

Simulating Meteor Ablation at the Hypersonic Materials Environmental Test System

12th Ablation Workshop

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NASA Ames Research Center

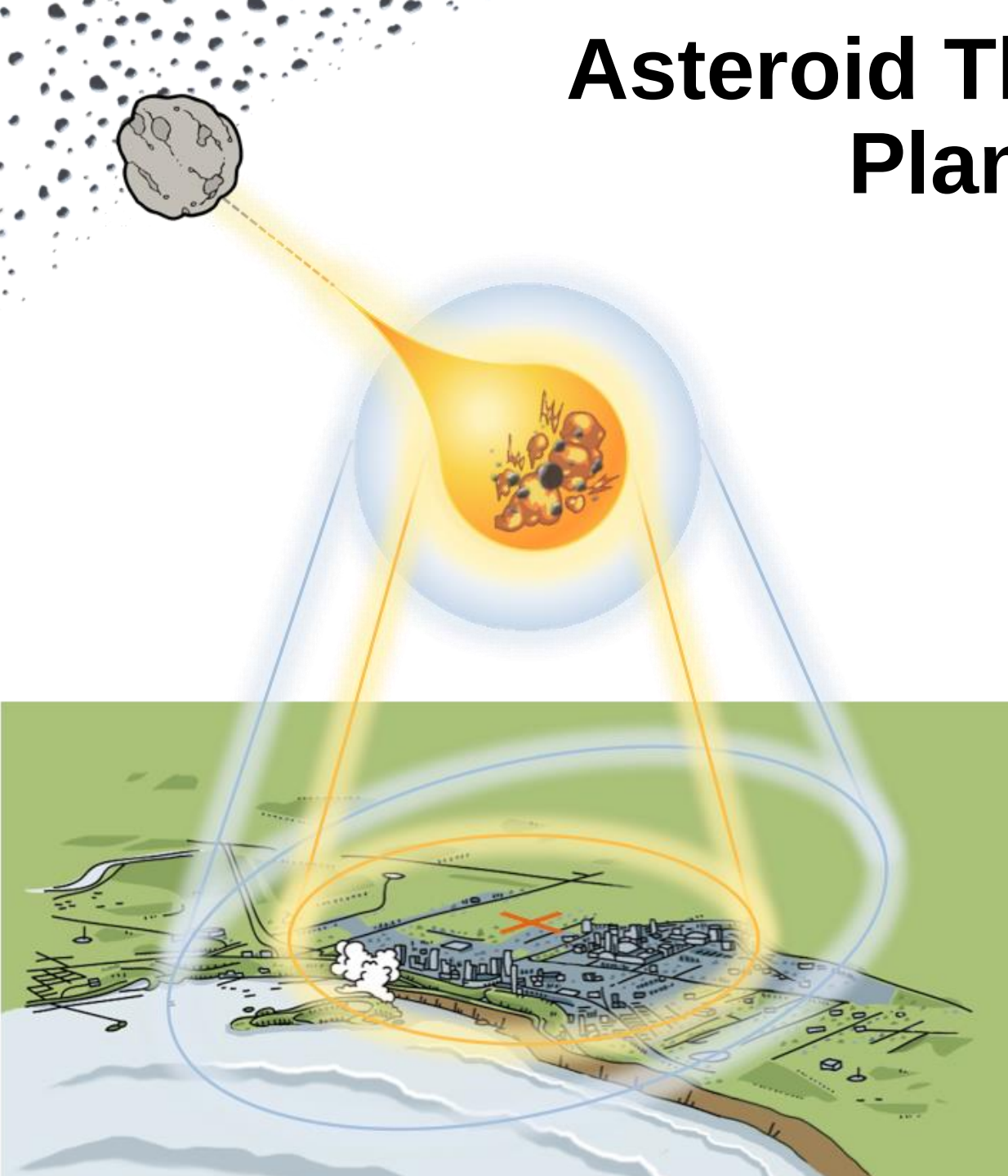
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Asteroid Threat Assessment for Planetary Defense

Objectives:

- Develop models and data to characterize the potential damage and risks due to asteroid strikes on Earth
- **Provide results that can help guide decisions and planning:**
 - Asteroid surveys
 - Mitigation systems
 - Disaster response



Meteorite Classification & Composition

Stony

- Primarily composed of rock forming silicates with decreased concentrations of iron alloy.

Stony-Iron

- 50% iron alloy imbedded in a silicate matrix.

Siderites

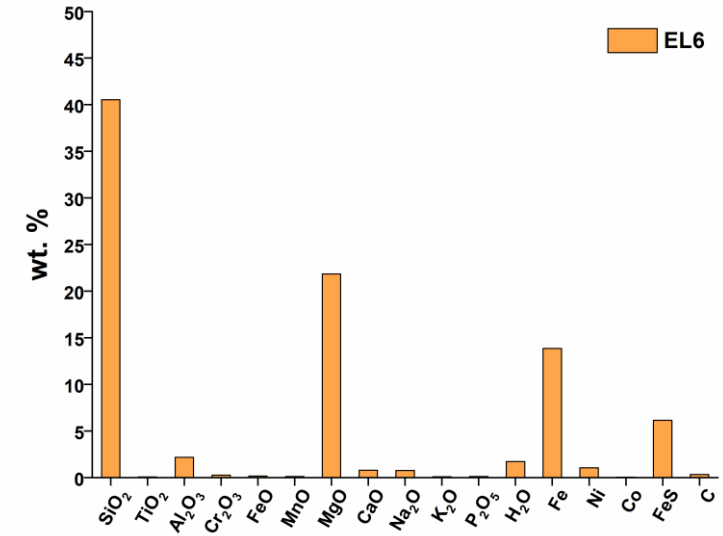
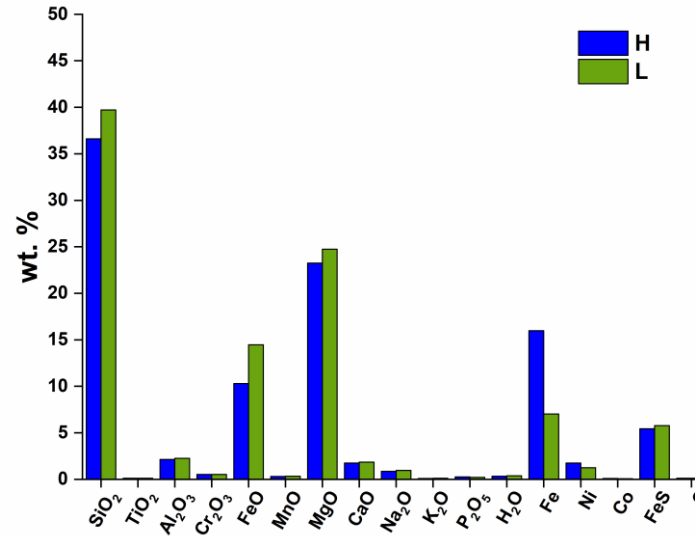
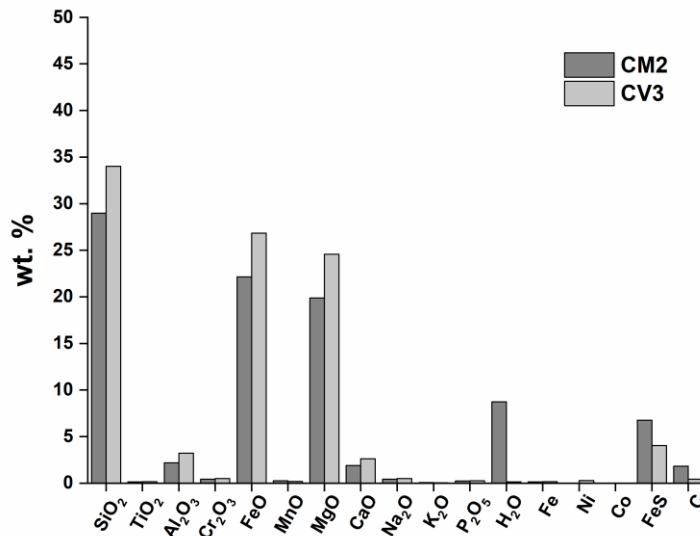
- Composed of 90-95% iron-nickel alloy (e.g., kamacite and taenite) with trace elements.
- Rare! 5.7% of all witnessed falls.

