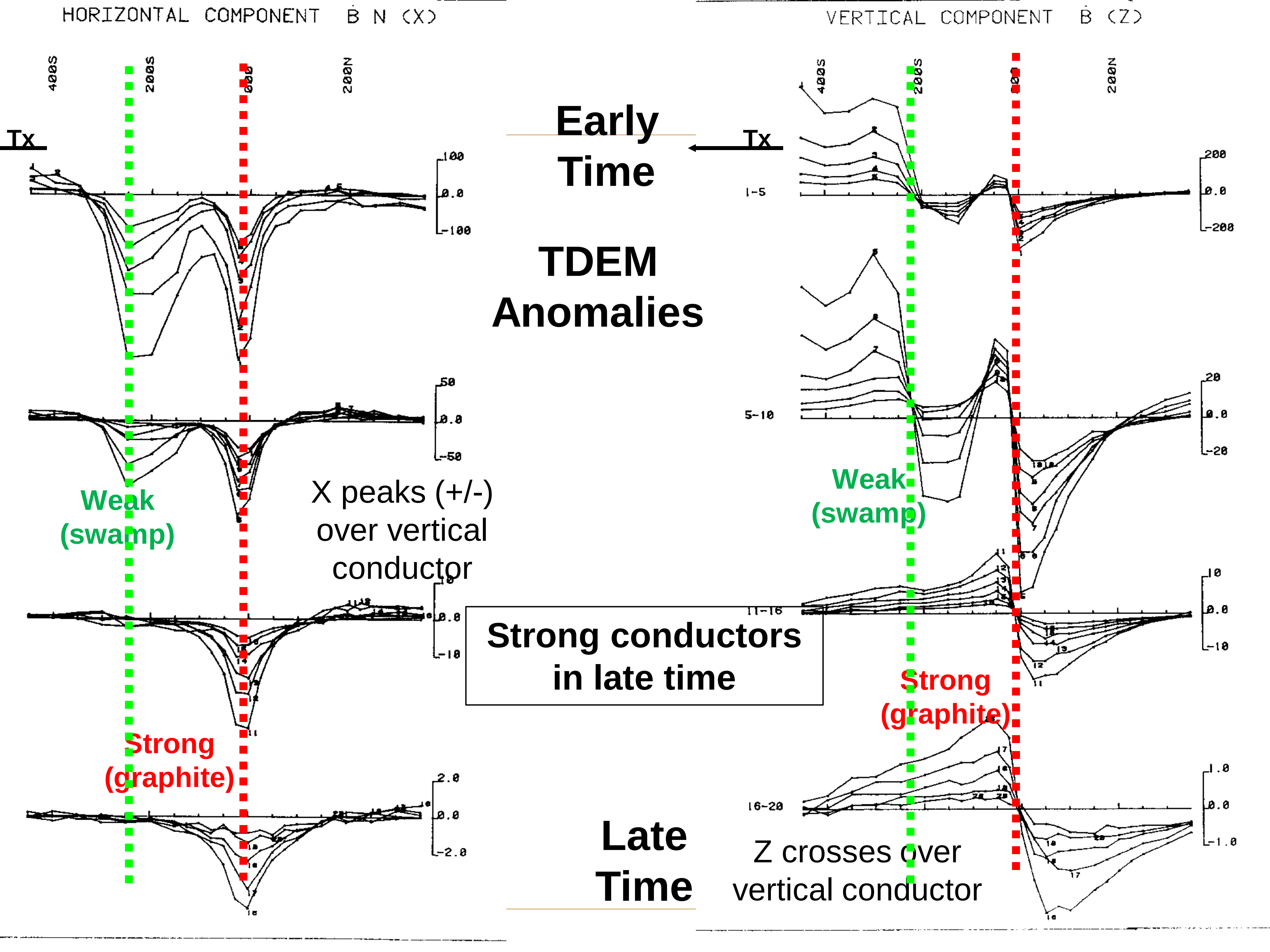


Sampling Of Data For TDEM Surveys

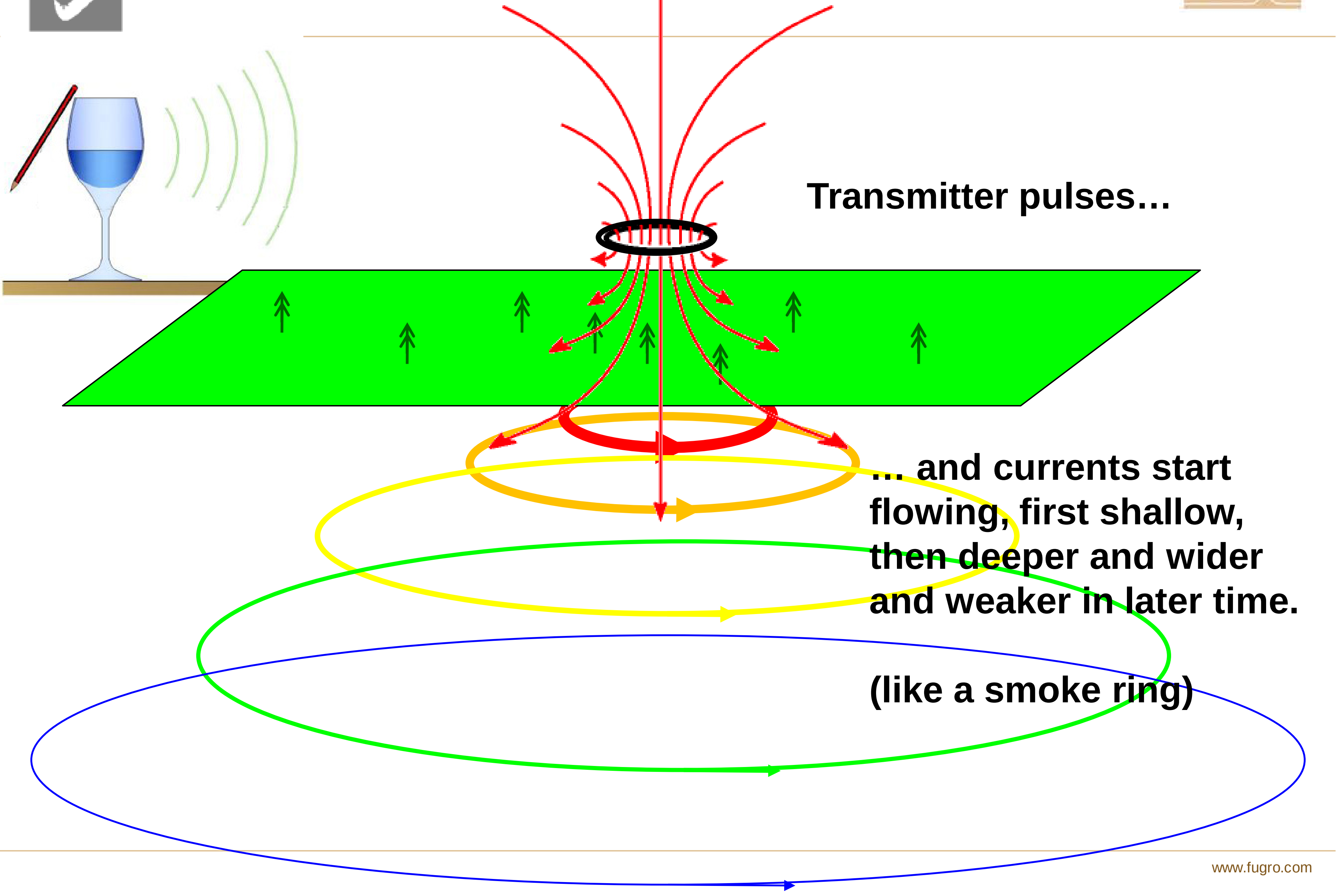


Poor conductor has strong early response, decaying quickly (short Tau). (Look for these in early time channels.)

Good conductor has weaker early response, but decays more slowly, (long Tau). (Look for these in late time channels.)


HORIZONTAL COMPONENT Ḃ N (X)
VERTICAL COMPONENT Ḃ (Z)
400S
200S
000
200N
Tx
Early Time
TDEM Anomalies
1-5
5-10
11-16
16-20
100
0.0
-100
50
-50
10
-10
2.0
-2.0
200
-200
20
-20
1.0
-1.0
Weak (swamp)
X peaks (+/-) over vertical conductor
Strong conductors in late time
Strong (graphite)
Late Time
Z crosses over vertical conductor

Current Flow – Time-domain

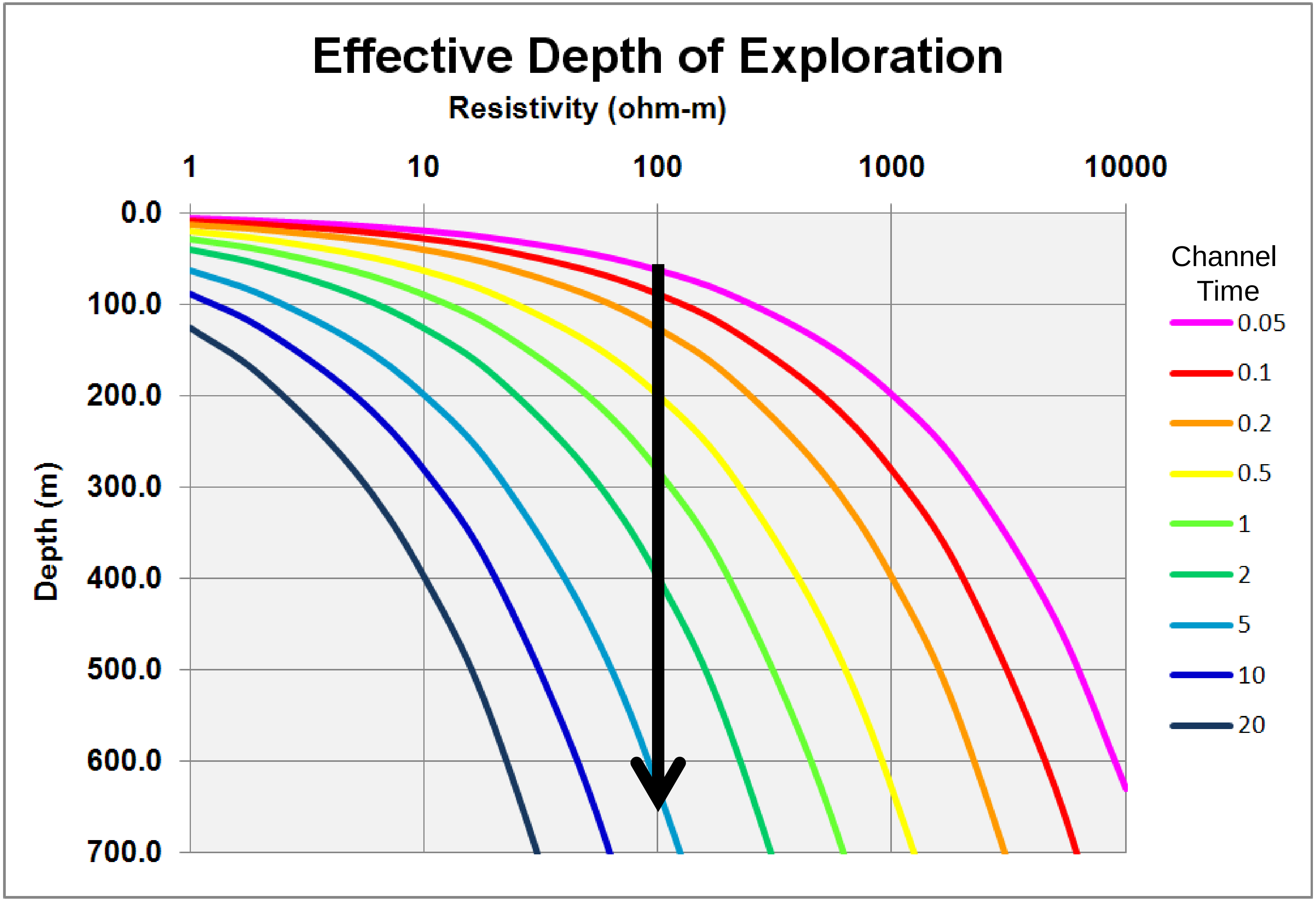


Transmitter pulses…

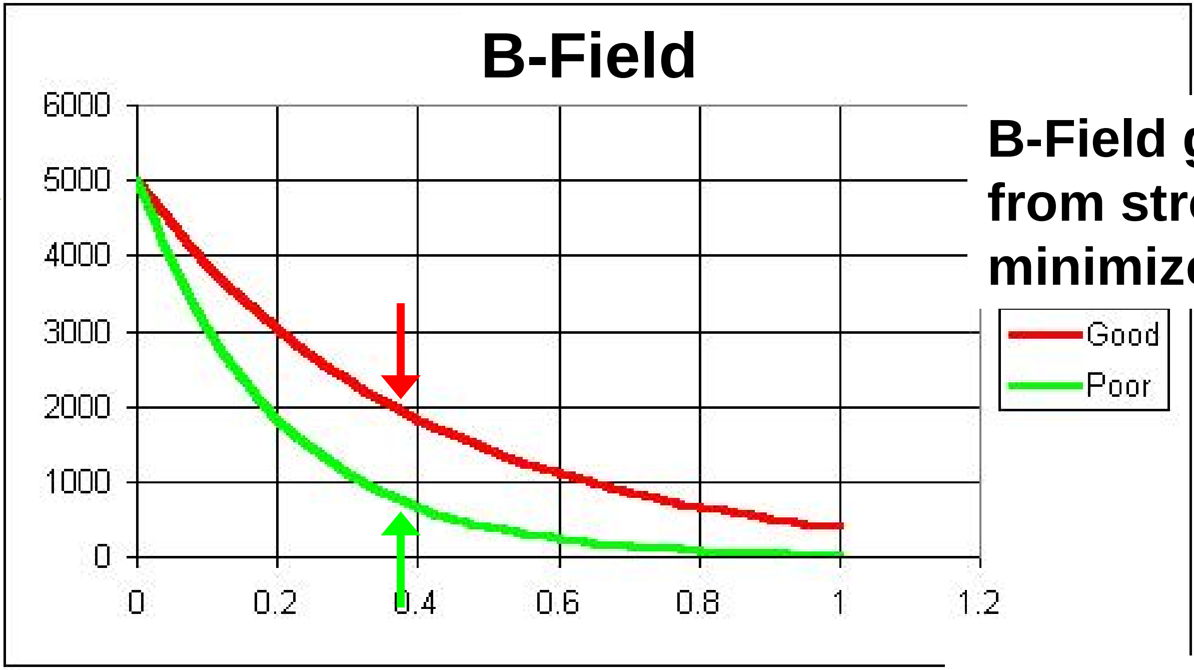
… and currents start flowing, first shallow, then deeper and wider and weaker in later time.

