

EAGE

CONFERENCE & EXHIBITION

NEAR SURFACE GEOSCIENCE'25

31st

European Meeting of
Environmental and
Engineering Geophysics

6th

Conference on Geophysics
for Mineral Exploration
and Mining

3rd

Conference on Hydrogeophysics
Contribution to Exploration and Management
of Groundwater, Land-Use and Natural Hazards
under a Changing Climate

1st

Conference on
Geohazard Assessment
and Risk Mitigation

1st

Conference on
UXO & Object Detection

Aquifer detection and characterisation with airborne frequency domain electromagnetic surveying - case studies from Ireland and Oman

7-11 SEPTEMBER 2025 | NAPLES, ITALY

#NSG2025



Aquifer detection and characterisation with airborne frequency domain electromagnetic surveying - case studies from Ireland and Oman

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Greg Hodges

Sander Geophysics



Sander Geophysics

Overview

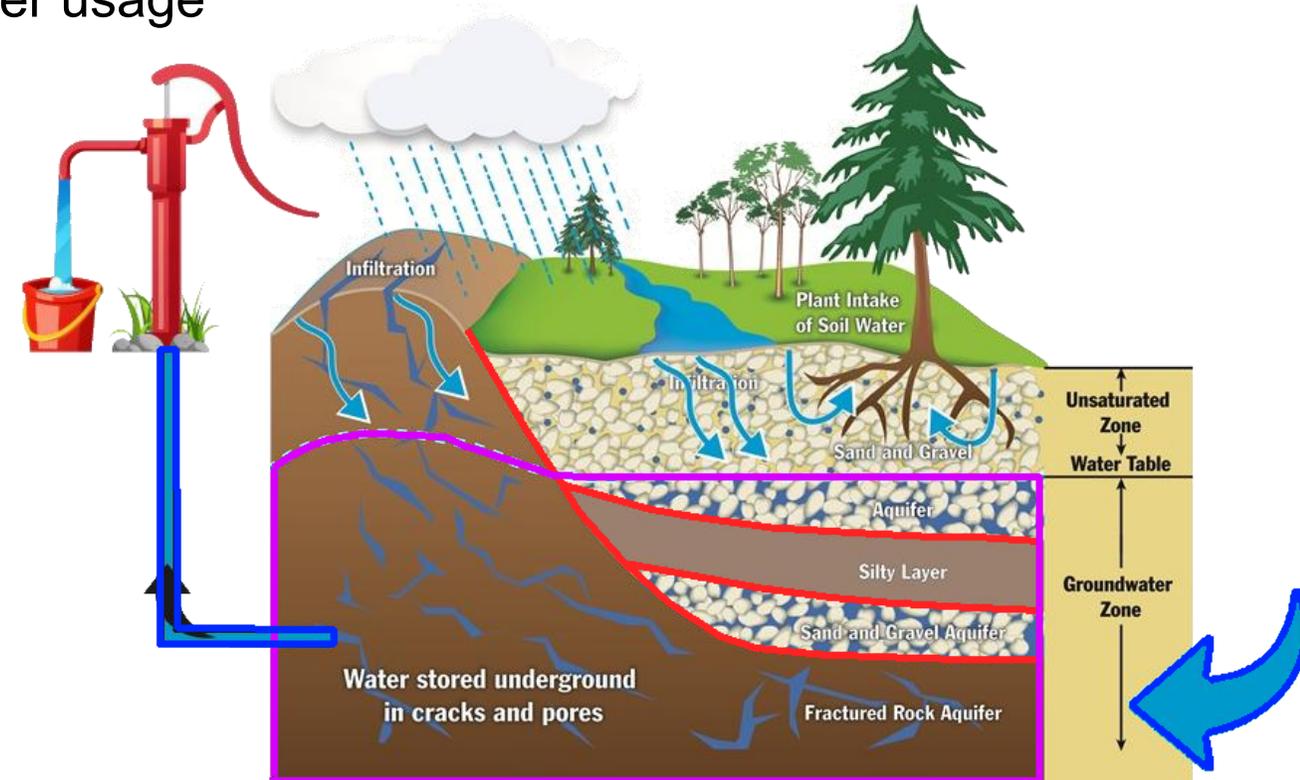
- Showcasing results from multi-parameter surveys
 - Magnetic susceptibility, radiometrics, density, electrical resistivity
- Using FDEM products to delineate and characterise ground water resources and structural constraints
 - Interpretation of apparent resistivity to constrain aquifer boundaries
 - Inversion of FDEM results to estimate depth and resistivity of saturated unit



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Groundwater Exploration

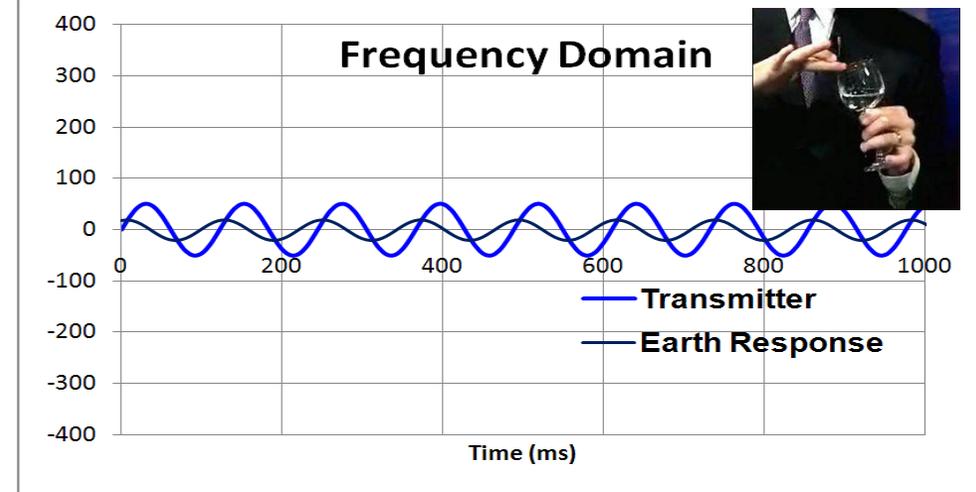
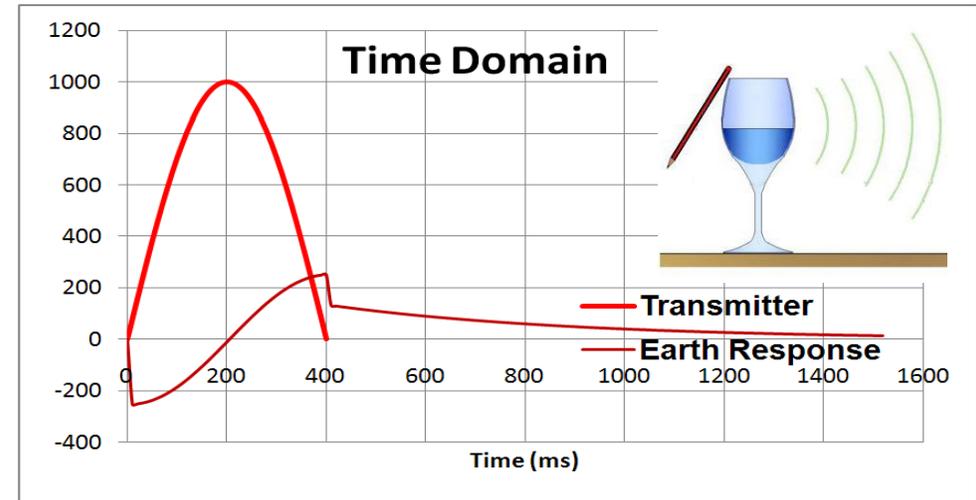
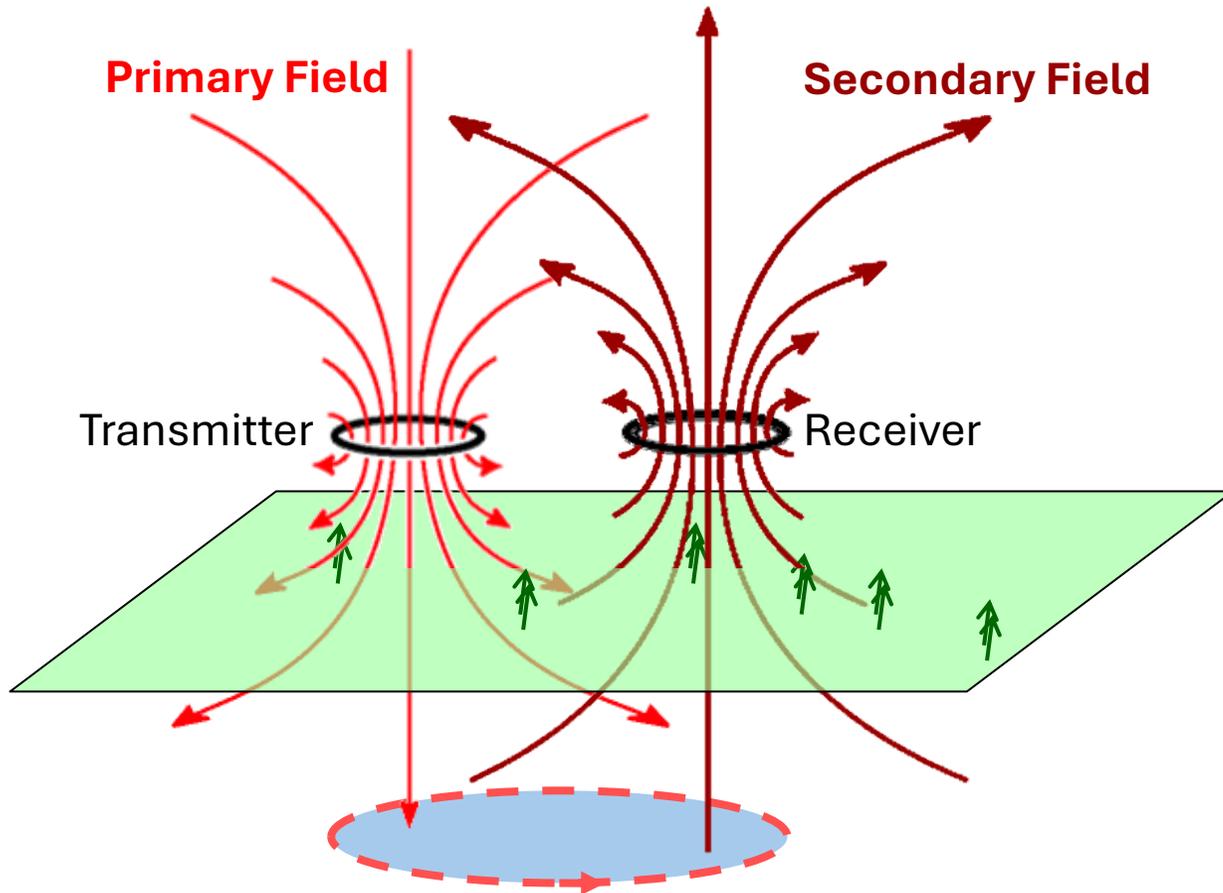
- Water is the most essential natural resource worldwide
- Roughly 1% increase each year in ground water usage over past 40 years (UNESCO, 2023)
- Increase in ground water demand requires:
 - Mapping
 - Where are ground water sources?
 - Characterisation
 - What are the structural constraints
 - Estimate extent/size
 - Estimate salinity
 - Monitoring
 - Is the aquifer depleting?
 - Are there saline intrusions?





