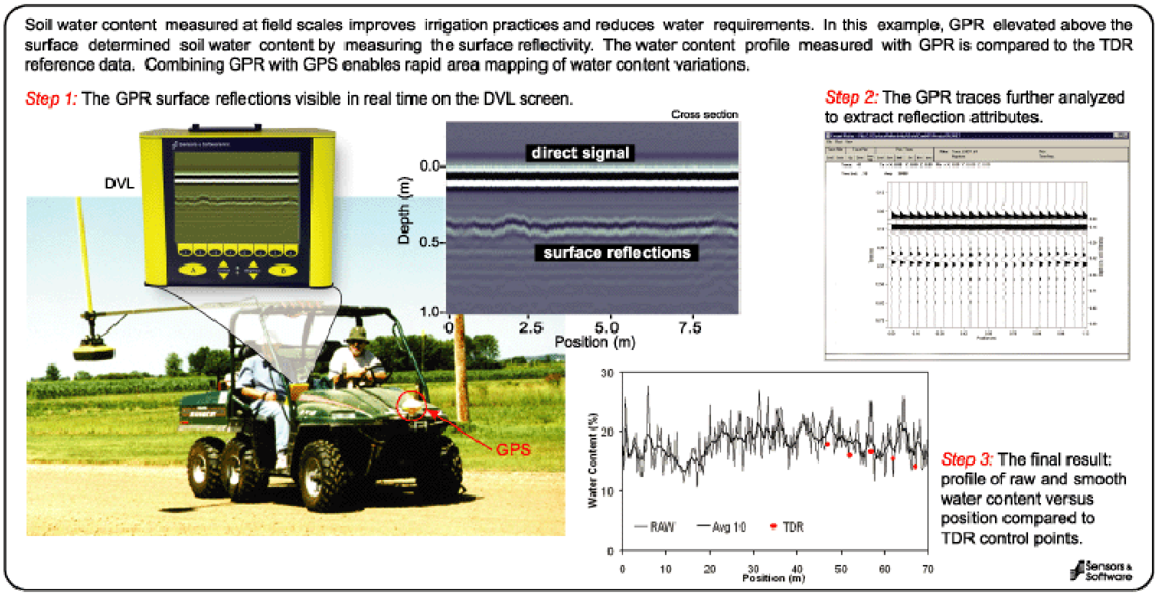
E4 : Applications of ground-penetrating radar

E4.1 Geotechnical and environmental applications of GPR

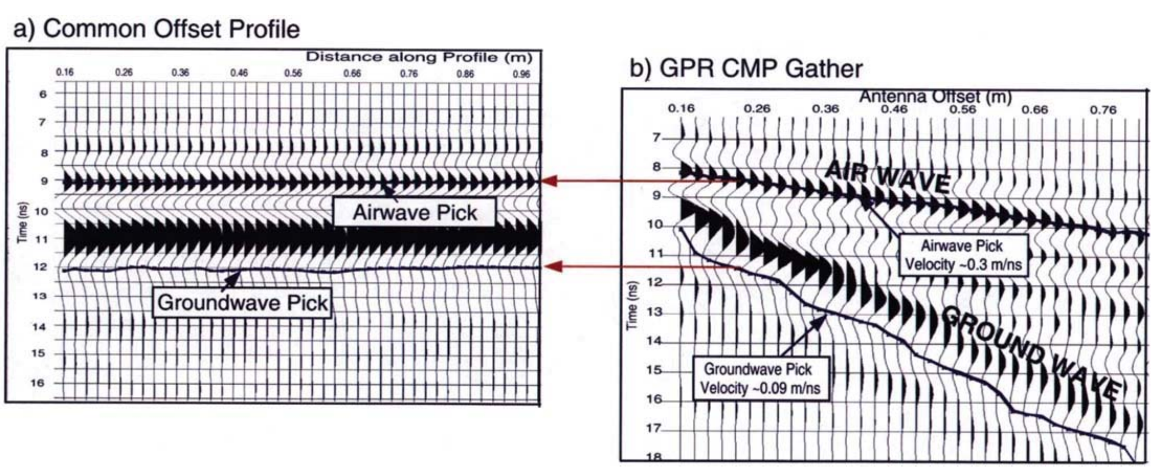
The following examples of GPR data are from http://www.sensoft.ca
Sensors and Software Ltd. are thanked for permission to use these figures.

E4.1.1 Soil water content

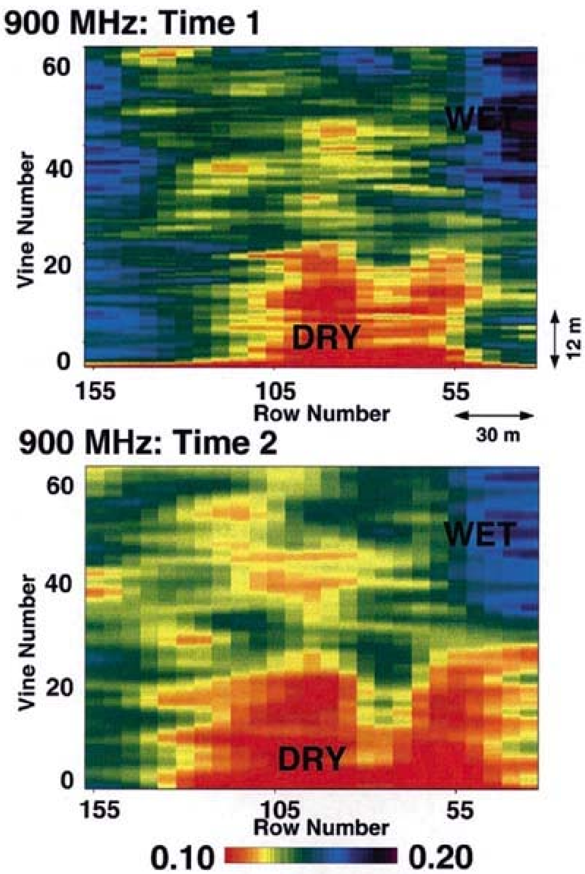


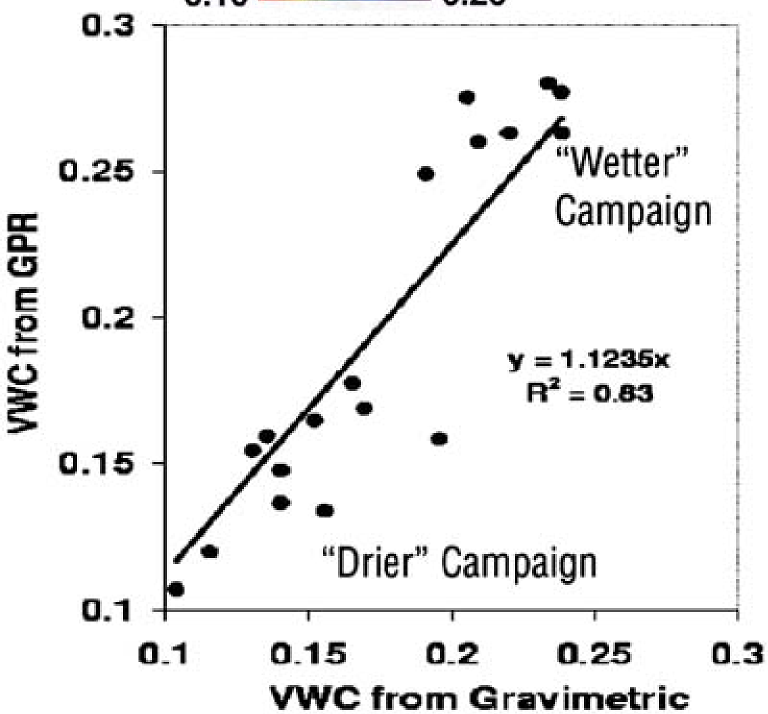
From http://www.sensoft.ca/applications/geotech/geotech.html

Soil water content of a California vineyard



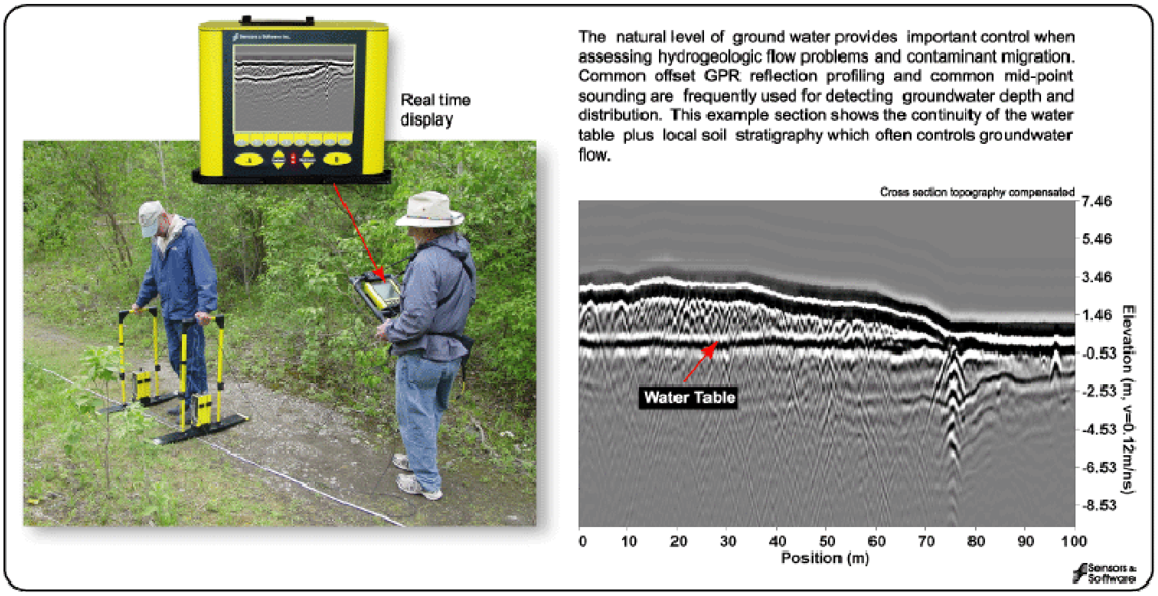
- Velocity of the ground wave decreases as the water content of the soil increases. This allows for non-invasive mapping in locations such as in a vineyard.