(like a smoke ring)

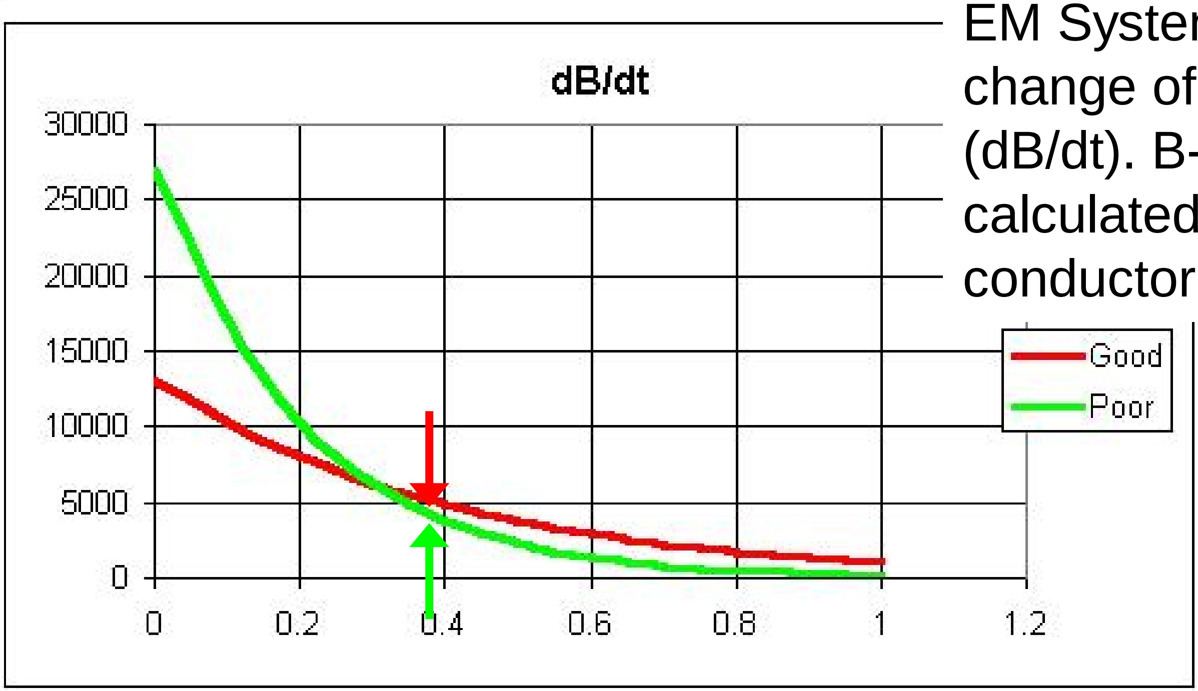
Time Domain



0.71 x Skin Depth (Weidelt)

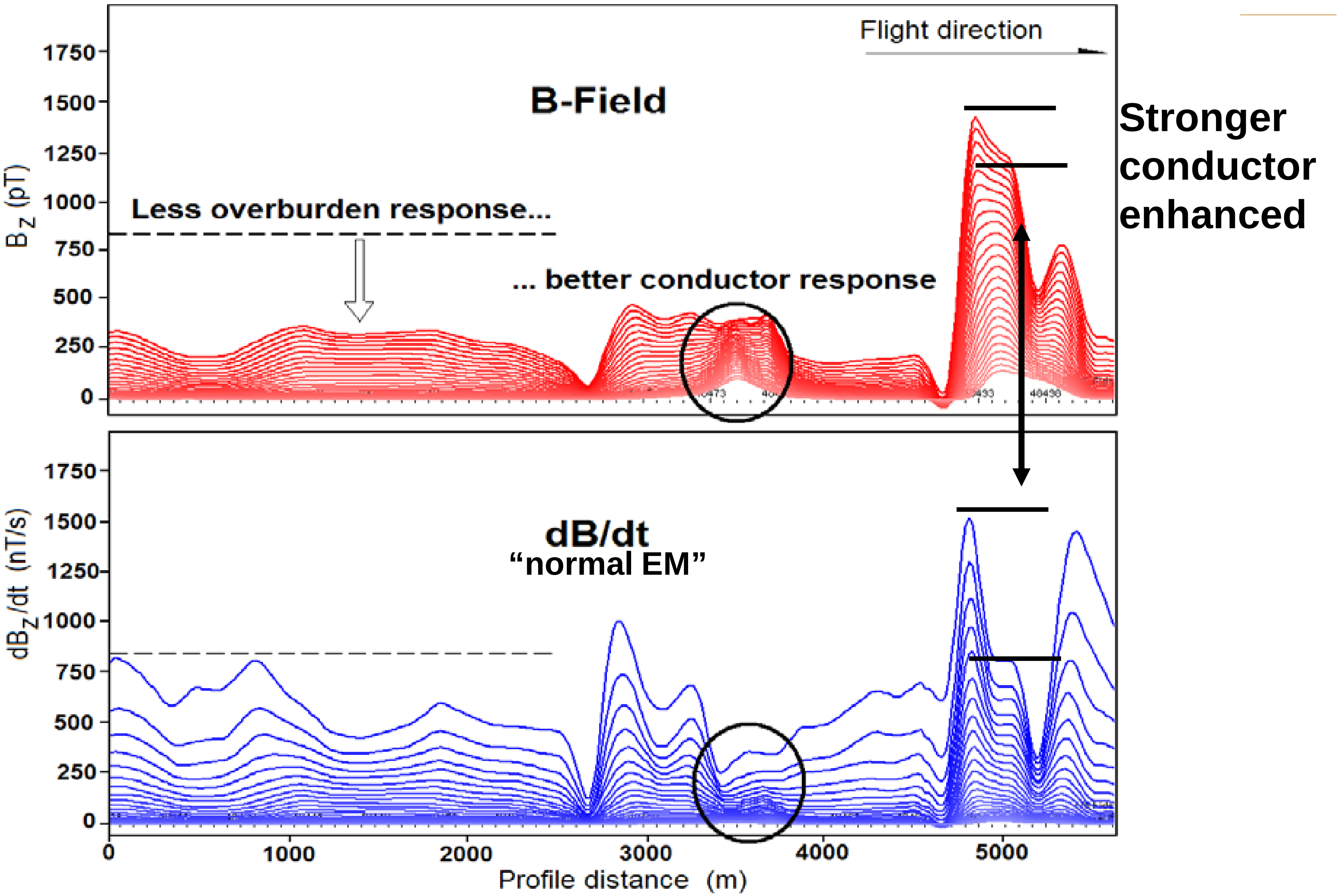


B-Field gives stronger response from stronger conductors, and minimizes overburden and host.

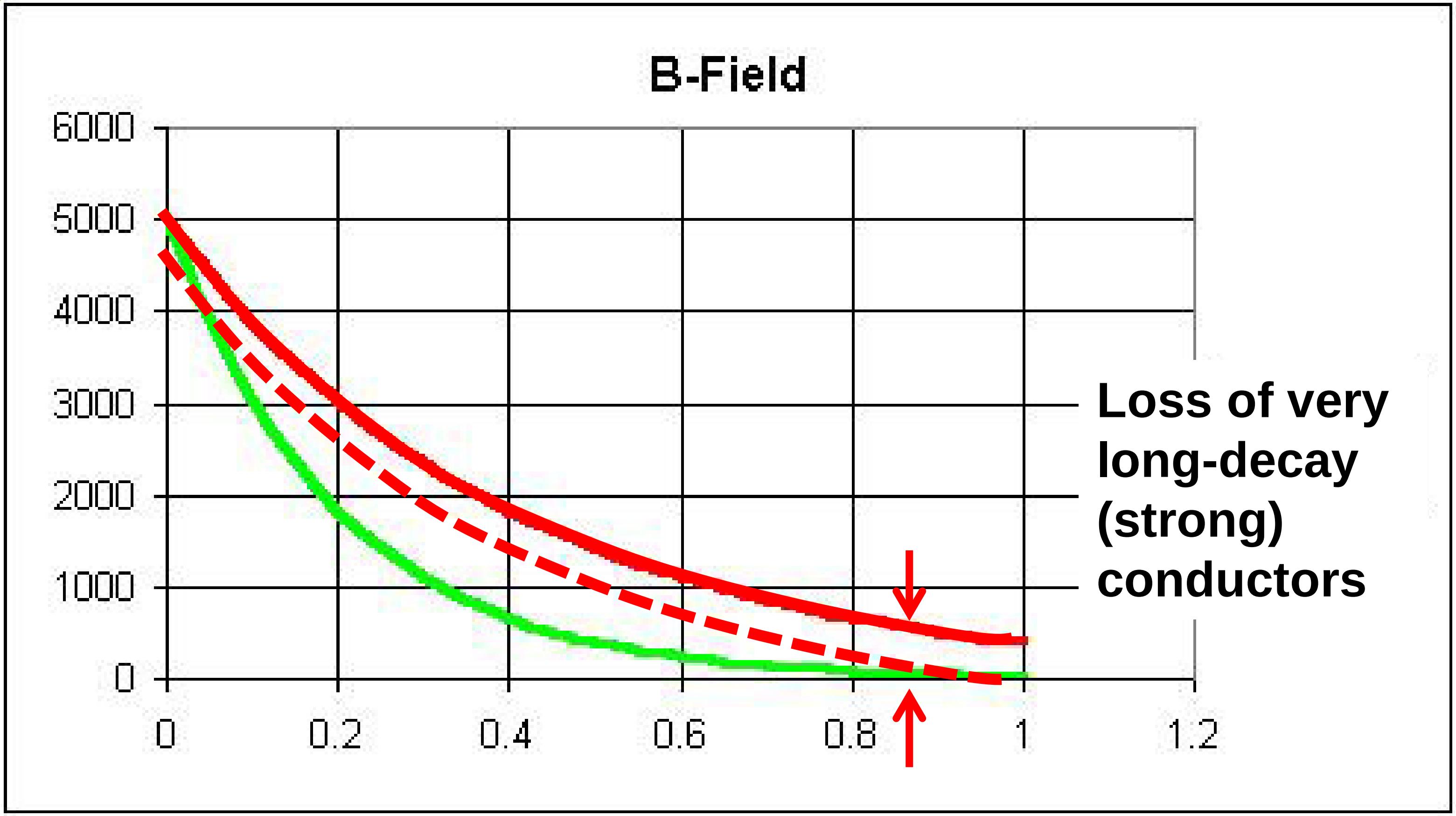


EM Systems with coils measure rate of change of induced magnetic field (dB/dt). B-Field is measured or a calculated product to enhance strong conductor responses.

B-Field Example



B-Field: Measured or Calculated



Integrating B from dB/dt loses the constant of integration.

Measured

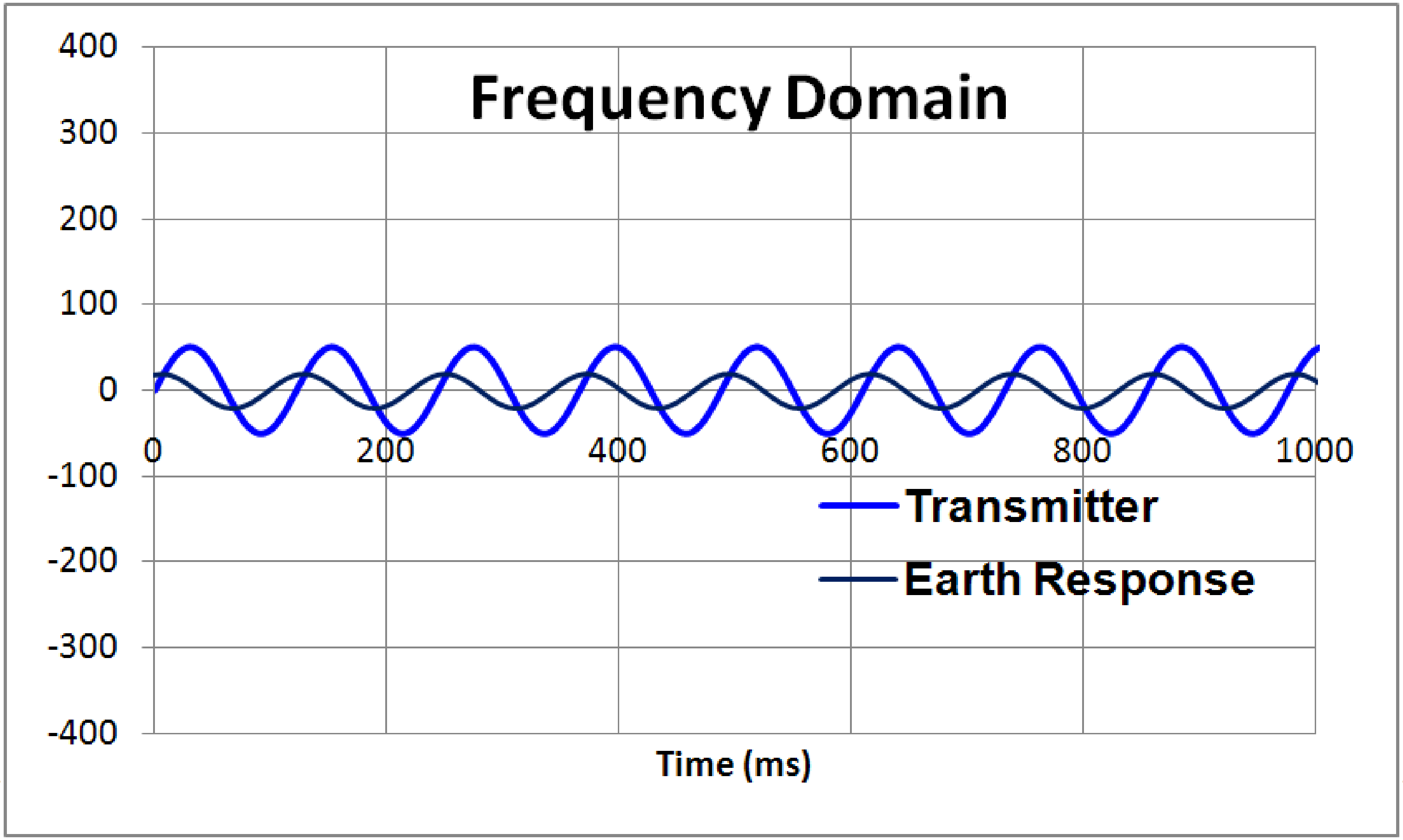
- **Better strong conductors**
- **Slower surveying**
- **Not in borehole or airborne**

