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PLANETARY SPACECRAFT DEBRIS - THE CASE FOR PROTECTING THE SPACE ENVIRONMENT

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ABSTRACT

In the early years of the Space Age spacecraft debris and spent rocket stages were deposited on the surface of the Moon, ostensibly in the name of space science. Although this was not considered 'pollution' then, as we look forward to further manned lunar missions and subsequent development, the status of the lunar surface and orbital environment should be of greater concern, not least with regard to the safety of future travellers. By extension, the effect of spacecraft impacts on the surfaces of other planetary bodies and the formation of planetary orbital debris should be of similar concern to the wider space community.

In addition to a commentary on the origins and objectives of the Scientific-Legal Round Table of which this paper is a part, the paper presents an initial catalogue of spacecraft impacts on planetary bodies and the resulting debris that may still be found on their surfaces. It also considers the future of scientific exploration and commercial exploitation of the planetary bodies and presents the case for protecting the space environment.

In conclusion, the paper calls for the formation of an international consultative study group, or similar body, to consider the issues relevant to **'Protection of the Space Environment'** and to raise awareness of the subject among the growing body of space professionals and practitioners.

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INTRODUCTION

In the early years of the Space Age, the exploration of the solar system was considered a triumph of man over nature described in terms of 'the conquest of space'. Among other things, it led to the surface of the Moon being littered with spacecraft debris and spent rocket stages, ostensibly in the name of space science [1].

The first spacecraft to impact the Moon, on 15 September 1959, was Luna 2. The main intention of the Russian mission was to deliver a political message in the form of a 26kg sphere which, according to one author, disintegrated on impact, scattering tiny medallions "carrying Russia's hammer-and-sickle badge, over the surface of the Moon" [2]. In fact the force of the impact is more likely to have buried the sphere under several meters of lunar crust.

The first American spacecraft to strike the Moon was Ranger 4, which, although inactive because the master clock in its central computer had stopped [3], became the first to crash on the far side of the Moon in April 1962. Later in the decade, an era where the 'trashing' of the lunar surface seemed of little import, NASA's Lunar Orbiters ended their successful lives by being commanded or allowed to crash on the Moon to "prevent interference" with Apollo [4]. And even the Apollo lunar seismic experiments involved purposely crashing Saturn V third stages onto the surface, so that previously sited seismometers could detect the resulting lunar reverberations.

Any suggestions then that this was tantamount to pollution of the space environment were not taken seriously, but today, as we look forward to further manned lunar missions and subsequent development, the status of the lunar surface and orbital environment should be of greater concern, not least with regard to the safety of future travellers. By extension, the effect of spacecraft impacts on the surfaces of other planetary bodies and the formation of planetary orbital debris should be of similar concern to the wider space community.

THE CASE FOR PROTECTION

There is already a mature and growing awareness of the real and potential damage to the Earth's environment caused by the activities of mankind. More recently, this awareness has been extended to the problems of spacecraft and launch vehicle debris in Earth orbit.

Most space practitioners are now familiar with the potential for orbital debris to restrict access to some of the low Earth orbits (LEO) and cause damage to satellites in geostationary orbit (GEO). So far, however, there has been very little publicity attached to the environmental damage caused to planetary surfaces. It has been suggested that this is at least partly because the damage is caused by scientific spacecraft, which tend to be seen as 'benevolent' as opposed to commercial or exploitative. However, the spacecraft debris which already litters the lunar surface provides evidence against this rather rose-tinted view [5].

Logically, recent experience with vehicle explosions and collisions in LEO should argue for a concerted and coordinated policy of debris mitigation throughout the rest of the solar system. This is especially important if mankind intends to return to explore and develop the Moon, and/or Mars, since a point will be reached when the volume of traffic in orbit around these bodies becomes sufficiently significant for the production of orbital debris to be considered.

More difficult is the case for protection of surface environments, as experience on Earth has shown. A policy of 'out of sight, out of mind' is considerably easier to establish where planetary environments are concerned. But does this remove responsibility from those involved in exploring and later developing the planetary bodies? Are we in danger of treating them as an extension of our own untidy backyard? It would be as well to consider this now, as opposed to waiting until there is a need for remedial action, as there is already in LEO. The old adage 'prevention is better than cure' is particularly apposite.

