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2.11. Impactites

A proposal on behalf of the IUGS Subcommission on the Systematics of Metamorphic Rocks

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ABSTRACT

This work presents the provisional results of the IUGS Subcommission on the Systematics of Metamorphic Rocks in respect to impactites. It is proposed to distinguish between impactites resulting from a single impact (e.g., at terrestrial impact craters) and those resulting from multiple impacts (e.g., lunar rocks or meteorites). The former are subdivided into two major groups: Proximal and distal impactites. Proximal impactites are: (1) Shocked rocks, (2) Impact melt rocks, and (3) Impact breccias. Distal impactites comprise (1) Tektites, Microtektites, and (2) Air fall beds. Impactites formed by multiple impacts fall into two groups: (1) Impact regolith and (2) Shock-lithified impact regolith.

INTRODUCTION

The Subcommission for the nomenclature of Metamorphic Rocks (SCMR), a branch of the IUGS Commission on the Systematics in Petrology, was initiated in 1985 under the chairmanship of Rolf SCHMID (succeeded in 2001 by Douglas FETTES). The Subcommission consisted initially of 31 members, distributed in 11 Study Groups devoted to special topics, and a Working Group of more than 100 earth scientists world-wide. The main work of the Subcommission was done during annual or biennial working meetings and by correspondence. This main discussion phase of the Subcommission's task is now complete and emphasis is on publishing its recommendations.

The SCMR aims to publish international recommendations on how metamorphic rocks and processes are to be defined and named, as was previously done for igneous rocks by the Subcommission on the Systematics of Igneous Rocks (LE MAITRE, 1989). The principles used by the SCMR for defining and classifying metamorphic rocks are outlined in SCHMID ET AL. (2002).

A Study Group, under the leadership of D. Stöffler (Berlin) has formulated this proposal for the classification and nomenclature of impactites. The following scientists have participated actively in the Study Group on "Impactites": W. von ENGELHARDT (Tübingen), V. I. FELDMAN (Moscow), F. HÖRZ (Houston), K. KEIL (Honolulu), and R. A. F. GRIEVE (Ottawa). Contributions were also made by B. M. FRENCH (Washington) and W. U. REIMOLD (Johannesburg). After having evaluated proposals by the members of the Study Group and by scientists working with impactites, this work presents a provisional classification and nomenclature of such rocks for comment.

CLASSIFICATION

The term "impactite" is defined as a collective term for all rocks affected by one or more hypervelocity impact(s) resulting from collision(s) of planetary bodies. A classification scheme is proposed for products of single and multiple impacts (Table 1). It is applicable to terrestrial and extraterrestrial rocks, such as lunar rocks and meteorites of asteroidal, lunar, and Martian provenance. The basic classification criteria are based on texture, degree of shock metamorphism, and lithological components. Shock metamorphism is the irreversible changes in (geologic) materials resulting from the passage of a shock wave (Fig. 1). Additional criteria for a subclassification of the main types of impactites relate to the mode of occurrence with respect to the parent impact crater and to the geological or structural setting of the impactites (Fig. 2, Table 2). The proposed classification has made use of previous recommendations (Stöffler et al., 1979, 1980; Stöffler and Grieve, 1994, 1996).

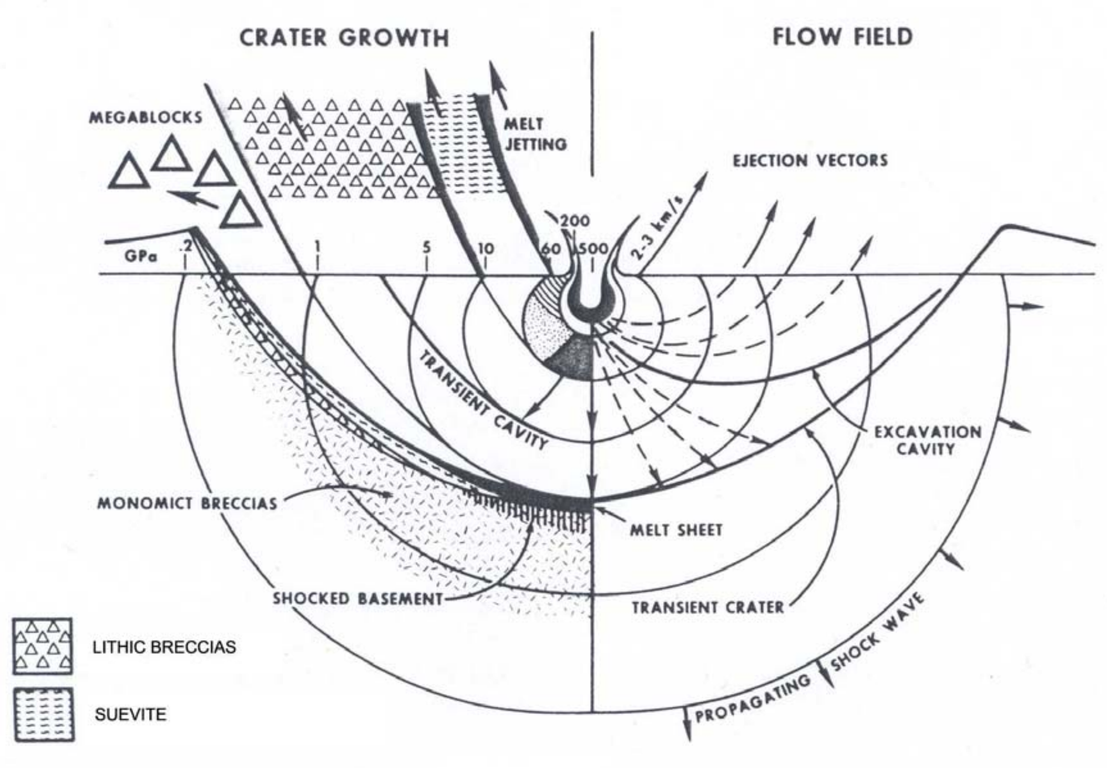


Fig. 1: Schematic representation of the shock zoning and particle motion in an impact crater based on various data and models, e.g. Dence et al. (1977), Grieve et al. (1977), O'Keefe and Ahrens (1978), Stöffler (1977), Croft (1980), Kieffer and Simonds (1980), and Orphal et al. (1980)

Impactites from a single impact are classified into 3 major groups (Table 1) irrespective of their geological setting which is not known for most extraterrestrial rocks such as meteorites and lunar rocks:

Shocked rocks are defined as non-brecciated rocks, which show unequivocal effects of shock metamorphism, exclusive of whole rock melting. They are subclassified into progressive stages of shock metamorphism (Tables 3 – 7),

Impact melt rocks are subdivided into three subgroups, according to the content of clasts. These three subtypes may be subclassified according to the degree of crystallinity into glassy, hypocrystalline, and holocrystalline varieties. The first two subtypes include "impact glass" as well as "tektites",

Impact breccias fall into three subgroups, according to the degree of mixing of various target lithologies and their content of melt particles. *Lithic breccias* and *suevites* are generally polymict breccias except for single lithology targets. The matrix of lithic breccias is truly clastic and consists exclusively of lithic and mineral clasts whereas the matrix of suevite additionally contains melt particles and may therefore be better called “particulate matrix”. This primary matrix of suevite may be altered by secondary (mostly hydrothermal) processes.

