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Characteristics of pebble and cobble-sized clasts along the Curiosity rover traverse from sol 100 to 750: Terrain types, potential sources, and transport mechanisms

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ABSTRACT

We combine the results of orbitally-derived morphologic and thermal inertia data with in situ observations of abundance, size, morphologic characteristics, and distribution of pebble- to cobble-sized clasts along the Curiosity rover traverse. Our goals are to characterize rock sources and transport history, and improve our ability to predict upcoming terrain. There are ten clast types, with nine types interpreted as sedimentary rocks. Only Type 3 clasts had morphologies indicative of significant wear through transport; thus, most clast types are indicative of nearby outcrops or prior presence of laterally extensive sedimentary rock layers, consistent with the erosional landscape. A minor component may reflect impact delivery of more distant material. Types 1 and 4 are heavily-cemented sandstones, likely associated with a "caprock" layer. Types 5 and 6 (and possibly 7) are pebble-rich sandstones, with varying amounts of cement leading to varying susceptibility to erosion/wear. Type 3 clasts are rounded pebbles likely transported and deposited alluvially, then worn out of pebbly sandstone/conglomerate. Types 9 and 10 are poorly-sorted sandstones, with Type 9 representing fragments of Square Top-type layers, and Type 10 deriving from basal or other Mt. Sharp layers. Types 2, 8 and 9 are considered exotics.

There are few clear links between clast type and terrain surface roughness (particularly in identifying terrain that is challenging for the rover to navigate). Orbital data may provide a reasonable prediction of certain end-member terrains but the complex interplay between variables that contribute to surface characteristics makes discriminating between terrain types from orbital data problematic. Prediction would likely be improved through higher-resolution thermal inertia data.

1. Introduction

Geologic field studies generally focus on bedrock outcrop, because lithologic units found in context provide a less

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ambiguous record of the processes and environment in which that rock formed or was deposited. However, loose rock fragments on the surface (clasts) can provide important clues to bedrock geology where bedrock is either not well exposed or cannot be readily accessed. Float rock fragments on the surface can yield unique information regarding the processes that have modified them through wind, water, gravity and other forces, and also their pre-depositional history. The morphologic characteristics of clasts, including shape, roundness, texture and observable lithology, all inform the nature, timing and extent of transport, sorting and abrasion experienced by those clasts. Clast characteristics record primary and secondary processes as a function of time, distance, or both, so that variation in clast characteristics from location to location inform our understanding of the effects of clast transport, and of separating the effects of clast emplacement from those of secondary modification. In circumstances where outcrop cannot be accessed or is viewed from a distance too great to allow the resolution required to answer fundamental questions (a common occurrence in non-terrestrial settings), clasts that can plausibly be tied to an outcrop record the morphology and texture of both fresh surfaces and worn ones, potentially yielding a proxy for studies of outcrop geology and other characteristics. Similarly, lack of clast modification may indicate abrupt, short, or no transport and thus in certain cases clasts may be used to identify the prior presence of outcrop that has been eroded away. Finally, clasts are an important component of the surface in terms of trafficability and rover safety (e.g., Heverly et al. (2013)), both as potential obstacles, and as indicators of nearby outcrop that could pose risks.

Combining the contextual perspective of orbital data with the detailed assessment possible with high-resolution in situ data, permits us to assess the transport histories and potentially the sources of surface clasts. Doing so also provides information to predict how clast properties may contribute to the morphology of terrain in a potential rover path, including those that could endanger a roving vehicle during landing or traverse. Building on previous work from sols 0 to 100 (Yingst et al., 2013), here we assess morphologic characteristics (size, shape, roundness, texture) of clasts in the pebble to cobble size range (2–256 mm) in Gale crater imaged along the path of the Curisoty rover from sols 100 to 750. We assess how clasts contribute to terrain characteristics as assessed from orbit, categorize clasts and terrains based on this assessment, and interpret this information in terms of clast formation mechanisms, potential sources, and transport mechanisms.