Chondrites

Carbonaceous

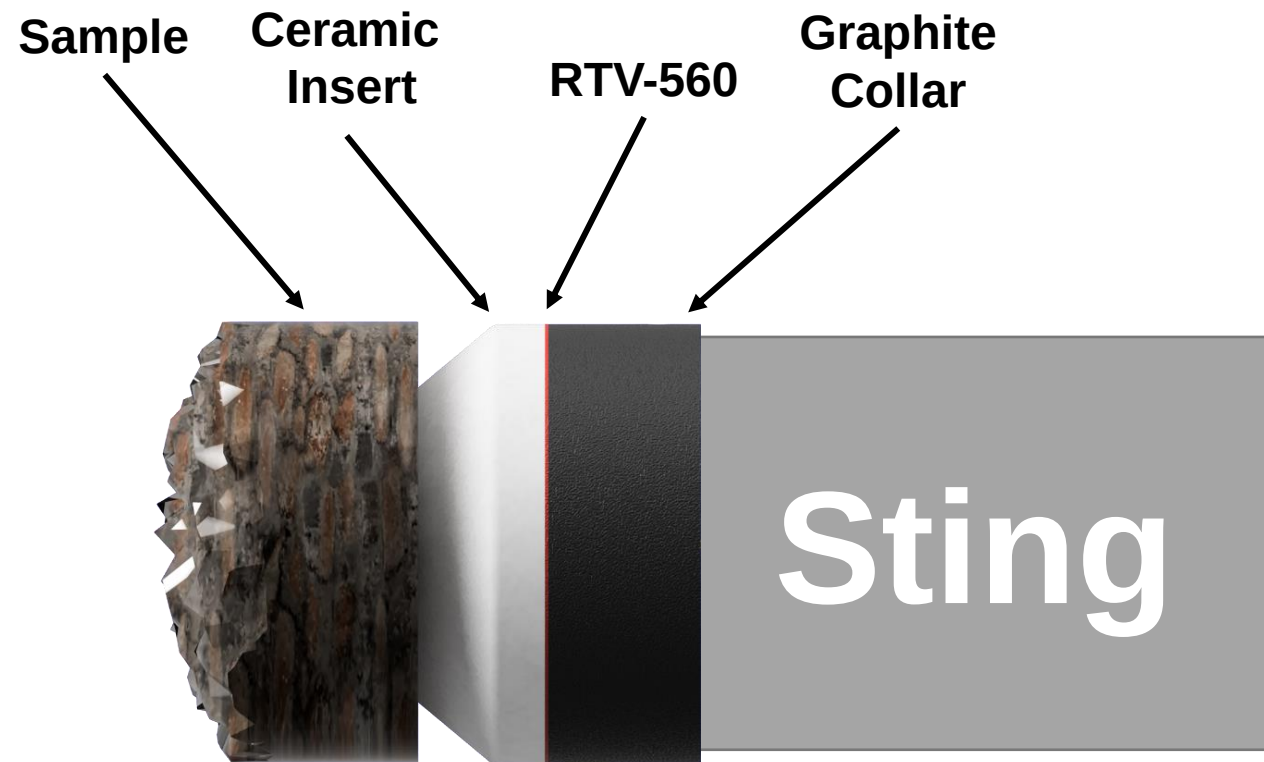
Ordinary

Enstatite

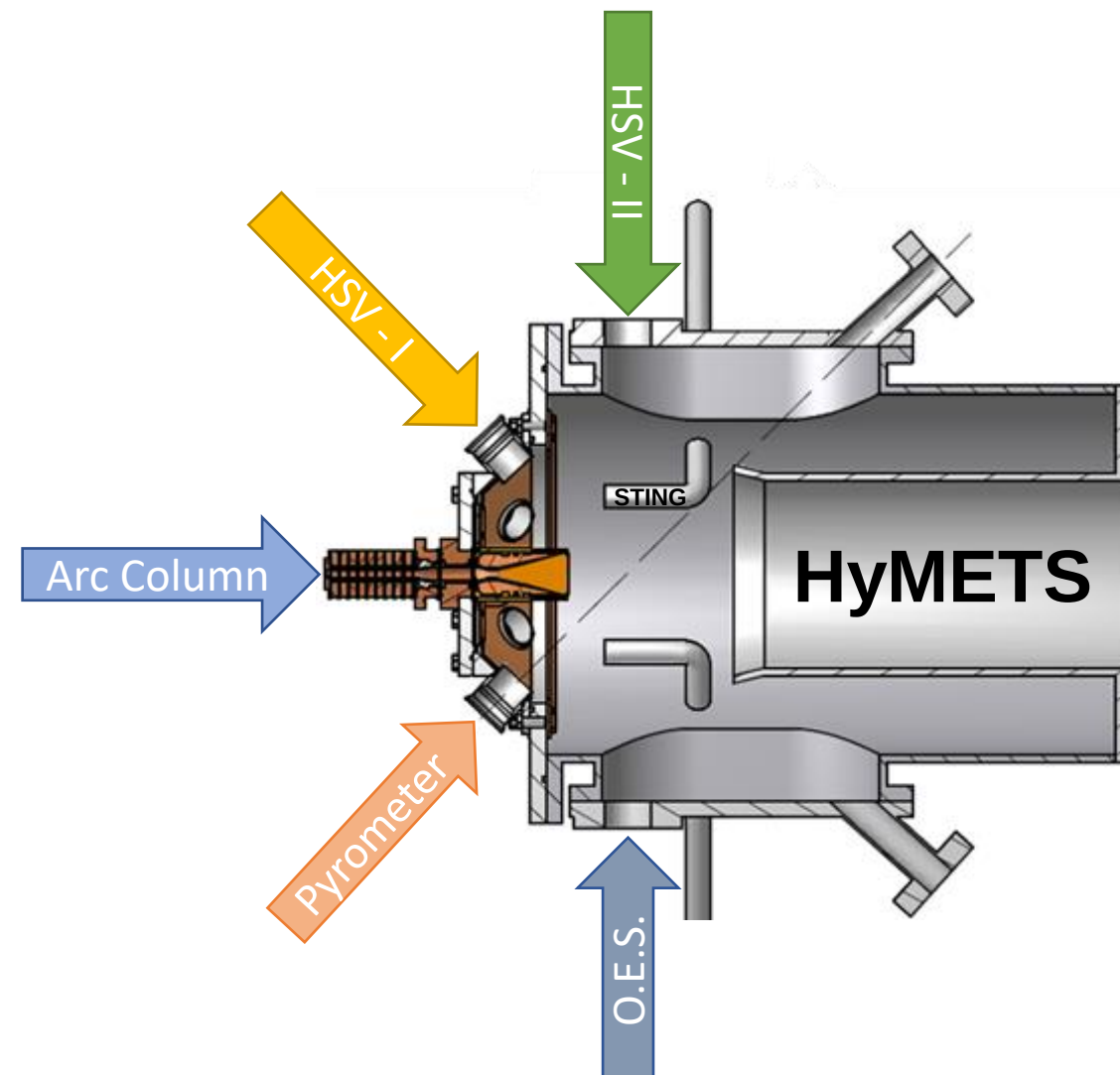


85% of observed falls!