Table 1: Classification of impactites formed by single and multiple impacts

1. Impactites from single impacts
  1.1. Proximal impactites
    1.1.1. Shocked rocks*
    1.1.2. Impact melt rocks[1]
      1.1.2.1. clast-rich
      1.1.2.2. clast-poor
      1.1.2.3. clast-free
    1.1.3. Impact breccias
      1.1.3.1. Monomict breccia
      1.1.3.2. Lithic breccia (without melt particles)[2]
      1.1.3.3. Suevite (with melt particles)[2]
  1.2. Distal impactites
    1.2.1. Consolidated
      1.2.1.1. Tektite[3]
      1.2.1.2. Microtektite[3]
    1.2.2.Unconsolidated
      1.2.2.1. Air fall bed[4]
2. Impactites from multiple impacts
  2.1. Unconsolidated clastic impact debris
    2.1.1. Impact regolith[5]
  2.2. Consolidated clastic impact debris
    2.2.1. Shock-lithified impact regolith[5]
      2.2.1.1. Regolith breccia[5] (breccia with in-situ formed matrix melt and melt particles)
      2.2.1.2. Lithic breccia[5] (breccia without matrix melt and melt particles)

*see Tables 3-7 for further subclassification,
[1] may be subclassified into glassy, hypocrystalline, and holocrystalline varieties,
[2] generally polymict but can be monomict in a single lithology target,
[3] impact melt (generally glassy) with admixed shocked and unshocked clasts,
[4] pelitic sediment with melt spherules, shocked and unshocked clasts,
[5] generally polymict but can be monomict in a single lithology target

Impactites from multiple impacts, as known from the Moon and from meteorites, as samples of the meteorite parent bodies, are subdivided into two main groups (Table 1):

Impact regolith (unconsolidated clastic impact debris), and *Shock lithified impact regolith* (consolidated clastic impact debris). This group is subclassified into *Regolith breccias* (with matrix melt and melt particles) and *Lithic breccias* (without matrix melt and melt particles). The term lithic breccia is synonymous to "fragmental breccia" which has been used for lunar rocks and meteorites (STÖFFLER ET AL., 1980; BISCHOFF AND STÖFFLER, 1992). Note that the matrix melt is formed in-situ by intergranular melting induced by the shock lithification process (Table 7).

Irrespective of the geological setting of a specific rock type *progressive stages of shock metamorphism* (STÖFFLER, 1966; 1971; CHAO, 1967; Tables 3 – 7) can be identified in all target rocks affected by the shock wave. They are defined on the basis of shock effects of the constituent minerals and of the shock-induced changes of the primary rock texture. The definition of progressive stages of shock metamorphism depends on the mineralogical composition and on the primary texture (e.g., porosity) of the material shocked. Therefore, the shock classification is different for different lithologies. Since quartz, plagioclase, and olivine (CHAO, 1967; STÖFFLER, 1972; 1974; STÖFFLER ET AL., 1991; STÖFFLER and LANGENHORST, 1994; FRENCH, 1998) are the most sensitive shock indicators, separate classification schemes have been proposed for quartzo-feldspathic rocks (Table 3), basaltic-gabbroic rocks (Table 4), dunitic and chondritic rocks (Table 5), sandstone (Table 6), and particulate rock material, e.g. sand and regolith (Table 7). Shock metamorphism of carbonates and shales is difficult to recognise on a macroscopic and microscopic scale and reasonable classifications have not yet been established.

DISCUSSION

The process which results in the formation of impactites is related to the interplanetary collisions that all planetary bodies have undergone since their formation. The term "impact" or more correctly "hypervelocity impact" is defined as the collision of two (planetary) bodies at or near cosmic velocity, which causes the propagation of a shock wave in both the impactor and target body (MELOSH, 1989). A shock wave is a compressional wave with material transport (whereas seismic waves are compressional waves without material transport). It can be defined as a step-like discontinuity in pressure, density, particle velocity, and internal energy, which propagates in gaseous, liquid or solid matter with supersonic velocity. Shock compression is non-isentropic and results in the production of post-shock heat (waste heat), which increases with increasing pressure and eventually results in the melting or vaporisation of the shocked material (DUVALL and FOWLES, 1963; ASAY and SHAHINPOOR, 1993; GRAHAM, 1993).

The material engulfed by the shock wave is affected by what is collectively called "impact metamorphism". Impact metamorphism should be applied only for natural rocks and minerals and it includes solid state deformation, melting and vaporisation of the target rock(s) and their constituents minerals. The term shock metamorphism is a more general term which can be used irrespective of the process which generates a shock wave: Natural impacts or artificial hypervelocity impacts or explosions of chemical or nuclear explosive devices (FRENCH AND SHORT, 1968; STÖFFLER, 1972, 1974, 1984; RODDY ET AL., 1977; FRENCH, 1998). Unequivocal residual shock effects in minerals of shocked rocks are generally formed above the so-called Hugoniot elastic limit (HEL), which is in the order of several GPa for silicate minerals. Consequently, the typical range of shock pressures resulting in remanent or residual shock effects is between 5 and 100 GPa for solid state effects and melting, and above 100 GPa for vaporisation. Typical maximum pressures and temperatures at the point of impact are in the order of several 100 GPa or greater and several tens of thousands degrees for all impacts within the inner solar system (terrestrial planets).

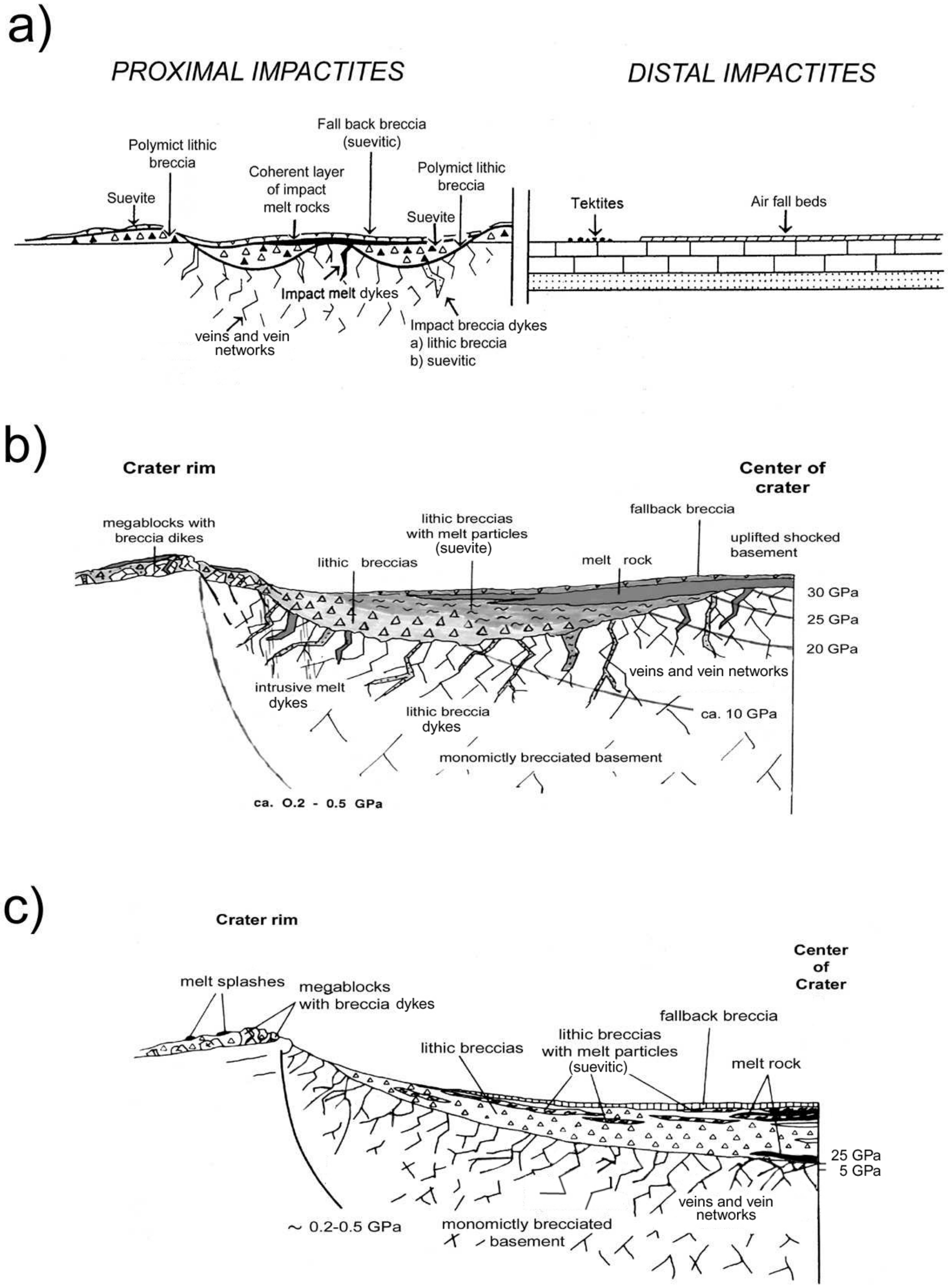


Fig. 2: Geological setting of impactites on Earth: a) proximal and distal impactites, b) proximal impactites at a simple impact crater (diameter range on Earth: ~ 30 m to about 2-5 km); c) proximal impactites at a complex impact crater with central uplift