2. Geologic setting

Gale crater is an approximately 154 km diameter impact structure that is centered near the martian equator, at approximately 5°S, 139°E, and straddles the martian dichotomy boundary. Orbitally derived geomorphic, mineralogical, and geochemical data sets (Malin and Edgett, 2000; Anderson and Bell, 2010; Milliken et al., 2010; Grotzinger and Milliken, 2012; Siebach and Grotzinger, 2013; Wray, 2013) suggest that Gale crater preserves an extensive record of aqueous activity, likely over a broad range of depositional environments. Deposits are ~3–3.5 Gyr based on age results for the interior surface between the Gale crater rim and the central mound (Thomson et al., 2011). Since August 2012, the Mars Science Laboratory Curiosity rover has been exploring distinct geological regions within Gale crater to better understand what appears to be a complex record of deposition, diagenesis, and erosion (Williams et al., 2013; Farley et al., 2014; McLennan et al., 2014; Ming et al., 2014; Nachon et al., 2014; Siebach et al., 2014; Stack et al., 2014; Vaniman et al., 2014), and to determine the extent to which Gale crater preserves potentially habitable geologic environments (Grotzinger et al., 2014a).

Geologic environments explored by the Curiosity rover during sols 100–750 lie within Aeolis Palus (shown in Fig. 1), a broad geographic region represented by the lowland plains between the rim of Gale crater and the layered strata that defines Aeolis Mons (herein referred to by its informal name, Mount Sharp). Aeolis Palus can be divided into three distinct geomorphic provinces: the Peace Vallis fan, flat light-toned strata associated with Yellowknife Bay, and Bradbury Rise (Bradbury Rise is the informal name of the topographic rise where the Curiosity landing occurred). The Peace Vallis fan consists of a well defined alluvial fan associated with sediment transport from a catchment outside of the northern rim of Gale crater (Palucis et al., 2014). Detailed mapping of the landing ellipse and surrounding regions (Sumner et al., 2013) indicate interfingering between strata associated with the Peace Vallis fan and a succession of predominantly flat-lying, light-toned layers (FLT) that occurs at the distal margin of the fan system. Potential interfingering relationships suggest that flat, light-toned strata represent downslope facies related to either the Peace Vallis fan or to similar, yet more ancient, alluvial systems that derived from the crater rim. For example, indicators of paleocurrent point to a predominantly southerly or eastern transport direction, as would be predicted for sediment derived from the crater rim (e.g., imbricated and aligned pebbles in Hottah (Williams et al., 2013), cross-stratification geometry at Shaler (Edgar et al., 2014)). These observations match the overall geologic setting of the landing site at the distal end of the Peace Vallis alluvial fan (Anderson and Bell, 2010; Palucis et al., 2014), as well as in situ observations of south-dipping bedding geometry observed at multiple locations on Aeolis Palus interpreted to reflect a southward prograding fluvial-lacustrine system (Grotzinger et al., 2014b; Gupta et al., 2014). However, other paleocurrent indicators vary. For example, imbricated clasts within the Baker River conglomerate imaged on sol 665, may indicate westward transport if these blocks have not tilted or rotated during deposition (Fig. 2). While flow direction cannot be inferred from a single location, this data point supports the possibility that pebble size clasts at this location may have derived from Mt. Sharp. Variable flow directions near the landing ellipse boundary are predicted by the working stratigraphic model of interfingering relationships between lower Mt. Sharp and Aeolis Palus deposits (Grotzinger et al., 2015). If coarse material from Mt. Sharp was transported to the location of Baker River (and possibly further), this places important constraints on the formation mechanisms for the lower mound strata, including eliminating an entirely aeolian origin (e.g. Kite et al. (2013)).

Approximately 6 meters of light-toned strata were investigated by Curiosity in Yellowknife Bay. Basal strata (Yellowknife Bay Formation (Grotzinger et al., 2014a)) exhumed at Yellowknife Bay are represented by laterally continuous fluvial-lacustrine mudstone and sandstone facies of the Sheepbed and Gillespie Lake members, respectively. These units are broadly basaltic in composition, and contain a substantial clay fraction within finer-grained components (McLennan et al., 2014; Vaniman et al., 2014). In contrast to the lateral continuity of the basal Yellowknife Bay formation, the uppermost Glenelg member consists of a laterally variable suite of fine-to-coarse grained sandstone and conglomerate facies that are interpreted to reflect a range of fluvial to alluvial depositional environments (Fig. 3) (Grotzinger et al., 2014a; Kah and MSL Science Team, 2015).

Most of the materials traversed by Curiosity between sols 100–750, however, occur along Bradbury Rise, south of the Peace Vallis Fan and associated light-toned strata (as seen in Fig. 1). Bradbury Rise consists of a variety of morphologically diverse regions that include well-indurated and distinctly cratered surfaces (CS) and hummocky terrain (HMT) marked by thermal inertias consistent with an indurated surface overlain by unconsolidated material (Fergason et al., 2012) interspersed with regions of distinctly