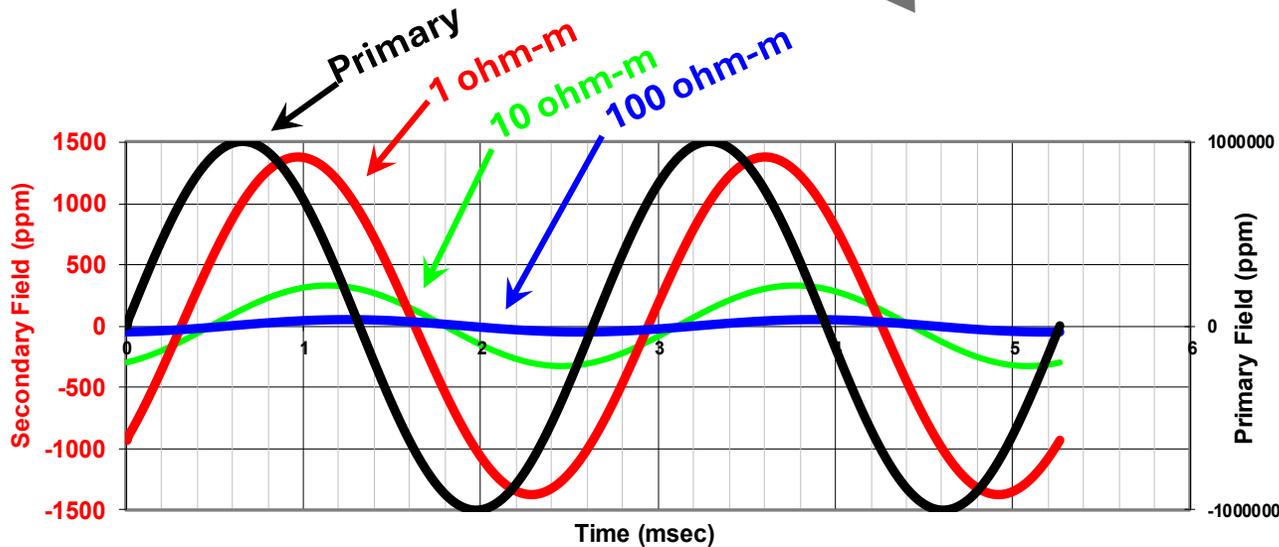
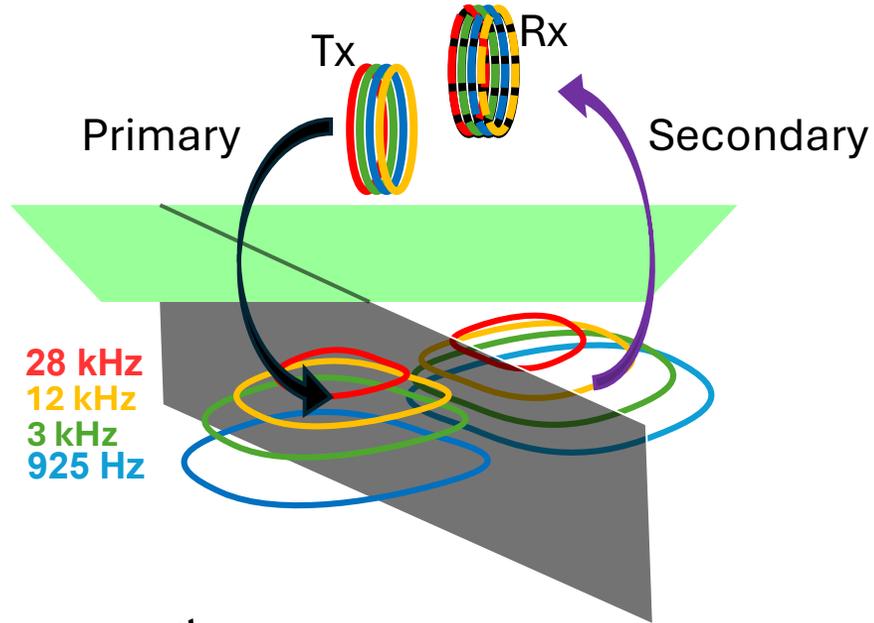
Electromagnetic Surveying

- Apply current to coil loop to produce primary field
- Induces current in subsurface
- Secondary field response related to subsurface resistivity





Frequency Domain Electromagnetic (FDEM) Surveying

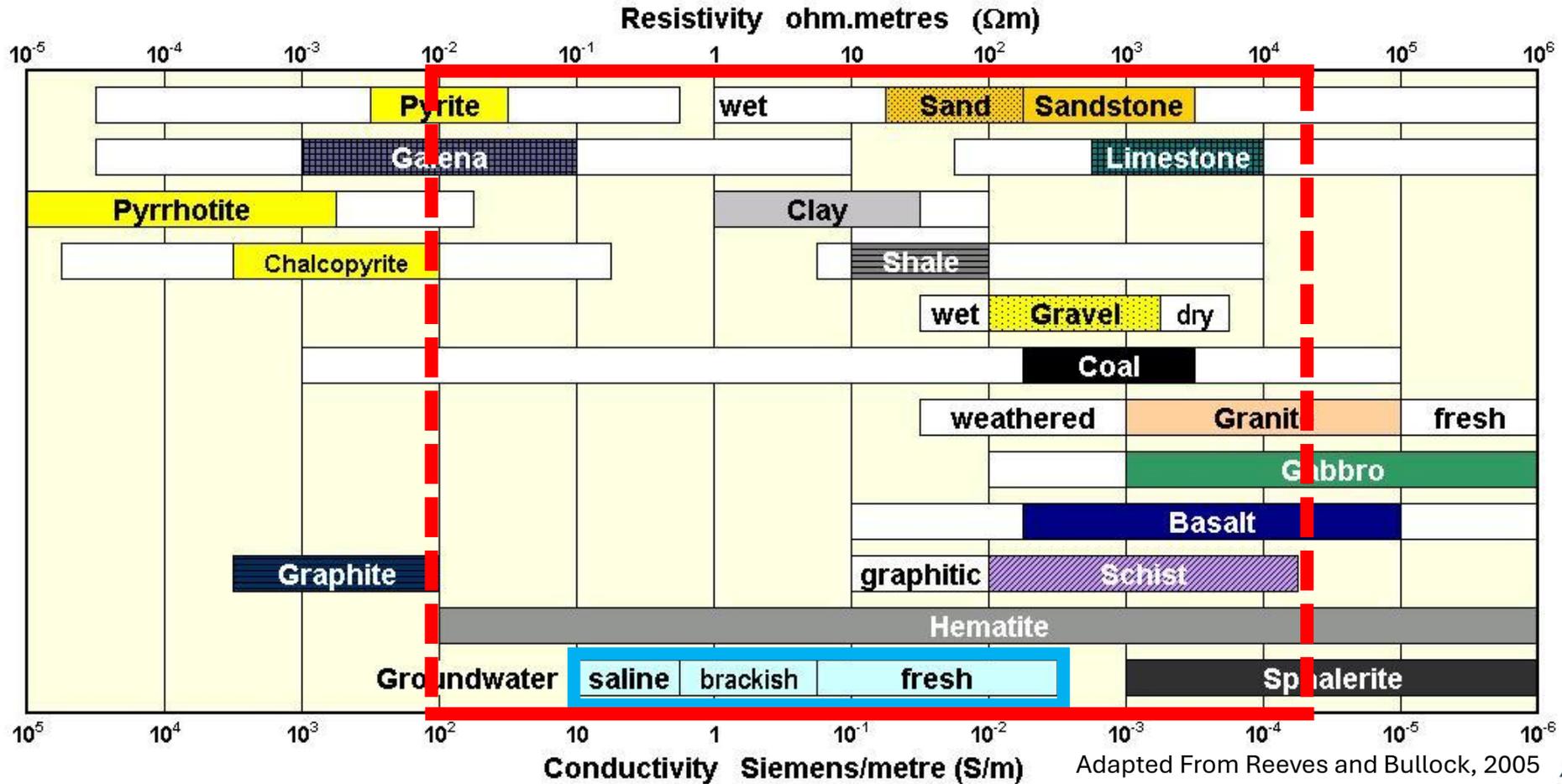


- Mapping of resistive (or conductive) geology, targets, and alteration zones
- Resistive units decrease signal amplitude as well as cause a phase delay
- Resistivity is controlled by mineralogy (sulphides, oxides, clay minerals) and by porosity, saturation and salinity
- Depth of investigation can be controlled with transmit frequency and power
 - Lower frequency is more representative of deeper geology
 - Higher frequency represents shallower geology

Resistivity Ranges

FDEM Range
 $\rho: <10^{-2} - 3 \times 10^4$ ohm-m

Groundwater
 $\rho: 10^{-1} - 10^2$ ohm-m





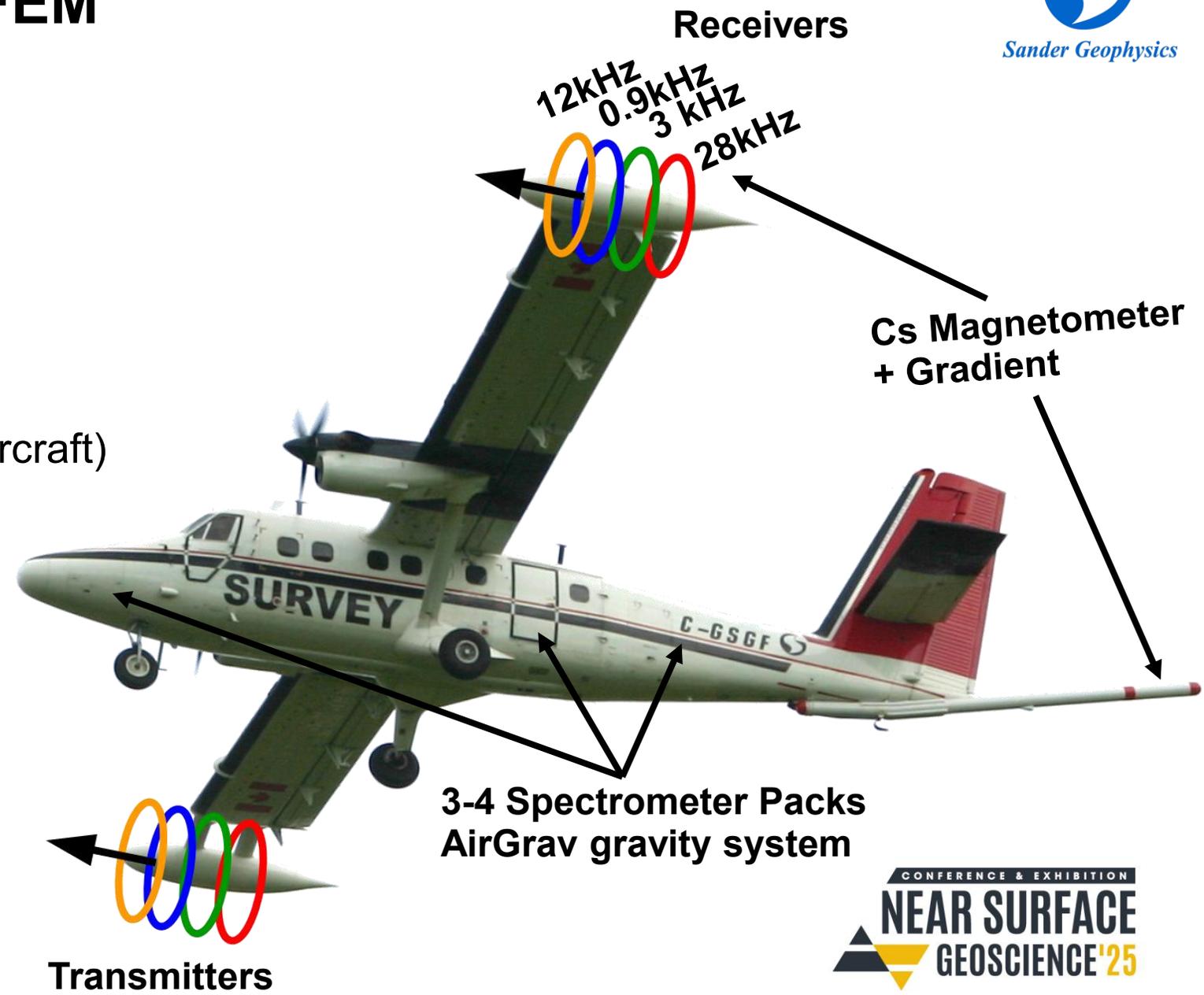
DHC-6 Twin Otter and SGFEM

Fixed-wing Advantages

- High-speed, low-cost coverage
- Instrument load
- Magnetics, radiometrics, gravity
- 60 m nominal altitude
- Able to fly over
 - Built up regions (twin engine aircraft)
 - Water

Frequency Domain Advantages

- Broad resistivity range
- Depth estimation
- Efficient system
- Interference rejection
 - Sferics
 - Power line





Digital SGFEM

- Updated to be almost fully digital
 - Transmit and receiver coils cannot be digital
- Improved data quality
 - Calibrated during each flight
 - No orthogonality tests needed
- Improved noise mitigation
 - Sferics
 - Cultural Noise
 - Power Line monitoring



