The main phase of global OBP development and associated valley network and fan deposit formation is constrained to end in the late Noachian or Early Hesperian (Irwin et al., 2005b; Fassett and Head, 2008a). OBPs are often found in chains, where the outlet valley of one OBP becomes the inlet valley of another (Cabrol and Grin, 1999; Irwin et al., 2005b; Fassett and Head, 2008b), and they sometimes integrate into extensive valley systems that debouche into large basins. OBPs sometimes, but not always, contain morphological features, such as sedimentary fans (Fassett and Head, 2005; Wilson et al., 2007; Burr et al., 2009), which have been interpreted to be deltas similar to those found in lacustrine environments on Earth (e.g. Malin and Edgett, 2003; Moore et al., 2003; Bhattacharya et al., 2005; Wood, 2006).

In this paper, we report on evidence for OBPs and associated hydrologic activity in Erythraea Fossa. First we use topographic and image data to show evidence for three OBPs, some with well-preserved intra-basin fans. We also make the case for interconnecting fluvial valleys that, in cases, are sinuous and show preserved inner channels. Measurements based on data from the Mars Orbiter Laser Altimeter (MOLA) are used to show that the Erythraea Fossa OBPs had a storage capacity for water on the order of tens of cubic kilometers. We then present evidence that the OBP system in Erythraea Fossa was fed by precipitation (rain, snow, or direct condensation) and runoff for at least part of its existence, and evidence that the OBP system probably experienced variations in hydrological conditions. Last, we discuss the implications for the climate and hydrology in the surrounding region, including the Uzboi–Ladon–Margaritifer system (Grant, 2000; Grant and Parker, 2002) and Holden crater (Pondrelli et al., 2005; Grant et al., 2008).

2. Methods

Orbital missions to Mars in the past decade have supplied us with detailed information on the topography and morphology of the martian surface. For topographic information, we make use of Mars Orbiter Laser Altimeter (MOLA) 1/128 pixel per degree gridded data (463 m/px) (on board Mars Global Surveyor, see Smith et al., 1999), and High-Resolution Stereo Camera (HRSC) digital terrain models at up to 125 m/px (on board Mars Express, see e.g. Gwinner et al., 2009). Morphologic information is primarily derived from the Context Camera (CTX) (on board Mars Reconnaissance Orbiter, see Malin et al., 2007) image data at resolution ~5 m/px. To augment CTX data, we use Thermal Emission Imaging System (THEMIS) (on board Mars Odyssey Spacecraft, see Christensen et al., 2003) VIS (~18 m/px) and IR (100 m/px) images and nadir HRSC (Neukum et al., 2004) images (up to 12.5 m/px); High Resolution Imaging Science Experiment (HiRISE) (on board Mars Reconnaissance Orbiter, see McEwen et al., 2007) images (0.25 m/px) were also used in available locations. The data was compiled and co-registered in the ArcMap GIS environment using the USGS ISIS software package.

We inspected several hundred catalogued proposed paleolakes (Cabrol and Grin, 1999; Fassett and Head, 2008b) and their nearby areas. The likelihood that Erythraea Fossa (31.5 W, 27.3 S) was a paleolake was first recognized in this survey. It was chosen for detailed investigation on the basis that it was not previously described in detail and exhibited clear and well-developed sedimentary deposits, inlet and outlet valleys, and had high-quality data available.

We used a combination of morphologic data and topographic data to identify inlet and outlet valleys and determine the direction of their local slope. Surface areas and volumes of the newly-proposed OBPs were obtained by finding the highest elevation closed contour, based on HRSC data, in the sub-basin containing the OBP. The topography within these closed contours was then extracted, enabling direct measurement of the surface area and volume of the paleolakes by using 3D Analyst Tools in ArcMap 9.3.

Fans discussed in this paper were identified following the criteria outlined by Williams and Malin (2008) and Metz et al. (2009).

3. Description of Erythraea Fossa

3.1. The case for paleolakes

Erythraea Fossa is a trough that extends radially east ~4000 km from Tharsis. Similar graben extend a comparable distance westward from Tharsis (Wilson and Head, 2002), and Erythraea Fossa may have been formed by cracking of the crust due to the propagation of a radial dike fed by magmatism from Tharsis. Alternatively, many large impact craters are characterized by anomalously large secondary crater chains that are generally radial to the crater and that taper in width distally (e.g. Mars: Moreux crater; the Moon: Schrodinger crater). The position of Erythraea Fossa on the rim of Holden, its generally radial nature, and its tapering and decreasing depth distally, suggest that this feature may be a secondary crater chain formed during the Holden crater-forming event. The Erythraea Fossa structure is superposed by ejecta from Holden crater (Fig. 1), and thus if it is a radial crater chain, it formed during the early phase of ejecta emplacement during the cratering event. There are three sub-basins in Erythraea Fossa (East, Middle, and West) that are divided from each other by topographic highs such that each has a closed contour delineating it as a distinct sub-basin (Figs. 2, 3, and 4A).

The sub-basins in Erythraea Fossa each have at least two large incisions into their margins: at the point where (i) a valley enters from higher elevation into the sub-basin and (ii) the bounding contour is breached by a valley leading to lower elevation than the incision (Figs. 4 and 5). There are also several small incised valleys that cross the graben rim (Fig. 6B and C). The observed valleys trend down-gradient on the basis of the present topography, many of them are sinuous, and one exhibits what appears to be well preserved inner channels (Fig. 5). Therefore, we interpret the valleys entering from higher elevations as inlet valleys—the large ones being the principal inlet valleys and the small ones being minor inlet valleys. We interpret the valleys leading to lower elevations as outlet valleys. This implies that, while the basins were fed primarily through the principal inlet valleys, flow into the basin was also augmented via flow through the minor inlet valleys.

Additionally, many of the valleys in Erythraea Fossa terminate in fan-like features, such as at the terminus of the outlet valley from West sub-basin (Fig. 5) and the lobate feature at the terminus of an inlet valley (Fig. 6B). There are also small valleys entering the graben from the south that terminate in flat, bright-tipped, lobate features (Fig. 6). The lobate features have a range of slopes from 1.3° to 4.6°, with an average slope of 2.6°. These are likely to be alluvial fans or deltas (e.g. Howard et al., 2005; Metz et al., 2009). On the south-facing slope of the graben, there are low-albedo lobate features that appear to have slumped or been transported by some other mass wasting process; these have a steeper average slope of 6.4° (Fig. 6D and E). Additionally, the features on the south side have a longer lateral extent than the features on the north side, which is also consistent with wetter processes on the south side (e.g. Williams and Malin, 2008). Mass wasting or destabilization of these slopes may or may not have been related to the period of lacustrine modification of Erythraea Fossa.

The termini of the inlet valleys to East sub-basin are at an elevation of ~−410 m and the valley connecting East sub-basin and Middle sub-basin breaches the basins at an elevation of −400 m (Figs. 2 and 3). The incision into the rim of Middle sub-basin from the inlet valley to West sub-basin is at ~−315 m. The elevation of the fan at