Evidence of shallow subsurface ice at Tianwen-1 landing site

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INTRODUCTION

Water ice on Mars is crucial for understanding climate history and supporting future human exploration. While polar ice is well-documented, its distribution at low-to-mid latitudes remains elusive.

• **Mission:** China's Tianwen-1 lander targeted southern Utopia Planitia (Fig. 1), a region with evidence of ancient hydrological activity.

• **Instrument:** The Zhurong rover carries the Mars Rover Penetrating Radar (RoPeR), capable of high-resolution subsurface imaging.

• **Goal:** This study investigates a mysterious low-loss layer at ~15m depth to determine if it contains water ice.

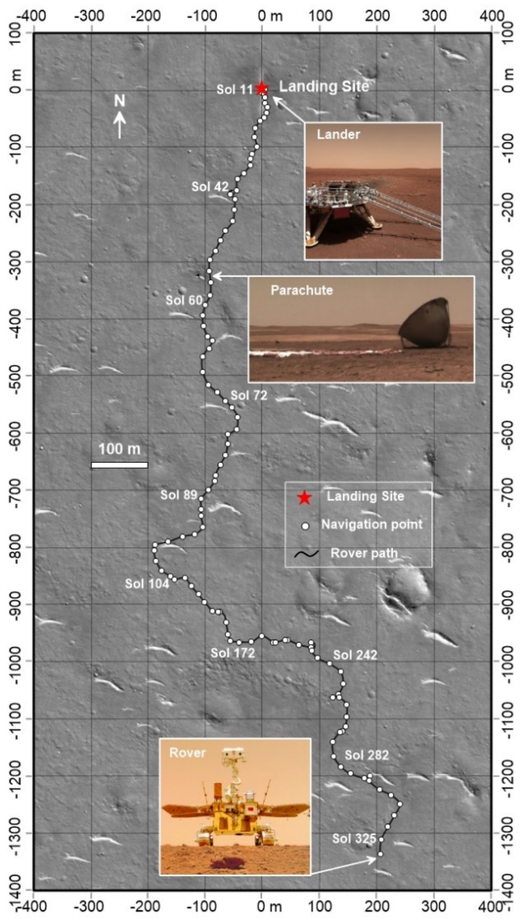

Fig. 1: Zhurong rover traverse path (~2000m) in Utopia Planitia

DATA & METHODS

We utilized RoPeR data (15-95 MHz & 0.45 GHz to 2.15 GHz), Short-Wave Infrared (SWIR) spectral data and the Navigation and Terrain Camera (NaTeCam) data. Radar processing steps included:

- Convert data format
- Stitch the data in order
- Delete self-check traces
- Unify the inter-trace spacing
- Direct current shift removal
- Noise Removal
- Band-pass filtering
- Migration.
- Intra-channel equalization
- Time-depth conversion

RESULTS & DISCUSIONS

We identified three distinct subsurface units (Fig. 2). Unit II exhibits anomalous properties consistent with water ice:

• **Depth:** Located at a depth of ~15 m with a thickness of ~7 m.

• **Permittivity (ε):** Calculated as ~3.86, significantly lower than the surrounding regolith (ε≈4.29).

• **Loss Tangent (tan δ):** Extremely low value of 0.0030 ± 0.0018 (Fig. 3). This is a key indicator, as pure ice typically has tan δ < 0.0026, whereas dry regolith exhibits tan δ > 0.01.

• **Composition:** The data suggests **'dirty ice'**—ice mixed with a small amount of dust/stones.

1. RoPeR on Zhurong Rover detects the subsurface stratigraphy

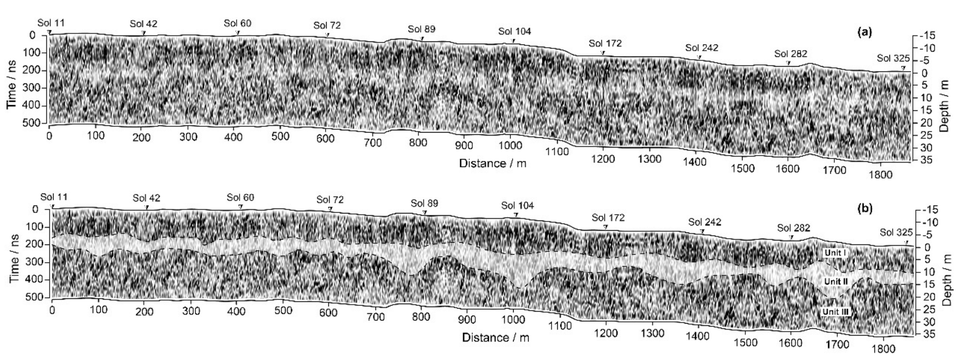

Fig. 2: Processed Radargram. Note the weak echo layer (Unit II) between Unit I (Regolith) and Unit III (Sediment)