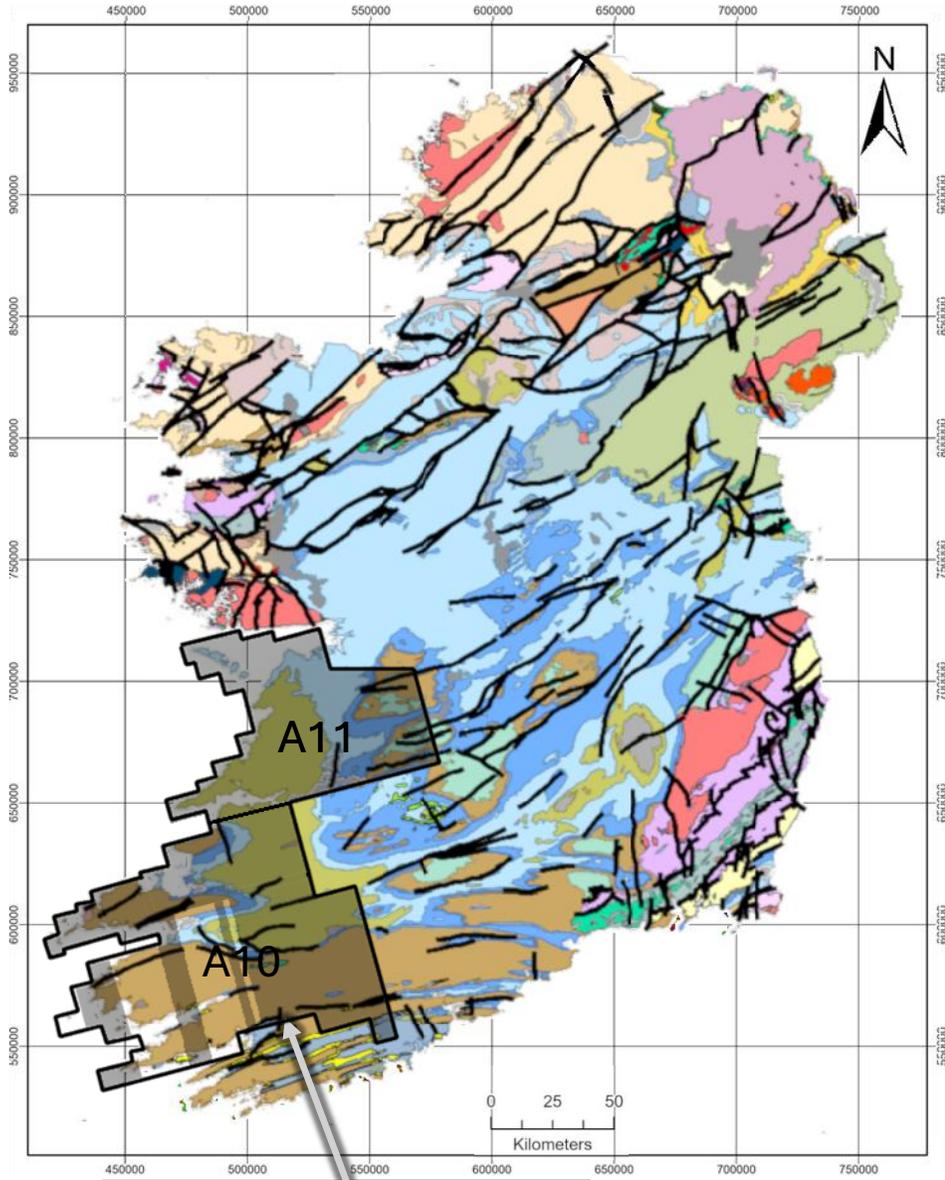
The Tellus Project – Ireland – Bedrock Geology



Sander Geophysics

- A national programme to gather geochemical and geophysical data across Ireland
 - <https://www.gsi.ie/ga-ie/programmes-and-projects/tellus/>
- Ongoing airborne geophysics project being flown by SGL
 - Aeromagnetics
 - Radiometrics
 - Frequency Domain EM
- Northern and south eastern region hosts
 - Volcanics
 - Dykes
- Southern region is predominantly sedimentary
 - Silicates
 - Carbonates

Courtesy of:



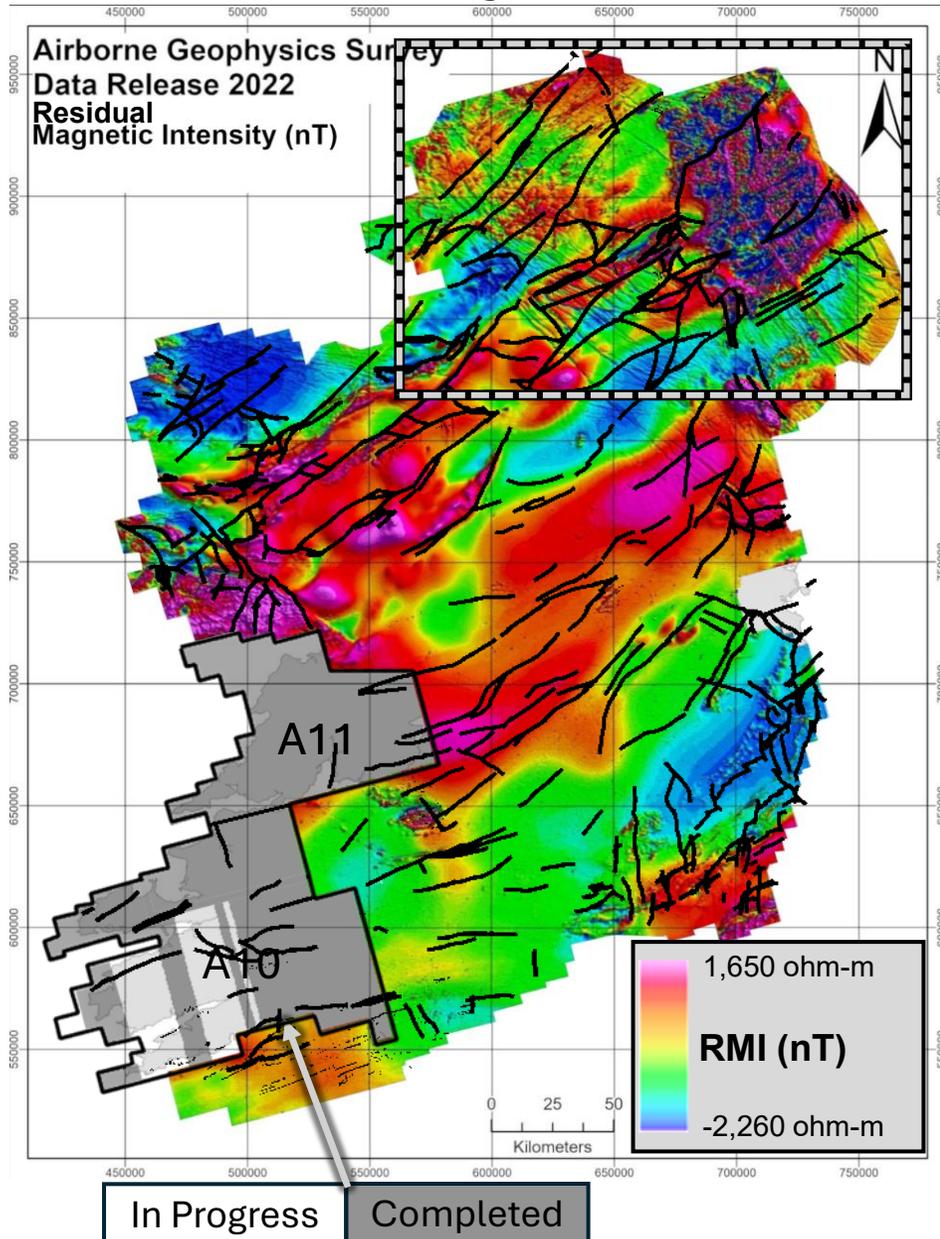
In Progress Completed

The Tellus Project – Ireland – Aeromagnetics



Sander Geophysics

- Ongoing airborne geophysics project being flown by SGL
 - Aeromagnetics
 - Radiometrics
 - Frequency Domain EM
- Typically measures bedrock response
- Northern and south eastern region hosts
 - Volcanics
 - Dykes
- Southern region is predominantly sedimentary
 - Silicates
 - Carbonates



Courtesy of:

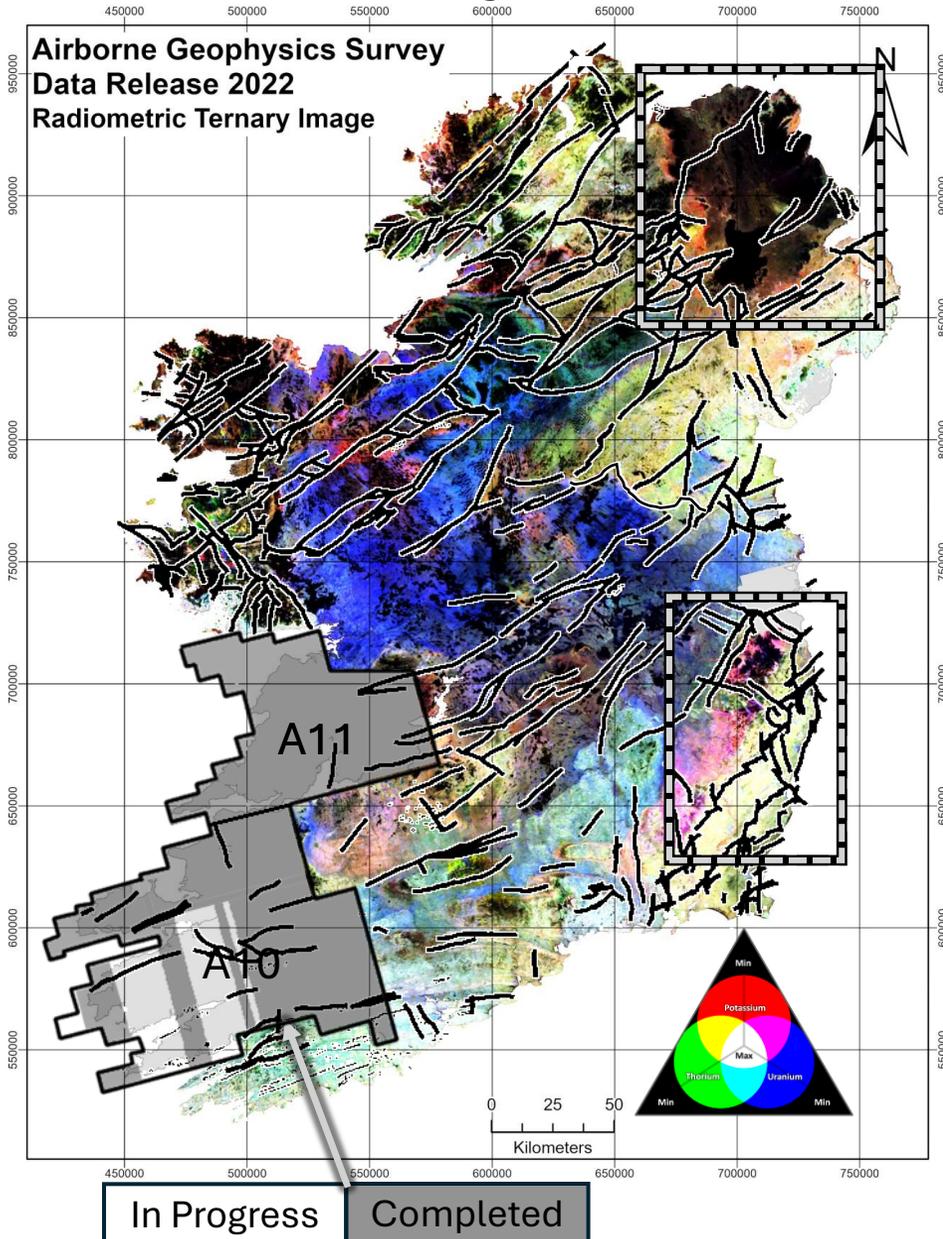


The Tellus Project – Ireland – Radiometrics



Sander Geophysics

- Ongoing airborne geophysics project being flown by SGL
 - Aeromagnetics
 - Radiometrics
 - Frequency Domain EM
- Typically measures surficial (10 cm) response
- Northern region is dominantly basalts
 - Minimal radiometric response
- Western region is predominantly sedimentary (carbonates)
 - Elevated Uranium
- South-eastern region contrasts granite (pink) and sandstones (yellow)



Courtesy of:

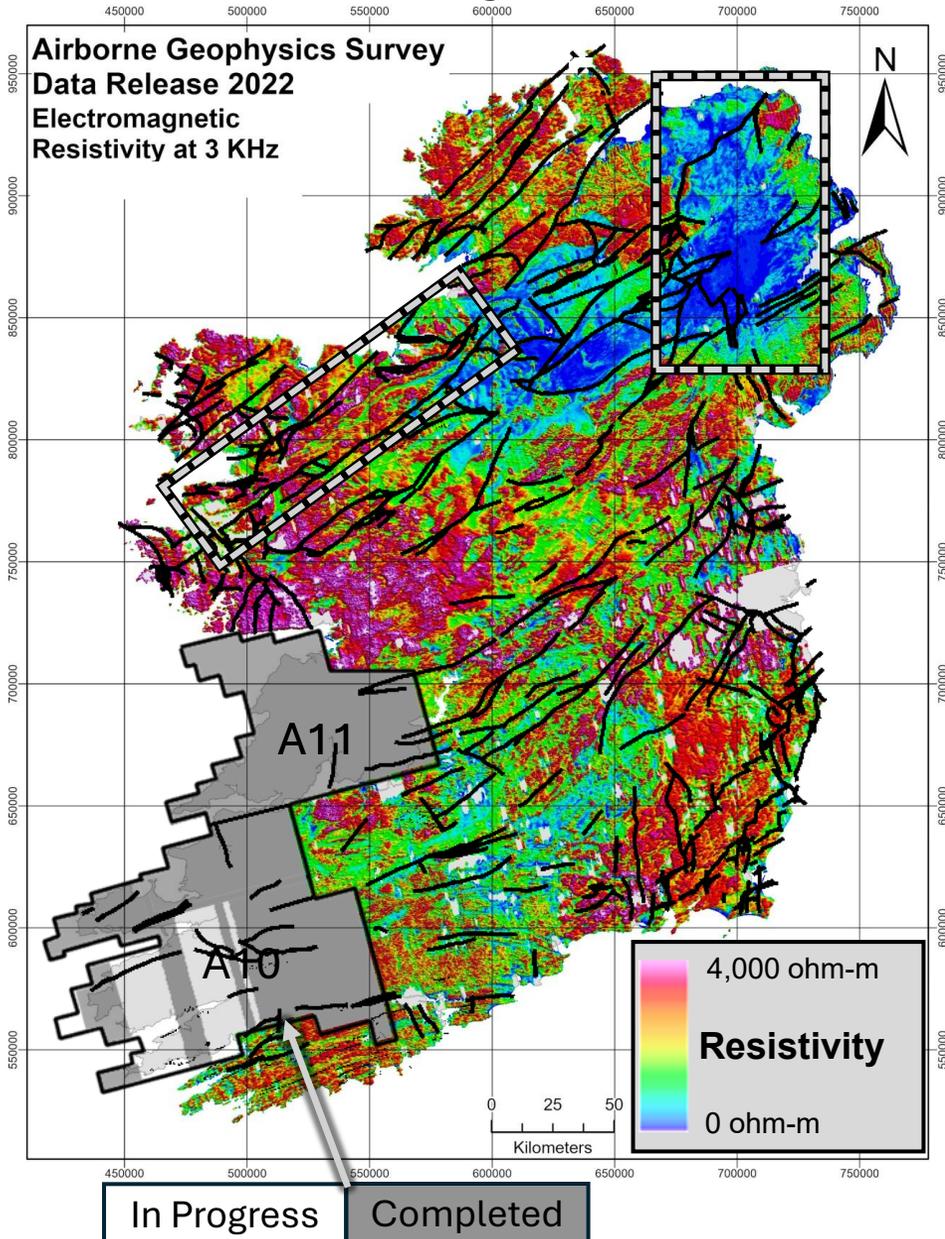


The Tellus Project – Ireland – FDEM



Sander Geophysics

- Ongoing airborne geophysics project being flown by SGL
 - Aeromagnetics
 - Radiometrics
 - Frequency Domain EM
- Typically measures upper 120 m
- Northern region is predominantly volcanics (lower resistivity)
- Geological structure due to conductivity variation
- Blocks A10 and A11 are being flown with digital FDEM system



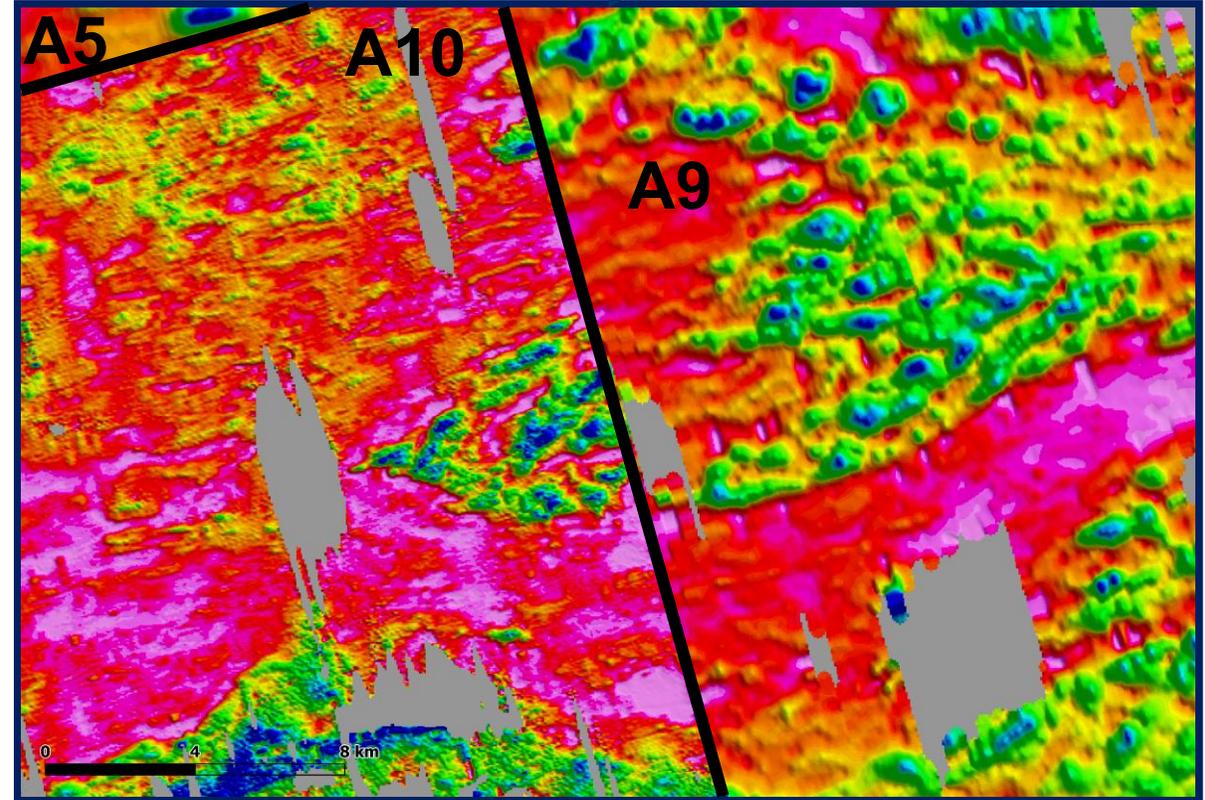
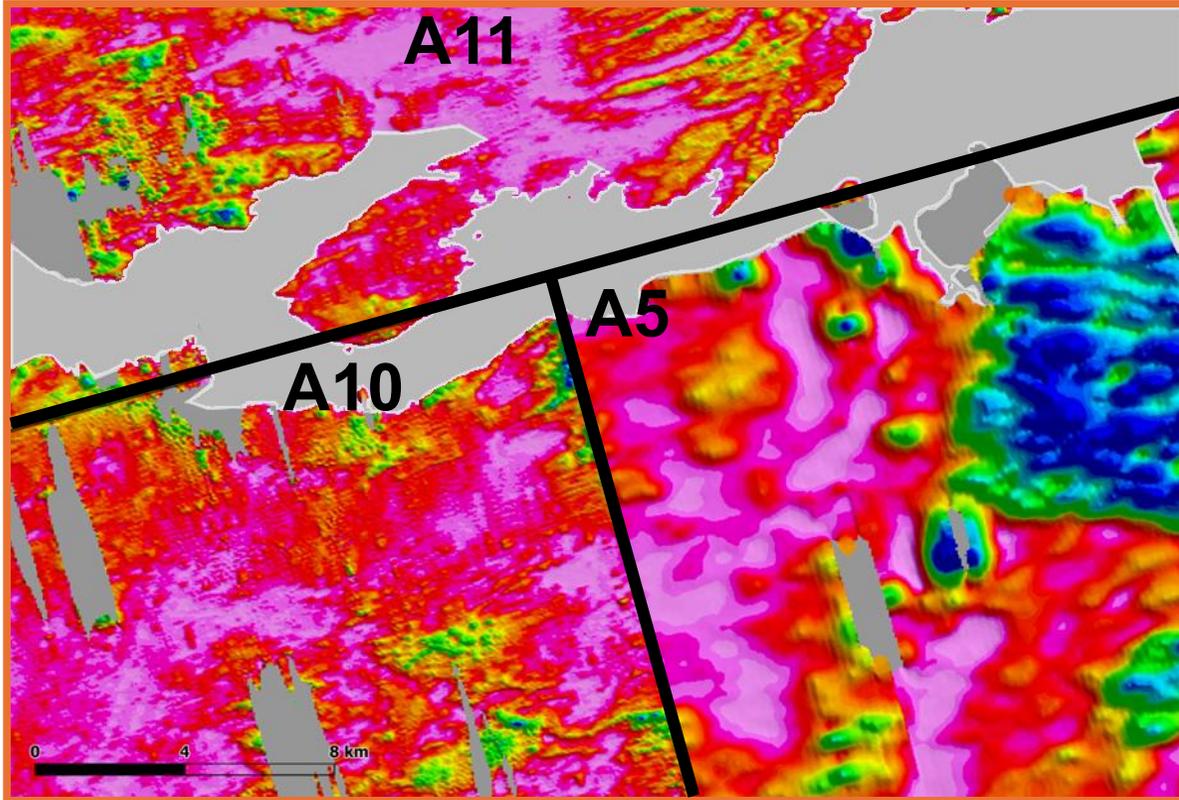
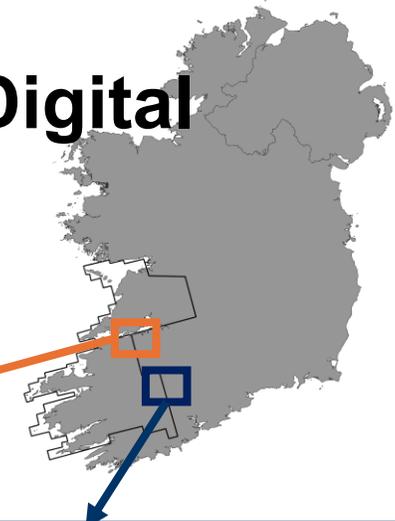
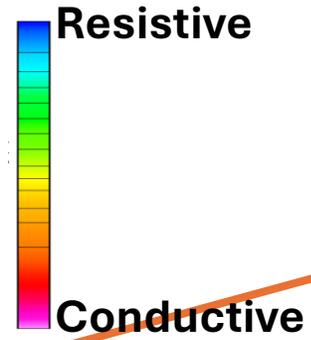
Courtesy of:





Apparent Resistivity – Comparison of Analog & Digital

- Analog FDEM block – A5 (2018) and A9 (2021)
- Digital FDEM blocks – A10 and A11
- Structural trends continue across blocks
- Improved resolution with digital FDEM system