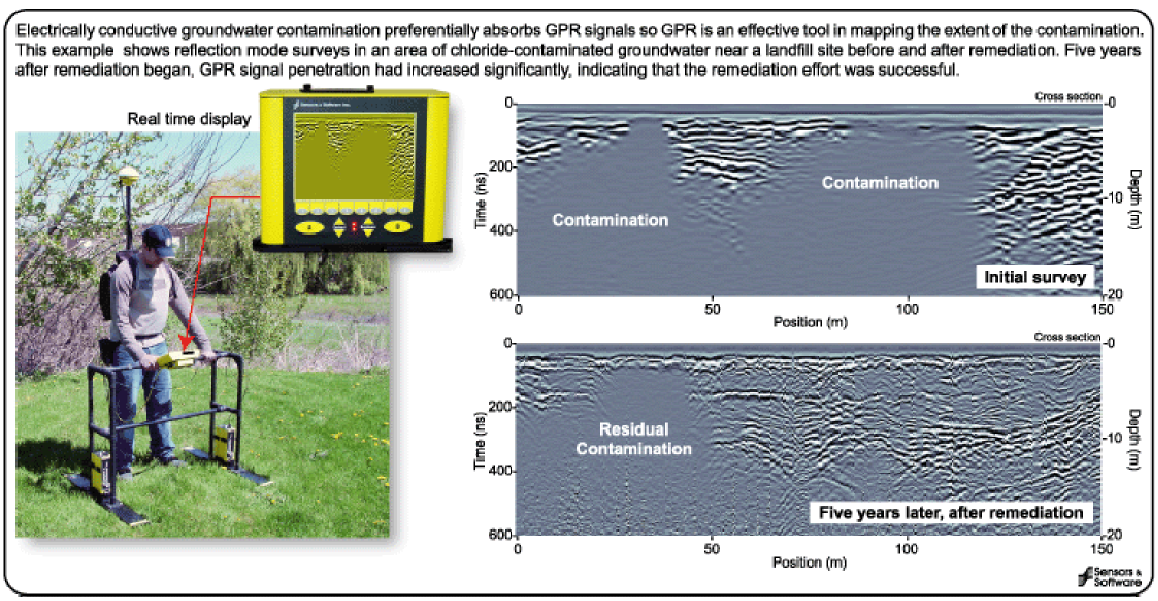
- The radar measurements give good agreement with other methods of measuring soil-water content. Details in Hubbard et al., The Leading Edge, (2002)

E4.1.2 Water table depth



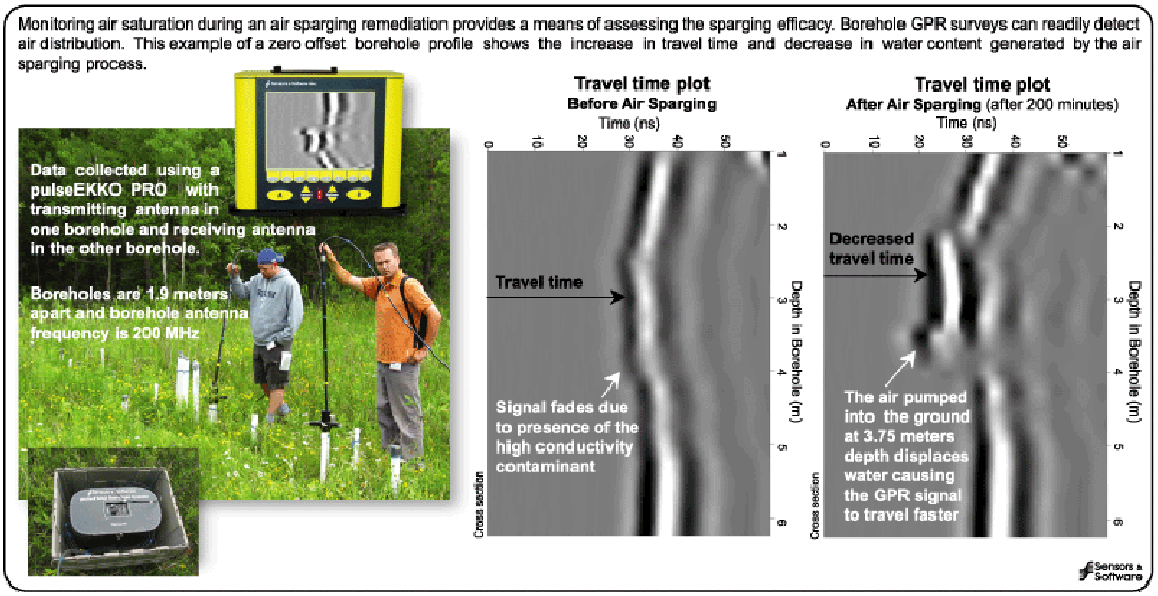
From http://www.sensoft.ca/applications/geotech/geotech.html

E4.1.3 Contaminant mapping



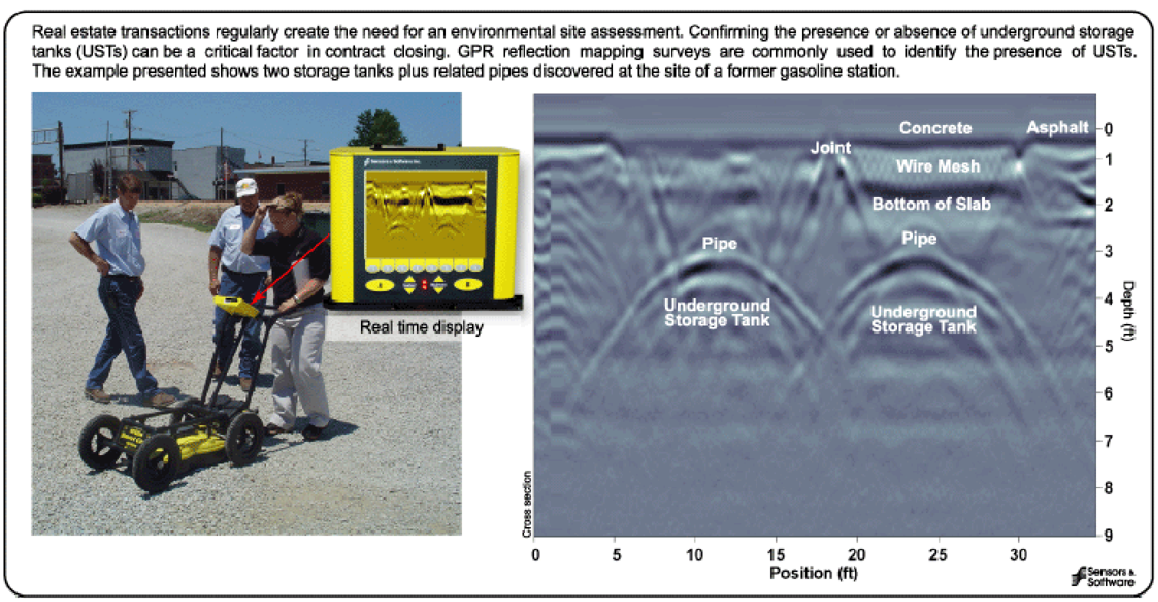
From http://www.sensoft.ca/applications/geotech/geotech.html

E4.1.4 Contaminant remediation



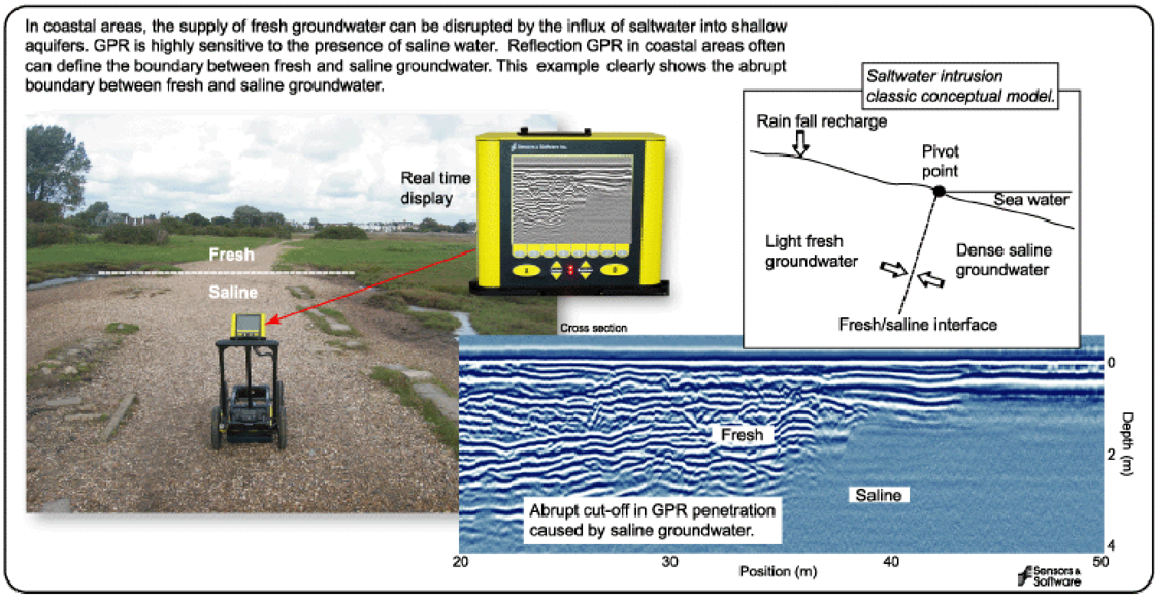
From http://www.sensoft.ca/applications/geotech/geotech.html

E4.1.5 Underground storage tanks



From http://www.sensoft.ca/applications/geotech/geotech.html

E4.1.6 Saltwater intrusion



From http://www.sensoft.ca/applications/geotech/geotech.html

E4.1.7 Depth to bedrock

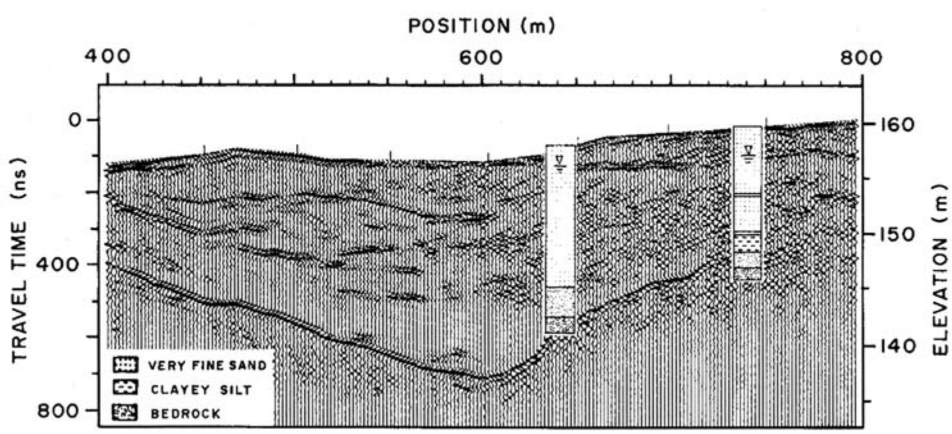
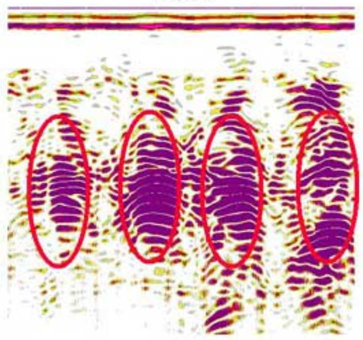


FIG. 12. The same profile as Fig. 11 but with increased gain. The reflections in the sand are from silt and clay layers.

