Improved Resolution of Tephra Deposits with Ground Penetrating Radar

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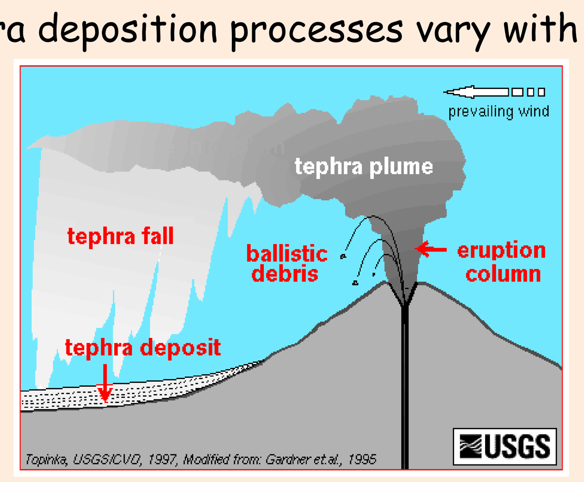
Abstract

Numerical simulation and inversion of high resolution data on tephra fallout deposits offers an opportunity to fundamentally improve our ability to estimate eruption parameters from deposits. Traditional trenching data is insufficient to adequately constrain eruption parameters. Ground penetrating radar (GPR) can change this by providing high resolution data along continuous transects, particularly where deposit thickness is too great to trench. In addition, real tephra deposits vary from ideal numerical solutions. Using traditional contouring techniques and few data, these real variations can be missed or masked in the interpretation process. Because inversion produces a best-fit solution, and a fit that is easily quantified, departures of the numerical model from the actual deposit can be readily identified. These departures between observations and simulations provide details about the physics of volcanic eruptions not captured by current models and provide clues about the limits of current models. This is crucial for understanding how to apply these models in tephra hazard forecasts. Because GPR transects provide an essentially continuous record of variation in the deposits, these data can have real impact on our analysis of tephra deposits, our simulations of volcanic eruptions using numerical methods, and our confidence in using such techniques to forecast volcanic eruptions. Studies on Cerro Negro, Nicaragua and Irazú, Costa Rica demonstrate that GPR is beautifully suited to imaging tephra blankets in both dry and wet environments. Surveys with 100 and 200 MHz antennas show clear reflectors within the tephra fallout sequence are imaged to 20 meters depth. In accord with trench data, we interpret the bright reflectors as weathered horizons (paleosols in some cases) and abrupt changes in grain size and porosity that mark intervals between eruptive events. On Cerro Negro, inversions for eruption parameters show excellent model fits to tephra volumes measured in trenches in medial and distal facies. However the same models show very poor fits to GPR-derived tephra thicknesses in areas close (wihtin 2 km) of the vent.

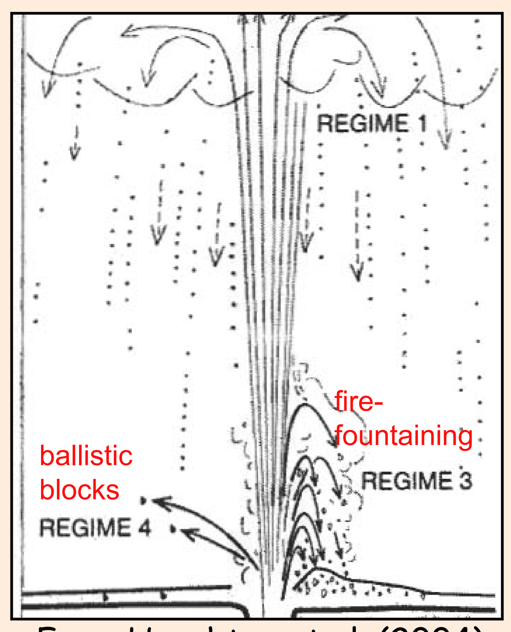
(1) The Problem

illustrated at **Cerro Negro, Nicaragua**. Cerro Negro is a small basaltic cinder cone that has erupted repeatedly since 1850.