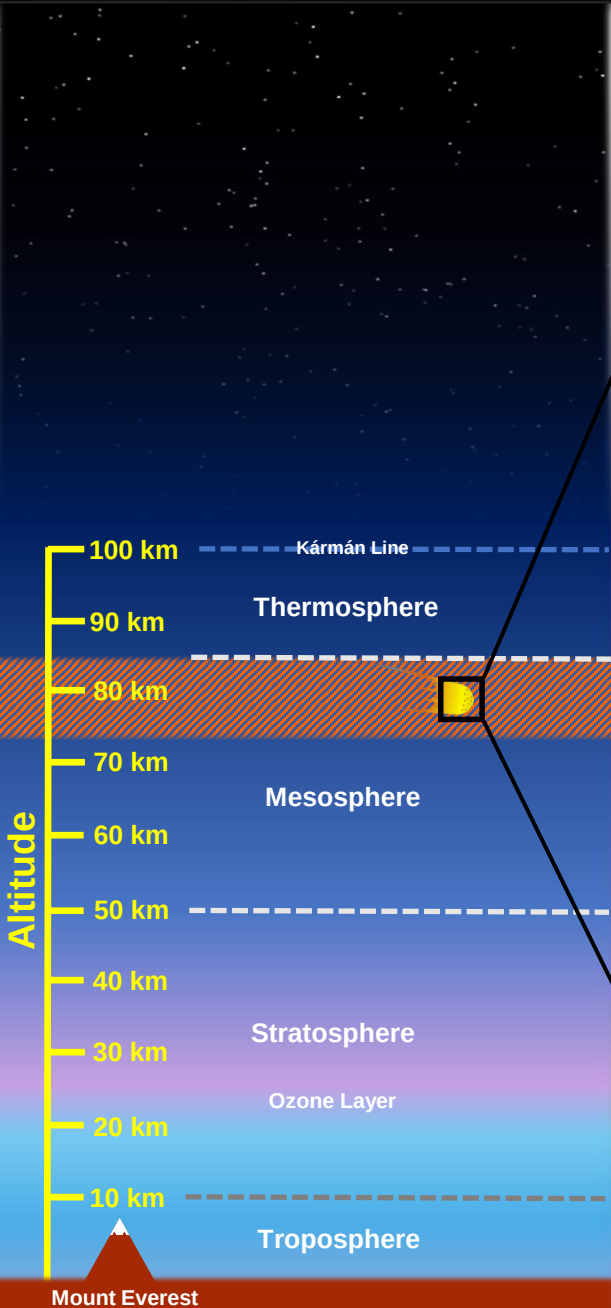
Sample Architecture and HyMETS Facility



- Compare the material response of basalt vs. ordinary chondrite (Tamdakht).
- Models subjected to testing in air flow.
- Heat flux range: $150 - 350 \text{ W cm}^{-2}$.
- Stagnation pressure range: 3-7 kPa.



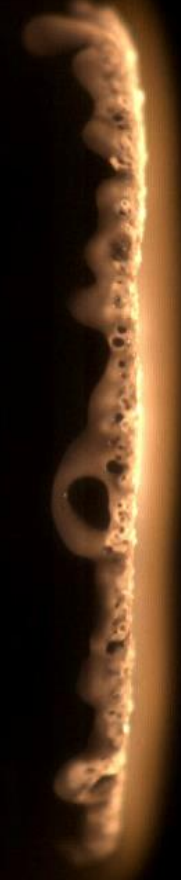
Ablation Mechanisms / High-Speed Video



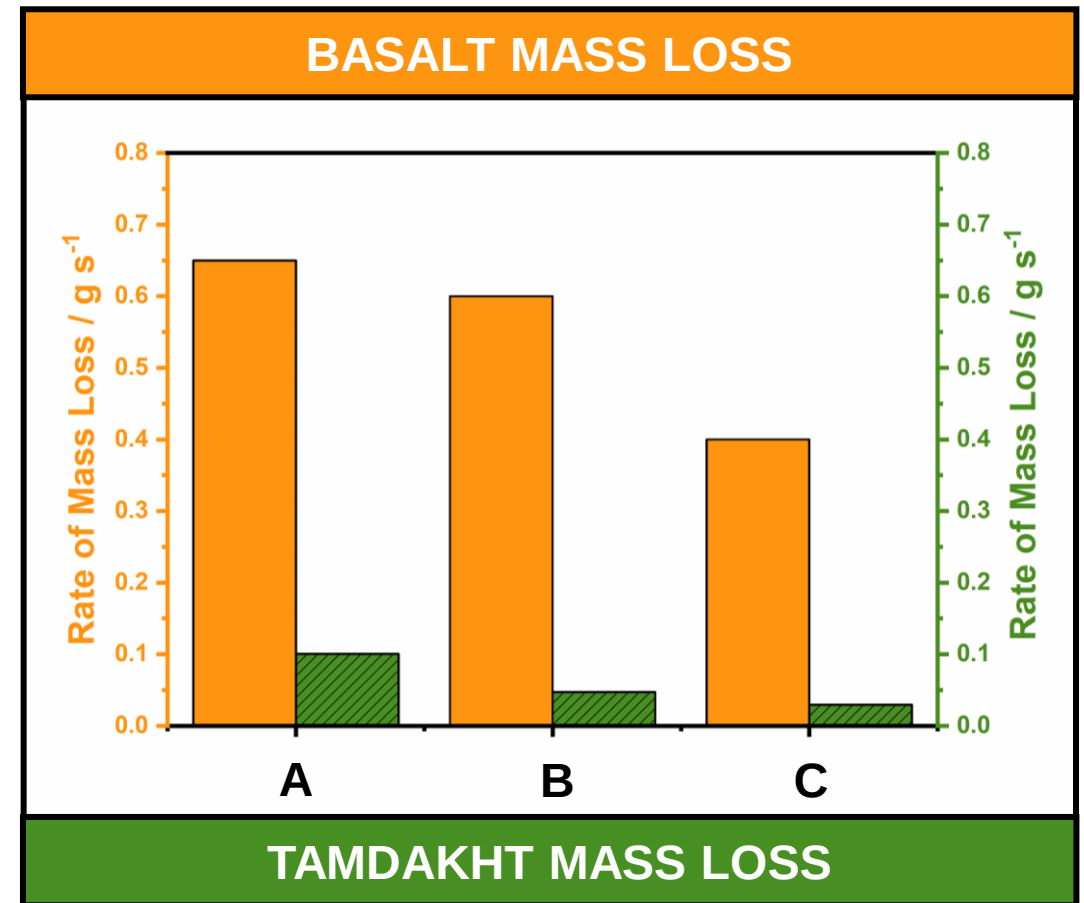
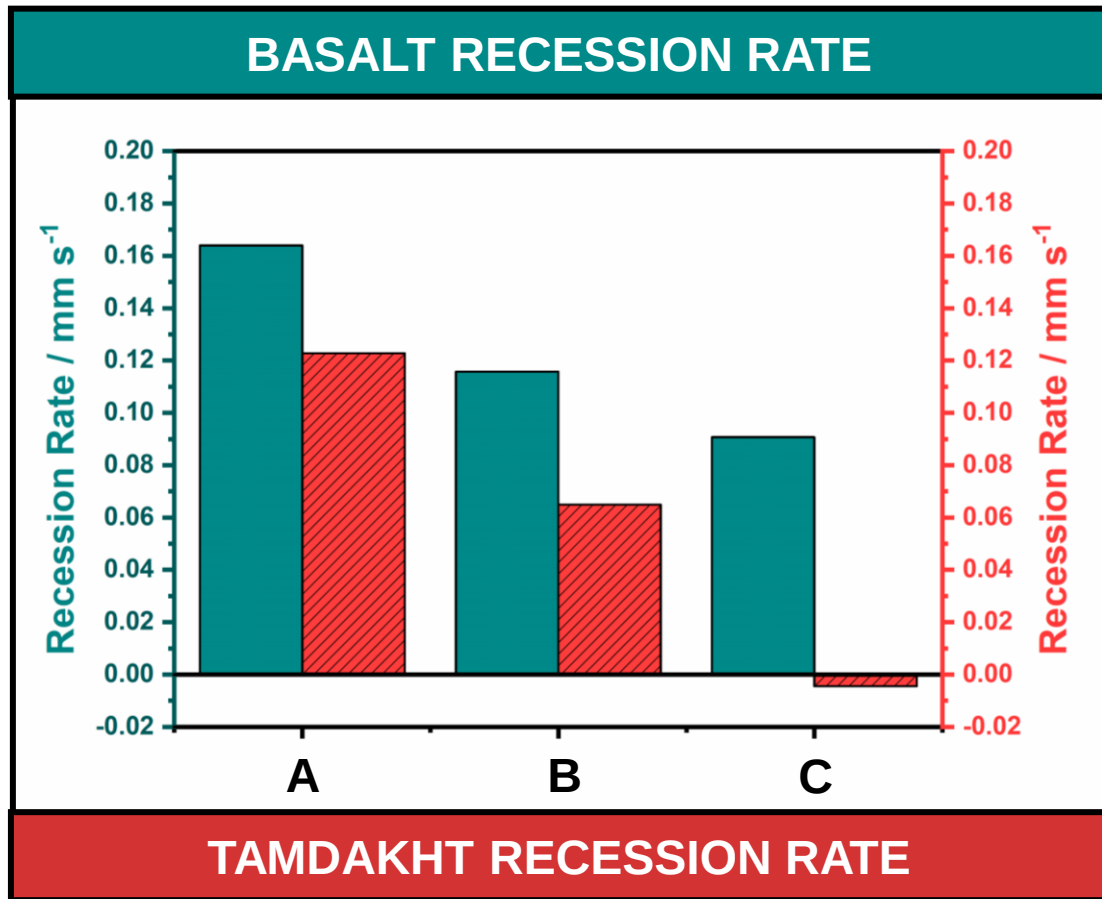
TAMDAKHT
 $T_s \text{ max} \sim 1,900^\circ\text{C}$



