THE USE OF DIGITISED BACK-SCATTERED ELECTRON IMAGING AND ELEMENT MAPPING FOR THE IDENTIFICATION OF IMPACT RESIDUES IN THE SOLAR ARRAY PANELS OF THE HUBBLE SPACE TELESCOPE. G. A. Graham[1,3], A. T. Kearsley[2], M. M. Grady[3] and I. P. Wright[1],[1]Planetary Sciences Research Institute, Open University, Walton Hall, Milton Keynes, MK7 6AA, UK, e-mail: g.a.graham@open.ac.uk, [2]Division Of Geology & Cartography, School Of Construction & Earth Sciences, Oxford Brookes University, Gipsy Lane, Headington, Oxford, OX3 7AB, UK, [3]Department Of Mineralogy, Natural History Museum, Cromwell Road, London, SW7 5BD, UK.

Abstract: The development of digitised back-scattered electron imaging and X-ray emission elemental mapping has lead to the rapid identification and classification of impact residues in nine cells from the recovered solar array from the HST. The results indicate that the majority of impact are as a consequence of natural material (micrometeoroids) rather than artificial space debris.

The HST was launched in 1990 and deployed in a low Earth orbit (LEO) (614 km). During a routine service mission in 1993, one of the solar array panels was successful retrieved and returned to Earth [1]. The panel offered the opportunity to study the effects of space exposure on hardware from LEO and to distinguish between impacts created by natural micrometeoroids (i.e. residues containing Mg, Fe, Ni, S etc.) and space debris such as paint fragments (i.e. residues containing Ti, Ag, Al etc.). The techniques used in LDEF to identify the impact features, e.g. [2] have been employed in previous attempts to classify the HST solar cell impact residues, e.g. [3]. These have shown that the analytical techniques used have often proved to time consuming in the identification process. Here we report on the development of techniques used in previous studies [2,3] that enable the rapid identification of impact residues and if enough data is obtained, the classification as well.

The underlying success of this new technique is the selection of samples to be analysed. The solar cells are composed of CMX (borosilicate glass) top protective layer (150µm thick) for the underlying silicon solar cell (250µm thick) which is then support by an adhesive substrate (210µm) containing a fibre-glass backing tap. (all the layers are held in place by a silicone adhesive) [4]. The best preservation of impact material will in solar cells were only the upper layers of the cell have been penetrated [5], this tended to be in the smaller sized impact features (up 100µm diameter). Previous work [6] dealt with a larger (up to 1mm in diameter) impacts which had penetrated all the layers of the cell and thus made identification of residues a complex procedure.

Nine impact features were selected after a preliminary optical analysis at x10 x20 and x40 magnification. The high magnification (x40) examination enables the identification of any extraneous material to the cell. This material when present appeared as fibrous particles with a black metallic lust in colour. The samples were then carbon coated and the features characterised using a Jeol JSM-840 Scanning Electron Microscope (SEM) fitted with an Oxford Instruments eXL X-ray energy dispersive spectrometer. The analytical work was carried out at an accelerating voltage of 20kV with a beam current of 2nA and a working distance of 32mm. The analysis protocol initially involved digitised back-scattered electron imaging (BEI) of the impact feature at low magnification (x250) with high pixel resolution. If an area of interest was located then this procedure was carried out at higher magnification. The second protocol utilised a series of digitised x-ray emission maps, for a suite of elements present in both the cell and any extraneous impactor (both natural and man-made) including carbon, oxygen and fluorine. The mapping was again carried out in two stages, initially at low magnification and low pixel resolution (low data depth) over the entire feature. This identifies the areas where the extraneous material is located within the feature. A higher pixel resolution and magnification (>x750) map is then produced of these areas and when coupled with spot X-ray micro-analysis enabled the identification and classification of the residue using a scheme similar to the criteria used for LDEF [2,7].

The digitised BEI analysis enables the manipulation of data (pixel resolution) to clearly define the compositional changes in the different layers in the cell and more importantly any extraneous material. This material has under back-scatter a distinctive molten vesicular appearance, which in some cases shows evidence of gas or air bubbles which has been trapped in the melt. The natural residues not only exhibit these features but also show as micron sized (1-10µm) melt spherules which appear to be both attached to and embedded with the cell melt itself. These embedded spherules cannot normally be identified in secondary electron images, but the back-scatter images are able to identify such fine compositional changes even within the cell melt layers. The embedded spherules also highlight the extent to which melt-mixing of cell and impactor occurs.

The digitised X-ray elemental maps again enable the manipulation of data to distinguish between the various melt states which occur within the crater, e.g., the impactor melt residue, the impactor plus cell host melt mix and the cell host melt. The melt mix between the impactor and the cell host can be identified by a whispering effect. The maps can also identify minor

elemental variations across the sample substrate at low magnifications (<x250). This can be used to identify and locate small impact features (<50μm in diameter): the CMX glass has a micron-thin top surface coating of magnesium fluoride, which is removed by impact, thus wherever the MgF is depleted then a impact pit is present.

The results from the study have shown that seven out of twelve impacts residues identified (cells contained multiple impacts) have been classified as being caused by extraterrestrial origin, two as space debris. Two features were unclassified as the chemical signatures of their residues were ambiguous and could have been formed from either natural or space debris; the remaining feature contained no residue.

The impact residues identified as space debris were classified as paint fragments (containing Ti), human waste (potassium salt crystals) and a residue of Fe with accessory Ni and Cr. The presence of Cr implies that the impactor was some type of stainless steel (which has numerous space applications). Due to the size of the impact residue (1-10μm) and the fact the it was located on a fibre-glass backing medium it was not possible to carry out any quantitative analysis on the residue to classify further the type of stainless steel. Note that one impact feature caused by a natural impactor (see below) contained a Ti-based paint fragment fused to the rim of the crater. This implies that it is possible for samples to be exposed to several impactors which may or may not be the cause of the crater. This finding shows the complex nature of post-flight investigations because it means that it is possible to wrongly identify an impact feature

The natural impact residues identified can be classified as, Fe-Ni sulfides, mafic silicates (e.g. olivines and pyroxenes), these residues are typical of the LDEF finding [2,7-9]. A third class of residue was identified as Fe-Ni metal which could represent a new class of micrometeoroid [10]. The mafic silicates included the identification of an Mg-olivine, which LDEF studies [8] failed to observe. This highlights the fact that this technique is able to characterise residues which contain volatile elements such as Mg which were thought to devolatilised during the metamorphic impact process. The results also show that a higher percentage of Fe-Ni sulfides (42%) are identified in these samples than in the LDEF studies (3%) [2]. This implies that a large number of natural impacts are caused by impactors were the dominant mineral phase is Fe-Ni sulfide such as in carbonaceous chondrites. Although it is possible to identify the natural micrometeoroids as extraterrestrial, it is not possible to classify the in terms of meteorite class using the present schemes [2,7]. This is because the Fe-Ni sulfides have been identified in a range of meteorites from carbonaceous chondrites to stony irons and the same is for mafic silicates and because the impact residues only contain partially chemistries of the origin impactor, it is only possible to give a limited classification of origin.

The selection of specific samples with small impact features (100μm) which have only penetrated the top layers of the solar cell has created a sample bias in terms of previous HST work [3,6], but is actually at the higher end of the sample selection used for LDEF studies (10-<75μm). The results from this study suggest that a greater number of impacts is caused by natural particles than space debris in space hardware, this supports the findings of LDEF [2] and previous HST impact residue studies [3]. This technique has proved that impact residues can be readily identified and could be employed in identifying new features when future samples (e.g. LDEF2) are returned to Earth

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