Quantitative interpretation of geophysical electromagnetic data for groundwater investigations

Colin G. Farquharson and Ken Witherly

Inco Innovation Centre, and
Department of Earth Sciences,
Memorial University of Newfoundland;

Condor Consulting, Inc.,
Lakewood, Colorado.

Acknowledgments

- Bruce Smith

- Dick Irvine

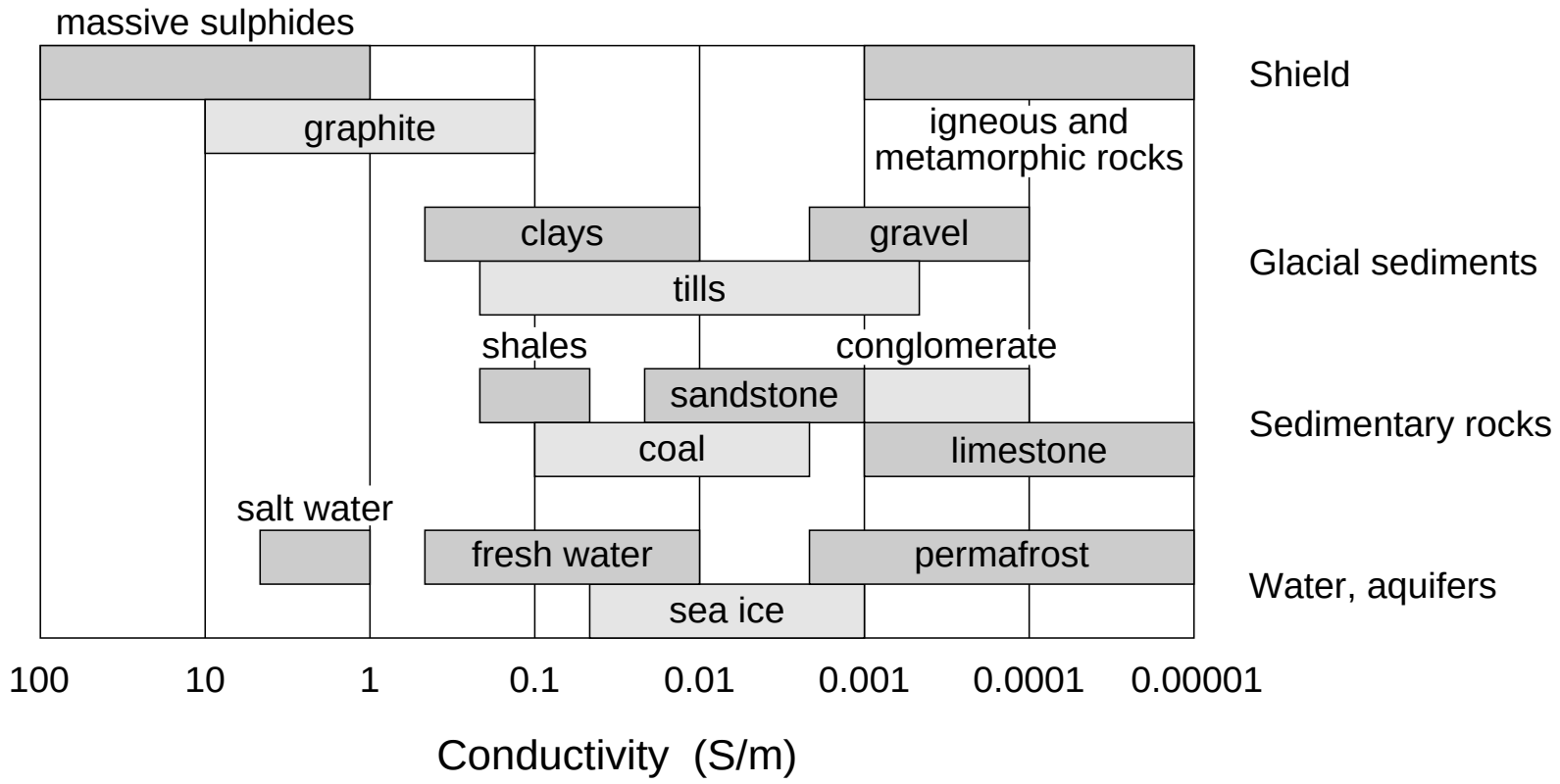
Outline

- Introduction.
- Typical geophysical electromagnetic method.
  - Electrical conductivities of the subsurface.
  - Electromagnetic induction.
  - Sensitivity of airborne EM measurements.
  - Interpretation – apparent conductivities/resistivities.
  - Interpretation – 1-D inversion.
- Example from the Edwards aquifer, Texas.
- Summary.

Outline

- Introduction.
- Typical geophysical electromagnetic method.
  - Electrical conductivities of the subsurface.
  - Electromagnetic induction.
  - Sensitivity of airborne EM measurements.
  - Interpretation – apparent conductivities/resistivities.
  - Interpretation – 1-D inversion.
- Example from the Edwards aquifer, Texas.
- Summary.

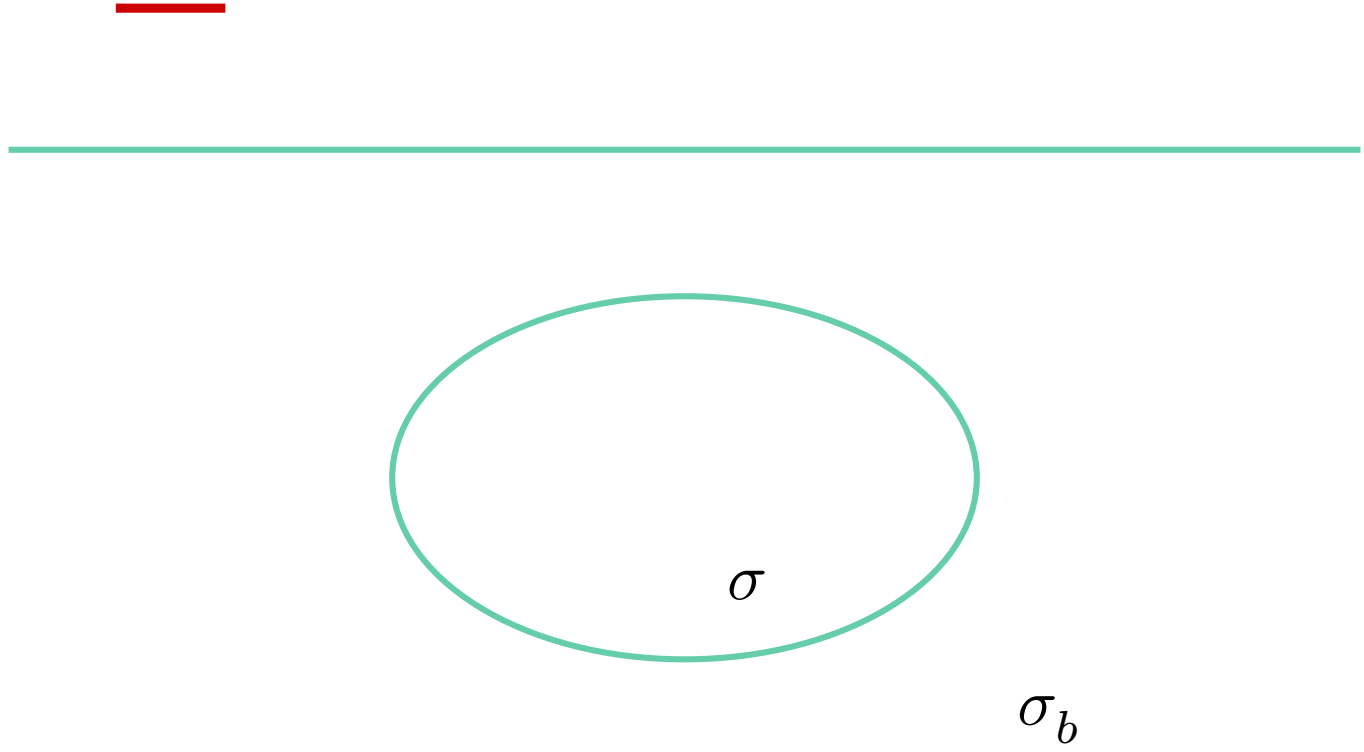
Electrical conductivities of the subsurface



- ⋆ Conductive mineralized zones in resistive shield rocks.
- ⋆ Water content & salinity increase conductivity.
- ⋆ Crustal conductors from tectonic processes.
- ⋆ Unexploded ordnance.
- ∗ Conductivity varies over orders of magnitude.

