BRECCIA DIKES IN IMPACT CRATERS ON EARTH: CHARACTERITICS AND CRITERIA FOR RECOGNITION ON MARS. J. W. Head[1] and J. F. Mustard[1], [1]Department of Geological Sciences, Brown University, Providence RI 02912 USA (james_head@brown.edu).

Introduction: Impact cratering is one of the most significant processes shaping planetary geomorphology, particularly in early planetary history [1]. Keys to the nature of the impact cratering process lie in exposures on Earth of impact craters planed off to different depths by erosion [2], on the Moon in the exquisite preservation of pristine surface textures and fresh crater morphology formed without an atmosphere [3], and on Venus in the very well-preserved morphologies representing interaction of the ejecta and the atmosphere [4]. On Mars, a wide range of distinctive lobate ejecta deposit morphologies are interpreted to be related to substrate volatiles [5] or interaction of the ejecta with the atmosphere [6]. Active eolian processes and episodic fluvial activity on Mars, as well as regional blanketing and exhumation, however, have obscured the detailed fine-scale morphology of the all but the most recent impact craters [7]. Thus, in using different planetary environments to study impact cratering, Mars tends to lie between the Earth and the Moon, with more gradation than the Moon, but much less planation than the Earth.

Recent Mars exploration has obtained high-resolution imaging, spectroscopy and altimetry data that permit the further analysis of impact cratering deposits in much more detail than previously possible. These new data, combined with an increased understanding of both the impact cratering process in general and deposition/exhumation processes on Mars, has led to renewed interest in the role that Mars can play in further decoding important aspects of the cratering process. In this paper we report on the discovery of a complex system of ridges on the floor of an impact crater that we interpret to be breccia dikes formed in concert with the impact cratering event and subsequently exhumed. We document the characteristics of these features, show the nature of the overlying deposits and their exhumation, assess their role in the cratering process through comparison with terrestrial breccia dikes, develop criteria for the recognition of these features and distinguishing them from magmatic dikes. In this abstract we outline the nature of breccia dikes on Earth and summarize criteria for their recognition o Mars.

Breccia Dike Characteristics in Terrestrial Craters: Breccia dikes are a common feature in eroded terrestrial complex impact craters [e.g., 8]. In a classic study, Lambert [8] proposed a classification system of breccia dikes in crystalline rocks distinguishing Type A (range up to a few cm in width, consist of small rounded commonly monomineralic fragments embedded in a cryptocrystalline matrix which often displays fluidal texture and which can be subdivided into liquid and solid particle flows) and Type B (angular to subrounded rock, mineral and glass fragments with a wide size distribution in a matrix of similar but finer grained material). Type B dikes can be subdivided into monomict and polymict subtypes and the polymict dikes show both no wall displacement (B_1) and relative displacement of the fracture wall (B_2). B_2 dikes range from cm to m wide and form simple, straight continuous dikes. B_1 dikes are very complex and variable in geometry and size. They bifurcate, anastomose, and show sharp changes in direction and thickness. On the basis of these characteristics and relationships, Lambert [1] concluded that 1) breccia dikes are not limited to the central uplift zone, but influence large areas of the crater target area; 2) A single impact can produce several successive generations of fractures and breccia diking; 3) Type A dikes form first as part of the initial shock compression; 4) Type B dikes form during and/or after pressure release in the modification phase, with B_1 dikes emplaced by high-energy intrusion into the transient crater as it grows, and B_2 dikes forming during the modification stage as blocks are displaced. Early stage fracture-producing processes serve to reduce target strength and angle of internal friction, enhancing movement in the modification stage.

Impacted sedimentary rocks exhumed from even deeper levels show abundant evidence of breccia dike development, particularly in the central peak region. The Upheaval Dome structure in Utah, USA, exposes a complex sandstone dike network emplaced and injected during crater formation and central peak formation (Figs. 1, 2) [9]. The dike system is characterized by extreme variations in thickness (0.1-10 m) even over short distances, decreasing mean dike width with increasing distance from the crater center, flow bulges with greatest thicknesses at nodular points, marking branch points where the dike bifurcates in two or more directions, all forming a honeycomb-like interconnected network of breccia dikes. Erosional outliers of dikes peripheral to the central peaks suggest that breccia dike networks were common throughout the crater subfloor at shallower levels.

