The Rebirth of VLF Geophysical Technology

A new tool for cost effective imaging of the subsurface

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Presentation Summary

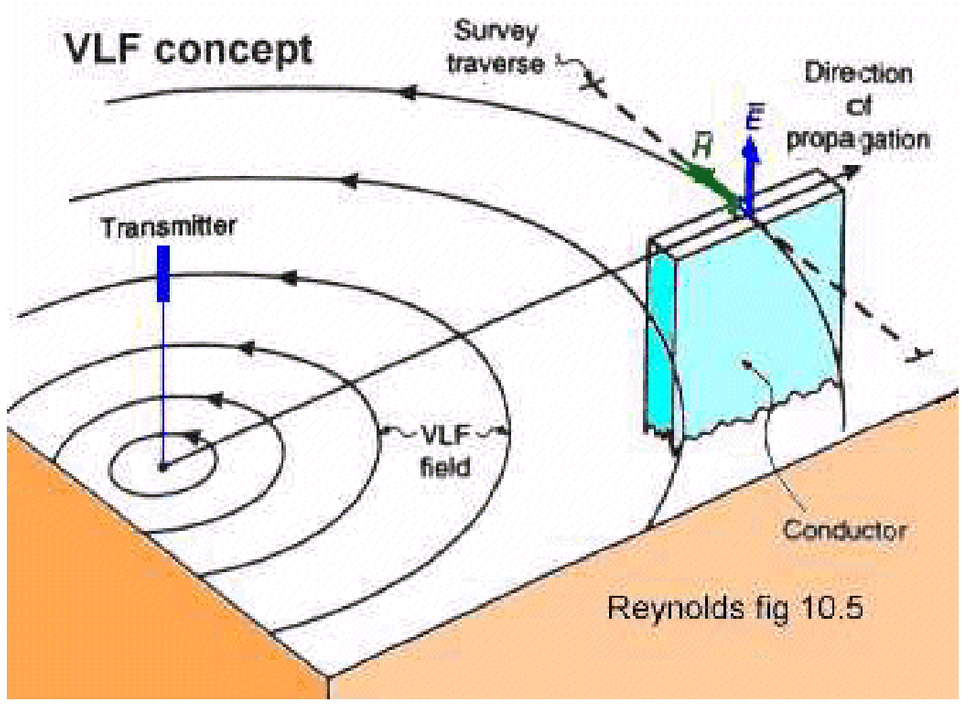
- The VLF Method
- History of Application
- Data Presentation
- New Developments & Technologies
- Examples
- Conclusions

The VLF Method

REF. www.eoas.ubc.ca

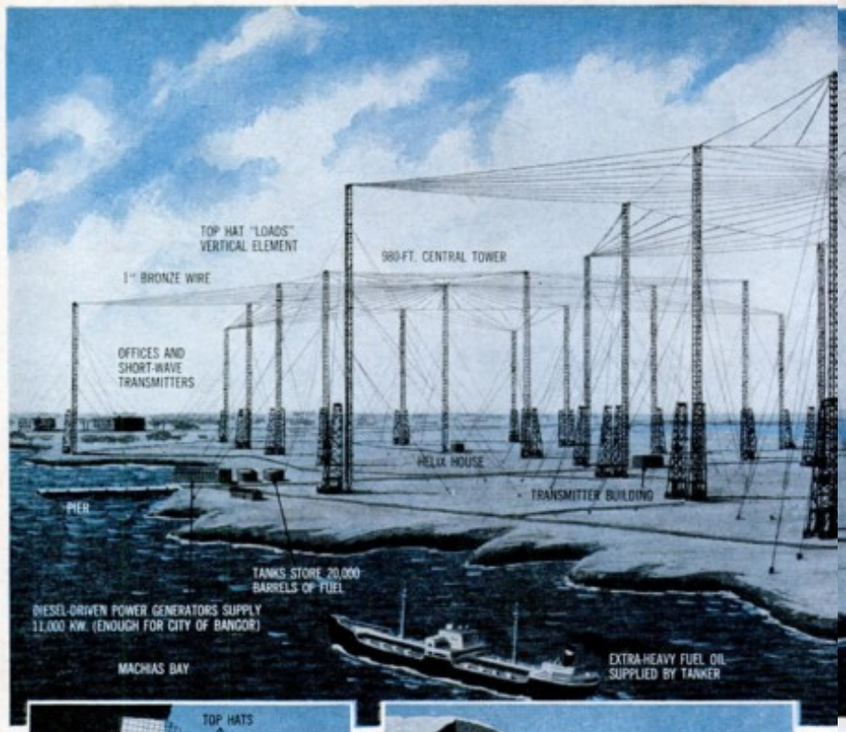
- Measurement of **V**ery **L**ow **F**requencies

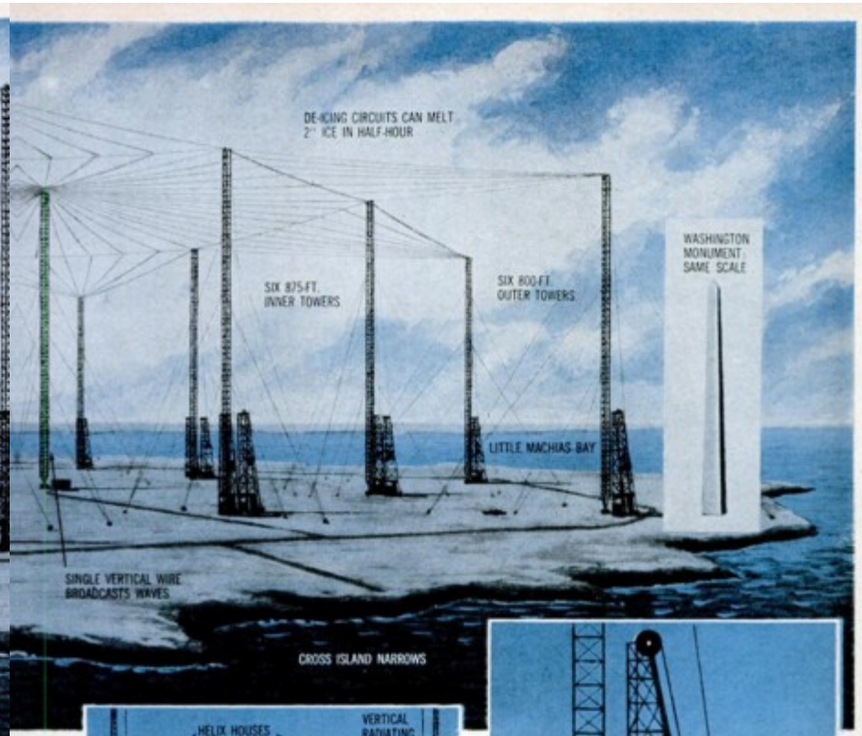
- VLF surveying involves measurement of the earth's response to EM waves generated by transmitters a great distance from the survey site. The source fields are effectively planar and of fixed orientation so the response depends on the orientation of buried objects with respect to the source fields. It is therefore usual to measure the signals caused by two or three different transmitters. Six parameters describing the secondary magnetic field are commonly measured. They are the in-phase and quadrature phase components in all three vectoral directions (x,y,z).



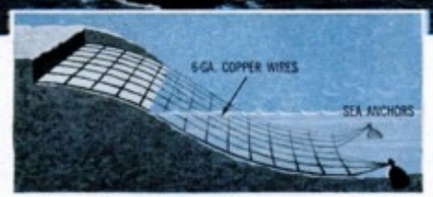
History of the VLF Method

- 1933 – Feldman uses wave tilt technique to measure dielectric constant and conductivity of the earth
- 1963 Paal observed radio waves at VLF frequencies
- (3-30kHz) could be used to prospect for electrical conductive orebodies – “horizontal VLF magnetic field enhanced over orebodies where modulus of vertical became minimum
- 1965 Vaina Ronka and Patterson – first commercially available VLF … “The EM-16”





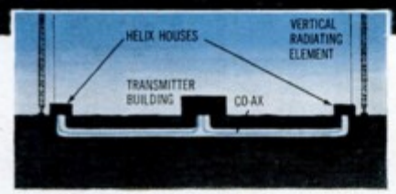
STAR-SHAPED TOP HAT for each antenna covers area big enough for 11 Pentagons.