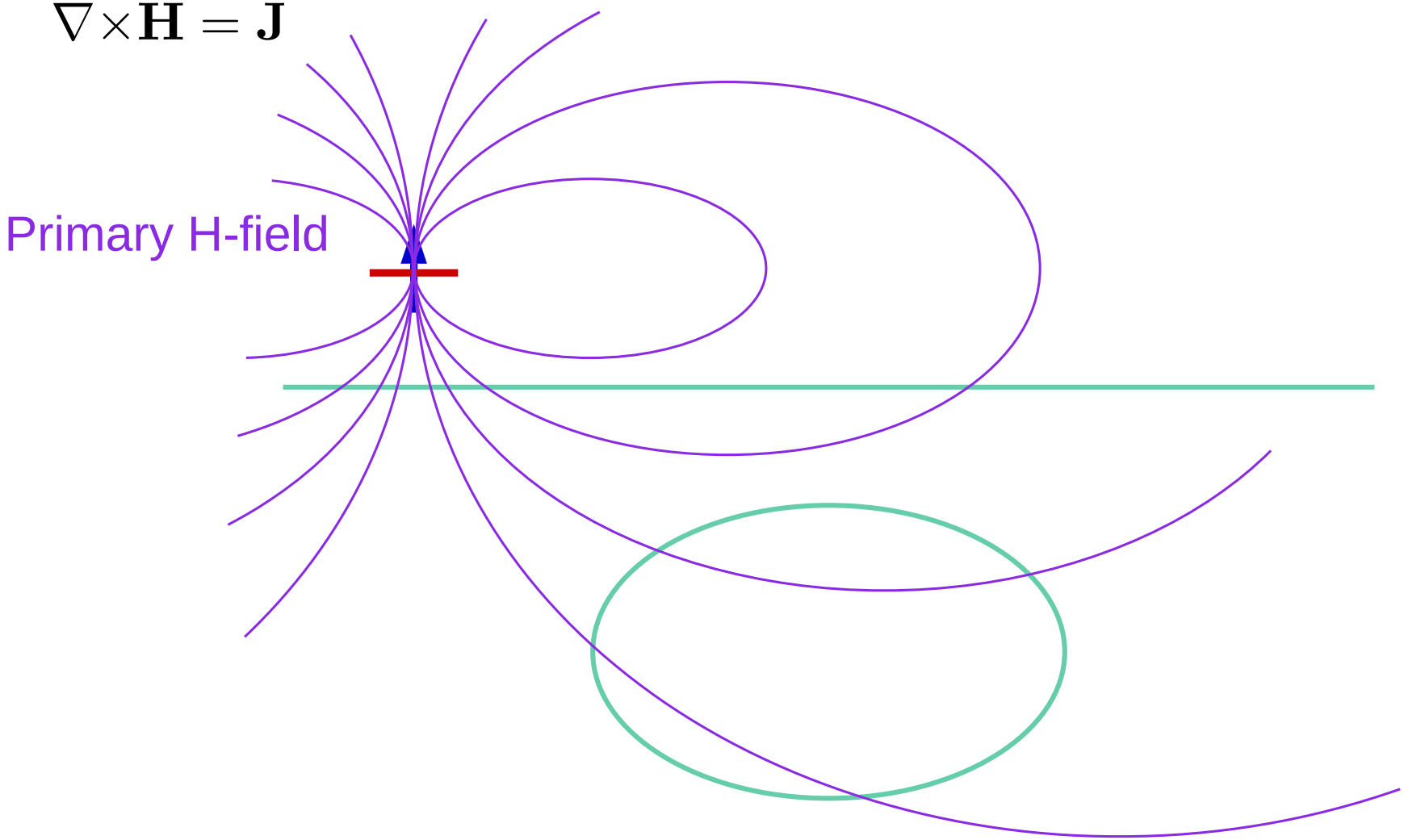
Electromagnetic induction

$I(t) \sim \sin \omega t$



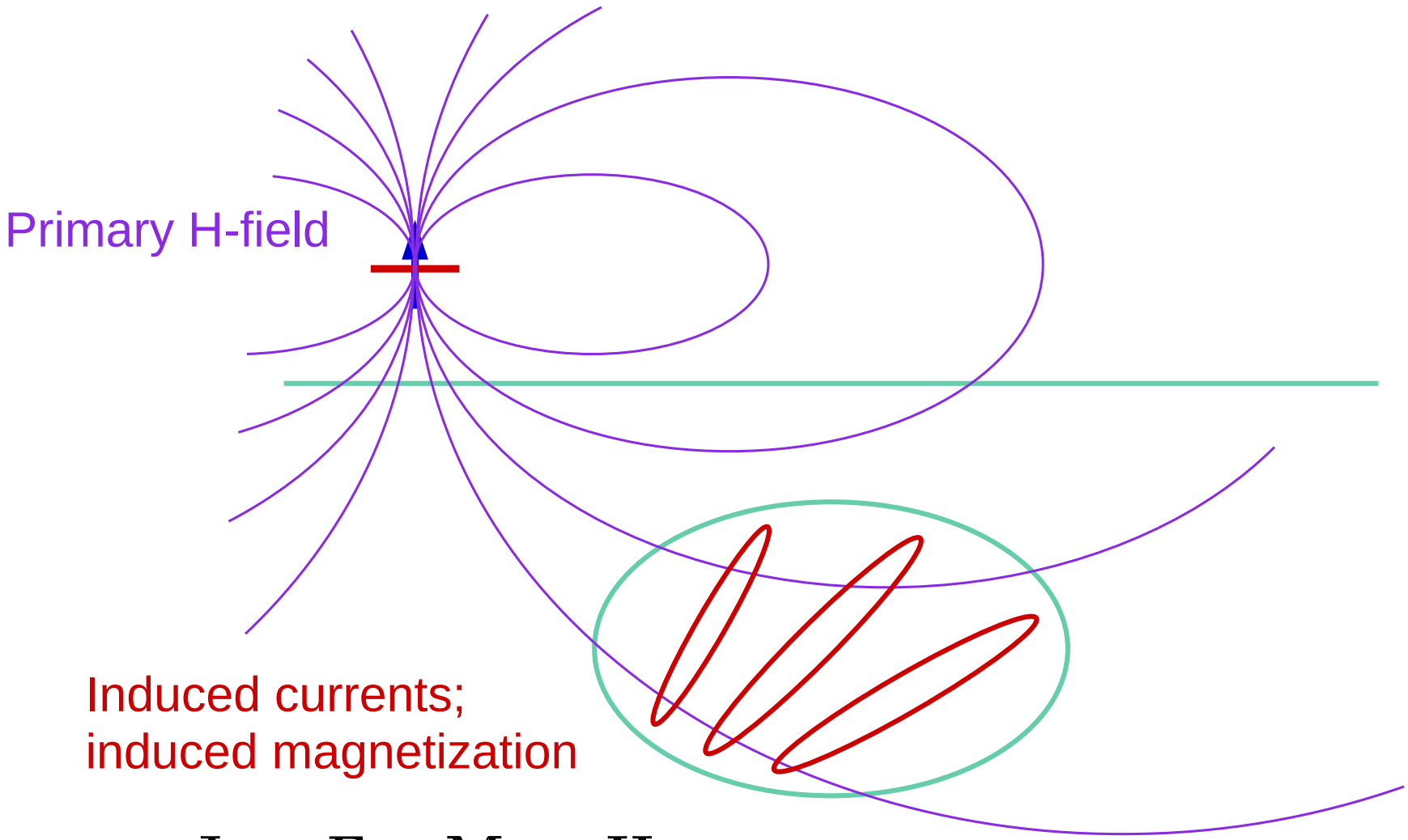
Electromagnetic induction

$$\nabla \times \mathbf{H} = \mathbf{J}$$



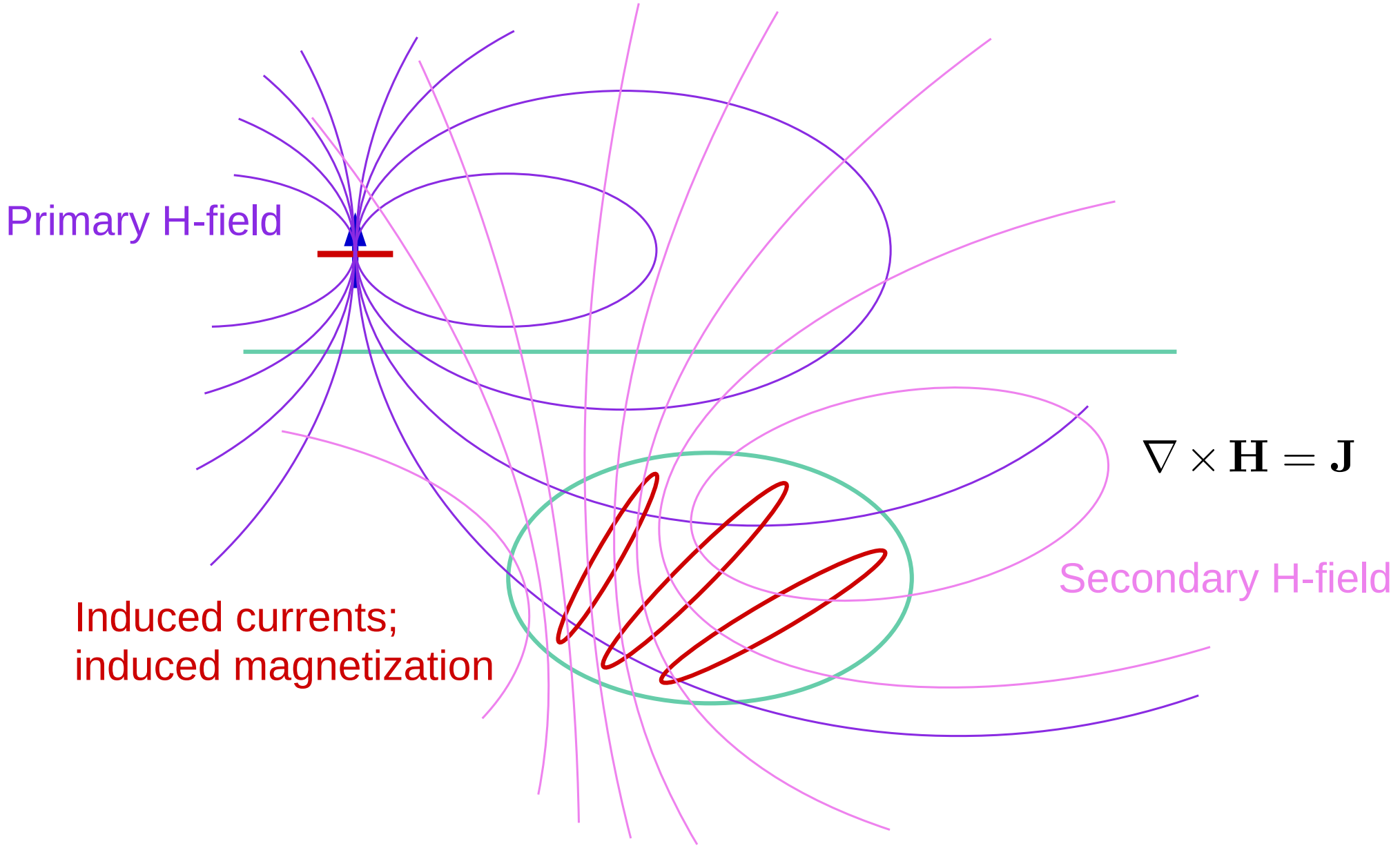
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

