Introduction and Motivation

- Previous work suggested that mare basin-related extension on the Moon largely ended \(-3.6\) Ga and contractional deformation ended \(-1.2\) Ga.
- Wrinkle ridges are often associated with mascons (large positive gravity anomalies), yet ridges occur in Mare Frigoris even though a large mascon is not observed.
- Lunar Reconnaissance Orbiter Camera (LROC) enables the discovery of recent tectonic landscapes at scales not previously imaged\(^6,7,8\).
- Landform morphology and stratigraphic relationships imply a complex history of deformation of the Moon.

Landform Distribution

- Radial and concentric graben in eastern Mare Frigoris similar to pattern in other circular mare mascon basins.
- Several landforms parallel to basin boundaries in NW Mare Frigoris, suggest stress localized.
- Numerous ridges in southern Mare Frigoris argue against a basin origin by giant slump\(^9\).
- Sets of parallel ridges in western and central Mare Frigoris trend NW/SE inconsistent with typical mascon stress fields; perhaps from Procellarum basin\(^10\).
- \(\approx250\) km en echelon series of scarps at eastern end of basin.
- Influenced by basin loading, boundary conditions, and/or changes in mechanical properties\(^3,5,9,10\).

Crosscut Craters

- Small craters quickly destroyed from impact gardening.
- Craters \(\geq 80\) m in diameter are \(\leq 1.0\) Ga\(^11\).
- Crosscut craters are older than superposed structures.
- Wrinkle ridges now observed crosscutting craters as small as 21 m, some still showing bright ejecta.
- Calibrated degradation rates for small craters\(^11\) suggest observed crosscut craters as young \(-40\) Ma (\(\leq 3x\))
- Seismic shaking would decrease retention age, so crosscut craters will appear older and more degraded.

Small Graben

- Meter-scale graben occur near some ridges/scarps.
- Usually either parallel or perpendicular to nearest ridge or scarp.
- Inferred principal stresses consistent with flexure or back-limb extension during nearby ridge/scarp growth.
- Some have pit crater chains similar to Vitello graben\(^6\)
- Similar meter-scale graben estimated to be \(<50\) Ma\(^6\).
- Suggests associated ridges/scarps active within \(<50\) Ma.

Conclusions

- More recent tectonism in Mare Frigoris than previously identified.
- Identified many crisp lobate scarps (<1.0 Ga globally).
- Identified numerous small graben (~50 Ma globally) associated with some scarps and ridges.
- Small crosscut craters suggest that some wrinkle ridges were active within last 1.0 Ga and as recently as 40 Ma.
- Wrinkle ridges may have accommodated strain from late-stage global radial contraction.

Landforms

- Lobate Scarp: A simple curvilinear, asymmetric hill formed by near-surface fault\(^4,5,7,8\) (Fig. 1a).
- Wrinkle Ridge: A complex of curvilinear, asymmetric hills formed by folding over a blind fault or faults\(^3,5,10\) (Fig. 1b).
- Graben: A trough formed between two normal faults\(^4\) (Fig. 1c).

Fig. 1: Block diagrams of a) lobate scarp, b) wrinkle ridge, and c) graben.

References

- Hiesinger et al. (2003) JGR 108, E003E85. \(^2\)
- Williams N.R. et al. (2013) JGR 118, doi:10.1002/jgrb.50201. \(^8\)

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Fig. 2: LROC WAC global context of Mare Frigoris (trapezoid).

Fig. 3: Tectonic map of Mare Frigoris over LROC WAC DEM\(^4\).

Fig. 4: Complex ridge-scarp transition in SW Mare Frigoris.

Fig. 5: Examples of small craters crosscut by wrinkle ridges.

Fig. 6: Small graben near eastern Mare Frigoris.

Fig. 7: Small crosscut craters and classify degradation state to determine age\(^11\).

Fig. 8: Map tectonic landforms using ArcGIS.

LROC Narrow Angle Camera (NAC) images with meter-scale resolution.

Nearly continuous NAC image coverage from 45°N to 65°N and 45°W to 45°E.

Map tectonic landforms using ArcGIS.

Determine principal stress relationships.

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