BURIED COPPER NET—electrical ground for antennas —underlies most of peninsula, trails off into sea.

SKINNY AND TALL, towers soar as high as 980 feet.

Navy Builds World's Most Powerful Transmitter

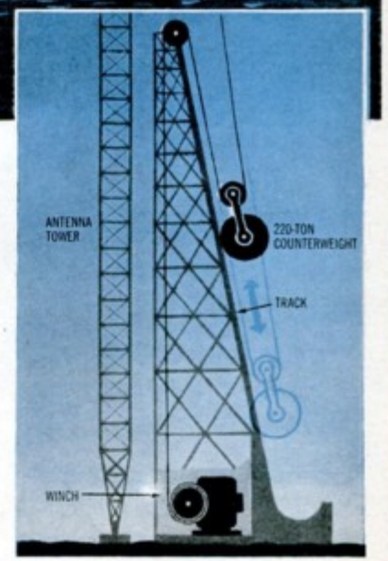


TUNNELS A MAN CAN WALK THROUGH hold huge co-ax feeding transmitter output to antennas.

A 2,000,000-watt radio station will achieve the "impossible": signaling U.S. subs underwater

By Martin Mann

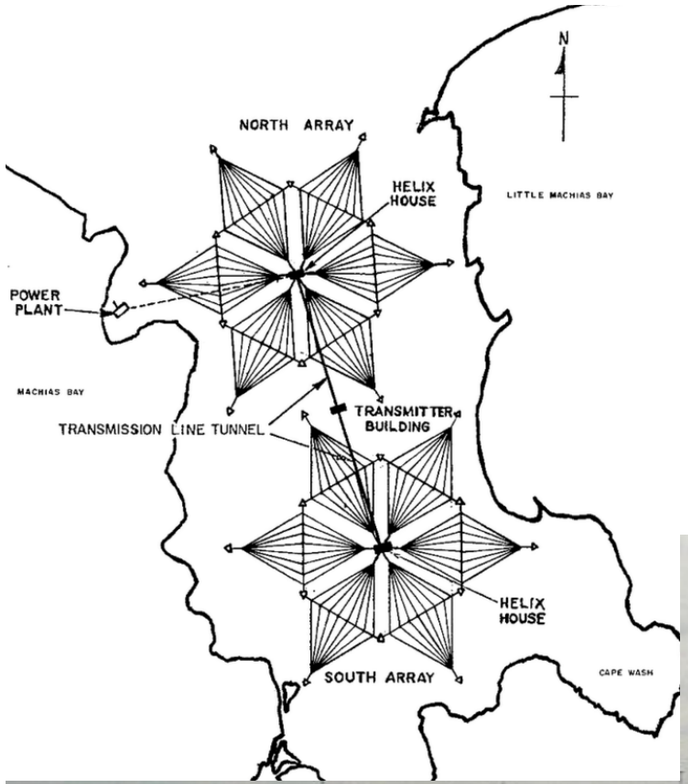
A FANTASTIC spider web covers an entire peninsula at the easternmost tip of Maine—715 acres of bronze lace 800 feet and more above ground. This is the antenna for the most powerful radio broadcasting station ever built.

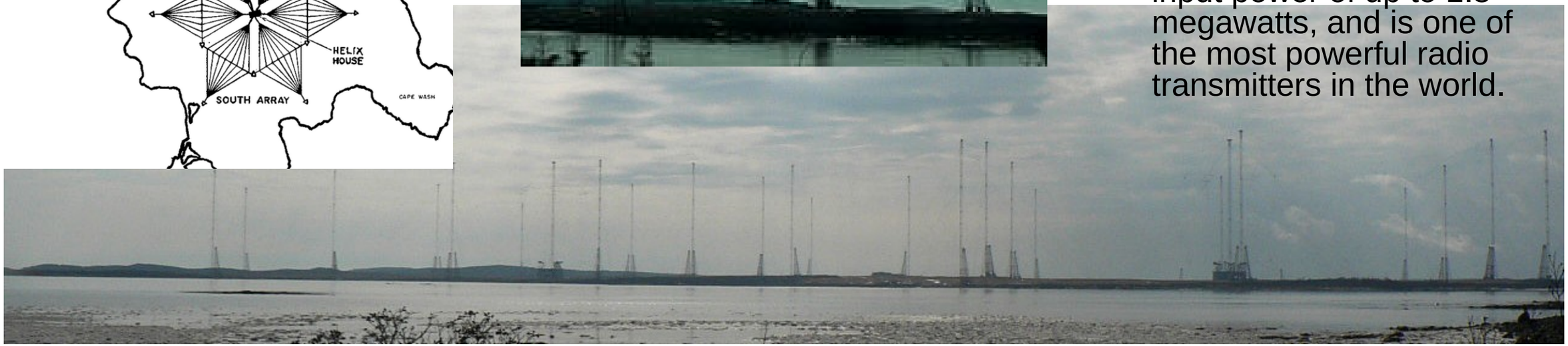


COUNTERWEIGHTS, riding track, keep antenna cables aloft, compensate for sway in wind.

CONTINUED

Example – Cutler 24.0 Khz





- The station provides one-way communication to submarines in the Navy's Atlantic Fleet, both on the surface and submerged. It transmits with call sign NAA, at a frequency of 24 kHz and input power of up to 1.8 megawatts, and is one of the most powerful radio transmitters in the world.

History of the VLF Method & Technology

- 1967-8 – Collet and Becker “RadioOhm” used vlf vs natural source (calculated resistivity) from (Cagniard 1953 Magnetotelluric methods)
- 1973 – Tilsley Portable VLF transmitter suggested
- 1980’s – First multi component receivers (EDA)
- 1990’s ABEM, Scintrex, Iris
- 1995 GEM

$\rho a = (1/\omega\mu)\,(E/H)^2$

where :

ω: $2\pi f$, f is the frequency
E : the electric field
H : the magnetic field
μ : $4\pi.10^{-7}$ permeability in free space.

When using the practical units, this expression becomes :

