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EXPLOSIVE VOLCANISM, SHOCK METAMORPHISM AND THE K-T BOUNDARY

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The issue of whether shocked quartz can be produced by explosive volcanic events is important in understanding the origin of the K-T boundary constituents. Proponents of a volcanic origin for the shocked quartz at the K-T boundary cite the suggestion of Rice [1,2], that peak overpressures of 1000 kbars can be generated during explosive volcanic eruptions, and may have occurred during the May, 1980 eruption of Mt. St. Helens. We have previously drawn attention to the fact that peak overpressures during explosive eruptions are limited by the strength of the rock confining the magma chamber to <8 kbars even under ideal conditions [3]. Here we further examine the proposed volcanic mechanisms for generating pressures sufficient to shock quartz (>60 kbars). We present theoretical arguments, field evidence and petrographic data showing that explosive volcanic eruptions cannot generate shock metamorphic features of the kind seen in minerals at the K-T boundary.

Model Considerations. Rice [2,4] models magma chambers as huge charges of chemical explosives, but explosive volcanic eruptions are not detonations or deflagrations but events of sustained decompression. Chemical and nuclear explosions are irreversable reactions of metastable substances; explosive volcanic eruptions are driven by the exsolution of volatiles from the magma as it ascends (decompresses) and crystallizes. Exsolution is self-buffering, because if volatile expansion is not accommodated by expansion of the magma chamber (rupture of the country rock), pressure builds up and impedes further exsolution.

Crystallization of the magma greatly reduces the solubility of volatiles, driving them into the melt. Rice suggests that extremely rapid crystallization can be brought about by the quenching effects of Soret convection [2], but Soret convection, itself is not considered to be a viable fractionation process in magmas [e.g. 5] because: a) there is no evidence that Soret convection operates on the scale of magma chambers; b) Soret convection gives chemical gradients opposite to those found in nature [6]; and, c) chemical gradients attributed to Soret convection [e.g. 7,8] have been shown to be consistent with crystal-liquid fractionation processes [5,9,10].

To generate overpressures sufficient to shock quartz requires that the propagation velocity of the crystallization front exceeds the seismic velocity of the magma (several km s^{-1}), otherwise the rocks confining the magma chamber will fail elastically before pressures can significantly exceed the yield strength of these rocks. Such a velocity exceeds calculated maximum nucleation rates [11,12,13] by orders of magnitude.

Any mechanism involving H_2O as the volatile phase in magmas is constrained by the P-V-T relations of water which would limit the pressures obtainable to only a few kilobars; in a sub-volcanic environment it is likely to be <1 kbar. Second boiling [14,15], which is a natural consequence of crystallization upon cooling in an H_2O-saturated magma, could theoretically generate enormous pressures (tens of kilobars) under the low pressures characteristic of the subvolcanic environment [15,16]. However, in geologically plausible situations the theoretical maximum is never reached, and the maximum pressure is always limited by the lithostatic load [3,15].

Field Evidence. Over 150 years of research in volcanology, utilizing a wealth of field, chemical, and theoretical data, demonstrates that explosive volcanic eruptions progress by systematic evacuation of magma chambers, some of which were stably compositionally and thermally stratified [e.g. 17,18]. This stratification, perhaps resulting from double-diffusive processes [19,20], is preserved (inverted) in the deposits [17]. It is difficult to envisage how any zonation could be preserved if the magma chamber contents were accelerated instantaneously to velocities of several km s^{-1}, as would be required to initiate shock metamorphism in the magma and country rocks.

Detailed studies of two well preserved and exposed ash-flow calderas; the Emory Cauldron [21] and the Questa Caldera [22], New Mexico, give us a useful insight into the nature and character of relic magma chambers and their country rocks. There is no evidence at these localities for highly brecciated chill zones, wall rocks with abundant planar features, maskelynite, high pressure phases of quartz and pseudotachylite dykes, that are commonly found in shocked environments, such as impact structures.

Petrographic Evidence. Evidence for shock metamorphism of tectosilicates in the volcanic environment has never been demonstrated. Reports of "shocked minerals" associated with volcanic deposits of Toba and Bishop Tuff [23] are limited to such features as "mosaicism" in feldspar, and rare (< 1% of total) occurrences of quartz clasts each containing a single set of deformation lamellae that bear only superficial resemblance to those produced by shock [24,25]. Our studies of these rocks and of over 100 samples from some of the most energetic and extensive volcanic terrains in the world, substantiates the rarity of deformation features in these deposits. We note that the mosaic texture in feldspar at Toba is associated with the post-caldera domes which post-date the explosive event. If a shock event occurred, the post-explosion magma of the domes would not have experienced it. We suggest then, that the mosaicism cannot be considered as evidence of shock metamorphism and that it is more likely that the deformation features associated with volcanic events represent a newly recognized class of such features which like tectonic (Boehm) lamellae and shock lamellae, are distinctive products of the particular P-T-strain rate environment in which they were formed.

In excess of 25% [25] of the clastic quartz-grains contained in K-T boundary layers of Western N. American sections show multiple sets of planar lamellae which correspond primarily to rational crystallographic orientations [24,25] and are identical to those that have been documented at over 100 terrestrial impact structures [24,26,27]. We find absolutely no occurrences of similar multiple set features in the volcanic samples we have studied, and none have been reported elsewhere [24,25]. While these results cannot exclude the possibility that shocked quartz might occur in unsampled volcanic units, they do indicate that volcanically shocked quartz, if it exists, is extremely rare and could not possibly account for abundances found at the K-T boundary. The only natural environment in which unambiguous evidence of shocked quartz has been demonstrated is that of hypervelocity impact craters.

We conclude that no association of explosive volcanic eruptions with overpressures great enough to induce shock metamorphism in tectosilicates has yet been demonstrated and that the generation of the required pressures is improbable. The absence of explosive silicic volcanism at the K-T boundary on any exceptional scale renders the arguement for volcanic shock irrelevant, while the impact origin of shocked quartz at the K-T boundary appears well established.

References

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