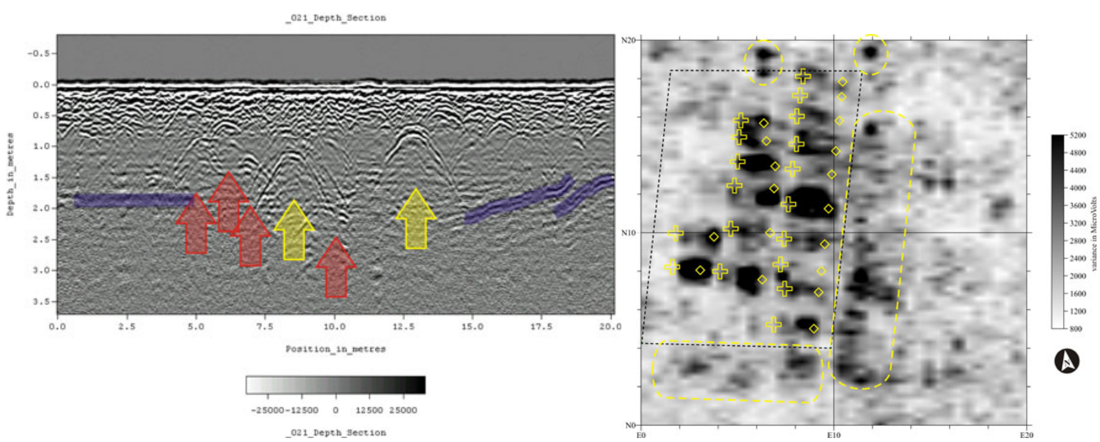
From Davis and Annan, *Geophysical Prospecting*, (1989)

E4.2 Archaeology

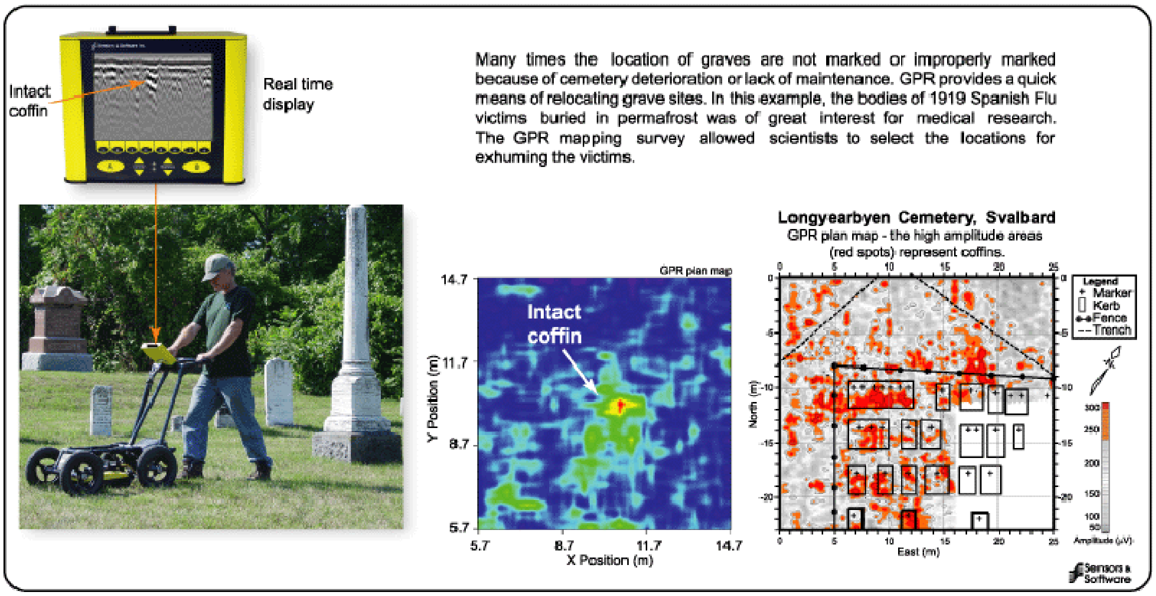
Example of Radar data showing historic burial sites



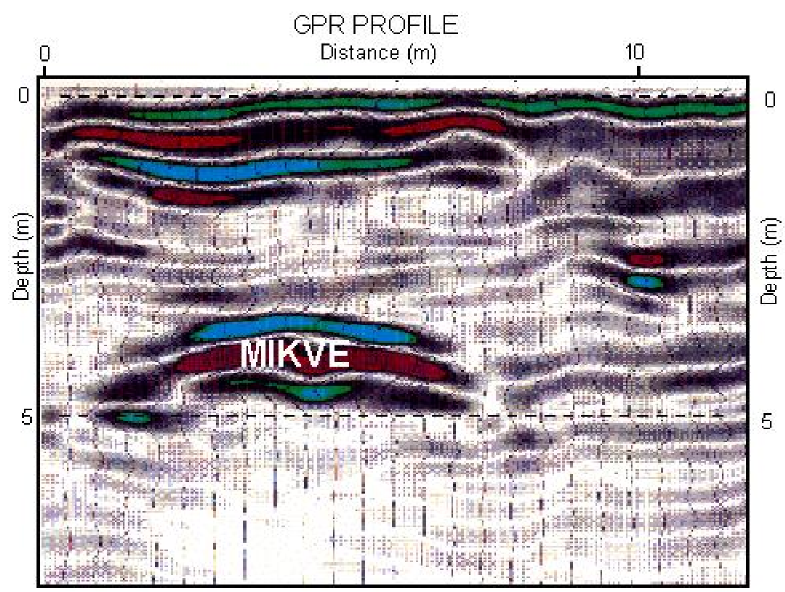
http://www.geosurvey.co.nz/cases.html



http://www.sha.org/publications/technical_briefs/volume03/article04.htm



http://www.sensoft.ca/applications/forensics/forensics.html

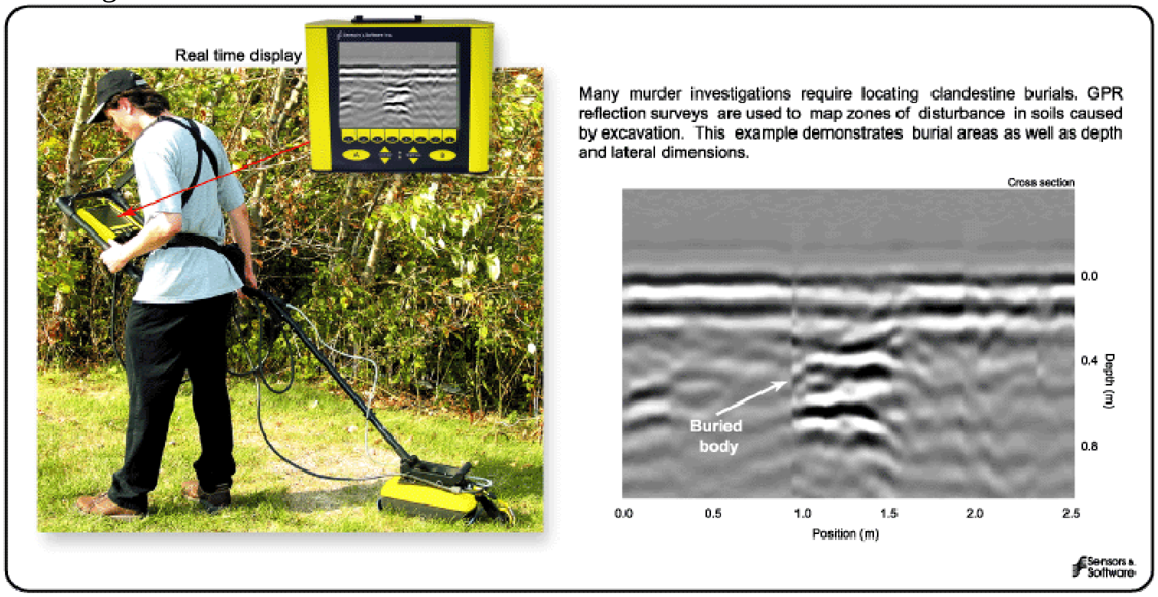


http://www.geo-sense.com/GPR.htm

- Detection of an archaeological cave in the Biblical city of Nysa (Shomron, Israel) using a GPR survey, from the time of Joshua Bin-Nun (around 1300 BC). This cave is known as the "Mikve" of the city.

