THE EFFECT OF LAYERED TARGET ON THE EFFICIENCY OF PROJECTILE IMPACTS AS A MEAN FOR ASTEROID DEFLECTION: LABORATORY IMPACT EXPERIMENTS AT VARIED GRAVITATIONAL ACCELERATION COMBINED WITH 3D NUMERICAL SIMULATION.

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Introduction and aim: Most asteroids are either completely composed of relatively poorly consolidated rock fragments (i.e. rubble pile), or have such materials forming a regolith layer that may have substantial thickness relative to the size of the asteroid. During a projectile impact event a porous, unconsolidated target material strongly affects the transfer of kinetic energy and the shock wave propagation, thus greatly influencing the cratering efficiency [1, 2] This is of great importance when estimating the effects of an artificial projectile impact to change the trajectory of an asteroid on a collision course with the Earth. Pioneering work on the effects of target layering on the cratering process was done by Quaide and Oberbeck [3] in their studies on the lunar regolith thickness, and by Gault and Sonett [4] in experiments with targets including a surface layer of water. The study by Quaide and Oberbeck [3] describes how so-called concentric craters (i.e. craters with a nested, deeper crater in a rigid basement surrounded by a wider, shallow crater in a weaker surface layer) develop in layered targets such as regolith covered lunar basalts. If the dynamic yield strength of the substrate exceeds the pressure of the shock wave transferred to the substrate then cratering will only occur in the upper layer causing a relatively wide, flat-bottomed crater. When the surface layer is so thin that the energy transmitted to the substrate overcomes its dynamic yield strength a concentric crater develops. Both the crater in the weak layer and the nested crater in the substrate grow simultaneously but the crater in the weaker surface layer grows to a greater size. While much of the kinetic energy of the projectile is released in the upper weak layer, this layer also requires relatively less energy to be cratered, i.e. less energy is consumed by the crushing and melting of rock. The Quaide and Oberbeck model is possibly applicable only to strength dominated cratering. However, the target layering seems to affect also gravity dominated craters on both Earth and Mars [4] and the Moon [5].

The transition from strength dominated to gravity dominated cratering is primarily a function of the gravitational force of the cratered body, but may also strongly depend on the actual strength properties of the impacted target. For a 2 km in diameter asteroid the transition crater diameter may be well above the size of the target, giving that all impacts on such small objects would be strength dominated, although for large asteroids such as Vesta the transition diameter allows both strength and gravity dominated cratering. Nevertheless, even in the case of strength dominated substrates, the weak layer consisting of granular cohesion-less material will still be gravity-dominated. Obviously, the cratering process behind the concentric craters with diameters well above the transition size-range must be different from that suggested for the small strength dominated craters in lunar regolith and previous experiments. Likewise, if the kinetic energy is dissipated into a porous, low-strength target it may have the consequence that the necessary magnitude of the artificial impact needs to be significantly greater than anticipated in order to achieve the demanded effect. Notwithstanding that most cratering on asteroids, and especially of the magnitude of artificial impacts for asteroid deflection, will occur in the strength dominated regime, we are currently investigating the influence of a weak and/or low density layer on the kinetic energy transfer in both strength and gravity dominated cratering.

Methodology and preliminary results: The studies are carried out as projectile impact experiments in the new Laboratory for Experimental Impact Cratering at Centro de Astrobiología (CAB), Spain, and at the centrifuge impact lab of the Boeing Corporation, Seattle, USA. Shots are done into granular targets with layers of different density but similar granulometry. The results are compared with advanced 3-D numerical simulations, as well as with remote sensing on publicly available data of natural impact craters on low-gravity celestial objects (e.g. asteroids, moons). The first shots have been able to successfully generate concentric craters, and with different morphology depending on the relative thickness of the upper, less dense layer.The anticipated outcome of the study will be a better assessment on the effects of an artificial impact on an Earth-threatening asteroid in order to change its trajectory.

References: [1]Wünnemann K., et al. 2006. *Icarus* 180: 514–527. [2]Love S.G., et al. 1993. *Icarus* 105: 216–224. [3]Quaide W. L. and Oberbeck V. R. 1968. *Journl. Geophys. Res*. 73: 5247-5270. [4]Ormö J. et al. 2013. *Meteoritics & Planetary Science* 48(3): 403-419. [5]Wünnemann K., et al. 2012. Abstract #1805 43rd Lunar & Planetary Science Conference.