GLOBAL Fracture Pattern on Mercury Revealed by Polygonal Impact Craters.
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Introduction: Mercury’s surface was predominantly shaped by impact cratering, volcanism, and tectonic activity. Due to global contraction—the volume decrease of the planet associated with a long, sustained period of cooling—shortening structures form the most dominant and widespread tectonic landforms on Mercury [1]. Previously observed distributions of these shortening structures show north-south orientations in the equatorial and mid-latitudes and either no preferred orientations [1] or a concentric pattern around the poles [2]. Thrust fault distributions predicted to result from global contraction superposed by tidal despinning—the slowing of rotation to lock Mercury in its current 3:2 spin-orbit resonance with the sun—would show north-south orientations in the equatorial and mid-latitudes and random orientations at the poles [3], largely matching the observations. Joints that are predicted to form from tidal despinning alone would be oriented east-west in the equatorial regions and have no preferred orientations at the poles [3]. Taken together, patterns of the observed and predicted global distribution structures all systematically vary across the planet.

Mercury’s surface is heavily cratered. An impact crater forms when a small planetary object, such as an asteroid or comet, hits the solid surface of a larger planetary body. Impact craters are commonly assumed to possess circular plan-view geometries. However, polygonal crater geometries are commonly observed across the surfaces of planetary bodies in our Solar System [4]. Perhaps the most prominent example of a polygonal impact crater is the nearly square Meteor Crater, AZ [5]. Polygonal impact craters are also observed on the rocky bodies in the inner Solar System [e.g., 6–9], as well as icy bodies in the outer Solar System [e.g., 10–12]. Regional fracture sets within the target bedrock that pre-date the impacts are generally accepted to produce crater rims with straight segments, which parallel and directly utilize the fractures [e.g., 13–15].

Methods: In order to evaluate if systematically oriented fracture sets on Mercury govern the shapes of impact craters, we have mapped 7,146 impact craters in the diameter range of 20 to 400 km using Mercury Surface Space ENvironment GEnochemistry and Ranging (MESSENGER) global image and topography datasets [16]. To map consistently across Mercury’s surface, we re-centered the projection of the map area for every 10° by 10° bins and mapped the crater rims with polylines placing regularly spaced vertices at 2 km using the ArcGIS stream mode. We then used the simplify tool in the ArcGIS Toolbox to determine which parts of the crater rims did not display any change in orientation. The simplify tool removed the vertices that did not contribute toward defining the plan-view crater shape. Next, we split the polylines into individual segments and calculated the geodetic lengths and orientations of all crater rim segments. The distribution of all straight rim segments longer than 15 km is displayed in Figure (1).

We analyzed the orientations of a total of 124,671 crater rim segments. The orientations of all straight rim segments longer than 10 km were analyzed by plotting rose diagrams using the R software environment. In particular, we weighted our rose diagrams by the length of the individual crater rim segments, as longer straight rim segments likely reflect more prominent fracture sets in the bedrock. For the preliminary interpretation of our data in this abstract, we displayed our results in 30° by 30° geographical bins across the surface of Mercury and display the results in equirectangular projection (Figure 2). We color coded our rose diagrams to display the density of measurements that went into our analysis, where warmer colors represent a greater total length of crater rims per geographical bin area. To assess any broader-scale variations of fracture patterns, we also plotted rose diagrams in bins that span entire latitudinal and longitudinal bands (Figure 2, pink rose diagrams).

Results: Our mapping results are presented in Figure (1), and the orientations of crater rim orientations are displayed in Figure (2). Of all mapped craters (Figure 1, gray lines) approximately 70% include straight rim segments (Figure 1, red lines). Visual inspection of the map show various orientations without clear systematic patterns. But our analysis of rose diagrams reveals that straight rim segments of craters show a pronounced preferred east-west orientation at the poles (Figure 2). In the equatorial and mid-latitudinal regions, however, they only show weak north-south or random orientations.

Conclusions: Our findings indicate that fracture patterns revealed by polygonal impact craters on Mercury show a global pattern. This pattern can be compared to previously observed distributions of fault-related landforms and to predictions. The fracture pattern revealed by straight crater rims to show preferred east-west orientation at the poles is consistent with observed fault orientations [e.g., 2]. However, orientations of straight crater rims do not show a strong visual correlation with those of the mapped faults at the
equatorial and mid-latitude regions. In addition, our observations do not match the global joint pattern predicted to have formed from tidal despinning [3]. These results have implications for the global tectonics and fault reactivation on Mercury. Future statistical and geospatial analyses will be performed to further assess the variations of fracture patterns and their relationship with the observed geology across Mercury.

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Figure 1: Map of plan-view shape of impact craters between 20 and 400 km across Mercury (gray lines) superposed with those crater rims determined to be straight segments (red) presented in equirectangular projection.

Figure 2: Rose diagrams showing the distribution of straight rim segment orientations on Mercury in 30° by 30° bins, color-coded by density of measurements. Pink rose diagrams include measurements of entire longitudes (bottom row) or latitudes (left row).