IMPACT EJECTA IN METEORITES FROM ASTEROID 4 VESTA: SOME POSSIBLE IMPLICATIONS TO EARTH. M. S. Sisodia, A. Basu Sarbadhikari, R. R. Mahajan and N. Bhandari. PLANEX Physical Research Laboratory, Ahmedabad, India (E-mail: sisodia.ms@gmail.com; amitbs@prl.res.in).

Introduction: The interactions between cosmic bodies of the solar system through impact followed by post-impact accretion is responsible for the formation of planet's interior; composition of solid, liquid and gaseous phases and the geological processes. The accretion processes and their consequences are fully dependent on the nature of impact flux [1]. The most direct remnants of the original building blocks that formed the planets of our solar system are the asteroids. The asteroids contain a pristine record of the initial conditions that existed in the solar nebula 4.6 Ga ago. The meteorites, particularly those that have been derived from the differentiated asteroids can tell us much about how planets, in particular Earth, have evolved with time [2]. The howardite-eucrite-diogenite (HED) family of basaltic achondrite meteorites that have fallen on Earth are derived from asteroid 4 Vesta [3,4]. Vesta compared to planets is a very small body but has differntiated into crust, mantle and core and therefore is called a protoplanet [5]. We report here the results of the study of compositional constituents of Lohawat howardite (fall, 1994) and Piplia Kalan eucrite (fall, 1996).

Petrography and Mineral Chemistry of Lohawat: Lohawat is a heterogeneous breccia containing a variety of mineral and lithic fragments [6]. It is highly fragile. The loosely bound material after simple crushing was examined under stereo microscope that revealed Lohawat as an assortment of different minerals and fragments such as: carbonaceous chondrites, impact spherules, micro-meteorites, phyllosilicates, hydrated minerals, and oxidized regolithic material (Fig. 1). Pyroxene, feldspar and olivine are the main constituent minerals but they also occur as coarse single mineral grains. The occurrence of main constituent minerals as single grains and not as compact igneous rock can possibly be due to weathering (Fig. 2). Under polarizing microscope Lohawat shows different minerals and fragmented clasts embedded in a fine pulverized matrix. Coarse single mineral grains of olivine, pyroxene and plagioclase often do not show any intergrowth relationship between other minerals but show intense shock effects or shock metamorphosed transformation. Four different fractions of Lohawat namely; bulk (mixed mass), impactites (spherules), matrix and diogenite clasts were separated based on textural variations for geochemical study. Trace element concentrations were measured using a quadrupole ICP-MS (Thermo-X series2) at PRL. REE-trend of the glassy spherules in the Lohawat howardite displays an enriched pattern (~ 10xCI-chondrite) amongst different fractions and show a relatively large negative Eu-anomaly (Eu/Eu* ~ 0.9) (Fig. 3).

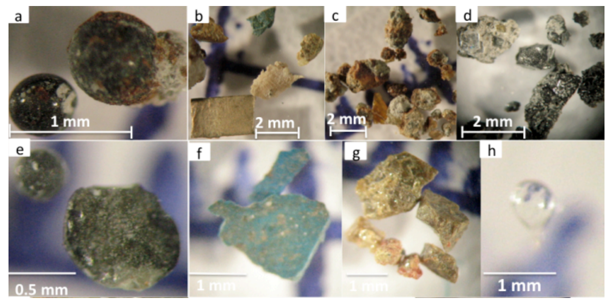

Fig.1 The compositional constituents of Lohawat howardite (a) Impact spherules; (b) Phyllosilicate and hydrous minerals; (c) Regolith material; (d) Carbonaceous chondrite; (e) Micro meteorites; (f) Hydrous mineral; (g) Serpentine; (h) Tear shaped, transparent impact spherule;

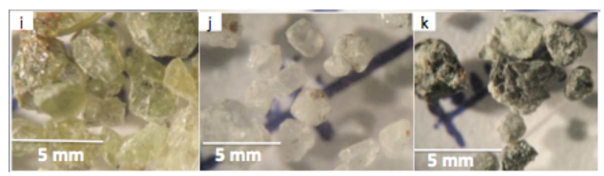

Fig. 2. Constituent minerals occuring as coarse single mineral grains (probably due to weathring) (i) Pyroxene; (j) Feldspar; (k) weathered olivine.

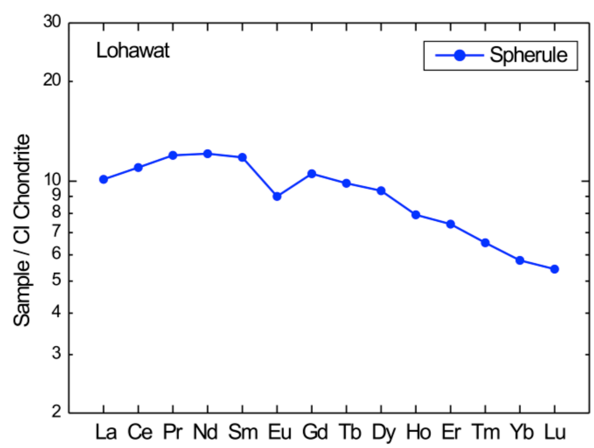

Fig.3. REE abundance of impact glassy spherules of Lohawat howardite. Normalization values are from Anders and Grevesse [7].

