Dioctahedral vs. Trioctahedral Clays and the Diagenetic Process

Research context – why were dioctahedral clays traditionally better understood, and how has that affected research development? [Hower et al., Chang et al.]

Consequences of differences between illitization and chloritization and their respective chemical requirements [Chang et al.]

The organization of diagenetic conversion, “reshuffling” of chemical building blocks, and interlayer interactions [Hower et al., Chang et al.]

Detecting Diagenesis in Shales

How can we be sure we’re measuring a result of burial metamorphism, given other outside forcings (e.g., changes in source regions, depositional settings)? [Hower et al.]

Can we adequately account for local variations when testing samples from adjacent regions? [Chang et al.]

Burial depth vs. sediment composition in driving progression of illitization/chloritization.

Given the range of time-intensive techniques used to track the evolution of diagenesis, what is the minimum amount of information (and/or simplest technique) necessary to determine these pathways?

Timelines: laboratory analysis of core profiles vs. fitting with reaction kinetics.

Using Clay Mineral Chemistry to Deconvolve Martian Hydrologic History

Deep burial transformation vs. near-surface preservation: which is more likely? [Tosca and Knoll]

Extrapolating from the presence of clay minerals to hydrologic timescales during deposition, lithification, and after [Tosca and Knoll].

The role of rovers vs. orbital data in deriving local and regional diagenetic histories: how good can we make our timelines?

Reaching a geochemical consensus (or not) in the Mars community.
Hover et al. (1976):

Figure 3. Proportion of illite layers in illite/smectite as a function of depth in the finest and coarsest clay fractions.

Chang et al. (1986):

Figure 4. Plot of illite content of illite/smectites (<2 μm) from dioctahedral clay-rich shales vs. depth. Solid symbols indicate ordered interstratification.

Figure 12. Plot of average chlorite content of chlorite/saponites (<2 μm) from shales (Cassipore basin) vs. depth. Solid symbols indicate ordered interstratification.
Fig. 3. Time–temperature integral curves as a function of depth and post-depositional time. Using the burial, geothermal and heat flux functions specified in Fig. 1, models show that burial depths of ~300 m and greater would convert smectite to non-detection.

Fig. 4. Time–temperature integral curves as a function of depth and post-depositional time (Fig. 3, with a change in the x-axis scale). According to this burial scenario, smectite buried to 1000 m would be converted to non-detection in ~480 Ma.
For our first look at lithification and diagenesis, we discussed three papers that trace the development of our historical understanding of diagenesis of clay-rich sediment on Earth and Mars. As the foundation of our understanding rests on an understanding of how clay minerals form and function, we began our discussion with a review of clay minerals, including the distinction between 7, 10 and 14 Å clays (1:1, 2:1, and 2:1+1 variations in the tetrahedral-octahedral structure) as well as the variation in dioctahedral and trioctahedral clays (the number of cations occupying the octahedral layer, with dioctahedral referring to two 3+ cations, typically Al\(^{3+}\) and Fe\(^{3+}\) and trioctahedral referring to three 2+ cations, typically Mg\(^{2+}\) and Fe\(^{2+}\)). We also discussed the interlayer cations and the water molecules associated with them to balance the charges, as these interlayers represent a location of structural change. Understanding the structure of these clays informed the methods used by Hower et al. (1976) and Chang et al. (1986) to conclusively track the smectite to illite and smectite to chlorite transitions in their cores, and thus informs our understanding of their seminal papers.

From this discussion of clay structures, we turned to the complexities of what actually occurs during diagenesis. Specifically, we noted that illite, the well-known product of dioctahedral diagenesis as established by Hower et al. (1976) and many others, is poorly understood – it is not a mineral, but a transitional material whose stability and formation mechanisms are unclear. Pointing out the uncertainty concerning illitization at the atomic level is a crucial concept, as it illuminates the difficulties associated with truly understanding clay mineral transitions and how they might be extrapolated. As a class, we established what is necessary for these transitions (S/I and S/C) to occur as a starting point for further thought – mass transfer, as cations must be supplied to the clays through water in order for the necessary chemical reactions to proceed. Thus, we suggested that permeability of the clays must exist to facilitate mass transfer. However, we also noted that an open system (via fluid flow) must not always be required, as CI chondrites possess serpentine despite the unique circumstances under which such a reaction must have taken place.

Following our exploration of what is and is not required for diagenesis, we used Tosca and Knoll (2009) as a starting point for discussion and debate over what is necessary for diagenesis in the martian system, and what is known about martian clays from spectral data. We discussed multiple proposals to transform clays in situ (without burial) in colder martian conditions, including ice-rock interactions and intermittently present thin films of water. While the class desired constraints on timescales and water quantity, consensus was reached that many unknowns continue to persist due to inherent difficulties in testing illitization and chloritization at lower temperatures. The larger factor of time required for the reactions forces us to extrapolate from higher-temperature experiments, which is unsatisfying but currently necessary. We also noted the problems with orbital data, as our interpretations of different clay minerals on the martian surface may be skewed by the affect certain ions have on the spectral signature (particularly Mg).

We ended our discussion in class with an exploration of the presence and consequences of life to diagenetic reactions, and the difficulties in applying the diagenetic pathways observed in terrestrial ocean basins to the processes affecting clays on the surface of Mars. The class agreed that such differences represent an area of confusion that may be difficult to alleviate with our current knowledge base and technology. Our understanding of these complex processes continues to be an area of growth, both in terrestrial and planetary science.