PROPOSAL OF A REVISED SHOCK PRESSURE CLASSIFICATION SCHEME. J. Fritz[1], A. Greshake[2] and V. A. Fernandes[2], [1]Saalbau Weltraum Projekt 64646 Heppenheim, e-mail: joerg.fritz@kino-heppenheim.de, [2]Museum für Naturkunde Berlin 10115 Berlin Germany.

The current shock classification scheme: Based on shock experimental studies and observations of naturally shocked rocks in the last decades, a classification scheme was established that assigns shock pressures and temperatures to different rocks types [1]. This classification scheme progressively assigns shock levels ranging from S0 to S6 by mainly referring to destructive shock metamorphic effects in the rock forming minerals olivine, pyroxene, plagioclase and quartz [1-3]. These so called "destructive shock effects" (increase in disorder and volume) include deformations such as fracturing, mosaicism and planar deformation features as well as the formation of diaplectic glasses.

In addition to the destructive shock effects, this classification scheme also includes the so called "constructive shock effects" (increase in order and density). Constructive shock effects are the formation of high pressure phases such as coesite, ringwoodite, diamond, and many others [4-11]. Most of the high pressure phases form by kinetically controlled processes requiring high temperatures as the high pressure conditions during natural impacts only last for microseconds to few tens of milliseconds and rarely up to seconds in large low velocity collisions.

Problems with the current scheme: Including these high pressure phases into the classification scheme turned out to be problematic due to the apparent mismatch between the shock pressures deduced from the destructive shock metamorphic effects in rock forming minerals, and the stability field of the high pressure polymorphs as determined by static high pressure experiments. Currently, the presence of mafic high pressure phases such as wadsleyite, ringwoodite, majorite or akimotoite are considered as indicative for the highest shock level S6 (55-90 GPa), as rocks dominantly composed of mafic silicates will melt at shock pressures above 60 GPa [1].

However, for the Martian meteorite Chassigny, which contains ringwoodite in localized melt pockets, the overall degree of shock metamorphic overprint [12-13] and the effects of the deduced post shock temperatures on the determined noble gas abundances [14] are inconsistent with shock pressures and temperatures in S6 rocks (55-90 GPa; 850-1750°C). Similar observations were also reported for ringwoodite-bearing L6 chondrites [15-16]. Obviously, high pressure phases such as ringwoodite (diagnostic for S6) occur in shocked meteorites that according to the destructive shock effects should be classified as S4 to S5 and not S6 [12-16].

The recent identification of bridgmanite, a highly metastable high pressure polymorph of pyroxene, in the Tenham L6 chondrite [17] illustrates the problems in associating mafic high pressure phases with highly shocked rocks [1]). The highly metastable bridgmanite is analytically difficult to identify as it decomposes at ambient pressures and temperatures above 40°C [17]. Consequently, the post shock temperatures of the Tenham meteorite had to be below 40°C to allow the preservation of bridgmanite. Such low post shock temperatures appear reasonable for moderately shocked rocks (S3 to S4) because the initial temperatures of the asteroid were likely below minus 160°C allowing for a post shock-temperature increase of up to 200°C.

The shock induced temperatures of the whole rock are of relevance for formation and preservation of high pressure phases that occur within or attached to formerly hot melt veins and pockets. The bulk rock has to be cold enough during shock to serve as a heat sink for the quickly cooling melt vein [8,13]. At ambient pressures, bridgmanite decomposes at temperatures >40°C [17], $MgSiO_3$-akimotoite >700°C [18] and ringwoodite >900°C [19] in less than a second, i.e., much faster than the ~30 min cooling time for a 0.4 m sized meteorite in space [12]. Metastable high pressure phases can only survive in rocks that were not shock heated to temperatures exceeding the threshold value for their back-reaction.

The shape of the shock wave in shocked rocks: For shocked rocks (<60 GPa) the shape of the arriving shock wave is governed by the impact velocity. This is because a shock wave with a broad pressure plateau is restricted to the region inside the isobaric core (Fig. 1). Only low velocity impacts (<4 km/s) allow for shock metamorphism inside the isobaric core, because high velocity (>5 km/s) impacts induce high shock pressures inside the isobaric core causing the target lithologies to melt or vaporize.

