The Association Between Crater Dimensions and Ejecta Complexity in Martian Craters

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Introduction

- The depth–diameter ratio (d/D) is a fundamental metric for interpreting crater formation because the initial depth reflects the impact energy, while the final depth records how the crater slumps under gravity, material strength, and subsurface ice content (Collins, Melosh, & Osinski, 2012)).
- On Mars, variations in d/D provide insight into buried ice, soil properties, and long-term erosional modification, making the ratio central to understanding both impact processes and surface evolution (Barlow, 2003).
- More complex ejecta patterns are often associated with ice-rich substrates and higher-energy impacts, suggesting that ejecta structure may encode subsurface conditions similarly to d/D (Barlow, 2003).
- If ejecta morphology reliably preserves these conditions, then ejecta types should serve as predictors of d/D ratios.
- However, this presumed relationship has not been tested at scale, raising the central question of whether ejecta patterns actually capture the same physical information encoded in crater depth measurements.

Results

Univariate

- Univariate tests show that ejecta complexity is statistically related to depth–diameter ratios ($p < 0.001$), but the effect is extremely small, accounting for only $R^2 = 0.0017$ of the variance.
- Each one-level increase in ejecta complexity corresponds to an average increase of just 0.003 in the depth–diameter ratio.
- Post-hoc comparisons indicate systematic differences among ejecta categories, with complex ejecta craters exhibiting depth–diameter ratios approximately 0.0117 higher than simple ejecta craters.

Bivariate

- When examined in relation to individual geographic or physical predictors, depth–diameter ratios vary far more strongly with latitude and crater diameter than with ejecta characteristics.
- Absolute latitude shows the largest single-factor influence on d/D, reflecting broad-scale environmental controls on crater morphology.
- The interaction between crater diameter and ejecta complexity suggests that the effect of ejecta type is not uniform but instead varies across crater sizes.

Multivariate

- A full multivariate model, combining polynomial terms for diameter and latitude with ejecta complexity and interaction effects achieves the strongest performance ($R^2 = 0.4431$)
- Even within this comprehensive framework, ejecta complexity contributes only modest predictive power, indicating that it captures a limited portion of the subsurface and impact conditions recorded in crater depths.