BASALT
 $T_s \text{ max} \sim 1,900^\circ\text{C}$



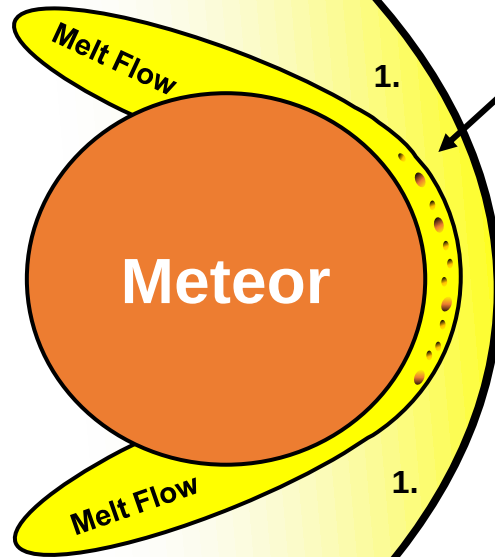
Recession Rates and Mass Loss



Mass loss and recession rates are higher for basalt.

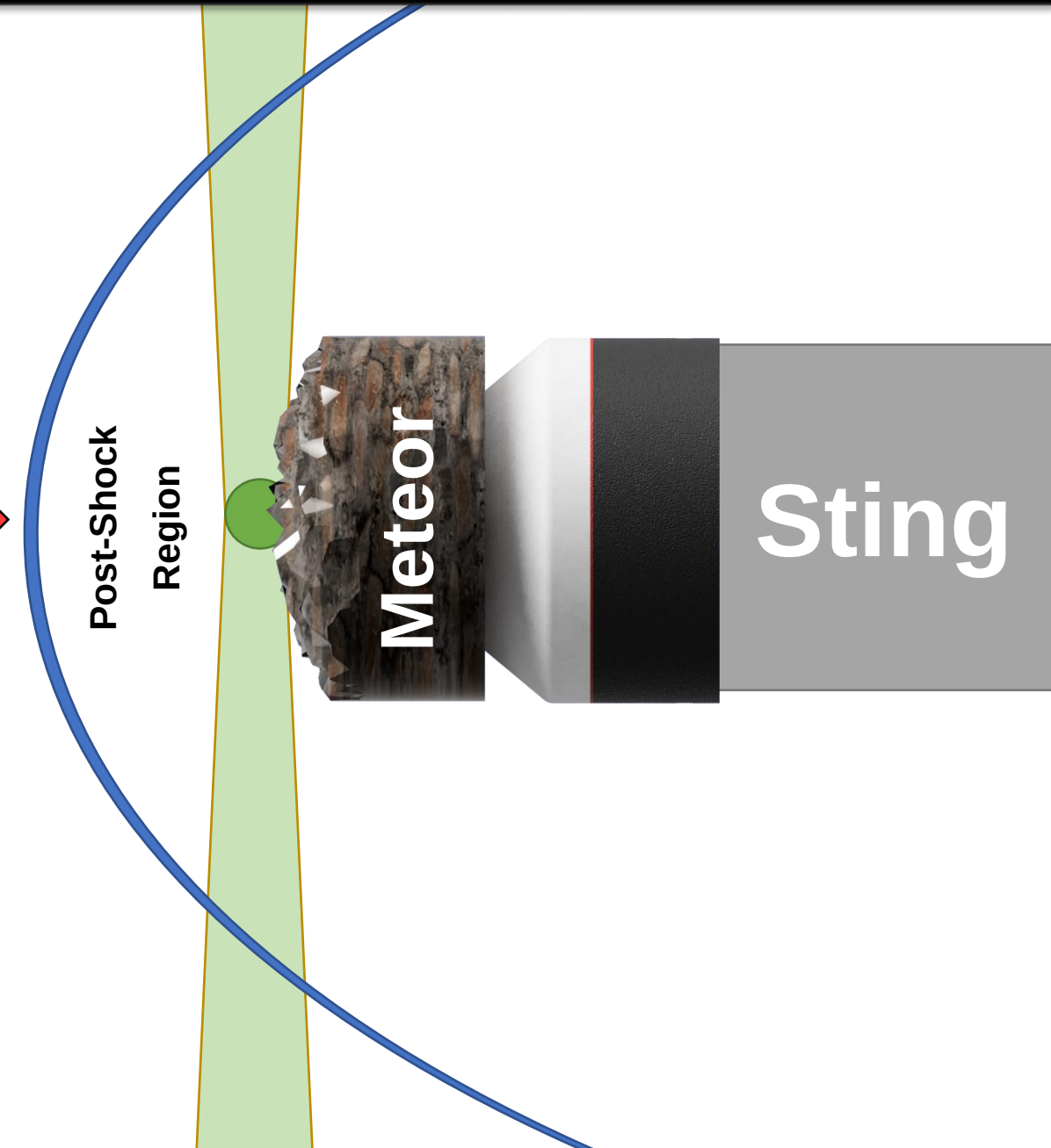
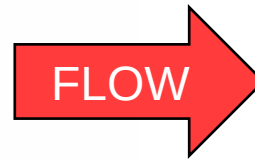
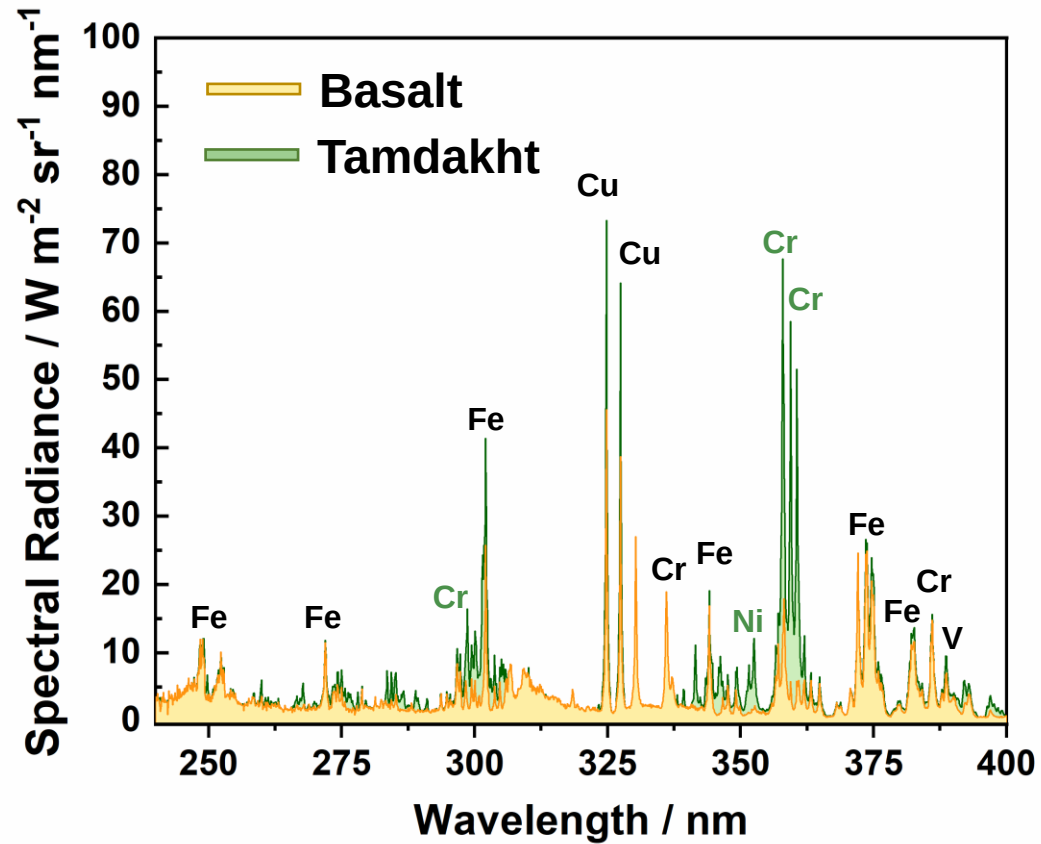
Meteor Ablation Mechanisms

