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THE SOLAR MAXIMUM SATELLITE CAPTURE CELL: IMPACT FEATURES AND ORBITAL DEBRIS AND MICROMETEORITIC PROJECTILE MATERIALS.

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The Solar Maximum satellite (Solar Max) was launched on February 14, 1980 into a near circular orbit at 570km altitude. After its orbit had decayed to 500km, the satellite was retrieved by the STS 41-C crew on April 12. 1984. Some Solar Max surfaces were brought back to Earth after 4 years and 55 days of exposure to the near-Earth space environment. The returned surfaces include ca. 1.5m^2 of thermal insulation materials (multiple-layered blankets) and 1.0m^2 of aluminum thermal control louvers (two 140µm-thick Al-foils separated by about 3mm). These surfaces have been completely scanned by optical microscopy for impact features, i.e. craters and penetration holes. In this survey only impact features with diameters larger than ~40µm were mapped. Smaller impact features on the thermal insulation blankets may have been partially obliterated because atomic oxygen has eroded ~20µm of the exposed Solar Max Kapton surfaces [1].

Impact features up to ~500µm were observed on the thermal insulation blankets. The thickness of the first (Kapton) layer of the thermal blankets is different for various parts of Solar Max, e.g. the first layer on the Attitude Control System (including blankets #6 and #9) is initially 50µm thick while this layer on the Main Electronics Box (MEB) is initially 75µm thick. The observation that impact features >70µm in diameter on blankets #6 and #9, and impact features >80µm in the MEB blanket, are usually penetration holes rather than craters is probably related to the difference in thickness of this layer [1, 2]. In the following we will concentrate on our observations of the MEB thermal blanket which, to date. is the most intensely studied surface recovered from Solar Max.

The MEB thermal blanket consists of an initially 75µm thick, Al-coated (backside) Kapton layer followed by 15 doubly-aluminised Mylar layers (6µm thick) and finally an Al-coated (frontside) 25µm thick Kapton layer, each separated by a ~100µm thick Dacron mesh. We recognised two basic types of impact features in the first layer: craters ranging up to ~140µm in diameter and penetration holes 80-500µm in size.

One or more of three different types of halos on the front side of the first layer can be recognised surrounding each impact feature, viz. a bright halo, an irregular spall halo with a jagged outer margin in which a thin surface layer of material has been removed and a dark smokey halo [2]. The dark smokey halo is a rather diffuse phenomenon that sometimes extends a considerable distance away from an impact feature. Generally confined within this halo, a spall zone may surround an impact feature. We tentatively suggest that an impact feature surrounded by a spall zone represents a lower velocity impact compared to an impact feature of similar size but without a spall halo. A narrow, bright halo often directly surrounds an impact feature. The bright halo is confined well within the spall halo. The origin of the bright halo is uncertain but we suggest that this halo represents a shock metamorphosed region of the Kapton layer, viz. a region of structural or chemical changes. One or more halo types are typically present around holes but they may be absent around craters.

The rims around craters are generally smooth, raised and may be overturned although in some cases the rims are subdued or lacking. The holes are typically surrounded by raised, usually overturned, nearly circular rims on both the "entrance" side and rear (exit) side [2]. The almost identical rims on both front and rear sides of the first layer are evidence for hypervelocity impact [3]. Partially detached rims could be consistent with hypervelocity impact [3].

A generally circular spray pattern of roughened second layer material with elongated pits, holes and entrapped particles is found beneath most of the first layer holes [4]. The pits and holes may be arranged in a concentric symmetric pattern in some cases but show no apparent symmetry in others. The diameter of the spray pattern is typically larger than the diameter of the hole on the first layer by ratios of 2.5-20.0 : 1 [2]. In a few impact features the projectile penetrated the second layer. Penetrations of subsequent layers are rare. Penetration holes in the second, or subsequent, layers are typically irregular and have no raised rims.

Small-sized (1-50μm) particles are present in craters, on the front and backsides of the first layer around a penetration hole, and within spray patterns on the second layer beneath a penetration hole [5]. However, in these locations the amount of particles can be highly variable. These particles may represent the remains of impacted micro-meteorites and orbital debris or derive from molten target (Solar Max) material [4].

Particles on Solar Max surfaces were studied using a JSM-35CF scanning electron microscope equipped with a PGT System IV energy dispersive spectrometer for in situ micro-analysis. Selected particles were removed from impact features for detailed mineralogical analysis using a JEOL 100CX analytical electron microscope [4-6]. Because of the extreme sensitivity of the technique, contamination is a serious concern in electron microscope studies of small-sized particles [7]. This issue is of particular concern in analysis of Solar Max particles. However, the satellite was not designed to be returned for laboratory studies and appropriate stringent pre-flight cleanliness procedures were not invoked.