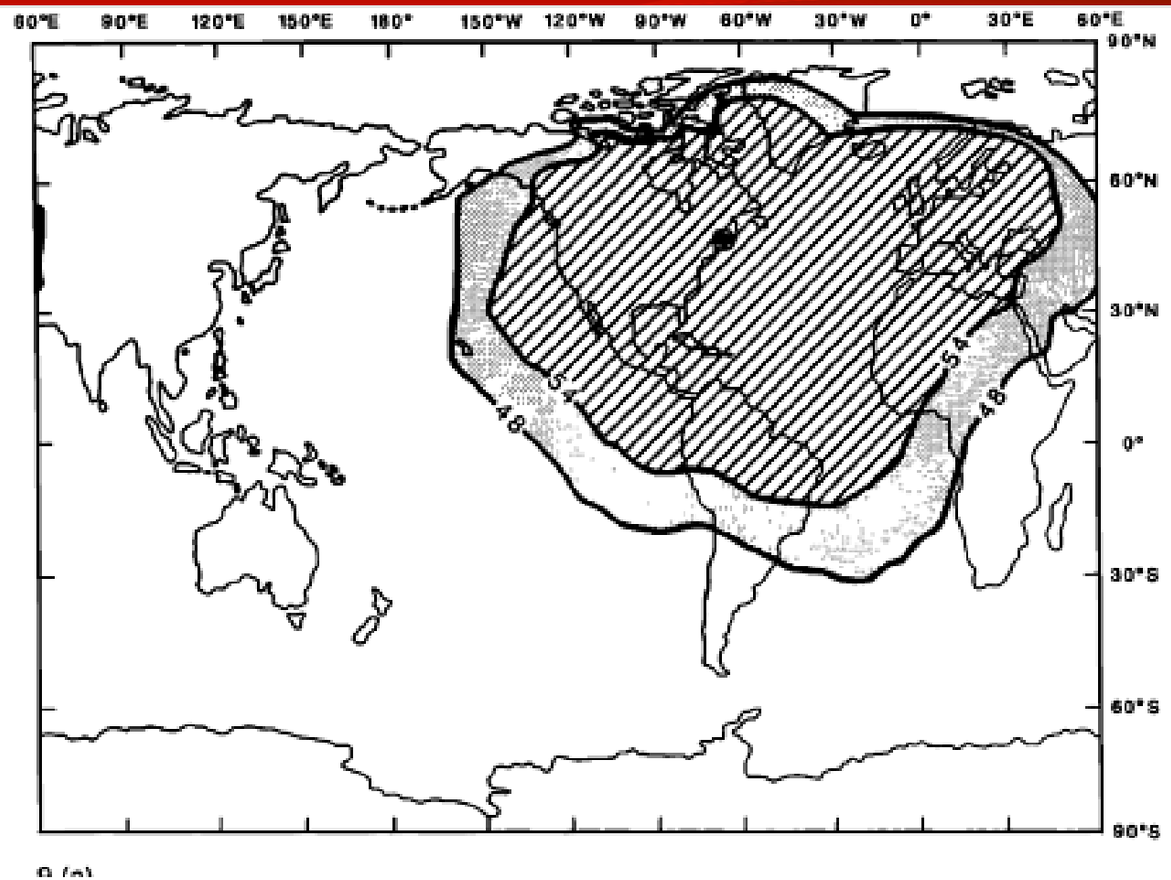
$\rho a = (1.25\ 10^5/f)\,(E/H)^2$

f in Hz
E in μV/m
H in μA/m
ρa in Ωm.

From EBAY last week $12,000 US (not serviceable)
Plus Scintrex Envigrad-vlf-Obsolete
Wadi - discontinued

Signal Level from Cutler

- Good and Marginal
- Signal Strength contour maps - From McNeill and Labson (by Hauser and Roads, 1974)
- Investigations in Geophysics No.3
- Skin Depth of Investigation for 24kHz, in a relatively conductive ground (the earth) is about 100m



Traditional and Typical Uses of VLF

VLF surveys have provided insight on:

- Water bearing fractures
- Linear conductive bodies

And related structure

- Survey grid required
- Write it down
- 2 fixed – preprogrammed stations
- Potential to add electrodes for a resistivity measurement

Example of VLF data from mineral exploration (Telford 7.96)

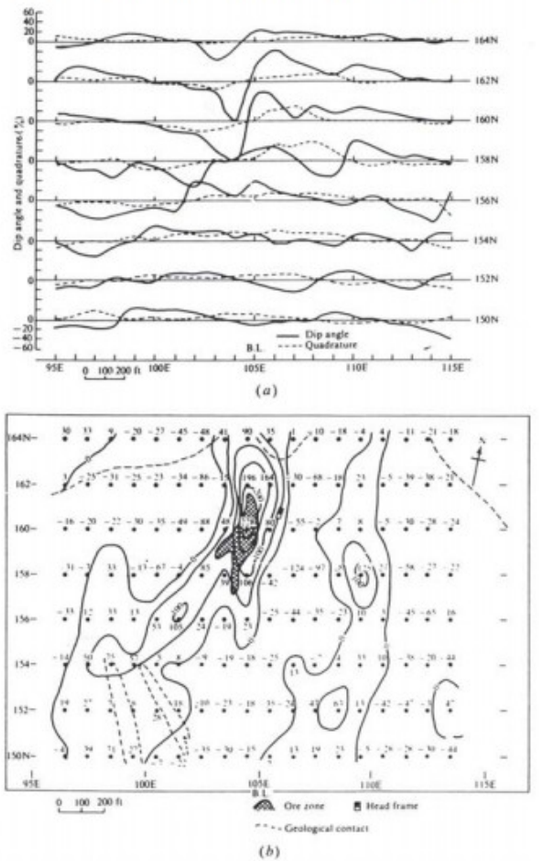
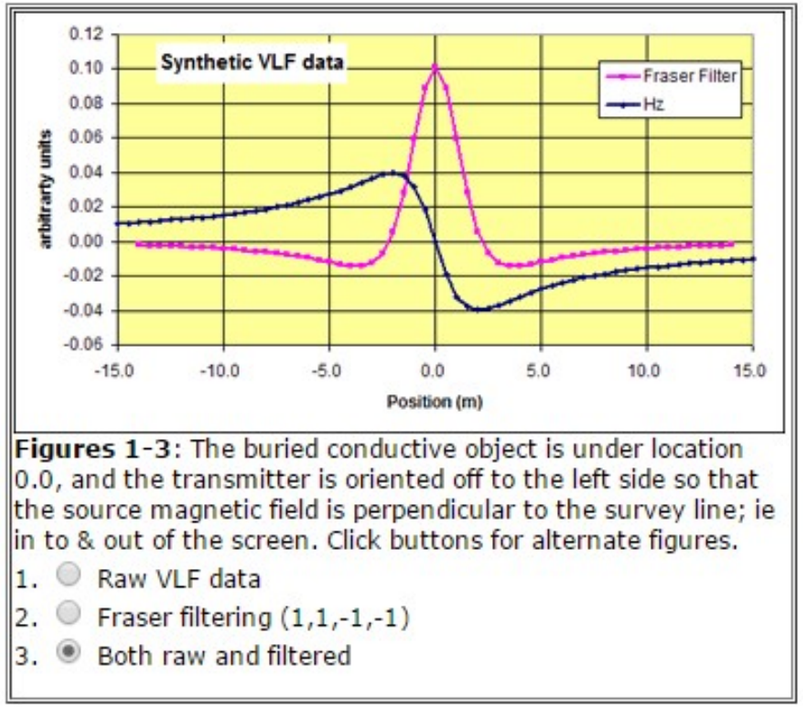


Figure 7.96. Results of VLF survey, Atlantic Nickel property, southern New Brunswick. Transmitter station: Cutler, Maine (24.0 kHz). (a) VLF profiles. (b) VLF contours.

Data Presentation

Qualitative Interpretation

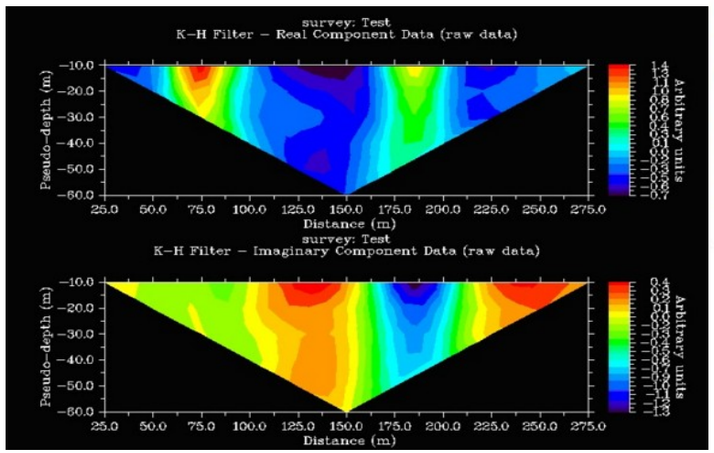
- 1969 Fraser Filter – Difference filter or first derivative



Figures 1-3: The buried conductive object is under location 0.0, and the transmitter is oriented off to the left side so that the source magnetic field is perpendicular to the survey line; ie in to & out of the screen. Click buttons for alternate figures.