The problem, of course, is obtaining a consensus. Research conducted for this paper (see 'Round Table Origins' below) has shown that some people consider planetary bodies other than the Earth to be barren, unwelcoming worlds which are either 'ripe for plunder' in terms of material wealth, or need to be 'civilised', perhaps by terraforming.

This view is analogous to the American public's view of nature in the nation's early history, when, according to author Howard McCurdy, wilderness areas were considered "savage, uncontrollable, and evil" [6]. It was not until landscape paintings which romanticised those areas as places of great natural beauty were exhibited in the early 19th century that the concept of conservation became realistic. Later that century, paintings of the Rocky Mountains and Yosemite Valley helped build support for the national park movement and Congress was even moved to appropriate $20,000 for similar examples to hang in the US Capitol, according to McCurdy.

Currently, as far as the space environment is concerned, it is not the general public that needs convincing; it is the space professionals and organisations which procure, design and finance space hardware that must be made aware of the need to protect planetary environments. In the future, when the Apollo landing sites become tourist attractions - perhaps even 'International Parks' - the visiting public will thank the space professionals for their foresight.

Failure to place a value on planetary environments now could have irreversible effects, as the following scenarios are intended to show.

- Without proper safeguards, an increase in spacecraft traffic in lunar or other orbits could lead to the same type of orbital debris problem now experienced in low Earth orbit. Mission plans should include debris mitigation measures and, at least, removal to graveyard orbits analogous to those used for geostationary satellites.

- Removal of defunct spacecraft by de-orbiting has an arguably greater environmental impact for the Moon or Mars, for example, than it does for the Earth, due to the lack of an appreciable atmosphere. Spacecraft and debris will impact a planetary surface rather than burn up in an atmosphere, and 'ocean disposal' is not an option.

- Spacecraft and launch vehicle stages which have already struck the Moon have produced craters and metallic debris on the surface, which may present a safety problem to future explorers. Moreover, whereas the Earth's environment has a natural ability to repair itself, the lunar environment has no such capability and will bear the scars of man's intervention for the foreseeable future.

- Planetary science spacecraft are designed under the assumption that they will analyse chemical constituents native to a planetary body and not contamination from Earth. Those which crash, or break up on entry, may spread debris over a wide area, contaminating a formerly 'pristine' planetary environment. This will not immediately be harmful to humans, but it could prove extremely harmful to science[5].

- Certain types of industrial surface development could disfigure the surface of a planetary body. If, for example, open cast mining of the lunar surface is undertaken, to what extent should it be controlled: so as not to be visible from Earth with the average naked eye; through the average amateur telescope; or from a low lunar orbit?[5] As Hungarian astronomer Ivan Almar has pointed out, a typical open cast mine on the Martian moon Phobos, which is smaller than a city the size of London, could destroy its unique groove system forever[7].

- Further exploration could damage historic landing and exploration sites. If the Apollo landing sites, and others, are to be valued as historic sites and/or become revenue-earning tourist attractions, they must be preserved from accidental damage or trophy hunting by the next-generation (pre-tourism) lunar explorers. For example, a US company (Lunacorp) has announced plans to launch an 'intelligent' robot rover to the Moon "to trek among historic Apollo sites", as its President puts it[16]. A remotely-controlled vehicle may be preferable to crowds of tourists, but initiatives such as this should be carefully monitored.

ROUND TABLE ORIGINS

It was consideration of possibilities such as the above that led to the proposal that 'protection of the space environment' should be the subject of an IAA/IISL Scientific-Legal Round Table.

The author of this paper, and coordinator of the Round Table, had long been suspicious of terraforming and its inherent assumption that an alien planetary environment could arbitrarily be transformed into an Earthlike environment, apparently without consideration of the scientific or aesthetic importance of the original. The impression that other planetary bodies were not valued for their geomorphology was augmented during research into the history of lunar exploration (referred to above[1]) and on reading the announcement that Japan's Lunar-A spacecraft would carry penetrators which would add to the catalogue of manmade lunar surface debris.

This led to the production of an IISL paper - entitled 'Protection of the Space Environment Under the Outer Space Treaty'[5] - and the publication of a number of articles and commentaries[8-12], submitted in an attempt to evoke reaction. Two of the five[9,11] had the desired effect and engendered three published letters between them[13-15] (names have been omitted to preserve privacy); predictably, they fell firmly into either the 'pro' or 'anti' camp.

