Tectonic Mapping of Mare Frigoris Using Lunar Reconnaissance Orbiter Camera Images

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Introduction and Motivation

- Previous work suggested that extensional tectonism on the Moon largely ended ~3.6 billion years ago[1] and contractional deformation ended ~1.2 billion years ago[2]
- Wrinkle ridges are often associated with mascons (large positive gravity anomalies),[3] yet ridges occur in Mare Frigoris even though no mascon is observed
- Lunar Reconnaissance Orbiter Camera (LROC) enables the discovery of new populations of lobate scarps, wrinkle ridges, and graben at scales not previously imaged[4,5,6]
- Landform morphology[7] and stratigraphic relationships imply a complex history of deformation of the lunar crust

Landforms

a. Lobate Scarp: A simple curvilinear, asymmetric hill formed by near-surface fault[4,5,7] (Figs. 1a&4)

b. Wrinkle Ridge: A complex of curvilinear, asymmetric hills formed by folding over a blind fault[2,8,9] (Figs. 1b&4)

c. Graben: A trough formed between two normal faults[6] (Figs. 1c&5)

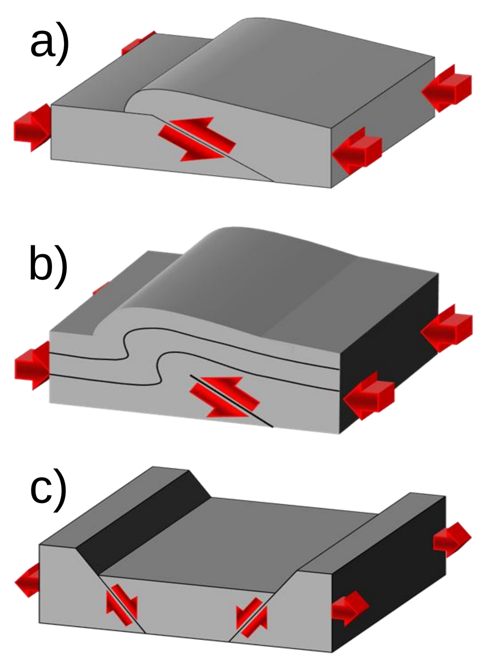

Fig. 1: Block diagrams of a) lobate scarp, b) wrinkle ridge, and c) graben

Methods

- LROC Narrow Angle Camera (NAC) images with meter-scale resolution
- Swath of nearly continuous image coverage from 55°N to 67°N and 50°W to 15°E
- Map tectonic landforms in NACs using ArcGIS
- Infer principal stress directions and sources from landform orientations and distributions
- Compare overlapping images with different lighting conditions

Landform Distribution

- Cumulative lengths of ~3000 km of wrinkle ridges, 270 km of lobate scarps, and 40 km of graben
- Ridges and scarps often (but not always) parallel mare-highland boundaries
- Influenced by basin loading, boundary conditions, changes in mechanical properties, or all of the above?[3,8,9]