(diameter range on Earth: ~ 5 km to 50-60 km); shock pressure isobars are shown in the parautochthonous crater basement

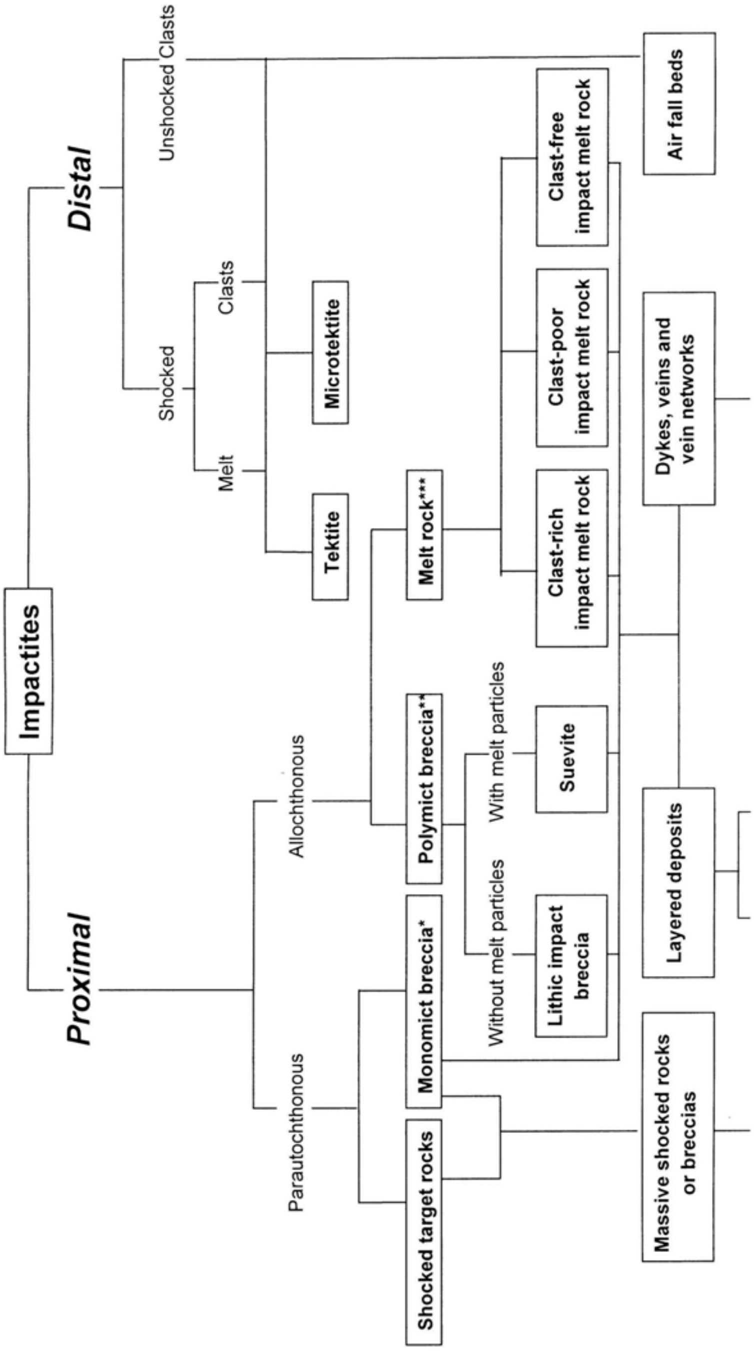
Impactites are formed during a complex but very short sequence of processes: Shock compression of the target rocks (compression stage), decompression and material transport (excavation stage), and deposition upon ballistic transport and upon collapse of the central ejecta plume which takes place during or after the collapse of the transient crater cavity (modification stage) (Fig. 1). Consequently, shock metamorphosed material (shocked rocks and impact melts) commonly displays disequilibrium and can be mixed with unshocked lithic and mineral fragments forming polymict breccias in and around the parent crater: *layered* impact formations, such as *impact melt rocks* or *impact breccias*, and *dyke breccias,* which both occur inside the crater and as part of the continuous ejecta blanket extending some 2 to 3 crater radii (proximal impactites) and continuous *airfall beds* or discontinuous ejecta deposits, such as *tektites* (distal impactites) (Table 2). The geological setting of shocked rocks or impact melts is, therefore, variable (Fig. 2). *Impact melt lithologies* occur as (1) allochthonous coherent melt sheets, (2) inclusions in polymict impact breccias (suevite), (3) dykes and veins in the autochthonous crater basement, in displaced shocked rock fragments and in displaced (unshocked) megablocks, (4) individual melt particles on top of the ejecta blanket, glassy or crystallised spheres in global air fall beds, and (5) glassy tektites. *Shocked minerals and rocks* are found as allochthonous clasts within polymict impact breccias, impact melt rocks and air fall beds and as (par)autochthonous material of the crater basement. *Monomict breccias* formed during shock compression and dilatation are characteristic of the crater basement but are also common constituents of polymict breccias. Displaced megablocks within the continuous ejecta blanket are usually monomictly brecciated. *Dyke breccias* can be related to all major phases of the crater formation process and up to 4 generations of dykes have been observed in a single impact event (LAMBERT, 1981; STÖFFLER ET AL., 1988; SPRAY, 1998). *Shock veins and vein networks* (previously termed "pseudotachylites") are formed during the compression stage, since they often occur as clasts within later formed breccia dykes. The injection of dykes of polymict lithic breccias starts during the compression stage and continues during the excavation stage. A final generation of dykes (polymict or monomict breccias) is produced during the modification stage, while the transient crater collapses and more conventional (but still very high strain rate) faulting takes places.

The time for the formation of the final crater and of some early formed impactites (shocked rocks, melt, dykes) is in the order of seconds to minutes for craters ranging from about 1 to 100 km and the total time for the deposition of the proximal ejecta ranges from minutes to hours (MELOSH, 1989; IVANOV AND ARTEMIEVA, 2002). This time is very short compared to all other geological processes. Despite this, superposition contacts between layered impact formations or contacts at discordant dykes are quite common at impact craters, e.g., sharp contacts of sheets of impact melt to the monomictly brecciated, unshocked or mildly shocked crater basement or contacts between the continuous ejecta deposits (polymict lithic breccias) and the overlaying suevite are characteristic, as are discordant dykes intersecting displaced megablocks.

Impactites from planetary bodies with a thin or non-existent atmosphere and with very low intensity of endogenous geological activity, such as the moon, the asteroids and, in part, Mars, show evidence of multiple impacts. This is most conspicuous for the moon and the asteroids, where the outer zone of the crust is reworked by multiple impacts of all sizes with impactors ranging in size from hundreds of kilometres to micrometers. Because of the inverse proportionality between impactor size and impact frequency (NEUKUM ET AL., 2001) the fraction of very small impactors is so large that a fine grained *regolith* is formed in the upper few meters (5 to 15 m in the case of the moon). This regolith rests on top of a megaregolith, which is composed of the ejecta blankets from larger impact craters superimposed on each other

(HARTMANN, 1973, 2003). This megaregolith was essentially formed during the so-called “early heavy bombardment” of the terrestrial planets (4.5 to 3.8 Ga ago); whereas, the fine-grained regolith was built up during the past 3.5 Ga when the impact rate had declined by a factor of about 1000 (TAYLOR, 1982; HEIKEN ET AL., 1991; NEUKUM ET AL., 2001; STÖFFLER AND RYDER, 2001). Impactites from the megaregolith display all characteristics found at single terrestrial

Table 2: Classification of impactites from single impacts according to geological setting, composition, texture, and degree of shock metamorphism (see text for details)



* Typically monomict; **Generally polymict but can be monomict, e.g. in a single lithology target; ***Includes glassy, hypocrystalline and holocrystalline varieties

craters (STÖFFLER ET AL., 1980); whereas, impactites from the *regolith* are either represented by unconsolidated clastic impact debris or by shock lithified consolidated *regolith breccias,* as sampled on the moon during the Apollo and Luna programmes (e.g., HEIKEN ET AL., 1991; see Table 1). Among *asteroidal meteorites* regolith breccias, lithic breccias, impact melt rocks, and shocked rocks are represented in proportions, which reflect the multiple cratering of asteroids and the relatively lower impact velocity in the asteroid belt. The lower impact velocity explains the scarcity of impact melt lithologies (BISCHOFF AND STÖFFLER, 1992; KEIL ET AL., 1997). According to expectations, *Martian meteorites* are exclusively shocked rocks or monomict breccias of basaltic, gabbroic and peridotitic provenance (NYQUIST ET AL., 2001; FRITZ ET AL., 2005). In some of the Martian plutonic rocks, now occurring as meteorites, more than one shock or impact event is recorded.