- Improving tephra hazard estimates requires improved models of eruptions
- Tephra deposition processes vary with distance from the vent



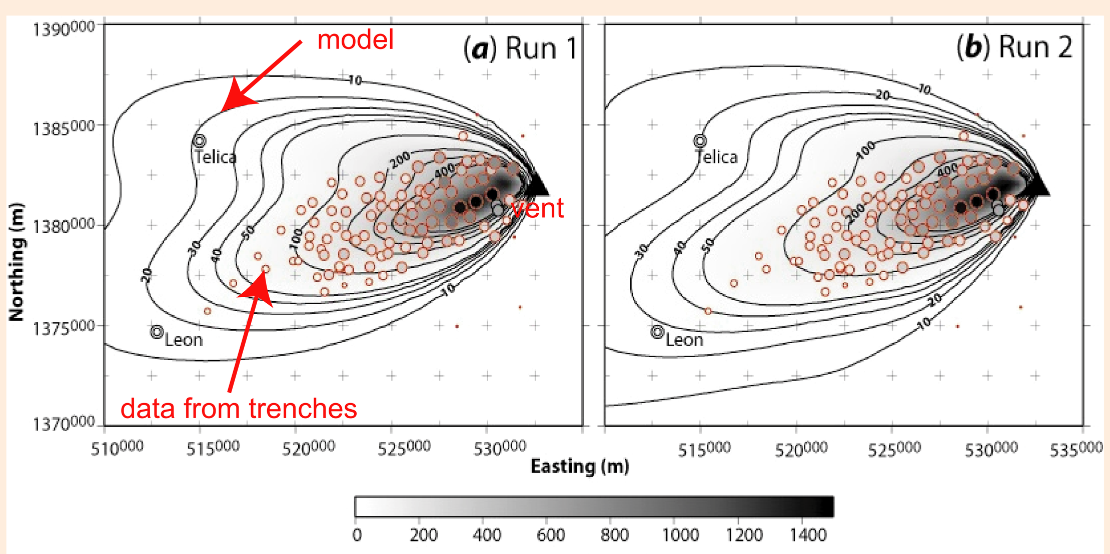
Near-vent sedimentation may be dominated by Houghton et al.'s regimes 3 and 4.



From Houghton et al. (2004).

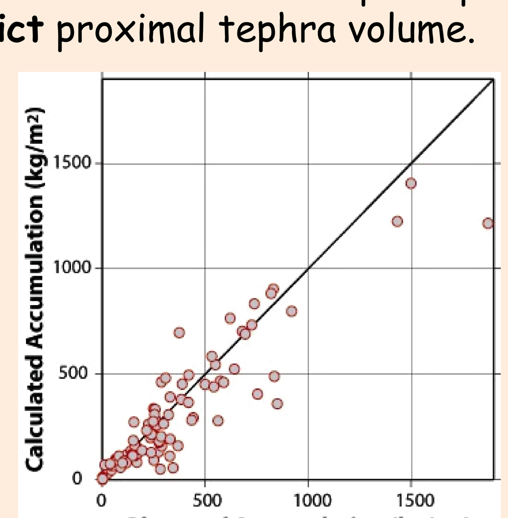
- So...tephra volumes from trenches in distal areas cannot be easily used to extrapolate deposition at proximal areas

In distal parts of the tephra blanket, deposits are thin enough to be trenched.



Best-fit isomass contours based on inversions of the 93 trench sample points of the 1992 tephra blanket. These models could be significantly improved with proximal data. From Connor and Connor (2005).

- Inverse models for eruption parameters based on medial and distal data **under-predict** proximal tephra volume.

