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Overview of Secondary Phosphate Facies observed by Chemcam in Gale Crater, Mars

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Phosphorus was essential to the development of life on Earth because it enters into the composition of molecules important for biology. Since the development of organisms is often limited by phosphorus supply, secondary phosphate facies are often controlled by biological activity, especially in lacustrine and marine environments. Understanding the formation of phosphate minerals on Mars is therefore interesting not only from an astrobiological standpoint, but also to understand the phosphorus cycle in a presumably abiotic world. Here, we provide an overview of the different secondary P-rich facies that have been observed by the ChemCam instrument.

Since 2012, *Curiosity* has been exploring geological records of a paleo-lacustrine environment in Gale crater. After encountering fluvio-deltaic and lacustrine deposits in the lowermost unit, Bradbury, it explored ~300m of stratigraphy through the Murray formation, composed predominantly of laminated clay-rich mudstones and fine-grained sandstones deposited in an extended lacustrine environment. While crossing the Sutton Island member of this formation (an heterolithic unit composed of mudstones and sandstones), a series of subhorizontal dark laminae enriched in Fe and P were found, progressively giving way to mm-size dark nodules enriched in Mn, Mg and P in the overlying Blunts Point member, growing in size with elevation [1], and to Mn-rich sandstones [1,2,3]. These laminae and nodules were interpreted as syndepositional or early diagenetic features formed in a shallow lake or lake margin environment [1,2,3]. An initial interpretation of their mineralogy, based on chemical measurements, suggested they could be hydrous Fe- and Mn-oxides formed under oxidizing conditions (with Eh increasing along the stratigraphy) at the water-sediment interface, having sorbed ($MgHPO_4$) complexes [1], with nodules' growth possibly controlled by reworking and winnowing. Dark nodules enriched in (Fe,Mg,P) were also observed in Ca-sulfate-filled fractures across all these units [1]. These dark

features suddenly disappeared when the rover reached the Vera Rubin ridge, where only isolated and detached nodules enriched in (Mn,Fe,P), probably eroded from overlying strata, and dark-toned rock patina enriched in (Fe,P) were observed. None of these facies were then observed during the first ~500 Sols of the traverse through the Glen Torridon region, including the base of an unconformity with an overlying Aeolian sandstone unit. In the Groken area of the Glen Torridon region, dark mm-sized nodules arranged in thin layers were again discovered. A rock sample was analyzed by X-ray diffraction by CheMin, which did not detect any crystalline forms of oxides nor phosphates [4]. Meanwhile, the phosphorus and manganese abundances measured by ChemCam have been quantified, which led us to revise prior interpretations. The constant P/Mn ratio in the Groken nodules and their P abundance (too large to be explained by P-sorption to oxides) suggest they are composed of nano-crystalline or amorphous hydrous (Mn,Mg)-phosphates. Previous occurrences are now interpreted as hydrous (Fe,Mn,Mg)-phosphates with varying (Fe,Mn,Mg) proportions. Several formation scenarios are being explored by geochemical modeling [5].

[1] Meslin et al., LPSC, 2018

[2] Gasda et al., LPSC, 2018

[3] Lanza et al., LPSC, 2018

[4] Treiman et al., LPSC, 2022

[5] Loche et al., LPSC, 2022