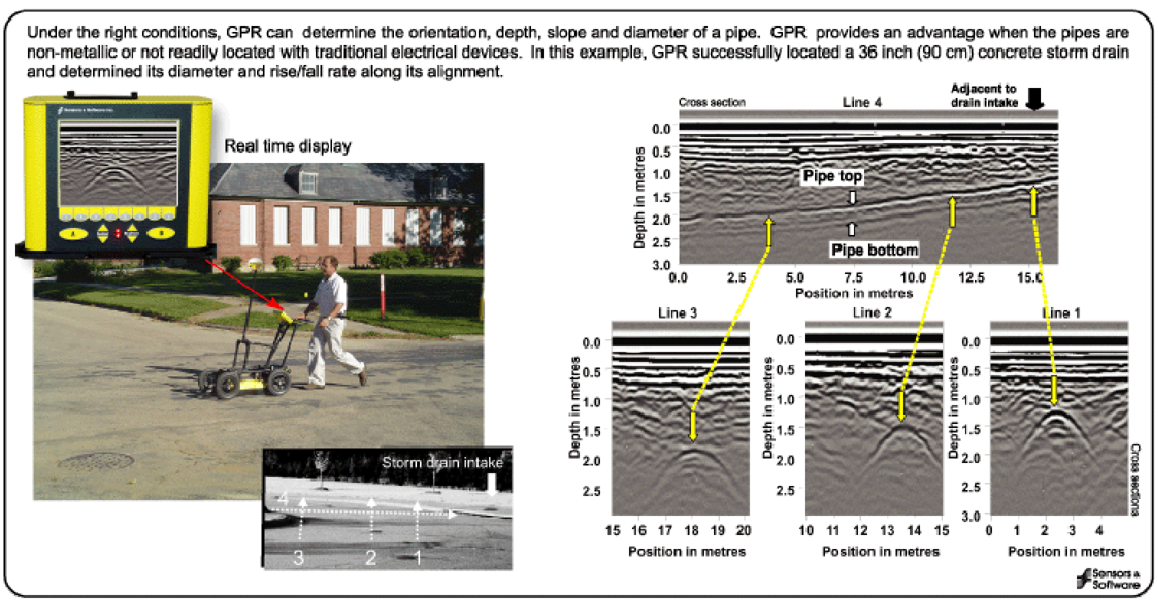
E4.3 Forensics

Locating clandestine burials



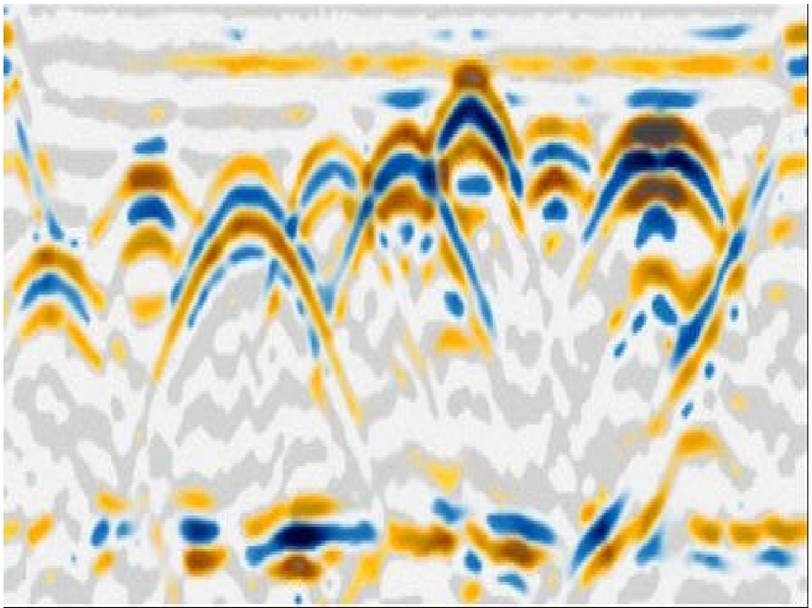
http://www.sensoft.ca/applications/forensics/forensics.html

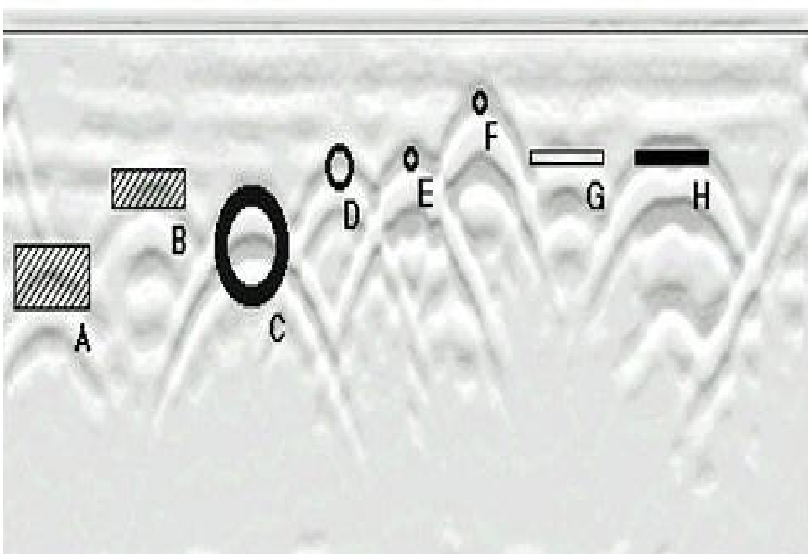
E4.4 Concrete and rebar



From http://www.sensoft.ca/applications/structure/structure.html

E4.5 Location of buried utilities





http://www.accuratedetection.com/products/easy_locator.html

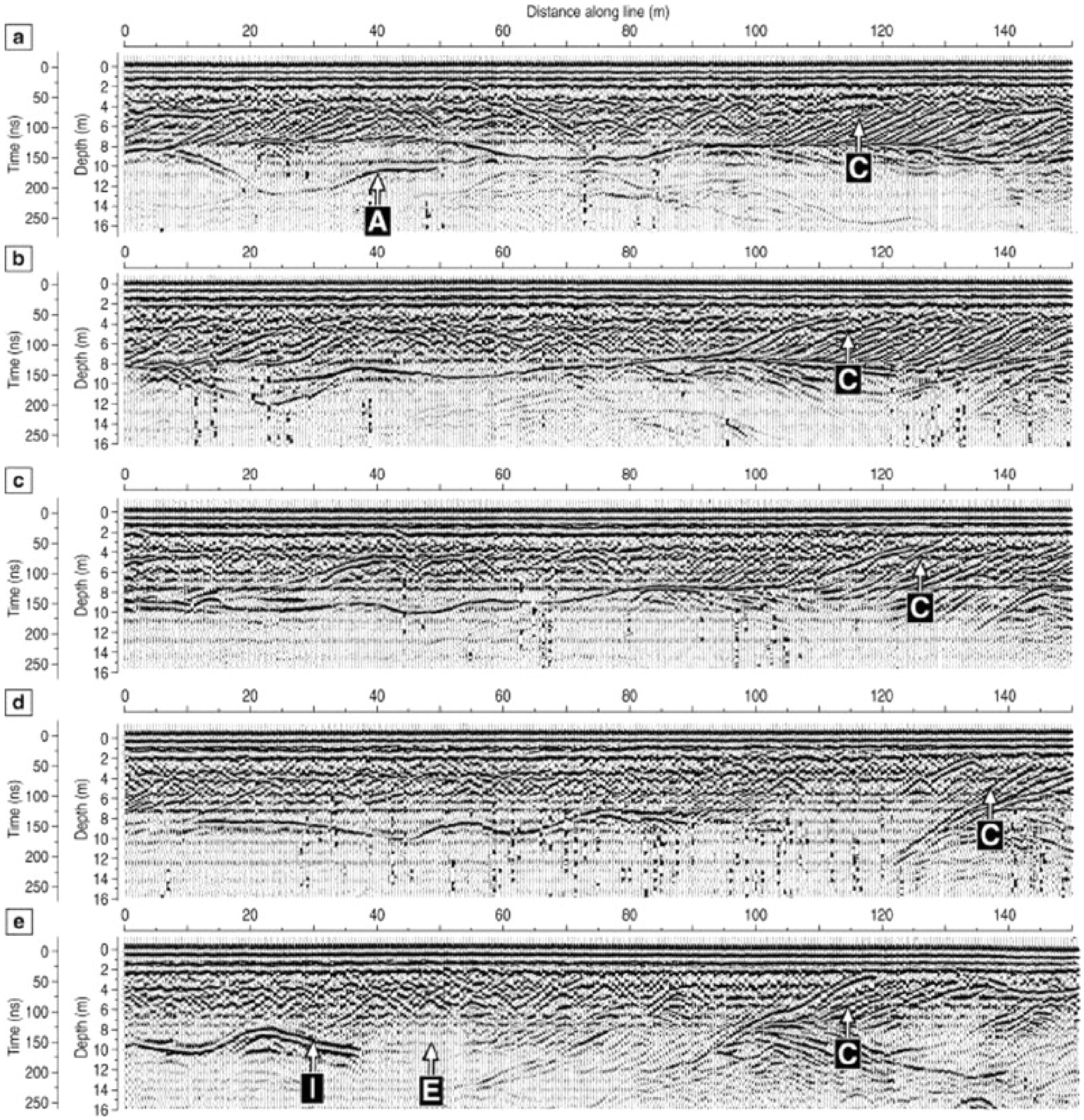
E4.6 Military applications

Applications include landmine clearance, unexploded ordinance detection and location of clandestine tunnels and bunkers.

http://www.sensoft.ca/applications/security/security.html

E4.7 Sedimentology

http://www.see.leeds.ac.uk/research/igs/seddies/best/jamunabar.htm



Real time studies of sedimentation in a gravel bar in Bangladesh from Best et al., (2003)

E4.8 Mining

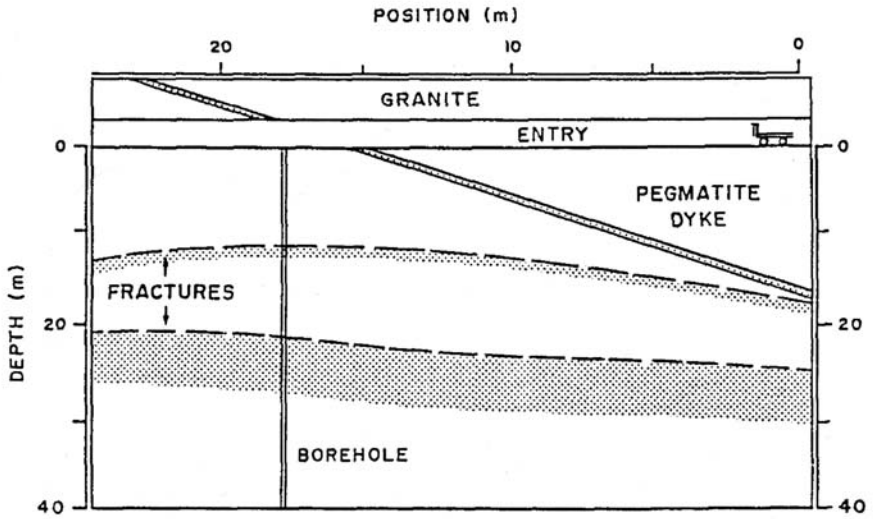


FIG. 14. A geological section along the survey line in Fig. 13 as derived from visual observations, borehole core logs and shaft excavation data.