The responses served to convince the author that a programme to increase awareness of the issue was justified and necessary. For example, one correspondent's response to the question of whether the space environment constitutes "a body of resources to be plundered" was "of course"; in fact, he believed that it was "hopeless to attempt to regulate it". As a welcome counterpoint, a private letter in response to the published material suggested an extension to the national park slogan ('take only photographs, leave only footprints') quoted in the article: "you can look, but don't touch". Opinion is evidently polarised.

Moreover, concerning the historic nature of planetary landing sites, one correspondent would "criminalise the vandalism or theft of old spacecraft or their component parts with internationally binding legislation that reflects the statutory protection given to artefacts on terrestrial archeological sites" [15].

Another correspondent [14] took issue with the suggestion that the Moon had an 'environment' worthy of protection, apparently because it has no significant atmosphere. In fact, as most space professionals know, its 'external conditions or surroundings' are virtually synonymous with the vacuum, thermal and radiation *environment* of outer space.

This indicates the need to address, among others, the following questions. Should 'lifeless' worlds be open to unlimited exploitation simply because they have no detectable ecology? Is life the only measure of worth? Should we not recognise the inherent beauty of geology and geomorphology? If a planet's physical environment is not important, then perhaps we should sanction the construction of condominiums on the mesas of Grand Canyon or the mining of the Giant's Causeway for patio materials!

This is not the first time that the subject of planetary protection has been aired [7, 17-20]. It is however, the first time it has been recognised as sufficiently important to merit in-depth coverage at an IAA/IISL Scientific-Legal Round Table (the objectives of which are summarised in Appendix 1). The papers presented at the Round Table will form a special addendum to the Proceedings of the IISL for 1999. Whether the subject progresses beyond that will depend on interest within the space community and the abilities of those already involved to publicise their ideas as widely as possible.

The author's IISL paper of 1997 [5] concluded with the suggestion that two possible activities may help to lay the groundwork for development of an agenda for protection of the space environment:

- a continual review of space missions to the planetary bodies, to compile a catalogue of the debris from spacecraft impacts that may still be found on their surfaces

- consideration of the future of scientific and commercial exploration and exploitation of the planetary bodies, in both ethical and pragmatic terms, with a view to a sustainable balance between the productive activities of mankind and the desire to retain the purity of the space environment.

An initial attempt at the first is presented in this paper as Appendix 2, while the Round Table itself marks an early step in the second. To this end, speakers were invited to cover a variety of aspects related to the subject, including:

- the environmental effects and the future potential for damage
- the possible detrimental effects of future space development on astronomy and planetary research
- the potential for space debris in lunar orbit
- the possibility of legislation to protect the space environment
- the scientific and legal implications of exobiology and planetary protection
- terraforming and the ethical dimensions of space settlement.

CALL FOR ACTION

Initial research has suggested that, while many people have an inherent appreciation of the need for planetary protection, many more remain to be convinced. In this sense the situation is broadly analogous to that of the terrestrial case.

As with the Earthbound environmental movement, there is a need to raise awareness among both space professionals and the general public. However, terrestrial experience of 'ecowarriors' and 'greens' of various shades argues for caution, since over-zealous and inaccurate claims broadcast in emotive language may lead to alienation rather than understanding.

The intention must be to provide education without alienation, perhaps taking the line of the 19th century wilderness painters quoted by McCurdy [6], although it will not be easy. Whereas photographs of the Moon, particularly those resulting from the Apollo missions, had an important affect on society, arguably even kick-starting the terrestrial environmental movement, images of the more distant planetary bodies are unlikely to provide such a fundamental boost to the 'planetary environment movement'. Whereas everyone who lives on the Earth has a vested interest in protecting the planet's environment, no such interest exists for the Moon and Mars, possibly because there is no concept of 'ownership' (in the emotional sense).

The emergence of constructive proprietorial feelings may have to await the development of space tourism, at which point a vested interest in preserving both planetary surfaces and historic sites thereon may exist. Of course the development of tourism facilities is not without its environmental concerns and it may be that legislation is the only recourse in protecting the space environment.