Calculated

- **Faster and cheaper**

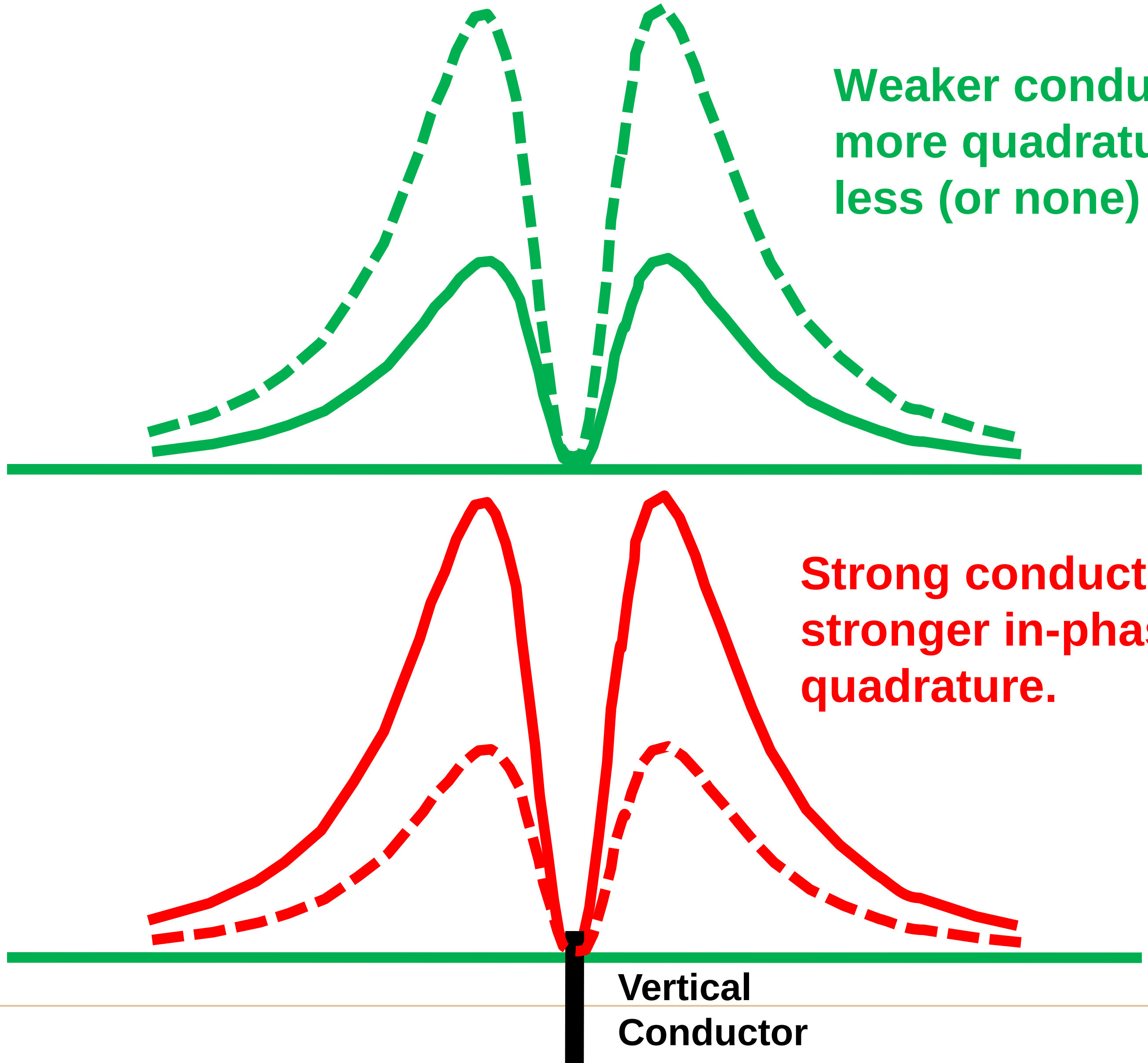
Frequency Domain

Frequency Domain:
Low power, continuous transmission on many frequencies.
Earth response continuous, measured through transmitter.
Data measured as in-phase and quadrature (out-of-phase) components for each frequency.



Frequency Domain Target Conductance

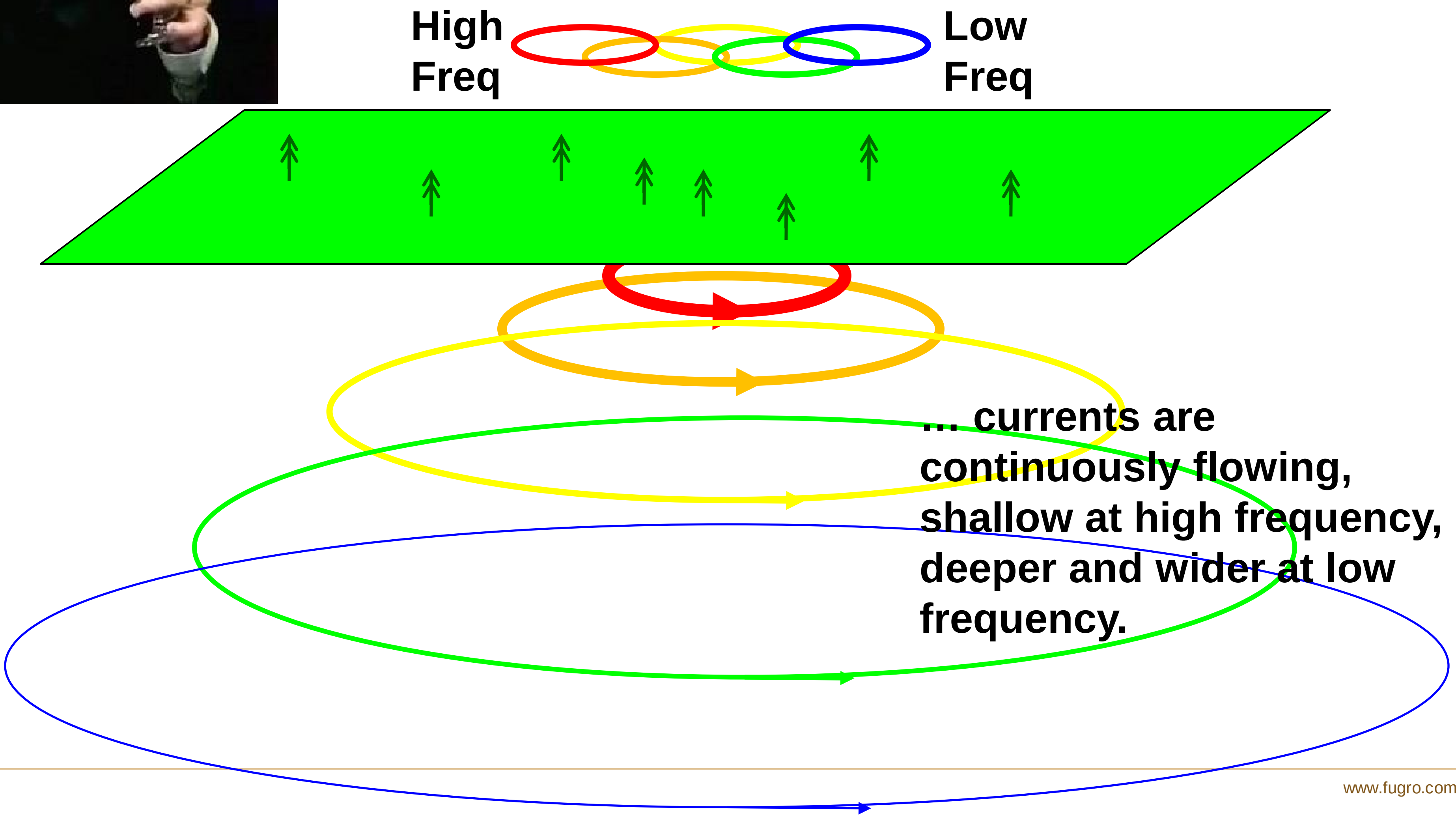
Weaker conductor has more quadrature and less (or none) in-phase



Strong conductor has stronger in-phase than quadrature.

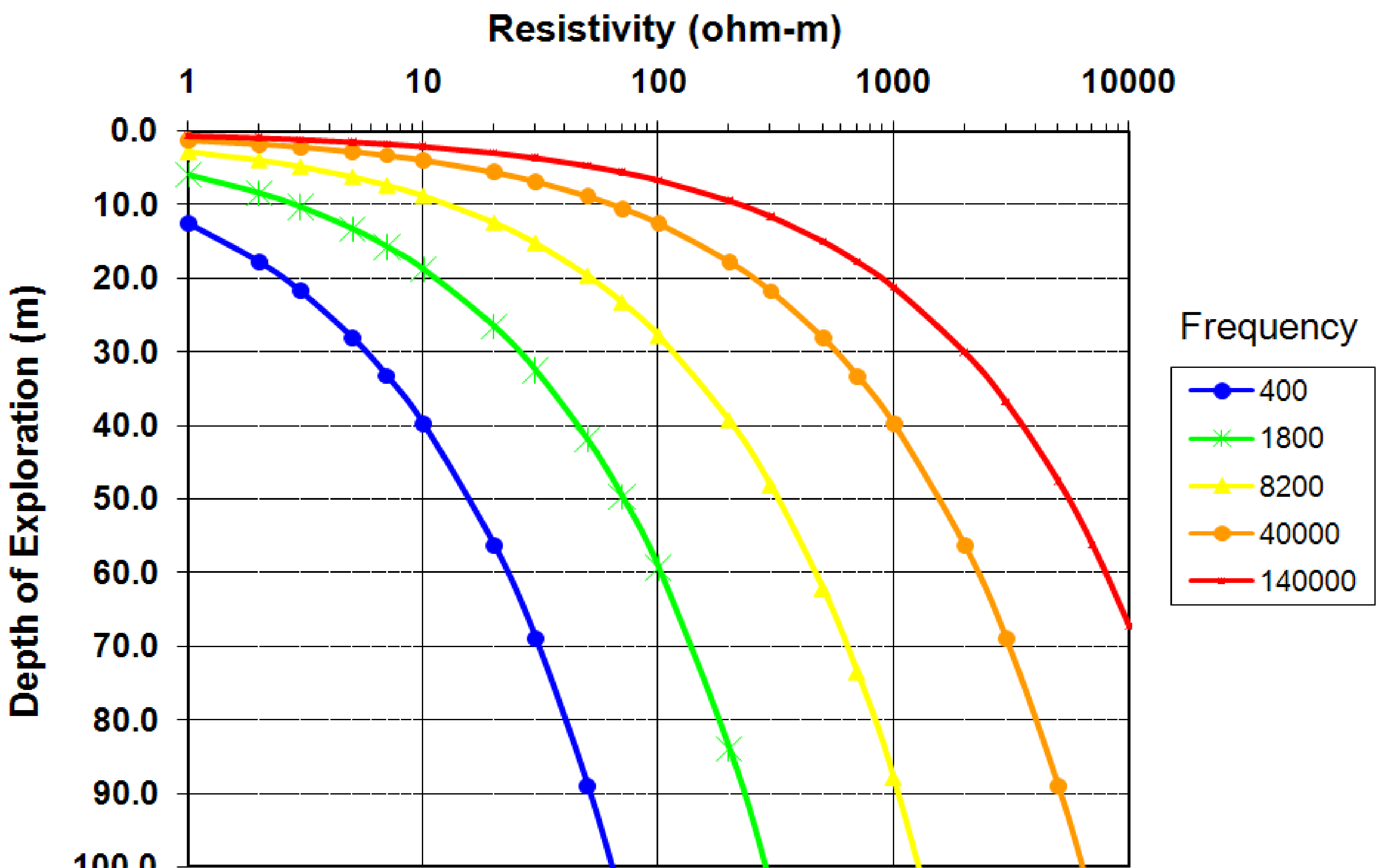
Current Flow – Frequency domain

Five transmitters always on…



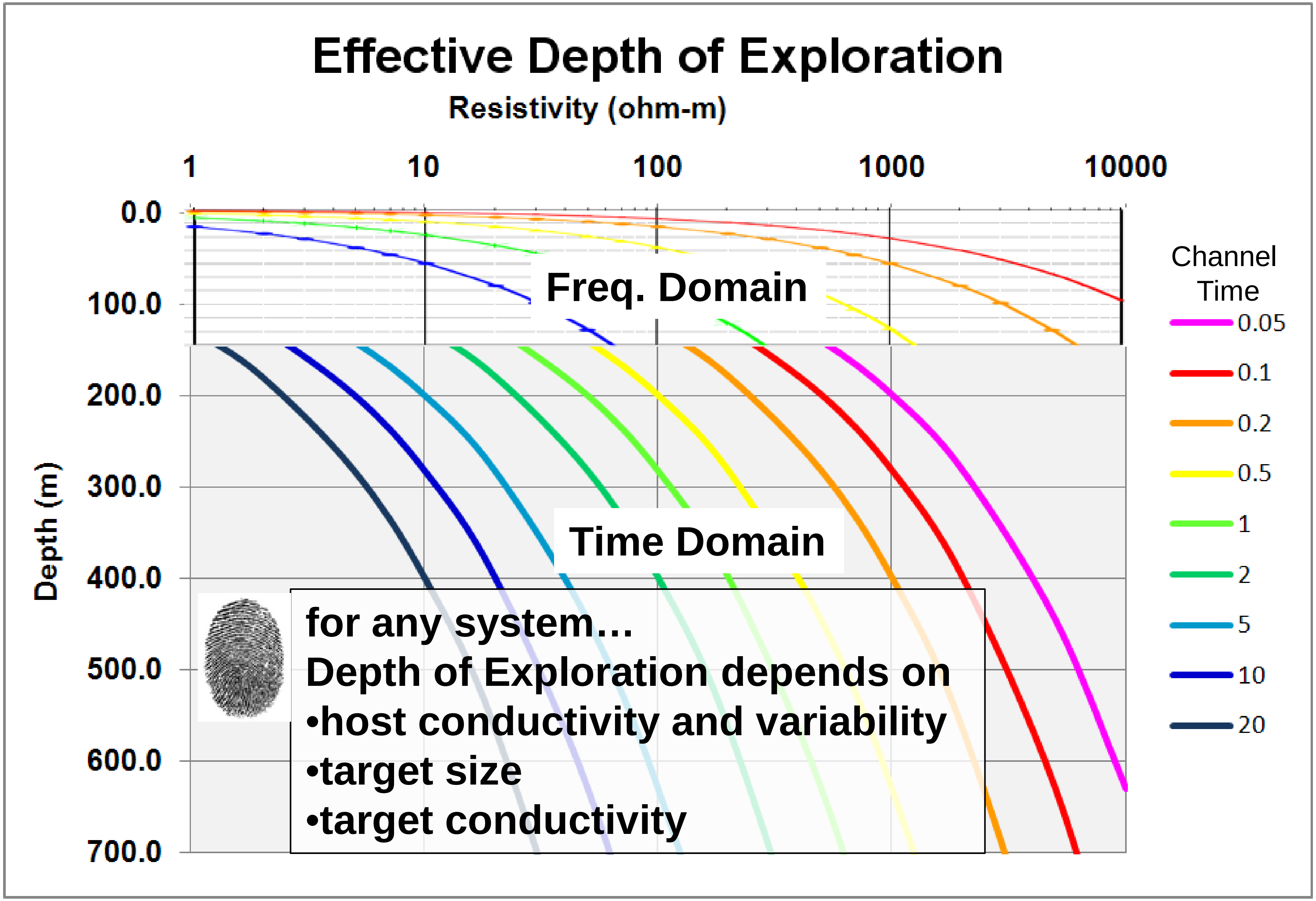
… currents are continuously flowing, shallow at high frequency, deeper and wider at low frequency.