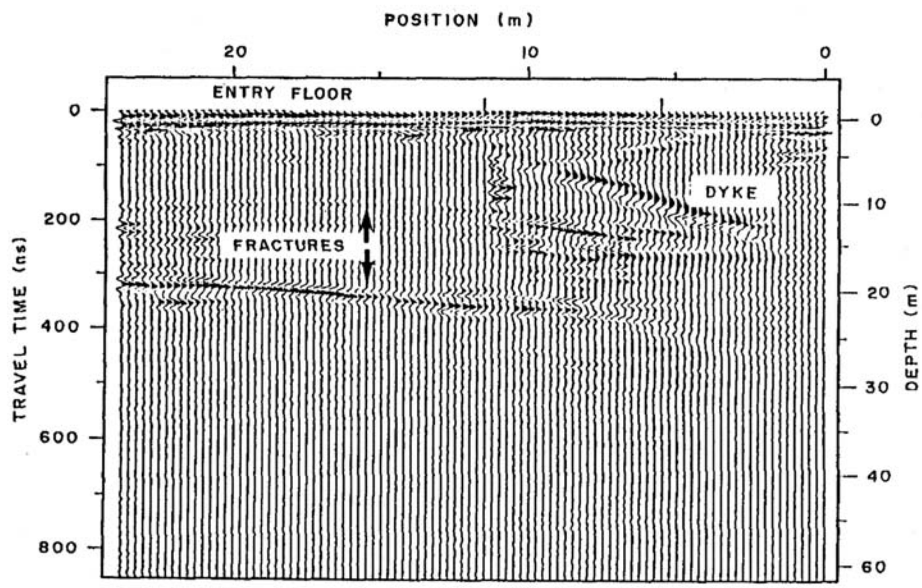


FIG. 13. A pulseEKKO III radar record obtained in a tunnel in granite.

- Example from Davis and Annan (1989) of GPR data collected in a mine.
- Fractures can be identified, as well as a dyke.

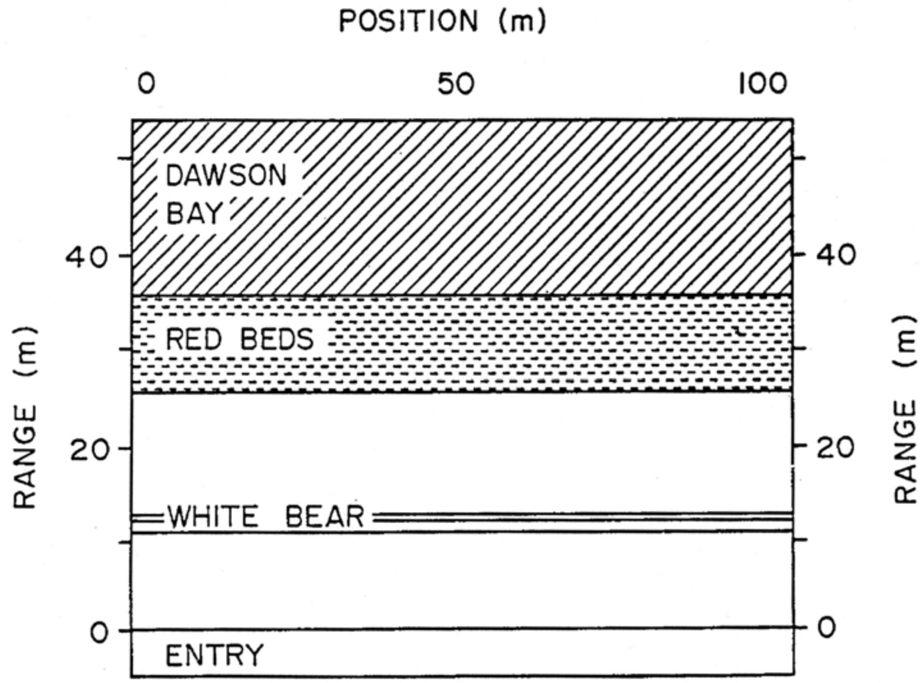


FIG. 15. A geological section above a potash mine based on borehole logs.

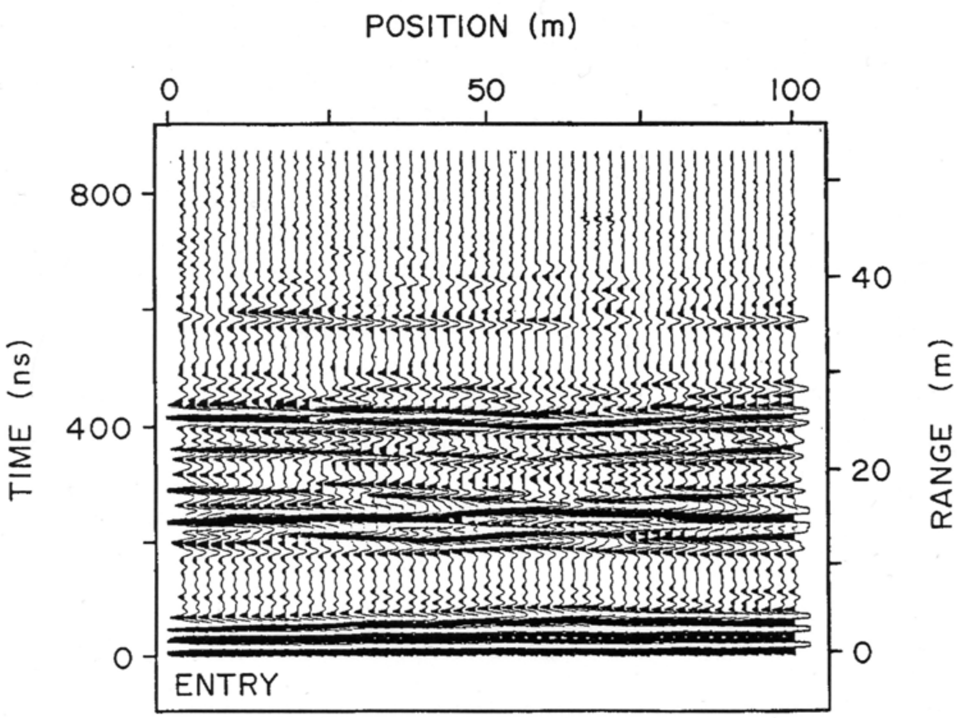


FIG. 16. A pulseEKKO III radar record obtained in the potash mine shown in Fig. 15.

