Shock metamorphism as a fundamental process in the evolution of planetary bodies: Information from meteorites

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Abstract: Shock effects in meteorites comprise two major phenomena: (1) Shock metamorphism defined as the mechanical deformation and transformation of rocks below or above the solidus by shock compression and (2) breccia formation which involves ballistic or non-ballistic transport and the relative movement of rock fragments and melts by displacement from the primary location in the parent target bodies. Various collision scenarios lead to specific combinations of shock metamorphism and breccia formation if the relative sizes and velocities of the colliding bodies and the specific impact energy are freely variable above a certain threshold value of the impact velocity. In the low velocity regime "accretionary breccias" can be formed by catastrophic disruption and reaccumulation of the fragmented bodies. These breccias may lack distinct shock-induced features of their constituents. In the impact cratering regime (impact velocities >0.5 to 1 km/s) shocked rocks and impact melts are formed and incorporated into crater deposits or in the crater basement of asteroidal surface-subsurface units in which various types of "impact breccias" can be recognized: monomict breccias and polymict breccias such as regolith breccias, fragmental breccias, impact melt breccias and granulitic breccias. Shocked and brecciated meteorites may also directly evolve from high velocity catastrophic fragmentation of the colliding bodies when the fragments exceed the escape velocity. Shock effects have been observed in all major groups of meteorites. They affect not only the petrographic characteristics but also the chemical and isotopic properties and the ages of the primordial meteoritic material. Progressive stages of shock metamorphism in the range of ≈ 5 to 80 GPa have been observed in ordinary chondrites. Localized melting (veins, melt pockets) is a feature in the 10-80 GPa range. Ordinary chondrite breccias are formed by shock lithification of clastic asteroidal surface debris or by accretion of disrupted parent body material. Enstatite and carbonaceous chondrites were also affected by shock metamorphism. Fragmental and regolith breccias are known for the enstatite and carbonaceous chondrite groups. It appears that accretionary breccias occur among carbonaceous chondrites. Basaltic achondrites are affected by all stages of shock metamorphism but the shock-induced melts occur only as clasts within polymict breccias. Ureilites have been shocked up to about 60 GPa and form rarely polymict breccias, whereas aubrites display no severe shock (<20 GPa) but polymict breccias are quite common. The SNC-meteorites are never breccias but either shocked or unshocked rocks. The lunar meteorites are clearly derived from the regolith or subregolith rocks. The regolith or fragmental breccias are exclusively polymict and show variable degrees of shock metamorphism; the basaltic lunar meteorites appear to be volcanic rock fragments. Iron meteorites range from unshocked to shock melted and display variable degrees of static thermal annealing.

It appears that collision-induced hypervelocity impacts took place prior to, simultaneously with, and subsequent to the end of accretion and early differentiation of the parent bodies to which ordinary chondrites and differentiated meteorites are related. A better understanding of shock metamorphism and breccia formation in meteorites is necessary in order to better resolve not only the early processes of accretion, differentiation and evolution (regolith) of the parent bodies but also the primordial composition of the accreted material itself.

Keywords: shock metamorphism, shock effects, impact velocities, chondrites, achondrites, lunar meteorites, fragmental breccias, regolith breccias, parent bodies.

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