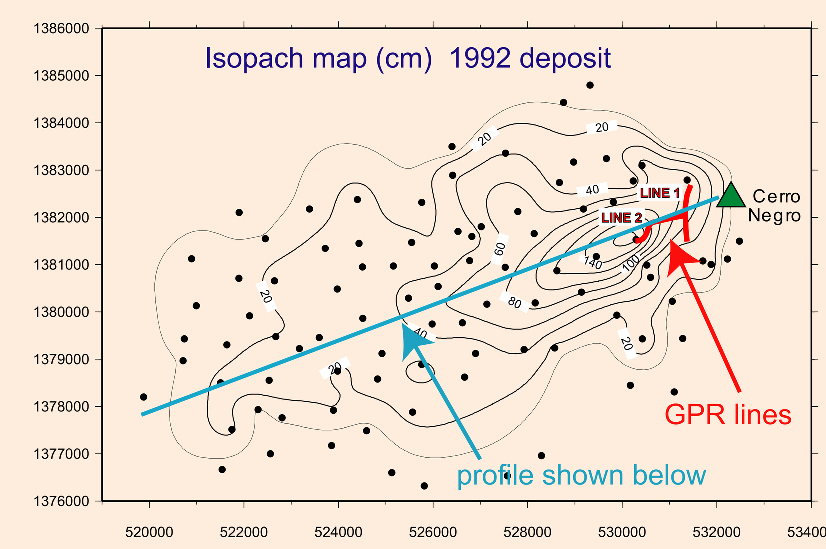


Observed tephra accumulation from the 1992 eruption at 93 Cerro Negro sites compared with calcualted value in numerican inversion. Although the fit is very good, thicker accumulations (upper right) are poorly repsented and hence under-weighted in the model.

- But observations in proximal areas are difficult to make because these deposits are rarely accessible and too thick to trench.

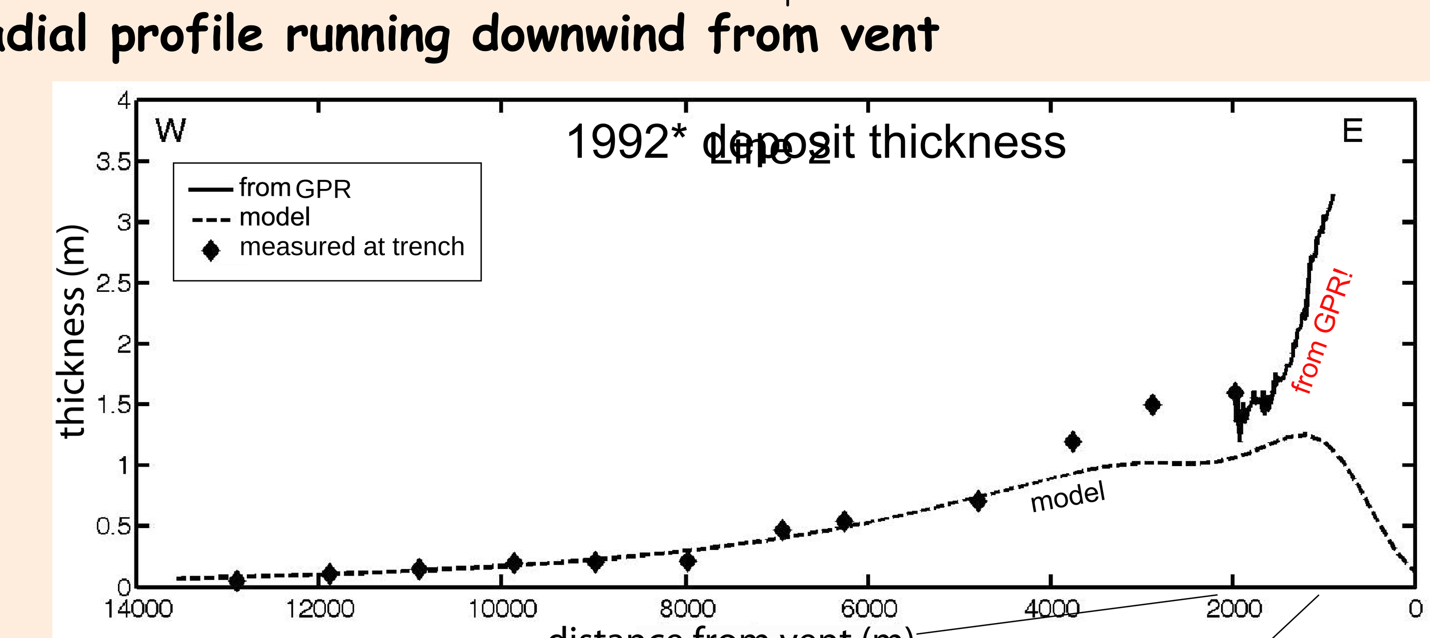
(2) Ground Penetrating Radar Profiles Can Fill This Data Gap

