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Evidence for two stages of compressive deformation in a buried basin of Mercury

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ABSTRACT

The surface of Mercury shows abundant compressive tectonic landforms, including lobate scarps, wrinkle ridges and high-relief ridges, which are different manifestations of thrust faults, and long-wavelength topography variations, which could be the expression of large scale folding. These landforms probably relate to planetary cooling, although other factors such as mantle convection, tidal despinning or true polar wander could affect the distribution, expression and orientation patterns of compressive features. In this work we show that an area of smooth plains including a buried ~500-km-diameter impact basin experienced two different stages of deformation. The younger deformation stage is characterized by a set of NW–SE oriented wrinkle ridges affecting the smooth plains and having the same approximate orientation as the wrinkle ridges and lobate scarps deforming the surrounding terrains. The older set of tectonic structures consists of NE–SW oriented, closely spaced, subparallel, quasi-rectilinear and low-relief ridges, partially buried by the smooth plains material and crossed by the wrinkle ridges. Therefore, our results suggest that several events occurred between both deformation stages: at least one stage of basin filling; a change in stress orientation, an increasing in the wavelength and amplitude of deformation, and maybe an increasing of the thickness of the deformed layer. Our observations imply a complex stress history for compressive deformation, maybe influenced by the internal and/or orbital/rotational history of Mercury, and are illustrative of the complexity of tectonic history likely to have affected many or most other regions of the planet.

1. Introduction

The surface of Mercury shows abundant tectonic landforms, mostly indicating surface contraction (Strom et al., 1975; Dzurisin, 1978; Watters et al., 2009). Compressional features on this planet mainly include lobate scarps, wrinkle ridges and high-relief ridges (for reviews of the tectonics of Mercury see Watters and Nimmo (2010) and Byrne et al. (2014)). Lobate scarps usually have an arcuate to linear form and an asymmetric cross section characterized by a steeply rising scarp face and a gently declining back scarp; wrinkle ridges are sinuous, morphologically complex (including front and back scarps), and generally located on volcanic plains; high-relief ridges are proportionally scarce and symmetric in cross section. Both types of features are interpreted as different surface manifestations of thrust faults, whose appearance depends of factors such like angle of fault dip and type of material on the deformed surface (Watters et al., 2009; Watters and Nimmo, 2010; Ruiz et al., 2012; Byrne et al., 2014). Also, there is evidence of long-wavelength topography variations, which affect even relatively young terrains as the northern smooth plains and Caloris basin, which could also be the expression of global contraction, and maybe large scale folding of Mercury (Zuber et al., 2012; Klimczak et al., 2013). The ubiquitous contraction observed is considered to be due to global planetary cooling (e.g., Strom et al., 1975), although it is debated if other factors such as mantle convection, tidal despinning or true polar wander affect the pattern of distribution and orientation (and maybe expression) of compressive features (e.g., Melosh and McKinnon, 1988; King, 2008; Matsuyama and Nimmo, 2009).

Many of the large, hundreds of kilometer long or even longer, thrust-fault related tectonic structures observed on the mercurian surface formed early (e.g., Watters and Nimmo, 2010; Ferrari et al., 2013; Banks et al., 2014), although tectonic deformation continued throughout the planet history, and several lobate scarps, including

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small-scale ones (of ten of kilometers of length or shorter), continued to be formed in relatively recent times (Watters et al., 2009; Banks et al., 2012). Large-wavelength topographic deformation affects the smooth plains, but their absolute timing is currently unclear, although it postdates the emplacement of Calorian smooth plains (Balcerski et al., 2012; Dickson et al., 2012; Solomon et al., 2012; Zuber et al., 2012). However, there is some information suggesting a relatively early age, roughly contemporaneous to the formation of large lobate scarps, for at least part of that large-scale topographic deformation (Ruiz et al., 2013).

Regardless of the absolute timing of deformation, improving our knowledge of the relative timing between different deformation structures is very important in order to understand the tectonic and stress history of Mercury. In this work we show that an area of smooth plains close to the equator of this planet (Fig. 1) including a nearly circular buried basin (which is most probably an impact basin; Fasset et al., 2012), was affected by two main deformation stages. These stages are characterized by two distinctive sets of compressive tectonic features: (1) a NE–SW oriented set of quasi-rectilinear ridges, with relatively low relief and that seem partially buried by the smooth plains material and (2) a NW–SE oriented set of large wrinkle ridges that affects the smooth plains and the low-relief ridges. We also show that there was a change in the style, amplitude and orientation of most of the tectonic structures, indicative of a complex stress history.