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Tables 3 – 7:

Table 3: Classification of shocked quartzo-feldspathic rocks (progressive stages of shock metamorphism); modified from Stöffler (1971, 1984); post shock temperatures are relative to an ambient temperature of 0° C.

Shock stage	Peak pressure (GPa)	Post-shock temperature (^{o}C)	Shock effects
0			Fractured minerals
	~5-10	~100	
Ia			Quartz with planar fractures and planar deformation features: feldspar with planar deformation features
	~20	~170	
Ib			Quartz and feldspar with planar deformation features and reduced refractive index; stishovite and minor coesite
	~35	~300	
II			Diaplectic quartz and feldspar glass; coesite and traces of stishovite; cordierite glass
	~45	~900	
III			Normal feldspar glass (vesiculated) and diaplectic quartz glass; coesite; cordierite glass
	~60	~1500	
IV			Rock glasses or crystallized melt rocks (quenched from whole rock melts)
	~80-100	>2500	
V			Rock glasses (whole rock melts condensed from silicate vapour)

Table 4: Classification of shocked basaltic-gabbroic rocks (progressive stages of shock metamorphism); based on data of Kieffer et al., 1976; Schaal and Hörz, 1977; James, 1969; Ostertag, 1983; Stöffler, 1984, and Stöffler et al, 1986; post-shock temperatures are relative to an ambient temperature of 0°C and in part based on Raikes and Ahrens (1979); (?) uncertain values with errors of ~ ± 50 °C

Shock stage	Equilibration shock pressure (GPa)	Post-shock temperature (^{o}C)	Shock effects and textural characteristics	Accompanying disequilibrium shock effects
0			Unshocked (no unequivocal shock effects)	none
	~1-5	~0		
1			Fractured silicates; mechanical twinning on pyroxene and ilmenite; kink bands in mica; rock texture preserved	none
	~20-22	~50-150		
2a 2b	~28-34	~200-250	Plagioclase with planar deformation features and partially converted to diaplectic glass Diaplectic plagioclase glass; mechanicl twinning in pyroxene and ilmenite; mosaicism in olivine and other silicates	Incipient formation of localized ‘mixed melt’ and glassy veins Localized mixed melt’ and melt veins (glassy or microcrystalline)
	~42-45	~900(?)		
3			Melted plagioclase glass with incipient flow structure and vesicles; mafics and ore as in stage 2	
	~60	~1100 (?)		
4			Melted plagioclase glass with vesicles and flow structure; incipient contact melting of pyroxene; incipient recyrstallisation of olivine	
	~80	~1500(?)		
5			Melted plagioclase increasingly mixed with melt of mafic and ore minerals; olivine recrystallised; whole rock melts at pressures of c. >100GPa	

Table 5: Classification of shocked chondritic meteorites and olivine-rich crystalline rocks (progressive stages of shock metamorphism) modified after Stöffler et al. (1991); shock pressure data are based on experimental data given in Stöffler et al. (1991); pressures given in columns 4 – 6 indicate the upper limit of the shock stage in question; temperature data refer to the ambient temperature before shock compression; *from Stöffler et al. (1991); **from Schmitt (2000)

Shock stage	Effects resulting from equlibration peak shock pressure			Effects resulting from local P-T-excursions	Pressure GPa* (293 K)	Pressure GPa** (293 K)	Pressure GPa** (920 K)
	Olivine		Plagioclase				
Unshocked S1	Sharp optical extinction Irregular fractures	Angular variation of extinction position: Low grade: < 1° High grade: 1° – 2°	Sharp optical extinction Irregular fractures	none	< 4 -5		
Very weakly shocked S2	Undulatory extinction Fractures	Angular variation of extinction position: < 2°	Undulatory extinction Irregular fractures	none	5 - 10		
Weakly shocked S3	Planar fractures (PF) Undulatory extinction Irregular fractures	Low grade: maximum of 2 sets of PF High grade: 3 or more sets of PF	Undulatory extinction	Opaque shock veins, incipient formation of melt pockets (sometimes interconnected)	15 - 20	10 - 15	10 – 15
Moderately shocked S4	Mosaicism (weak)	Low grade: incipient mosaicism, PF, and PDF High grade: mosaicism, PF, and PDF	Low grade: undulatory extinction High grade: partially isotropic, PDF	Melt pockets, interconnected melt wins, opaque shock veins	30 - 35	25 - 30	20 – 25
Strongly shocked S5	Mosaicism (strong) Planar fractures Planar deformation features (PDF)		Maskelynite (diaplectic glass)	Pervasive formation of melt pockets, veins and dykes, opaque shock veins	45 - 55	45 - 60	35 – 45
	Restricted to local regions in or near melt zones						
Very strongly shocked S6	Recrystallization; yellow-brown staining; ringwoodite and wadsleyite; high pressure phases of pyroxene (e.g., majorite, akimotoite)		Shock melted (normal glass)	as in stage S5	75 - 90		45 - 60
Shock melted	Whole rock melting and formation of melt rocks						

Table 6: Classification of shocked sandstone (progressive stages of shock metamorphism); modified after Kieffer (1971) and Kieffer et al. (1976); ranges of pressure estimates are given in parentheses; post-shock temperature are relative to an ambient temperature of 0°C

Shock stage	Equilibration shock pressure, GPa	Post-shock temperature, °C	Shock effects
0			Undeformed sandstone
	0.2-0.9	~25	
1a			Compacted sandstone with remnant porosity
	~3.0 (2.2-4.5)	~250	
1b			Compacted sandstone compressed to zero porosity
	~5.5 (3.6-13)	~350	
2			Dense (non-porous) sandstone with 2-5% coesite, 3-10% glass and 80-95% quartz
	~13	~950	
3			Dense (non-porous) sandstone with 18-32% coesite, traces of stishovite, 0-20% glass and 45-80% quartz
	~30	>1000	
4			Dense (non-porous) sandstone with 10-30% coesite, 20-75% glass and 15-45% quartz
5			Vesicular (pumiceous) rock with 0-5% coesite, 80-100% glass (lechatelierite) and 0-15% quartz

Table 7: Classification of unconsolidated sediments and particulate materials (progressive stages of shock metamorphism); based on data from shock recovery experiments and theoretical models (e.g. Kieffer, 1975)

Equilibration shock pressure (GPa)	Particulate basalt 75035*	Lunar soils			H5 Chondrite powder		L6 chondrite powder	Quartz sand 63-125µm
		15101* 45-150 µm	Model soil	65101*	16% porosity <150 µm	<5% porosity <150 µm	ALH 85017* 125 – 250 µm	
	vesiculated glass	vesiculated glass					Vesiculated glass (50 % melt at ~ 65 GPa)	
40					?	?		
	lithification	lithification						vesiculated glass
30	by	by						
	glass cement	glass cement			lithification by glass cement	lithification by glass cement	intergranular glass (starting at ~ 25 GPa)	
20		minor intergranular glass	vesiculated glass	glass bonding	minor intergranular glass	minor intergranular glass		minor intergranular glass
10	lithification and compaction	lithification and compaction	lithification compaction	lithification	lithification and compaction	lithification and compaction	lithification and compaction (complete at 14.5 GPa)	lithification and compaction
	Schaal et al. (1979)	Schaal and Hörz (1980)	Kieffer (1975)	Christie et al. (1973)	Bischoff and Lange (1984)	Bischoff and Lange (1984)	Hörz et al. (2005)	Stöffler et al. (1975)

* Refers to lunar sample numbers and meteorite names

Glossary definitions for impactites, version of June 15, 2006

by D. Stöffler and R. A. F. Grieve

Exlanation: **ABCD = recommended terms,** ABCD = non-recommended terms**; abcd =** useful terms; first citation in parentheses indicates first appearance in the literature; OU = origin of term unknown; term given in italics = term explained somewhere in the list

ALLOCHTHONOUS IMPACT BRECCIA *Impact breccia* in which the component materials have been displaced from their point of origin. It includes polymict breccias (*lithic breccias, suevite*) and (impact) melt rocks of the *proximal impact formations. cf. autochthonous impact breccia*.