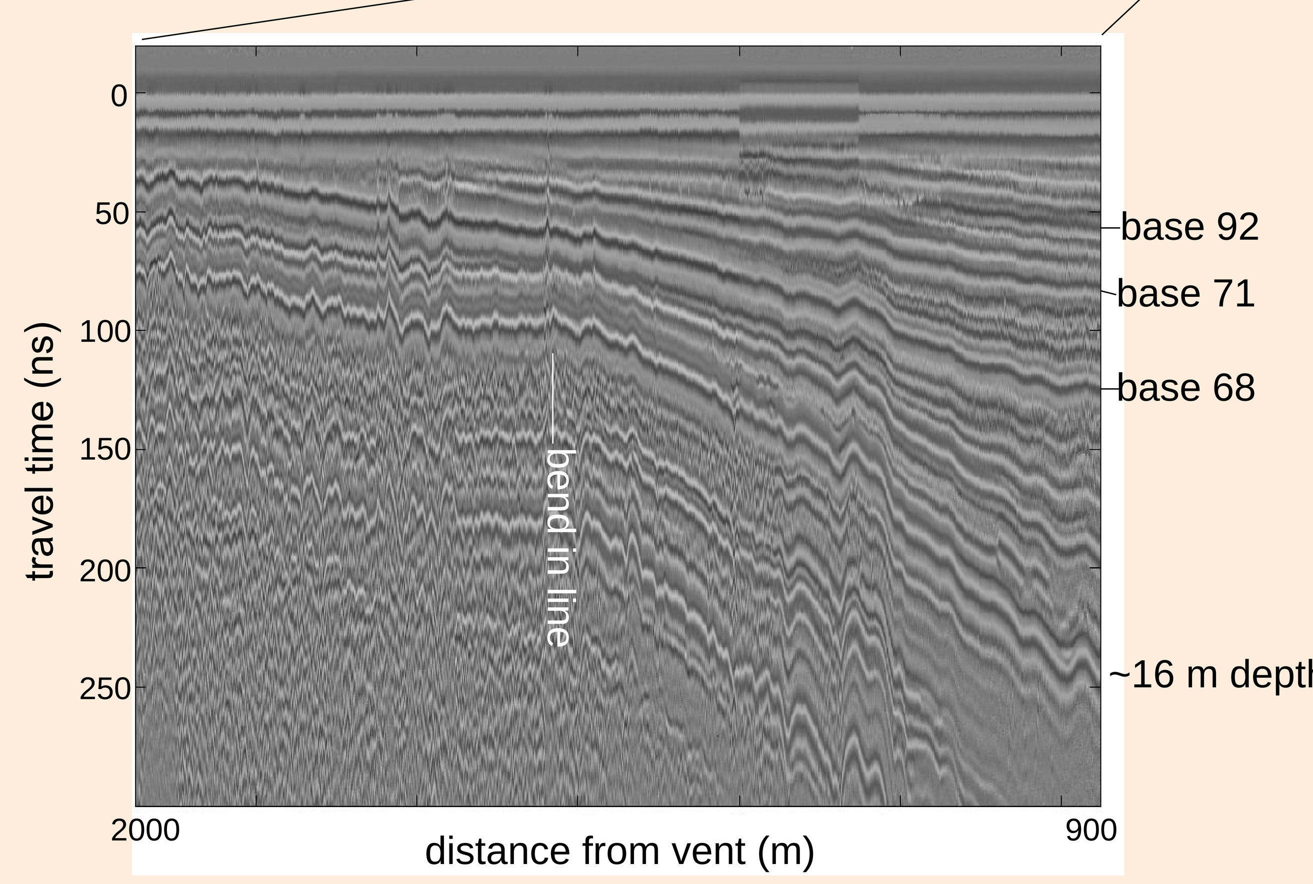
Pilot studies on several volcanoes show that GPR is an excellent tool for imaging tephra up to thicknesses of 20 meters or more.