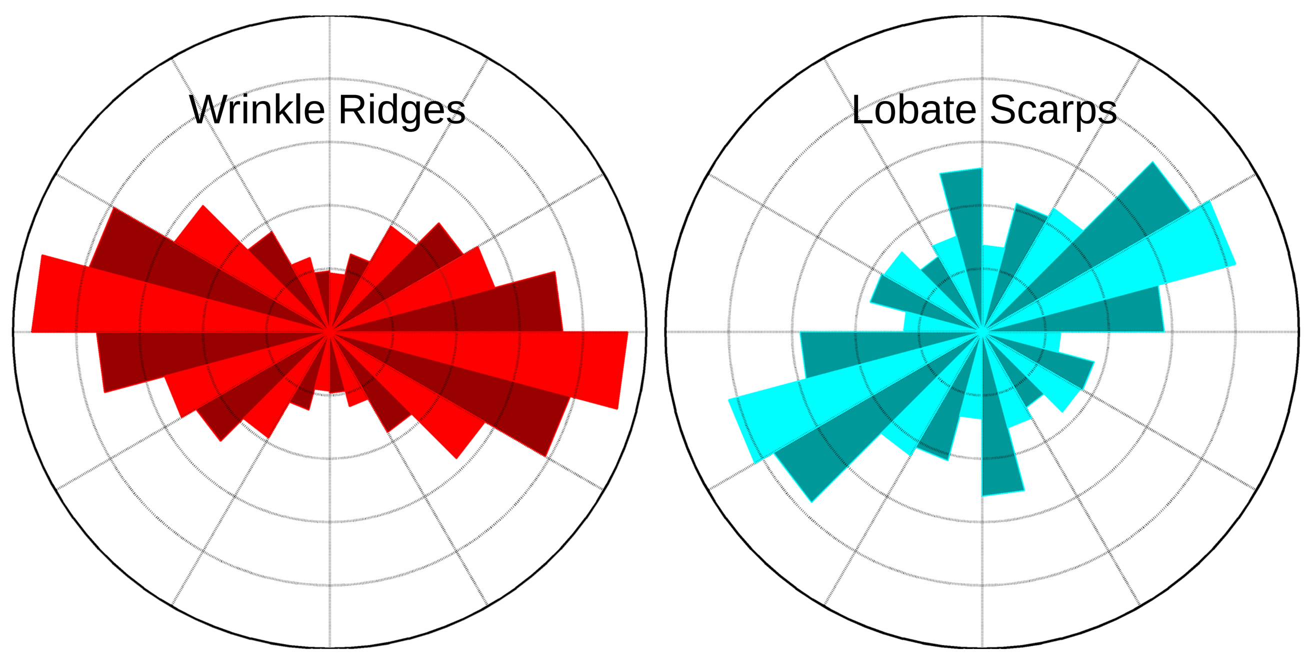

Fig. 2: Length-weighted rose diagrams of wrinkle ridges and lobate scarps. Preferred orientations suggest an anisotropic stress field.

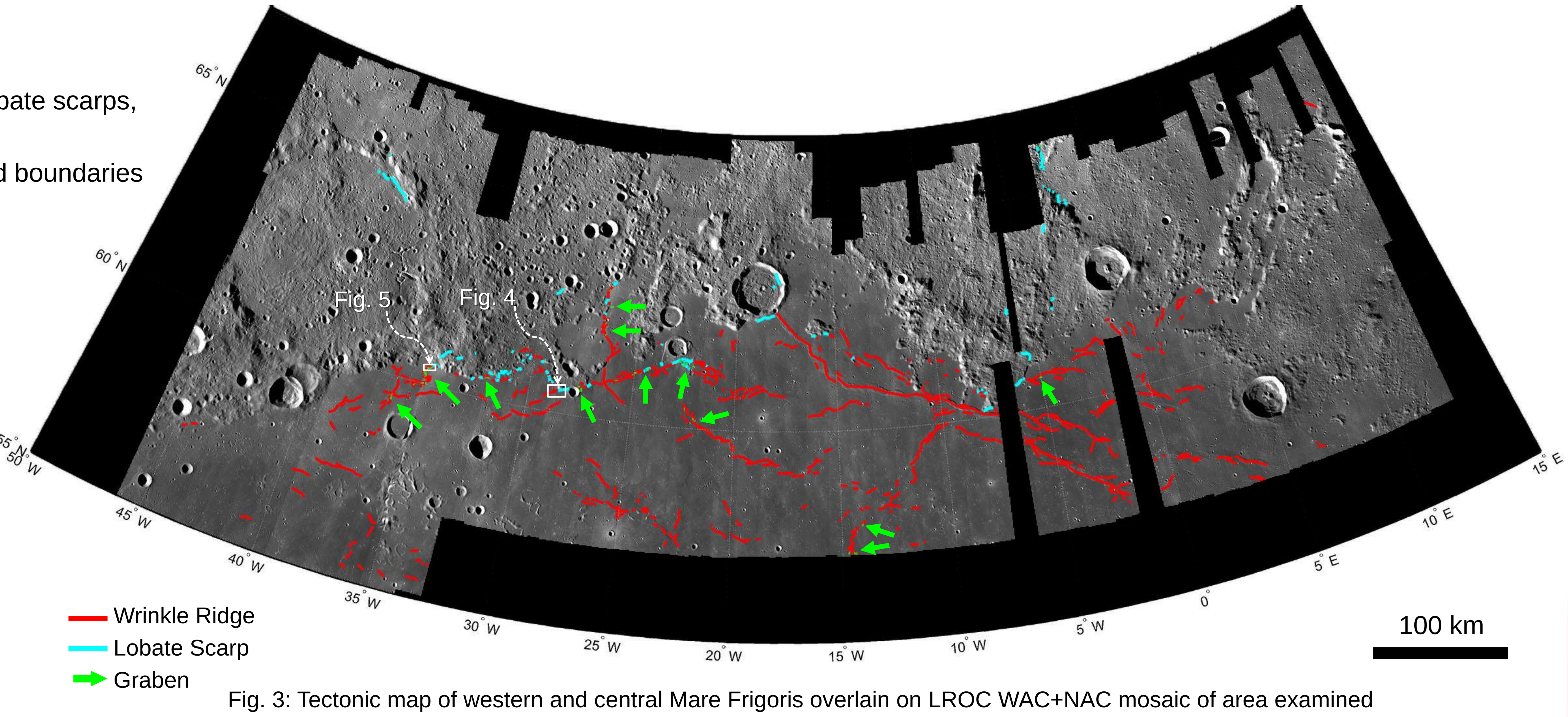

Fig. 3: Tectonic map of western and central Mare Frigoris overlain on LROC WAC+NAC mosaic of area examined