1. Vaporization



Optical Emission Spectroscopy

Emission Data

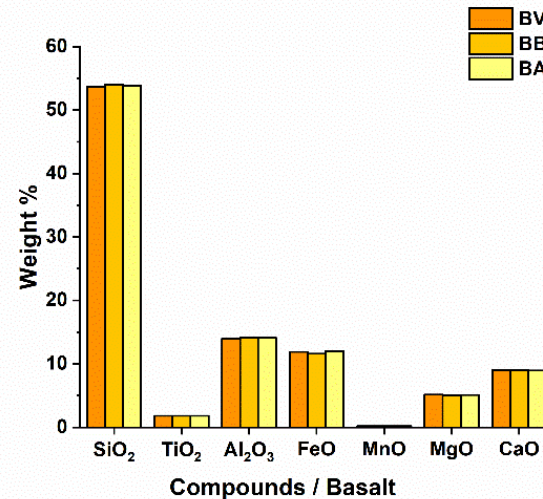


X-ray Fluorescence (XRF) / Post-Test Melt

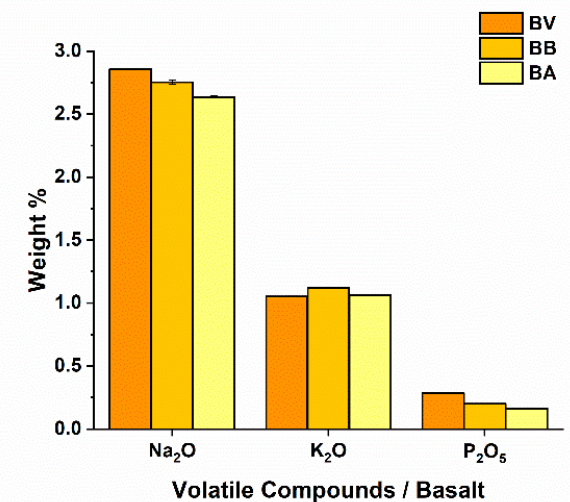


- Primary compounds of the post-test melt are invariant with respect to the virgin material.
- Volatile compounds decrease under more severe test conditions.

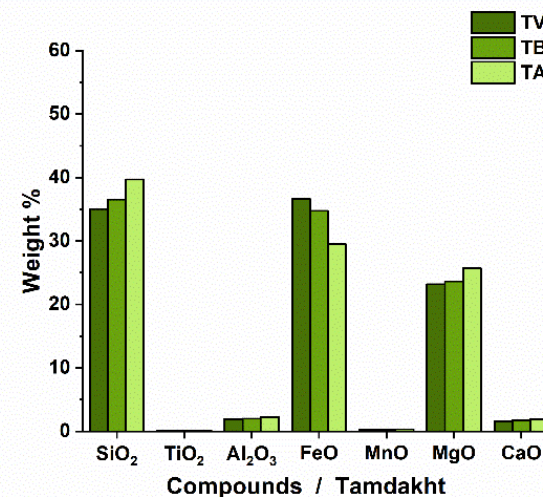
Basalt / Primary Compounds



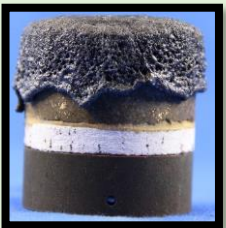
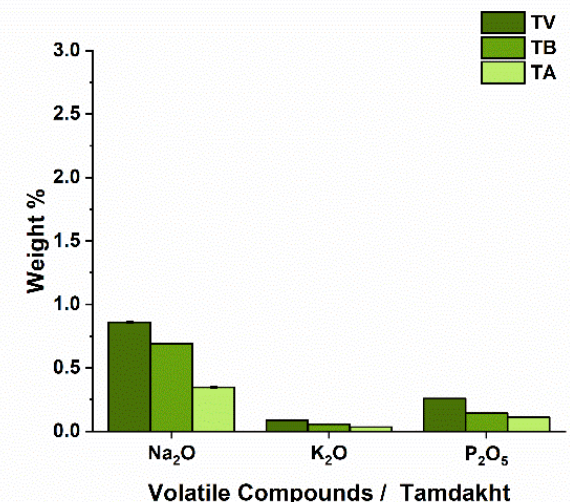
Basalt / Volatile Compounds



Tamdakht / Primary Compounds



Tamdakht / Volatile Compounds

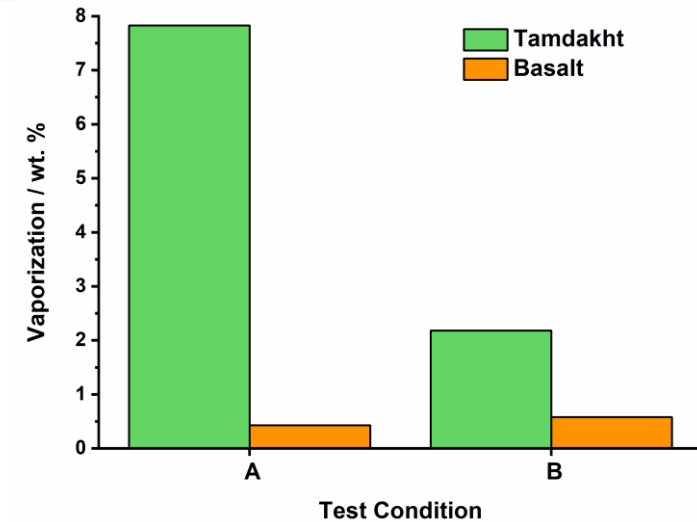


- Concentrations of primary compounds change significantly as a function of test condition.
- Volatile species decrease relative to the bulk material.
- Analysis does not account for FeS.

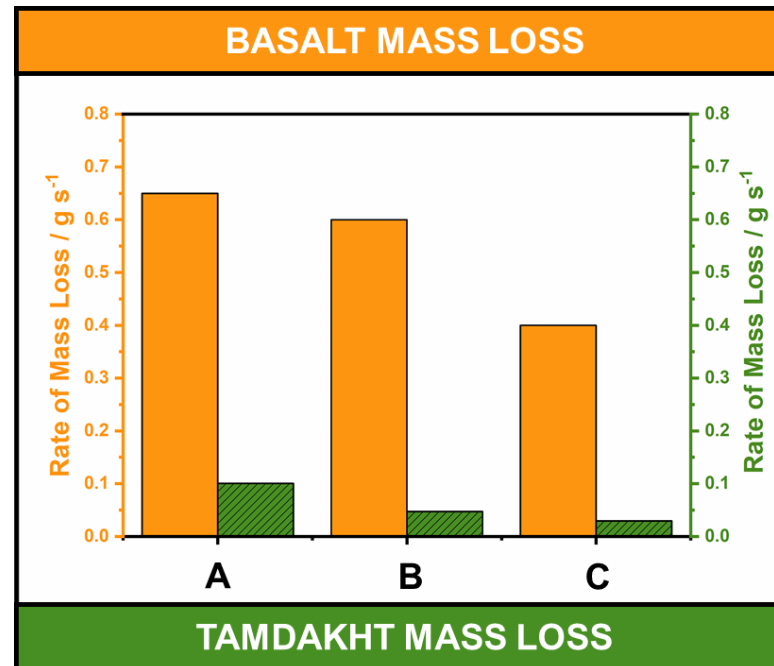
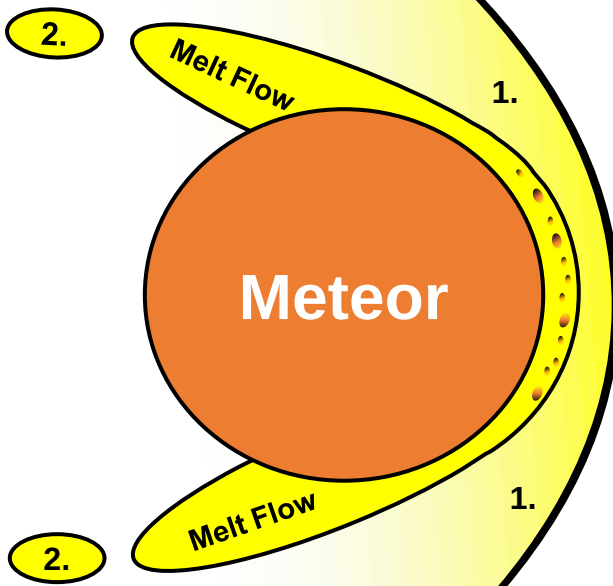
Meteor Ablation Mechanisms

1. Vaporization

- Vaporization of Tamdakht is 18x greater than Basalt.