GPR surveys were run across proximal parts of the Cerro Negro tephra deposits. Line locations shown in red at left. Dots on figure at left show trench sites, lines are tephra thickness (cm) contours for the deposits from the 1992 eruption.

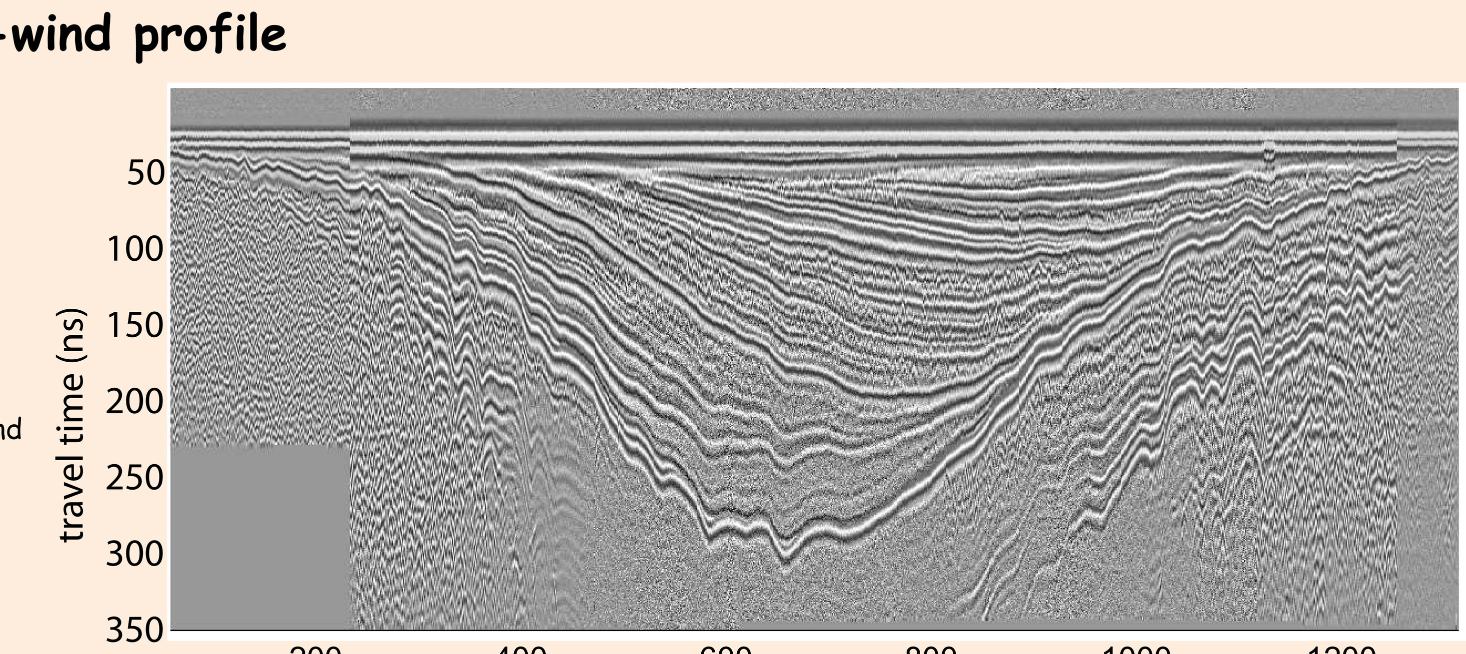
- **radial profile running downwind from vent**