(OU; Dence, 1964, p249; Pohl et al., 1977, p352; Grieve, 1998, Figure7)

Allogenic impact breccia Synonymous with *allochthonous impact breccia.*

(OU; Cassidy, 1968, p120)

APOLLONIAN METAMORPHIC ROCKS (from the Apollo mission to the Moon, itself from the ancient Greek god *Apollo)* Pre-Imbrian lunar highland rocks, generally of noritic-anorthositic composition, with granoblastic to poikiloblastic texture (lunar *granulitic rocks*). These rocks are ubiquitous in the lunar highlands and have been found at all lunar landing sites. However, it is not clear whether this kind of thermal metamorphism is a more local effect possibly induced by proximity to cooling *impact melt sheets* within the lunar *megaregolith* or whether it represents a global process which affected the whole lunar crust at some depth. The rocks are not *granulites* in the terrestrial sense because they result from very low pressure-high temperature metamorphism. Consequently, the process and the heat sources are not well defined although the rocks are clearly recrystallized crustal rocks with an average composition of a ‘noritic anorthosite’.

(Stewart, 1975, p774)

APOLLONIAN METAMORPHISM (from the Apollo mission to the Moon, itself from the ancient Greek god *Apollo*) Thermal metamorphism of the pre-Imbrian lunar crust leading to the formation of lunar *granulitic rocks*.

(Stewart, 1975, p774)

ASTROBLEME Unnecessary synonym for *impact crater.*

(OU; Dietz, 1961, p2)

Authigenic impact breccia Synonymous with *autochthonous impact breccia*.

(OU; Cassidy, 1968, p121)

AUTOCHTHONOUS (PARAUTOCHTHONOUS) IMPACT BRECCIA Cataclastic *(monomict) impact breccia* in which the component materials have not been displaced any significant distance from their point of origin. cf. *allochthonous impact breccia*. (OU; Dence, 1964, p249; Pohl et al., 1977, p352; Grieve, 1998, Figure7)

BRECCIA see *impact breccia*

BRECCIA DYKE Dyke formed in the *(par)autochthonous* basement or in displaced *megablocks* of *impact craters* consisting of *impact breccia* (*polymict breccias* such as *impact melt rock*, *suevite*, *lithic breccia* or more rarely *monomict breccia*).

(OU; Dence, 1971, p5555; Lambert, 1981, p61, Table 1; Stöffler et al., 1988, p287 and Table 2)

Bunte breccia (Bunte Breccie or Bunte Brekzie or Bunte Bresche, Loc. Ries impact crater, Germany) Local term for polymict *lithic breccia* forming the continuous ejecta blanket at the Ries impact crater, Germany; first detailed description as “Kalkbreccie” by C. W. von Gümbel in 1870.

(OU; Gümbel, 1870, p182; Bentz, A., 1925, p97; Engelhardt, 1971, p5567; Pohl et al., 1977, p352)

CENTRAL UPLIFT Structurally uplifted central volume, which can be manifested as a central peak (commonly with an irregular circular shape in plain view) in *complex impact craters* of intermediate size formed by the dynamic collapse of the *transient crater* cavity.

(OU; Dence, 1964, p249; Grieve 1987, p248; Melosh, 1989, p18; Dence, 2004, p277, Fig. 10)

COMPLEX IMPACT CRATER Impact crater with relatively small depth/diameter ratio and with central uplift, annular trough, and down-faulted, terraced rim structure. Central uplift can be expressed topographically as a peak or a peak ring. In very large craters the central uplift is replaced by two or more concentric topographic rings (*multi-ring crater*). Complex craters are formed by the collapse of a deep, bowl-shaped *transient crater* cavity.

(OU; Dence, 1964, p259; Dence, 1968, p170, p180; Grieve 1987, p248; Melosh, 1989, p18; Dence, 2004, p276)

CRYPTOEXPLOSION STRUCTURE Term previously used for *(impact) craters* , where an origin by impact or volcanic explosion (cryptovolcanic structure) was not clear.

(Bucher, 1936, p1005; Bucher, 1963, p1241; Dietz, 1959, p496; Dietz, 1963, p650; French & Short, 1968, p11)

CONTINUOUS EJECTA BLANKET See *ejecta blanket.*

DECORATED PLANAR DEFORMATION FEATURES Annealed planar deformation features consisting of discontinuously aligned vugs and inclusions formed during recrystallisation of the originally amorphous lamellae. Typically present in shocked tectosilicates in the floor of *impact craters* and in high-temperature *impact breccias*, such as *suevite* and *impact melt rocks*, also known from shocked olivine in thermally annealed chondrites, where the decorations consist of ultra-fine-grained troilite and metal droplets.

(Robertson et al., 1968, p439; Engelhardt & Bertsch, 1969, p206, Fig. 1; Stöffler et al., 1991, p3875 and Fig. 18)

DEPOSITIONAL TEMPERATURE Equilibration temperature of an *allochthonous impact formation* deposited by ballistic or ground surge transport within or around an *impact crater*; the temperature is achieved by heat exchange between the breccia constituents, which are at different temperatures, e.g., hot melt particles, cold lithic clasts and matrix.

(OU; Stöffler et al., 1991, p3848 and Fig. 3)

(BASAL) DEFORMATION LAMELLAE Unnecessary term used for planar microstructures oriented parallel to the basal plane (0001) in shocked quartz.

(Carter, 1965, p786, 791)

DIAPLECTIC GLASS (from the Greek *diaplesso, to destroy by striking or beating*) Amorphous form of crystals (‘solid state glass’) resulting from shock wave compression and subsequent pressure release of single crystals or polycrystalline rocks; most commonly observed in tectosilicates.

(Engelhardt et al., 1967, p93; Engelhardt & Stöffler, 1968, p163; Dence & Robertson, 1989, p527)

DISTAL IMPACTITE *Impactite* occurring as distal ejecta outside the outer limit of the continuous *ejecta blanket*. It includes *tektites*, *microtektites* and *impactoclastic (global) air fall beds.* cf. *proximal impactite.*

(SCMR)

DYKE (IMPACT) BRECCIA *Impact breccia* occurring in the form of a dyke; see breccia dyke.

(OU; Dence, 1971, p5555; Lambert, 1981, p 61, Table 1; Stöffler et al., 1988, p287 and Table 2)

EJECTA BLANKET (**continuous ejecta blanket**) Continuous ejecta deposit around an *impact crater*.

(OU; Melosh, 1989, p89)

EJECTA PLUME Synonymous with *vapour plume.*

EQUILIBRATION SHOCK PRESSURE Transient equilibration pressure achieved in a polycrystalline or porous rock via *shock wave* reverberations at grain boundaries leading to transient local pressure and temperature variations from grain to grain before a uniform P-T-state is achieved within all grains.

(OU; Stöffler et al., 1991, p3847 and Fig. 2)

FALLBACK Said of *impact ejecta* that is deposited inside the *impact crater.* Hence, ***fallback formation***.

(OU; French & Short, 1968, p11; Engelhardt, 1971, p5566)

FALLOUT Said of *impact ejecta* that is deposited outside the *impact crater.* Hence, ***fallout formation***; term originally used for radioactive air fall deposits induced by nuclear explosions.

(OU; Engelhardt, 1971, p5566)

FRAGMENTAL (IMPACT) BRECCIA Synonymous with *lithic (impact) breccia*.

(OU; Stöffler et al., 1980, Table 1)

GRANULITIC (IMPACT) BRECCIA Thermally metamorphosed (recrystallised) *impact breccia* with granoblastic or poikiloblastic *texture*. The term is used for lunar rocks and meteorites.

(Warner et al., 1977, p2052; Stöffler et al., 1980, Table 1; Bischoff & Stöffler, 1992, Table 1)

HUGONIOT CURVE (named after the French physicist Pierre *Hugoniot* (1851-1887)) Locus of all shock states that can be achieved by *shock wave* compression of variable intensity in any specific material. It is commonly expressed in the pressure-volume or pressure-particle velocity space.