Larger impact structures produce even wider and more extensive impact-related dikes. The 200-250 km diameter Sudbury impact structure displays a series of steeply-dipping dikes oriented radially and concentrically around the structure. Known as the "Offset Dikes" because they often terminate and then reappear laterally offset by a few km [10], these features occupy footwall faults and fractures related to the excavation and modification stages of the impact event. One such dike feature, the Hess Offset, is at least 23 km long, 10-60 m wide, and located within, and oriented subconcentrically to, the large Sudbury crater. The dike is granodioritic, undulates in thickness along strike, and splays locally to form claw shaped apophyses, originating during the modification stage of the impact event [11]. Similar Sudbury dikes (Whistle-Parkin Offset Dike, 12 km long, ~30 m wide [12]; Foy Offset Dike, 36 km long, 50 m wide and up to 400 m wide at the source [13]). Multistage emplacement (compression, excavation and modification) is implied for these dikes and the offsets are interpreted to be due to modification-stage crater adjustments.

Often encountered in larger impact structures are pseudotachylites and breccia belts, which are in turn cut by breccia dikes. For example, at Sudbury, the South Range Breccia Belt is a 45 km long and tens to hundreds of meters thick breccia with a very fine-grained matrix, interpreted to have been emplaced as a result of high strain-rate seismogenic slip during rim collapse of the Sudbury crater [14], and often referred to as a 'superfault' [15].

Summary: In summary, breccia dikes are seen in most of the eroded terrestrial complex craters and are developed in both crystalline and competent sedimentary target rocks [8]. They are characterized by wide variations in petrology and mineralogy (commonly related to the target material and the stage in the cratering processes), can range up to many tens of meters in thickness, and tens of kilometers in length. They occur in complex honeycomb like patterns and are often offset along late-stage crater-related faults. Individual dikes can undulate in width and branch, anastomose and bifurcate along strike. Although terrestrial weathering and vegetative cover inhibit complete mapping of breccia dikes, where detailed mapping has been done [e.g., 9] breccia dikes can be comprehensively developed (Fig. 1, 2) and drilling data on terrestrial craters further suggests that breccia dikes are very common [8]. In a separate abstract we use these basic characteristics of breccia dikes associated with impact craters on Earth as criteria to assess the breccia-dike-like features discovered on Mars [16].

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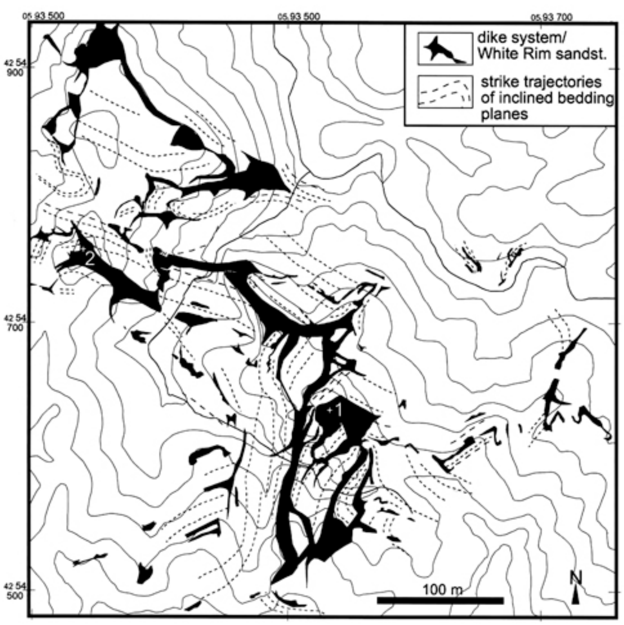

Fig. 1. Distribution of the White Ridge Sandstone dike system in the central uplift of the Upheaval Dome.

Fig. 2. Sketch of a localized occurrence of the White Ridge Sandstone dike network [9].