ASSESSMENT OF POTENTIAL LANDING AND SAMPLING SITES FOR A FUTURE MISSION TO THE SURFACE OF CERES, VIA GEOLOGIC MAPPING AND ASSOCIATED TECHNIQUES. Jennifer E. C. Scully[1], Samantha R. Baker[1,2], Julie C. Castillo-Rogez[1], Debra L. Buczkowski[3]. [1]Jet Propulsion Laboratory, California Institute of Technology, California, USA (jennifer.e.scully@jpl.nasa.gov), [2]University of Chicago, Chicago, Illinois, USA, [3]Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, USA.

Introduction: The astrobiological relevance of the 940 km diameter dwarf planet Ceres has been recognized as the result of the Dawn mission [1]. The crust is ~40 km thick on average and is composed of rock, salts, clathrate hydrates and ≦40 vol.% water ice, while the mantle is aqueously altered rock [2,3]. There was likely an ancient subsurface ocean, most of which froze relatively early [4]. Limited amounts of interior liquid were retained until present, which forms a deep brine reservoir at the crust/mantle boundary, perhaps in the form of pore fluids [2,3,5]. This deep brine reservoir is likely the source of the bright faculae in Occator crater [e.g., 6-8] and the isolated mountain Ahuna Mons [9,10]. Haulani crater exposed shallow crustal material, which is only slightly altered by space weathering and infall contamination [11].

Background – Future Ceres Exploration: Dawn revealed Ceres to be a complex relict ocean world with astrobiological relevance that, as a non-tidally heated body (unlike most ocean worlds), is a key piece in the puzzle of our understanding of ocean world evolution [1]. The NASA Roadmap to Ocean Worlds study classified Ceres as a candidate ocean world [12]. Moreover, the results from the last phase of the Dawn mission confirm the presence of liquid within Ceres, at least on a regional scale [13]. In addition to its scientific richness, Ceres is located at ~2.8 AU in a mild radiation environment. Thus, it is by far the most accessible of the confirmed/candidate ocean worlds.

As a result, there is great community interest in sending an in-situ mission to Ceres. For example, a Ceres mission concept study was funded by NASA ROSES C.30 Planetary Mission Concepts Studies (PMCS) to explore landed mission and/or sample return options [11]. Such future exploration requires a detailed understanding of the surface in order to identify scientifically compelling sites accessible with a small lander (~1-5 m). Here we identify potential landing/sampling sites for a future Ceres mission based on the best data returned by the Dawn spacecraft, within three potential landing/sampling regions: Occator crater, Haulani crater and Ahuna Mons.

Background – Precedents: Following the community standard 5:1 rule of thumb, images of ~20 cm/pixel to ~1 m/pixel characterize ~1 m to ~5 m scale hazards on Mars [e.g., 14]. For the Europa Lander mission concept, slopes must be <25° and vertical relief no more than 0.5 m [15]. Martian landing ellipses are much larger than those on Europa and Ceres, which are on the order of ~100 m in diameter, because parachuting through the atmosphere results in greater uncertainties in landing site placement.

Here we require slopes ≦10° and images of a few decimeters per pixel to ~1 m/pixel to characterize slopes and hazards on the scale of a ~1-5 m lander. A landing/sampling *region* is an entire geologic landform (e.g., a crater, a mons). A landing/sampling *site* is a smaller specific location, within a region, in which a spacecraft would touch down, which we define as 100 m diameter circles [11,16 for details].

Methods: We used geologic maps and greyscale mosaics to understand the 2D properties of the regions, identify the presence of hazards and locations that are particularly scientifically compelling. Mineral abundances were also used to identify locations that are particularly scientifically compelling. We used the shape models and slope maps to understand the 3D properties of the regions and to identify topographic hazards. We also assessed the material properties, based on Dawn datasets and terrestrial analog data.

Results – Occator crater: The Vinalia Faculae bright region and Homowo Regio ejecta are particularly scientifically compelling, because of their connection to the current deep brine reservoir and ancient subsurface ocean, respectively, along with high abundances of a variety of materials, including salts [e.g., 11,17,18] [Fig. 1]. The Cerealia Facula are also scientifically compelling, but there are only limited areas with slopes ≦10° within Cerealia Facula.

We find that there are multiple hazards (fractures, pits and boulders), which likely occur at smaller sizes than can be resolved in the highest resolution Dawn data (~5 m/pixel). Precision landing would be needed to avoid these hazards. There are large areas of the crater interior and ejecta with slopes ≦10°, which could be confirmed on a ~1-5 m lander scale by higher spatial resolution data. The design of an in-situ mission would need to take into account the faculae's estimated load bearing capacity of ~1-2 GPa. We identify ten example potential landing/sampling sites in both Vinalia Faculae and Homowo Regio, which occur in locations with slopes of ≦10° and are free of hazards.

