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Caloris basin, Mercury: History of deformation from an analysis of tectonic landforms

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ABSTRACT

The 1640 km diameter Caloris basin is the largest impact basin on Mercury and hosts three distinct suites of tectonic structures in its substantially deformed smooth plains, indicative of the basin's complex history. These structures, i.e. radial graben comprising Pantheon Fossae, concentric graben/troughs arranged in an irregular pattern, and wrinkle ridges, are found at various regions throughout the basin and occasionally interact. We document the locations, orientations, and cross-cutting relationships of these structures using high-resolution MESSENGER images. We suggest that Caloris shows a history of continuous deformation, resulting from the contemporaneous formation of sets of strain compatible tectonic structures, rather than discrete stages of deformation producing each suite independently in temporal sequence. We propose that radial graben formed continuously in the basin's early deformational history, following initial wrinkle ridge formation possibly representative of a multi-ring basin structure, overlapping with continued wrinkle ridge formation, and persisting with the formation of concentric graben after contraction ceased.

1. Introduction

The Caloris basin on Mercury is the planet's largest impact basin and one of the largest recognized basins in the Solar System. It measures approximately 1640 km in diameter and is also host to one of the most tectonically deformed smooth plains on the planet, the Caloris Planitia (Byrne et al., 2013). The basin was first imaged by Mariner 10 during its Mercury flybys in 1974–1975, though only a portion of its eastern side was initially visible (Fig. 1). It has since been fully imaged by the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft (Fig. 1), which conducted its first flyby of the planet in 2008 (Solomon et al., 2008), went into orbit around the planet on March 18th 2011, and recently ended its mission on April 30th, 2015 by impact on the planet's surface.

From its initial imaging by Mariner 10, the Caloris basin appeared to be unique due to its large size and the variety of observed landforms, and now a more detailed and complex view of the basin is available from the high resolution images returned by the MESSENGER spacecraft. There are several distinct suites of tectonic structures of both contractional and extensional character found at various regions throughout the basin, which occasionally interact and show complex relationships; dominantly concentric wrinkle ridges, appearing as raised linear or sinuous crests, and populations of graben, normal-fault bounded trenches of both radial and concentric orientations, are found within the interior plains. Each of these types of structures is representative of a set of hoop (azimuthal) and radial strain observed at their respective locations, and the relations between these interacting tectonic structures, as well as their positions and orientations, allow for insight into the basin's development and derivation of its history of tectonic deformation. Previous research has described the sequence of tectonic events of the basin in terms of discrete stages of a dominant character, with either contraction predating extension (Watters et al., 2009b), or alternating suites of extension and contraction occurring in sequence (Basilevsky et al., 2011). In this paper, we describe a more complex history of deformation of the basin through mapping of tectonic landforms and analysis of their locations, cross-cutting interactions with other structures, orientations, and the strains accommodated by these landforms, using MESSENGER images. We propose that certain sets of orthogonal structures may have formed contemporaneously or overlapping in time. In addition, we compose a partial strain profile of the basin in order to provide constraints for future formation models. By determining a rigorous history of tectonic deformation, we can gain further insight into the geologic history of the Caloris

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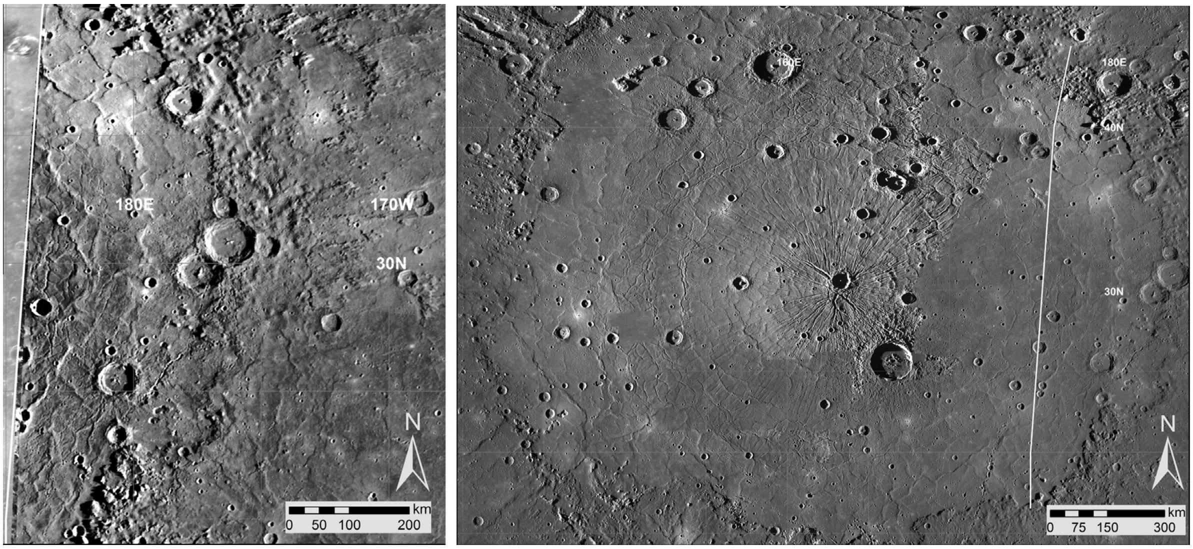