Most Sensitive Depth of Exploration



Approximately 0. 5 skin depth

Time and Frequency Domain

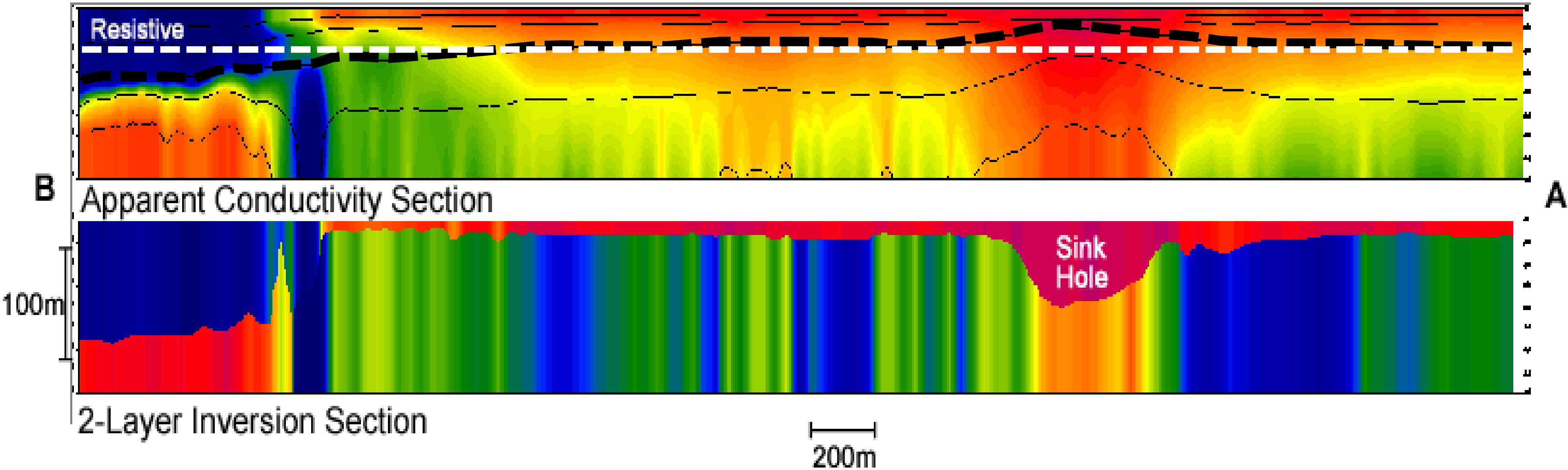


0.71 x Skin Depth (Weidelt)

Depth varies as Resistivity

Resistive
Deeper

Conductive
Shallower

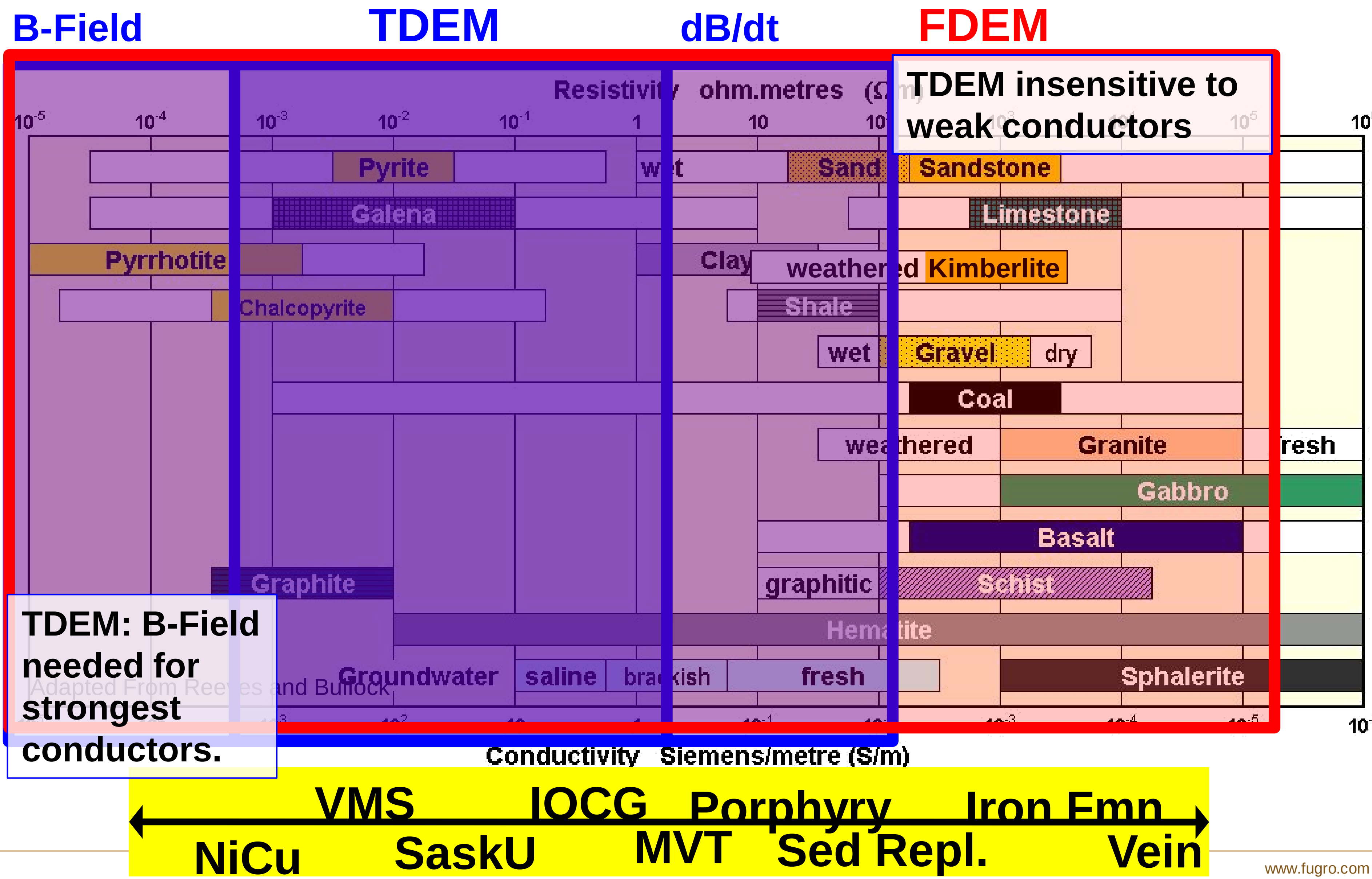


for any system…
Depth depends on host resistivity

Frequency Domain, dB/dt or B-Field?

Feature	Freq	Time dB/dt	Time B-Field	
Weak Conductors	Best	OK	Poor	
Strong Conductors	Good	Better	Best	
Depth	Poor	Better	Best*	*Strong conductors only
Speed / Cost	Best	OK	Worst	
Multi-component	Yes	Yes	Yes*	*Three sensors
Borehole	No	Yes	No	
Airborne	Yes	Yes	Calc*	*Calculated from dB/dt

Sensitivity and Deposit types



Time and Frequency Domain: Key Points

Time Domain: High power pulse of energy, and then sample

- Power, to great depth (+700m)
- Pulse shape, off-time (for sampling)
- Strong conductors

Strong conductors, deep targets: IOCG, VMS, Ni, Sask U

Frequency Domain: Low power on many frequencies.

- High spatial resolution,
- Precision, near-surface (150m)
- High frequency for weak conductors/ high resistivity mapping

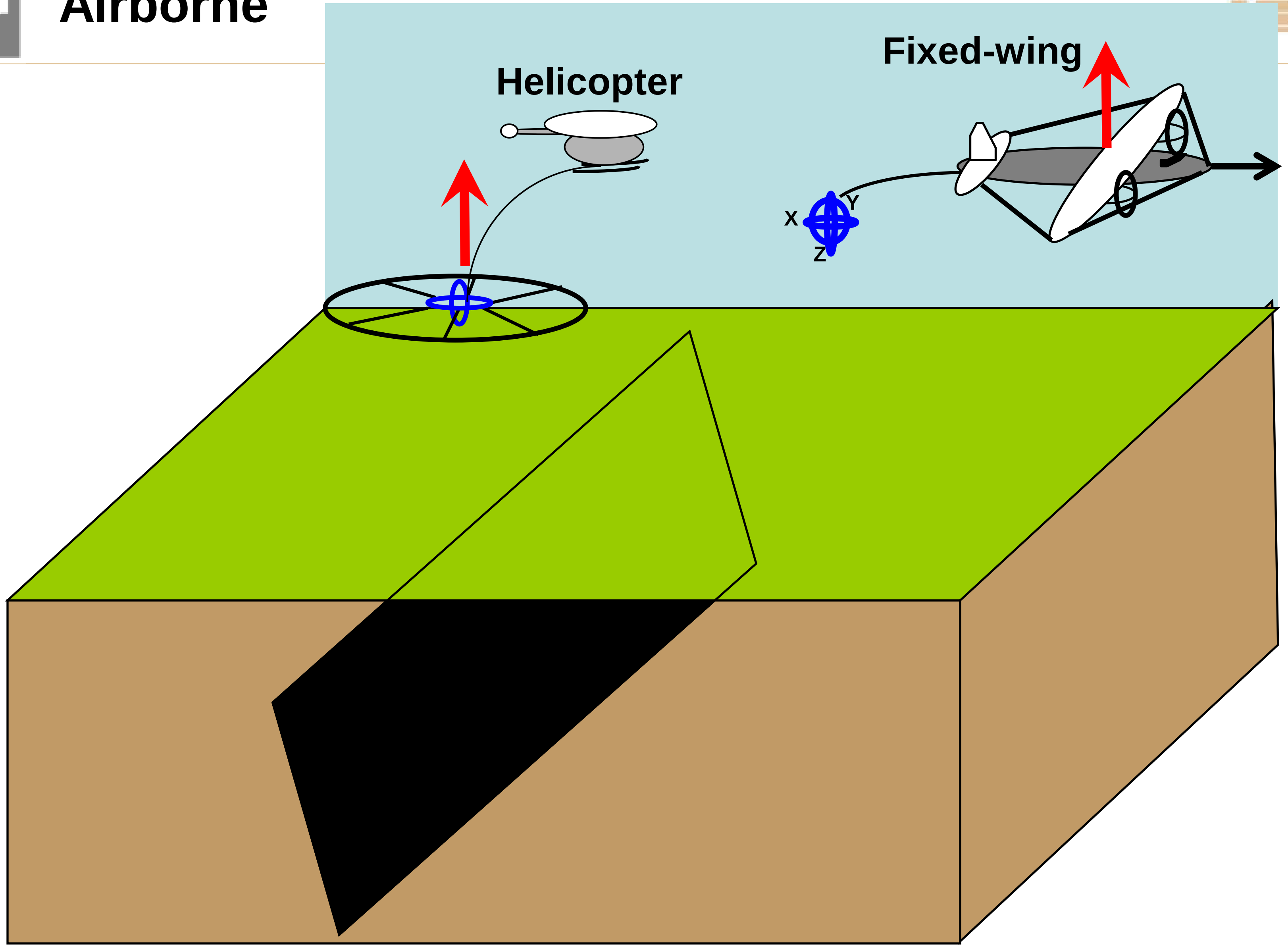
Weaker conductors, small targets: Gold, Diamonds, Env+Eng

EM Systems

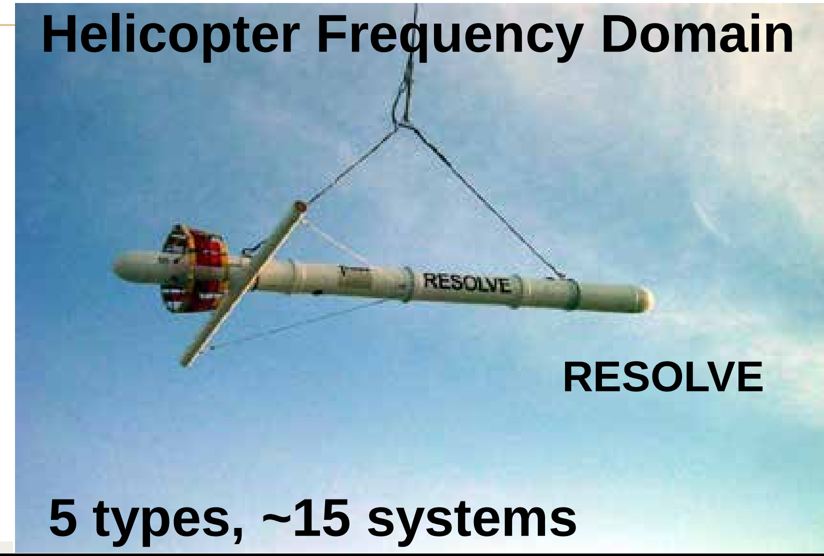
	Moving Tx Centre Rx	Moving Tx Offset Rx	Fixed Tx Moving Rx
Small Tx → Large Tx	DIGHEM GEM2A IMPULSE RESOLVE *AEROTEM SKYTEM* *SIROTEM* *VTEM HELITEM*	MAX-MIN Promis *PEM,* *P-THEM* *TEMPEST GEOTEM MEGATEM*	*UTEM CSAMT PROTEM PEM SIROTEM INFINITEM* FLAIRTEM
Distant Tx			VLF VLF
Natural Tx			MT