Electromagnetic induction

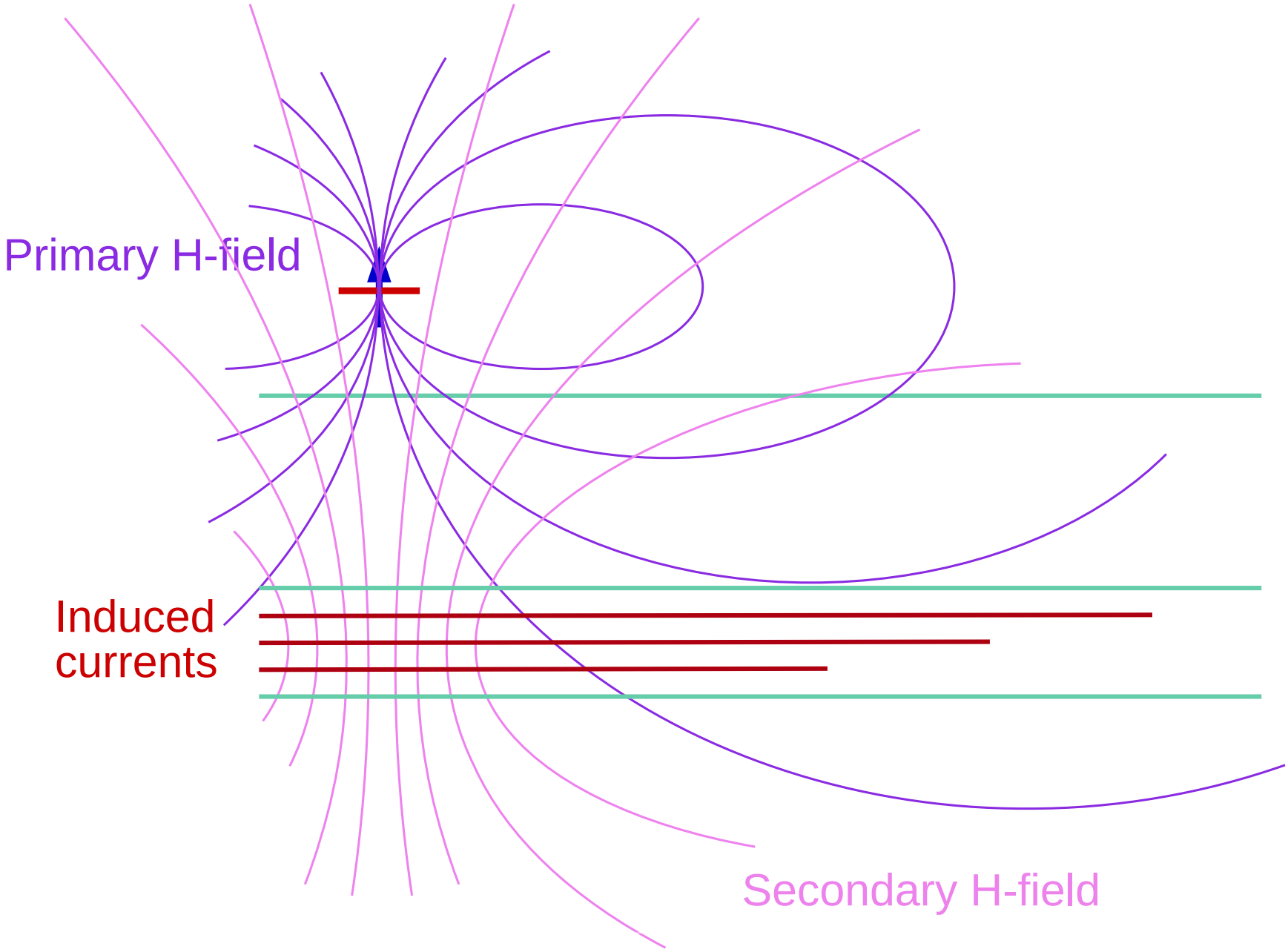


$$\mathbf{J} = \sigma\mathbf{E}; \quad \mathbf{M} = \kappa\mathbf{H}$$

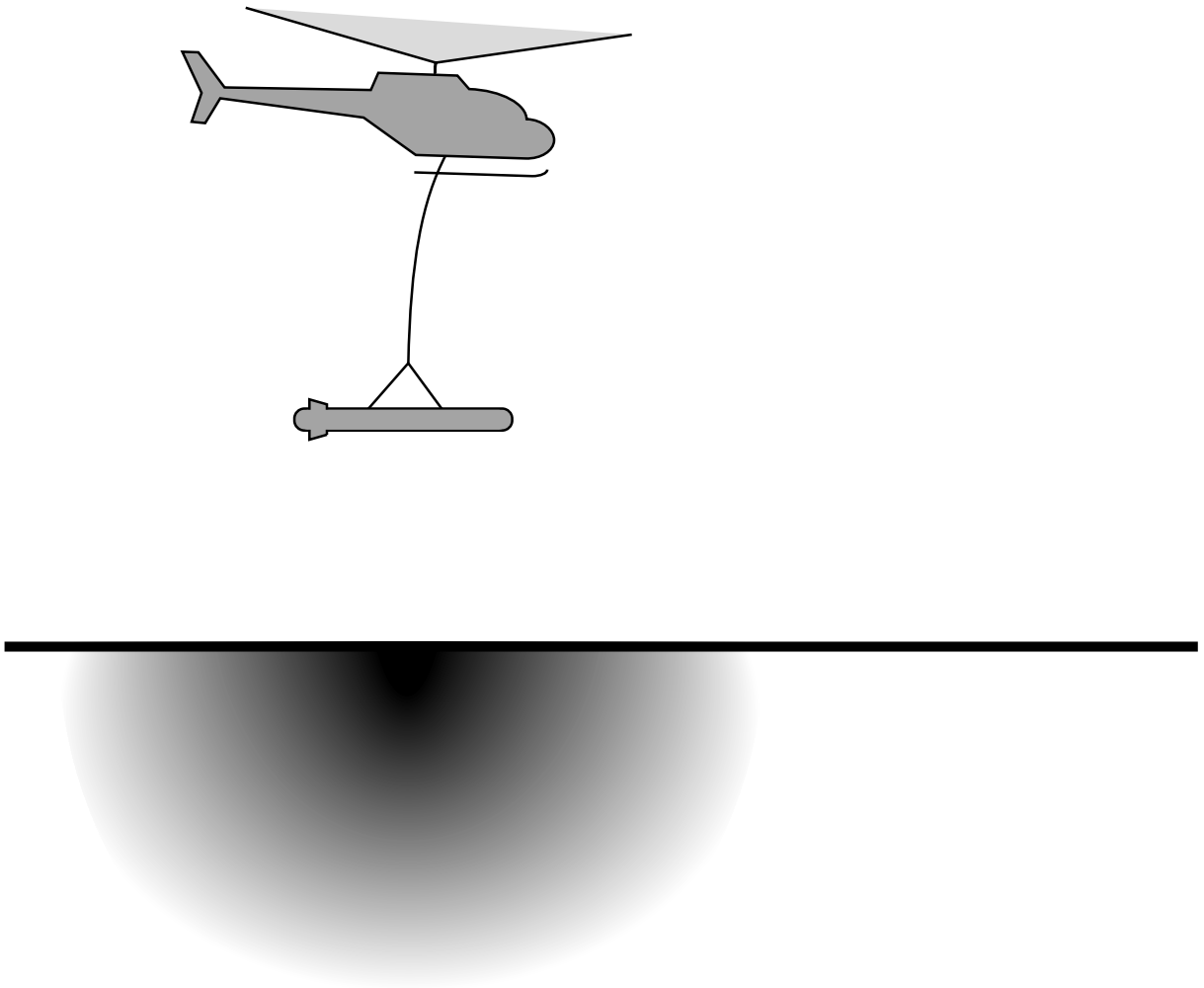
Electromagnetic induction



Electromagnetic induction

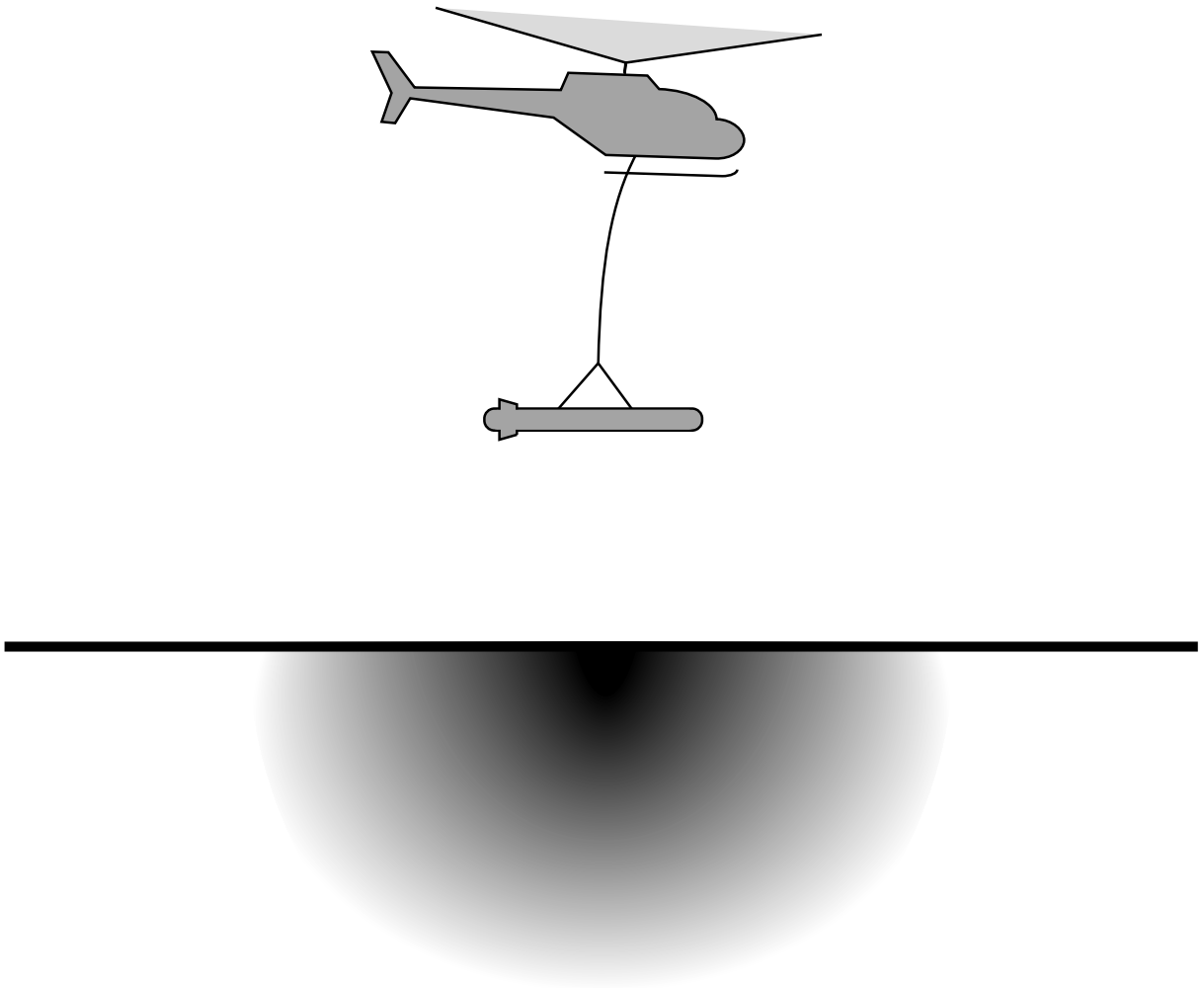


Lateral and depth sensitivity

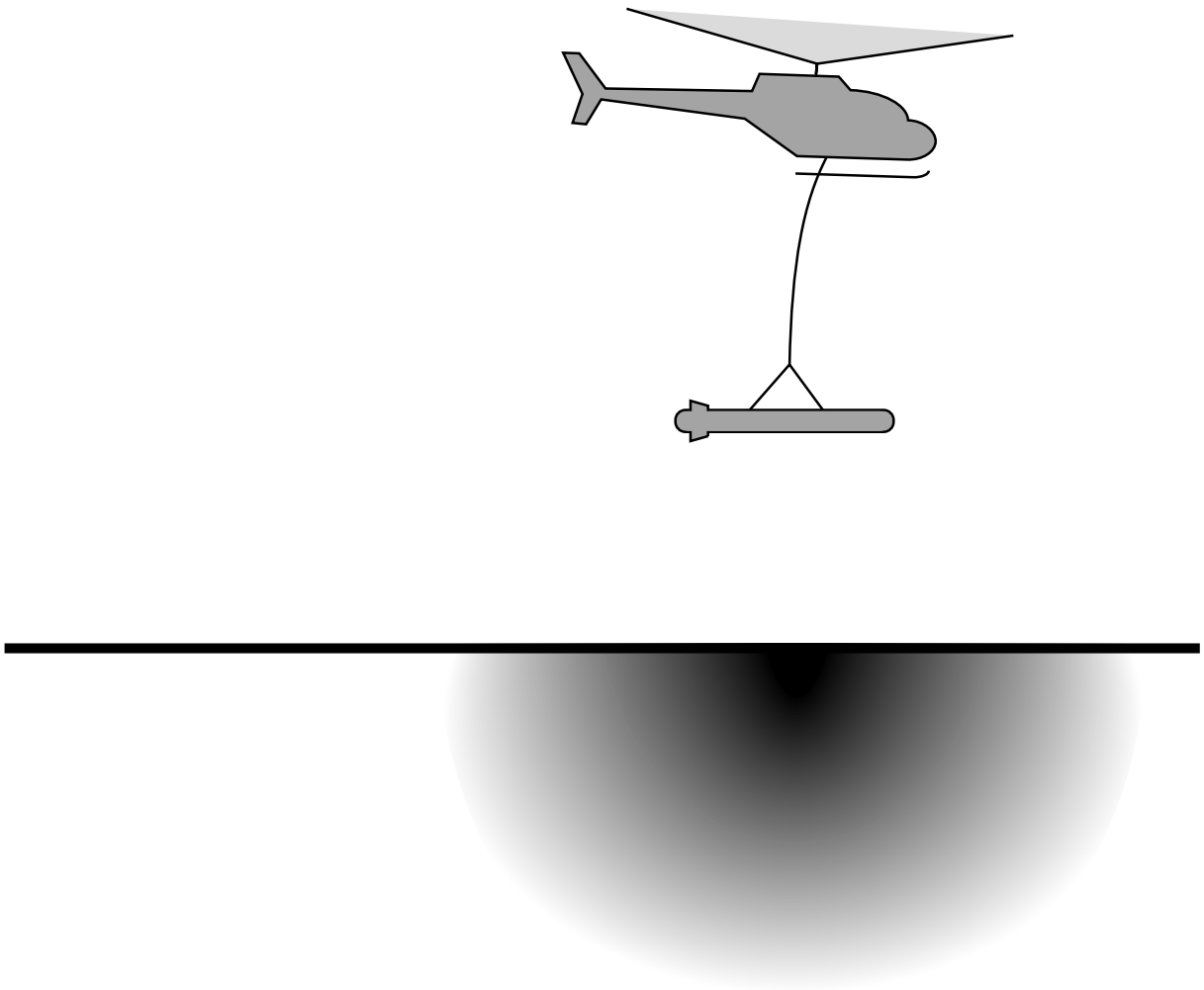


(Schematic; not really to scale.)

