# AN ALTERNATIVE HYPOTHESIS FOR THE ORIGIN OF FERROAN RINGWOODITE IN THE PUMICE OF EL GASCO (CÁCERES, SPAIN).

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**Introduction:** Ferroan ringwoodite was recently identified by XRD in pumiceous rocks from northern Cáceres province (Extremadura, western Spain) [1], and confirmed by electron microprobe analysis [2]. The quartz-rich vitrocrystalline rock (Fig. 1) crops out atop a hill near the village of El Gasco. The outcrop was originally interpreted as volcanic in origin [3], and more recently reinterpreted as impact-related based on the presence of high-temperature and high-pressure mineral phases such as lechatelierite (silica glass), hercynite, ferroan ringwoodite (iron silicate spinel), and iron droplets (Fig. 2) [1, 2, 4]. The geochemistry confirms that the pumiceous rock originated through partial-melting of the quartzite from the local substrate [4]. A volcanic origin (rhyolite) was discarded based on geochemistry and petrology, and an anthropogenic origin (slag) or lightning-strike origin (fulgurite) were discarded based on the large volume involved and absence of ore minerals [5]. An estimated volume exceeding 50 m$^3$ has already been extracted for industrial use and local craftsmanship.

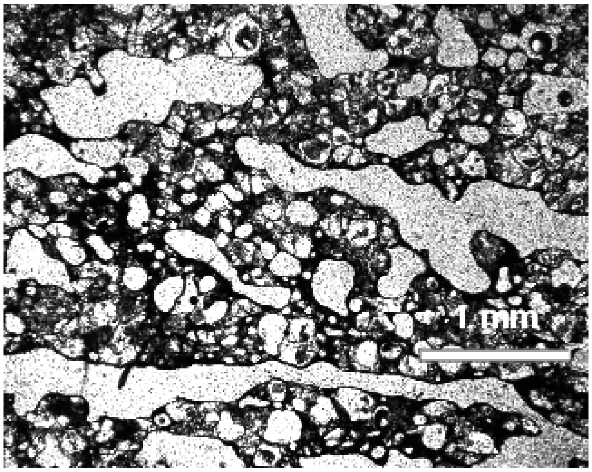

Figure 1: Transmitted-light optical microscope image of the pumiceous rock. Scale bar is 1 mm.

**Critique of the impact hypothesis:** Many colleagues (A. Deutsch, C. Koeberl, J. Melosh, etc.) contributed with constructive criticism at several workshops of the ESF IMPACT Programme, pointing out several incongruencies of the impact hypothesis [2, 5]. However, no alternative came out from these discussions to explain the presence of ferroan ringwoodite in the pumiceous rock. Arguments against the impact hypothesis were mostly based on the lack of widespread evidence for shock metamorphism. An impact generating such an amount of partial melting in quartzites should have allowed for the formation of PDFs, coesite and stishovite, which have not yet been found. Furthermore, the impact hypothesis cannot explain several other features found at the outcrop, such as swollen clasts with bulged bread-crust surfaces (Fig. 3), wood casts and silica glazing. We investigated other plausible processes generating large volumes of glass with all these features, and concluded that vitrification [6] is the most coherent explanation. However, the presence of ferroan ringwoodite still remained unexplained.

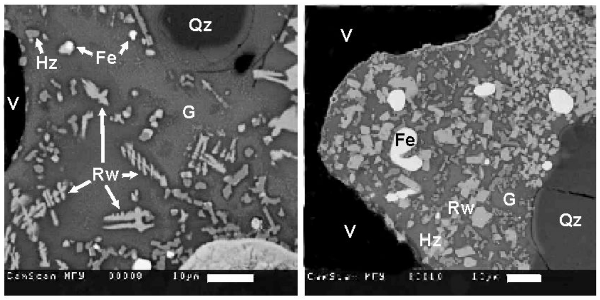

Figure 2: Back-scattered SEM images of material adjacent to vesicles (V) in the pumiceous rock. Metallic iron droplets (Fe), ferroan ringwoodite (Rw), and hercynite (Hz) display different brightness according to their iron content. The rest of the material is mostly just quartz (Qz) and glass (G). The scale bar in the lower-right corner of both images is 10 microns. Images by L. Glazovskaya [2, 4].

**Proposed conceptual model:** We herein propose an alternative hypothetical model which better explains all the features found so far in the pumiceous rock of El Gasco, including the formation of ferroan ringwoodite. We envision the mechanism as due to discrete, microscale, localized high-pressures originated by cavitation at the moment of break-up of a closed system during partial melting of the quartzite. Petrographic study of the quartzites from the substrate indicates that a 3D quartz framework originated during diagenesis and low-grade metamorphism of the siliciclastic turbidites by cementation of the quartzarenite, mostly through sintaxial overgrowth of skeletal quartz grains. The process of ferroan ringwoodite formation may be described as follows. Upon melting of the chloritic matrix (with melting point lower than quartz), the resulting volatiles exerted a high partial pressure within this closed, confining, quartz 3D-framework.