- GPR Data collected in a potash mine

E4.9 Glaciology

E4.9.1 Measuring ice thickness and bedrock topography

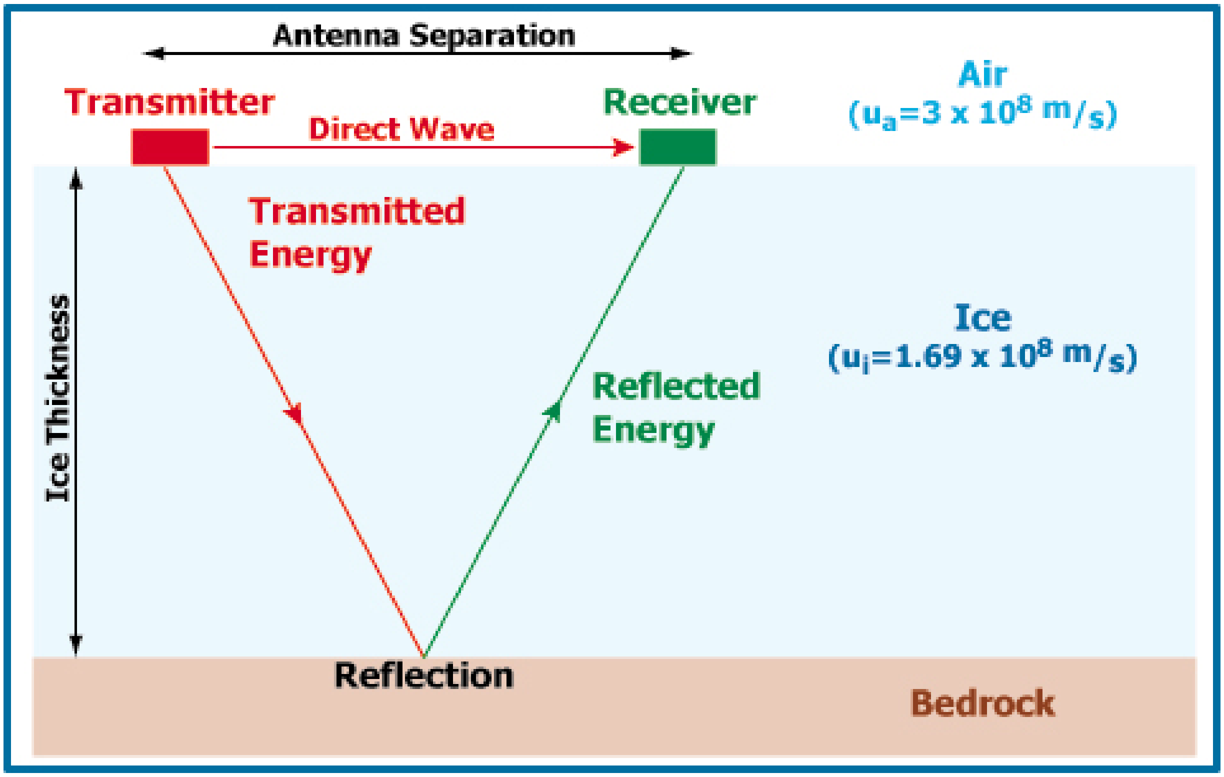
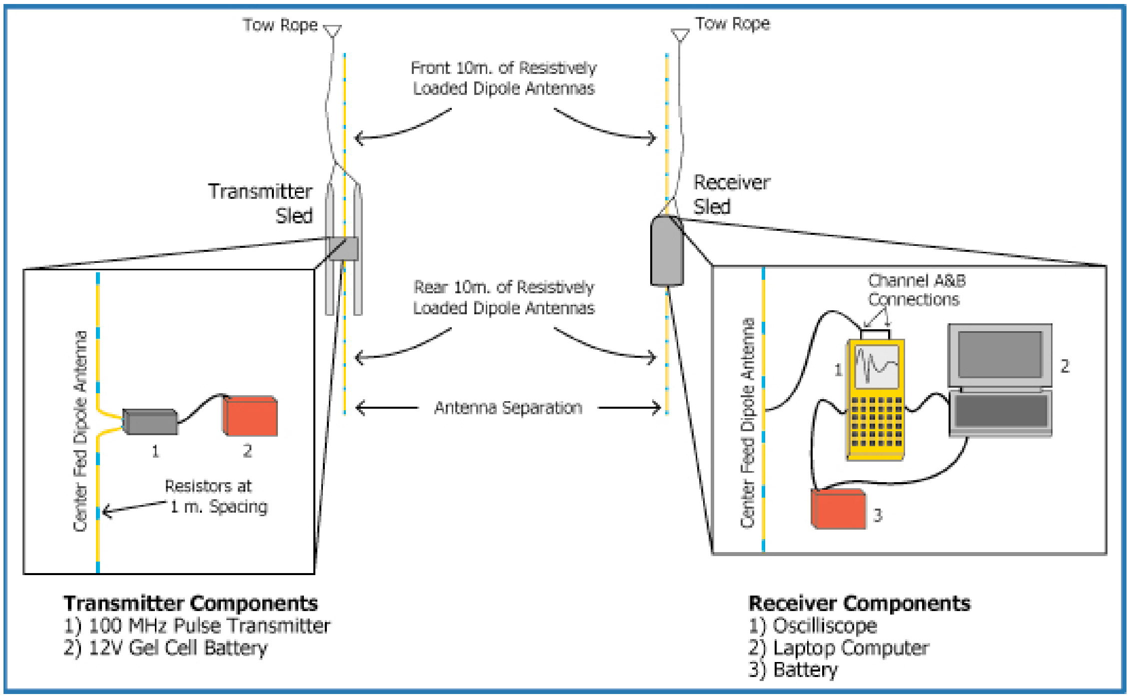
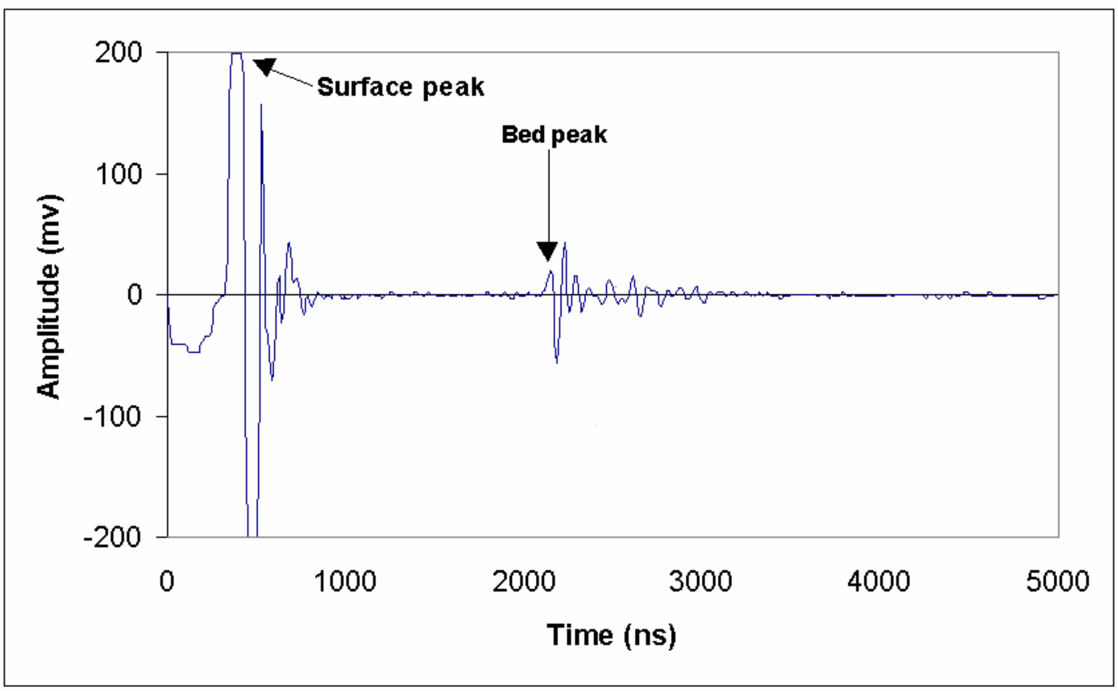


Figure from Martin Sharp (EAS)

Problems:

- off-nadir returns (migration), internal reflections, scattering from crevasses, absorption by water
- Resolution/penetration trade-off in frequency selection
- Map internal reflectors, bed reflection power as indicators of thermal structure





Figures from Martin Sharp (EAS)

No. 4956 October 24, 1964 NATURE 317

RADIO ECHO SOUNDING THROUGH AN ICE SHELF

By M. E. R. WALFORD

British Antarctic Survey and Scott Polar Research Institute, Cambridge

IN December 1963 a tractor journey of 200 miles was made on the Brunt Ice Shelf from the British Antarctic Survey base at Halley Bay (Base *Z*, 75° 31′ S., 26° 40′ W.) and some unexpected results were obtained with a radar instrument developed for the penetration of polar ice masses. They seem to be different from the observations made by Waite (private communication) with a higher frequency apparatus on the Ross Ice Shelf. The techniques have been described by Evans[1] and the important parameters of the present apparatus are given in Table 1.

The range of a radar target is indicated by the echo delay-time, with an accuracy determined mainly by the rise time of the receiver. The shortest measurable range is limited by the recovery time of the receiver after the transmitter pulse and in practice, by echoes from nearby surfaces, probably stratifications in the snow. The aerials can be seen in Fig. 1: they transmit and receive most power in their equatorial plane, which includes the vertical and the direction of travel. Due to refraction, the sensitivity in the ice is greatly reduced beyond 35° to the vertical. There is no other means provided

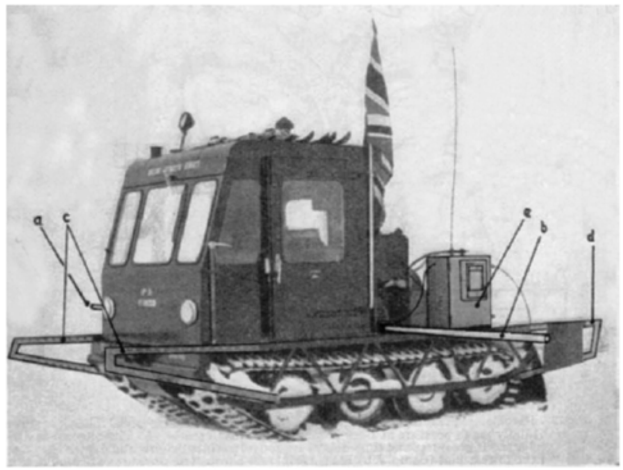


Fig. 1. Muskeg vehicle with separate unipole aerials (*a*, *b*) for transmission and reception. The 'Dexion' extensions (*c*, *d*), which increased the effective electrical length of the vehicle, were found necessary to reduce the direct coupling between transmitting and receiving aerials and to provide correct electrical loading. The box (*e*) contains the electronic equipment except for a display unit mounted in the vehicle cab

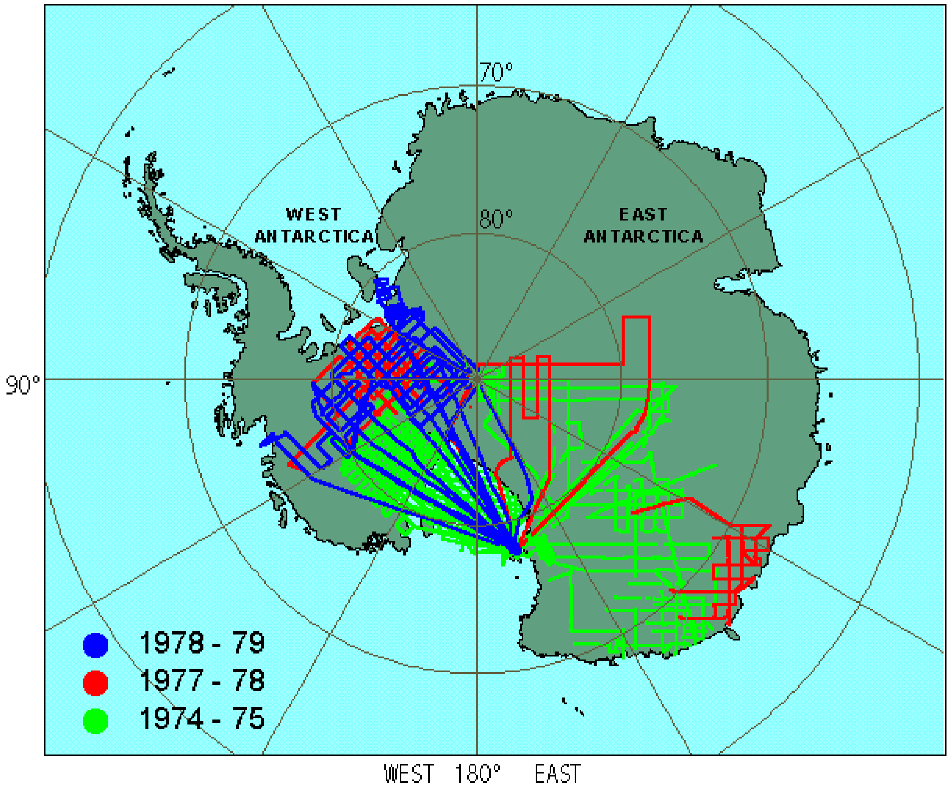
Photos from Martin Sharp and Jeff Kavanaugh (EAS)

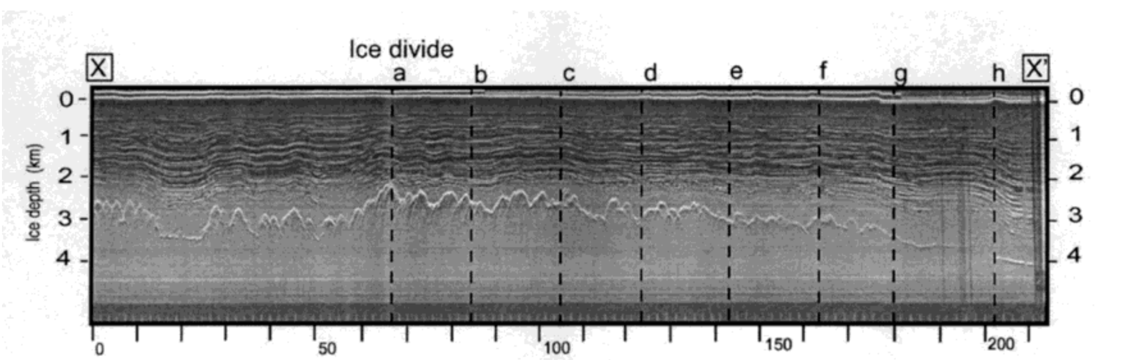
Antarctica

- One of the first applications of radar for measuring ice thickness was described by Walford (1964). Also called radio-echo sounding (RES). Radio waves travel at 0.168 m/ns. General review of radar applications in glaciology given by Plewes and Hubbard (2001).

