TWO ALTERNATIVE SCENARIOS TO EXPLAIN THE STRANGE EXTRATERRESTRIAL SPINEL GRAIN RECORD OF THE LATE EOCENE M. M. M. Meier[1], N. Artemieva[2,3]. [1]Institute of Geochemistry and Petrology, ETH Zurich, Switzerland (matthias.meier@erdw.ethz.ch); [2]Planetary Science Institute, Tucson AZ, USA; [3]Institute for Dynamics of Geospheres, Moscow, Russia.

Introduction: Sediments from the Late Eocene (ca. 34-37 Ma ago) show signs of extraterrestrial events affecting the Earth at the time: 1) a long-duration ^{3}He-peak [1]; 2) at least five large impact structures, among them Popigai (~90 km), the largest known in the Cenozoic, and Chesapeake Bay (~40 km) [2]; 3) global ejecta layers and Ir peaks, some of which have tentatively been connected to known impacts [3]; 4) a short-lived peak of extraterrestrial spinel grains identified within a 65 cm interval at Massignano (Italy), right above the lowest ejecta layer at that site [4]. There might actually be two slightly overlapping spinel grain peaks, as the 17 spinel grains in the lower 25 cm of the peak appear to be H-chondritic in chemical composition, while 7 of the 8 grains in the upper 40 cm appear to be L-chondritic (and only one H-chondritic) [4]. Several explanations have been put forward to explain at least one of the signs, including a comet swarm [1], interstellar clouds [5], dust ejected from the Moon [6], the break-up of a Mars-crosser asteroid [7], an asteroid break-up event which formed the Brangäne asteroid family [8], gravitational perturbations of the asteroid belt and dust from asteroid tails [4]. The spinel grains confirm that ordinary chondritic bodies were involved, and add an interesting twist to the interpretation of the events of the Late Eocene. Why are the spinel grain peaks so short-lived (10s of ka at most) compared to the ^{3}He peak (~2.2 Ma), and why do they appear in the middle of the ^{3}He interval? The bed in which the grains were found starts immediately above the ejecta layer associated with Popigai (Chesapeake Bay ejecta is not present at Massignano) [2]. Schmitz et al. [4] suggest that the H- and L-chondritic grains were detached from the regoliths of the Popigai and Chesapeake Bay impactors, respectively, by tidal forces in space, and only settled on Earth a few 100 to 1000 years later. This would explain the gap in deposition of spinel grains between the Popigai ejecta blanket and the layer in which the lower spinel grain peak is found. However, a possible alternative interpretation of the gap is that the spinel grain peaks are not directly connected to the Popigai / Chseapeake bay events. Here we propose and discuss two such alternative scenarios.

Scenario 1: Tidal disruption of a Temporarily Captured Orbiter (TCO): TCOs are Near-Earth Objects (NEOs) which approach the Earth on slow trajectories, completing at least one orbit within three Hill-radii around the Earth in a geocentric reference frame, often following near-chaotic trajectories [9]. At any time, Earth should have one TCO of no more than 1 m diameter, but larger NEOs are occasionally captured over geologic time-scales [9]. About 1% of all TCOs eventually impact the Earth, and given the near-random distribution of their geocentric orbital elements as mapped by [9], roughly 10% of them should pass within the Roche limit at 20'000 km. Internally weak, large TCOs (i.e., rubble piles with a significant fraction of regolith) could then undergo tidal disruption. Fragments of tidally disrupted TCOs would continue their orbital evolution on TCO-like, near-chaotic orbits of their own, some of them eventually (typically within a few years [9]) colliding with the Earth. Using the spinel grain abundances (>63 μm) in ordinary chondritic meteorites given by [10], and an assumed global spinel grain layer similar in thickness to the one at Massignano, the 18 H-chondritic grains imply a globally deposited meteoritic mass of $(0.14\text{-}5.5) \times 10^{11}$ kg. The 7 L-chondritic grains imply a meteoritic mass of $(0.04\text{-}1.3) \times 10^{11}$ kg. If we conservatively assume that only 1% of the debris from the disrupted TCOs collides with the Earth (i.e., a piece of debris from a TCO tidal disruption has no higher chance of colliding with the Earth than a random TCO), the disrupted asteroids were km-sized, i.e., 1.1-3.7 km for the H-chondritic grains, and 0.9-2.3 km for the L-chondritic grains. Given the observed size-frequency distribution of NEOs [11] and the present-day capture frequency for H=24 objects given by [9], a km-sized (H < 18) TCO should be captured roughly once every ~3 Ma. Tidal disruption of a km-sized TCO should occur every ~30 Ma, and more frequently during times of increased impactor flux. A ~20 time higher flux of km-sized asteroids can likely account for the two spinel grain peaks during the Late Eocene (assuming both peaks are from TCO disruptions). Incidentally, similarly short-lived peaks of spinel grains from TCO disruptions might also be observed at other times in the Earth's sedimentary record.