Results – Haulani crater: We find that there are areas in the floor that would be safe for an in-situ investigation (i.e., slopes ≦10° and a smooth surface with no hazards such as pitted terrain and fractures) and would be particularly scientifically compelling. The design of an in-situ mission would need to take into account material with an estimated load bearing capacity of ~13 GPa. The northwestern and southwestern crater floor contain higher abundances of the minerals of interest [19], which would facilitate an in-situ investigation. We place ten example landing/sampling sites in these areas, with an emphasis on where the intermixed material, smooth material and high abundances of sodium carbonate intersect.

Results – Ahuna Mons: The most scientifically compelling area are the flanks because of their apparent freshness [9,10,20]. The northern flank is richest in the minerals of interest [20]. The flank slopes (~30-40°) mean that an in-situ mission could not touch down, and the summit area is too highly fractured. However, the northern flanks could be observed from adjacent areas of smooth material that have slopes of ≦10° and are ~4-5 km in size. We identify ten example potential landing/sampling sites in these two areas, which have an estimated load bearing capacity of ~13 GPa. The centers of these areas are only ~3-4 km from the base of the mons, and would therefore provide an excellent vantage point for in-situ remote sensing.

Conclusions: While hazards are present (slopes >10°, fractures, pitted terrain and boulders), our analysis illustrates that safe sites likely exist in Occator crater, Haulani crater and in the vicinity of Ahuna Mons, and that they could be plausibly reached safely by an in-situ mission to Ceres. We demonstrate the general process that a future mission would undertake to identify a landing/sampling site. However, the Dawn data (up to ~5 m/pixel) do not allow for the identification of slopes and hazards on the scale of a ~1-5 m lander, which requires data of a few decimeters per pixel to ~1 m/pixel. Thus, we recommend that an orbital reconnaissance phase capable of acquiring such data be included in any future mission. Combining orbital reconnaissance and TRN/hazard avoidance would be the most robust way to land on, and possibly also collect a sample from a specific site. The ability to land precisely (within a circle that is ≦100 m in diameter) on Ceres' surface is an enabling factor for future in-situ exploration because there are numerous ~100 m diameter potential landing/sampling sites present within each landing/sampling region. Thus, it is highly probable that at least one would be a safe and scientifically compelling site in which to continue our exploration of this relict ocean world from its surface. For more details, see our paper in press [16].

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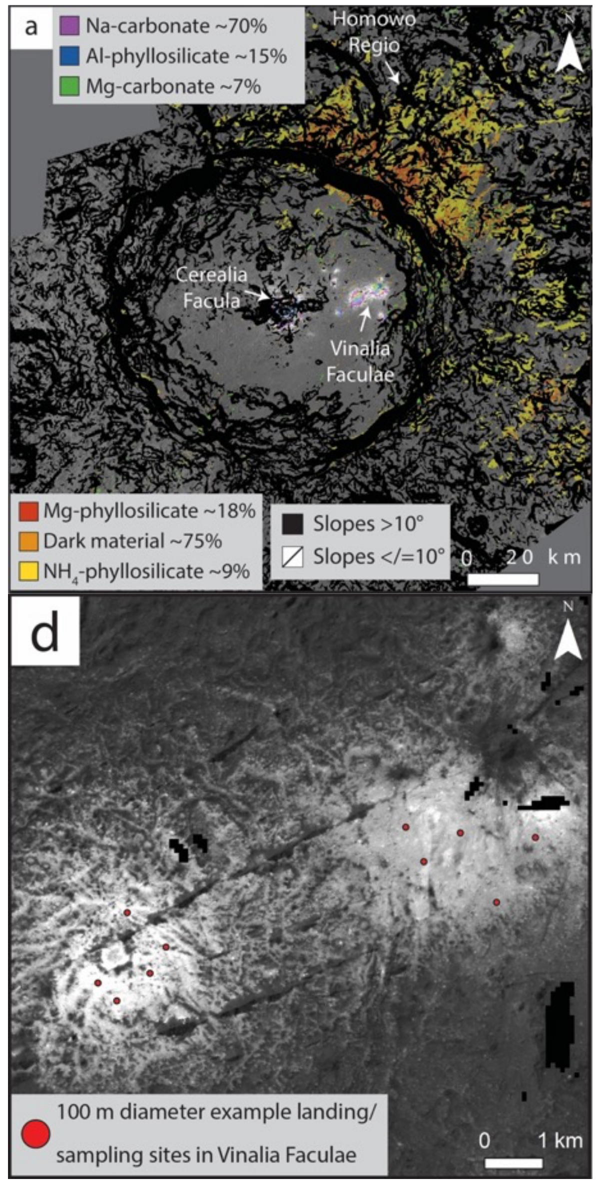

Fig. 1. Occator crater. (Top) Colors show areas that contain high abundances of a variety of materials. Black areas have slopes >10°; non-black areas have slopes ≦10°. (Bottom) Example 100 m diameter potential landing/sampling sites in the Vinalia Faculae.