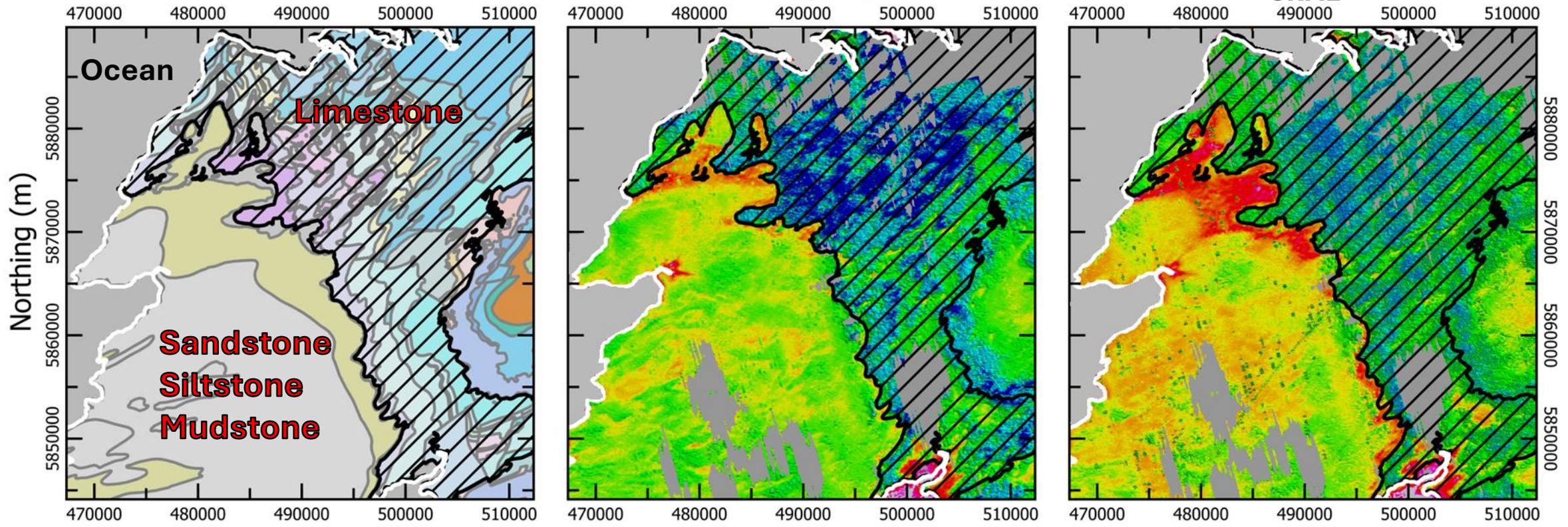


The Burren - Apparent Resistivity

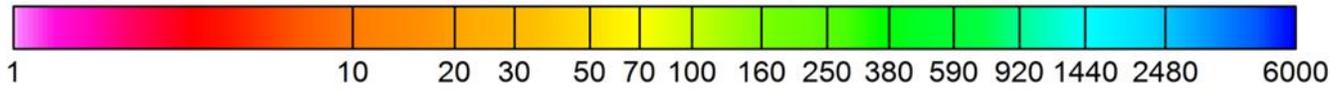
- Regionally important aquifer
 - Limestone karsts (conduit)
 - Resistive region



Shallower → Deeper
28kHz **3kHz**



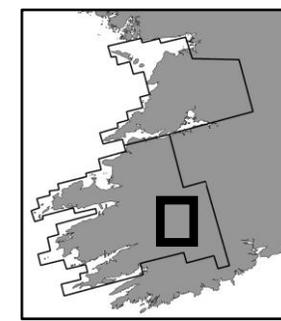
WGS 84 UTM 29N



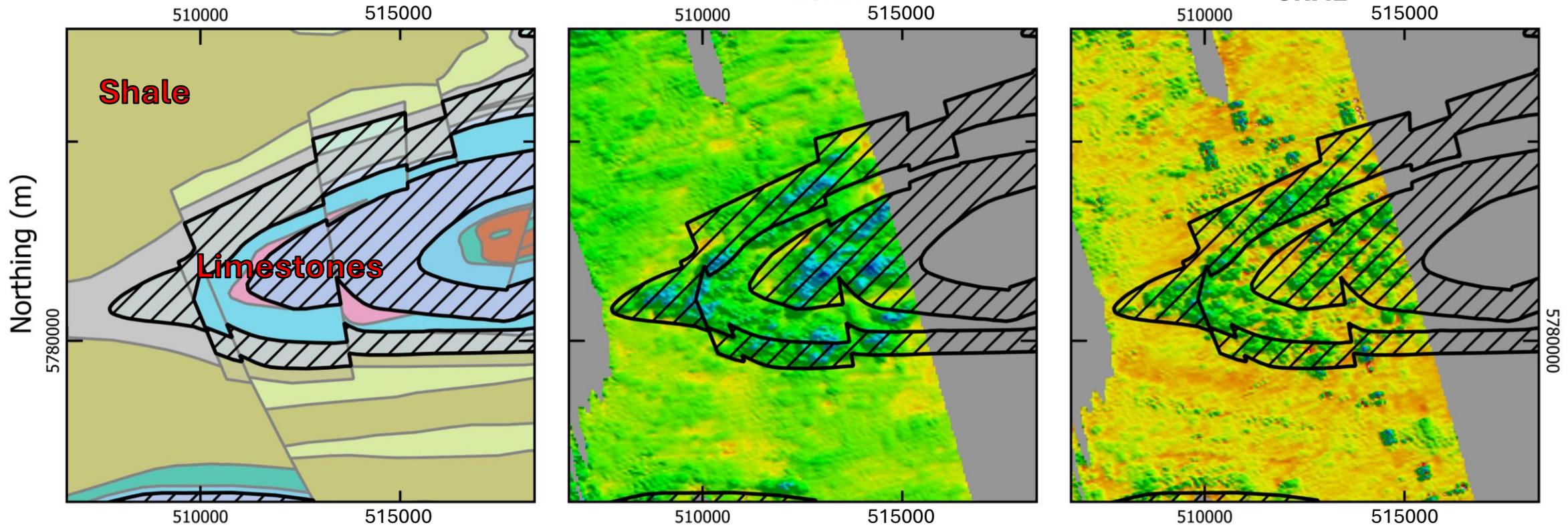
Apparent Resistivity
ohm-m

Kanturk – Apparent Resistivity

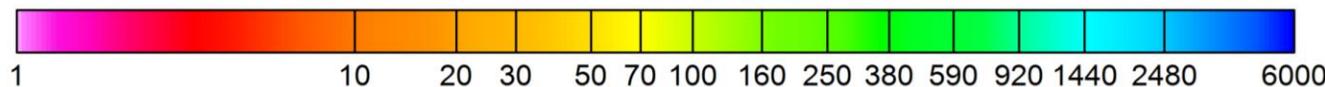
- Regionally important aquifer
 - Limestone karsts (diffuse)
 - Resistive region



Shallower \longrightarrow Deeper
28kHz **3kHz**



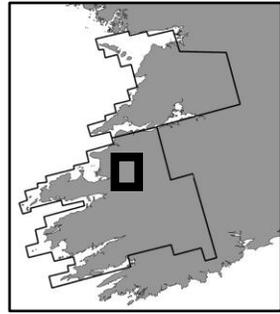
WGS 84 UTM 29N



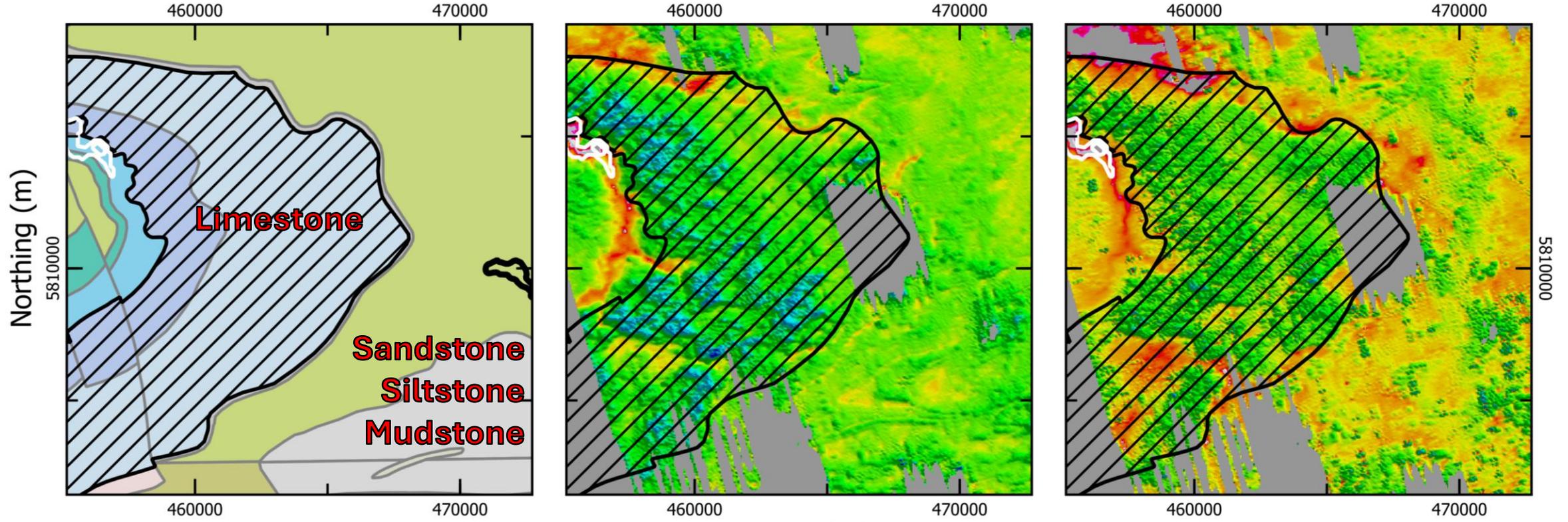
Apparent Resistivity
ohm-m

Listowel – Apparent Resistivity

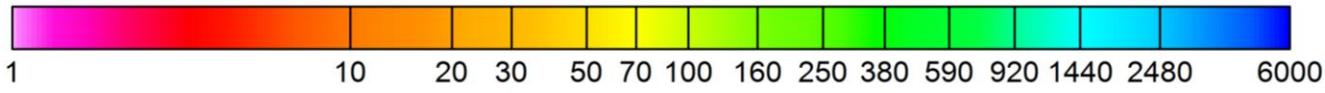
- Regionally important aquifer
 - Limestone karsts (diffuse)
 - Resistive region



