Towards a unified nomenclature of metamorphic petrology:

11. Impactites

A proposal on behalf of the IUGS Subcommission on the Systematics of Metamorphic Rocks.
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ABSTRACT
This paper presents the provisional results of the IUGS Subcommission on the Systematics of Metamorphic Rocks in respect of impactites.

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 spread worldwide. 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 currently being placed 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 was set up to work out a proposal for the classification and nomenclature of impactites. After having evaluated proposals by the members of the Study Group and by scientists working with impactites, this paper presents a provisional classification and nomenclature of such rocks for comment.

CLASSIFICATION

The term 'impactite' is defined as a collective term for all rocks being affected by one or several 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. The basic classification criteria are based on texture, degree of shock metamorphism, and lithological components. 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 (Table 2).

Impactites from a single impact are classified into 3 major groups 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 exclusive of whole rock melting.
Impact melt rocks are subdivided into three subroups (Table 1) according to the content of clasts. These subtypes may be subclassified into glassy, hypocrystalline, and holocrystalline varieties. The first two subtypes include 'impact glass' as well as 'tektites' (see below).
Impact breccias fall into three subgroups (Table 1) 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.

Impactites from multiple impacts as known from the Moon and from the meteorite parent bodies are subdivided into two main groups:
Impact regolith (unconsolidated impactoclastic debris).
Shock lithified impact regolith (consolidated impactoclastic 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. IUGS

NOMENCLATURE

1. Definition of terms for general metamorphic processes and states

IMPACT = 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

SHOCK WAVE = shock front = a step-like discontinuity in pressure, density, particle velocity, and internal energy, which propagates in gaseous, liquid or solid matter with supersonic velocity

SHOCK WAVE VELOCITY = velocity of a shock wave (shock front) propagating into material at rest

PARTICLE VELOCITY = velocity of shock compressed material moving behind the shock front

SHOCK STATE = thermodynamic state of matter under shock compression

HUGONIOT EQUATION-OF-STATE (RANKINE-HUGONIOT-EQUATION) = thermodynamic equation describing a shock transition from an uncompressed state, P_o, r_o, E_o , to a compressed state, P_1, r_1, E_1, in terms of pressure P, density r, and internal energy E

HUGONIOT CURVE = locus of all shock states, that can be achieved by shock wave compression of variable intensity in any specific material; commonly expressed in the pressure - volume or pressure - particle velocity space

HUGONIOT ELASTIC LIMIT = specific shock pressure below which the shock compressed material behaves elastically

IMPACT METAMORPHISM = metamorphism of rocks or minerals caused by the passage of a shock wave due to impact of a planetary body (projectile or impactor) on a planetary surface (target). It includes melting and vaporization of the target rock(s)

SHOCK METAMORPHISM = metamorphism of rocks or minerals caused by shock wave compression due to impact of a solid body or due to the detonation of high-energy chemical or nuclear explosives

SHOCK EFFECT = deformation and/or transformation of minerals and rocks induced by the passage of a shock wave; may be transient during shock compression or permanent after pressure release (residual shock effect)

SHOCK MELTING = melting of solid matter by shock wave compression resulting from high post-shock temperature after pressure release

SHOCK VAPORIZATION = vaporization of solid or liquid matter by shock wave compression and resulting from high post-shock temperature after pressure release

SHOCK DEFORMATION = deformation by shock wave compression at shock pressures above the Hugoniot elastic limit leading to either transient or residual shock effects after pressure release

SHOCK TEMPERATURE = transient temperature achieved in gaseous, liquid or solid matter during shock wave compression

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

DEPOSITION TEMPERATURE = equilibration temperature of an allochthonous impact formation deposited after ballistic or ground surge transport within or around an impact crater; temperature achieved by heat exchange between breccia constituents of different temperature, e.g. hot melt particles and cold lithic clasts

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

PROGRADE SHOCK METAMORPHISM = increasing grade of shock metamorphism displayed either by the autochthonous rocks of the impact crater basement (approaching radially the point of

impact) or by individual rock clasts (impactoclasts) of a polymict impact breccia; synonymous to PROGRESSIVE SHOCK METAMORPHISM