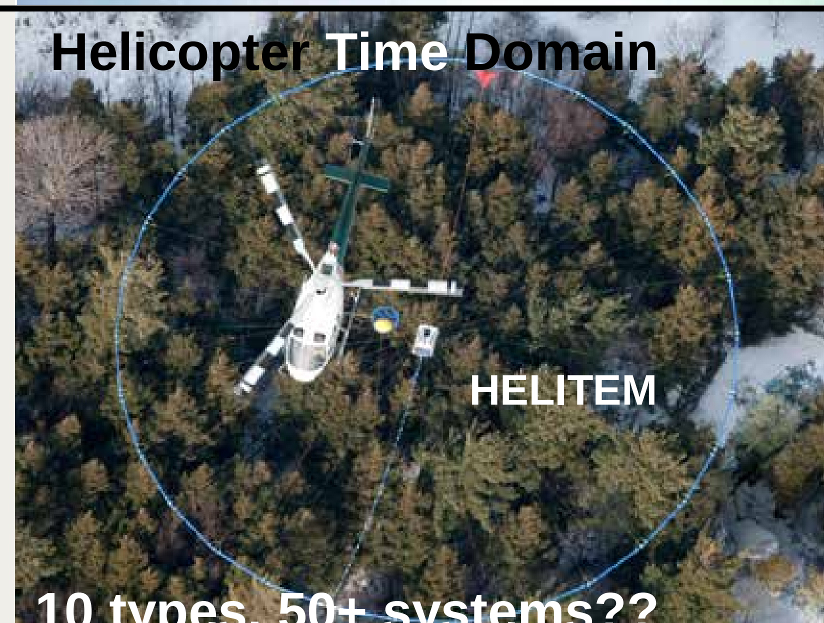
Airborne *Ground* Freq Domain, *Time Domain* **SIZE**,SIZE = Importance

Airborne



The Airborne EM Gang





The Airborne EM Gang

Fixed-Wing Frequency Domain

Scarce
Low power, poor depth
Poor resolution (altitude)
Fast mapping, lower cost

1-2 types, ~1 systems

Helicopter Frequency Domain

Highest resolution
Maximum resistivity range
Best for mountains
Low power – poor penetration

5 types, ~15 systems

Fixed-wing Time Domain

High Power – good depth
High speed, low cost
Many sensors
Lowest resolution
Poor for terrain

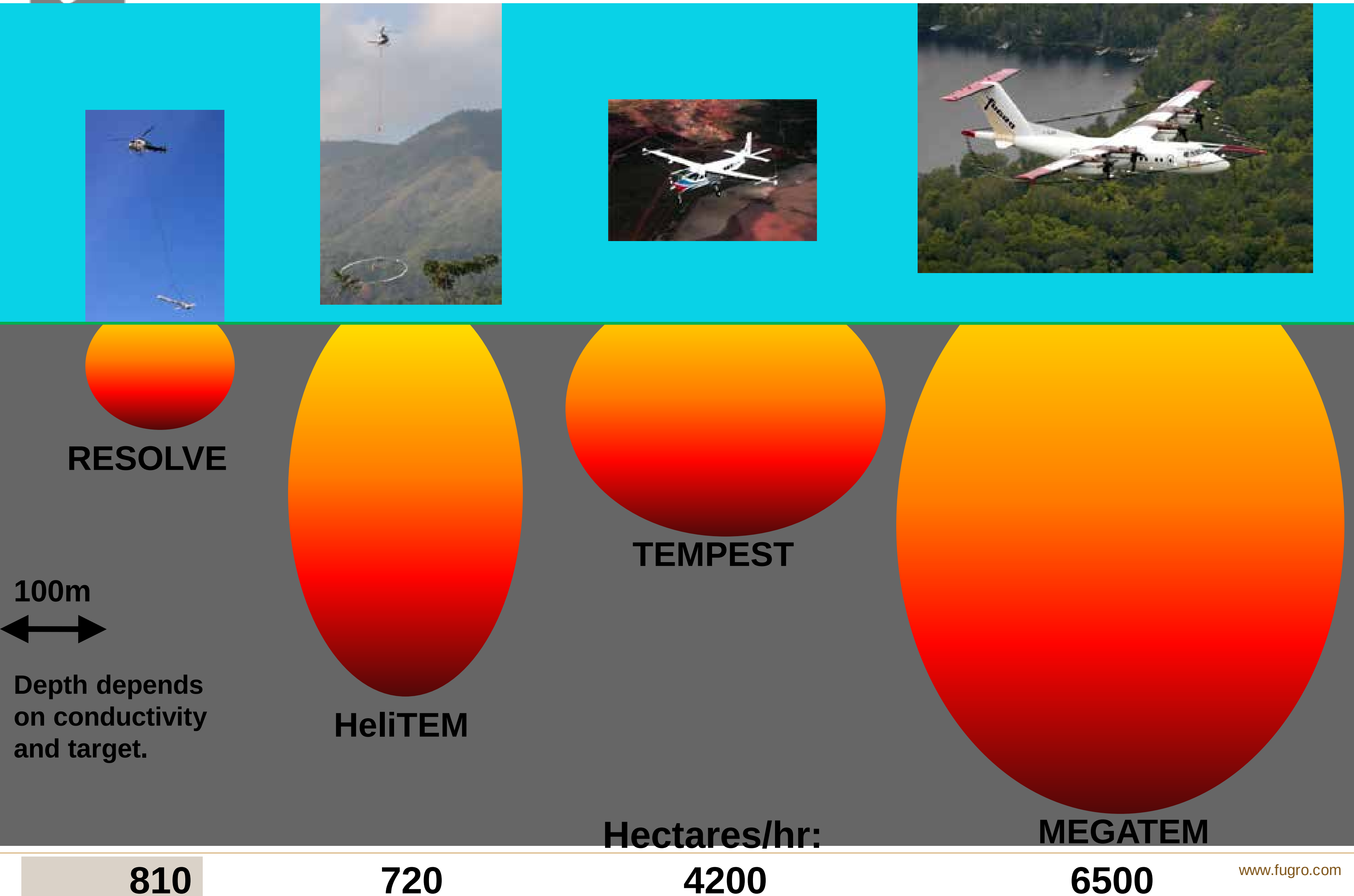
4 types, ~7 systems

Helicopter Time Domain

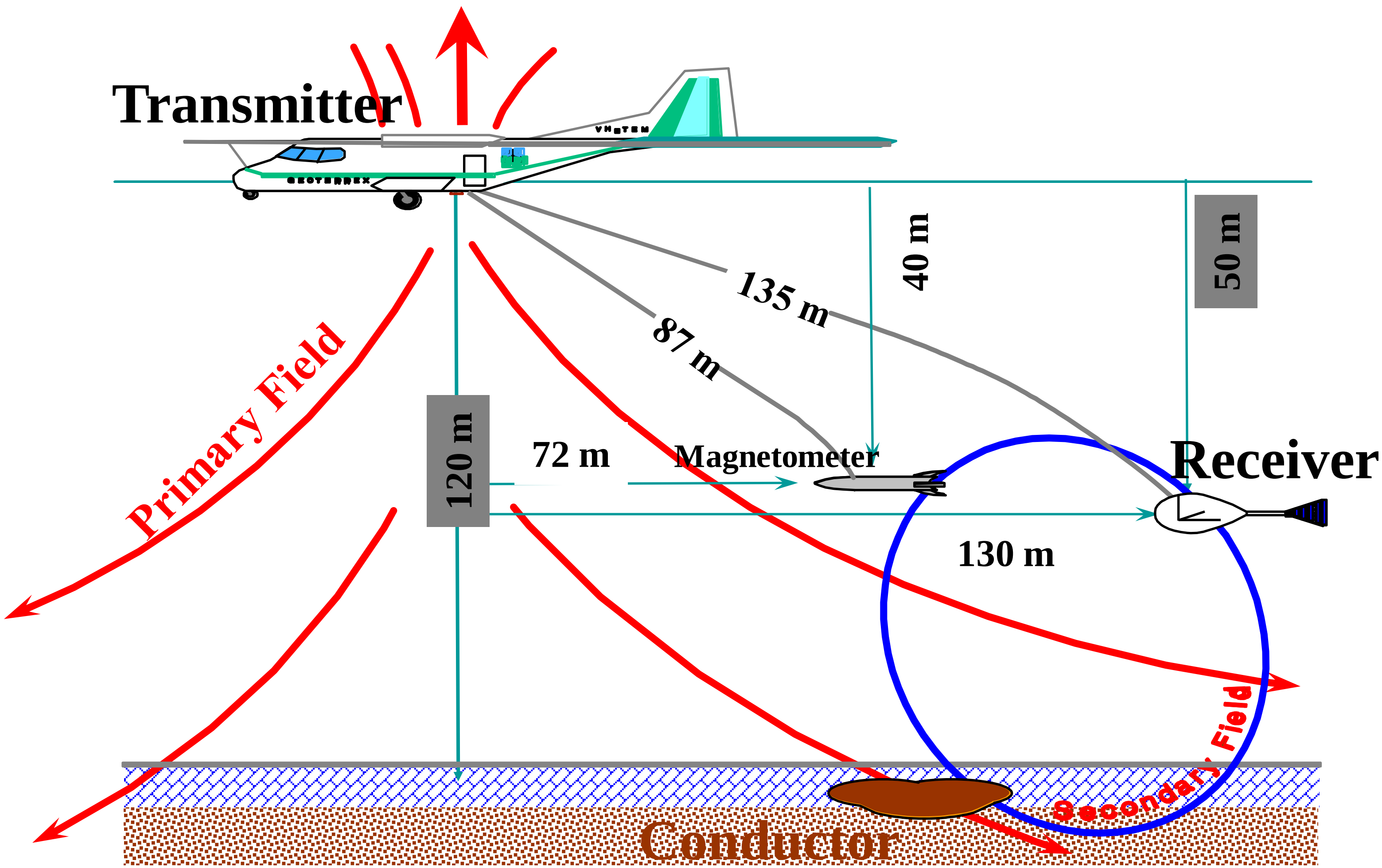
High Power – good depth
Good resolution
Modest terrain
Low conductivity range
Plenty of choice!

>10 types, 50+ systems??