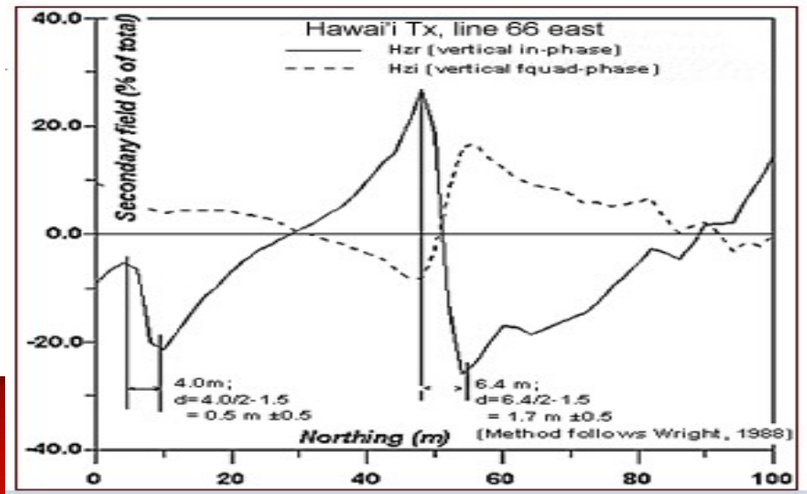
1. Raw VLF data
2. Fraser filtering (1,1,-1,-1)
3. Both raw and filtered

- 1983 Karous Hjelt – 6pt linear filter – obtain current density cross section with pseudo depths



(From eoas UBC)

- 1988 Wright 1988 – simple depth estimate from (half the peak to peak width – distance of instr. Above ground



Traditional Problems with VLF Surveys

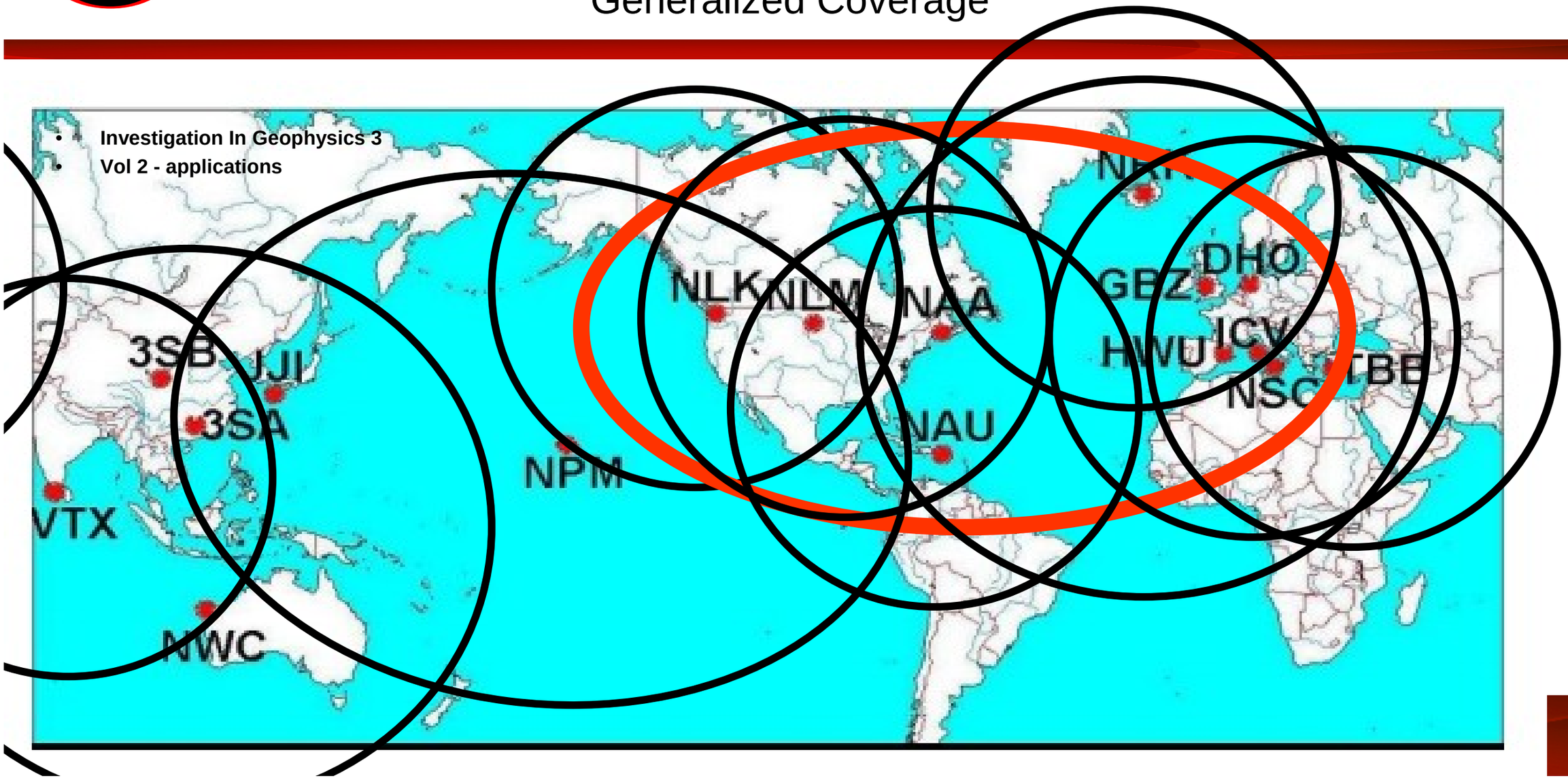
- Transmitting Stations are not always on
- Station orientation with respect to the “strike of the geology” is not optimal
- Area not covered by station
- When coupled with airborne surveys that are not dependant on exterior sources of tx signal (EM methods) or other passive methods like Magnetics, an industry attitude developed ---

  “DO NOT STOP flying if the stations go off.”

  – This contributed to the continuous marginalizing of the method.
  – “VLF is generally collected along with magnetic data on a 'best efforts' basis.” - and “Thrown in for Free” are common qualifiers from modern airborne companies.

VLF Transmitting Stations

Generalized Coverage



New Developments & Technologies

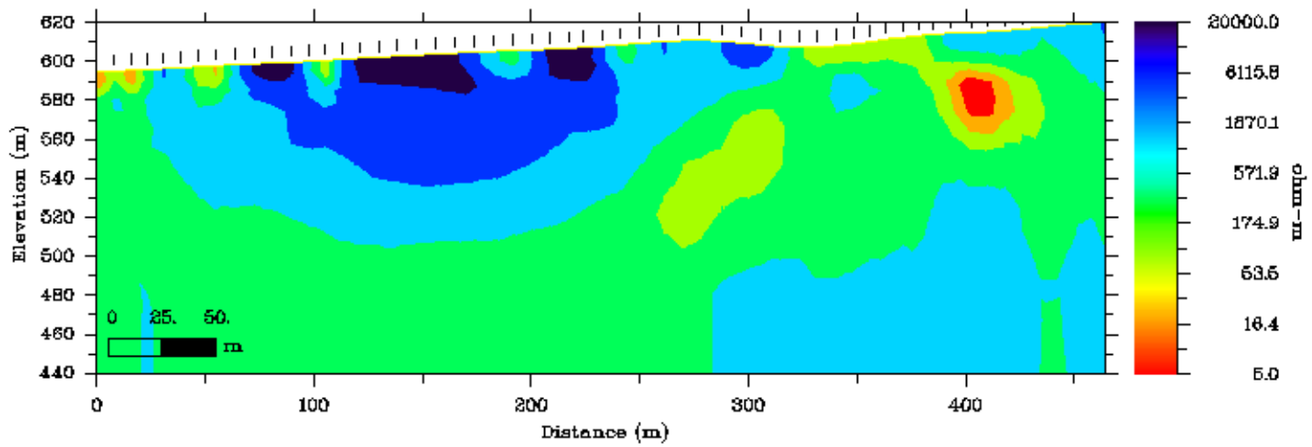
Quantitative Interpretation

- 1997 Kaikkonen – Paper “Some Points of view concerning interpretation of VLF
- 2004 OSKOOI – Upsala – Paper summarising work from 2000 to 2004 (Uppsala, Pederson, Oskooi)

- 2005 Monteiro – creates software because nothing is available for 2d Inversion – based on the OCCAM technique
- 2010 Monteiro partners with a Geologist Shaun Parent to improve software - packages a variety of standard processing coupled with 2d inversion VLF2dMF and map making
  - **Profiling**
  - **Fraser Filtering**
  - **Karous Hjelt - Pseudo conductivity sections**
  - **Apparent Resistivity Depth Sections**