- Extensive data base collected in Antarctica in the 1960's and 1970s using airborne radar system. More than 400,000 km of profile data collected Scott Polar Research Institute, NSF and Technical University of Denmark.

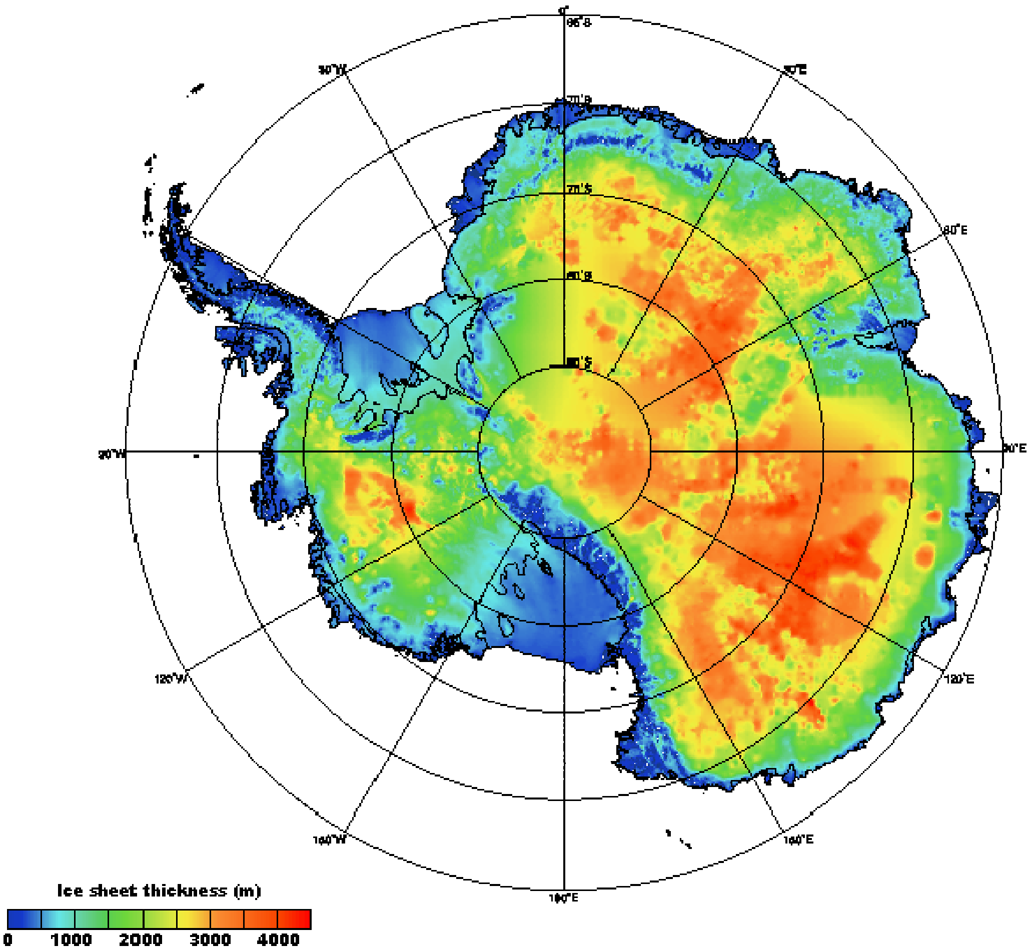
- Figures below are from http://www.bgc.bris.ac.uk/research/RES



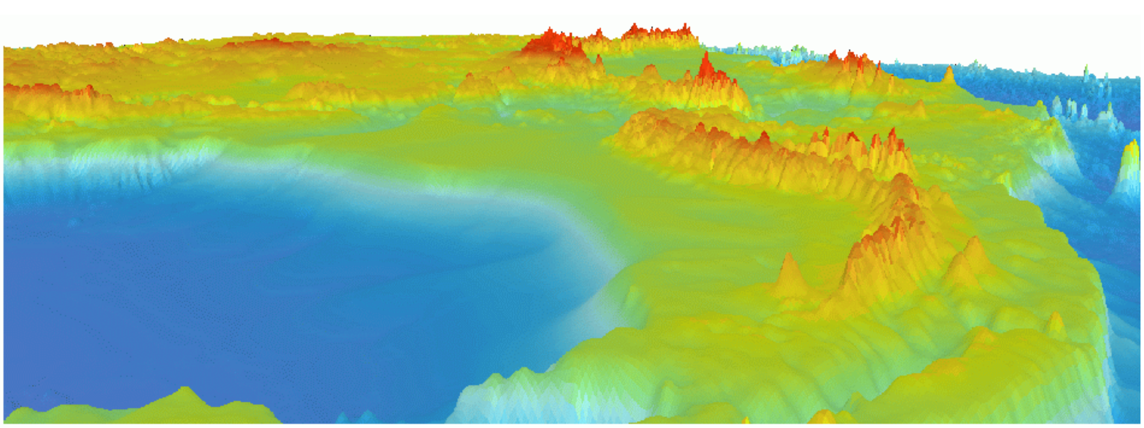


- Recent compilation of ice thickness data in the BEDMAP project

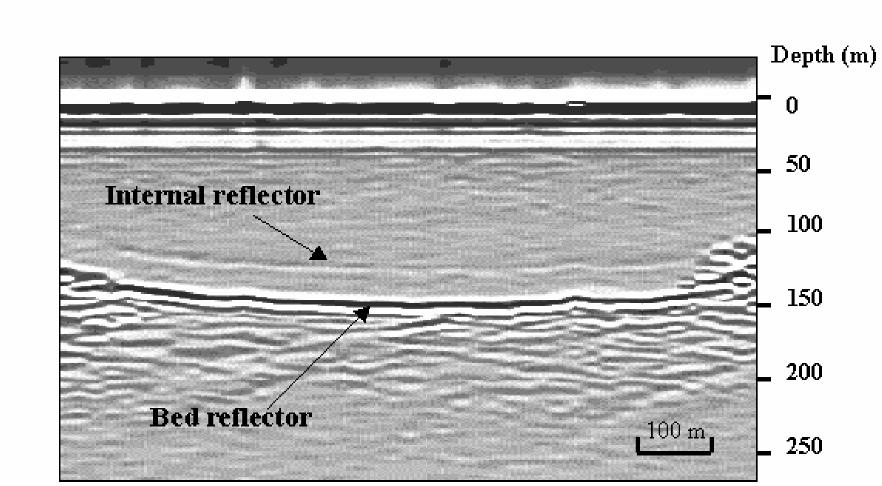
http://www.antarctica.ac.uk//bas_research/data/access/bedmap/



