METEORITIC MATERIAL RECOVERED FROM THE 07 MARCH 2018 METEORITE FALL INTO THE OLYMPIC COAST NATIONAL MARINE SANCTUARY. M. Fries[1], J. Waddell[2], OET and crew of E/V *Nautilus*[3], SOI and crew of R/V *Falkor*[4], B. Pugel[5], R. Zeigler[1], R. Harvey[6], L. Welzenbach[7], F. McCubbin[1], and P. Abell[1]. [1]NASA JSC, [2]NOAA Olympic Coast NMS, [3]Ocean Exploration Trust, [4]Schmidt Ocean Institute, [5]NASA GSFC, [6]Case Western Reserve U., [7]Rice U. Email: marc.d.fries@nasa.gov

Introduction: On 07 March 2018 at 20:05 local time (08 March 03:05 UTC), a dramatic meteor occurred over Olympic Coast National Marine Sanctuary (OCNMS) off of the Washington state coast ("OCNMS fall", henceforth). Data to include seismometry (from both on-shore and submarine seismometers), weather radar imagery (Figure 1), and a moored weather buoy, were used to accurately identify the fall site. The site was visited by the exploration vessel E/V *Nautilus* (Ocean Exploration Trust) on 01 July 2018 [1] and by the research vessel R/V *Falkor* (Schmidt Ocean Institute) from 03-06 June 2019. Remotely operated vehicles (ROVs) from both vessels were used to search for meteorites and sample seafloor sediments. These expeditions performed the first attempts to recover meteorites from a specific observed fall in the open ocean. Analysis of weather radar data indicates that this fall was unusually massive and featured meteorites of unusually high mechanical toughness, such that large meteorites were disproportionately produced compared to other meteorite falls (Figure 2)[2-4].

We report the recovery of many (>100) micrometeorite-sized melt spherules and other fragments, and one small (~1mm^3) unmelted meteorite fragment identified to date. Approximately 80% of the fragments were recovered from a single sample, collected from a round pit in the seafloor sediment. Melt spherules are almost exclusively type I iron-rich spherules with little discernible oxidation. Analyses are currently underway to attempt to answer the primary science question by identifying the parent meteorite type. Also, differences in the number and nature of samples collected by *Nautilus* and *Falkor* reveal a distinct loss rate to oxidation over the 15 months following the fall that is useful to inform future recovery efforts.

The Meteorite Fall: Most of Washington state was under cloud cover at the time of the fall, but eyewitnesses reported that the meteorite fall momentarily brightened the sky. Those near the coast reported sonic booms loud enough to shake homes and cars. Data from

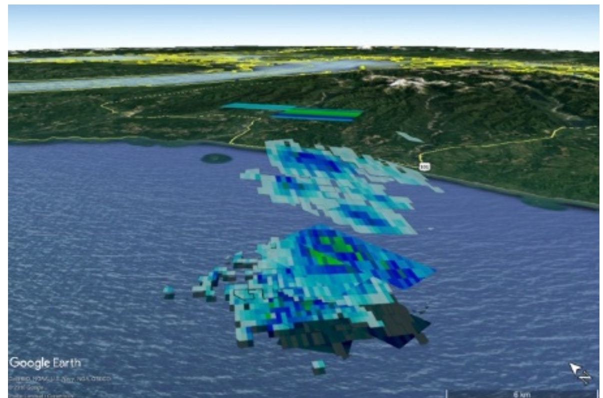

Figure 1: Composite image of falling meteorite material, collated from NOAA NEXRAD radar imagery. All superimposed pixels in this image represent radar energy reflected from falling meteorites.

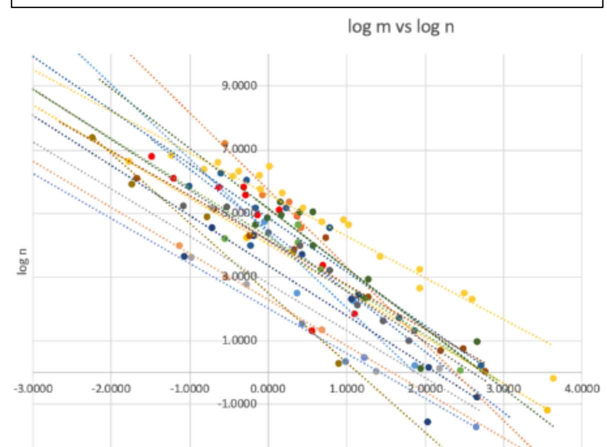

Figure 2: Mass distribution of 15 meteorite falls observed in NEXRAD data from the Niðhöggr model. Total fall mass is expressed in how high up on the graph a distribution plot lies. Fragmentation behavior is a function of the slope. Most falls produce a slope of ~-1.6. Three falls feature an overabundance of small meteorites (e.g. steep slopes) consistent with a mechanically weak progenitor meteoroid. The Pacific Coast fall (yellow line, at top) was not only massive but features a shallow slope of -1.29 - a mechanically tough body where an unusual number of large meteorites survived.