On the basis of our experience with spacecraft debris in Earth orbit alone, it is evident that the subject of planetary spacecraft debris deserves serious consideration, possibly under two headings: debris monitoring and awareness raising.

- It is necessary to monitor the formation of debris on a continuing basis and to consider a policy of mitigation (as is already underway for Earth orbiting debris). It is suggested that this could be engineered through the formation of an international consultative study group, or similar body, to consider the issues relevant to 'Protection of the Space Environment'.

- It is necessary to enhance awareness of the issues among the growing body of space professionals and practitioners, and to encourage discussion of all aspects, not least to allow feedback on initial ideas. The Round Table of which this paper is a part is a small step in the right direction, but should be seen only as a starting point on what may be a long journey.

A key word in any discussion must be 'compromise'. Few space professionals whose livelihood depends on using technology in space will want to close the door on space exploration and development; indeed, many were attracted to the profession by thoughts or actual examples of planetary exploration. But exploration and development of the planetary bodies should be conducted with a view to the rights of future explorers and developers. Some 'damage' to the space environment is inevitable, but, with forethought and understanding, damage can be limited. On the other hand, if 'practical utility' is to be the sole driver for the desirable and inevitable expansion of mankind into the solar system and beyond, we should wait until we have gained the degree of maturity and responsibility that befits this momentous and important goal.

The aim of this paper, and by extension the Round Table, is that the issue of 'planetary debris' should some day be recognised among space professionals in the same way that 'orbital debris' is today. Once that aim is achieved, awareness of the problems, and their solutions, can be extended to future users, owners and developers of the space environment.

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APPENDIX 1: ROUND TABLE OBJECTIVES

(i) To present the facts regarding actual and potential degradation of the space environment by human activity, particularly that of the planetary bodies which has received relatively little publicity. It is *not* intended to include in-depth discussion of orbital debris, which is now well recognised and has been well covered in previous symposia.

(ii) To allow discussion of the problems and seek professional opinions on their importance and relevance to future solar system exploration and exploitation

(iii) To attempt to discuss environmental ethics, in both technical and legal contexts, and to consider how awareness of the problems might be enhanced among the space community.

APPENDIX 2: INITIAL CATALOGUE

Tables compiled mainly by Nicholas Johnson, with additions by Mark Williamson.