- 2015 - Revised interest in the issue of anisotropy of rocks as highlighted by applying fields in different directions, so not just interpreting structures in different directions, but also potential resistivity properties

Apparent Resistivity Depth Sections



New Developments & Technologies

Automated Ground VLF

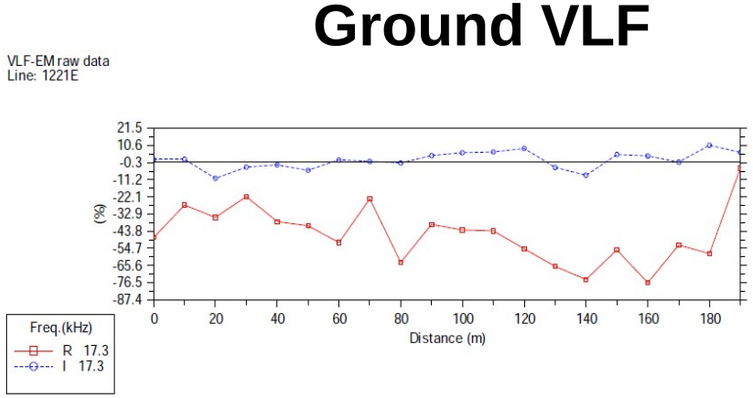
- Multi-Station Capability
- Up to 3 stations sequentially measured
- Non-magnetic Air coils
- Multi-survey at same time
- Rapid data collection
- Transmitters are free (i.e. Cost effective)
- GPS - Real time location

- Better data processing tools

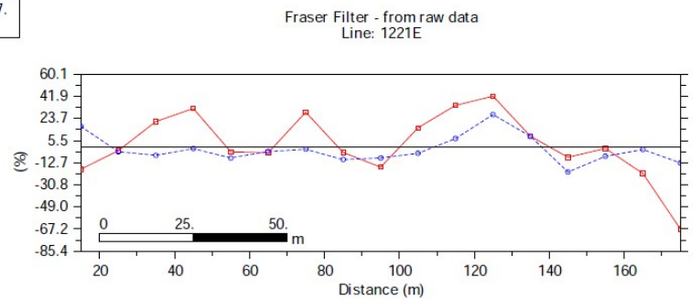
Water Exploration

Southern Angola, Africa

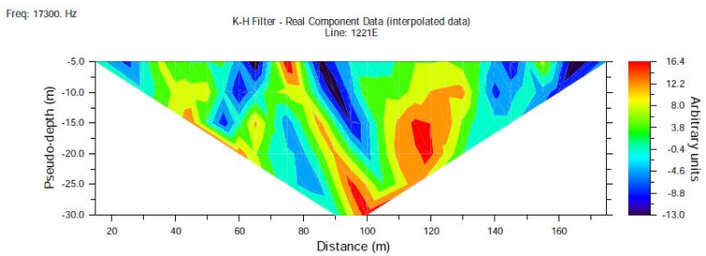
Ground VLF



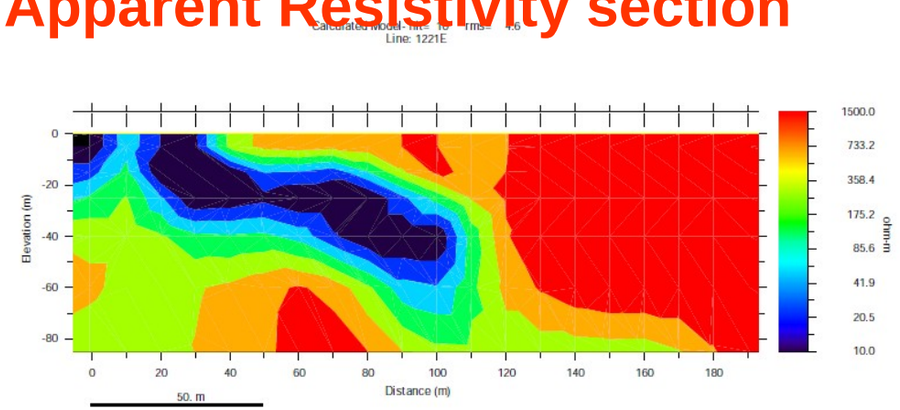
Fraser Filter



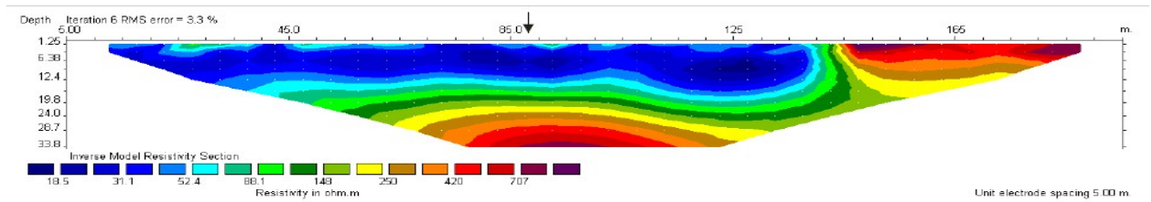
Harous Kjelt Filter



2D Apparent Resistivity section



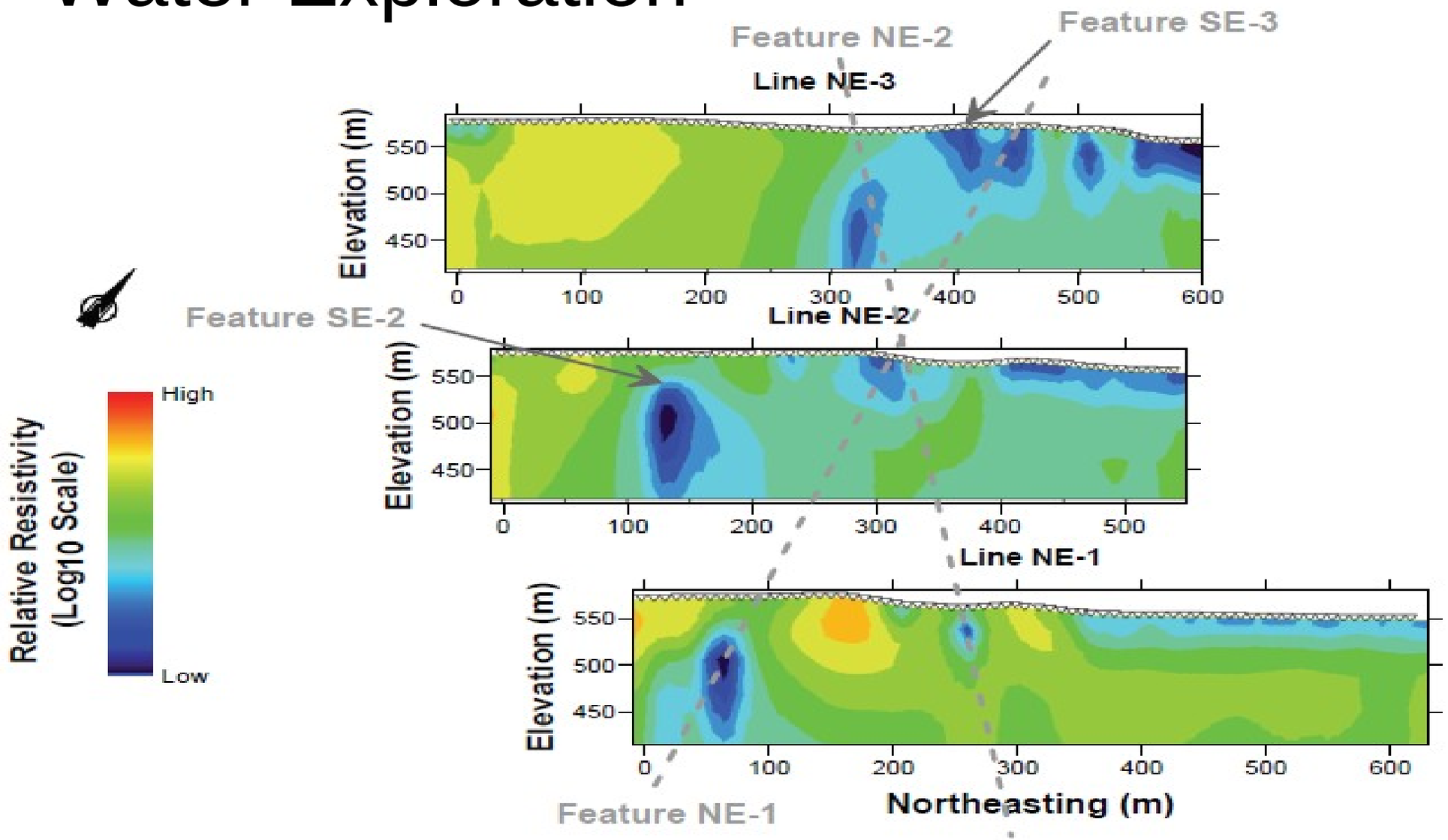
2D Resistivity section from ERT Schlumberger array