seismometers (including several mounted on the seafloor), weather radars, and even a moored weather buoy indicate that a massive meteorite fall resulted from this event, with many kilograms of meteorites deposited into the ocean around 47.441713° N 124.661732° W. Dominant winds were out of the WSW, and so the largest meteorites landed at the western end of a strewn field approximately 11 km long, with progressively smaller meteorites trending towards the east. The falling meteorites include individual rocks large enough to create splashes recorded by the KLGX radar (Langley Hill, WA) in the lowest-elevation radar sweeps which observe down to sea level. Initial calculations using the Jörmungandr strewn field model and the Niðhöggr fragmentation model indicated that this event was the largest meteorite fall to occur within the range of the NOAA NEXRAD nationwide radar network since the system went online in the mid-1990s (see Discussion section, however). During NEXRAD's operational lifetime, the network has recorded over two dozen recovered meteorite falls and over one dozen additional, unrecovered falls.

Discussion: This event was one of six meteorite falls observed in NEXRAD radar imagery to terminate over water. One of these events, the 06 Feb 2017 fall into Lake Michigan, is under active research and retrieval efforts by the Aquarius Project, an endeavor run largely by students from Chicago-area schools and institutions [5,6]. The other three were not pursued, even though one occurred into the Gulf of Mexico off of Corpus Christi, TX (02 Apr 2012) and is relatively close to the PI's home institution. The OCNMS event was different from other falls in that Niðhöggr indicates an anomalous fragmentation pattern (Figure 2). The OCNMS fall, however, exhibits a shallow number/mass slope indicating a mechanically tough body which produced an unusually high number of larger, surviving meteorites. The primary science question for this observation is simple: *What kind of meteorite did this?* Knowing the answer to that question will provide research access to an unusual type of meteorite, allow identification of future similar falls from radar data alone, and refine and calibrate Niðhöggr for a broader range of meteorite types.

At the time of the fall, the total meteorite mass was estimated using radar reflectivity from meteorites whose mass was calculated using observed fall times. Jörmagandr and Niðhöggr were used in concert to produce these estimates. Depending on the assumptions used, initial estimates of the fall mass ranged from 3-30x that of the Park Forest meteorite fall. Analysis of the recovered material suggests an iron-rich meteorite type with a density of ~4.5 g/cc, as opposed to an ordinary chondrite density of 3.2 g/cc. Radar reflectivity of individual fragments is also much higher for an iron-rich meteorite than for the original ordinary chondrite estimate. This means a smaller, but more iron-rich meteorite mass could generate the observed radar data, lowering the mass estimate. If this finding stands up to the additional analyses currently underway, then the total meteorite fall mass is closer to a total mass on par with Park Forest.

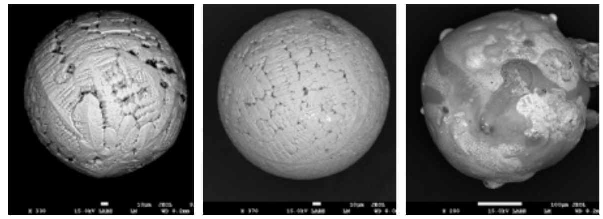

Figure 3: Melt spherules recovered from the meteorite fall site. Over 100 of these were recovered, predominantly type *I* spherules with a dendritic magnetite exterior. Small fusion crust fragments and a single, unmelted, fusion-crusted meteorite ~1mm^3 in size were also recovered. Analysis of these particles is underway.

Significance: Earth's oceans cover ~70% of the planet's surface, which means that fresh meteorite falls face a ~70% chance of landing in the ocean. If meteorites can be reliably retrieved from the ocean, then the number of recent meteorite falls available for research can increase by a significant amount. Seaborne meteorite recovery must contend with fiscal investment factors and seawater corrosion, but may be favored in cases of exceptional falls or for statistical study of the current meteorite flux for planetary defense reasons. For example, on 18 Dec 2019 a 173 kT bolide occurred over the Bering Sea. This event was second only to Chelyabinsk in terms of the energy of recent events. On 22 June 2019, a 6 kT bolide produced a massive meteorite fall into the Caribbean and was observed by a Puerto Rico weather radar. This event was the second most powerful event recorded in recent times over North America. Recovery of meteorites from these events can identify the meteorite type responsible and improve our understanding of potential infall hazards.

References: [1] Fries, M. and Waddell, J., 2019, *82nd MetSoc*. Abstract #6483. [2] Fries, M. and Fries, J., 2010. *MAPS*, 45(9), pp.1476-1487. [3] Jenniskens, P., et al, 2012. *Science*, 338(6114), pp.1583-1587. [4] Hankey, M., et al 2017. *PSS*, 143, pp.199-202. [5] Bresky, C.E. and Fries, M., 2018. *49th LPSC* Abstract #3004.[6] Hammergren, M., et al 2019, January. *AAS* Abstract #233.