During temperature rise, as soon as the discrete internal pressure reached the limit of quartz tenacity, the framework structure broke and vesicles expanded by hydrodynamic cavitation [7] as far as the highly-viscous glass full of quartz fragments allowed, releasing the pressure accumulated. The expansion stopped when the pressure equaled the high viscosity of the surrounding clast-rich glass. Our hypothesis requires experimental modelling and numerical simulation. We are currently carrying out experiments with hot-stage microscopy and high-heat furnace to determine the temperature and simulate the conditions undergone by the quartzite.

Figure 3: Clast of pumiceous rock with bulged bread-crust surface. Arrow indicates open crack with sheared echelon surfaces.

The vitrification hypothesis explains many features that the impact hypothesis does not, such as: (a) bulged bread-crust surfaces and partial deformation (sheering and rotation) of the quartzite clasts, which would be due to internal differential swelling related to cavitation and vesicle expansion, (b) different degrees of brecciation of the quartz fragments in the glass, and different vesicle sizes, both of which would depend on the different degrees of confinement and tightness of the quartz framework in the original quartzite, chlorite content, glass viscosity, etc., (c) location of hercynite, ferroan ringwoodite, iron droplets, etc. within the glass adjacent to vesicles, crystallized from the melt of the matrix's Fe- and Al-rich phyllosilicates, (d) lack of widespread shock metamorphism of the ubiquitous surrounding quartz, together with its abundant fracturing, (e) wood casts and silica glaze found on the surface of some pumiceous clasts, (f) water loss from the quartzite to the vitrocrystalline pumiceous rock, (g) extremely variable phosphorous values, possibly due to melting of apatite, incorporation of wood-ash, and addition of bones [6].

A localized standing fire of a human-made construction built with the local wood and stone can explain the origin of the pumiceous rock. Bronze-age and Iron-age vitrified forts in northern and western Europe present similar textures and mineral parageneses, with melting temperatures reaching up to 1235ºC [6, 8]. The ancient (now extant) local forest of heather trees (*Erica arborea*) is a potential source of high heat capacity wood. This material is currently used by local artisans to carve pipes for smoking. Ferroan ringwoodite can form at lower temperature and pressure than normal (Mg) ringwoodite: around 1200ºC and 6 GPa for the more iron-rich compositions [9]. Structure refinements have been performed at even lower pressures (4 GPa) [10]. Metallic iron spherules and droplets are also found in many Celtic vitrified forts [6, 8], implying strongly reducing conditions during melting. The reducing conditions and high temperatures may allow for even lower pressures needed for the formation of ferroan ringwoodite. The pumiceous rock of El Gasco may be a particular case of vitrification in which the quartzite source clasts had a tight confining quartz framework which allowed for the accumulation of high pressures during melting and vaporization of the quartzite matrix. The name of the hill where the outcrop is located ("Peña del Castillo" or Castle Rock) may be a relic of its former protohistorical use, still alive in the local toponimy.

**Conclusion:** El Gasco is the first location where ferroan ringwoodite (iron silicate spinel) is found on Earth. We propose a hypothesis to explain its origin with no relation to impact shock metamorphism, and with interesting implications for the study of high-pressure mineral phases.

**References:** [1] Díaz-Martínez E. et al. (2001) *Geogaceta, 30,* 47-50. [2] Glazovskaya et al. (2002) 8th Workshop of the ESF IMPACT Programme, Mora. Program, Abstracts and Fieldtrip Book, p. 23. [3] García de Figuerola L.C. (1953) *Estudios Geológicos, 9,* 385-393. [4] Sanz-Rubio E. et al. (2002) First Iberian Congress on Meteorites and Planetary Geology, Cuenca. Abstracts Volume, p. 39-40. [5] Díaz-Martínez E. (2002) 9th Workshop of the ESF IMPACT Programme, Praha. Abstract Book, p. 13. [6] Youngblood E. et al. (1978) *Journal of Archaeological Sciences, 5,* 99-121. [7] Spray J.G. (1999) *Geology, 27,* 695-698. [8] Kresten P. et al. (1993) *GFF, 115,* 13-24. [9] Agee C.B. (1998) *Reviews in Mineralogy*, 37, 165-204. [10] Finger L.W. et al. (1979) *American. Mineralogist, 64,* 1002-1009.