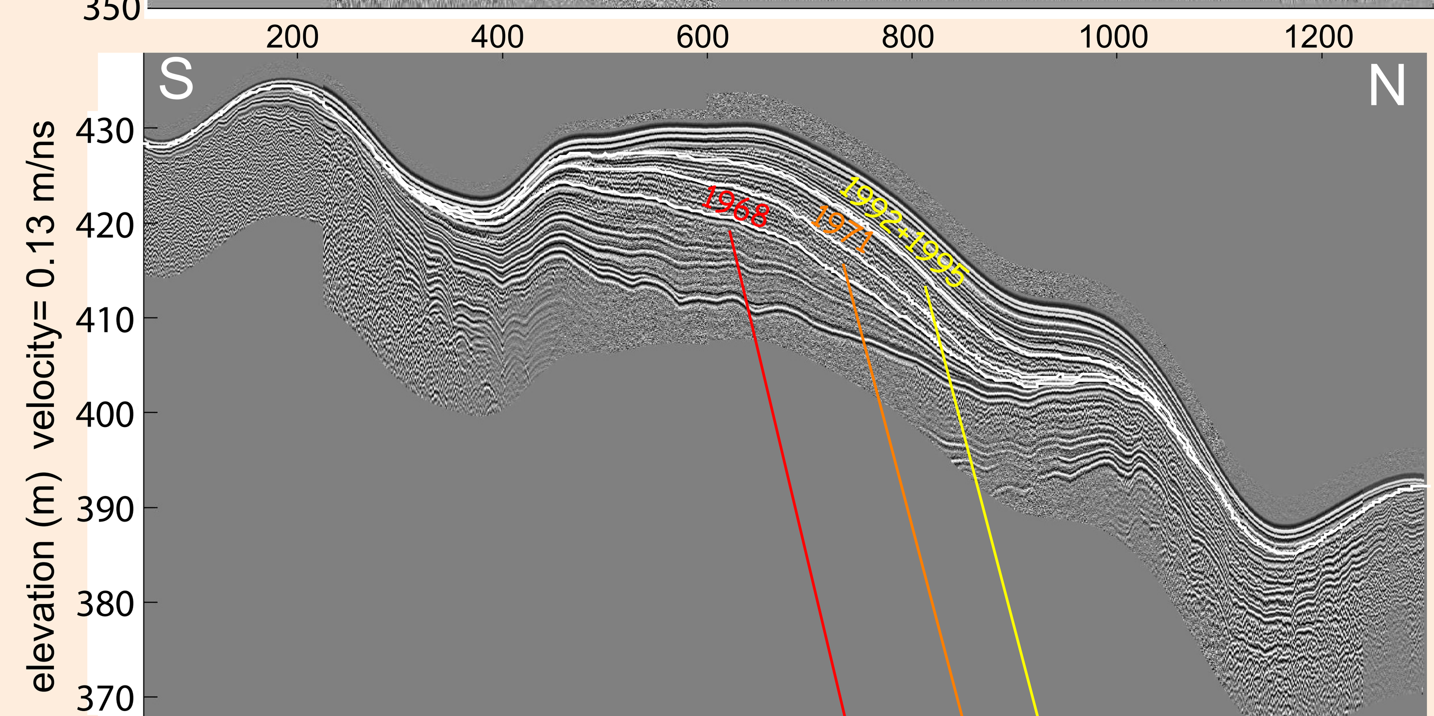


- **cross-wind profile**

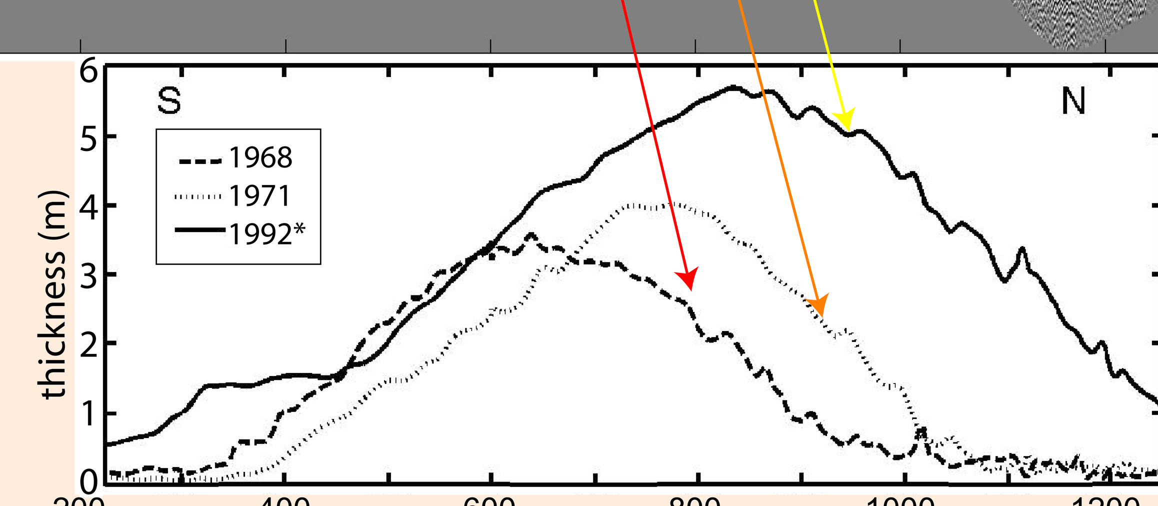
Location shown as Line 1 above. Data collected with 100 MHz antennas over central portion of profile; 200 MHz over ends with Sensors and Software, Inc. pulseEKKO 100 system.



Corrected for elevation, converted to depth assuming velocity of 0.13 m/ns (as measured in the field).