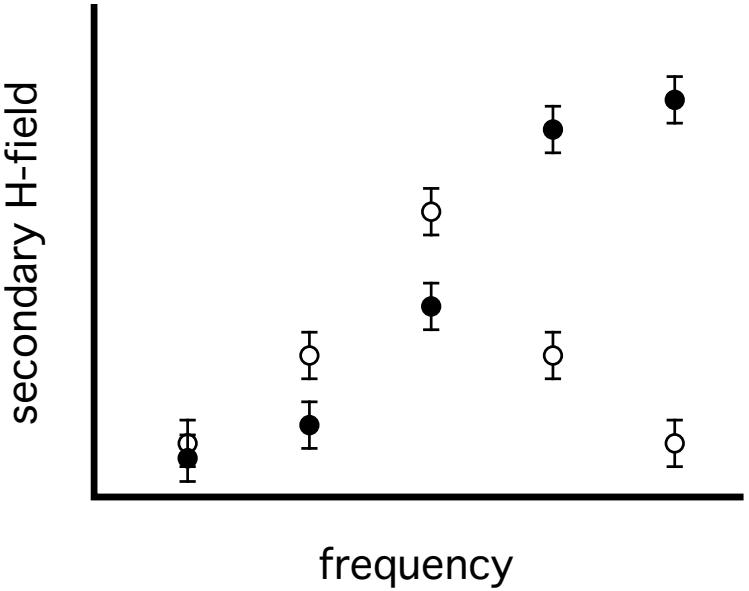
Lateral and depth sensitivity

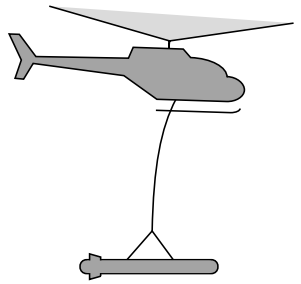


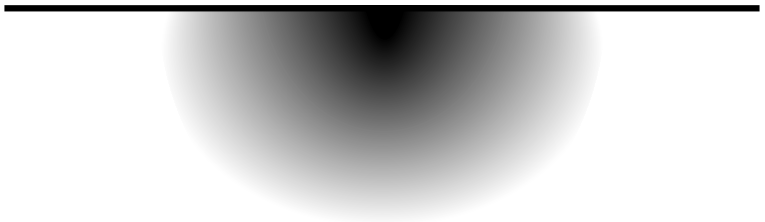
Lateral and depth sensitivity

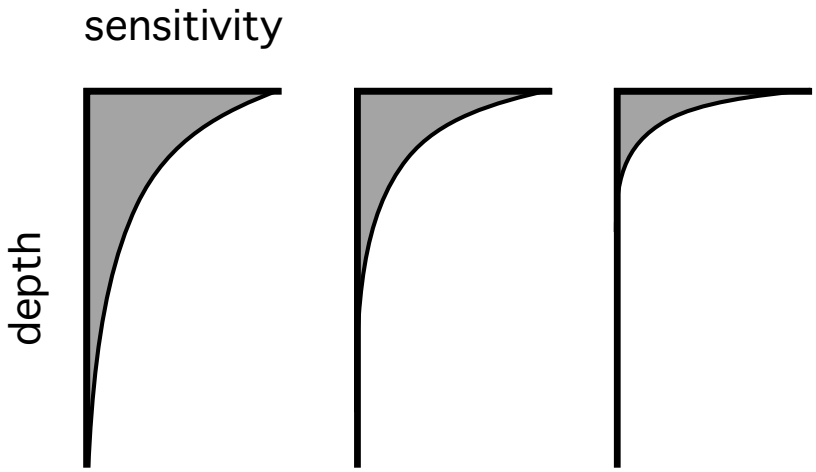


Depth sensitivity

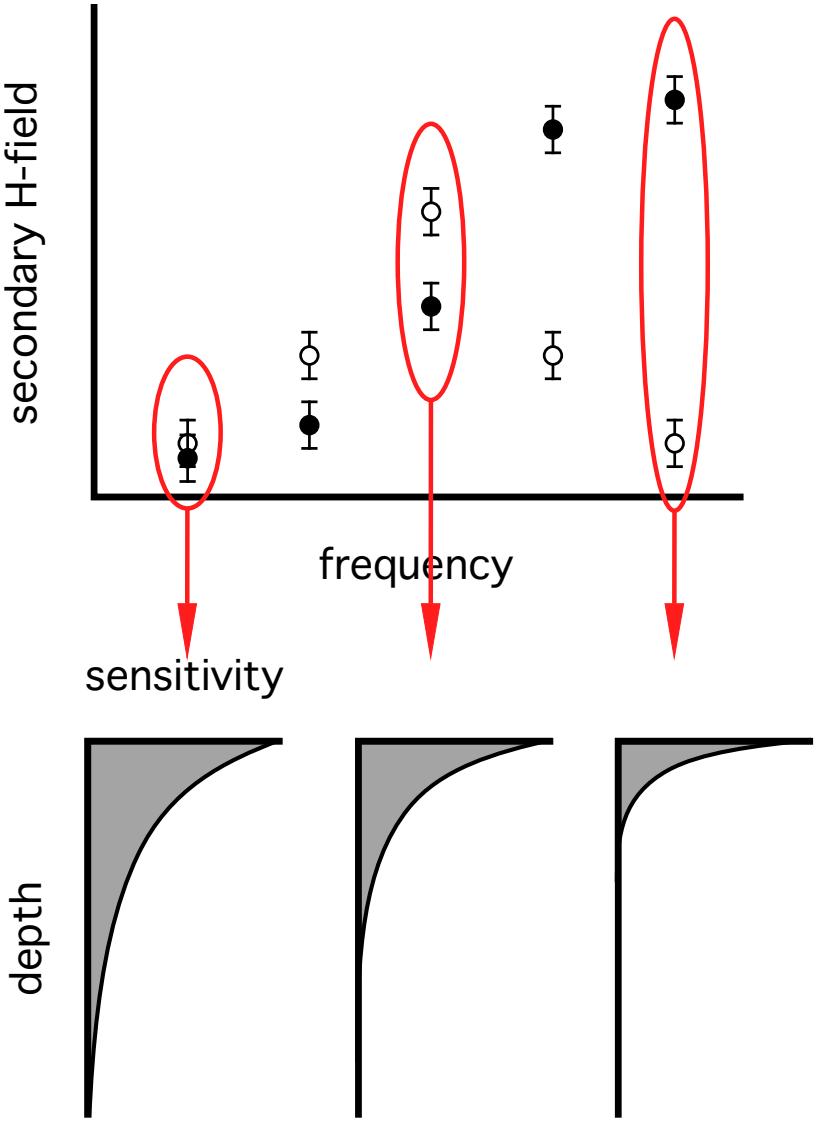


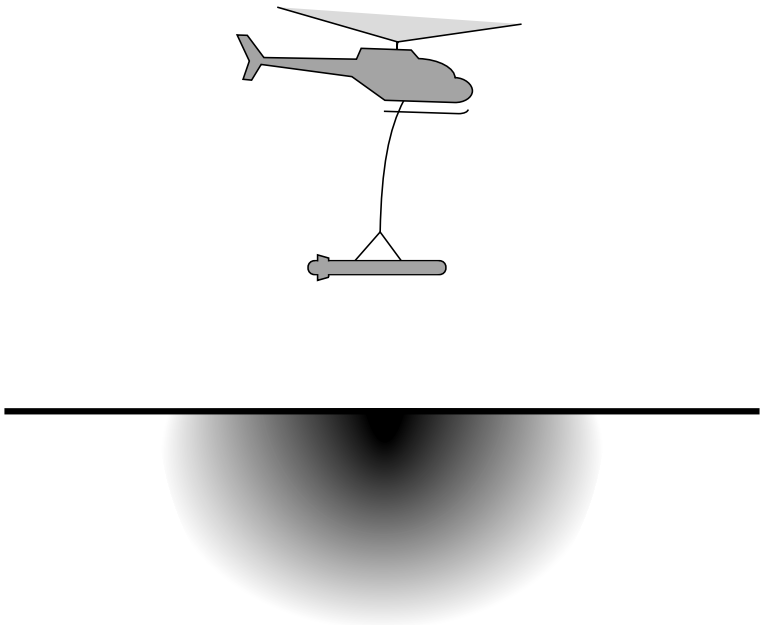




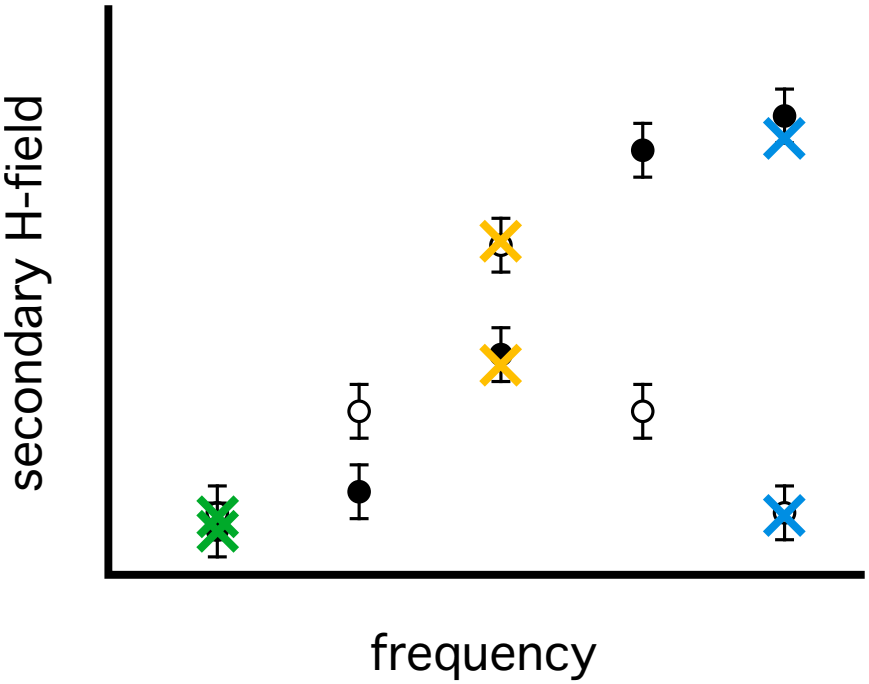


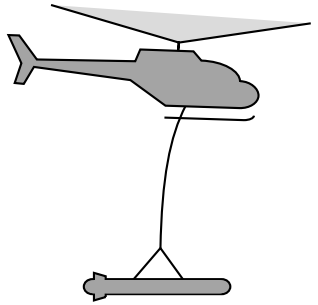
Depth sensitivity

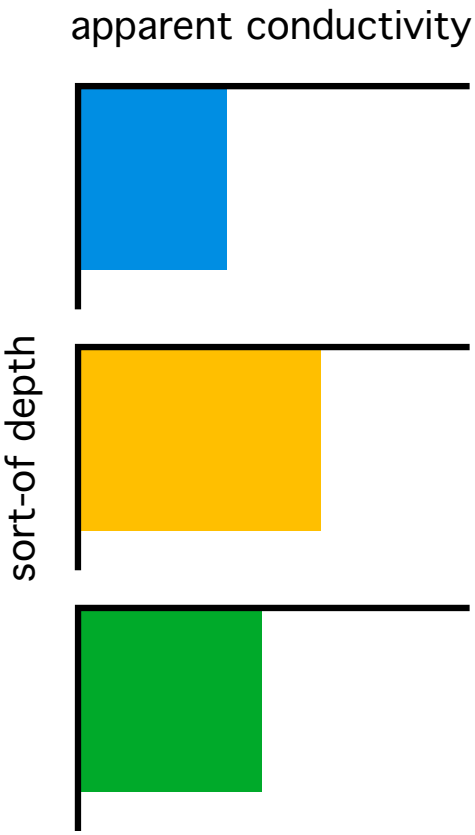




Apparent conductivities / resistivities

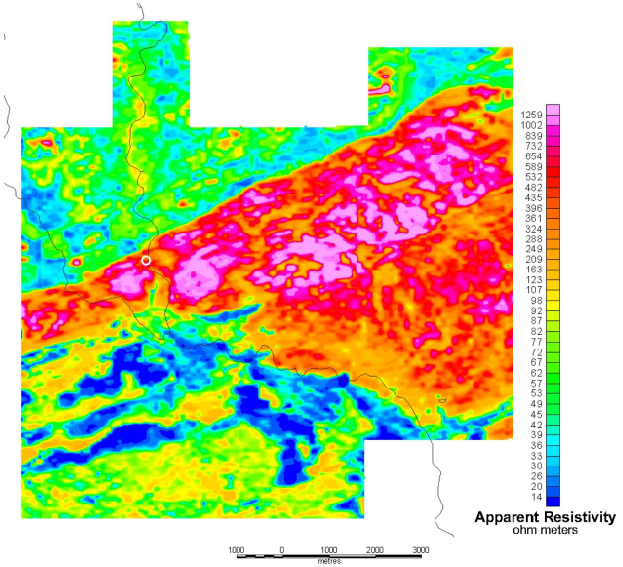




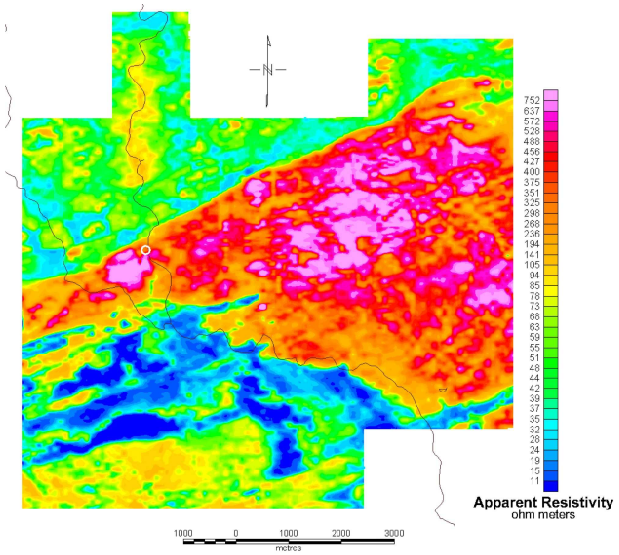


Maps of apparent resistivities