The minimum impact velocity is governed by the escape velocity of the impacted planetary body (in km s^{-1}, Vesta = 0.36; Moon = 2.38; Mars = 5.03; Earth = 11.2). Excluding atmospheric deceleration of small projectiles, low velocity impacts are restricted to asteroids, or in rare cases to the Moon. Notably, the average impact velocity is higher than the escape velocity. Thus, the simplified considerations of impact velocity and shock pressures inside the isobaric core shows that neither Martian nor terrestrial shock metamorphic rocks were exposed to a shock wave with a broad pressure plateau, because the shock pressures inside the isobaric core are too high. The situation might be different for chondrites shocked during low velocity impacts and, hence, low pressure conditions inside the isobaric core. Consequently, high pressure phases cannot be used to deduce the general maximum shock pressure in a rock as most of them form during shock pressure decline.

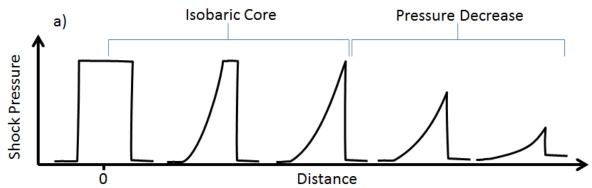

Figure 1: Pulse length and intensity of a shockwave with distance to the point of impact. The propagating shock wave interacts with the following faster release wave. In a planar impact approximation the broad shock pressure plateau decreases while the maximum shock pressure remains high (isobaric core). Once the release wave catches up with the shock front the maximum pressure declines more quickly. Note that the shock duration at elevated pressures is longer than the duration of the broad pressure plateau.

Proposed modifications of the current scheme: We propose that not the presence but the absence of metastable high pressure polymorphs are indicative for rocks subjected to the highest degree of shock pressure S6. Each type of high pressure phase provides maximum temperature and minimum pressure constraints for the shocked rock.

Destructive shock deformation effects allow deducing the general maximum shock pressure (sometimes called equilibration shock pressure). These shock pressures and resulting post shock temperatures [12] are expected to be consistent with the post shock temperature limits given by the threshold temperature for back-reaction of the present high pressure phases. Using the destructive shock effects for a general shock metamorphic classification appears essential because:

- destructive shock effects are the physical manifestation of the pressure-volume work achieved by the shock wave and, thus, are physically related to the shock induced temperature increase.
- destructive shock effects can be observed by optical microscopy and, thus, allows for classification in a reasonable time.
- destructive shock effects allow classifying weakly to strongly shocked rocks. Both the weakly and most strongly shocked rocks reasonably are, for different reasons, characterized by the absence of metastable high pressure phases.
- high pressure phases indicative for the highest pressures are likely increasingly metastable at ambient pressures; i.e., most difficult to preserve.
- melt veins and pockets may either not be present in all samples or are too thick (i.e., high temperatures for longer than shock) to allow preservation of the high pressure phases, or record the conditions during declining of shock pressure

Revisiting the shock pressure-temperature-time history of shocked rocks is timely and warranted since the apparent mismatch of deduced shock pressures and temperatures in meteorites containing high pressure phases resulted in the confusing current situation in which various shock pressure and temperature conditions are proposed for the same meteorites. For the Martian meteorite Shergotty the proposed values include ~30 GPa [2,12], >40 GPa [20] or <22 GPa [21] .

The problem of classifying shock metamorphic rocks appears most relevant for H and L chondrites as they by far represent the largest number of meteorites. Since ringwoodite is easily identified by its blue to green color in transmitted light microscopy it is common practice to use the presence of ringwoodite as diagnostic for shock level S6. Thus, a large number of meteorites might have an incorrect shock classification, with implications for the shock pressure and temperature history of these rocks and for systematic studies relying on such a classification.

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