Ridge-scarp Transitions

- Several complex wrinkle ridges transition to simpler lobate scarps at mare-highland boundary
- Some deformation across transition likely concurrent
- Previous estimates of age ranges for ridges and scarps don't overlap[2,4,5]
- If <1 billion years old, ridges could accommodate strain from late-stage global radial contraction

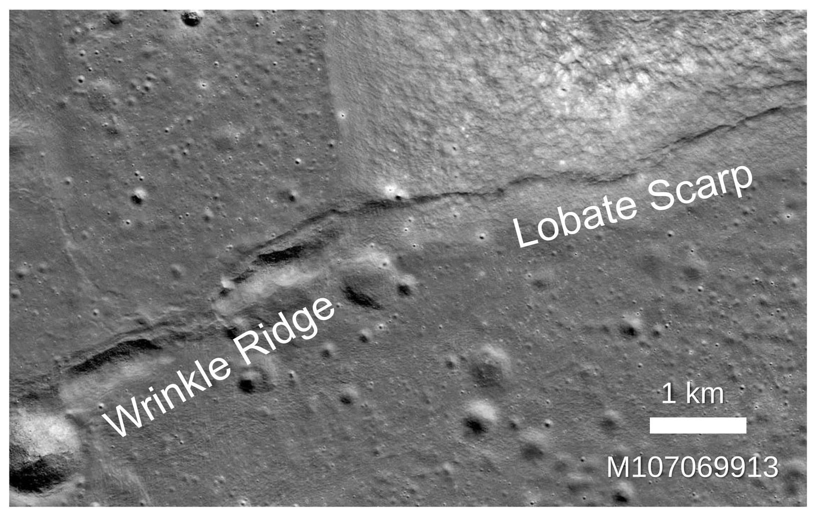

Fig. 4: A ridge-scarp transition along the northern edge of Mare Frigoris

Graben

- Often parallel or perpendicular to nearest ridge or scarp
- Consistent with stress field expected during ridge growth
- Some have pit crater chains similar to Vitello graben[6]
- Similar meter-scale graben estimated to be <50 million years old[6]
- Formed by flexural bending or intrusive inflation?[6]

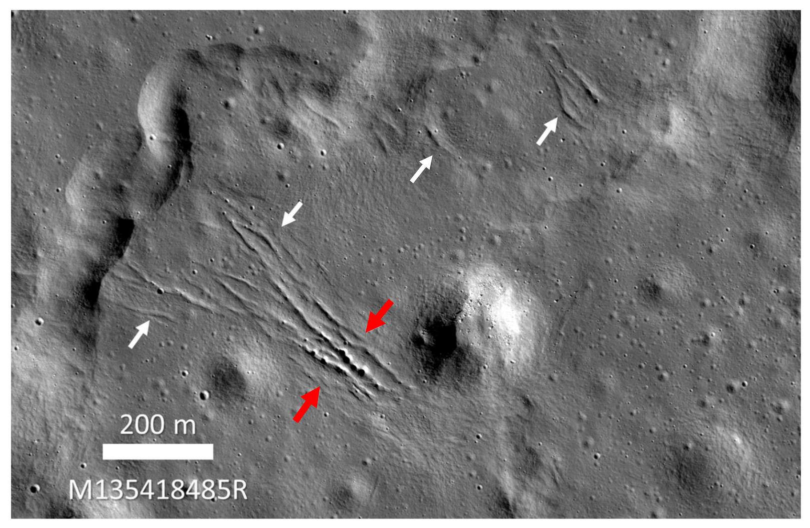

Fig. 5: Cluster of small graben and pit crater chains (red arrows) next to a wrinkle ridge

Lighting Bias Test

- Compared images with solar incidence >75° to mapped images with incidences down to ~60°
- Only a few very small, low-relief graben undetected
- Lighting bias primarily against very low-relief features
- Orientations not significantly biased by lighting

Future Work

- Extend tectonic map spatial coverage
- Examine additional images with different lighting
- Constrain ages with crater counts and regolith diffusion models[6]
- Examine landform topography with Lunar Orbiter Laser Altimeter (LOLA) and model subsurface geometries[10]
- Estimate stress magnitudes and compare to basin evolution models

Conclusions

- More complex and extensive tectonism than previously identified in Mare Frigoris
- Orientation and distribution controlled by basin-localized influences
- Possible genetic relationship between some scarps, wrinkle ridges, and graben
- Some wrinkle ridge deformation may be more recent than previously thought

References

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