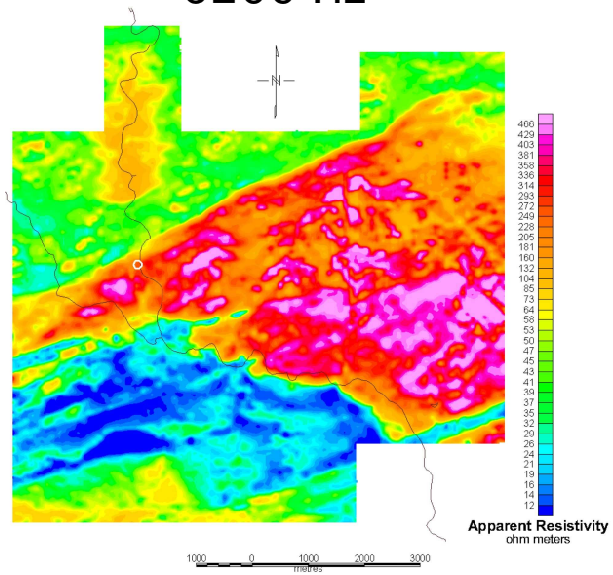
100 kHz



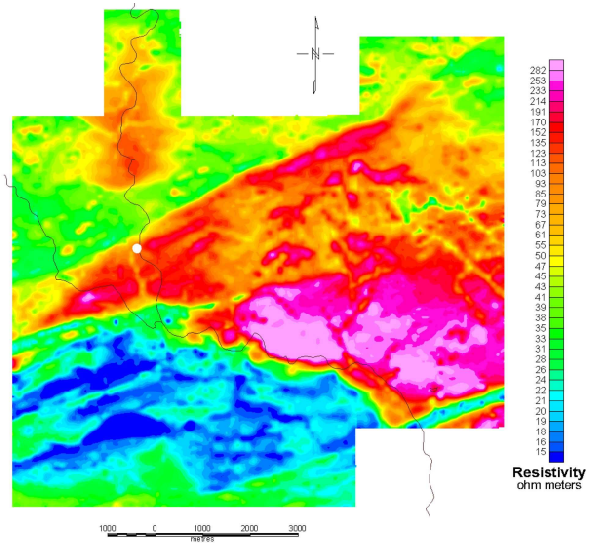
25 kHz



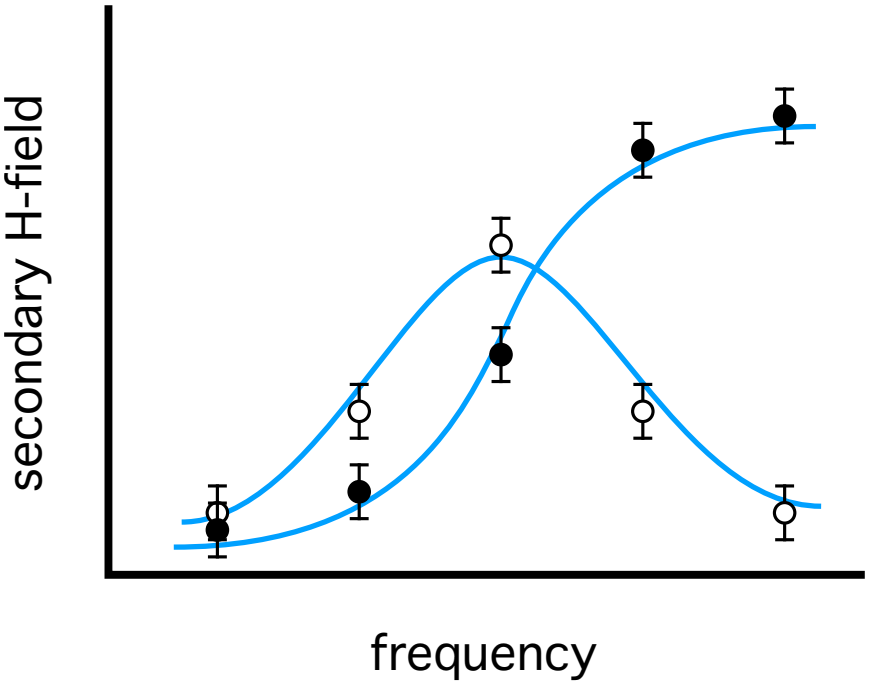
6200 Hz

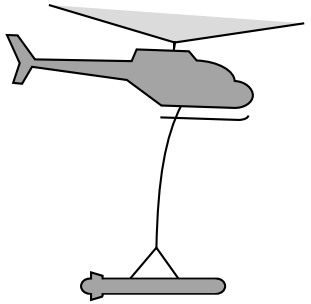


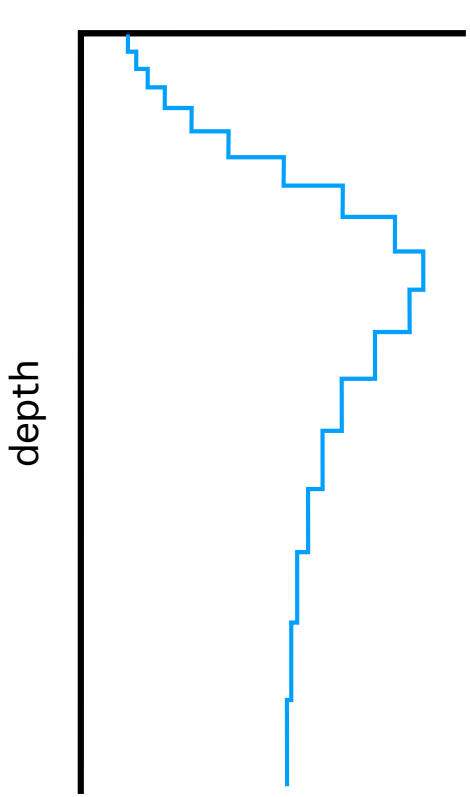
1500 Hz



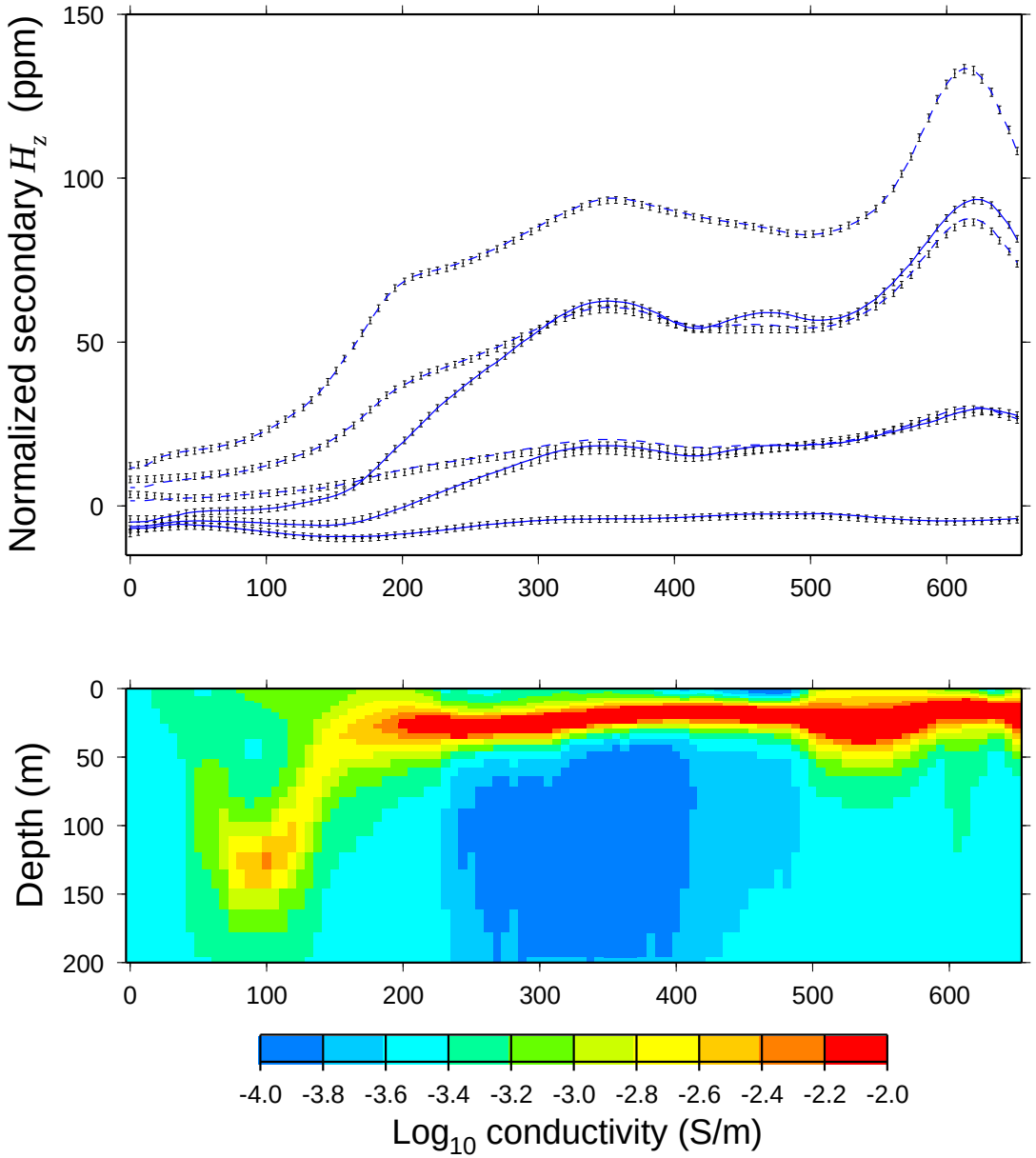
1-D inversion







Line of soundings / 1-D inversions

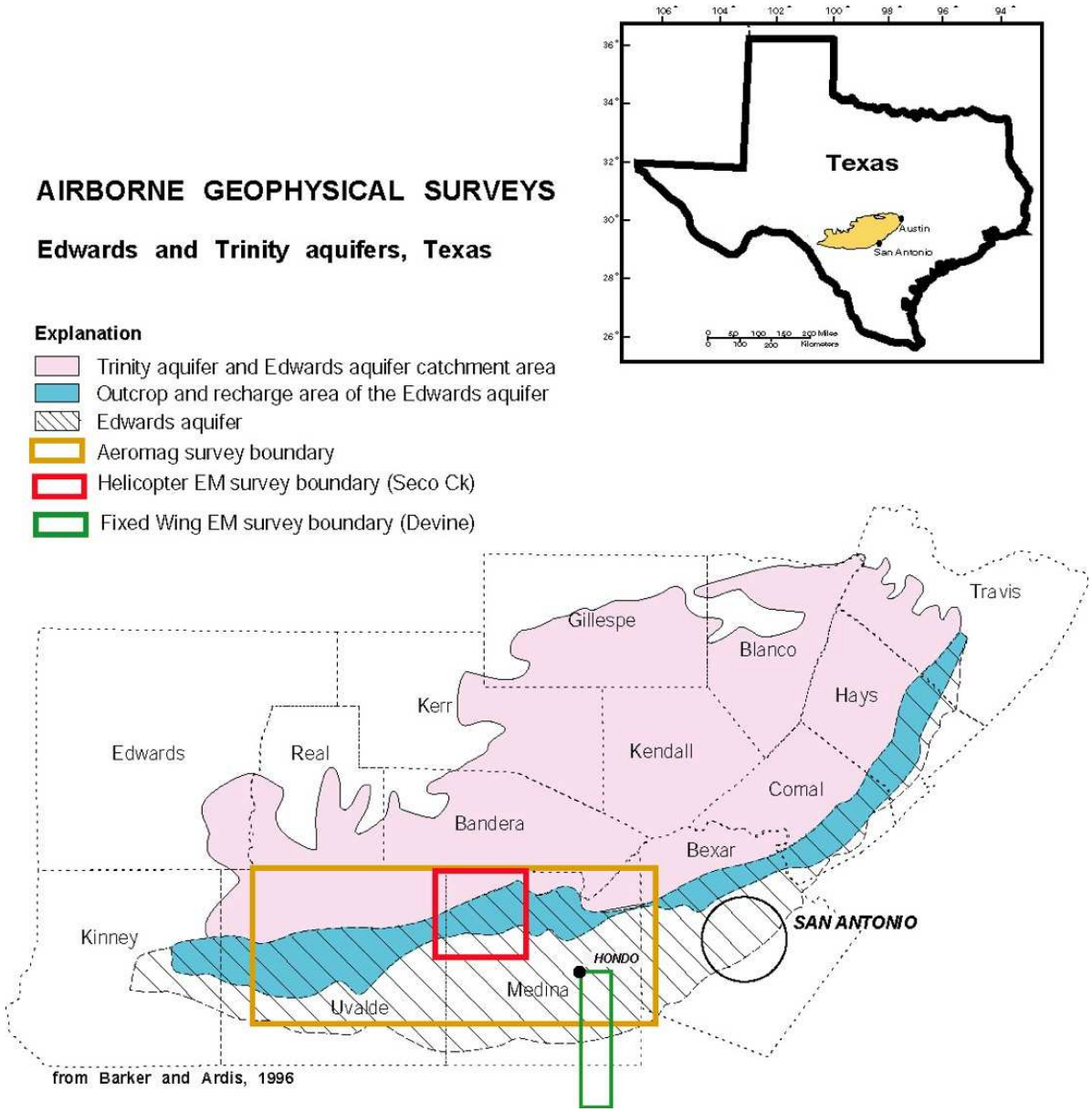


Outline

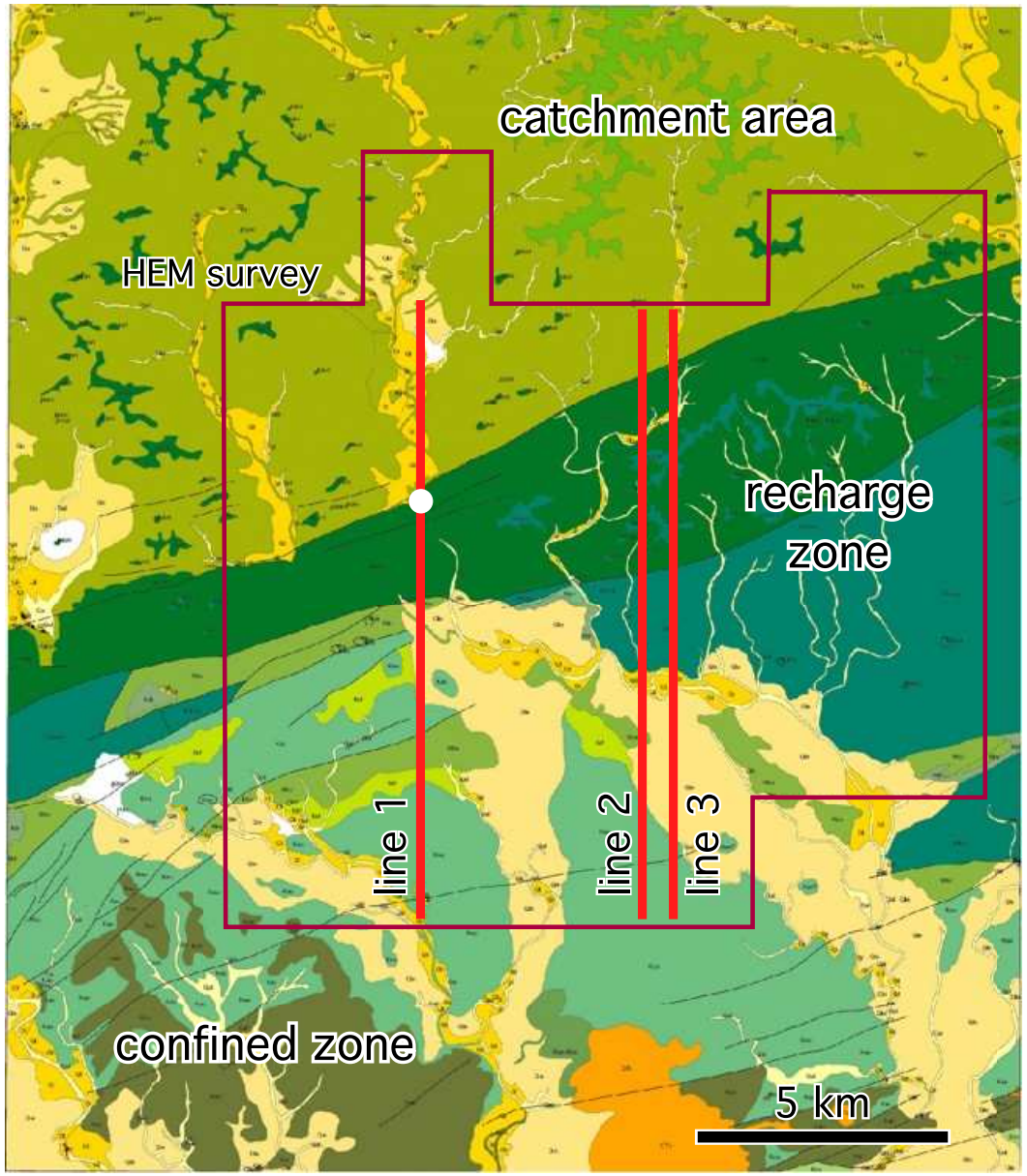
- Introduction.
- Typical geophysical electromagnetic method.
  - Electrical conductivities of the subsurface.
  - Electromagnetic induction.
  - Sensitivity of airborne EM measurements.