Lunar Impacts

Object	Launch Date	Lat	Long	Impact Nature	Other Debris
Luna 2	12/9/1959	30.0 N	0.0 E	Crash 15/9/59	Luna 2 upper stage
Ranger 4	23/4/1962	15.5 S	130.5 W	Crash 26/4/62	
Ranger 6	30/1/1964	9.2 N	21.5 E	Crash 2/2/64	
Ranger 7	28/7/1964	10.7 S	20.7 W	Crash 31/7/64	
Ranger 8	17/2/1965	2.7 N	24.8 E	Crash 20/2/65	
Ranger 9	21/3/1965	12.9 S	2.4 W	Crash 24/3/65	
Luna 5	9/5/1965	31.0 S	8.0 W	Crash 12/5/65	Propulsion unit + 2 debris
Luna 7	4/10/1965	9.0 N	49.0 W	Crash	Propulsion unit + 2 debris
Luna 8	3/12/1965	9.1 N	63.3 W	Crash	Propulsion unit + 2 debris
Luna 9	31/1/1966	7.1 N	64.4 W	Hard Landing	Propulsion unit + 2 debris
Surveyor 1	30/5/1966	2.5 S	43.2 W	Soft Landing	Propulsion unit
Lunar Orbiter 1	10/8/1966	6.7 N	162.0 E	Crash	
Surveyor 2	20/9/1966	5.5 N	12.0 W	Crash	Propulsion unit ?
Lunar Orbiter 2	7/11/1966	4.0 S	98.0 E	Crash	
Luna 13	21/12/1966	18.9 N	60.0 W	Hard Landing	Propulsion unit + 2 debris
Lunar Orbiter 3	25/2/1967	14.6 N	91.7 W	Crash	
Surveyor 3	17/4/1967	3.2 N	23.4 W	Soft Landing	Propulsion unit
Lunar Orbiter 4	4/5/1967	U	U	Crash	
Surveyor 4	14/7/1967	0.4 N	1.3 W	Crash ?	Propulsion unit?
Lunar Orbiter 5	1/8/1967	2.8 S	83.0 W	Crash 31/1/68	
Surveyor 5	8/9/1967	1.5 N	23.2 E	Soft Landing	Propulsion unit
Surveyor 6	7/11/1967	0.5 N	1.4 W	Soft Landing	Propulsion unit
Surveyor 7	17/1/1968	41.0 S	11.4 W	Soft Landing	Propulsion unit
Apollo 10 LM DS	18/5/1969	U	U	Crash (1969?)	
Apollo 11 LM DS	16/7/1969	0.7 N	23.5 E	Soft Landing 20/7/69	Experiments and Flag
Apollo 11 LM AS	16/7/1969	U	U	Crash (1969)	
Luna 15	13/7/1969	17.0 N	60.0 E	Crash 21/7/69	
Apollo 12 LM DS	14/11/1969	3.0 S	23.4 W	Soft Landing 19/11/69	Experiments and Flag
Apollo 12 LM AS	14/11/1969	5.5 S	23.4 W	Crash 20/11/69	
Apollo 13 SIVB	11/4/1970	2.4 S	27.9 W	Crash	
Luna 16 DS	12/9/1970	0.7 S	56.3 E	Soft Landing	
Luna 17 DS	10/11/1970	38.3 N	35.0 W	Soft Landing 17/11/70	Carried Lunokhod 1
Lunokhod 1	10/11/1970	38.3 N	35.0 W	Soft Landing 17/11/70	(on Luna 17)
Apollo 14 SIVB	31/1/1971	8.0 S	26.6 W	Crash	
Apollo 14 LM DS	31/1/1971	3.6 S	17.5 W	Soft Landing 31/1/71	Expts, Flag, Cart, 2 golf balls
Apollo 14 LM AS	31/1/1971	3.5 S	19.3 W	Crash 7/2/71	
Apollo 15 SIVB	26/7/1971	1.0 S	11.9 W	Crash	
Apollo 15 LM DS	26/7/1971	26.1 N	3.6 E	Soft Landing 30/7/71	Experiments and Flag
Apollo 15 LRV	26/7/1971	26.1 N	3.6 E	Soft Landing	
Apollo 15 LM AS	26/7/1971	26.4 N	0.3 E	Crash 3/8/71	
Apollo 15 Subsat	??/7/1972	U	U	Crash	
Luna 18	2/9/1971	3.6 N	56.5 E	Crash	
Luna 20 DS	14/2/1972	3.5 N	56.6 E	Soft Landing	
Apollo 16 SIVB	16/4/1972	1.8 N	23.3 W	Crash	
Apollo 16 LM DS	16/4/1972	9.0 S	15.5 E	Soft Landing 21/4/72	Experiments and Flag
Apollo 16 LRV	16/4/1972	9.0 S	15.5 E	Soft Landing	

Apollo 16 LM AS	16/4/1972	U	U	Crash 29/5/72	
Apollo 16 Subsat	??/4/1972	10.2 N	111.9 E	Crash	
Apollo 17 SIVB	7/11/1972	4.2 S	12.3 W	Crash	
Apollo 17 LM DS	7/11/1972	20.2 N	30.8 E	Soft Landing 11/12/72	Experiments and Flag
Apollo 17 LRV	7/11/1972	20.2 N	30.8 E	Soft Landing	
Apollo 17 LM AS	7/11/1972	20.0 N	30.7 E	Crash 15/12/72	
Luna 21 DS	8/1/1973	25.9 N	30.5 E	Soft Landing 16/1/73	Carried Lunokhod 2
Lunokhod 2	8/1/1973	25.9 N	30.5 E	Soft Landing 16/1/73 (on Luna 21)	
Luna 23	28/10/1974	13.0 N	62.0 E	Soft Landing	
Luna 24 DS	9/8/1976	12.8 N	62.2 E	Soft Landing 18/8/76	
Hiten (& Hagoromo)	1993	38.0 S	5.0 E	Crash	
Lunar Prospector	6/11/1998	88.0 S	45.0 W	Crash (7/99)	