(OU; Rice et al., 1958, p9; Duvall & Fowles, 1963, p216, Fig.5; Ahrens & Rosenberg, 1968, p60; Dence & Robertson, 1989, p526; Bischoff & Stöffler, 1992, p708)

HUGONIOT ELASTIC LIMIT (named after the French physicist Pierre *Hugoniot* (1851-1887)) Specific shock pressure above which the shock-compressed material no longer behaves elastically.

(OU; Rice et al., 1958, p11, Figure 4; Duvall & Fowles, 1963, p255, Fig. 42; Table V; Ahrens & Rosenberg, 1968, p61; Dence & Robertson, 1989, p526)

HUGONIOT EQUATION-OF-STATE (RANKINE-HUGONIOT-EQUATION) (named after the French physicist Pierre *Hugoniot* (1851-1887) and the British physicist William John Macquorn *Rankine* (1820-1872) Thermodynamic equation describing a shock transition from an uncompressed state (p_0, ρ_0, e_0), to a compressed state, (p_1, ρ_1, e_1), in terms of pressure (p), density (ρ), and internal energy (e).

(OU; Rice et al., 1958, p9; Duvall & Fowles, 1963, p211; Duvall, 1968, p24; Dence & Robertson, 1989, p526)

IMPACT (Latin *impactus*, past participle of *impingere*, to pack or drive firmly into something) Collision of two (planetary) bodies at cosmic velocity, which causes the propagation of a *shock wave* in both the *impactor* and *target* body, also called "hypervelocity impact". The impact origin of craters was first proposed for the moon by Franz von Paula Gruithuisen (1774-1852) in 1822.

(OU; Gilbert, 1893, p256; Roddy et al., 1977, p1; Melosh, 1989, p4)

IMPACT BRECCIA (Italian *breccia*, crushed rock) *Monomict* or *polymict breccia* that occurs around, inside and below *impact craters*.

(OU; Dence, 1964, p256; Stöffler et al., 1979, p641, Figure 1; Stöffler et al. 1988, p282)

IMPACT CRATER Approximately circular crater formed either by *impact* of an interplanetary body (*projectile*) on a planetary surface or by an experimental *impact* of a projectile into solid matter; craters formed by very oblique impacts may be elliptical. See *simple crater* and *complex crater.*

(OU; Gilbert, G.K., 1893, p272; Roddy et al., 1977, p1; Melosh, 1989, p6)

(IMPACT) EJECTA Solid, liquid and vaporised rock ejected ballistically from an *impact crater*.

(OU; Melosh, 1989, p. 74, Figs. 5.9 – 5.11)

IMPACT FORMATION Geological formation produced by impact. It includes various lithological and structural units inside and beneath an *impact crater* (***inner impact formations***), the continuous ejecta blanket (***outer impact formations***) and *distal impactites,* such as *tektites* and *impactoclastic air fall beds*.

(OU; Engelhardt, 1971, p5566; Pohl et al., 1977, p352)

IMPACT GLASS *Impact melt* quenched to glass. It includes semihyaline impact melt rocks.

(OU; Spencer, 1933c, p394; Dence, 1971, p5553; Stöffler, 1971, Figure 4; Stöffler, 1984, p466, Tables 1 and 2)

IMPACT MELT Melt formed by shock melting of rocks in *impact craters*.

(OU; Dence, 1968, p176; Dence, 1971, p5553; Grieve et al., 1977, p791; Dressler & Reimold, 2001, p205)

IMPACT MELT BRECCIA (Italian *breccia*, crushed rock) *Impact melt rock* containing lithic and mineral clasts displaying variable degrees of *shock metamorphism* in a crystalline, semihyaline or hyaline matrix, see *impact melt rock.*

(OU; Stöffler et al., 1979, Table1, p723.)

IMPACT MELT ROCK Crystalline, semihyaline or hyaline rock solidified from *impact melt* and containing variable amounts of clastic debris of different degree of *shock metamorphism*; should replace the previously used term *impact melt breccia*.

(OU; Dence, 1971, p5553; Grieve, 1987, p253)

IMPACT METAMORPHISM Type of metamorphism of local extent caused by the passage of a shock wave due to the impact of a planetary body (*projectile* or *impactor*) on a planetary surface (*target*). It includes melting and vaporisation of the *target rock(s)*.

(Pecora, 1960 p19; McIntyre, 1962, p1647; Yardley 1989, p13; Bucher & Frey 1994, p10)

IMPACT PSEUDOTACHYLITE (Greek *pseudès*, false, *tachys*,quick, and *lithos*, stone) *Pseudotachylite* produced by *impact metamorphism*. Dyke-like breccia formed by frictional melting in the basement of *impact craters,* resulting often in irregular vein-like networks. Typically, it contains unshocked and shocked mineral and lithic clasts in a fine-grained *aphanitic* matrix, see also *melt vein.*

(Shand, 1916, p198; Dence, 1971, p5555; Stöffler et al., 1988, p289, Fig. 8, Table 2; Reimold, 1995, p247 ; Spray, 1998, p195; Dressler & Reimold, 2004, p2-36)

IMPACT REGOLITH (Greek *rhegos*, blanket, and *lithos*, stone) Fine-grained *impactoclastic deposit* formed by multiple *impacts* on the surface of planetary bodies lacking an atmosphere, such as the moon, Mercury or asteroids. The lunar *regolith* (sometimes incorrectly named *lunar soil*) contains unshocked and shocked lithic and mineral *clasts*, glass fragments, glass bodies of revolution (spheres, dumbbells, etc.), and agglutinate glass, as well as solar-wind implanted rare gases.

(OU; Shoemaker et al., 1970, p452; Engelhardt et al., 1970, p363; Stöffler et al., 1980, Table 1; Warner & Simonds, 1989, p297; Heiken et al., 1991 p285)

IMPACT STRUCTURE Geological structure caused by *impact* irrespective of its state of preservation.

(OU; Grieve, 1987, p246)

IMPACTITE Rock produced by *impact metamorphism*. The term includes *shocked rocks*, *impact breccias, impact melt rocks, (micro)tektites,* and *air fall beds*. Term originally restricted to *impact glass*.

(OU; Carter, 1965, p786; Park,1989, p41)

IMPACTOCLAST Rock fragment resulting from impact-induced comminution of rocks. It may display variable degrees of *shock metamorphism* (different shock stages).

(SCMR)

IMPACTOCLASTIC AIR FALL BED Pelitic sedimentary layer containing a certain fraction of shock-metamorphosed material, e.g., shocked minerals and melt particles, which has been ejected from an *impact crater* and deposited by interaction with the atmosphere over large regions of a planet or globally.

(SCMR)

IMPACTOCLASTIC DEPOSIT Consolidated or unconsolidated sediment resulting from ballistic excavation, transport, and deposition of rocks at *impact craters*. It may contain glassy or crystallised particles of *impact melt*.

(SCMR)

IMPACTOR (Inter)planetary body (*projectile*) that collides with a second body (*target*) at cosmic velocity and generates a shock wave in both bodies. cf. *target*.

(OU; Melosh, 1989, p46),.

LITHIC (IMPACT) BRECCIA (Italian *breccia*, crushed rock) Polymict impact breccia with clastic matrix containing shocked and unshocked mineral and lithic clasts, but lacking cogenetic impact melt particles; synonymous with, and supercedes *fragmental breccia*.

(SCMR; Stöffler & Grieve, 1994, p1347)

LUNAR SOIL Unnecessary synonym for lunar *regolith*. It has been also defined as the submillimetre fraction of the lunar regolith by Heiken et al. (1991).

(OU; Engelhardt et al., 1970, p363; Warner & Simonds, 1989, p297; Heiken et al., 1991 p287

MASKELYNITE (in honour of the English astronomer Nevil *Maskelyne* (1732-1811) *Diaplectic* plagioclase glass; term originally used for amorphous plagioclase of shocked meteorites.

