MINERAL DIAGENESIS OF CLAYS AND OPALINE SILICA ACROSS MARS: EVIDENCE FOR CRUSTAL FLUIDS AND EXTENDED AQUEOUS ACTIVITY. V. Z. Sun, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA (Vivian.Sun@jpl.nasa.gov).

Introduction: Fe/Mg clays and hydrated/opaline silica represent the vast majority of hydrated mineral detections on Mars\textsuperscript{1–4}, thus a substantial portion of Mars’ aqueous history is encoded in these two mineral groups. Both clays and opals are unique in that they can undergo mineral diagenesis, where varying exposure to water will produce different mineral forms that can be detected via orbital near-infrared spectroscopy. Fe/Mg smectites will alter to chlorite with exposure to water and heat\textsuperscript{5,6}, and amorphous opal-A will convert to more crystalline opal-CT and quartz in the presence of water alone\textsuperscript{7}. This attribute of both clays and opals allows us to infer not only the past presence of water, but also the persistence of aqueous conditions.

Until recently, it was generally thought that aqueous conditions were limited and largely ceased after the widespread formation of clays on Mars\textsuperscript{1,8}. However, recent orbital studies have identified localities with more geochemically mature phases\textsuperscript{9,10}, and landed missions (Opportunity, Curiosity) have found to be uplifted from depths as great as 17 km\textsuperscript{11}. Importantly, these results suggest that fluids were present within the crust, possibly at significant depths up to 17 km, in order to enable diagenesis. The depths at which chloritization occurs (Fig. 2A) also carries implications for determining the geothermal gradient within the crust, as the conversion of smectite to chlorite process requires heat in addition to water\textsuperscript{5,6}.

Methods: Results from approximately 900 CRISM cubes and their overlapping HiRISE and CTX images are represented in this study. Fe/Mg smectites have narrow absorptions at 2.3 \(\mu\)m, and are distinguished from chlorites, which have a more complex absorption centered at 2.32–2.35 \(\mu\)m. Opaline silica has a diagnostic 2.2 \(\mu\)m absorption, but it is its 1.4 \(\mu\)m band position that distinguishes opal-A (absorptions <1.41 \(\mu\)m) from opal-CT and quartz (>1.41 \(\mu\)m)\textsuperscript{9}.

Burial Diagenesis of Fe/Mg Clays in the Crust: Our first investigation focuses on Fe/Mg clays detected within uplifted materials in central peak craters\textsuperscript{4}. We find that chlorite occurrences increase with crater uplift depth while smectite occurrences decrease (Fig. 2A), suggesting smectite-to-chlorite diagenesis in the crust. The transition from a smectite-dominated to a chlorite-dominated crust occurs at 4 km depth, and chlorite is found to be uplifted from depths as great as 17 km\textsuperscript{4}.

Diagenesis of Opaline Silica: Results from our second investigation show that opal-A and opal-CT are both present on Mars (Fig. 2B) but appear globally correlated with geologic setting. Opal-A tends to occur in bedrock units, while opal-CT is associated with mo-

**Fig. 1.** Global distribution of geochemically mature minerals – chlorite and opal-CT (bold circles) – suggesting extended aqueous alteration, and their geochemically immature counterparts (smectite and opal-A: pastel triangles).
bile, unconsolidated deposits. This suggests either that the opal-CT-bearing deposits represent older, eroded material, or that opal maturation was facilitated by H₂O trapped within particulates in the deposits. In the latter scenario, trapped fluids may intermittently interact with the silica, e.g., through freeze-thaw cycles, resulting in slow opal maturation through Ostwald ripening. Interestingly, there is an overall lack of opal-CT associated with bedrock, even in uplifted outcrops, which contrasts with the observations of chlorite in uplifted units.

**Timeline of Extended Aqueous Activity:** Although geochemically mature chlorite and opal-CT are both observed across Mars, they are associated with different geologic settings and therefore likely formed in different ways. If this hypothesis is true, what does this imply for the availability and persistence of water throughout Mars’ history?

These observations may reflect fluids and aqueous alteration during different time periods. Clays are typically understood to have formed during the Noachian, and opaline silica during the Hesperian. Indeed, some of the largest craters uplifting chlorite in our study are as old as 3.8-3.9 Ga, suggesting that this chloritization process in the crust must have occurred prior to this excavation age. These observations indicate that there was substantial burial diagenesis of clays occurring early in Mars’ history, but water availability in the crust eventually decreased as we observe incomplete chloritization at shallower depths (Fig. 2A). An overall decrease in water availability may also explain why opal-bearing outcrops have largely not been converted to opal-CT or quartz, as most opaline silica likely formed later during the drier Hesperian. Instead, conversion to opal-CT may have only occurred through slow opal maturation facilitated by pockets of fluids trapped within particulates (see above section).

This trend of decreasing water availability may also explain why widespread chloritization is not observed in the Noachian/Hesperian-aged Gale crater despite clay-bearing deposits being buried under several kilometers of sediment, although this appears contrary to Curiosity’s observations of abundant diagenetic features at scales below the resolution of orbital data.

**Summary and Outstanding Questions:** We have presented evidence for diagenetic processes acting on both Fe/Mg clays and opals on Mars, suggesting that aqueous conditions, though still limited compared to Earth, were more extensive than previously thought. This orbital perspective is corroborated by observations by landed missions, as Opportunity and Curiosity have both found extensive evidence for diagenetic processes and postdepositional fluids, albeit at a different scale of detection than orbital observations. However, several questions still remain:

1) When did these global, crustal diagenetic processes occur, especially relative to the global environmental changes from the Noachian to the Hesperian?

2) When did the local-scale diagenetic processes at Meridiani and Gale occur, relative to the broader-scale diagenesis processes inferred from the orbital data?

3) How can observations of mineral diagenesis in the crust be used to infer geothermal gradients during the Noachian and Hesperian?

These answers will inform our understanding of Mars’ geochemical and aqueous history, as well as its surface and subsurface habitability through time.