  - Interpretation – apparent conductivities/resistivities.
  - Interpretation – 1-D inversion.
- Example from the Edwards aquifer, Texas.
- Summary.

Example: Edwards aquifer, Texas

Example: Edwards aquifer, Texas



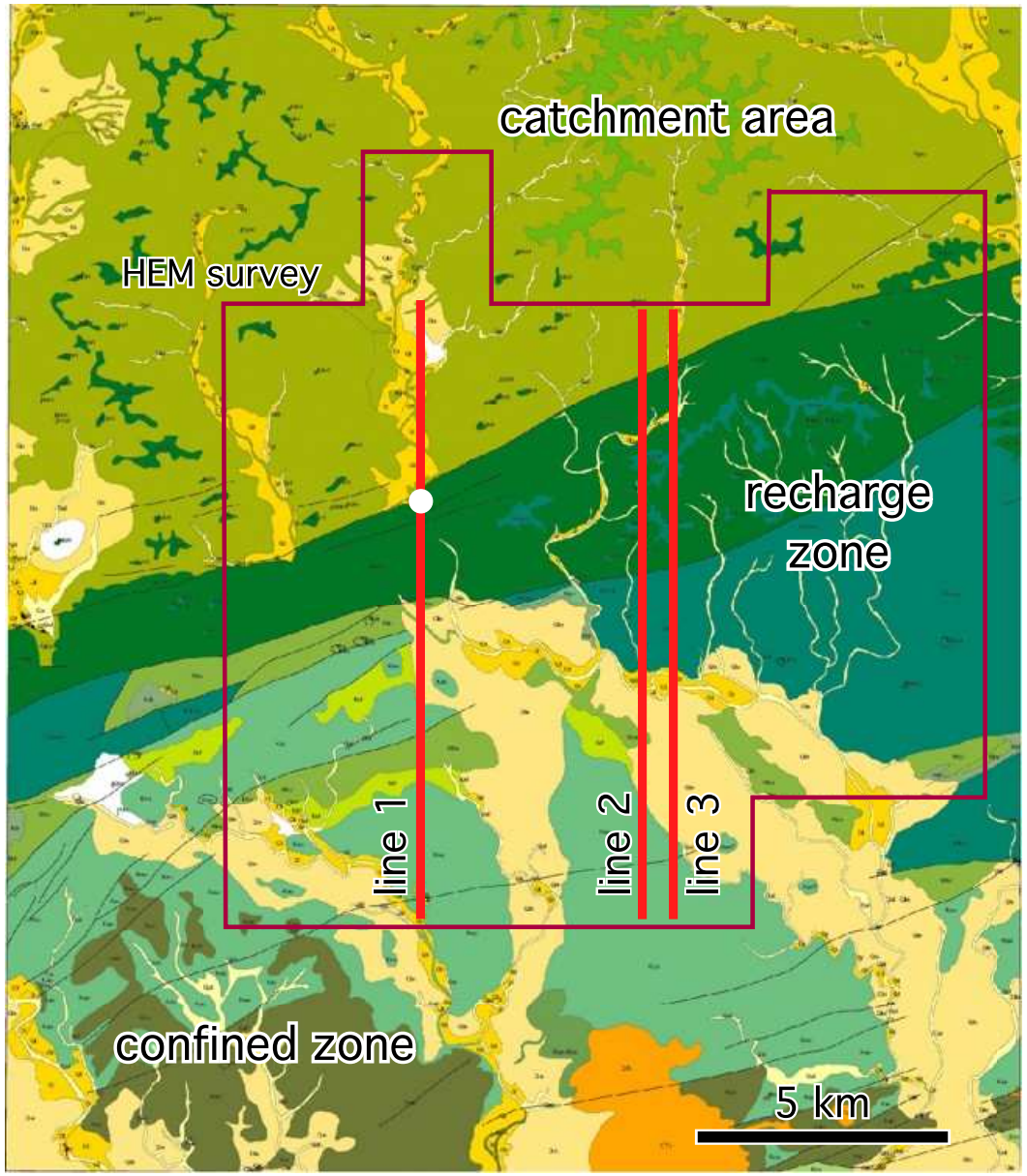
Example: Edwards aquifer, Texas



Example: Edwards aquifer, Texas

- Geological & hydrological setting:
  - Cretaceous limestones of the Trinity and Edwards Groups (and the Del Rio Clay unit);
  - northeast trending Balcones fault zone (Bat Cave sink-hole);
  - Trinity Group – low permeability – catchment zone;
  - Edwards Group – high porosity and permeability – recharge zone.