Petrography and Mineral Chemistry of Piplia Kalan: Piplia Kalan has been interpreted as equilibrated noncumulate breccia constituted of diverse components [8, 9]. Macroscopically it appears as breccia made up of mixed type, fine and coarse as well as molten fragments of crushed rocks and minerals (Fig. 4a). The minerals are mostly pyroxenes (hypersthene, pigeonite, augite) and plagioclase (anorthite) included in which are impact melts, pseudotachylitic veins and opaques such as ilmenite, troilite etc. (Fig. 4b). It shows shock-induced cracks, cleavages and fractures. Plagioclase is cloudy, has anomalous composition and is deformed. Pyroxenes are fractured and show mosaicism. Hypersthene shows shock features preceding its gradation to pigeonite. It is a compact basaltic achondrite with no loosely bound minerals/fragments unlike Lohawat. It shows two different textures: coarse and fine, that may be due to post-impact slow cooling and extensive reequilibration between melt and mesostasis. Three fractions namely bulk, coarse fraction and fine fraction were analysed for rare earth elements. Interestingly, the coarser fraction of this eucrite demonstrates a positive Eu-anomaly, while the finer fraction shows a negative Eu-anomaly [10].

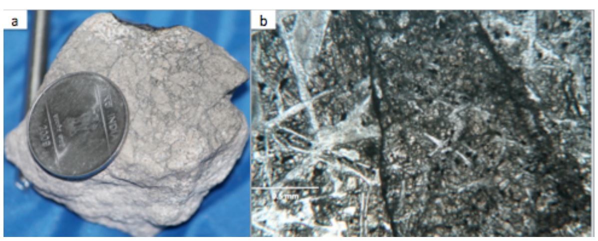

Fig. 4. (a) Piplia Kalan meteorite, a breccia, composed of fine, coarse and glassy fragments of crushed rocks and minerals. (b) Photomicrograph of Piplia showing texturally different (fine grained and coarse grained) fractions

Discussion: Vesta being a protoplanet mimics numerous dynamical, collisional and thermal events that have shaped the Earth. The surface of the Vesta is highly scarred by impacts, the study of which, signified by HED meteorites can be used to interpret the possible starting conditions as well as plodding events that sculpted Earth into its contemporary shape. The REE trend of the coarse fraction of Piplia together with petrographic study showing no zoning of pyroxenes or plagioclase suggest that it is an equilibrated eucrite while its bulk composition suggest that it is noncumulate eucrite [10, this work]. It can therefore be suggested that Piplia has been reequilibrated possibly due to combination of shock effects and later heating (e.g., experimental work by Walker et al [11]). Lohawat is a polymict breccia and is an assortment of diogenitic, eucritic and regolithic material. Diogenites form as cumulates in one or more magmas undergoing fractional crystallization [3]. Lohawat originated from the surface of Vesta and constitutes representative samples from its core, mantle and crust.

The observation of hydrated minerals and carbonaceous chondrite clasts in Lohawat is interesting [12]. Impacts on Vesta produce substantially less silica melt because lower surface gravity of Vesta induce lower velocities to the impactors [13]. Presence of hydrated minerals on vesta is of great importance for deducing the processes that operated in the earliest stages in the solar system history and origin of Earth's water. Isotopic systematics under study will elucidate whether these hydrated minerals were added to Vesta by carbonaceous chondrites. Direct geologic evidence of water activity on Vesta has recently been documented [4]. Sarafian et al [14] measured the hydrogen isotopic composition of the mineral apatite in eucrite meteorite from Vesta and concluded that Vesta and carbonaceous chondrites have the same hydrogen isotopic composition which is similar to hydrogen isotopic ratio of the Earth. The water and other volatiles such as carbon and nitrogen therefore should have accreted early on the Earth.

References: [1] Masaitis V.L. (2005) Austr. J. Earth Sc., 52, 509-528; [2] Bottke W. et al Editors (2002) *Asteroids III*, Arizona University Press; [3] Drake M.J. (2001) MAPS, 36, 501-513; [4] Scully J.E.C. et al, (2015) EPSL, 411, 151-163; [5] Russel C.T. et al, (2012) Science, 336, 684-686; [6] Sisodia M.S. et al, (2001) MAPS, 36, 1457-1466; [7] Anders and Grevesse (1989) GCA, 53, 197-214; [8] Shukla A.D. et al (1997) MAPS, 32, 611-615; [9] Bhandari N. et al (1998) MAPS, 33, 455-461; [10] Basu Sarbadhikari A. et al (2015) 46^{th} LPSC # 1464; [11] Walker et al (1978) Proceedings 9^{th} LPSC, 1369-1391; [12] Sisodia et al (2015) AbSciCon # 7069; [13] Williams D.A. et al (2014) Planet Space Sci. 103, 24-35; [14] Sarafian A.R. et al, (2014) Science, 346, 623-626.