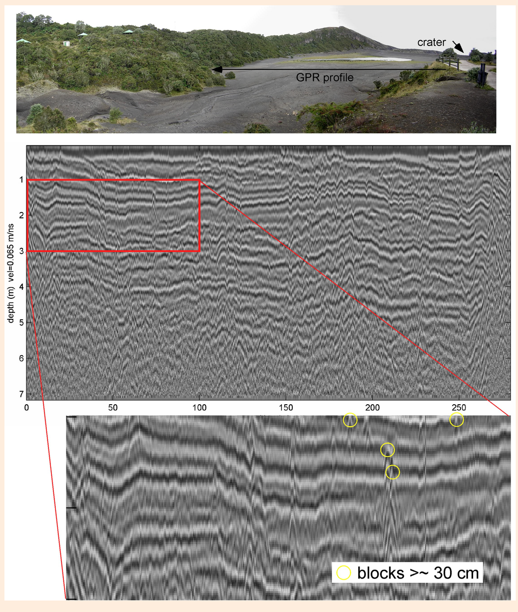


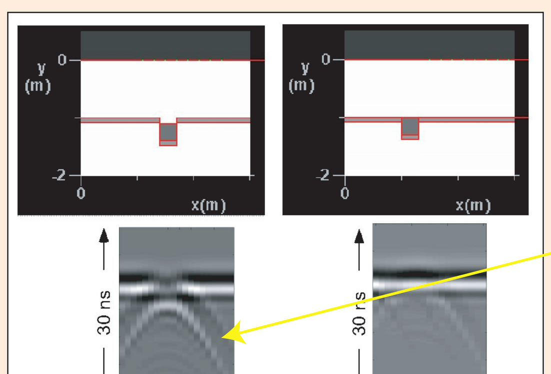
By calibrating the continuous GPR profiles against trenches, we can identify and compute thicknesses of the tephra deposits from different eruptions. Note the characteristic cross-profiles of the individual tephra blankets.

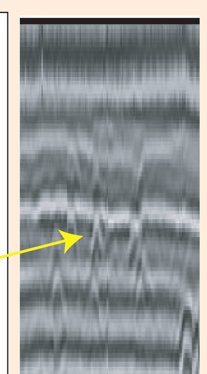


(3) Other Information One Can Get From GPR

Ballistics Distributions.