(Tschermak, 1872, p127; Milton & De Carli, 1963, p670; Binns, 1967, p1111)

MEGABRECCIA (Greek *megas*, large, Italian *breccia*, crushed rock) *Polymict impact breccia* containing lithic clasts up to the size of several hundred meter as part of the *ejecta blanket* of an *impact crater*. Recognized and defined at the scale of geological field studies. cf. *microbreccia.*

(SCMR)

MEGAREGOLITH (Greek *megas,*large, *rhegos*, blanket, and *lithos*, stone) Layer of fractured and possibly mechanically mixed primordial planetary crust formed by multiple large *impacts* on planetary bodies during the early intense impact bombardment (prior to about 4 billion years ago). The thickness of this layer can be on the order of kilometres to tens of kilometres.

(OU; Hartmann, 1973, p634)

MELT POCKET Region of localised quenched melt produced by shock-induced localised melting in moderately to strongly shocked rocks; typical for shocked mafic rocks including meteorites such as chondrites and achondrites.

(OU; Dodd & Jarosewich, 1979, p335 and 338, Fig. 1, Table 1; Stöffler et al., 1991, p3855, Figs. 15, 16, Table 1; Bischoff & Stöffler, 1992, p722)

MELT VEIN Irregular vein of quenched melt produced by shock-induced localised melting in moderately to strongly *shocked rocks*; commonly observed in the (par)autochthonous basement of impact craters and in allochthonous clasts of shocked rocks (terrestrial, lunar, and meteoritic).

(OU; Dodd & Jarosewich, 1979, p338, Table 1; Bischoff & Stöffler, 1992, p720; Spray, 1998, p200)

METEORITE CRATER Small *impact crater* with remaining fragments of the impacted meteoroid; previously used as a synonym for *impact crater*.

(OU; Spencer, 1932, p781; Spencer, 1933b, p227; Dence, 1964, p249, Table 1)

METEORITE IMPACT CRATER Synonymous with *impact crater.*

(OU; French & Short, 1968, p636)

Microbreccia (Greek *mikros*, small, Italian *breccia*, crushed rock) *polymict impact breccia* with clasts of small grain size, usually in the subcentimeter to submillimeter range; most commonly used for lunar and meteoritic impact breccias. cf. *megabreccia*.

(OU; Quaide & Bunch, 1970, p718)

Microcrystite (Greek *mikros*, small, and *kristallos*, crystal) *Microtektite*-like spherule containing quenched crystals usually of clinopyroxene and spinel; probably derived from condensation of *impact rock* vapour. Microkrystites are found in marine sediments and are associated with an iridium and other siderophile element anomalies (i.e. K/T boundary, Late Eocene, Late Pliocene).

(Glass & Burns, 1988, p455; Glass, 1990, p259)

MICROTEKTITE See *tektite*.

MOSAICISM General disorientation of a crystal structure as a result of *shock metamorphism* resulting in marked, highly irregular "mottled" extinction under the petrographic microscope. Weak mosaicism can also be caused by endogenic tectonic processes.

(OU; Stöffler 1971, p5542; Dence & Robertson, 1989, p527)

MONOMICT IMPACT BRECCIA (Greek *mono*, single, and *miktos*, mixed, Italian *breccia*, crushed rock) *Cataclasite* produced by *impact* and displaying weak or no *shock metamorphism*. It occurs in the (par)autochthonous floor of an *impact crater* or (up to the size of blocks and megablocks) within *allochthonous* (polymict) *impact breccias*. cf. *polymict impact breccia.*

(OU; Engelhardt, 1971, p5567; Stöffler et al., 1979 p652 and Fig. 6; Stöffler et al., 1980, Table1)

MULTI-RING (IMPACT) BASIN *Impact crater* with relatively small depth/diameter ratio and with at least two concentric rings inside the crater, first recognised on the moon; synonymous with *multi-ring (impact) crater*.

(OU; Melosh, 1989, p22; Grieve 1998, p111)

MULTI-RING (IMPACT) CRATER Synonymous with *multi-ring (impact) basin*.

PARTICLE VELOCITY Velocity of shock-compressed material moving behind the *shock front*.

(OU; Duvall & Fowles, 1963, p211-222, Fig. 9; Melosh, 1989, p29)

PLANAR DEFORMATION FEATURES (PDF) Submicroscopic amorphous lamellae occurring in shocked minerals as multiple sets of planar amorphous lamellae (optical discontinuities under the petrographic microscope), parallel to rational crystallographic planes; indicative of *shock metamorphism*. The lamellae may be (re)crystallised by thermal annealing forming *"decorated" PDF*. Synonymous with, and supercedes *deformation lamellae*, *planar elements, planar features,* and *shock lamellae*.

(Grieve et al., 1990, p1792; Stöffler & Langenhorst, 1994, p162)

Planar deformation structure Synonymous with *planar microstructure.*

(Engelhardt & Bertsch, 1969, p206)

PLANAR ELEMENTS Unnecessary synonym of *planar deformation features.*

(Stöffler, 1971, p5542; Stöffler, 1972, p82, Tables 1 and 2)

PLANAR FEATURES Unnecessary synonym of *planar deformation features.*

(Dence, 1968, p175, Table 1; Robertson et al., 1968, p333;)

PLANAR FRACTURES Fractures occurring in shocked minerals, as multiple sets of planar fissures parallel to rational crystallographic planes, which are usually not observed as cleavage planes under normal geological (non-shock) conditions. These shock-induced fractures were originally called "cleavage" by Englund and Roen (1962), Bunch and Cohen (1964) and Engelhardt and Stöffler (1965).

(Englund & Roen, 1962, p20; Bunch & Cohen, 1964, Carter, 1965, p786; Bunch, 1968, p415; Hörz 1968, p243; Engelhardt & Bertsch, 1969, p209, Fig. 6; Stöffler, 1971, p5542; Dence & Robertson, 1989, p527; Stöffler & Langenhorst, 1994, p162)

PLANAR MICROSTRUCTURE Collective term comprising shock-induced *planar fractures* and *planar deformation features*.

(Stöffler & Langenhorst, 1994, p162)

POLYMICT IMPACT BRECCIA (Greek *poly*, many, and *miktos*, mixed, Italian *breccia*, crushed rock) Breccia with clastic matrix or crystalline matrix (derived from the crystallisation of *impact melt*), containing lithic and mineral *clasts* with different degrees of *shock metamorphism*, excavated by an *impact* from different regions of the *target rock* section, transported, mixed and deposited inside or around an *impact crater* or injected into the *target rocks* as dykes. cf. *monomict impact breccia.*

(OU; Engelhardt, 1971, p5567; Stöffler et al., 1979, p652 and Fig. 6; Stöffler et al., 1980, Table1)

POST-SHOCK TEMPERATURE Temperature of a gaseous, liquid or solid matter after shock pressure release.

(OU; Stöffler, 1972, p53-56; Grieve, 1998, p115)

PROGRADE SHOCK METAMORPHISM Synonymous with *progressive shock metamorphism*.

PROGRESSIVE SHOCK METAMORPHISM Increasing grade of *shock metamorphism* displayed either by the autochthonous rocks of the *impact crater* basement (radially increasing towards the point of impact) or by individual rock clasts (*impactoclasts*) of a *polymict impact breccia*.

(OU; Stöffler, 1966, p16; Chao, 1967a; p192; Chao, 1967b, p 205; Engelhardt & Stöffler, 1968, p160; Dence, 1968, p170 and 173, Table 1; Stöffler, 1971, p5541).

PROJECTILE Synonymous with *impactor.*

PROXIMAL IMPACTITE *Impactite* occurring in the immediate vicinity of an *impact crater*, that is, inside the outer limit of the continuous *ejecta blanket*. It comprises all types of *impact breccias*, *impact melt rocks* and *shocked rocks*. cf. *distal impactite*.

(SCMR)

Pseudotachylite see *impact pseudotachylite.*

REGOLITH (rhegolith) (Greek *rhegos*, blanket, and *lithos*, stone) Mantle of fragmental and unconsolidated debris. *Impact regolith* is formed by multiple impacts on the surface of planetary bodies without an atmosphere (e.g., moon, asteroids).

(Merrill 1897, p299)

REGOLITH BRECCIA (Greek *rhegos*, blanket, and *lithos*, stone) *Regolith* lithified by shock compression due to *impact*, typically found on the moon and as meteorites.