2. Melt Flow Spray



Melt Viscosity

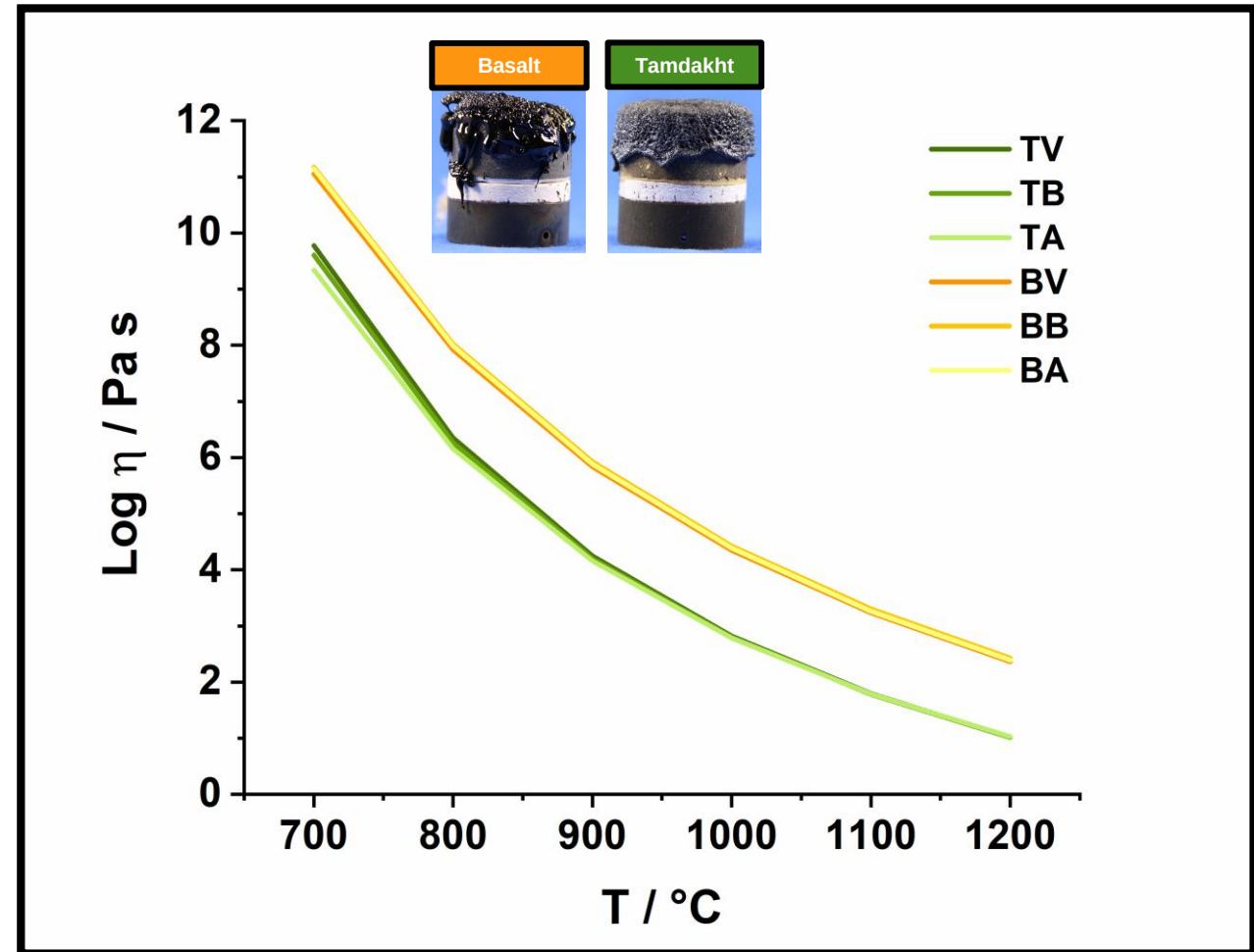
1. Giordano model used to predict silicate melt viscosities as function of temperature and composition.

2. Vogel-Fulcher-Tammann.

$$\text{Log } \eta = \frac{A + B}{(T(K) - C)}$$

3. XRF data used as input.

4. Viscosity of basalt is higher than Tamdakht.

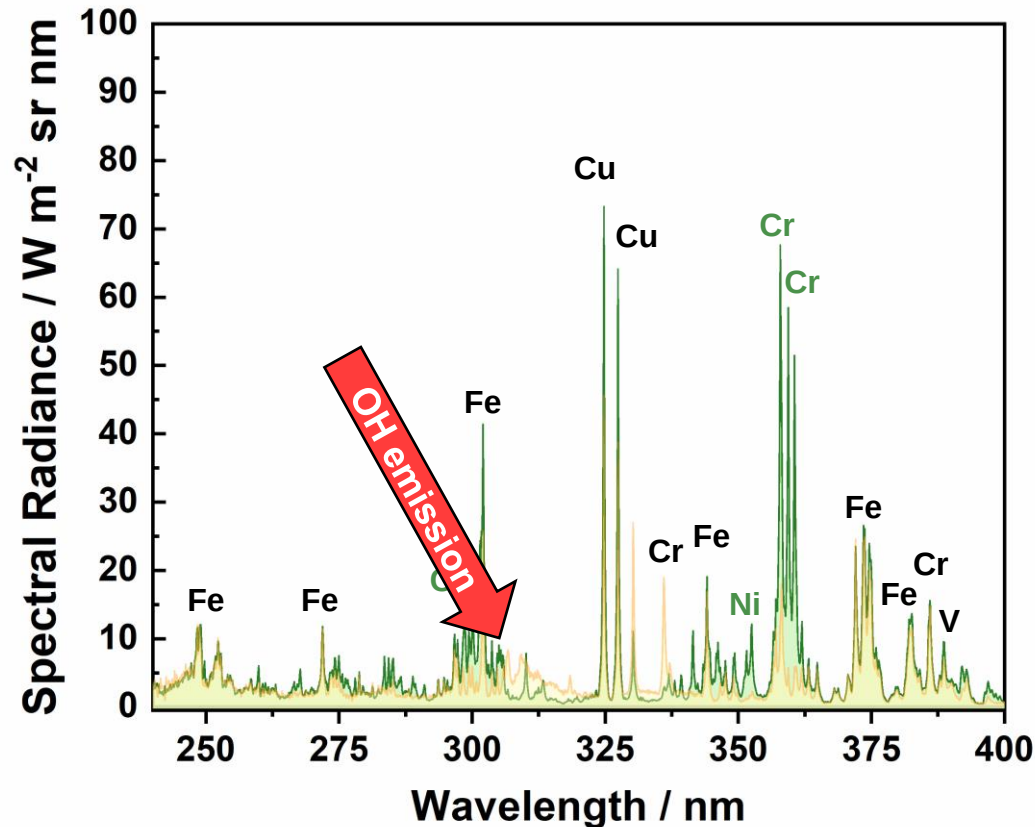


Melt Viscosity Calculated Using Giordano Melt Model

Giordano, D., Earth Planet. Sci. Lett. (2008)

