A TERRESTRIAL ORIGIN FOR SULFATE VEINS IN CI1 CHONDRITES.

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Introduction: CI1 carbonaceous chondrites are chemically the most pristine meteorites in matching best the chemical composition of the sun [1]. They are, however, petrographically very complex, and have endured extensive aqueous alteration on their parent-asteroid [e.g. 2]. One mineralogical feature commonly cited to indicate the nature and extent of this alteration is the ubiquitous and spectacular presence of white sulfate veins (see Fig. 1) first reported in 1961 by [3]. Despite, or maybe because of, their conceptual importance in meteoritics, the possible terrestrial origin of the sulfates veins has never been discussed in detail. In this work, we trace back the history of the sulfate veins in CI1 chondrites and conclude they have a terrestrial origin.

The sudden appearance of white sulfate veins: White sulfate veins were first reported in the Orgueil meteorite in 1961, a century after the meteorite fell in 1864 [3]. In 1962, [4] published the first picture of a salt vein in a thin section of the Orgueil meteorite and [5] published the first picture of a CI1 macroscopic sample (Ivuna) crosscut by a network of sulfate veins. In 1978, a long paper published in Meteoritics includes the following statement: «Several investigations, starting with Daubrée's (1864) study of the newly-recovered Orgueil meteorite, have reported that the fractures are primarily occupied by magnesium sulfate, but have been uncertain about which of the observed hydrates, epsomite or hexahydrite is the preterrestrial form» [6]. In the cited communication, Daubrée mentions only the salt contained in the meteorite that acts as a cement but does not report on any veins [7]. Facing such a sudden appearance (none had reported any veins before 1961), as well as widespread confusion in the reading of the original papers, we decided to determine if the sulfate veins had indeed been seen shortly after the meteorite fell.

Early descriptions of CI1 chondrites: The only CI1 carbonaceous chondrites that have been thoroughly documented soon after their falls are the first two ones: Alais and Orgueil which are also the meteorites for which the presence of white sulfate veins have been best described. Thénard [8] described the interior of the Alais stone (which fell in 1806) and did not report anything but a black, loose and friable material. In his first description of Orgueil, Daubrée [7] used a microscope with sufficient resolution to identify 50 µm large crystals of pyrrhotite and mentioned some salt contained in the meteorite and acting as a cement (see above). Breaking apart the Orgueil stone, Lemeyrie [9] found its interior to be absolutely black. Pisani [10] made several accurate observations about the stone's physical state. He mentioned for instance that the stone contained some sulfates and noted its high porosity as well as its extreme avidity for water. To illustrate this surprising property, he reported the following observation. After it had been heated at 110°C, the stone was left on a balance exposed to the laboratory's atmosphere. After a few hours the Orgueil stone had regained almost all the hygroscopic water it had lost (9.15 wt%) while being heated!

Soon after their falls, the Alais and Orgueil stones were described by talented scientists: the two stones were reported to be absolutely black. Both the exterior and the interior of the stones were examined thoroughly. Binocular microscopes good enough to characterize minute crystals were used. No white veins were reported. It is doubtful these skilled chemists and mineralogists who, lacking modern powerful analytical instruments, were beautifully trained at observing and describing samples of all kinds would have missed an «abundant network of sulfate veins». We conclude that there were no sulfate veins present in CI1 chondrites to be observed when they fell on Earth.

Sulfates veins formed in museums' atmospheres: The early thorough observations made by Thénard [8], Daubrée [7] and Pisani [10] may shed light on the formation process of white sulfate veins within CI1 carbonaceous chondrites. Daubrée reported salts in the Orgueil meteorite; Thénard and Pisani were struck by the loosiness, the high porosity and the extreme avidity for water of the stones they examined. We suggest that some sulfates were originally present within the stones. Reacting with atmospheric water, they dissolved and remobilized -probably changing their hydration state- and have reprecipitated in the many open spaces offered to them by the very porous rock [11]. The stresses provoked by this filling may have ultimately opened new fractures within the fragile rock permitting the dissolution/precipitation process to continue, with porosity increasing still further. The storage conditions of the rocks are known to have changed many times through history, implying that the atmospheric temperature and humidity they experienced have accordingly been highly variable and have lead to the diverse sulfate hydration states observed in the veins [5,6]. Our hypothesis is supported by the high reactivity of sulfates at room temperature. This reactivity is well known from petrologists who have seen at different occasions sulfate crystals growing on the top of the Orgueil thin sections they were examining. This sulfate vein formation hypothesis gives a straightforward explanation for the once striking observation of [12] that suggested, on the basis of strontium isotopic data, that some of the Orgueil calcium sulfate have formed recently. We do not definitely exclude the possibility that part of the sulfates have formed from the oxidation of the abundant sulfides contained in the CI1 chondrites [11]. However, in such a case, a reaction zone should be observed at the edge of the sulfides' grains. These reaction zones have not been reported so far, suggesting that only a minor amount of the sulfates observed in CI1 chondrites originate from sulfide dissolution.

Concluding remarks: From the early 1960s' on, numerous workers have reported abundant white sulfate veins within CI1 carbonaceous chondrites. Our reexamination of the original papers reporting on the Alais and Orgueil CI1 meteorites soon after their falls has revealed that these meteorites landed onto the Earth devoid of any white sulfate veins. We suggest that these veins have formed during the residence time of the meteorites on Earth by an active remobilization of originally extraterrestrial sulfates that lead to the filling of the numerous open spaces and to the opening of new fractures networks. This «historical study» points out that the mineralogy of extraterrestrial matter can be affected to a great extent by the sojourn of meteorites on our volatile-rich planet. One may also question the wisdom of using CI1 chondrites as a reference for the chemical composition of solar system [1]. Although remobilization of sulfates in veins may not change the bulk composition of CI1 chondrites, some other modifications taking place on Earth may generate chemical changes, at least for the most mobile elements.

CM2 meteorites may be a better choice for exemplifying the solar system chemical composition for two reasons. First, strong remobilization leading to the growth of sulfate veins is unknown in CM2 meteorites but in the nineteenth century fall Cold Bokkeveld [13]. This suggests that CM2 chondrites are less sensitive to the the interaction with the terrestrial environment than CI1 chondrites. Second, cosmic dust which is the most common extraterrestrial matter on Earth [14] has a CM2-like composition [15]. We would eventually like to emphasis that sulfate veins in CI1 chondrites can no longer be used as a supportive argument in favor of a late-stage oxidation event, or cm-scale fluid flow in the CI1 parent-asteroid [2]. We would deem this study useful if it led meteoricists to reexamine CI1 carbonaceous chondrites with a new eye.

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Fig. 1: A ~2 kg fragment of the Orgueil stone kept at the Musée d'Histoire Naturelle de Montauban. Although this fragment has been kept under a sealed cover for many years, spectacular sulfate veining has developed. Picture courtesy of Edmée Ladier.