AEM Systems: Relative Footprints



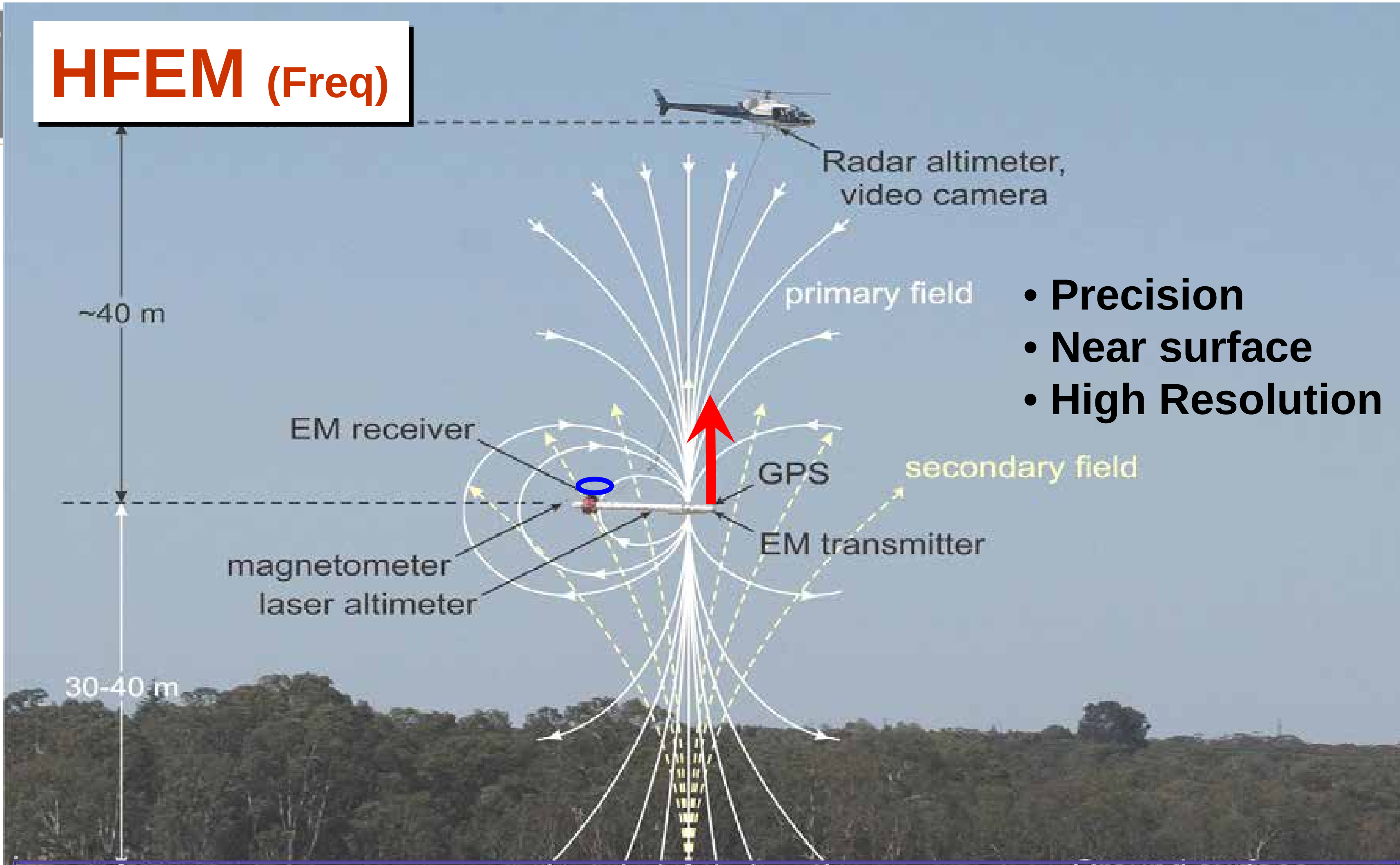
Fixed-Wing EM System Geometry

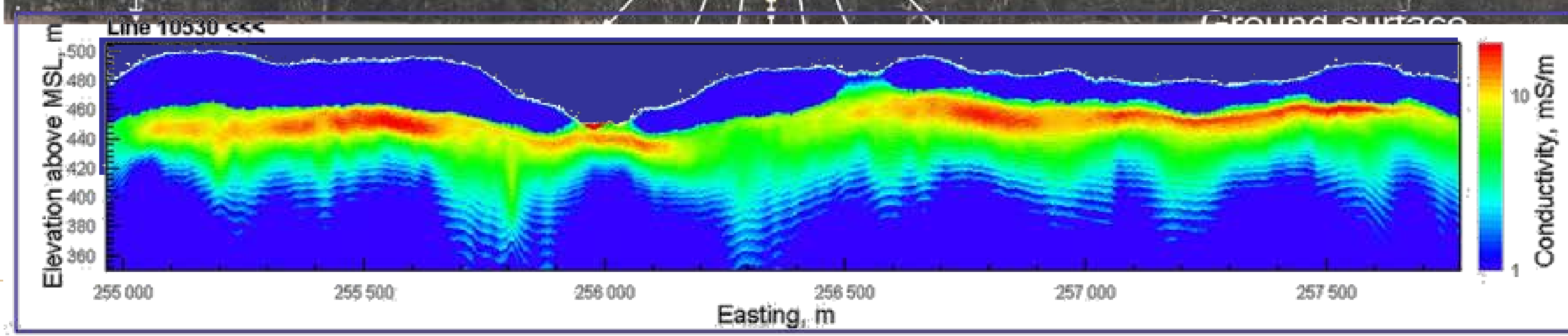


Fixed-wing EM Systems

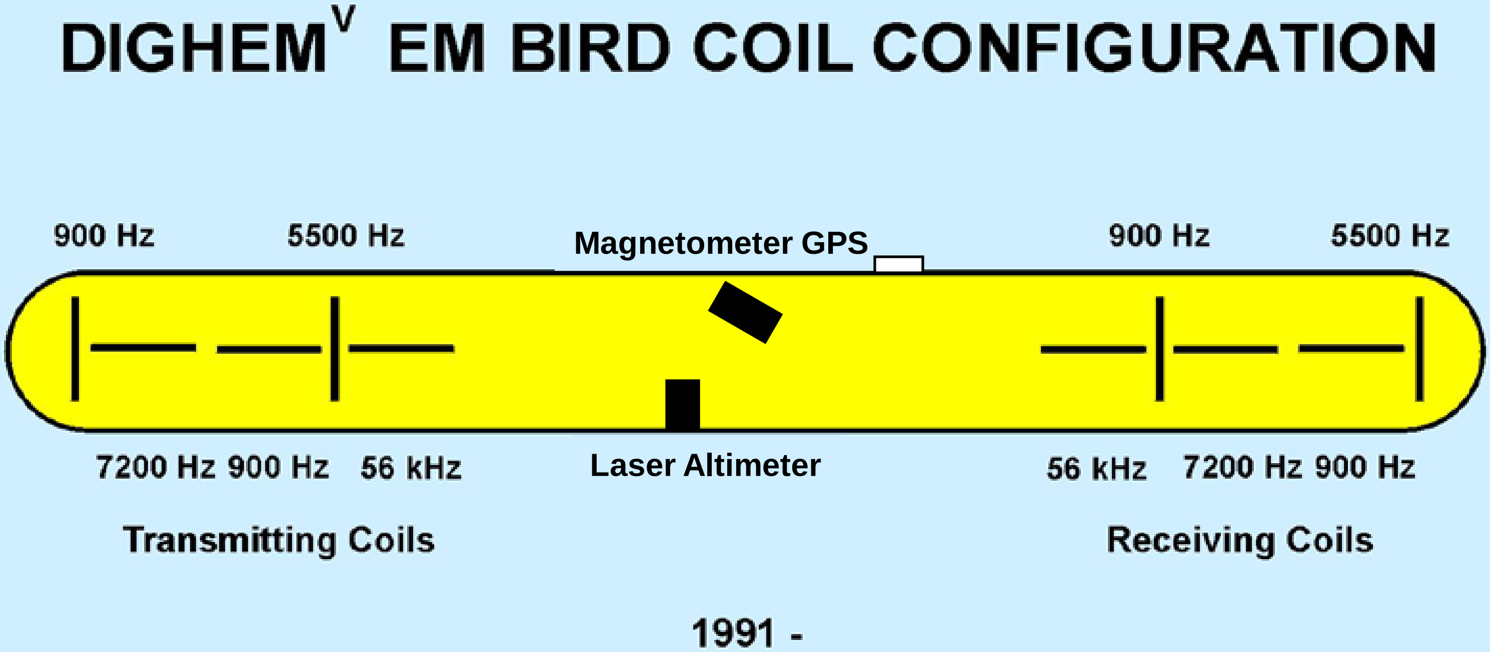
HFEM (Freq)

- Precision
- Near surface
- High Resolution

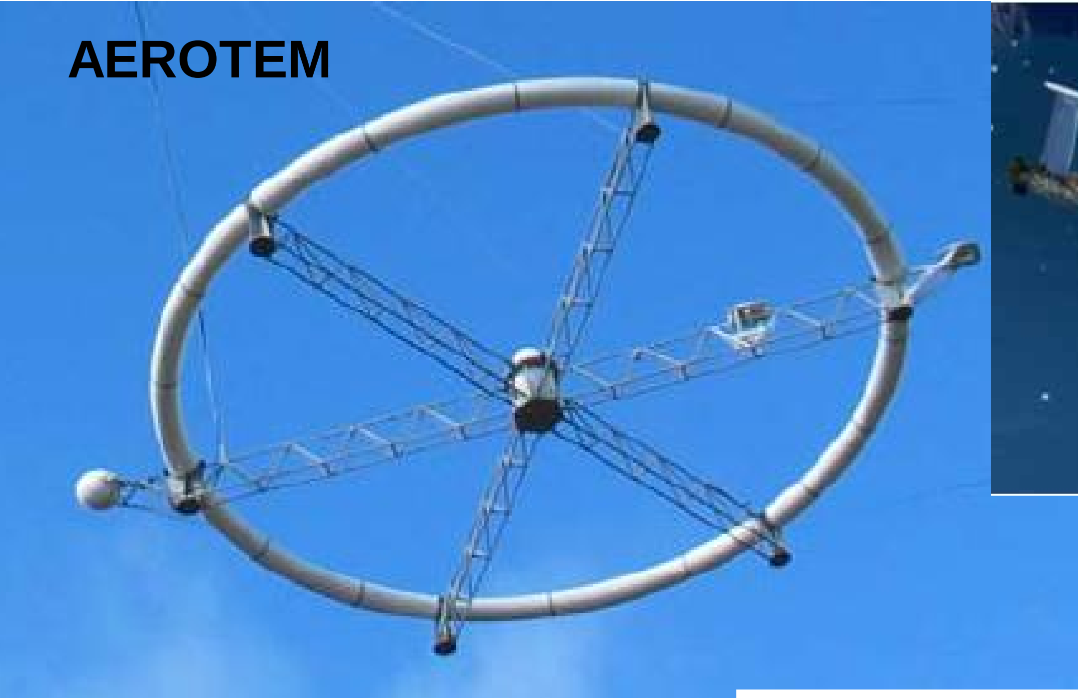




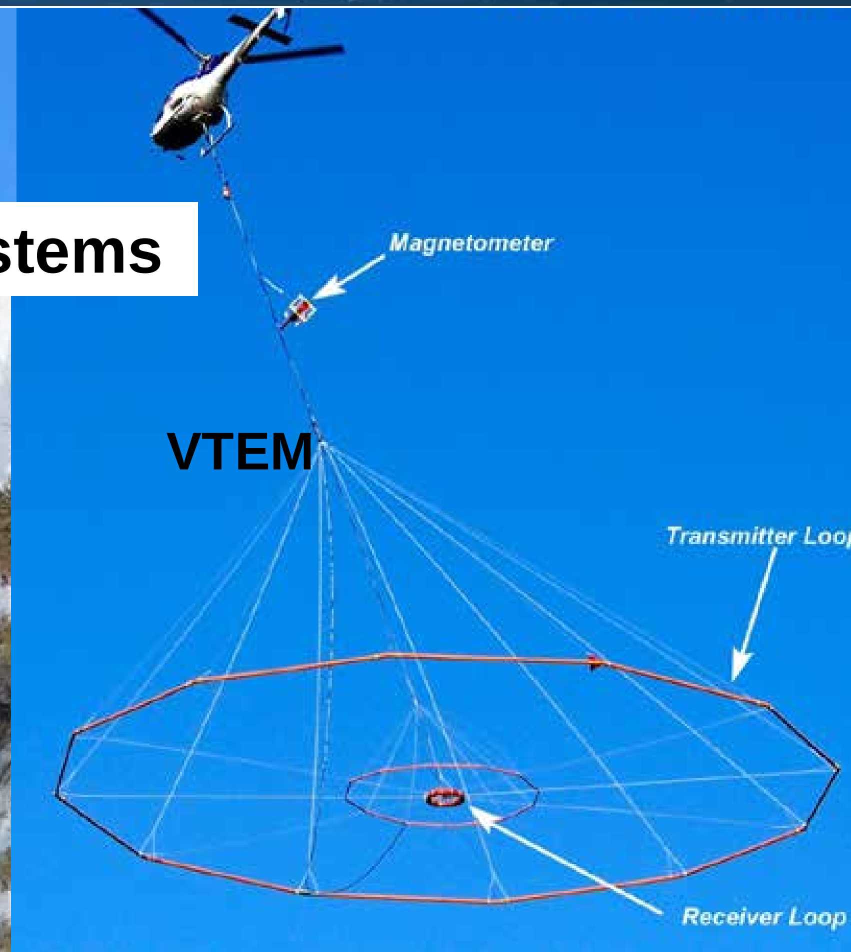
Frequency Domain EM

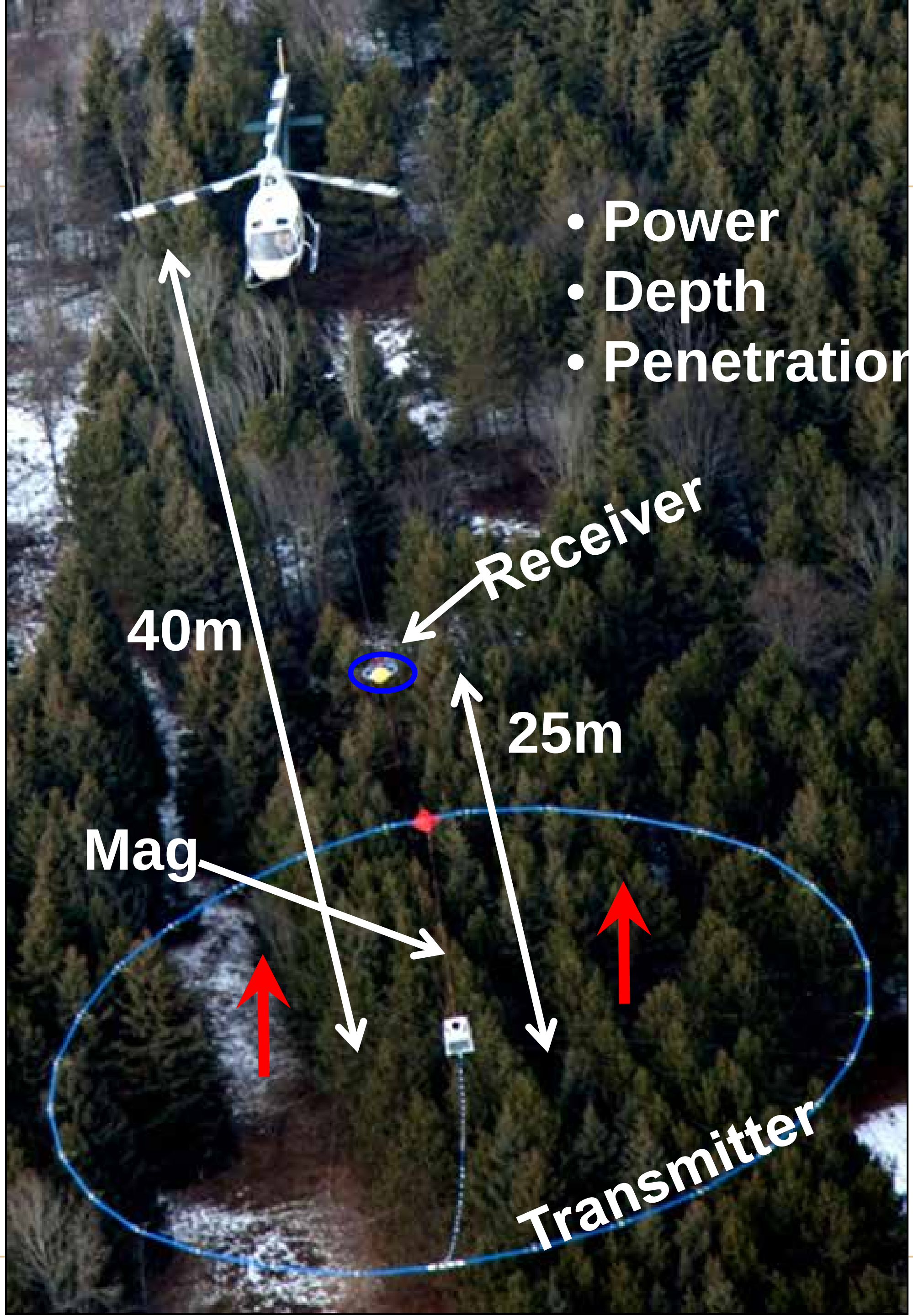


Mineral exploration, finding targets.



HTEM Systems

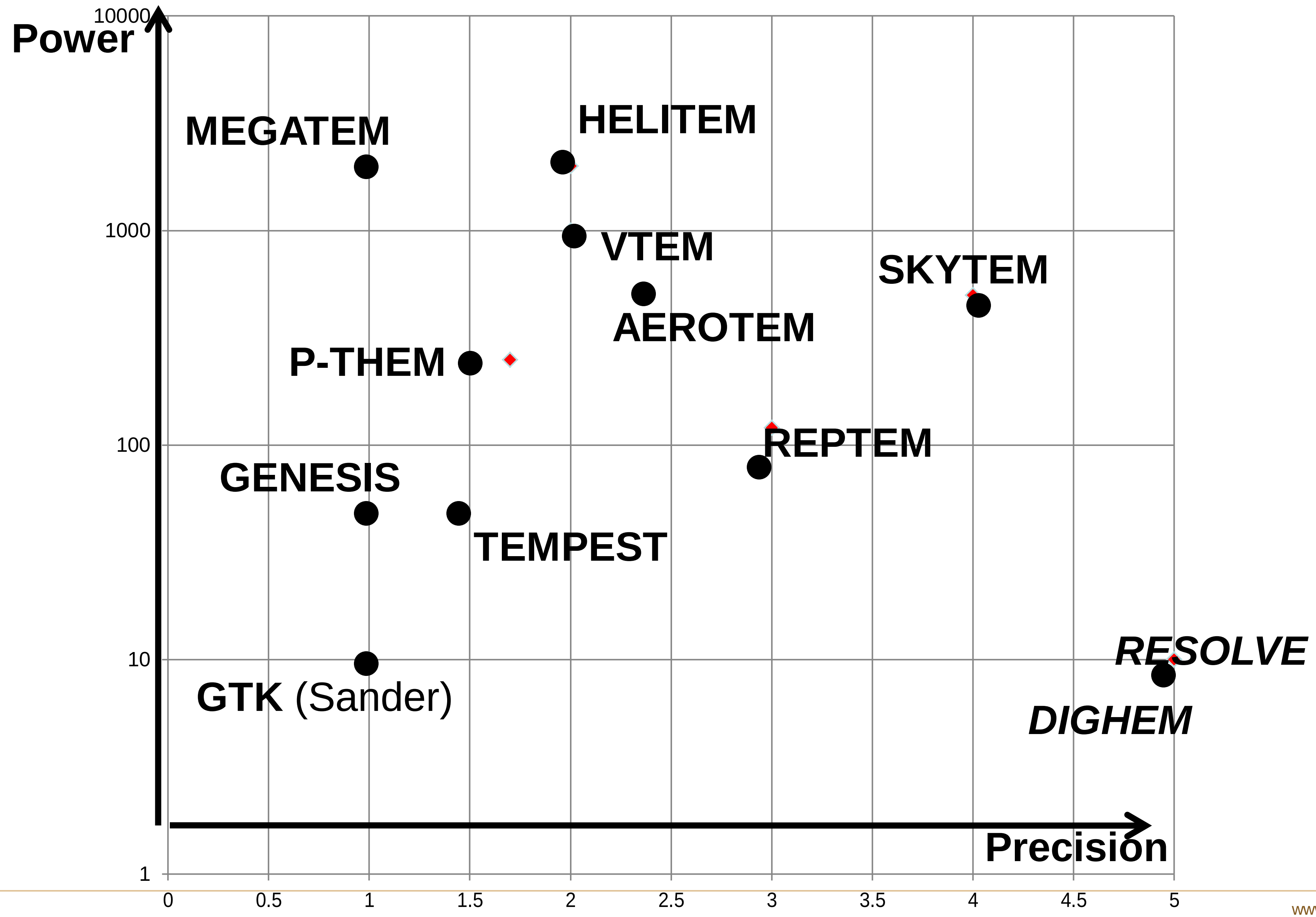




HELITEM
Time Domain

- §1,400 Amps
- §10,000 Times more powerful than RESOLVE

AEM Systems: power and precision



Some EM Choice Rules:

Where time-domain will be sensitive, use time-domain (for the depth)

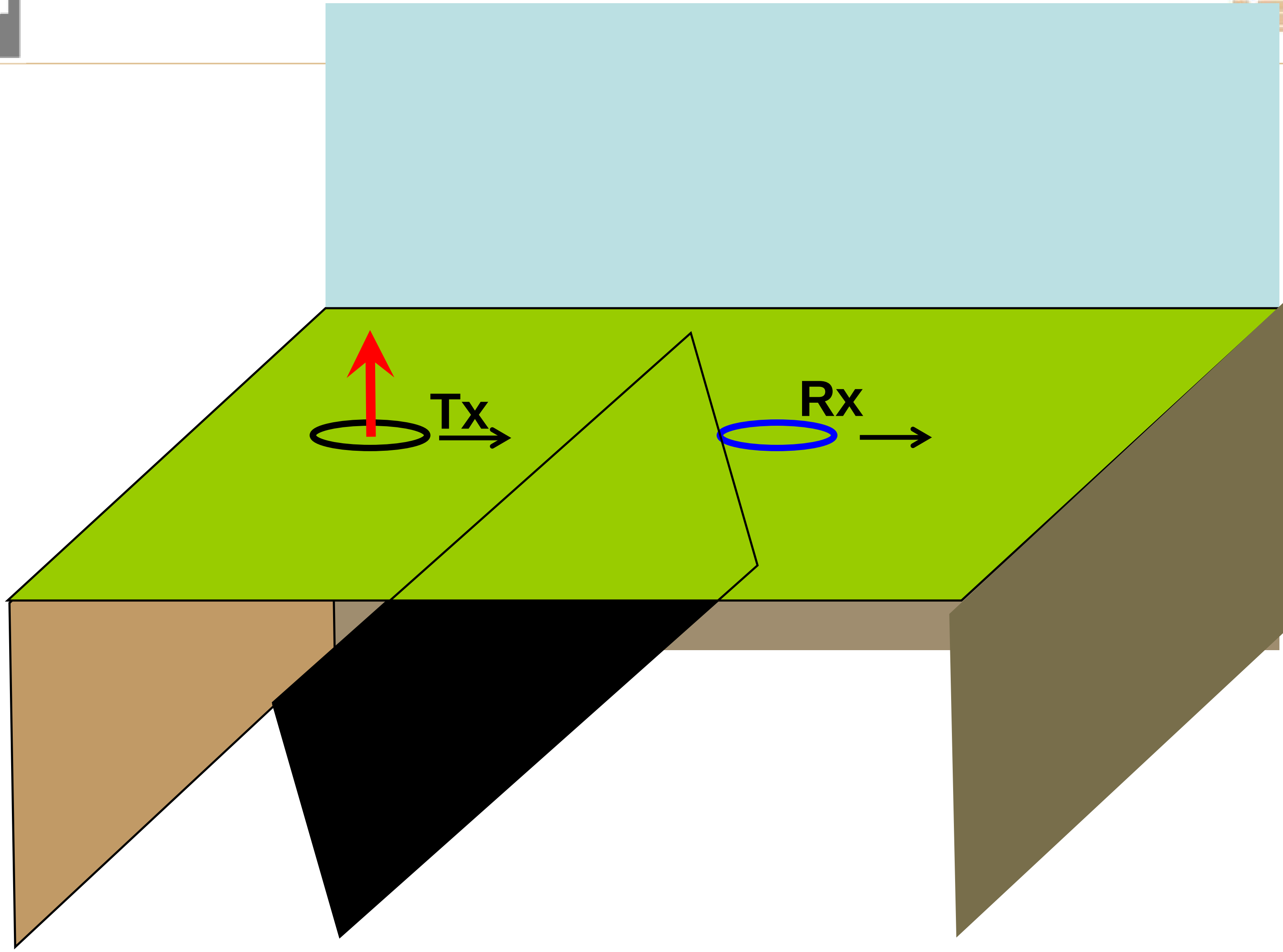
Where the conductors are very small or weak, consider frequency

Where fixed-wing can fly, consider fixed-wing first.

Use helicopter where resolution, access are issues.

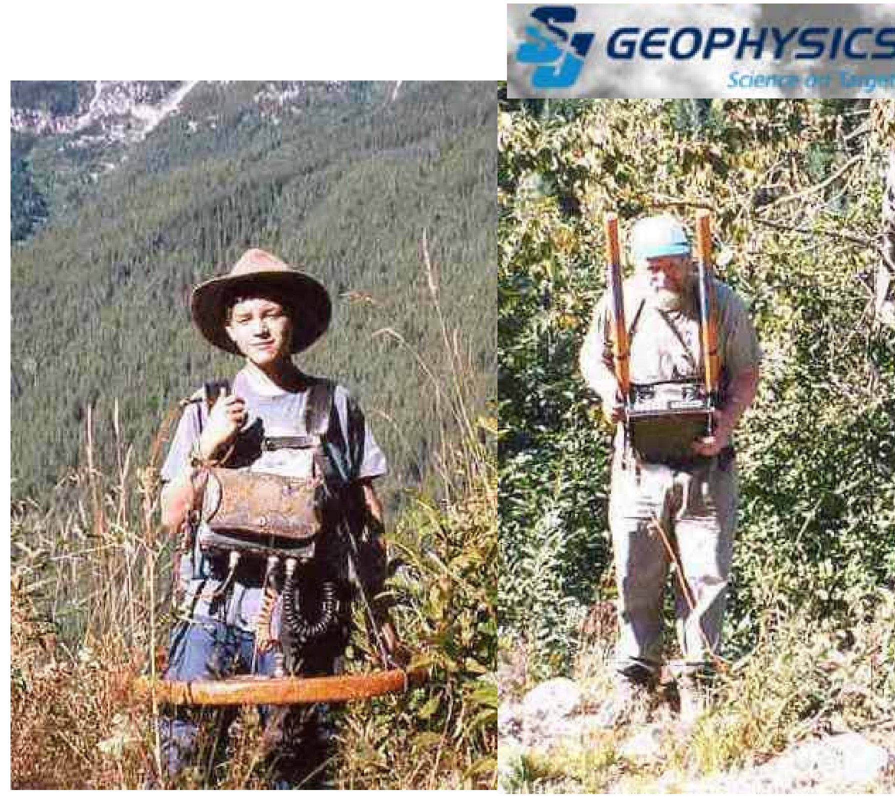
Consider ALL the options and consult with (unbiased) experts!

Ground: Small Transmitter Systems



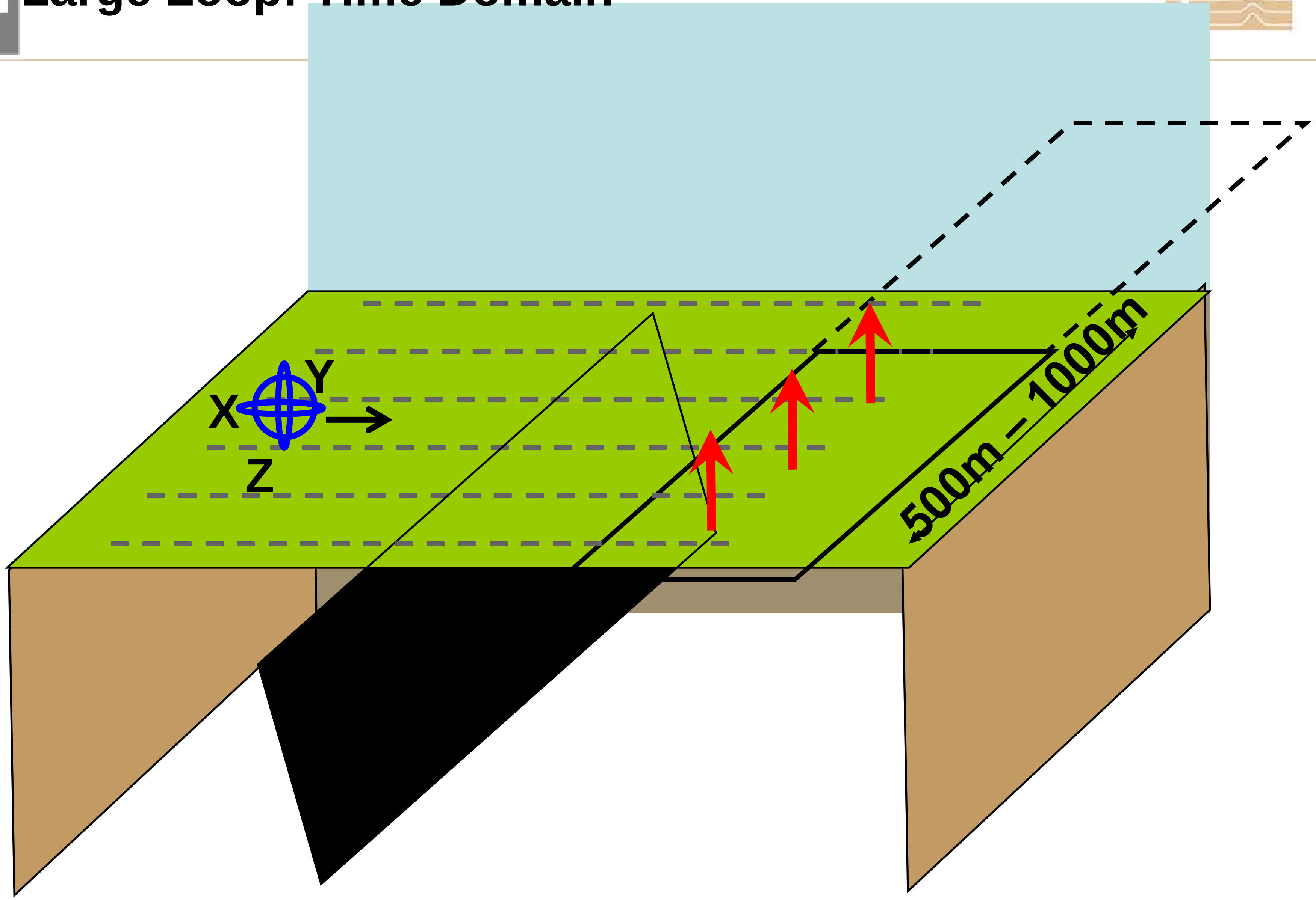
HLEM (small) Systems

Promis,
Iris Instruments

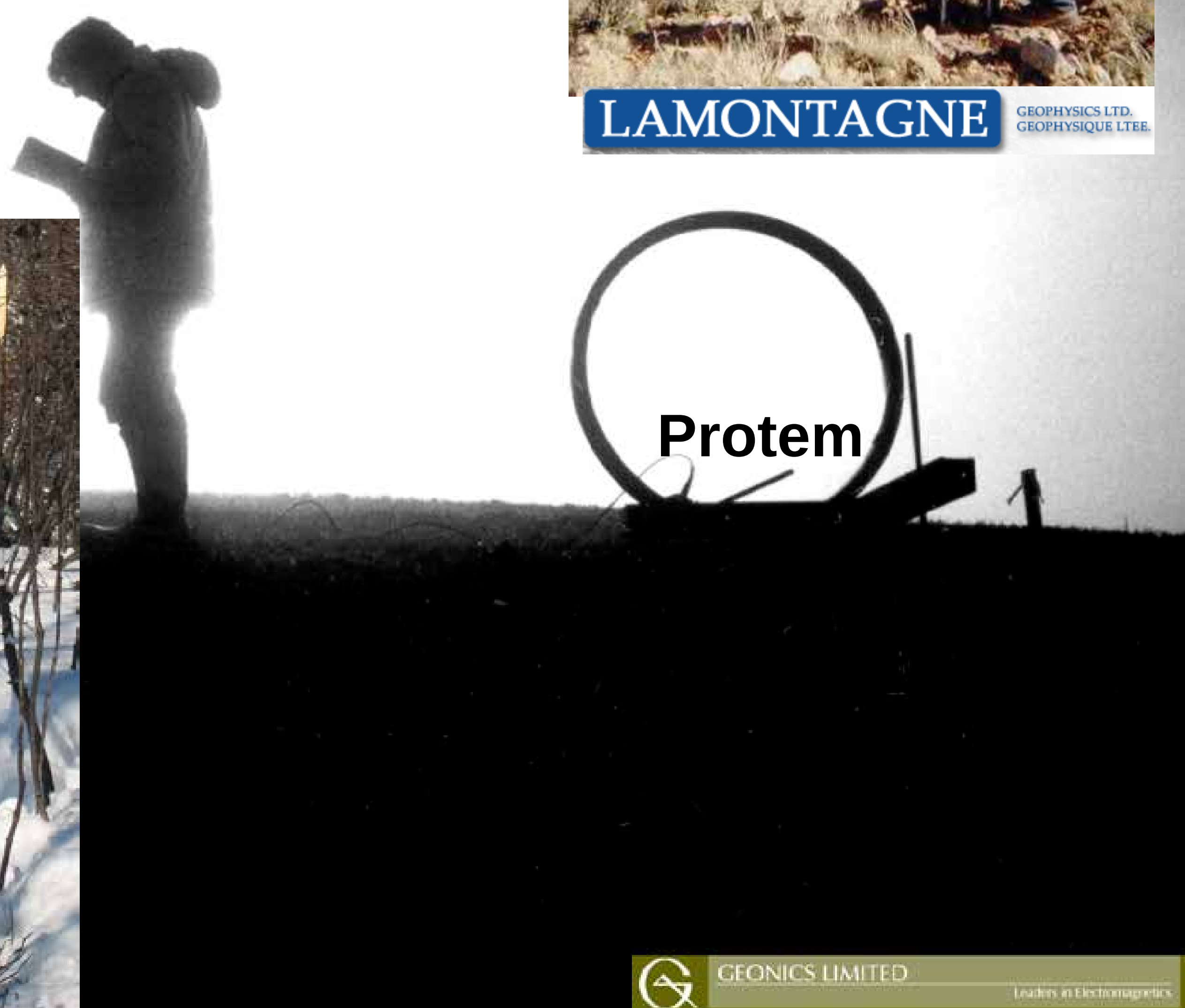


MaxMin system,
Apex Parametrics

Large Loop: Time Domain



Large loop TDEM



Ground EM Types

Large Loop Time Domain

High Power
Great Depth + Borehole
Expensive / complex
Very interpretable

Small Frequency/Time Domain

Low cost / simple
High resolution

Passive (receiver only)