Our World is Magnetics

Water Exploration

courtesy from Tim Bechtel (univ of Philadelphia)



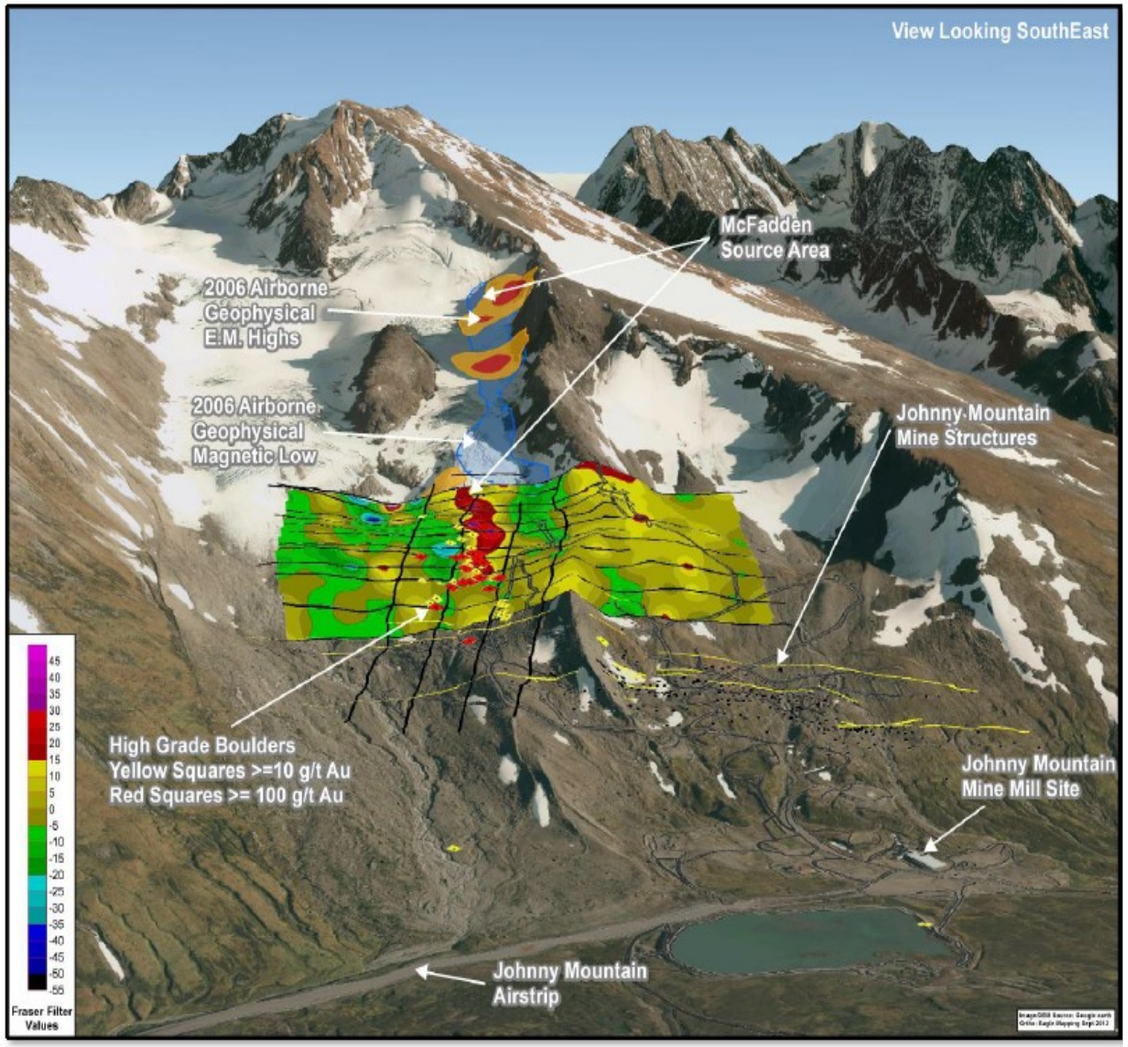
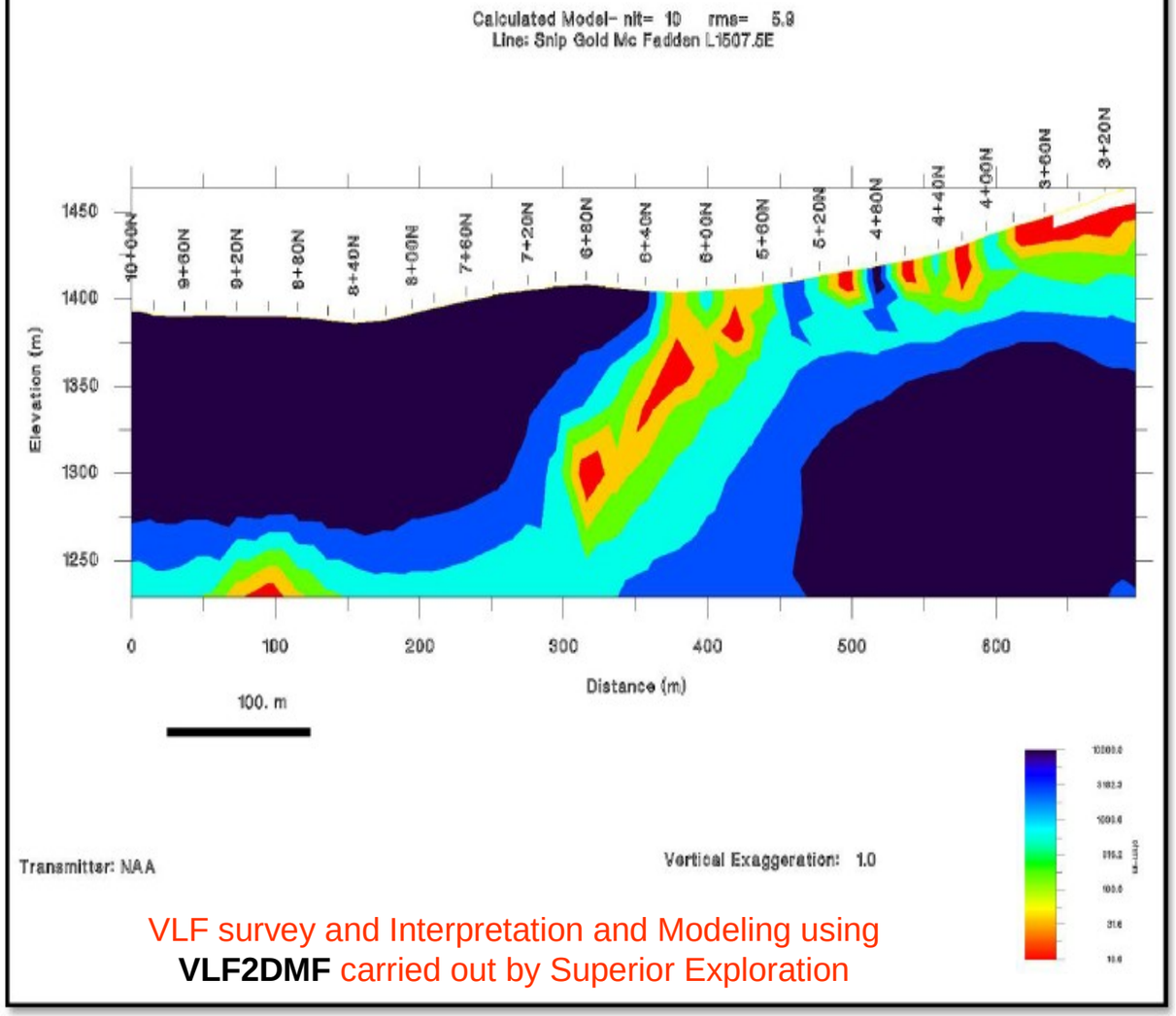