Planetary Impacts

Venus

Object	Launch Date	Lat	Long	Impact Nature	Other Debris/Comments
Venera 3 Capsule	16/11/1965			Hard Landing 1/3/66	Capsule cover; s/c bus destroyed
Venera 4 Capsule	12/6/1967			Hard Landing 18/10/67	Capsule cover; s/c bus destroyed
Venera 5 Capsule	5/1/1969			Hard Landing 16/5/69	Capsule cover; s/c bus destroyed
Venera 6 Capsule	10/1/1969			Hard Landing 17/5/69	Capsule cover; s/c bus destroyed
Venera 7 Capsule	17/8/1970			Hard Landing 15/12/70	Capsule cover; s/c bus destroyed
Venera 8 Capsule	26/3/1972			Hard Landing 22/7/72	Capsule cover; s/c bus destroyed
Venera 9 Lander	8/6/1975	32 N	69 W	Soft Landing 21/10/75	2 halves of protective sphere
Venera 10 Lander	14/6/1975	16 N	69 W	Soft Landing 25/10/75	2 halves of protective sphere
Venera 11 Lander	9/9/1978	13 S	60 W	Soft Landing 21/12/78	2 halves of protective sphere
Venera 12 Lander	14/9/1978	7 S	66 W	Soft Landing 25/12/78	2 halves of protective sphere
Pioneer Venus 2 bus	8/8/1978	33 S	70 W	Crash	
P'r Venus 2 Probe 1	8/8/1978	0	43 W	Hard Landing	
P'r Venus 2 Probe 2	8/8/1978	75 N	20 E	Hard Landing	
P'r Venus 2 Probe 3	8/8/1978	26 S	45 W	Hard Landing	
P'r Venus 2 Probe 4	8/8/1978	27 S	45 E	Hard Landing	
Venera 13 Lander	30/10/1981	8 S	57 W	Soft Landing	2 halves of protective sphere
Venera 14 Lander	4/11/1981	13 S	50 W	Soft Landing	2 halves of protective sphere
Vega 1 Lander	15/12/1985	7 N	178 E	Soft Landing 11/6/85	2 halves of protective sphere
Vega 1 Aerostat	15/12/1985			Soft Landing 9/6/85	(balloon)
Vega 2 Lander	21/12/1985	6 S	179 W	Soft Landing 15/6/85	2 halves of protective sphere
Vega 2 Aerostat	21/12/1985			Soft Landing 15/6/85	(balloon)
Magellan	4/5/1989			Crash 13/10/94	Probably destroyed during entry

Mars

Object	Launch Date	Lat	Long	Impact Nature	Other Debris/Comments
Mars 2 Lander	19/5/1971	45 S	58 E	Hard Landing 27/11/71	4 debris
Mars 3 Lander	28/5/1971	45 S	160 W	Hard Landing 2/12/71	4 debris
Mars 6 Lander	5/8/1973	24 S	110 E	Hard Landing 12/3/74	4 debris
Viking 1 Lander	20/8/1975	22 N	48 W	Soft Landing 20/7/76	
Viking 2 Lander	9/9/1975	48 N	134 E	Soft Landing 3/9/76	
Pathfinder Lander	4/12/1996	19 N	34 W	Soft Landing 4/7/97	3 debris
Pathfinder Rover	4/12/1996	19 N	34 W	Soft Landing 4/7/97	

Jupiter

Object	Launch Date	Lat	Long	Impact Nature	Other Debris/Comments
Galileo Probe	18/10/89			Crash 7/12/95	Probably destroyed during entry

Future Planned Impacts/Landings

Moon

Lunar-A	2002	penetrators
Selene	2003	lander

Mars

Mars Polar Lander - 2 penetrators
NASA sample return missions (lander and rover 1 to arrive 2004, 2 in 2006)
Mars aircraft 2003?

Titan

Huygens	15/10/1997	Hard Landing 27/11/2004

Comet Wirtanen

Rosetta	1/2003	Hard Landing 2011

Asteroid Nereus

Muses-C	7/2001	Soft Landing 9/2003

Key to Abbreviations

LM	lunar module
DS	descent stage (of LM)
AS	ascent stage (of LM)
SIVB	third stage of Saturn V
LRV	lunar roving vehicle
U	unknown

Notes

1. One or more objects left in lunar orbit may have impacted the surface by now.
2. Some Venus impact locations are incomplete.
3. Where other debris - released before impact/landing - is likely to have survived to the surface this is indicated.
4. Dates are presented in UK format: day-month-year.