http://www.antarctica.ac.uk//bas_research/data/access/bedmap/



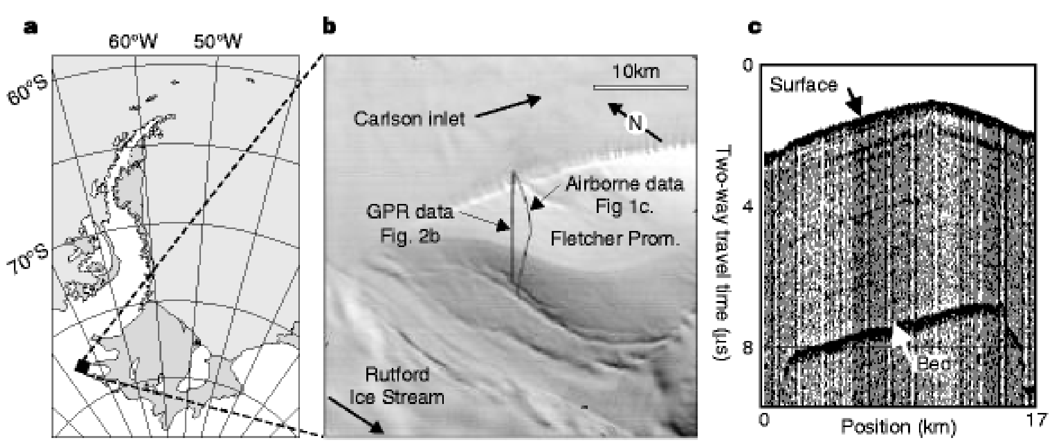
Canadian Arctic

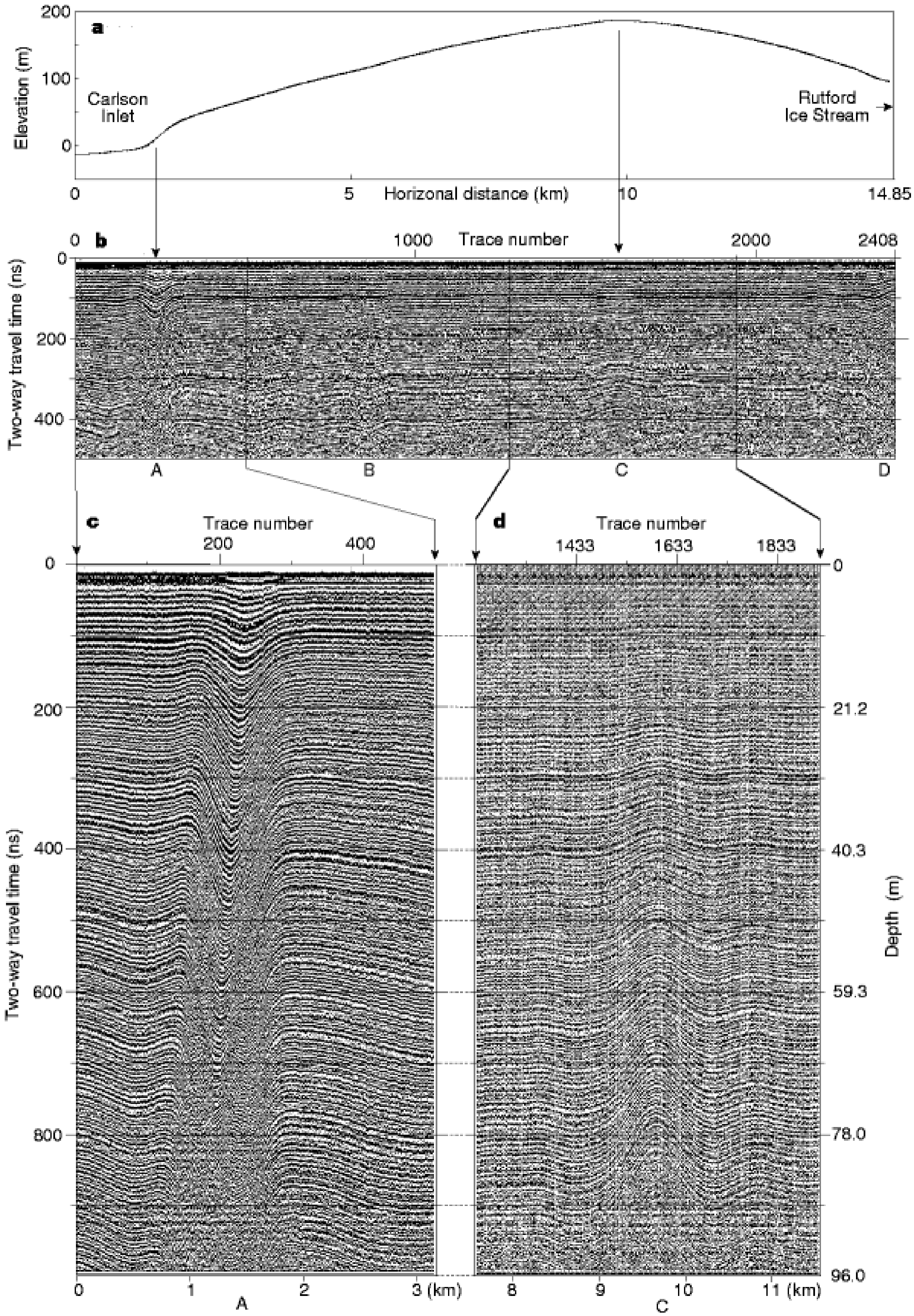


- Radar section from John Evans Glacier, Ellesmere Island. For details see Copland and Sharp (2001).
- Measuring ice thickness can confirm space geodetic studies of glacier volume.

E4.9.2 Mapping internal structure of ice sheets and glaciers.

- Internal reflections believed to be due to isochronous layers. Layers of dust from volcanic eruptions can give strong reflections. Example below is taken from the Fletcher Promontory, Antarctica and the undulations in the isochronous layers are not correlated with bedrock topography (Vaughan et al., 1999). One feature occurs at an ice divide and reflects non-linear rheology of ice.
- Mapping this internal structure helps with interpretation of ice core data. The internal reflections can also used to understand flow pattern of glacier.





Vaughan et al., *Nature*, (1999)

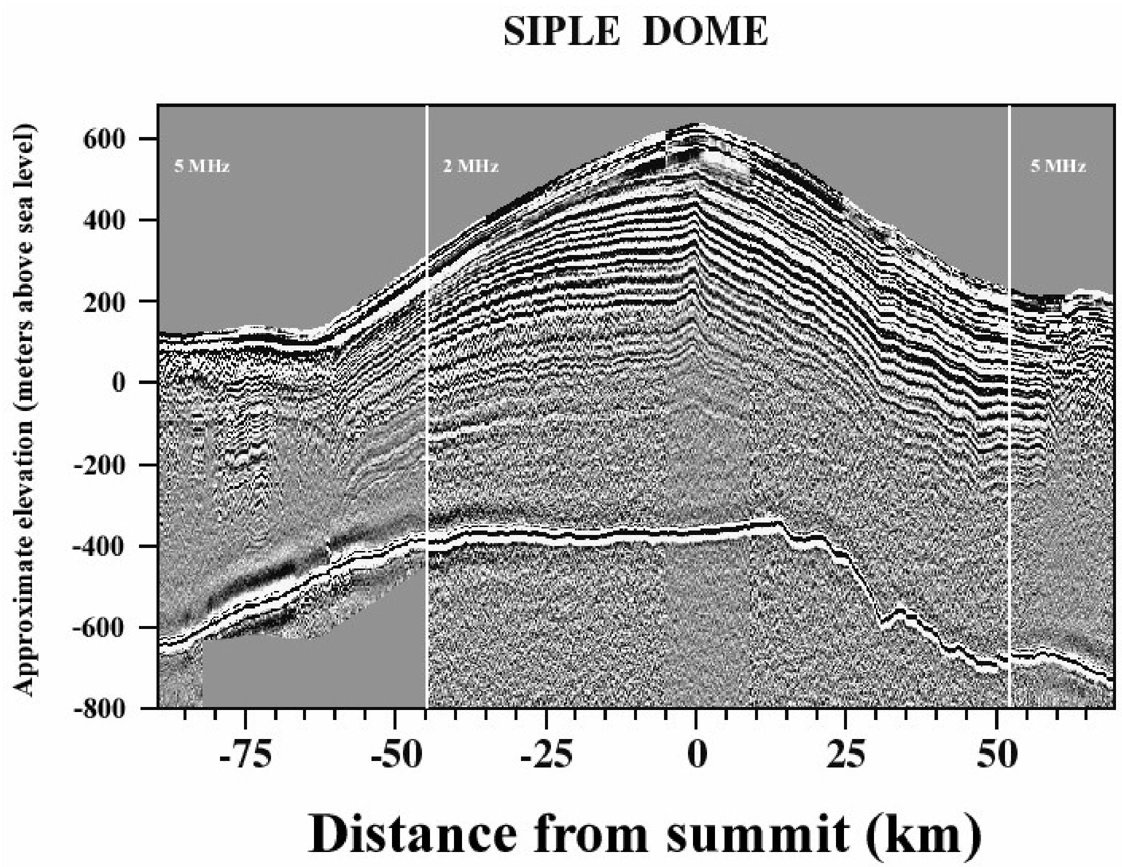


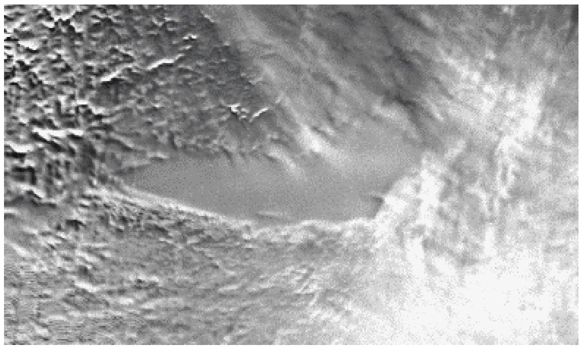
Figure from Martin Sharp (EAS)

- Local-scale snow accumulation variability on the Greenland ice sheet from ground-penetrating radar (GPR)
  http://cires.colorado.edu/~maurerj/gpr/gpr_cryosphere.html

E4.9.3 Determine basal conditions

- Sub-glacial lakes first identified on the basis of character of a flat basal reflection, and flat ice surface. http://www.bgc.bris.ac.uk/research/RES/RES/4_subg.html

  Lake Vostock was detected from both airborne and satellite radar.



  More information http://earthsci.org/education/Lake_Vostok/vostok.html

  Animation : http://www.earthinstitute.columbia.edu/news/vostok/vostok.swf

- Elsewhere the amplitude of the basal reflection can be used to study the composition of sub-glacial sediments. Reflections from a frozen base or one containing free water are quite different. This parameter is important for understanding how easily the glacier or ice sheet can move.

- For examples see Holt et al., (2006) who used airborne radar to infer that the bed of the Taylor Glacier is frozen.

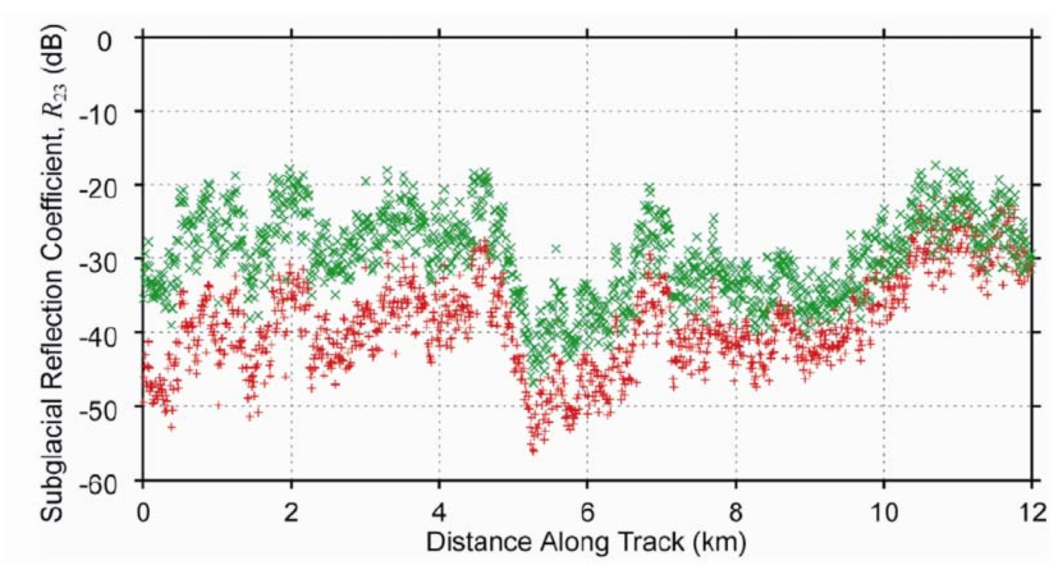


Table 1. Dielectric constant and subglacial reflection coefficient for materials hypothesized to occur beneath glaciers.

Subglacial Material	ε_{r3}	R_{23} (dB)
Fresh Water (fw)	80	– 3
Rock	7	– 14
Unfrozen Till (40% fw)	24	– 7
Frozen Till (40% ice)	5.2	– 18

E4.10 References

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Winebrenner, D.P., B.E. Smith, G.A. Catania, H.B. Conway, and C.F. Raymond (2003), Radio-frequency attenuation between Siple Dome, West Antarctica, from wide-angle and profiling radar observations. *Annals of Glaciology*. 37: 226-232.