2. The dielectric characteristics of Unit II

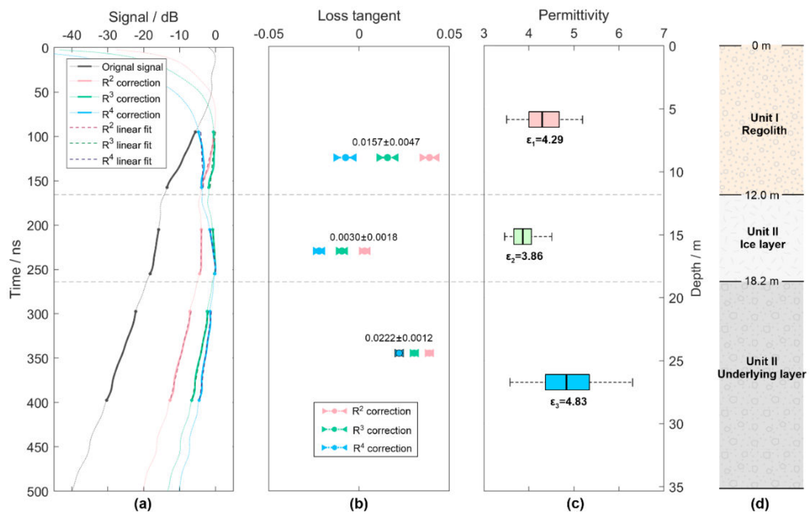

Fig. 3: Calculated loss tangents and dielectric constants for each layer, where Unit II parameters match the properties of the ice layer.

3. Comparison of different simulation results

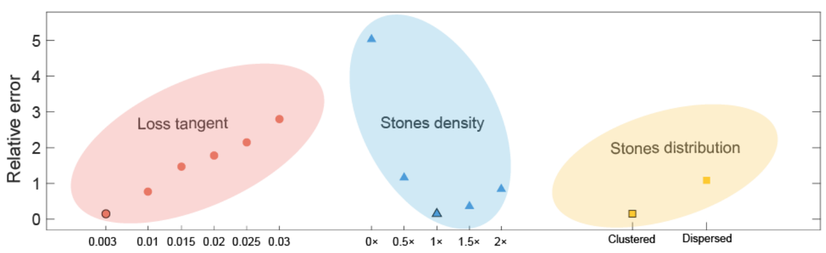

Fig. 4: Relative error analysis between different simulation results and RoPeR data

4. Analysis of central frequency attenuation and dispersion properties

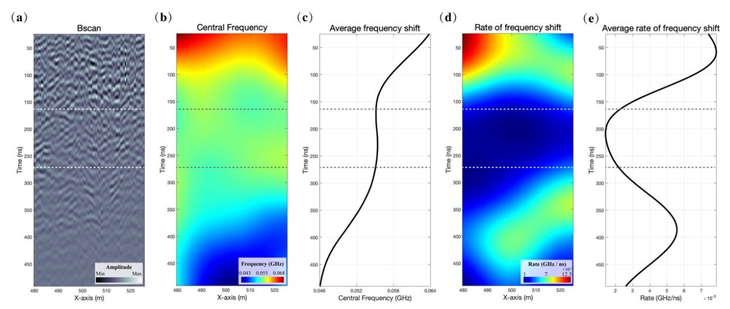

Fig. 5: Curve showing the variation of radar signal center frequency with depth (time). In the interval corresponding to Unit II, the curve exhibits a distinct "plateau," indicating no frequency shift.

5. Upward transport of H2O and interaction with upper substances

Fig. 6: NaTeCam, SWIR and high-frequency RoPeR data show traces of water activity.

6. Evolution model of ice at the landing site

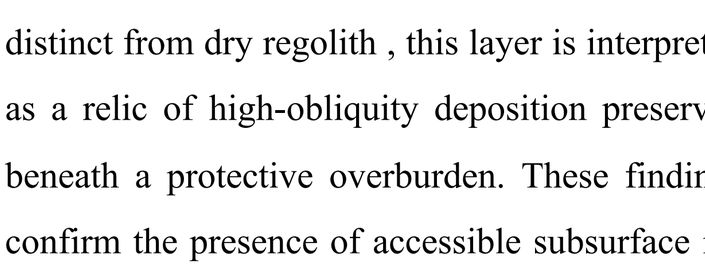

Fig. 7: Conceptual model of the evolution of ice or low-loss material at the Tianwen-1 landing site. During high-obliquity periods, water ice accumulated as frost or snow at mid-to-low latitudes, mixing with dust to form "dirty ice." As the climate dried, a thick aeolian regolith cover was deposited, inhibiting sublimation and preserving the layer.

CONCLUSION

Based on RoPeR data, we identify a shallow, ice-rich layer (Unit II) at ~15 m depth at the Tianwen-1 landing site. Characterized by specific dielectric properties and a lack of frequency dispersion distinct from dry regolith , this layer is interpreted as a relic of high-obliquity deposition preserved beneath a protective overburden. These findings confirm the presence of accessible subsurface ice at low-to-mid latitudes, offering critical insights into Martian hydrology and potential resources for future exploration.

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