SHOCK STAGE = degree of shock metamorphism of a rock within prograde (progressive) shock metamorphism

SHOCK FACIES = synonymous with shock stage; term obsolete

2. Definition of specific geologic, petrographic, and topographic terms

IMPACT CRATER = generally circular crater formed either by impact of an interplanetary body (projectile) on a planetary surface or by an experimental hypervelocity impact of a projectile into solid matter; craters formed by very oblique impacts may be elliptical

METEORITE CRATER = impact crater with remaining fragments of the impacted meteoroid

SIMPLE IMPACT CRATER = bowl-shaped impact crater with relatively high depth / diameter ratio

COMPLEX IMPACT CRATER = impact crater with relatively low depth / diameter ratio and with central uplift, annular trough, and down-faulted, terraced rim structure. Central uplift can be expressed topographically as a peak and/or ring.

MULTI-RING CRATER = impact crater with relatively low depth / diameter ratio and with at least two concentric rings inside the crater; synonymous with MULTI-RING BASIN

IMPACT STRUCTURE = geological structure caused by impact irrespective of its state of preservation

TARGET ROCK(S) = rock(s) exposed at the site of an impact before crater formation

(IMPACT) EJECTA = solid, liquid and vaporized rock ejected ballistically from an impact crater

EJECTA BLANKET = continuous ejecta deposit around an impact crater

IMPACTITE = Rock affected by impact metamorphism (includes shocked rocks, impact breccias and impact melt rocks)

PROXIMAL IMPACTITES = impactites occurring in the immediate vicinity of an impact crater, i.e., inside the outer limit of the continous ejecta blanket

DISTAL IMPACTITES = impactites ocurring as distal ejecta outside the outer limit of the continuous ejecta blanket; include tektites and impactoclastic (global) air fall beds

IMPACT FORMATION = geological formation produced by impact; includes various lithological and structural units inside and beneath an impact crater (inner impact formations), the continuous

ejecta blanket (outer impact formations) and distal ejecta such as tektites and impactoclastic air fall beds

IMPACT BRECCIA = monomict or polymict breccia, which occurs around, inside and below impact craters

MONOMICT IMPACT BRECCIA = cataclasite produced by impact and generally displaying weak or no shock metamorphism; occurs in the (par)autochthonous floor of an impact crater or as clast (up to the size of blocks and megablocks) within allochthonous impact breccias

POLYMICT IMPACT BRECCIA = breccia with clastic matrix or crystalline matrix (derived from the crystallization of impact melt) containing lithic and mineral clasts of different degree 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 dikes

ALLOCHTHONOUS (ALLOGENIC) IMPACT BRECCIA = impact breccia in which component materials have been displaced from their point of origin; includes clastic matrix breccias (lithic breccias, suevite breccias), and dike breccias

AUTOCHTHONOUS (AUTHIGENIC) IMPACT BRECCIA = cataclastic (monomict) impact breccia in which component materials have not been displaced any significant distance from their point of origin

IMPACTOCLASTIC DEPOSIT = Consolidated or unconsolidated sediment resulting from ballistic excavation, transport, and deposition of rocks at impact craters; may contain particles of impact melt rock

IMPACT REGOLITH = 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 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

REGOLITH BRECCIA = Regolith lithified by shock compression due to impact

MEGAREGOLITH = 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 kilometers to tens of kilometers

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

(IMPACTO)CLAST = Rock fragment resulting from impact-induced comminution of rocks; may display variable degrees of shock metamorphism (different shock stages)

IMPACT MELT = melt formed by shock melting of rocks in impact craters

IMPACT MELT ROCK = crystalline, semihyaline or hyaline rock solidified from impact melt containing variable amounts of clastic debris

IMPACT MELT BRECCIA = impact melt rock containing lithic and mineral clasts displaying variable degrees of shock metamorphism in a crystalline, semihyaline or hyaline matrix (term should be discarded)

IMPACT GLASS = Impact melt quenched to glass; includes semihyaline impact melt rocks

TEKTITE = impact glass formed at terrestrial impact craters from melt ejected ballistically and deposited sometimesas aerodynamically shaped bodies in a strewn field outside the continuous ejecta blanket; the size of tektites ranges from the submillimeter range (MICROTEKTITES, generally found in deep sea sediments) to the subdecimeter range, rarely to decimeters

