

**CURIOSITY, INSIGHT, PERSEVERANCE: CRUISE AND EDL HARDWARE IMPACTS.** P. J. Stooke<sup>1</sup>,<sup>1</sup>Department of Geography and Institute for Earth and Space Exploration, University of Western Ontario, London, Ontario, Canada N6A 5C2, [pjstooke@uwo.ca](mailto:pjstooke@uwo.ca).

**Introduction:** Curiosity, InSight and Perseverance were delivered to Mars by cruise stages which were discarded before atmospheric entry. Curiosity and Perseverance each carried balance masses which were discarded in two groups to guide the spacecraft during entry, descent and landing (EDL). MRO images by HiRISE and CTX show new features visible shortly after the landings but not in older images which can be linked to the impacts of those items of hardware. Curiosity impacts [1] serve as a guide to search for impacts associated with the other missions.

**Curiosity:** The impact sites of the Curiosity balance masses and cruise stage have been identified in HiRISE images [1, 2]. The two large balance masses (75 kg tungsten spheres) and two fragments of the cruise stage struck the surface 80 km west of the landing site, leaving prominent dark marks with obvious rays extending laterally and downrange (Figure 1, top). The six smaller balance masses (each 25 kg) crashed 12 km east of the landing site. The coordinates of the impact clusters are 4.38° S, 136.05° E and 4.60° S, 137.65° E. Later images show these markings fading. Hardware locations from these images suggest where InSight and Perseverance impact features might be found and what they might look like.

**InSight:** The InSight cruise stage would be expected to fall southwest of the landing site. There were no balance masses on this mission. CTX images taken before and after the landing of InSight reveal a new dark marking c. 100 km SSW of the landing site, not present in a 2008 image but clearly visible 6 weeks after InSight landed (Figure 1, middle). In CTX image K13\_058427\_1832\_XN\_03N225W the impact site shows as a small dark spot surrounded by a dark halo about 200 m across, elongated to the south. The Curiosity impact feature shown in Figure 1 is also more prominent to the south despite the impact direction being nearly towards the east, suggesting that wind can render these markings asymmetric. The location is 3.1° N, 134.7° E. By 2020 the dark marking had faded but was still visible. It is suggested to be the InSight cruise stage impact site, but it is noted that this feature is 60 km south of the lander groundtrack, which may make this interpretation suspect. No new features closer to the groundtrack have been identified, and though the timing is suggestive this identification must be regarded as uncertain. A HiRISE image of the feature has been requested.

**Perseverance:** The Perseverance impacts would be expected to resemble the Curiosity impact markings and to be located similarly with respect to the landing site. HiRISE images have been taken of both candidate impact areas. No obvious impact features are visible in HiRISE image ESP\_069165\_1985 taken east of the landing site where the small balance masses should have fallen, as all potential features are also visible in images taken before the landing date. To the west where the cruise stage and large masses might have fallen, three candidate features are visible in HiRISE image ESP\_069231\_1990. Before/after CTX images suggest that they are new (there is no 'before' HiRISE image). The features are all small craters with bright ejecta forming patterns commonly associated with low oblique impacts (faint downrange rays and more obvious 'butterfly' rays perpendicular to the direction of travel, well displayed by the Curiosity features). These features are all within about 1500 m of 19.0° N, 76.2° E (Figure 1, bottom). These are probably the cruise stage and large mass impacts, though it is not obvious which is which. They differ in albedo compared with the Curiosity impacts, having bright instead of dark ejecta, but this may be due to differing surface composition or other characteristics. The largest impact occurs in a field of sand dunes or ripples. No seismic signal was detected by InSight though models suggested the possibility ([3], perhaps because the largest impact interacted with loose sand or dust in the aeolian bedforms rather than rock or more consolidated/cemented regolith.

**References:** [1] HiRISE image release, 5 December 2012. [https://www.uahirise.org/ESP\\_029245\\_1755](https://www.uahirise.org/ESP_029245_1755). [2] HiRISE image release, 16 October 2013. [https://www.uahirise.org/ESP\\_033293\\_1755](https://www.uahirise.org/ESP_033293_1755). [3] Fernando, B., et al., 2021. *Nature Astronomy*, <https://doi.org/10.1038/s41550-021-01502-0>.

