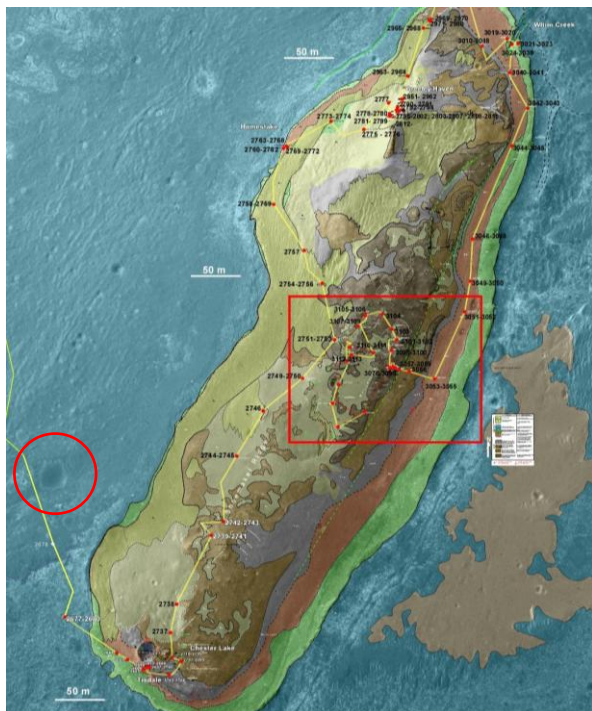


**HOLLOWED SPHERULES IDENTIFIED WITH THE MER *OPPORTUNITY* NEAR AND AT CAPE YORK, WESTERN RIM OF ENDEAVOUR CRATER, MARS.** A.G. Fairén<sup>1</sup>, S.W. Squyres<sup>1</sup>, J.P. Grotzinger<sup>2</sup>, W.M. Calvin<sup>3</sup>, S.W. Ruff<sup>4</sup>, and the MER Athena Science Team. <sup>1</sup>Department of Astronomy, Cornell University, agfairen@cornell.edu. <sup>2</sup>Division of Geological and Planetary Sciences, Caltech. <sup>3</sup>School of Earth Sciences & Engineering, University of Nevada-Reno. <sup>4</sup>School of Earth and Space Exploration, Arizona State University.

**Introduction:** The Mars Exploration Rover Opportunity has been since 2004 traversing across the Hesperian sulfate-rich sandstones of the Burns formation, where it discovered abundant spherical hematite concretions, typically 4 to 6 mm in diameter and lacking internal structure, nicknamed blueberries [1]. The rover arrived in August 2011 at Endeavour Crater, an impact crater ~22 km in diameter formed in ancient Noachian materials. Since Sol 2679, Opportunity explored Cape York, an eroded segment of Endeavour's rim where Burns formation strata unconformably overlie the lower rocks of the crater rim (Fig. 1) [2]. On Sol 3061, the rover arrived at a location on the eastern side of Cape York named Matijevec Hill, where Opportunity discovered a different type of spherules, nicknamed newberries: smaller (typically up to 3 mm in diameter), not iron-enriched, showing internal structure, and with different concentration and distribution than blueberries [3].

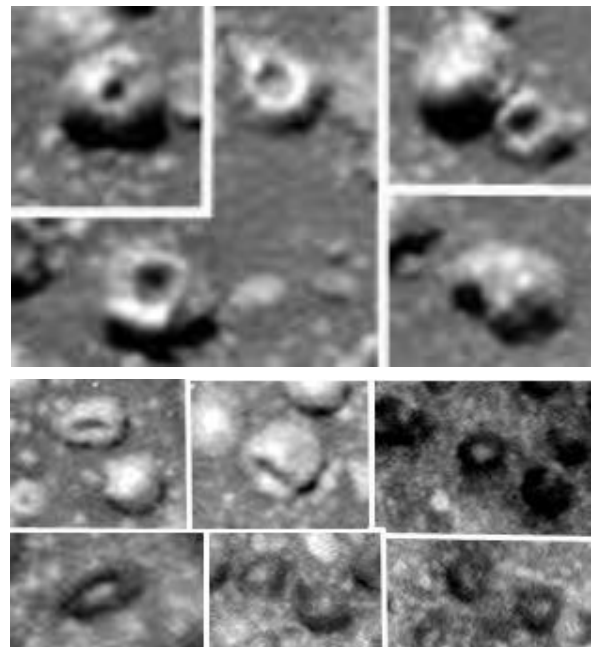


**Fig. 1:** Overview of the traverse on Cape York. To the West of the hill are the Burns formation sandstones, and to the East the walls of Endeavour crater. The red circle indicates Pathfinder crater, and the red square marks Matijevec Hill, the two locations where Opportunity found hollowed spherules.

Here we report the identification of a new type of spherules not previously described in Meridiani: hollowed spherules. They are distributed both in loose soils atop the Hesperian Burns formation and tightly embedded in bedrock on the highest reaches of the Noachian Matijevec Hill. Although the spherules we have identified are hollowed at both locations, it is not clear at this moment whether they share a common origin, or if similar erosional processes on differently formed spherules have resulted in the hollowed spherules we report here.

#### **Hollowed spherules before entering Cape York:**

On Sol 2670, Opportunity arrived at Pathfinder Crater, an impact crater ~40 m in diameter and approximately 100 m westward from the southwestern reaches of Cape York (Fig. 1). During the following 3 days of traverse, the rover encountered a high density of hollowed spherules, randomly intermixed with blueberries. Some of the hollowed spherules appear partially buried in the soil, looking like circular rims with hollow, bowl-like depressions (Fig. 2).