Scenario 2: An Eltanin-like marine impact: In this interpretation of the Late Eocene spinel grain peaks, they represent the weathering-resistant remains of an ejecta layer of a deep marine impact in the Mediterranean region at the time, similar to the more recent (~2.15 Ma) Eltanin impact in the Southern Ocean. The Eltanin impact site was discovered by the recovery of strongly disturbed Eocene to Pleistocene sediments, strongly enriched in up to cm-sized, unmelted meteoritic debris [12]. From mass estimates based on meteoritic debris density and Ir fluxes, an impactor diameter of 1-4 km has been suggested [13]. A surface density of meteoritic ejecta of about 2000 – 8000 g/m^2 is observed in the central regions of the debris field, extending for several 100 km. In comparison with the Late Eocene site at Massignano, the 18 H-chondritic grains of the lower peak and the 7 L-chondritic grains of the upper peak can be translated into surface densities of 0.03 – 1.1 g/m^2, and 0.007 – 0.26 g/m^2, respectively, using again the values given by [10]. These values are 3 to 5 orders of magnitude below the values observed at the Eltanin sites. Since the thickness of ejecta blankets scale with the inverse cube of the distance to the impact site [14], this might indicate a distance of a few 1000 km to the impact site, but local sea floor topography, currents and the asymmetrical shapes of ejecta blankets might also affect the debris density [15]. Given that at least five large terrestrial impact structures are known in the Late Eocene [2], we expect at least ten similarly large impact structures in the ocean. There is a ~35% chance that a random location on the sea-floor would be within 2000 km of one of these marine impact sites (however, land dominates within that radius of the Late Eocene Massignano). An internal consistency test of the marine impact scenario is given by the Ir abundance of 50-200 pg/g in the sediment layer in which the grains were found [16] (note that even higher Ir abundances are found within the ejecta blanket further below). Using an Ir concentration of 500 ng/g for H- and L chondrites [17], the meteoritic mass fraction is (1-4) × 10^{-4}, i.e., 100 kg of limestone from these layers should contain 0.01-0.04 g of meteoritic material. This is within (and close to the geometric mean of) the ranges of 0.005-0.18 g and 0.002-0.07 g derived from the spinel grain abundances in the lower and upper spinel grain peaks, respectively. Therefore, there was no selective fractionation of the Ir-carrier and the spinel grains, relative to ordinary chondritic values.

Testable predictions for the scenarios: In the TCO scenario, the spinel grains are distributed uniformly over the surface of the Earth. One would thus expect to observe a similar H- and L-chondritic spinel grain peak at other Late Eocene sites world-wide, regardless whether the site is marine or sub-aerial. Since the typical deposition time of TCO debris is a few years at most, sampling of a non-bioturbated section at high time-resolution should also provide a much sharper peak than the one found in Massignano. Furthermore, if all grains are derived from a loose asteroidal regolith, they would likely show a characteristic correlation between cosmic-ray-produced and solar wind (SW) light noble gases, as observed e.g. by [18,19]. The short time of space exposure after a TCO disruption (a few years) is unlikely to strongly influence the cosmogenic and SW content. If the H- and L-chondritic spinel grains represent two separate tidal disruption events of TCOs, their average SW content and cosmic-ray exposure age will likely differ, each representing the individual history of the disrupted asteroid. There is a small chance that the Popigai impactor was a large fragment of a disrupted TCO, and thus the spinel grains and the asteroid would have the same origin. In that case, the time of deposition of the spinel grains should be within a few years after the deposition of the ejecta blanket.

In the marine impact scenario, the spinel grain peaks at Massignano would be a local feature (within several 1000 km) and thus not expected at equal intensity at sufficiently remote places (other marine sites might have other, unrelated spinel grain peaks, while terrestrial sites should not have them). One could argue that since the grains are most likely sampling an interior position of the asteroid, they may not have been exposed to cosmic rays or SW implantation. However, [20] found cosmogenic radionuclides in a sample of Eltanin material, implying a position of that sample near the surface, within a few 100 ka before impact. In fact, since most large asteroids are rubble piles [21], it is conceivable that all interior material has at some point been close to the surface, where it was irradiated by cosmic rays and/or SW. The detection of cosmogenic and/or solar wind derived noble gases would thus not be sufficient to exclude the marine impact scenario.

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