OH Emission

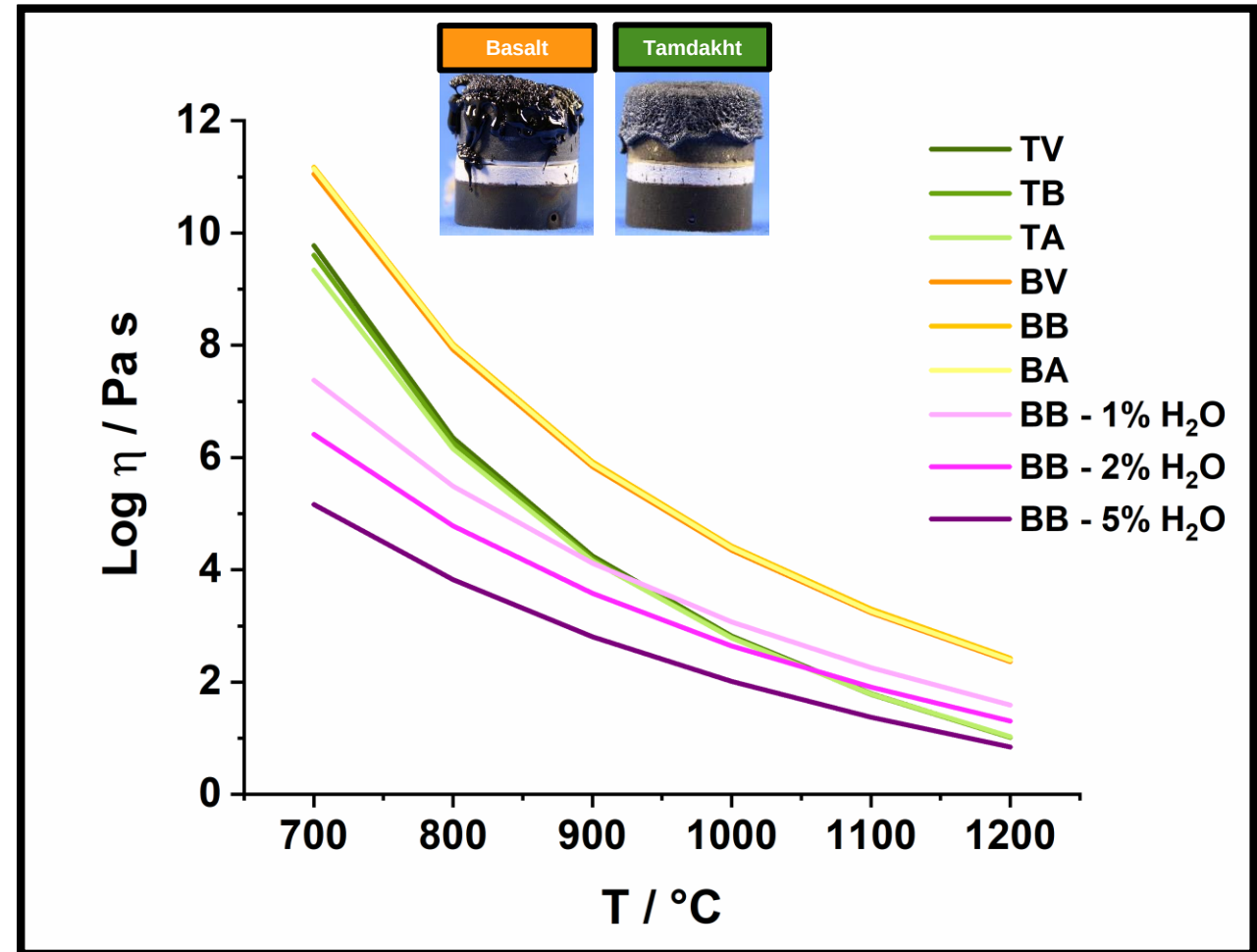
Emission Data



- Emission band heads near 306.7 nm and 308.9 nm indicate the presence of OH in the post-shock region of basalt.
- Emission bands for OH are not present in Tamdakht.

Melt Viscosity

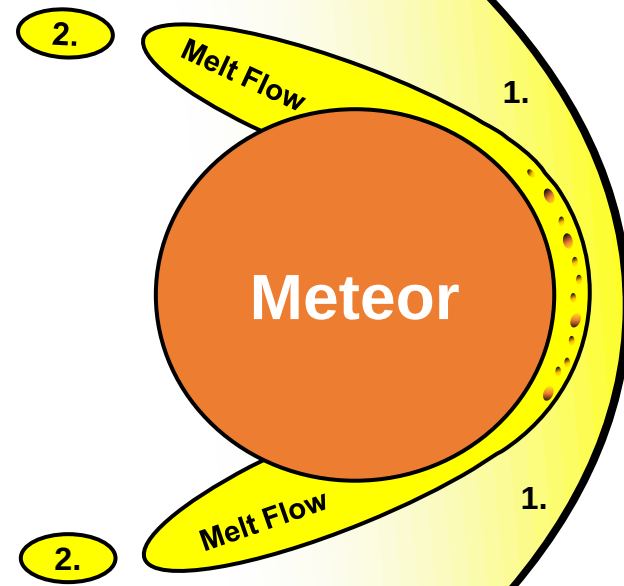
1. Total water content in the Columbia River Basalt Group can be as high as 1-2 wt.%.
2. Water is a network modifier and has a significant influence on the melt viscosity.
3. Melt viscosities converge to the same value at high temperature.



Melt Viscosity Calculated Using Giordano Melt Model

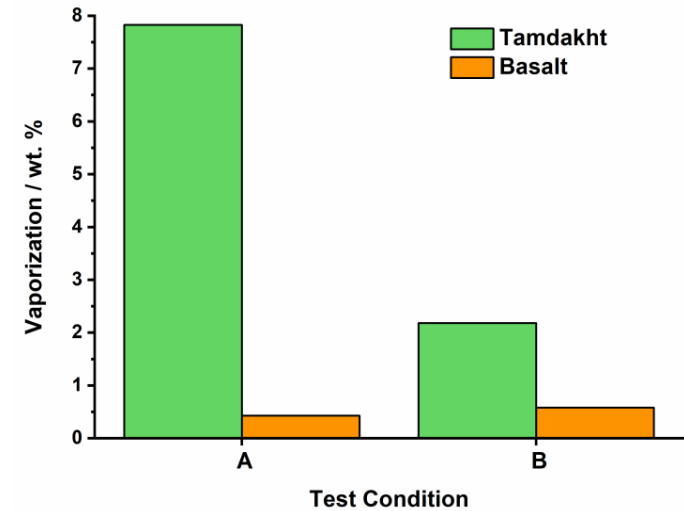
Giordano, D., Earth Planet. Sci. Lett. (2008)

Meteor Ablation Mechanisms



1. Vaporization

- Vaporization of volatiles from Tamdakht is 18x greater than Basalt.