Fig. 1. Left: Mariner 10 image of the eastern portion of the Caloris basin; right: MESSENGER 250 m/pixel global mosaic of the Caloris basin showing extent of Mariner 10 imaging (white line); simple cylindrical projection, center: 30°N, 163°E.

basin from both basin local and global mechanisms, and compile a sequence of events from impact to late-stage topographic modifications (Klimczak et al., 2013).

2. Basin tectonic structures: identification, description, mapping

The interior of the Caloris basin is filled with smooth volcanic plains that were deformed to yield the observed variety of tectonic structures (Murchie et al., 2008; Head et al., 2008). Its contractional and extensional tectonic structures can be categorized into three distinct classes. The first class is the array of radial graben located from the basin center to approximately 400 km, or 0.5*r* outward, called Pantheon Fossae (Murchie et al., 2008; Watters et al., 2009a). The second class is the concentric graben which primarily appear in an annulus between 350 km and 600 km from the center of the basin. This class consists of both circumferentially oriented graben, often curved or sinuous in shape, and features described as "polygonal troughs" (Watters et al., 2005), which are comprised dominantly of concentric graben with some radial graben. These graben are arranged in an irregular pattern that divides the terrain into roughly polygonal shapes. The third class is contractional wrinkle ridges, which are observed throughout the basin. They are dominantly concentric in nature, though show decreasing preference in orientation toward the basin rim where they exhibit random orientations forming polygonal patterns. Examples of radial wrinkle ridges can be observed in the inner regions of the basin at 320 km; however, these are few in number and likely represent either localized strain conditions not necessarily representative of the basin's trends, or the transition to the irregular pattern.

We identify and map features using the 250 m/pixel global mosaic of Mercury, compiled from MESSENGER images through NASA's Planetary Data System (PDS), and analyze each suite of tectonic structures separately and in combination with the others. Fig. 2 shows the number of structures in each class found in 100 km range bins from the center, and Fig. 3 shows maps of each class of tectonic landforms separately. The numbers of structures are not weighted by their length, and our counts are likely an underrepresentation of the total numbers of structures present in the basin due to lighting geometry bias preventing clear identification of all structures. In particular, the mosaic of the eastern portion of the basin features non-optimal lighting conditions relative to the orientations of the structures, and fewer structures were identified there relative to similar radial distances at other regions in the basin. The relatively high count of concentric graben is due to the large number of small graben structures, many of which compose the irregular trough structures.

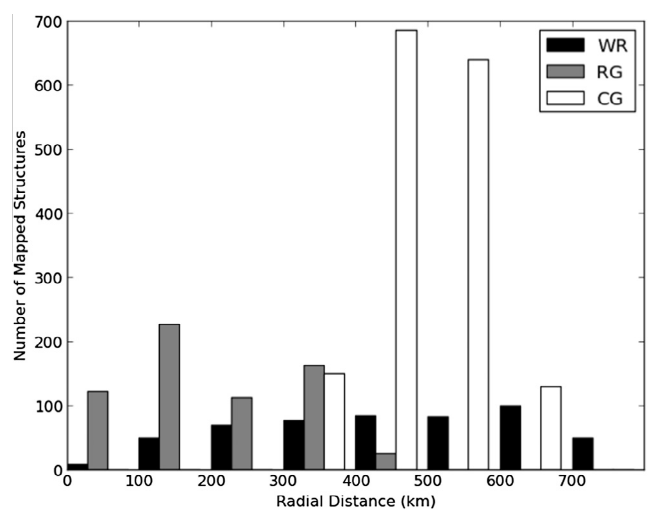

Fig. 2. Plot showing the distribution of structures mapped in the basin for each class of defined tectonic structures; WR = wrinkle ridges, RG = radial graben, CG = concentric graben. Counts are binned in radial ranges of 100 km.

2.1. Radial graben and Pantheon Fossae

The radiating suite of graben found at the center of the Caloris basin comprise its most unique feature, Pantheon Fossae. The radial graben have previously been described and categorized into two sets (Klimczak et al., 2010). All but five graben are included in Set 1; they have widths ranging between 1 and 2.5 km and are orientated radially to a central point just south of Apollodorus crater found near the center of the Caloris basin at approximately 30°N, 163°E. The other five radial graben form Set 2 and only appear at the innermost part of Pantheon Fossae surrounding Apollodorus. They are distinct due to their greater widths of up to 8 km and their