Blocks >20-30 cm produce characteristic diffraction patterns with 100-200MHz antennas. Synthetic models (FDTD method) show GPR profiles are very sensitive to the relative position of a block and neighboring layers. Note the diffractions on the Irazú profile peak below the nearest strong reflection. This is not easily explained as an out-of-plane effect.

This example is from Irazú volcano, Costa Rica.

Porosity? In areas with uniform water content, it may be possible to establish a relationship between GPR velocity and porosity.

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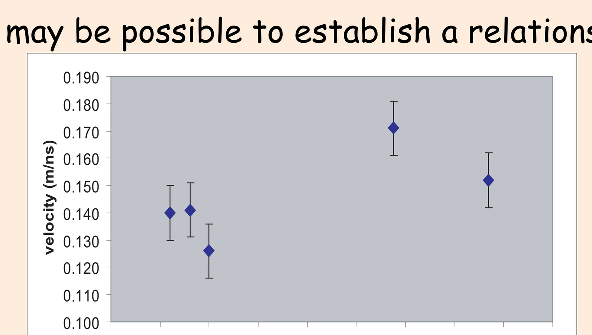
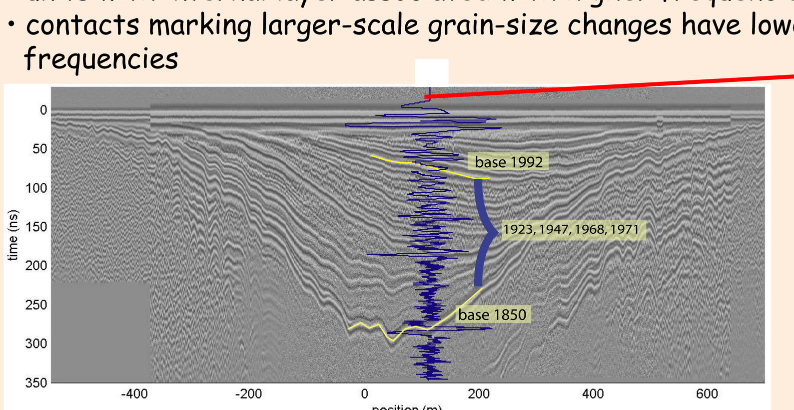
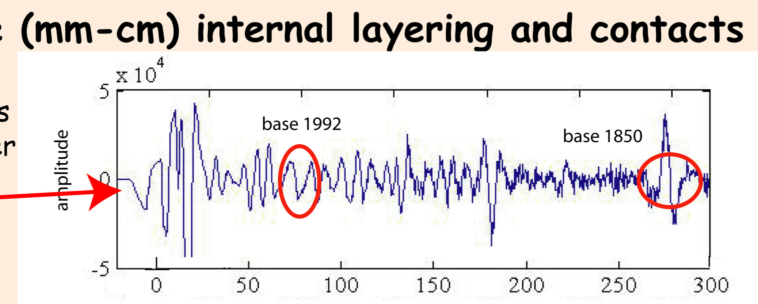
Our Cerro Negro surveys were conducted under very dry conditions. The figure at right shows velocity-porosity relationships for the 1992+1995 deposits at 5 test sites.

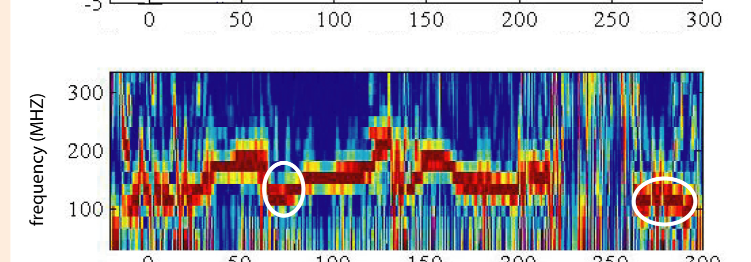


Spectral indicators of units with fine-scale (mm-cm) internal layering and contacts between units.

- units with internal layer associated with higher frequencies
- contacts marking larger-scale grain-size changes have lower frequencies







Acknowledgements

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References

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