Shallower **28kHz** → Deeper **3kHz**



WGS 84 UTM 29N



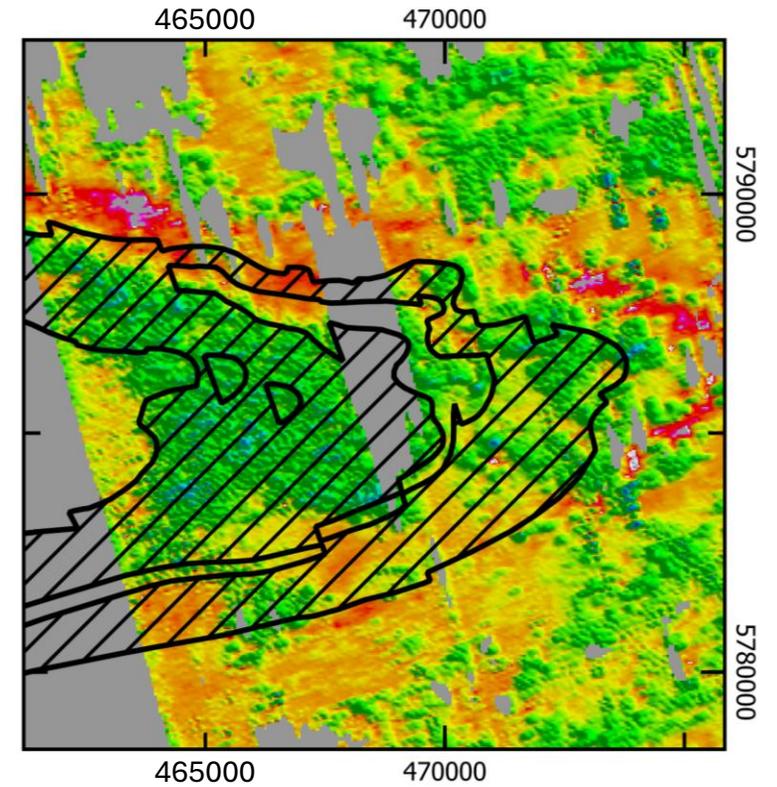
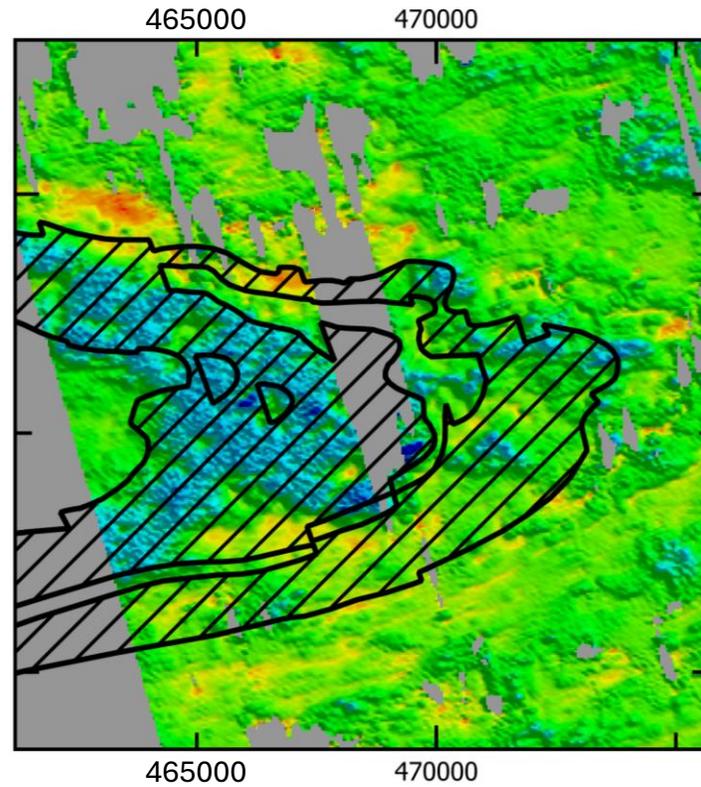
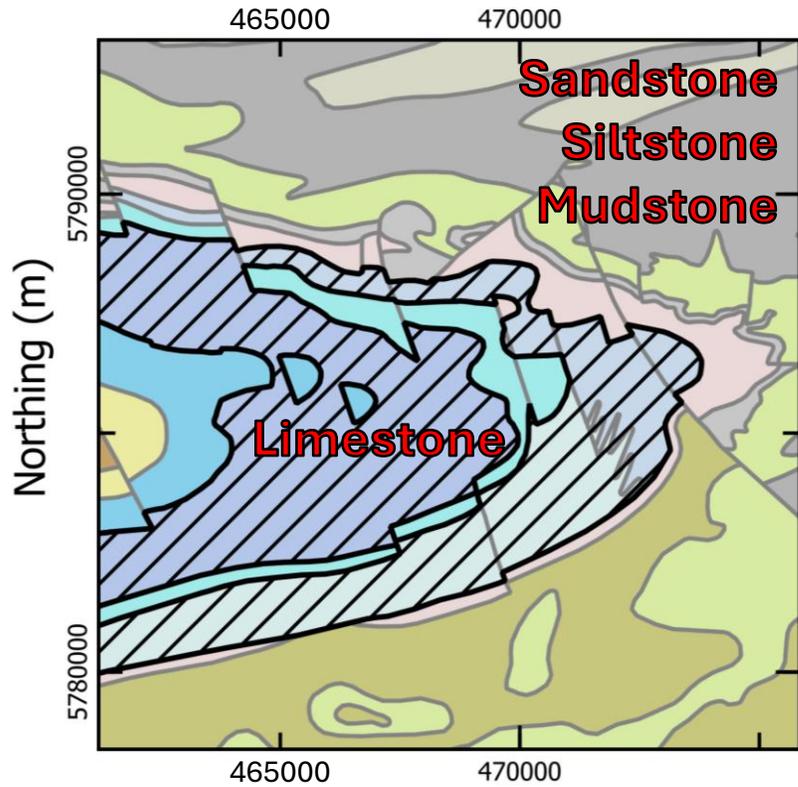
Apparent Resistivity
ohm-m

Castleisland – Apparent Resistivity

- Regionally important aquifer
 - Limestone karsts (diffuse)
 - Resistive region



Shallower → Deeper
28kHz → **3kHz**



WGS 84 UTM 29N



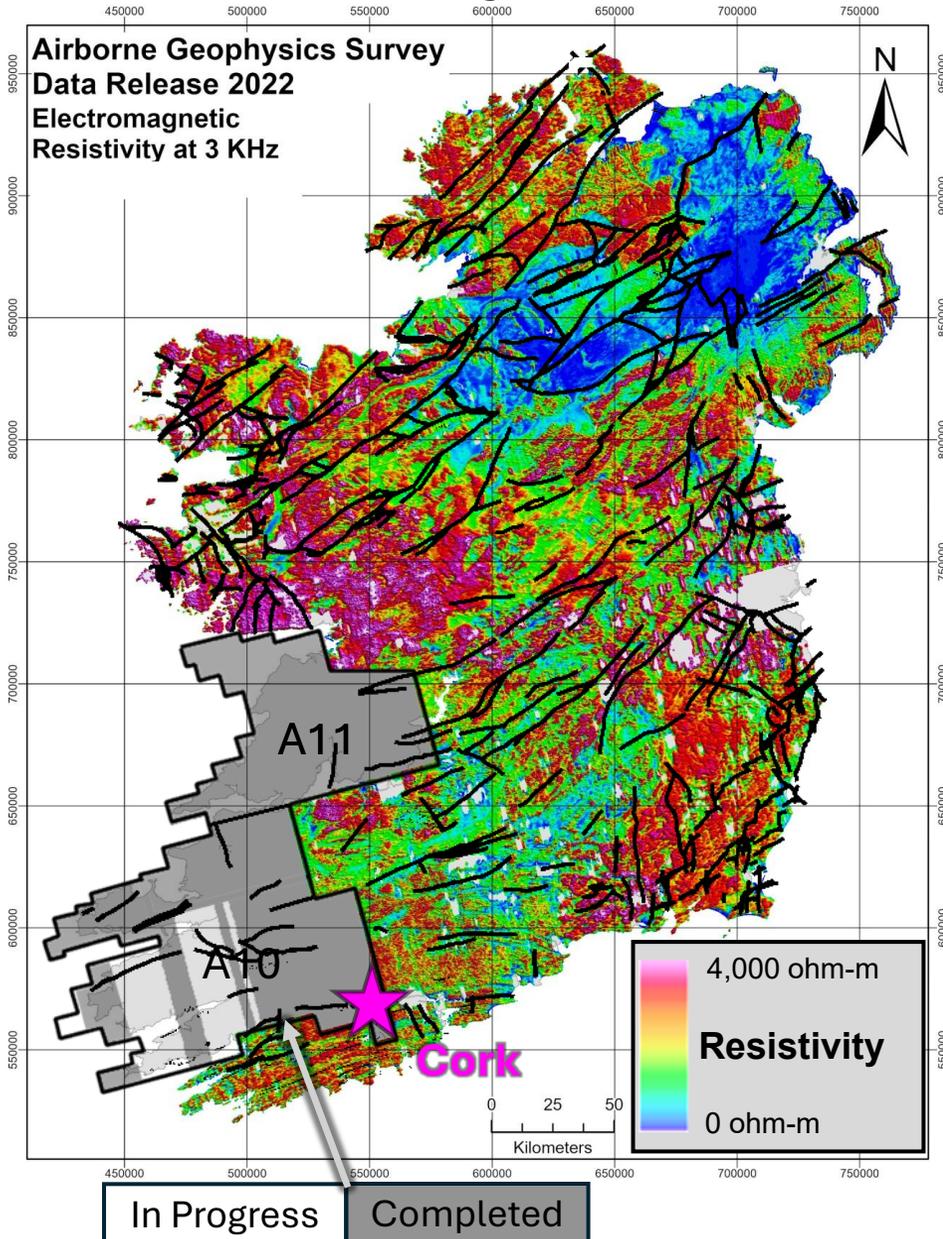
Apparent Resistivity
ohm-m



Sander Geophysics

The Tellus Project – Ireland – FDEM

- Ongoing airborne geophysics project being flown by SGL
 - Aeromagnetics
 - Radiometrics
 - Frequency Domain EM
- Typically measures upper 120 m
- Northern region is predominantly volcanics (lower resistivity)
- Geological structure due to conductivity variation
- Preliminary FDEM results from block A10
 - Over 60,000 l-km
 - 200 m line spacing
 - West of Cork
 - Example of aquifer delineation and characterization

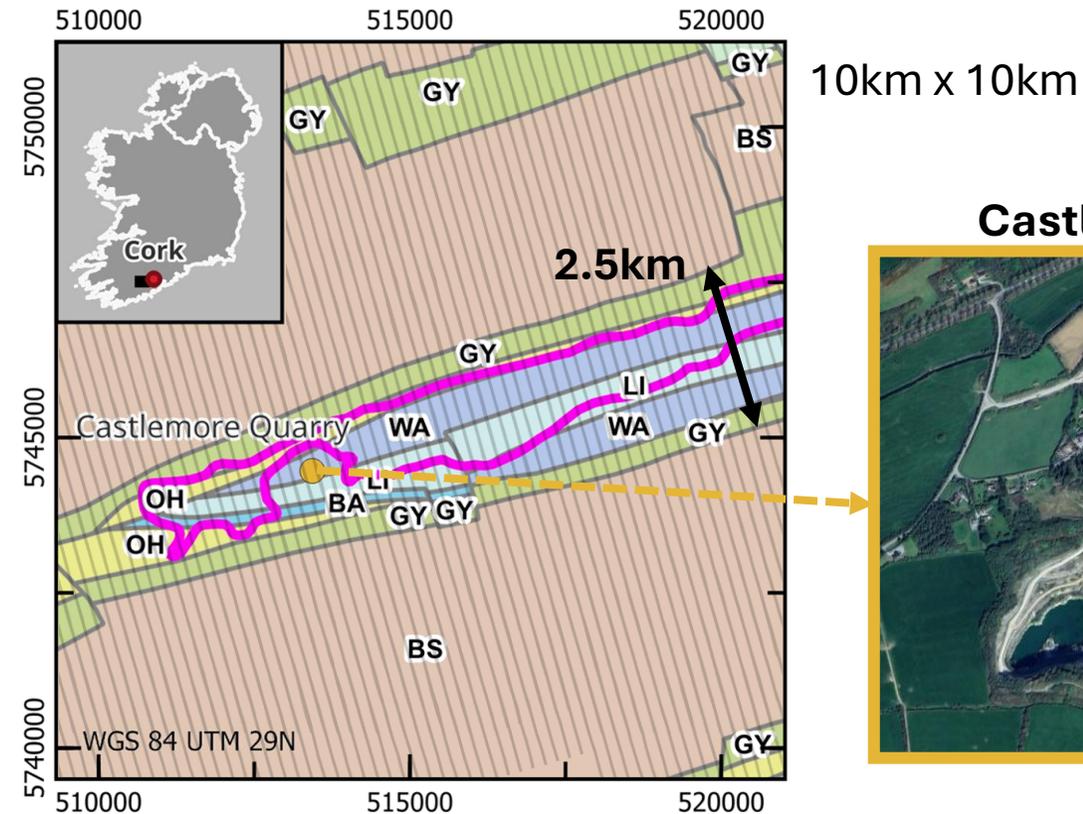


Courtesy of:



Cork, Ireland

- W–E syncline-controlled limestone units in the Ballincollig area near Cork, Ireland
- Variably thick Quaternary deposits (10 – 50 m) of well sorted gravels and sands that are locally exposed in valleys
- Groundwater within network of solution enhanced fractures and an upper weathered zone approximately 10 m thick
- Excavation below the local water table has resulted in continuous inflow of groundwater through bedrock fractures,
 - Dynamic permeability and porosity of the limestone aquifer