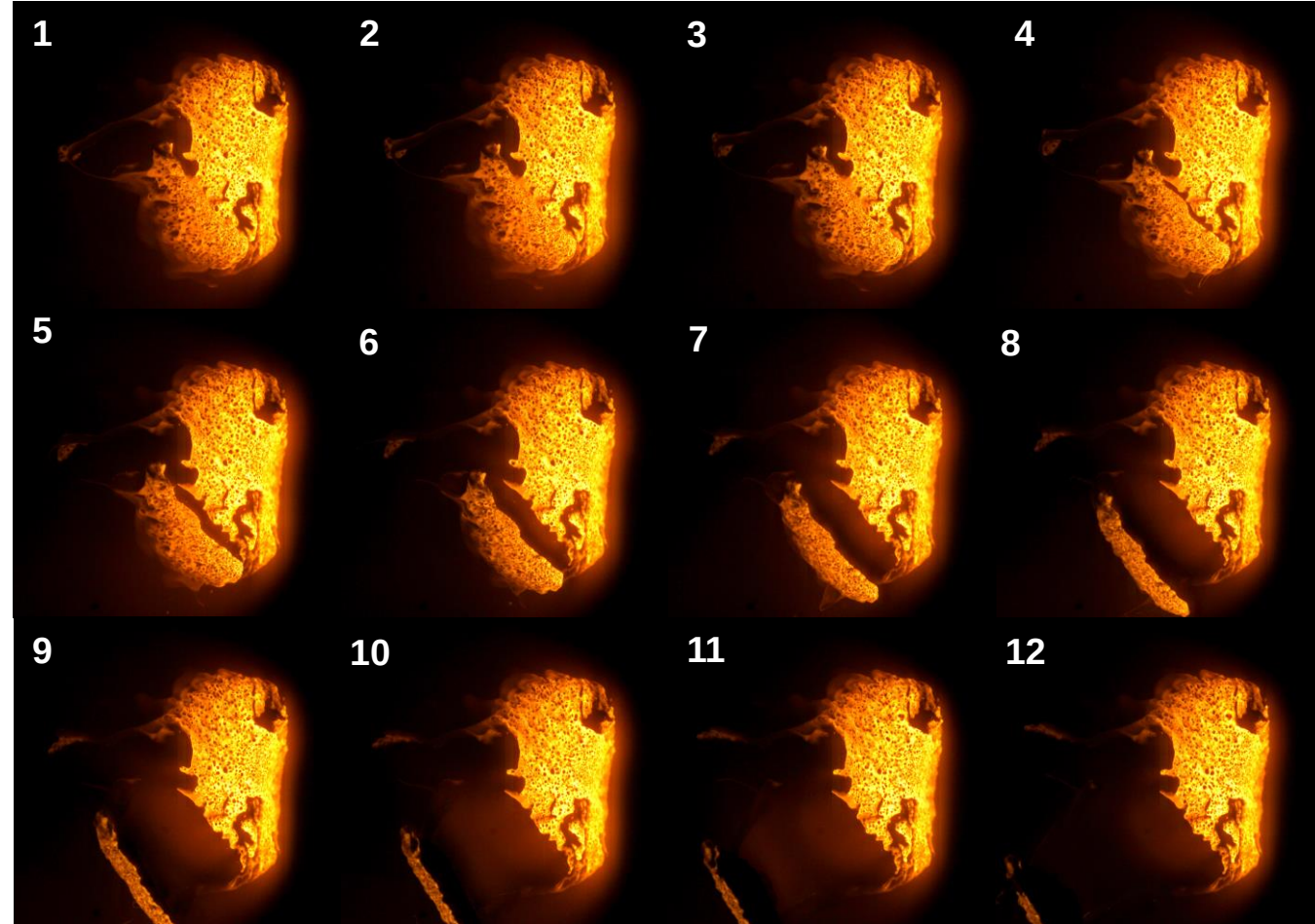
2. Melt Flow Spray

- Melt models predict higher melt viscosities for basalt unless water is present.
- The viscosities of both materials converge to the same value as the temperature increases.

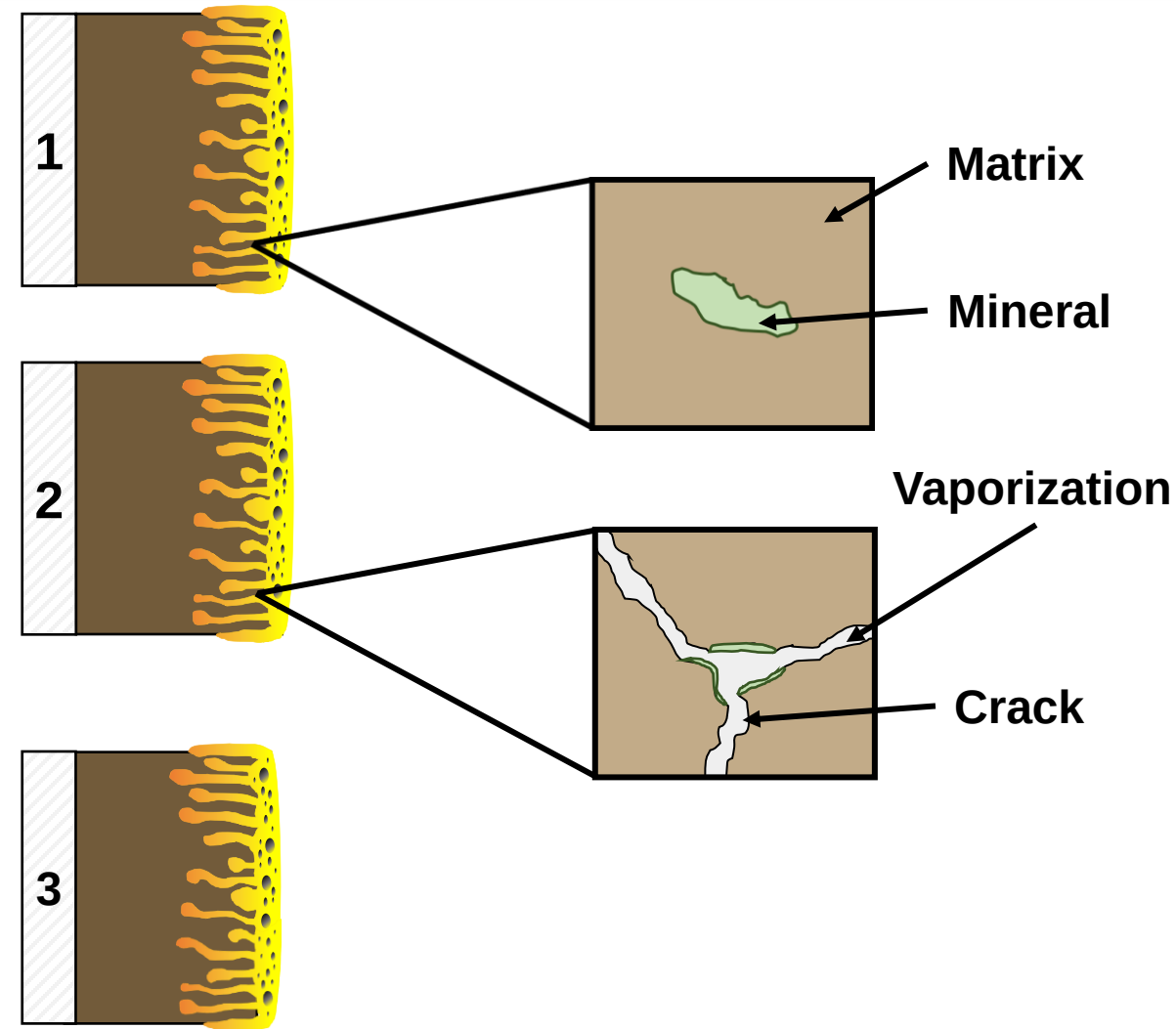
3. Fracture

Fracture and Spallation

- Images collected from a high-speed camera positioned to view the surface of basalt.
- Images are spaced apart by 1 millisecond.
- Images show the loss of a large section of the surface near the sample edge.
- Surface material lost to the flow is composed of viscous melt and a relatively cool subsurface.



Fracture Mechanism / Basalt



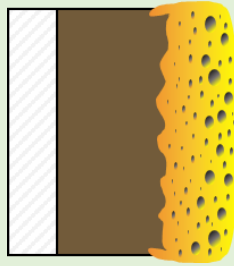
1) Basalt from the Columbia River Group likely contains hydrated minerals and inclusions.

2) Hydrated minerals decompose, and water vapor fills adjacent cracks.

3) Large sections of the sample are lost to the flow due to mechanical action from subsurface water vapor and shear at the edge of the sample.

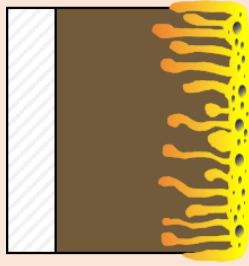
Conclusions

Tamdakht



- Ablation is dominated by vaporization.
- Recession rates are lower than basalt.
- Mass loss 6.5x lower than basalt.
- Viscous melt forms a flange at the edge of the sample and loss of mass via melt spray is low.

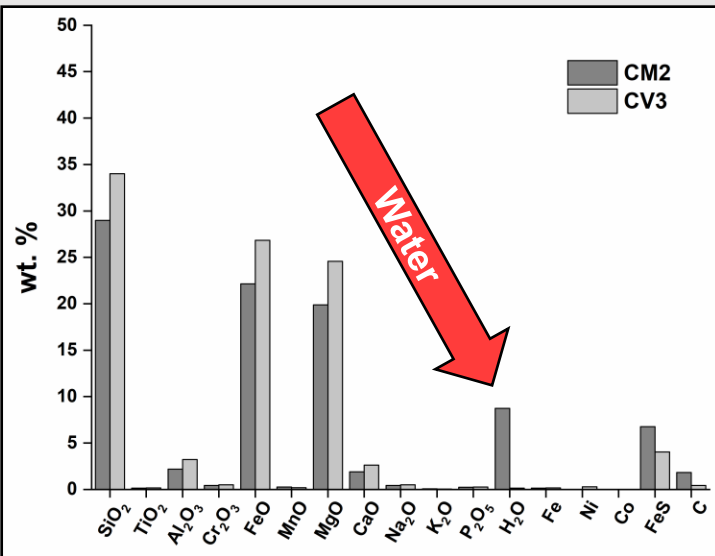
Basalt



- Ablation mechanisms are driven by the presence of water.
- Mass is lost through separation of a tenuous melt into the flow environment.
- Mass loss is dominated by the separation of large sections of the surface through fracture and shear.

Future Testing

- Basalt is inexpensive but is it a relevant analog?
- The composition of carbonaceous meteorite material is comparable to ordinary chondrites (e.g., Tamdakht).
- However, the concentration of water is much higher in carbonaceous chondrites.
- Are the ablation mechanisms comparable to basalt?



The End

Questions