DIKE (IMPACT) BRECCIA = impact breccia or impact melt rock occurring in the form of a dike

(IMPACT) PSEUDOTACHYLITE = pseudotachylite produced by impact metamorphism; dike-like breccia formed by frictional melting in the basement of impact craters; may contain unshocked and shocked mineral and lithic clasts in a fine-grained aphanitic matrix

SUEVITE or SUEVITE BRECCIA = polymict impact breccia with clastic matrix containing lithic and mineral clasts in various stages of shock metamorphism including cogenetic impact melt particles which are in a glassy or crystallized state; synonymous with suevitic impact breccia and mixed breccia

LITHIC (IMPACT) BRECCIA = polymict impact breccia with clastic matrix containing shocked and unshocked mineral and lithic clasts but lacking cogenetic impact melt particles

FRAGMENTAL (IMPACT) BRECCIA = synonymous to lithic breccia; polymict impact breccia with clastic matrix containing shocked and unshocked mineral and lithic clasts but lacking cogenetic impact melt particles (term should be discarded)

GRANULITIC (IMPACT) BRECCIA = thermally metamorphosed (recrystallized) impact breccia with granoblastic or poikiloblastic texture; term used for lunar rocks and meteorites

BUNTE BRECCIA = local term for fragmental breccias at the Ries impact crater, Germany

TAGAMITE = impact melt rock; term used in Russia

DIAPLECTIC GLASS = 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 for tectosilicates

THETOMORPHIC GLASS = diaplectic glass; term rarely used, should be discarded

MASKELYNITE = diaplectic plagioclase glass; term originally used for plagioclase of shocked meteorites

MICROKRYSTITE = microtektite-like spherule containing quenched crystals usually of clinopyroxene and spinel, probably derived from condensation of impact rock vapor. Microkristites 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)

PLANAR MICROSTRUCTURES = collective term comprising shock-induced planar fractures and planar deformation features

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

PLANAR DEFORMATION FEATURES = submicroscopic amorphous lamellae occurring in shocked minerals as multiple sets of planar lamellae (optical discontinuities under the petrographic microscope) parallel to rational crystallographic planes; indicative of shock metamorphism; synonymous with the terms "planar elements" and "shock lamellae" which should be discarded

DECORATED PLANAR DEFORMATION FEATURES = annealed planar deformation features consisting of discontinuously aligned vugs and inclusions formed during recrystallization of the originally amorphous lamellae; typically in shocked tectosilicates of the floor of impact craters, also known from shocked olivine in thermally annealed chondrites, where the decorations consist of ultra-fine grained troilite and metal droplets

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)

MELT VEIN = irregular vein of quenched melt produced by shock-induced localized melting in moderately to strongly shocked rocks

MELT POCKET = region of localized quenched melt produced by shock-induced localized melting in moderately to strongly shocked rocks; typical for shocked chondrites and achondrites

TABLE I. CLASSIFICATION OF IMPACTITES

I. IMPACTITES FROM SINGLE IMPACTS

1. Shocked rocks

2. Impact melt rocks*

2.1. clast-rich
2.2. clast-poor
2.3. clast-free

3. Impact breccias

3.1. Cataclastic (monomict) breccia
3.2. Lithic breccia (without melt particles)**
3.3. Suevite (with melt particles)**

* may be subclassified into glassy, hypocrystalline, and holocrystalline varieties
** generally polymict but can be monomict in a single lithology target

II. IMPACTITES FROM MULTIPLE IMPACTS

1. Impact regolith**
= unconsolidated impactoclastic debris

2. Shock lithified impact regolith**
= consolidated impactoclastic debris

2.1 Regolith breccias **
= breccia with matrix melt and melt particles

2.2 Lithic breccias **
= breccia without matrix melt and melt particles

** generally polymict but can be monomict in a single lithology target

Table 2: Classifcation of impactites from single impacts. * typically monomict; ** generally polymict but can be monomict, e.g., in single lithology target; *** includes glassy, hypocrystalline and holocrystalline varieties