Castlemore Quarry

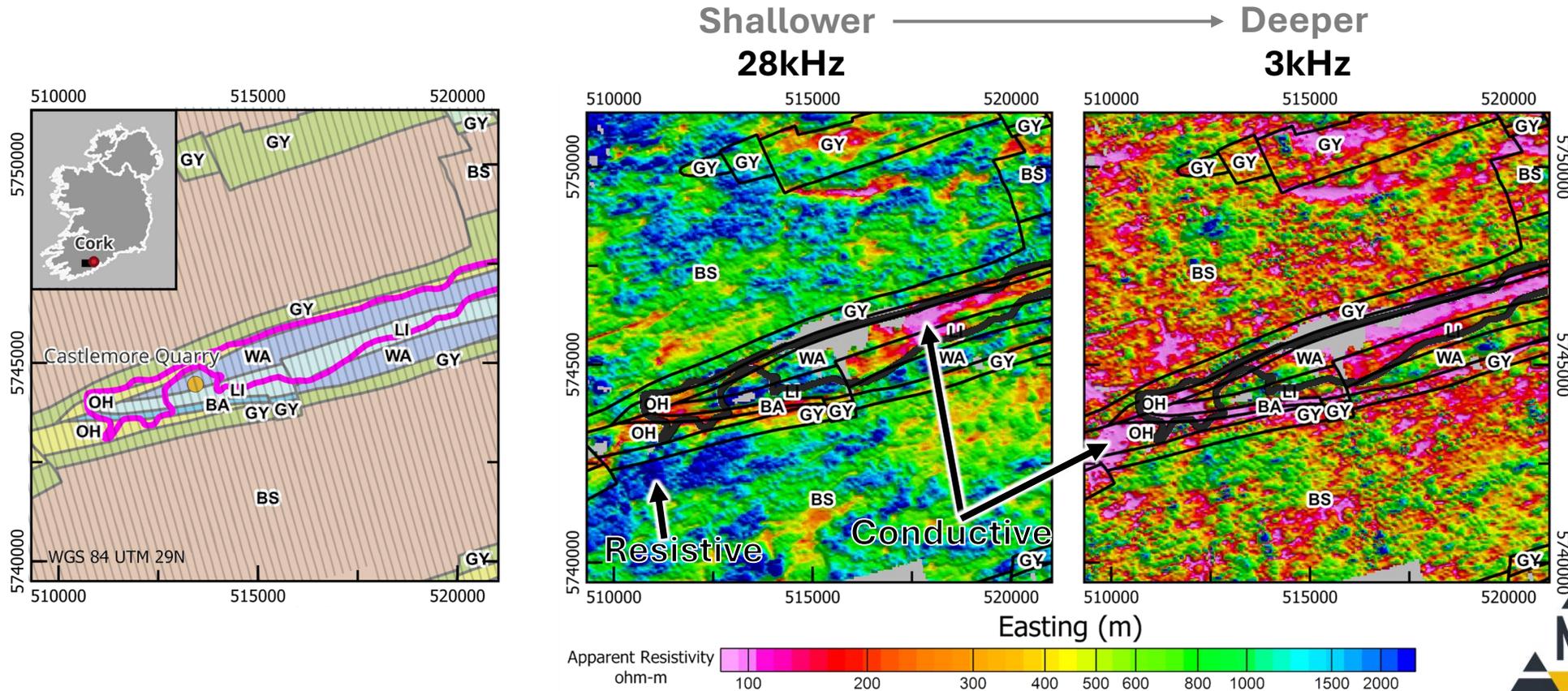


- Regionally significant aquifer
- Castlemore Quarry
- BS - Ballytrasna Formation
- GY - Gyleen Formation
- OH - Old Head Sandstone Formation
- BA - Ballysteen Formation
- WA - Waulsortian Limestone
- LI - Little Island Formation

Cork, Ireland – Apparent Resistivity



- Outlined aquifer agrees with preliminary FDEM apparent resistivity
- A weakly-conductive region is interpreted as the aquifer
 - 100 ohm-m to 200 ohm-m resistivity
- Resistivity around Castlemore Quarry suggests aquifer depletion due to continual excavation



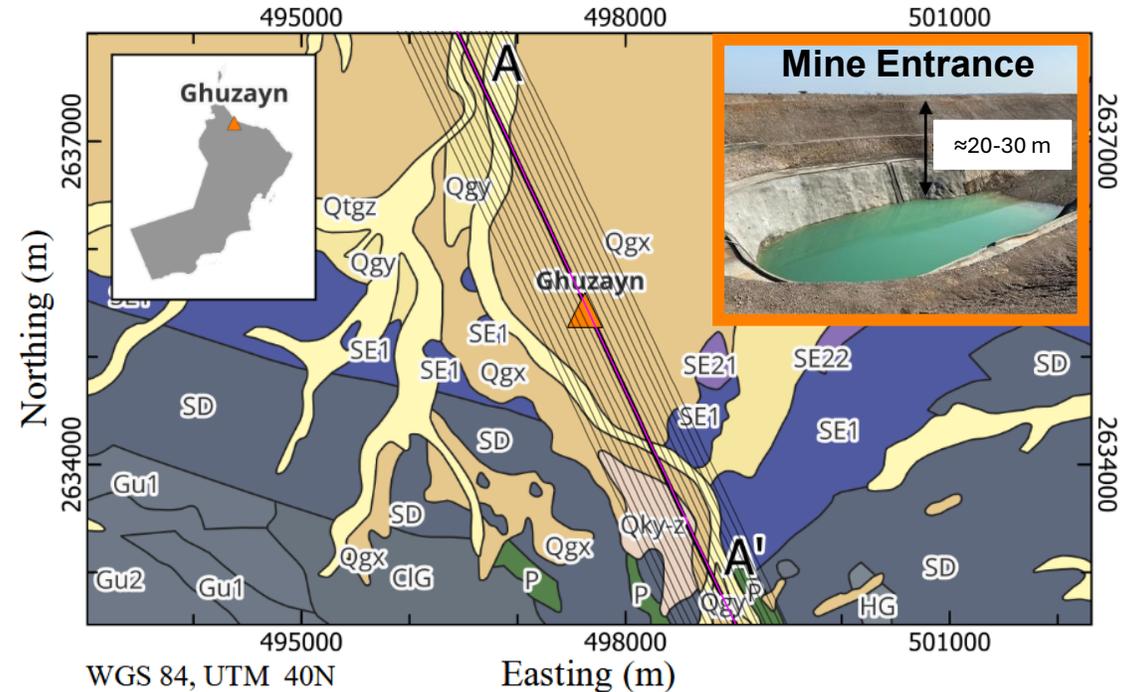
Ghuzayn, Oman

- As part of a set of regional surveys for Minerals Development Oman (MDO)
- Efficient application of the four geophysical methods on a commercially-viable survey
 - Aeromagnetic
 - Radiometric
 - Gravity
 - **Electromagnetic**
- Ghuzayn Mine is within the Lower Pillow Basalt
 - Ophiolites at depths below 150 m
- Quaternary alluvial aquifer overlays volcanics
 - Local depths to water reaching ~33.3 m below ground surface under heavy extraction
 - Mine entrance was flooded at time of surveying
 - 20 m to 30 m from surface



Sander Geophysics

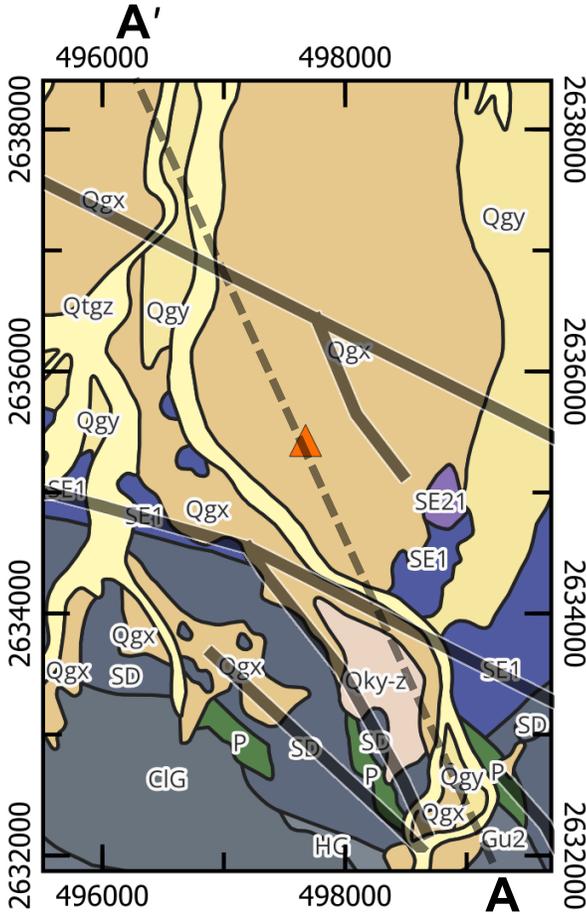
16 lines @ 100 m spacing
10 km lines



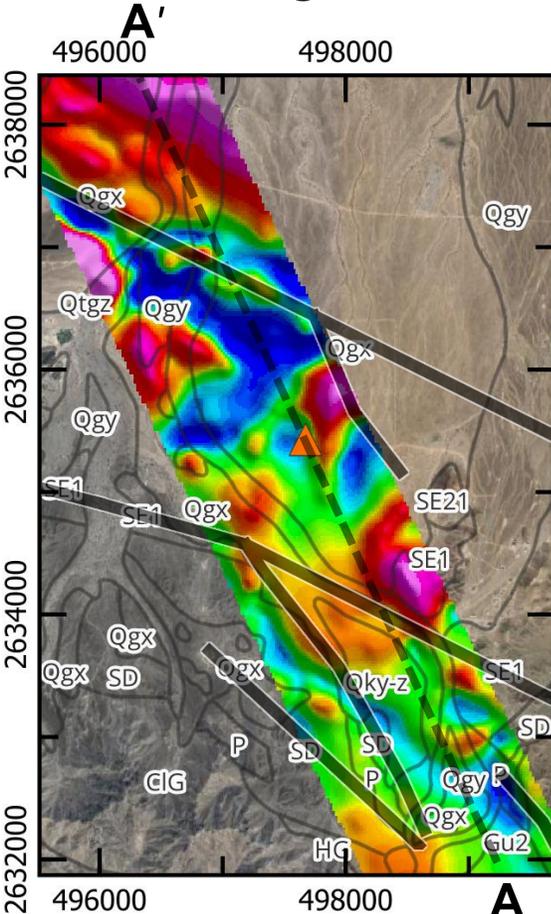
- ▲ - Ghuzayn Mine
- - Line inversion A-A'
- UmC - Aqil Formation
- HG - High level gabbro
- SD - Sheeted dyke complex
- SE1 - Lower extrusives
- P - Wehrlite
- SE21 & SE22 - Upper extrusives
- Gu1 & Gu2 - Uralitic gabbro
- Qgx - Ancient alluvium
- Qtz, Qky-z, Qgy - Recent alluvium



