Aerial Electromagnetic Sounding of the Lithosphere of Venus

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Robert E. Grimm, Southwest Research Institute

How does Venus lose its heat, and what are the implications for tectonics and volcanism?

Measure the thickness of the thermal lithosphere

Predictions: Mobile Lid ~100 km, Stagnant Lid ~500 km
EM Sounding

- Determines electrical structure from inductive response to natural or artificial sources.
- **Skin Depth (km)** = \(0.5 \sqrt{\rho/f} = 0.5 \sqrt{T/\sigma}\)
  
  \(f = \text{freq, Hz}; T = \text{period, s}\)
  
  \(\rho = \text{resistivity, } \Omega\text{-m}; \sigma = \text{conductivity, } \text{S/m}\)

- Very dry (resistive) extraterrestrial lithospheres raise frequency that can penetrate to a specified depth: simplifies measurements and improves SNR.
What is Measured?

- **Lightning confirmed by VEX.** Whistlers consistent with energy refracted vertically as it enters ionosphere from below. Extrapolated rate ~20% Earth’s. *(Russell et al., 2008).*

- **Lowest lightning frequencies suitable for lithospheric sounding.**
  - Schumann resonances = global interference patterns, 10-30 Hz.

- **Measure E- and B-fields for complete single-station sounding.**
  - Magnetotelluric and wave-tilt methods.
  - Aerial measurement analogous to terrestrial exploration at 1-20 kHz.
Multiple Measurement Locations

- Comparing measurements at 2 or more locations allows testing of principal hypotheses for lithospheric structure, independent of conductivity-temperature modeling.
  - Let maximum penetration depth = d(x,f).
  - Assume T(d) = const and dT/dz = const.
  - Isostatic $L_2 - L_1 = (h_2 - h_1)\rho_L/\Delta\rho$
  - Uniquely determine $L_1, L_2$
    - Select lowlands/rolling plains.

\[ L_2/L_1 = d_2/d_1 \]

Asthenosphere
\[ \rho_A = \rho_L - \Delta\rho \]
Model Demonstration


Heat Flow = 7.4 mW/m²
Mean Conductive Lid Thickness = 750 km

Heat Flow = 13 mW/m²
Mean Conductive Lid Thickness = 450 km

- Forward model EM response, convert to depth of penetration.
  - Does not depend on conductivity-temp assumptions as long as penetration depths 10s-100s km.
Model Demo, 2

- Single parameter $\rho/\Delta\rho \approx 50$.

EM-Derived Mean Lid Thickness

- EM-Derived Mean Lid Thickness $= 900$ km (target 750)
- EM-Derived Mean Lid Thickness $= 340$ km (target 450)
Summary

• EM sounding is an efficient way to probe the interior of Venus from tens to hundreds of kilometers.
  – Deep penetration of global Schumann resonances enabled by paucity of water in lithosphere.
  – Noncontacting electrical measurements, single platform: well-suited to balloon.
• Directly assess lithospheric thickness
  – Enabled by correlation between EM penetration depth and thermal-isostatic topography using global aerial mobility.
• Additional properties of interior derived using laboratory conductivity-temperature data.
  – Crustal thickness, mantle temperature and water content.