Natural Source:

GREAT Depth
Conductive
Slow and Expensive

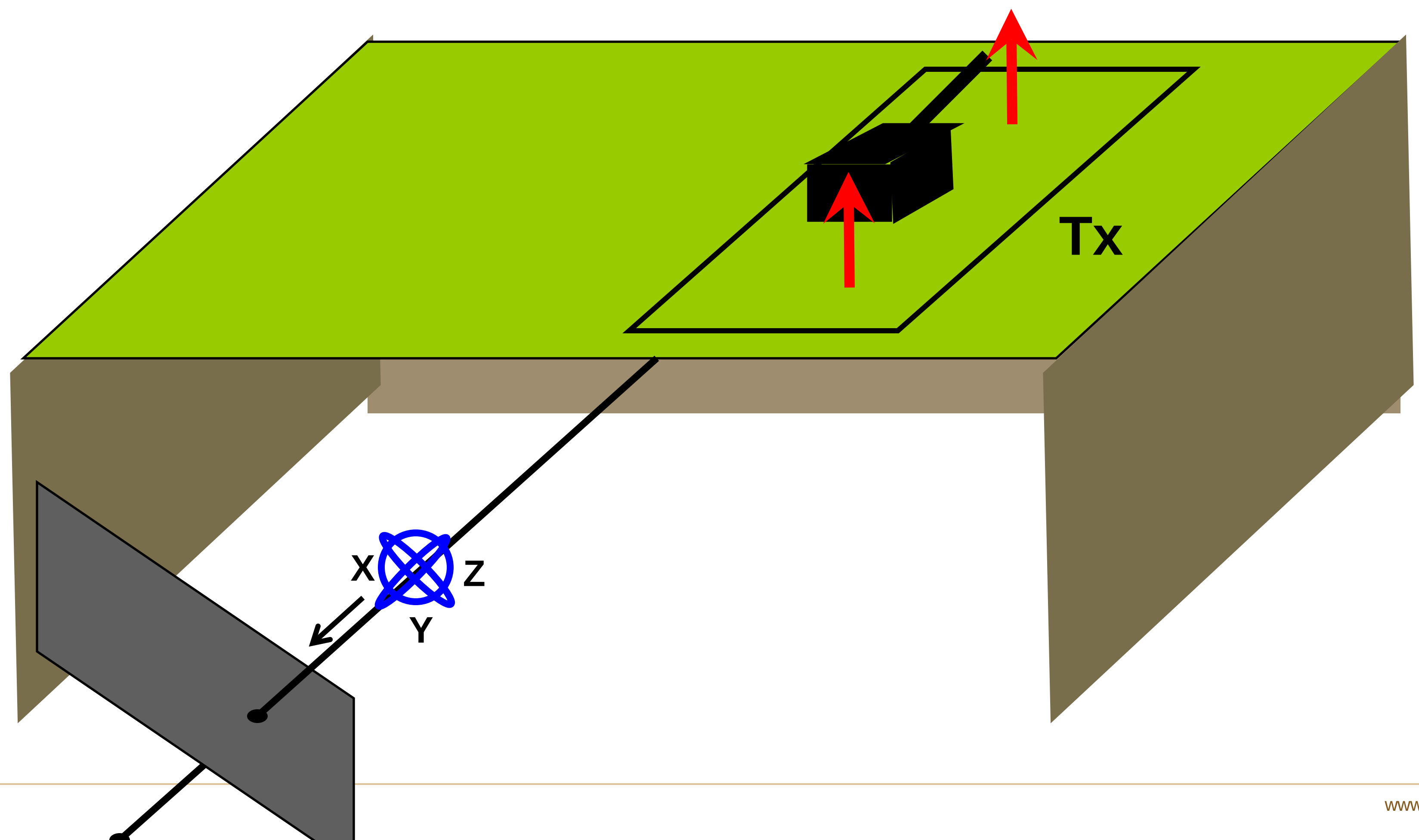
Man-made (VLF)

Cheap and fast
Poor depth

Engineering / UXO

Low power
Low cost / fast
High Resolution
Near surface

Borehole EM



The Borehole Mess!

§ UTEM - Borehole system, Lamontagne Geophysics

LAMONTAGNE GEOPHYSICS LTD. GEOPHYSIQUE LTEE.

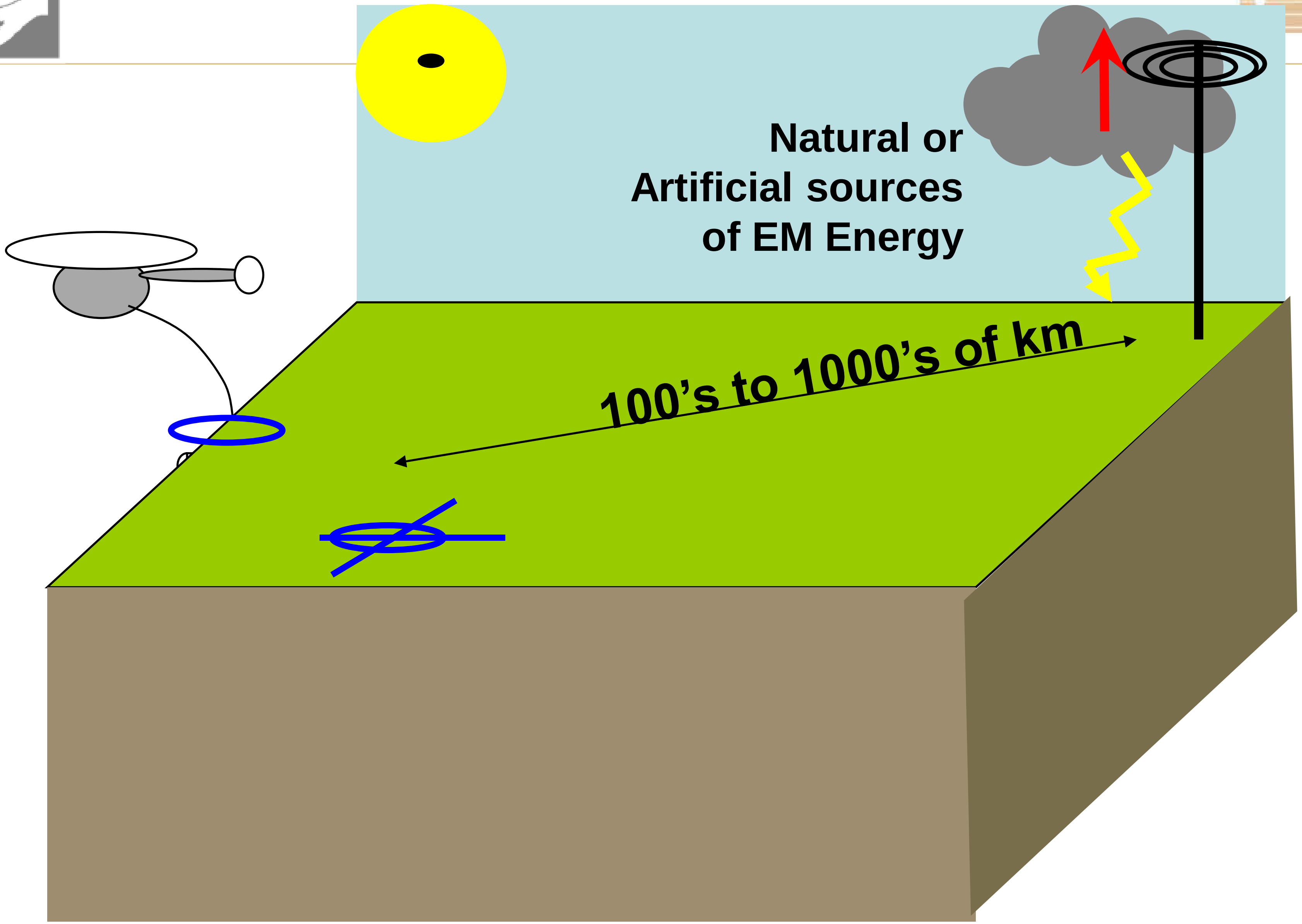
Borehole EM Characteristics

- Best geometric interpretation (of ANY EM).
- Complex 3D interpretation.
- Best sensitivity to small targets.
- Best depth of exploration (Rx is close to target)
- Good conductance sensitivity range.
- Off-hole detection distance depends on loop location, but is limited to ½ of borehole length.

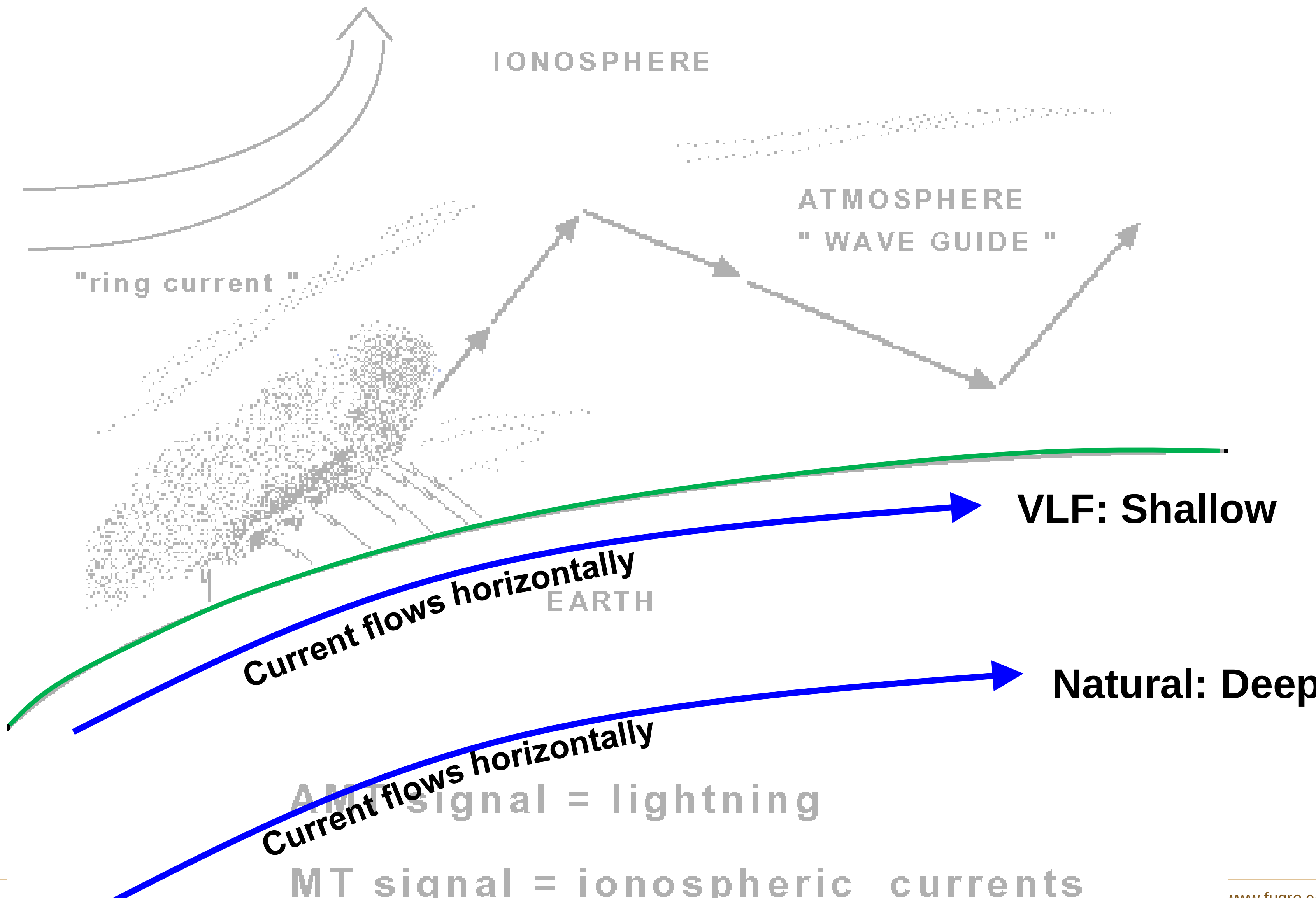
- Need a borehole - Bummer!

- Advanced stage projects.
- Complex mixed conductors. (e.g. detecting targets under other conductors).
- In-fill drilling.

Magneto-tellurics and VLF



MT and AMT Signal Sources



Planting MT Sensor

MT Characteristics

ZTEM (airborne)

- Vertical component (“Tipper”)
- Magnetic field only

    (Poor resistivity)

Natural Field (MT)

- No transmitter required
- Very deep penetration (dependent on recording time)
- Complex to operate
- Unreliable natural fields
- Not good for vertical conductors
- Poor resolution
- Insensitive to small conductors

Applications

- Deep Targets
- Conductive host rocks.
- Large targets
- Porphyrys!

VLF EM Characteristics

•Formerly an exploration mainstay
•Plagued by transmitter shut-down

•Generally shallow
•Shallow overburden
•Low cost survey
•Now generally 3-component

•Poor depth penetration
•Affected by overburden
•Directional sensitivity
•Unreliable sources

Key Points: EM

- Detect electrically conductive deposits and alteration, and to map geology by changes in electrical resistivity.
- Resistivity is controlled by mineralogy (sulphides, oxides, clay minerals) and by porosity, saturation and salinity.
- Understand the electrical nature of the target, the host geology, and over-lying geology (e.g. overburden).
- There is a HUGE range of EM systems to choose from!
- Time domain is power and depth.
- Frequency domain is high resistivity and resolution.
- Ground sees deeper, higher resolution: airborne is faster
- Helicopter is higher resolution, fixed wing is faster coverage

Thank You