Fig 2: Depth-Diameter Ratio vs. Absolute Latitude

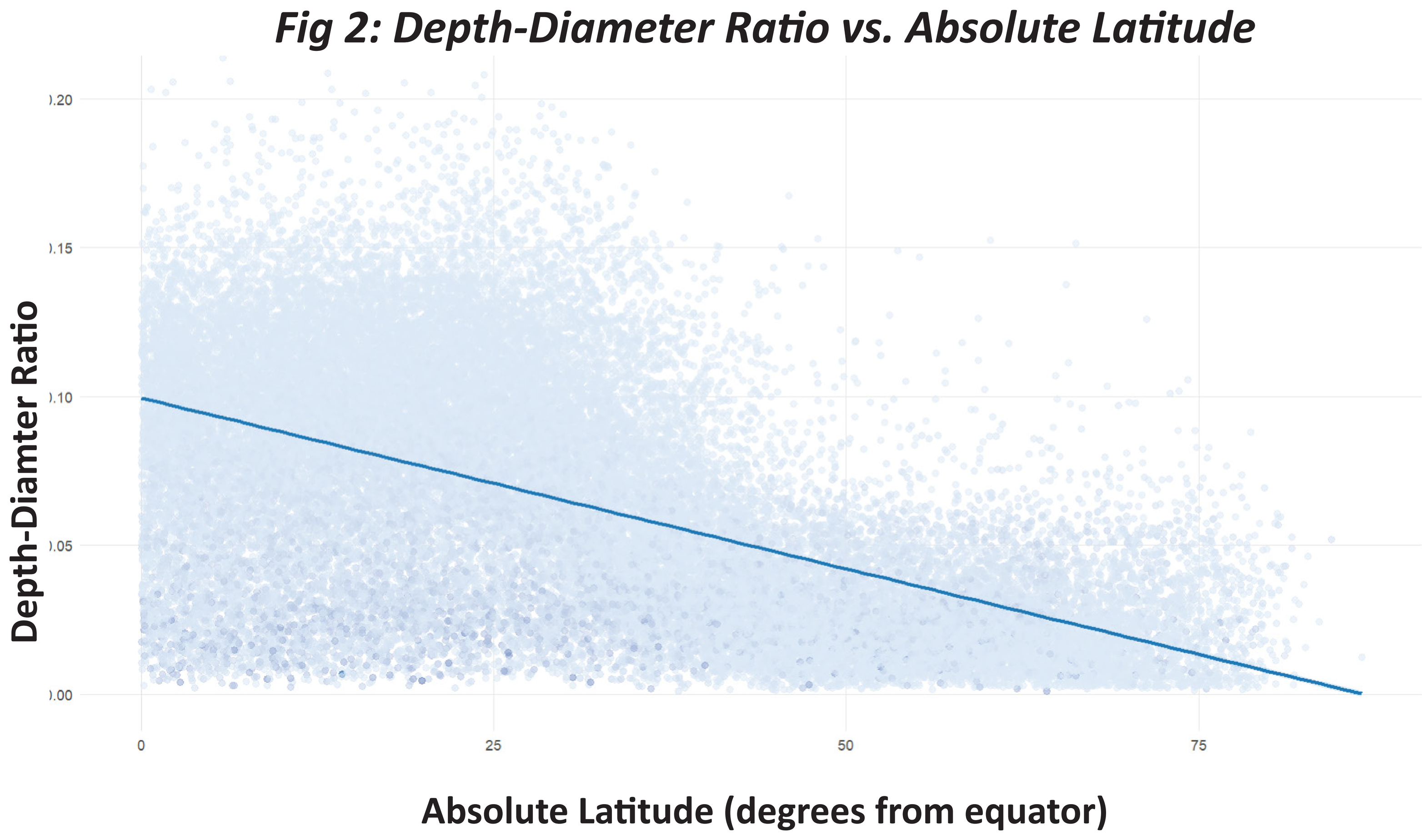

Table 4: Improved Model with Interaction Terms (Key Coeffiecinets)

Term	Estimate	Std. Error	Statistic	p-value
(Intercept)	0.1389	0.0016	88.3247	<0.001
Log Diameter	−0.0728	0.0031	−23.6826	<0.001
Log Diameter²	0.0079	0.0014	5.6907	<0.001
Absolute Latitude	−0.0006	<0.0001	−22.2699	<0.001
Absolute Latitude²	<0.0001	<0.0001	−19.7712	<0.001
Hemisphere (Southern)	0.0003	0.0009	0.3458	0.7295
Ejecta Complexity	0.0213	0.0028	7.6943	<0.001
Log Diameter × Southern Hemisphere	0.0119	0.0011	11.1567	<0.001
Log Diameter × Ejecta Complexity	−0.0188	0.0032	−5.8784	<0.001

Note: Additional layer terms and interactions omitted for brevity

Table 5: Model Summary: Improve Model

R^2	Adj. R^2	Sigma	F-statistic	p-value	n
0.4431	0.4428	0.0305	1,707.965	<0.001	38,657

Methods

Sample

- Impact craters with complete morphological data (n = 38,657) were drawn from the Mars Crater Database (Robbins & Hynek, 2012), a comprehensive catalog of Martian craters ≥1 km in diameter identified through Mars Reconnaissance Orbiter imagery and MOLA topographic data.

Measures

- Depth–diameter ratio (d/D): The d/D value is calculated as crater depth divided by crater diameter, and it serves as a proxy for both impact energy and the degree of crater preservation.

Research Question

- Does ejecta complexity predict crater depth-diameter ratios, or do geographic and physical factors dominate this relationship?