Figure 4. Displays the results of the 2015 La Moure, North Dakota (“**NML**”) EM survey. The anomalous readings display a linear conductor trending roughly at 120 Az. The red and magenta coloured response in the upper part of the colour rendered area indicates the area of strongest conductive response for this transmitter. This response is up-ice of the McFadden high-grade gold boulders. The figure also displays the grid lines used to complete the 2015 EM survey as bold black line traces, location of the high-grade McFadden boulders as red and yellow squares, surface traces of the Johnny Mountain Mine structures as yellow linear features, and the 2006 airborne EM anomalies as red and orange circles and the magnetic low as a blue shaded area outlined with a blue line.

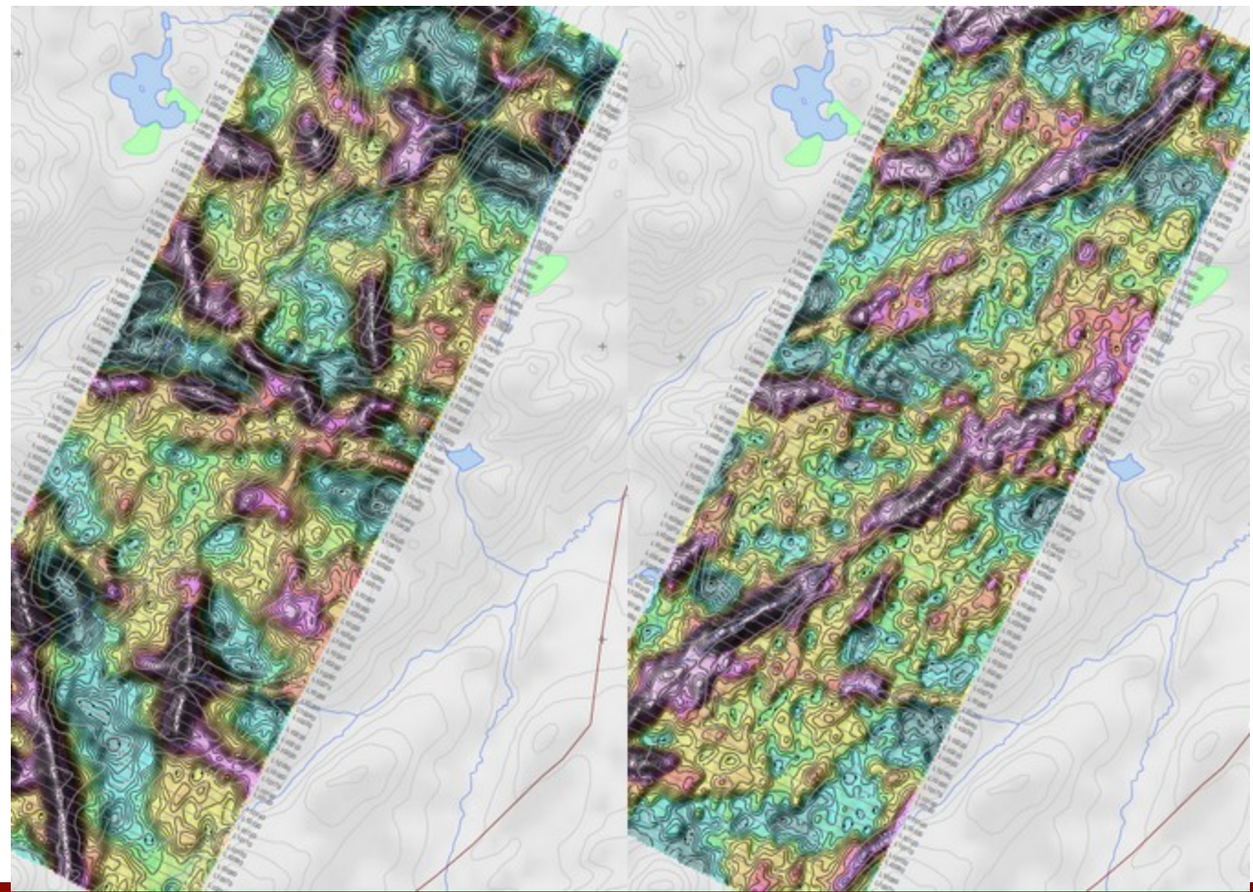
courtesy press release Mar 2016, Snip Gold



VLF survey and Interpretation and Modeling using **VLF2DMF** carried out by Superior Exploration

Figure 5. Displays the profile for the 2015 Cutler Maine (**NAA**) modeled data for section L1507.5E, the vertical cross section view looks easterly in an upslope direction. The surface trace of this profile is shown on figure 3. The areas noted from green to red show areas of higher conductivity and are interpreted to be the possible source for the high-grade boulders at McFadden.

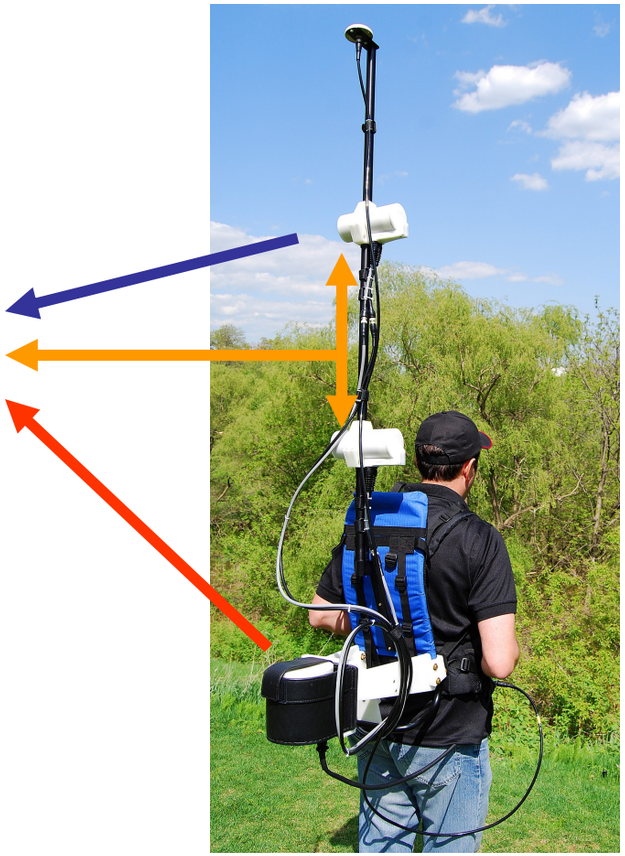
VLF 2 stations – what does it mean??