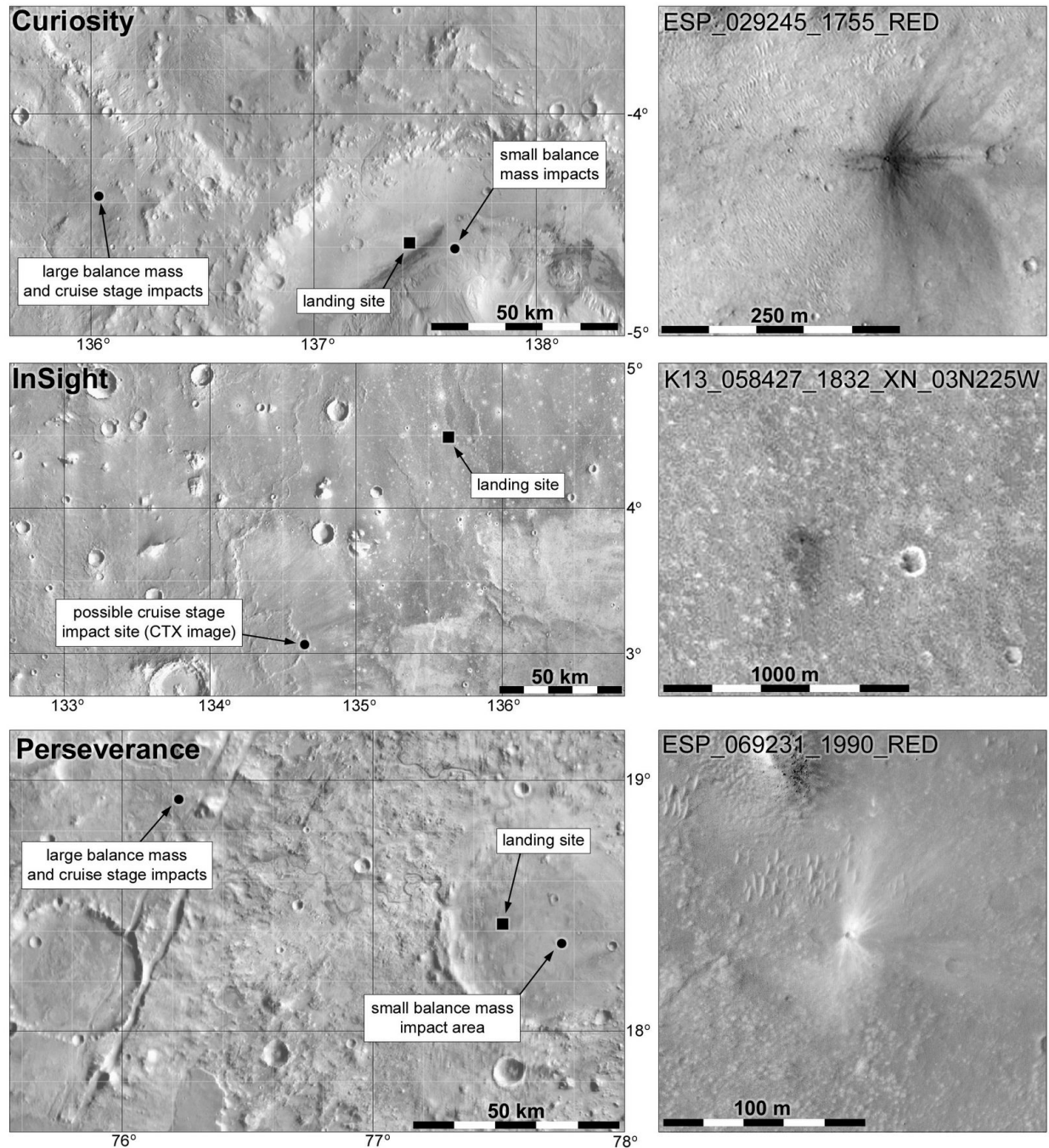


Figure 1. Impacts associated with recent landed missions. Top: Curiosity. Middle: InSight. Bottom: Perseverance. Left: context maps. Base images are THEMIS daytime infrared mosaics with inverted shading. Right: impact sites in orbital images. For Curiosity this feature was interpreted as caused by one of the balance masses [1]. For InSight the dark marking in a CTX image (taken 6 weeks after landing) is interpreted as the cruise stage impact site. For Perseverance the feature is either a balance mass or a cruise stage impact site.