Fig 1: Depth-Diameter Ratio vs. Ejecta Complexity

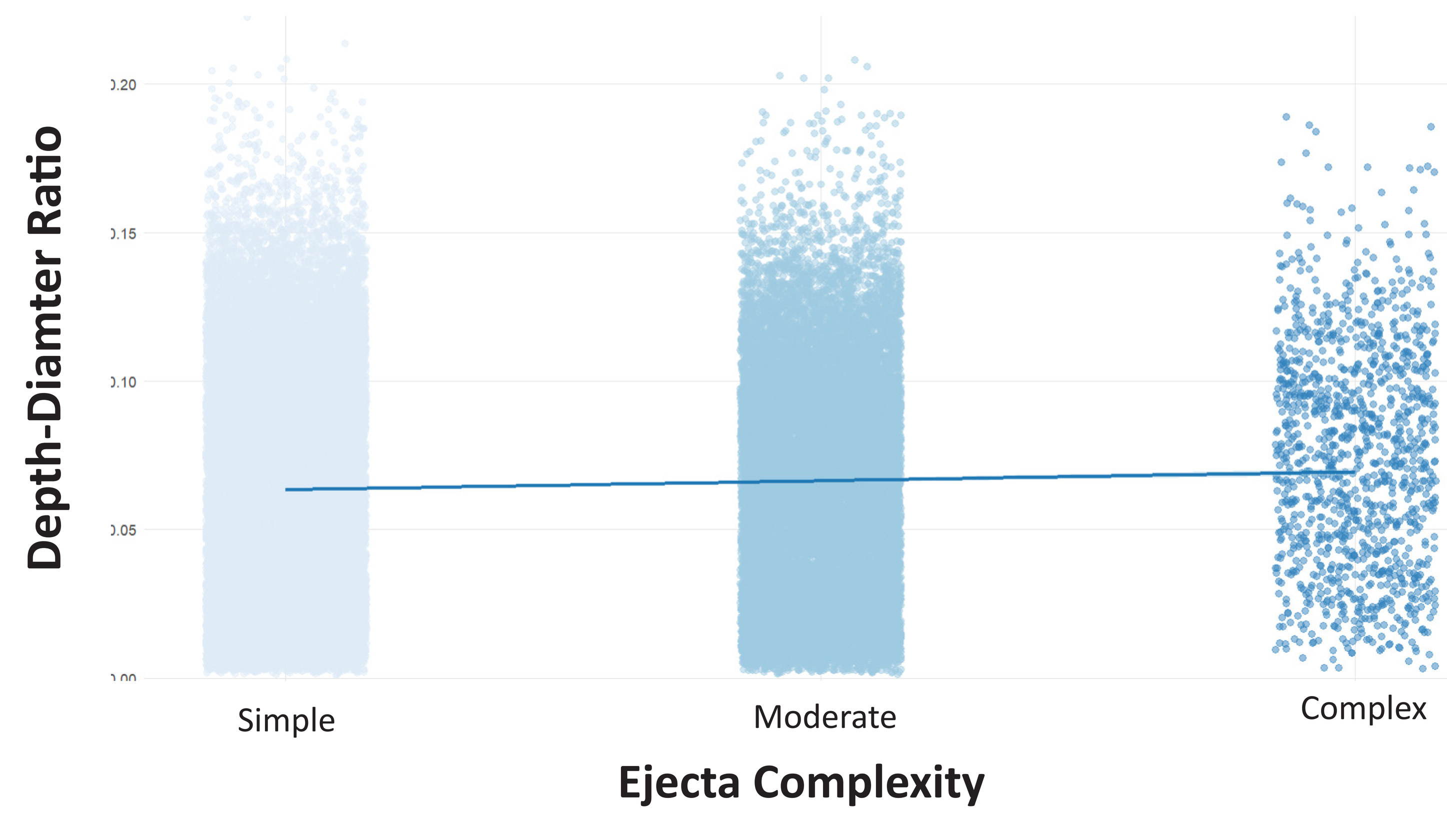

Table 1: Linear Regression: Depth-Diamter Ratio by Ejecta Compexity

Term	Estimate	Std. Error	Statistic	p-value
(Intercept)	0.0634	0.0003	228.2796	<0.001
Ejecta Complexity (Numeric)	0.0030	0.0004	8.0492	<0.001

Table 2: ANOVA: Depth-Diameter Ratio by Ejecta Complexity

Term	df	Sum Sq	Mean Sq	F-statistic	p-value
Ejecta Complexity	2	0.1660	0.0830	49.8956	<0.001
Residuals	38,654	64.2815	0.0017	—	—

Table 3: Tukey HSD Post-Hoc Comparisons: Ejecta Complexity Groups

Contrast	Estimate	95% CI Lower	95% CI Upper	Adj. p-value
Moderate – Simple (1-0)	0.0018	0.0008	0.0028	<0.001
Complex – Simple (2-0)	0.0117	0.0089	0.0146	<0.001
Complex – Moderate (2-1)	0.0099	0.0070	0.0128	<0.001

Discussions

Main Findings

- Ejecta complexity shows a statistically detectable but substantively trivial association with d/D
- Latitude dominates: Ice-rich subsurface at higher latitudes creates shallower, more degraded craters

Interpretation

- While impact energy theoretically links to both depth and ejecta complexity, environmental factors (subsurface volatiles, target material) overwhelm the morphological signal.

Implications

- Crater classification: Cannot infer impact energy from ejecta complexity alone

References

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