Example: Edwards aquifer, Texas



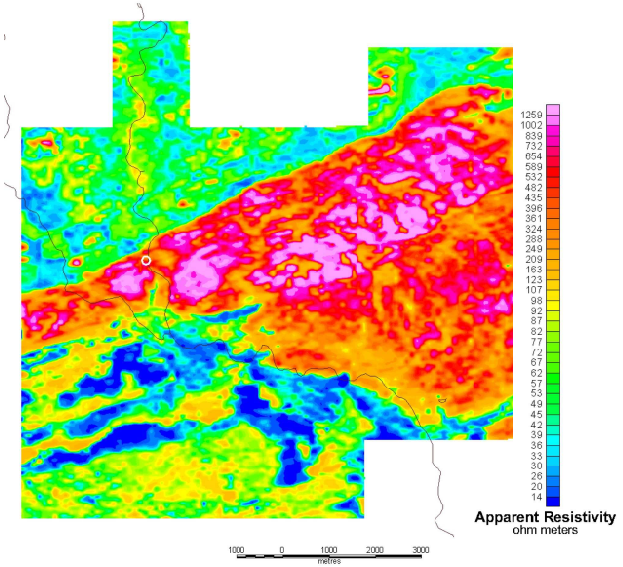
Example: Edwards aquifer, Texas

- Helicopter frequency-domain EM survey:
  - RESOLVE© system flown by Fugro Airborne Surveys;
  - coplanar – 386, 1514, 6122, 25960, 106400 Hz, and coaxial – 3315 Hz;
  - $\sim$ 30 m flight height;
  - $\sim$ 200 m line spacing, 95 lines, 209 km^2.