2. Study area

The area studied in this work is located in the equatorial region of Mercury, where there is a nearly circular, ~500-km-diameter, basin centered around 4°N, 74°E (Fig. 1). Fasset et al. (2012) have interpreted this basin as a probable impact basin (and referred to it as b12, nomenclature used in this work hereafter), but the term "probable" was used by these authors in a very conservative sense, since they consider impact basins verified only if they preserve a substantial part (at least 50%) of the outer rim. In any case, the exact origin of this basin is unimportant for our study, because the spatial pattern of the main tectonic structures analyzed in this work is unaffected by basin limits or shape (see Section 3), although there are limited cases of some structural by impact craters walls.

The b12 basin is east of the Firdousi crater and its NNE limit is superimposed on the SW rim of the Faulkner crater. The interior of the b12 basin is covered by smooth plains, which also extend into the terrains between the craters Firdousi and Faulknernd, as well as to the northwest of these three basins (Denevi et al., 2013). The approximate limits of the basin can be observed in the stereo-derived topography of Preusker et al. (2011; see their Fig. 6), where the plains covering the b12 basin floor exhibit the lowest elevation in the area, roughly 1–2 km lower than the exterior smooth plains.

For this work, we have used mosaics created by the USGS using high-incidence angle NAC images from MDIS instrument obtained during MESSENGER flybys. The illumination conditions of flyby images are more useful for the present study than higher resolution images from the orbital mission, because high incidence angle enhances the shadows, which emphasize the relief of geologic structures. This is important when dealing with tectonic structures, because it favors the identification of subtle structures.

3. Main tectonic structures

Fig. 2 shows the main tectonic features deforming the smooth plains in the b12 basin, and the crosscutting relations between them. The lobate scarp (Fig. 2, L1) superimposed on the east/southeast approximated location of the basin rim is the most prominent feature in the zone; the basin rim is not clearly visible in this part, maybe due to the deformation caused by the lobate scarp. The presence of tectonic structures (lobate scarps, wrinkle ridges or even grabens) on mercurian impact structure rims is frequent (e.g., Fasset et al., 2012; Rothery and Massironi, 2013). The lobate scarp L1 has more than 1 km of relief (see Preusker et al., 2011),

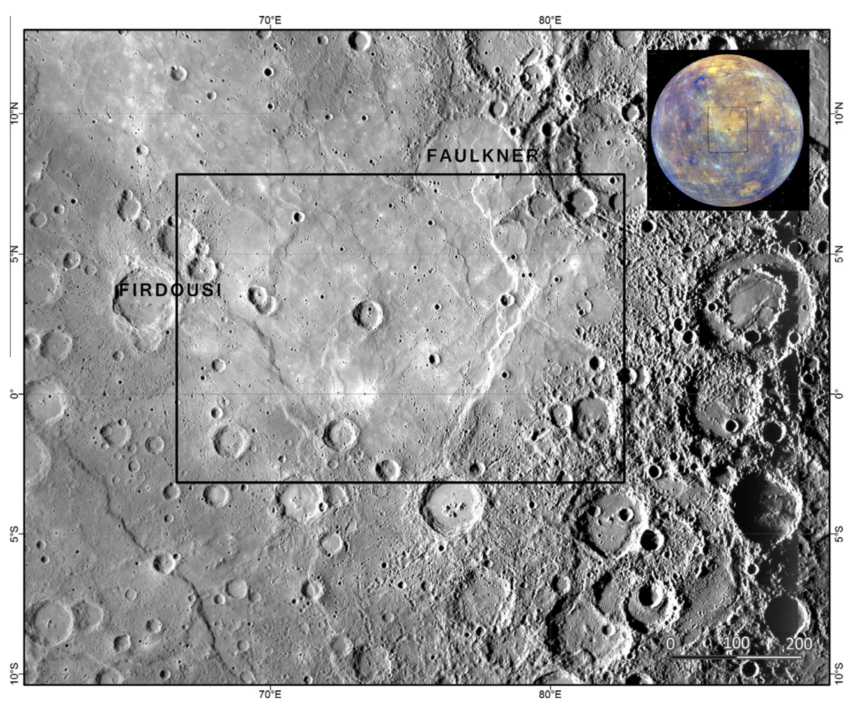

Fig. 1. The smooth plains-covered basin studied in this work, which is located west of the Firdousi crater and superimposed to the Faulkner crater. The area included in the box is the same in the globe and in the context image. Note the NW–SE oriented lobate scarp in the SW corner of the image, out of the box.