(OU; Quaide & Bunch, 1970, p718; Stöffler et al, 1979, p660; Stöffler et al., 1980, Table 1; Heiken et al., 1991, p257, p352; Bischoff & Stöffler, 1992, Table 1)

SHATTER CONE Striated cup-and cone structure resulting from hypervelocity impact; the structure occurs on the cm- to m-scale; first described as “Strahlenkalk” by W. Branco and E. Fraas at the Steinheim Basin impact crater, Germany.

(Dietz, 1959, p496, Branco & Fraas, 1905; p496; Dietz, 1960, p1781; Grieve, 1998, p115, Figure 9a)

SHOCK DEFORMATION Deformation by shock wave compression at shock pressures above the *Hugoniot elastic limit* leading to permanent (residual) *shock effects* after pressure release.

(OU; Bunch & Cohen, 1964, p1263; Stöffler, 1972, p71)

SHOCK EFFECT Permanent (residual) deformation and/or transformation of minerals and rocks induced by the passage of a *shock wave* after pressure release (***residual shock effect***).

(OU; Doran & Linde, 1966, p264; Chao, 1967b, p192; Stöffler, 1972, p69)

SHOCK FACIES Unnecessary synonym for *shock stage*.

(Stöffler, 1966, p16; Dence & Robertson, 1989, p526)

SHOCK FRONT Synonymous with *shock wave.*

(OU; Duvall & Fowles, 1963, p211; Stöffler, 1972, p53)

SHOCK IMPEDANCE Thermodynamic entity defined as the product of the density of any phase (before shock compression) times the shock wave velocity.

(OU; Stöffler 1972, p60)

SHOCK LAMELLAE Unnecessary synonym of *planar deformation features*.

(Chao, 1967a, p193, 1967b, p208; Chao, 1968, p137)

SHOCK MELTING Melting of solid matter by *shock wave* compression resulting from high post-shock temperature after pressure release; highest stage of *shock metamorphism* before *shock vaporisation* is induced at still higher *shock pressures.*

(OU, Stöffler, 1966, p21, Fig. 1; Chao, 1967b, p220; Stöffler, 1972, p100; Dence & Robertson, 1989, p527)

SHOCK METAMORPHISM A type of metamorphism caused by shock wave compression due to the hypervelocity impact of a solid body or due to the detonation of high-energy chemical or nuclear explosives.

(OU; French, 1968, p2; Grieve, 1987 p250; Dence & Robertson, 1989, p526; Bischoff & Stöffler, 1992, p711)

SHOCK STAGE The degree of *shock metamorphism* of a rock achieved during *progressive (prograde) shock metamorphism*; successive stages are characterised by specific features or sets of features in the shocked rocks and/or minerals.

(OU, Engelhardt & Stöffler, 1968, p160; Stöffler, 1971, p5545; Dence & Robertson, 1989, p529)

SHOCK STATE Thermodynamic state of matter under shock compression.

(OU; Duvall & Fowles, 1963, p214; Stöffler, 1972, p54)

SHOCK TEMPERATURE Transient temperature achieved in gaseous, liquid or solid matter during *shock wave* compression.

(OU; Duvall & Fowles, 1963, p215; Stöffler, 1972, p53)

SHOCK VAPORISATION Vaporisation of solid or liquid matter by *shock wave* compression and resulting from high *post-shock temperature* after pressure release.

(OU; Chao, 1968, p138; Stöffler, 1971, p5546, Fig. 2; Stöffler, 1972, p90 and p100)

SHOCK VEIN Thin vein of quenched melt produced by shock-induced localized (frictional) melting in moderately shocked rocks. Called ***opaque shock veins*** in metal and troilite-rich meteorites (chondrites); synonymous with *melt vein.*

(Fredriksson et al., 1963, p974; Dodd & Jarosewich, 1979, p338, Table 1; Bischoff & Stöffler, 1992, p720; Spray, 1998, p200)

SHOCK WAVE VELOCITY Velocity of a *shock wave* (*shock front*) propagating into material at rest.

(OU; Duvall & Fowles, 1963, p211-213; Stöffler, 1972, p54)

SHOCK WAVE (shock front) Step-like discontinuity in pressure, density, particle velocity, and internal energy, which propagates in gaseous, liquid or solid matter with supersonic velocity.

(Stokes, 1848, p353; Rankine, 1870, p278; Rice et al., 1958, p1; Duvall & Fowles, 1963, p211; Stöffler, 1972, p54; Melosh, 1989, p37)

Shock zone Synonymous with *shock stage.*

(Stöffler, 1966, p15; Dence, 1968, p170; Dence, 2004, p273, Fig. 8)

SHOCKED ROCKS Rocks affected by *shock (impact) metamorphism.*

(OU; French, 1968, p2; Chao, 1967b, p205 ; Dence, 1968, p172, Fig. 1; Stöffler, 1971, p5541)

SIMPLE IMPACT CRATER Bowl-shaped *impact crater* with relatively large depth/diameter ratio. Simple craters generally have diameters smaller than *complex impact craters*.

(OU; Dence, 1968, p170, p179; Grieve, 1987, p246; Melosh, 1989, p14; Dence, 2004, p271)

SOIL see LUNAR SOIL.

SUEVITE (suevite breccia, suevitic impact breccia, SUEVITIC MIXED BRECCIA) (from *Suevia*, the Latin name for the province "Schwaben" in southern Germany (from *"suevi"* teutonic tribe in Roman times), established in Bavaria Loc. Nördlinger Ries, Bavaria) *Polymict impact breccia* with particulate matrix containing lithic and mineral *clasts* in all stages of *shock metamorphism* including cogenetic *impact melt particles,* which are in a glassy or crystallised state; first detailed petrographic description as "rhyolitic tuff" by C.W. von Gümbel in 1870.

(Sauer, 1901, p88; Gümbel, 1870, p156; Engelhardt, 1971, p5568; Dence, 1971, p5553; Pohl et al., 1977, p359)

Tagamite Term used in Russia for an *impact melt rock.*

(Masaitis et al., 1975, p86; Masaitis, 1994, p155, Table 1, Figures 1 and 7)

TARGET Volume on a planetary body that is impacted by a second body (*projectile*) travelling at cosmic velocity and generating a *shock wave* in both bodies.

(OU; Melosh, 1989, p46)

TARGET ROCK Rock (lithology) exposed at the site of an *impact* before crater formation.

(OU; Melosh, 1989, p46)

TARGET LITHOLOGY Synonym for *target rock.*

TEKTITE (Greek *tèktos*, molten) *Impact glass* formed at terrestrial *impact craters* from melt ejected ballistically and deposited as aerodynamically shaped bodies in a strewn field outside the continuous *ejecta blanket*. The size of tektites ranges from the submillimetre range (*microtektites*, generally found in deep sea sediments) to the subdecimetre range, rarely to decimetres.

(Suess 1900, p191; Spencer, 1933a, p117; Park, 1989, p554; Glass, 1990, p393)

THETOMORPHIC GLASS (Greek *thêtos*, placed, and *morphê*, form) Unnecessary synonym of *diaplectic glass*.

(Chao 1967b, p228, Table 2; Chao, 1968, p148; Dence & Robertson, 1989, p529)

TRANSIENT CRATER (TRANSIENT CAVITY) (Latin *transiens*, transitional or temporary**)** Transient, bowl-shaped cavity of an *impact crater,* which is produced as a result of the compression and excavation stages of the crater forming process. It is unstable in case of all larger craters and collapses immediately in a highly dynamic process leading to a flat *complex impact crater* with either a central peak (uplift) or a peak-ring or multiple rings for increasing diameters of the transient cavity. First recognised and defined by M. R. Dence and co-workers and called “primary crater”.

(OU; Dence et al., 1968, p179-183; Grieve et al., 1977, p803, Fig. 5; Melosh, 1989, p77)

VAPOUR PLUME Vaporised, melted, and crushed *target rock* and *impactor* material being ejected from a hypervelocity impact crater after the *impactor* has reached its stagnation point. The plume forms in the central region of an impact crater and the material involved is ejected very early in the cratering process and at very high speed. Upon collapse of the plume, polymict breccias of the *suevite* type are formed and deposited inside and around the crater. At very large craters (> about 100 km in diameter), the plume material is distributed globally and forms *impactoclastic air fall beds*. Synonymous with *ejecta plume*.

(OU; Melosh, 1989, p.68-71)

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