Contamination may have occurred during handling of the satellite prior to launch, during STS rendez vous, or in the laboratory after return to Earth. Contaminants include materials of anthropogenic and natural (terrestrial) origin. For example, analysis of discolorations and wipe-marks on Solar Max surfaces show the presence of silicone oil [8, 9] while abundant silica-rich particles commonly associated with the wipe-marks may represent recrystallised silicone oil [8, 10]. In addition, Ca,P-particles were proved to be calcium-phophate used in the manufacture of this particular type Mylar [5]. Albeit rather unusual. ice particles from the shuttle waste management system impacted on Solar Max surfaces during STS rendez vous [1]. In addition, paint particles also contaminated Solar Max surfaces forming both low- and high-velocity impact features as well as a nevenly distributed spray on the front side of the first layer [5].

It should be remembered that Solar Max was not intended to act as a capture device. One important source of orbital debris is solid rocket effluent related to rockets fired in space [1, 11]. A typical sample of solid rocket effluent consists of spheres of Al_2O_3 [12]. However, the presence of aluminum on Solar Max (louvers and thermal blanket coatings) virtually eliminates the satellite as a detection device for externally derived Al-rich orbital debris even though Al-rich particles are commonly present near Solar Max features [4, 8].

After a detailed study of surfaces exposed in space, as well as surfaces shielded from the space environment, we developed the following criteria to separate contaminant particles from potential projectile materials.

Potential projectile materials are defined as particles associated with an impact feature. That is, they are (1) found within one crater or penetration hole diameter of the impact feature in the first layer, on both front and back sides, and occasionally on other penetrated layers and (2) within the spray pattern on the second or subsequent layers [5].

The particles associated with impact features generally show droplet (spherical or globular), irregular or fragmental (angular) morphologies [5, 6], although porous, fluffy particles have been reported [8].

The chemistry of associated particles is variable; however, two distinctive and major categories are prominent: meteoritic particles and paint particles. The former. associated with 12 out of 39 impact features, are concentrated on the front side of the second layer. Paint particles are associated with 25 out of 39 impact features and are concentrated on the front side of the first layer. Both particle types co-occur associated with six impact features [5].

Meteoritic particles include Mg-silicate (Mg,Si) particles and Mg-Fe silicate particles (MSF) [cf. ref. 4]. Some MSF particles are angular-shaped, unshocked olivine single crystals (Fo76-78) that survived capture without melting, although rounded olivine grains within the same impact feature appear to be slightly modified during impact [4, 6]. The composition and texture of olivine from Solar Max are comparable to those in primitive meteorites. The presence of Ca and/or Ni [1] and sulfur [8] in other MSF particles suggests a chondritic affinity [4. 8]. Some of these particles associated with penetration holes in the first layer have a fluffy morphology similar to chondritic micrometeorites collected from the stratosphere [8]. The chondritic micrometeorite particles in Solar Max impact features display varying degrees of fractionation as indicated by varying amounts of sulfur and the presence of metallic (Fe-Ni-Cr) mounds [8]. However, layer silicates in a chondritic micrometeorite particle associated with a crater are witness that shoch induced metamorphism is not always severe [8].

A second type of micrometeoritic particle are iron sulfides (Fe,S) and approximately stoichiometric Fe,Ni-sulfides (FSN) [4, 5, 8].

Paint particles associated with Solar Max impact features typically contain at least two of the elements Ti, Zn and Si as major elements. These elements are typically present in thermal-control spacecraft paint (MS74) which is a physical mixture of pigments (Ti- and Zn-oxides) in a potassium silicate binder and contains varying amounts of Ti, Zn, Si, K, Al [5]. A fraction of the paint particles also contain chlorine [1]. The source of chlorine in these particles is not yet understood. Small-sized (ca 2-3µm) paint particles associated a penetration hole and a crater on one of the louvers are mostly of the Zn,Si-type [13].

A third category of particles associated with impact features is formed by particles containing Al, Si, S, Fe, Ni, Cr, K and Cl in various combinations, Na-Cl, Ba-S. Bi-(Cl) and Ag-S. Particles from this category are the only type of particles associated with 8 out of 39 Solar Max impact features. Although the origin of this category remains largely enigmatic some particles probably derive from spacecraft paints and coatings [5].

CONCLUSIONS. The physical properties of impact features observed in the Solar Max MEB blanket generally suggest an origin by hypervelocity impact. We are confident that impact features containing only meteoritic particles are the result of impacting micrometeorites. The chemistry of micrometeorite material suggests that a wide variety of projectile materials have survived impact with retention of varying degrees of pristinity. Impact features that contain only paint particles are on average smaller than impact features caused by micrometeorite impacts. In case both types of materials co-occur, we believe that the impact feature, generally a penetration hole, was caused by a micrometeorite projectile. The typically smaller paint particles were able to penetrate though the hole in the first layer and deposit in the spray pattern on the second layer. We suggest that paint particles have arrived with a wide range of velocities relative to the Solar Max satellite. Orbiting paint particles are an important fraction of materials in the near-Earth environment.

In general. the data from the Solar Max studies are a good calibration for the design of capture cells to be flown in space (LDEF) and on board Space Station. The data also suggest that development of multiple layer capture cells in which the projectile may retain a large degree of pristinity is a feasible goal.

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