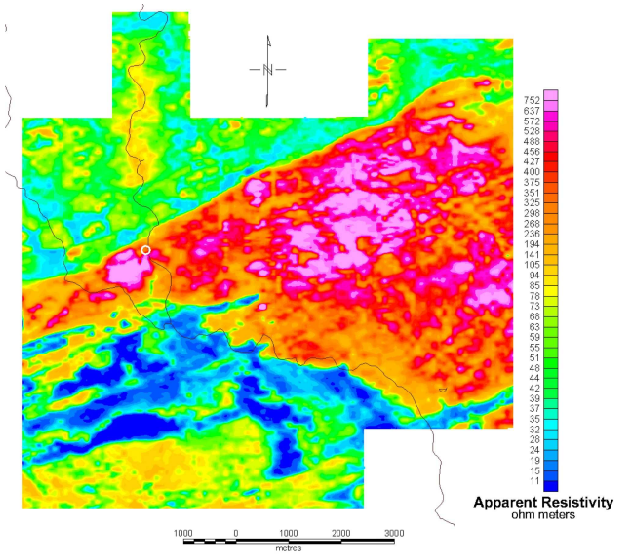
Example: Edwards aquifer, Texas

Example: Edwards aquifer, Texas

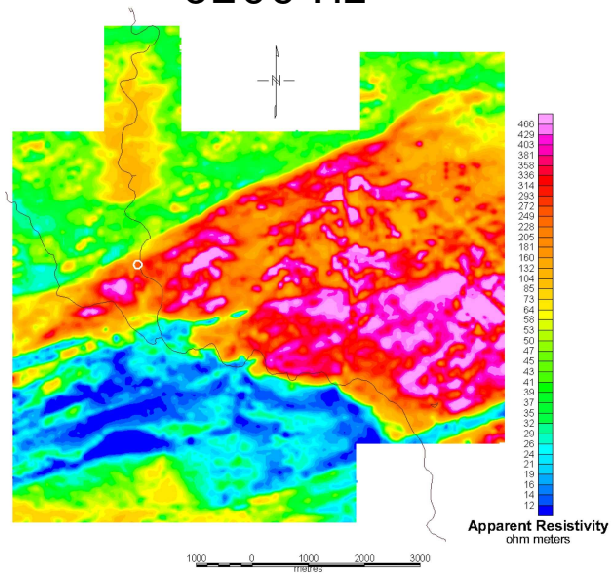
100 kHz



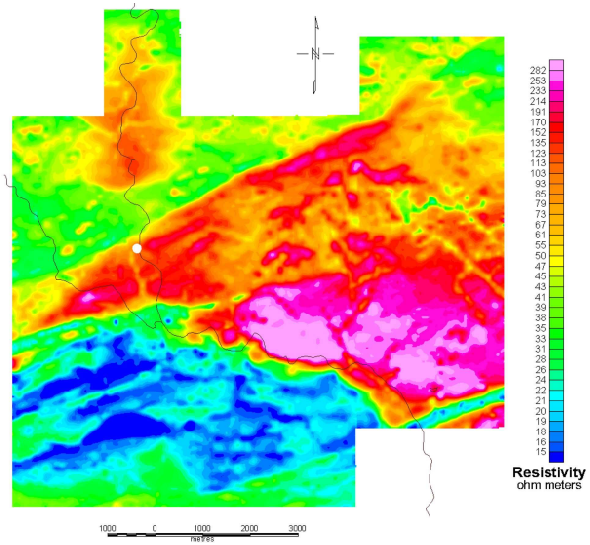
25 kHz



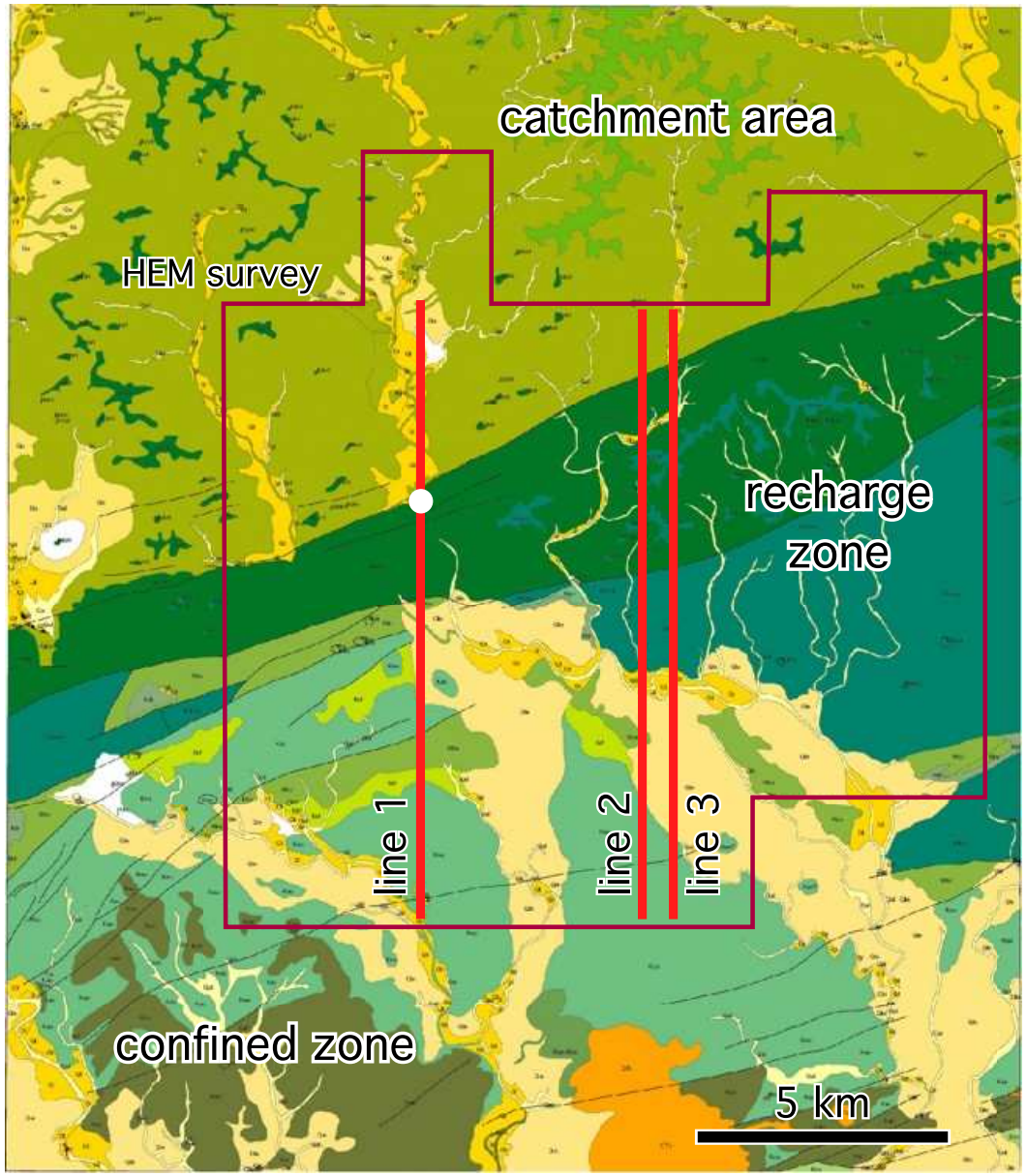
6200 Hz



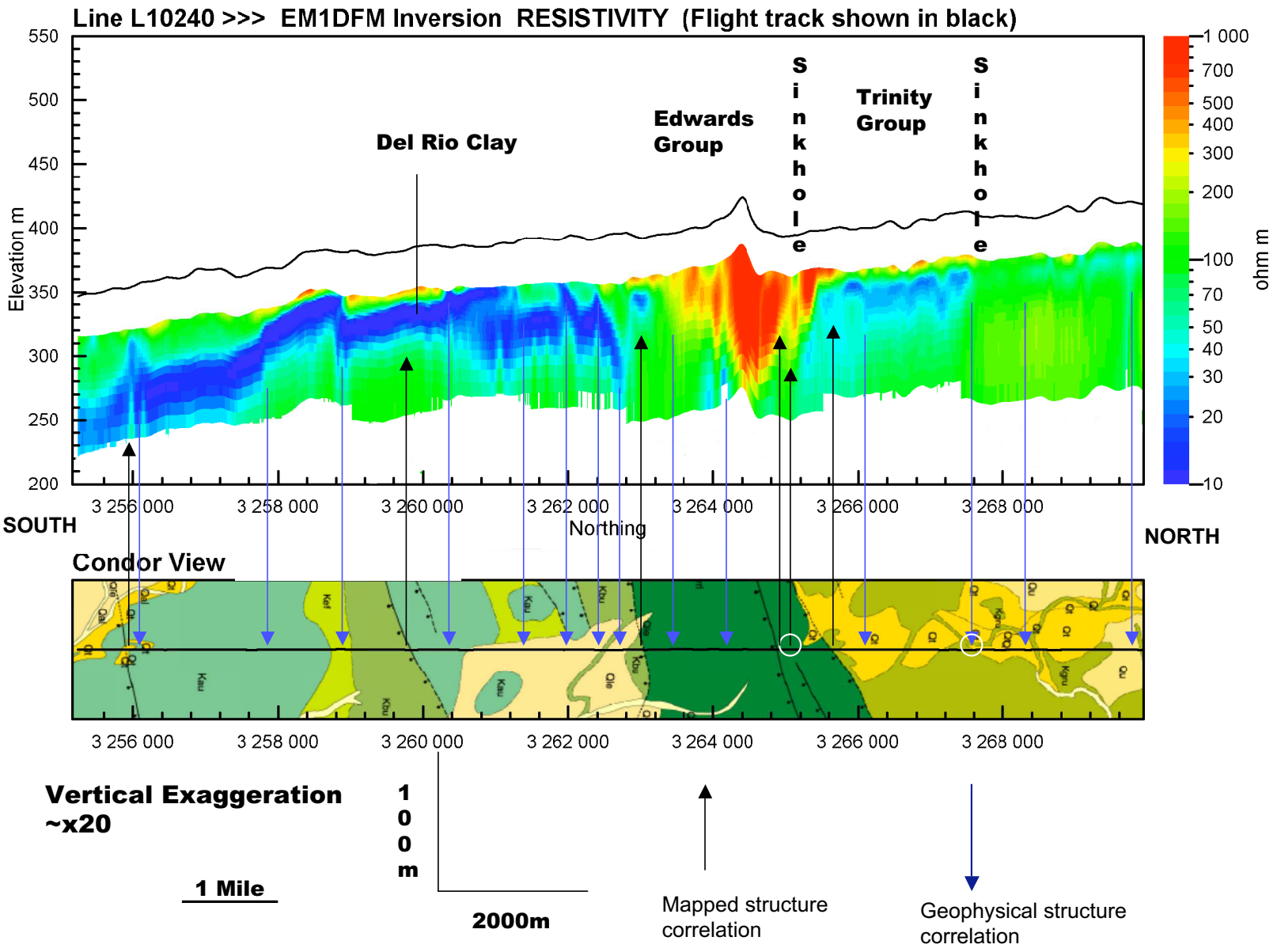
1500 Hz



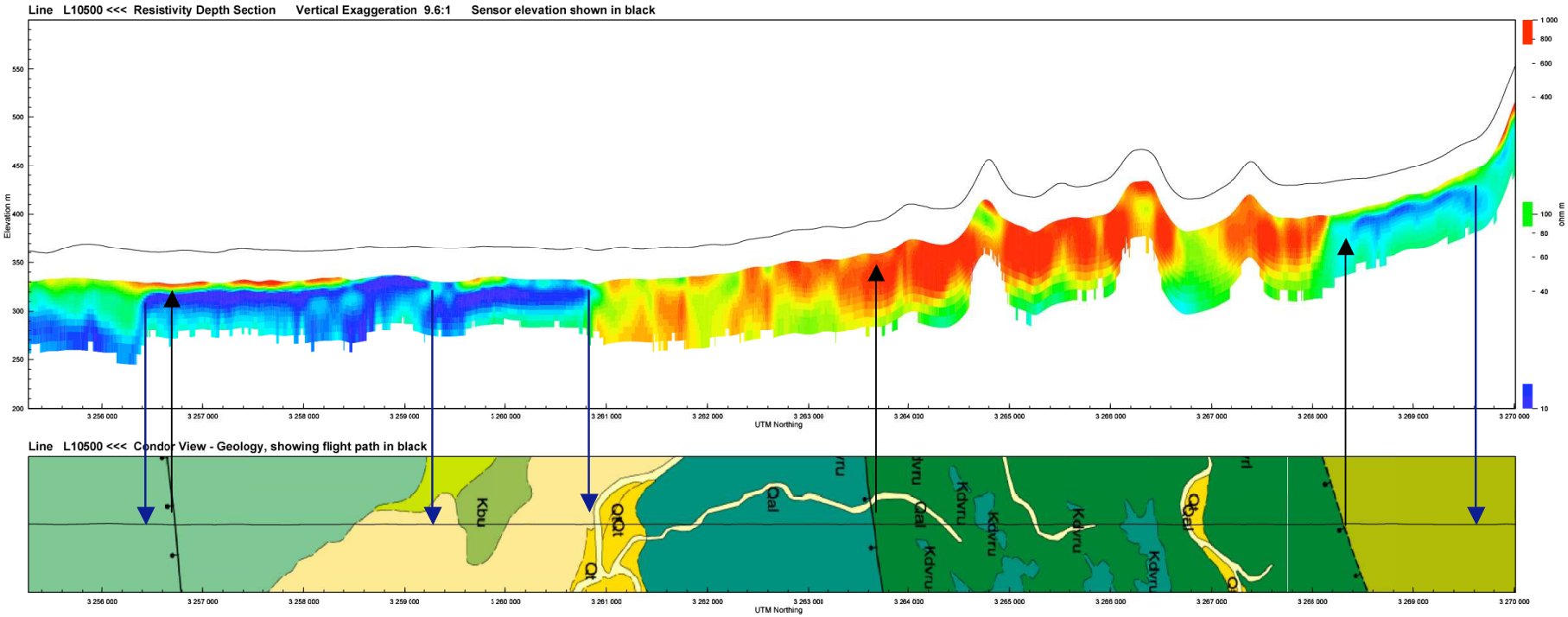
Example: Edwards aquifer, Texas



Example: Edwards aquifer, Texas



Example: Edwards aquifer, Texas



Vertical Exaggeration ~x10

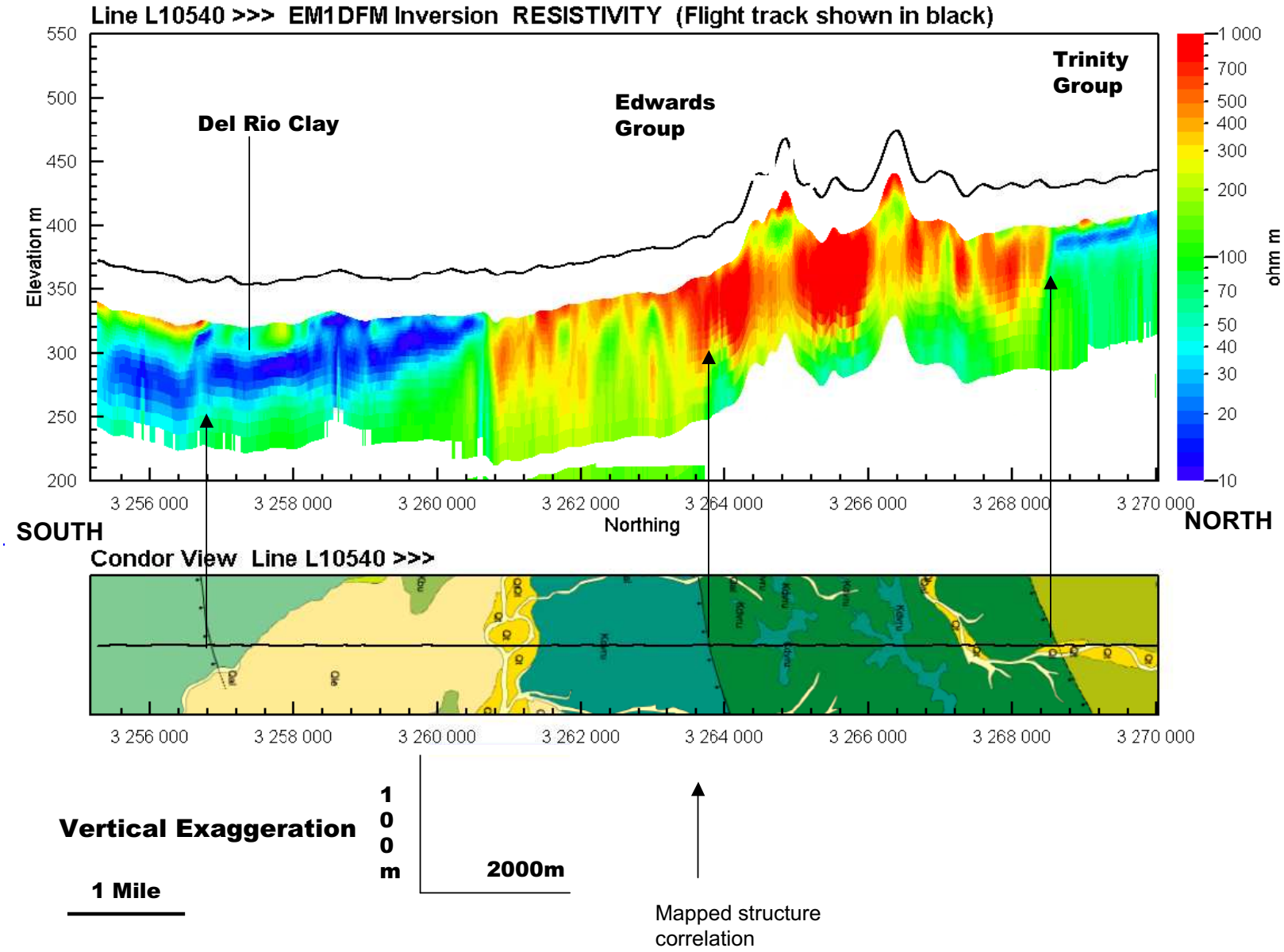
1 Mile

2000m

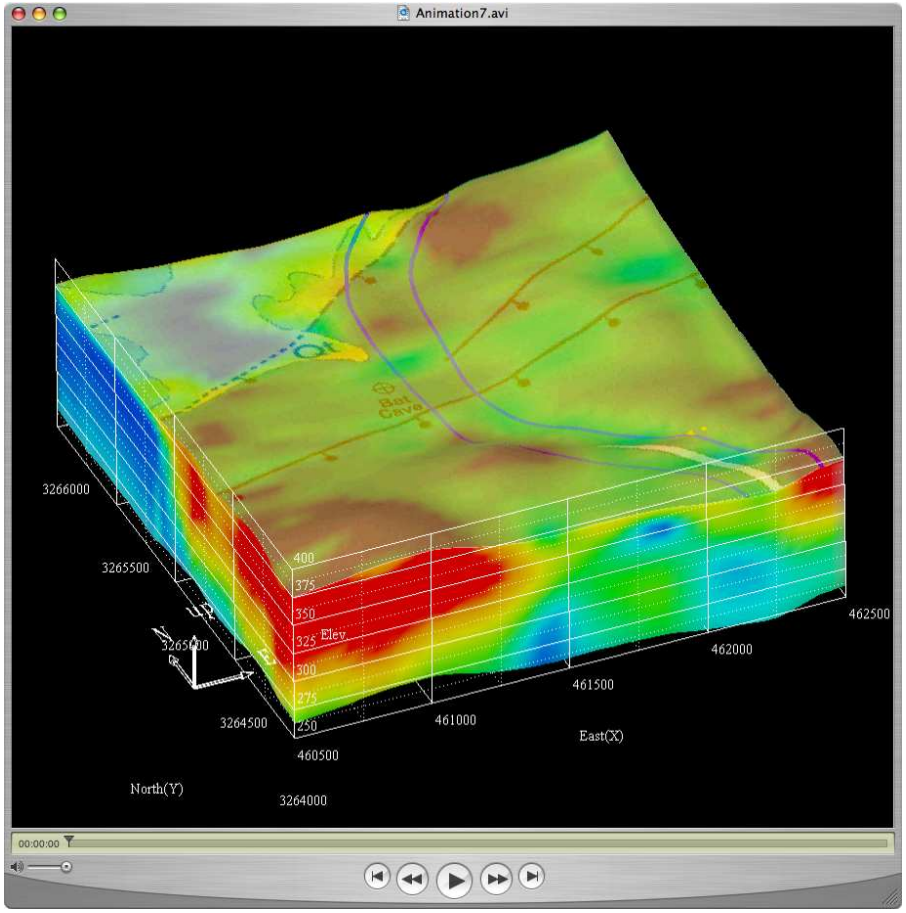
Mapped structure correlation

Geophysical structure correlation

Example: Edwards aquifer, Texas



Example: Edwards aquifer, Texas



Outline

- Introduction.
- Typical geophysical electromagnetic method.
  - Electrical conductivities of the subsurface.
  - Electromagnetic induction.
  - Sensitivity of airborne EM measurements.
  - Interpretation – apparent conductivities/resistivities.
  - Interpretation – 1-D inversion.
- Example from the Edwards aquifer, Texas.
- Summary.

Summary

- EM + quantitative interpretation → "see" into top 100 – 200 m (or more) of subsurface.

- Edwards aquifer:
  - depth & thickness of Del Rio Clay mapped;
  - more structures in recharge & confined zones revealed;
  - Devils River Formation sub-divided;
  - significant recharge feature mapped;
  - Glen Rose Group mapped.