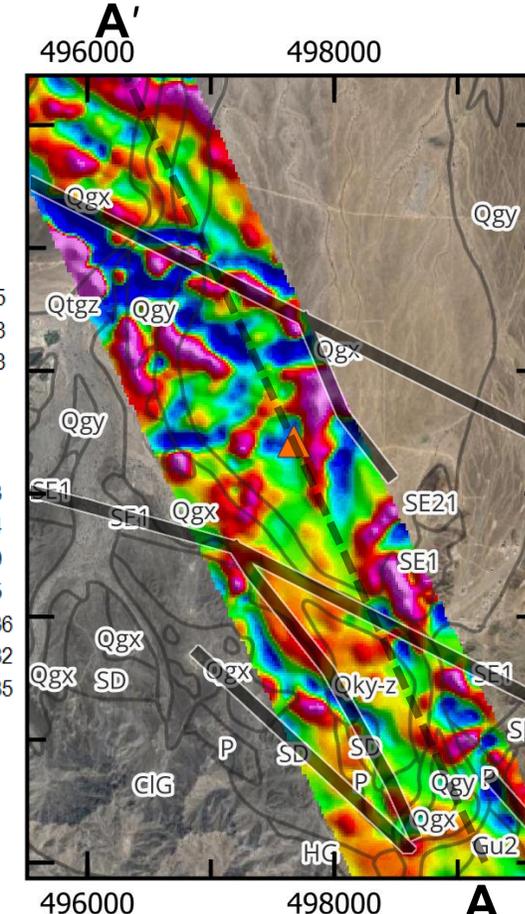
Ghuzayn, Oman – Aeromagnetics



Residual Magnetic Field



First Vertical Derivative



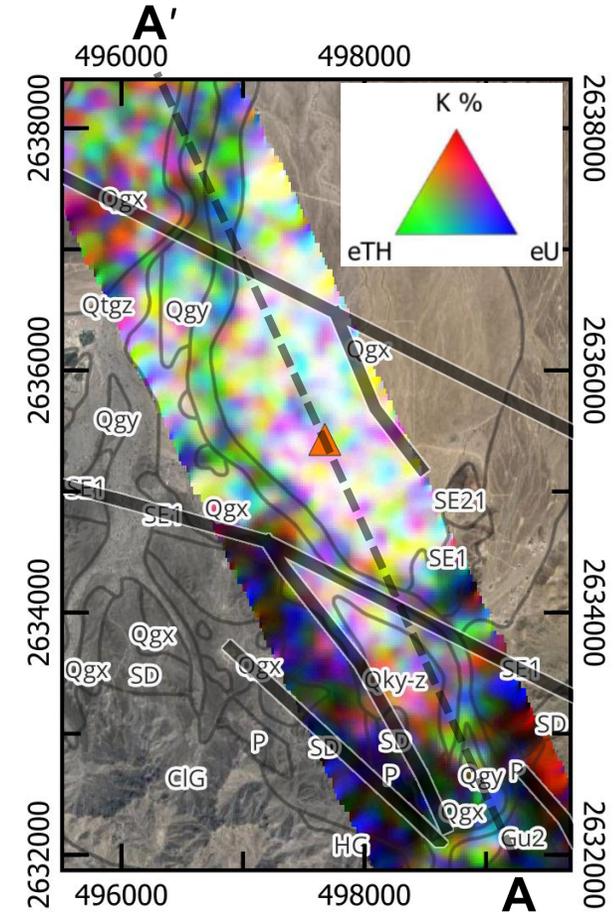
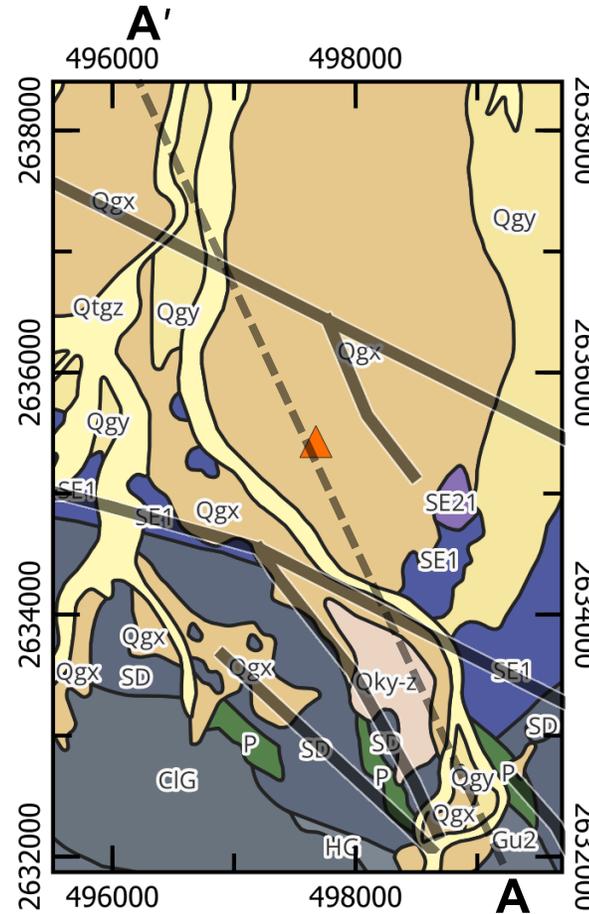
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- SE21 & SE22 - Upper extrusives
- Qgx - Ancient alluvium
- Qtgz, Qky-z, Qgy - Recent alluvium



Ghuzayn, Oman – Radiometrics

- Higher radiometric response in north from sediments
 - Quaternary units (Q)
 - Different K, U, and Th content suggests different source
- Lower response in south from volcanics
 - Sheeted dykes (SD)
 - Extrusives

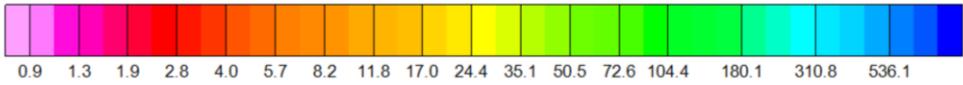
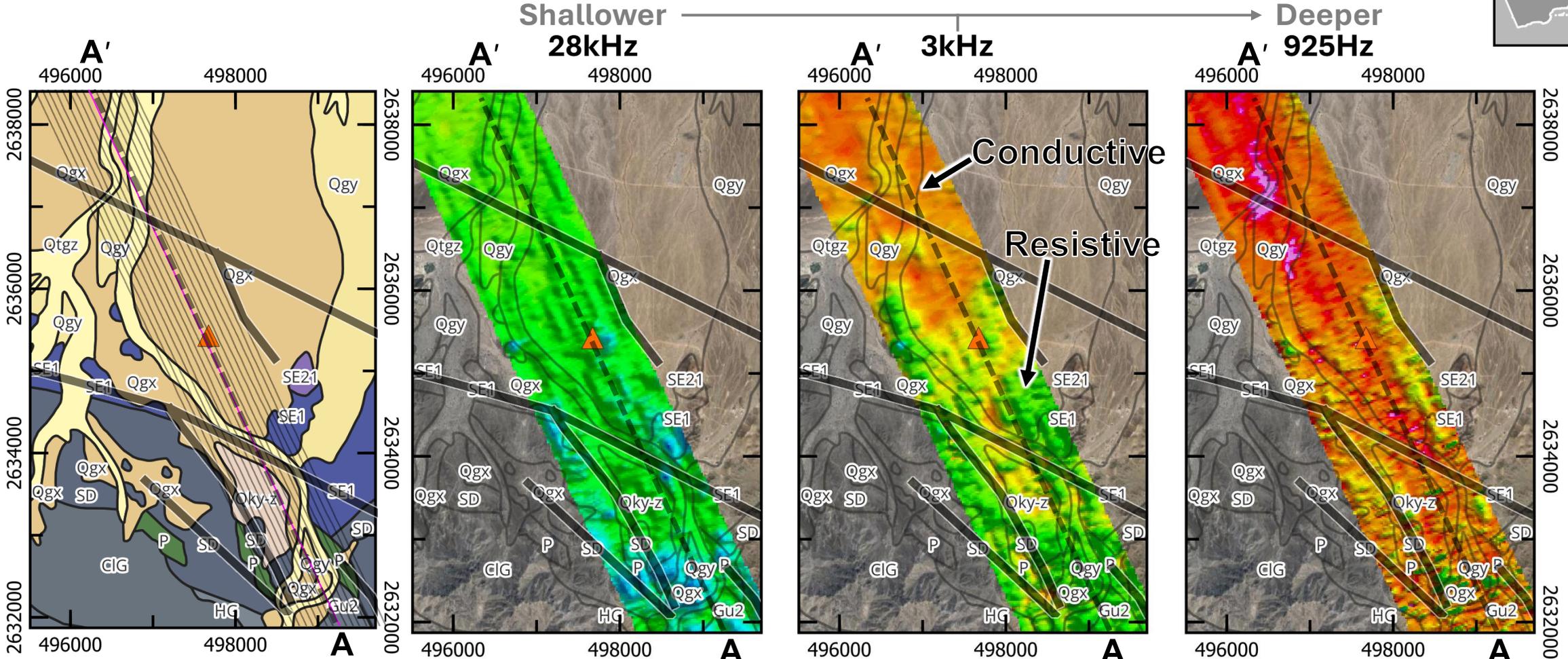


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Ghuzayn, Oman – Apparent Resistivity



Apparent Resistivity (ohm-m)

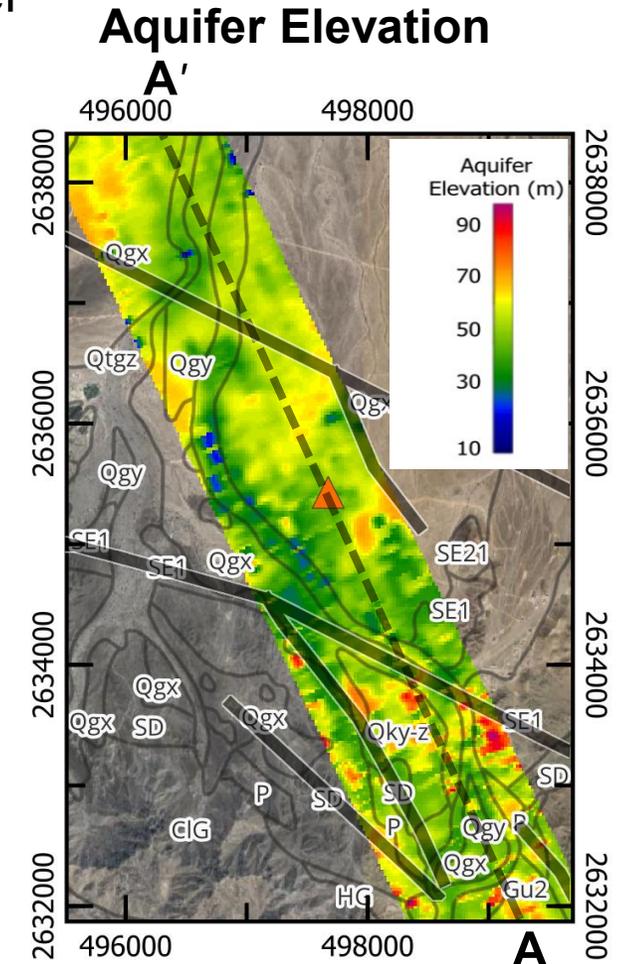
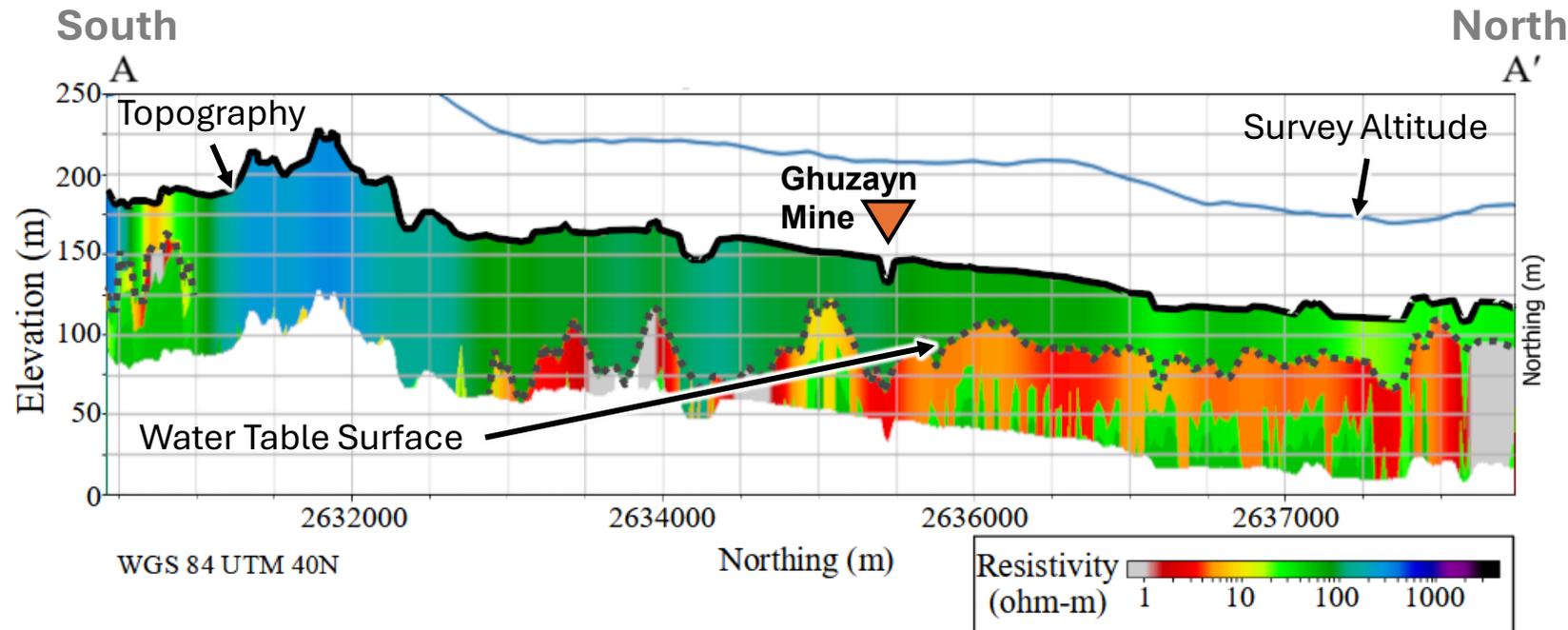
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Ghuzayn, Oman – FDEM Inversion

- Four-layer resistivity inversions (with CSIRO Airbeo) were calculated over the entire Ghuzayn area test survey
- Second layer interpreted as the aquifer
 - 2 ohm-m to 10 ohm-m (slightly saline to fresh water)
 - 20 – 50 m depths and increasing with topography
- Elevation of the water table is relatively flat
- Depths around Ghuzayn mine match inversion results





Conclusions

- Single survey aircraft with sensitivity to multiple rock properties
 - Resistivity, magnetic susceptibility, radiometrics, density
 - Cross-property correlation (geological units, structures, etc.)
- Quick interpretation of geological changes with depth
- Inversion results for more detailed results



Questions



Sander Geophysics

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Jonathan Walmsley, M.Sc., P.Geo.

Greg Hodges

Luc Lafrenière, Majo Ortiz, Andrea Reman, Javeria Saher, Keith Wells, ...

Thank You



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Tellus: <https://www.gsi.ie/en-ie/programmes-and-projects/tellus/Pages/default.aspx>



Minerals Development Oman

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