**Fig. 2:** Details of Pancams on Sols 2670 (top) and 2673 (bottom) near Pathfinder crater. The size of these hollowed out spherules is in the same range as blueberries (4 to 6 mm in diameter).

These hollowed spherules show a size range and distribution similar to blueberries, and they have been found sharing the Hesperian Burns formation with blueberries. However, we think they are different from blueberries because these hollowed spherules are significantly less abundant, and also they show internal structure in the form of an evident outer harder layer, and that is uncharacteristic of blueberries. All such spherules at this location were found in loose soil rather than embedded in bedrock.

#### Hollowed spherules up the hill at Cape York:

We also found hollowed spherule-like objects solidly embedded in bedrock during our walkabout on the Noachian Matijevec Hill (Fig. 1). Almost all the spherule-like objects at the 3117 and 3168 locations appear to be hollowed out: we only identified a few complete spherules (Figs. 3 and 4). This is different from anything seen elsewhere at Matijevec Hill. The outcrop imaged on Sol 3117 is an interesting location in which to find hollowed spherules, since it is pretty far up the hill, providing evidence for spherules high up on the Shoemaker formation breccias.

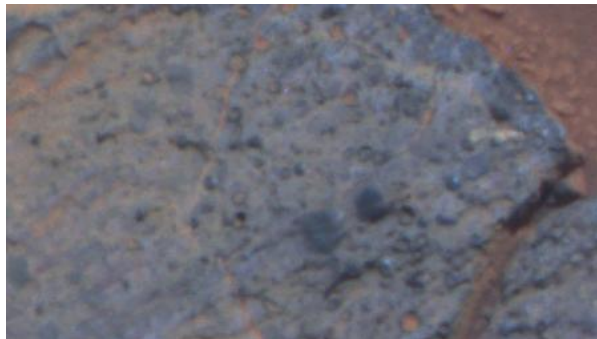


Fig. 3: Portion of Pancam image of the outcrop “Gertrude”, on Sol 3117. Frame covers ~8 cm in width.

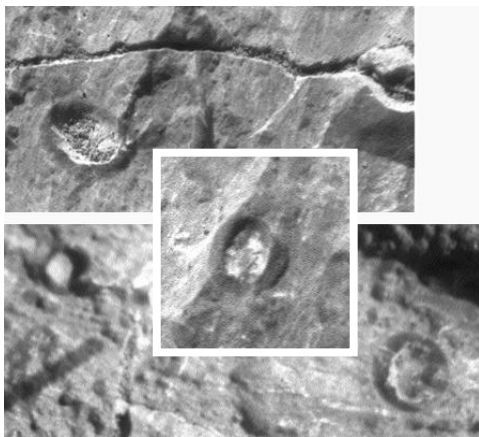


Fig. 4: Portions of MIs on Sol 3168 of the outcrop “Vermillion Cliffs”, including tall, bowl-like objects with similar sizes as newberries.

We are inclined to think that the spherule-like objects identified on Sols 3117 and 3168 are related to the newberries characteristic of Matijevec Hill [3], as they show a similar size and prevalence, their rim thickness and the size of their cores appear similar, and we have seen some sparse hollowed newberries at the hill (Fig. 5). However, if these spherule-like objects are actually hollowed newberries, the reason why they are mostly hollowed out at these two locations (contrasting with the typical newberry-rich outcrops such as Kirkwood, where the spherules are generally not hollowed out and only sparse hollowed newberries can be seen [3]) is still elusive.

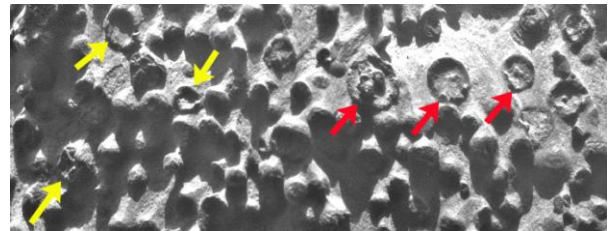


Fig. 5: Portion of MI image of the outcrop “Kirkwood”, on Sol 3064, showing some sparse hollowed (yellow arrows) and broken (red arrows) newberries. Image is ~5 cm across.

**Other locations:** We have also identified some additional hollowed spherules, similar to those around Pathfinder crater, during the traverse from Cape York to Solander Point, on the plains of Botany Bay, but here the occurrences are very sparse. Further, it has not escaped our notice that some of the hollowed spheroidal objects reported here are reminiscent of the “hollowed nodules” that have been identified in parts of Yellowknife Bay in Gale crater with the Curiosity rover [4,5], maybe some indication of similarity of genetic process.

**Looking forward:** Hollowed spherules are not rare in terrestrial settings where spherules are abundant [6]. We plan to continue working on the size statistics, prevalence and distribution of these hollowed spherules, as well as on hypotheses to explain the distribution of the different families of spherules in separate Noachian and Hesperian geological units, with the aim of better understanding their origin and role during the geological evolution of the Meridiani plains.

**References:** [1] Squyres S.W., et al. (2004) *Science* 306, 1698-1703. [2] Squyres S.W., et al. (2012) *Science*, 336, 570-576. [3] Arvidson, R.E., et al. (2014) *Science*, in press. [4] Stack, K., et al. (2013) *GSA Meeting*, abstract #43-2. [5] Grotzinger J.P, et al. (2013) *Science*, DOI: 10.1126/science.1242777. [6] Chan M.A., et al. (2007) *Geofluids* 7, 356-368.