Summary & Conclusions

- Slow but continuous improvement of technology and processing capability since the early 1960's
- New modelling methods and techniques have finally "commercially" arrived
- More potential use of tool as a quick first pass on exploration properties – Multi data **(Mag/Grad/Res)** sets are cost effective and more informative for targeting (thinking)
- Revised interest in the issue of anisotropy of rocks as highlighted by applying fields in different directions

- In time, case studies will continue to validate the potential and cost effective value of this traditionally marginalized technology



The Future

UAV Potential

- Further Space Studies
- Studies include Ionosphere D region height parameters (lowest level of the ionosphere)
- Electron densities lower at night
- Reflection changes in night time from 60-75km to 75-90km

Celebrating 35 Years

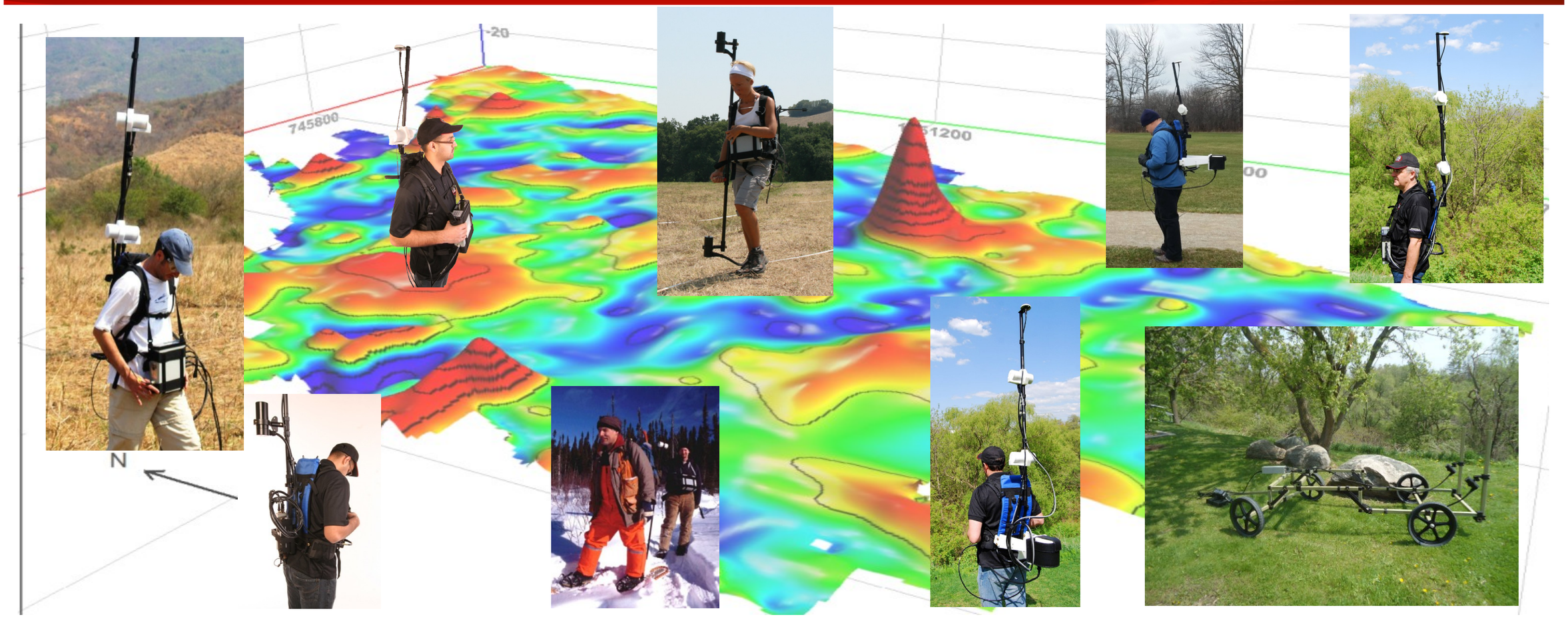
Leading the World of Magnetics

35 Years

Innovation

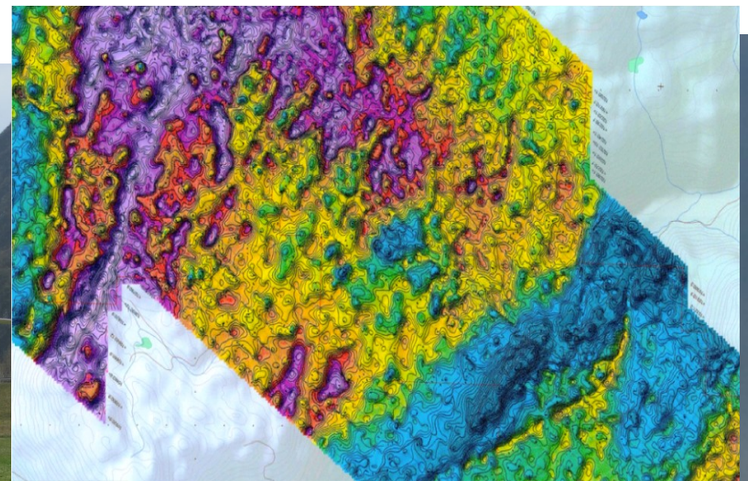
Reliability

GROUND SOLUTIONS

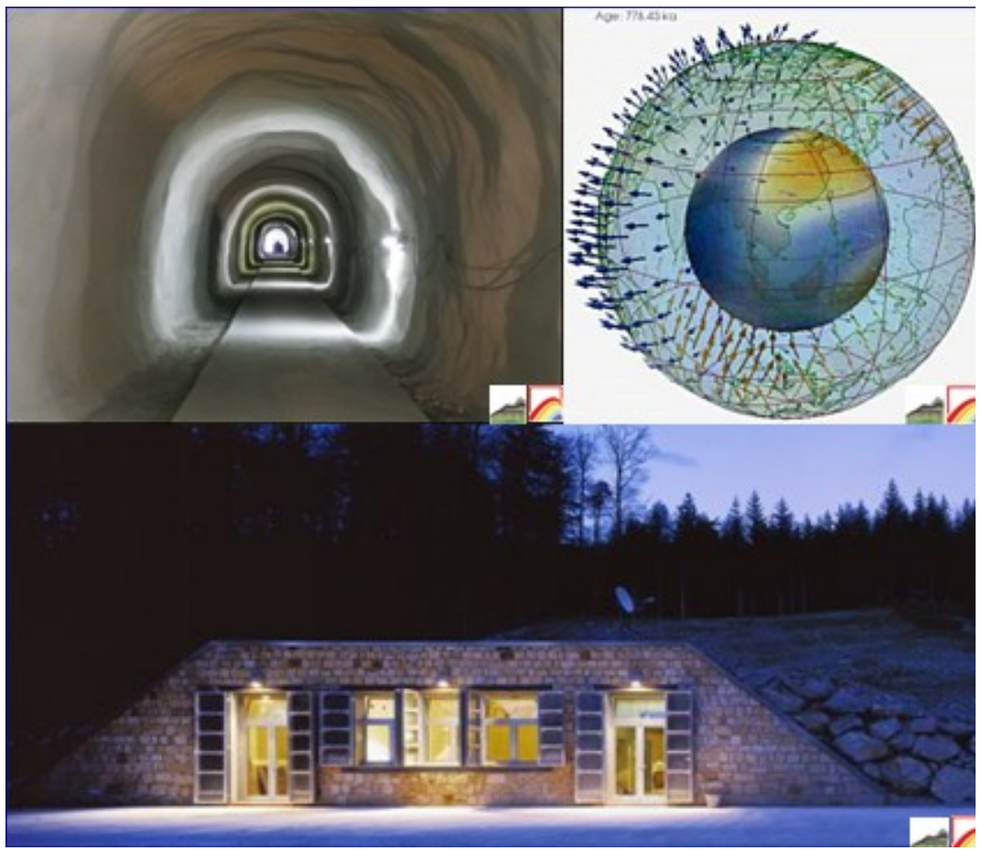


Our World is Magnetics

AIRBORNE SOLUTIONS



MONITORING SOLUTIONS



GEM SUPER-GRADIOMETER

- **Solid Earth Physics Research**
- **High Precision**
- **Long term large gradient monitoring system**

MONITORING SOLUTIONS

Overhauser Observatory Standard

GEM EUROMAG GSM-90 (Monitoring)

- **High Precision**
- **Long term monitoring system**
- Sensitivity .022nT@1Hz
- Resolution .01nT
- Absolute Accuracy +/- .1nT
- Available Sensitivity .015nT@1Hz
- Offered in **GSM-90PRO** model

Potassium Magnetometer

High Precision

- **GEM GSMP-35 (Magnetometer)**
- **GEM GSMP-35G (Gradiometer)**
- Sensitivity .0003nT@1Hz
- (Available with High Field option and with high sampling speed 20Hz and higher)

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