Formation of the ferruginous smectite SWa-1 by alteration of soil clays

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ABSTRACT

Clay minerals found in and near the surface of Mars contain unique information about the geochemical environment in the martian near-surface in the ancient past. To interpret this information, it is necessary to fully understand the environments in which different clay minerals form. Studies of terrestrial analog materials and environments are a useful way to address such questions, and some terrestrial materials are also important standards for remote sensing and in situ chemical and mineralogical analyses. This study presents new information on the formation environment of an unusual standard clay, the Clay Minerals Society source clay SWa-1 ferruginous smectite of Grant County. The SWa-1 collection locality is in the Columbia River Basalts (CRB), at the contact between a paleosol and a capping basalt flow. Features at the contact indicate the paleosol soil was wet when the capping flow was emplaced, that lava-sediment mixing occurred, and that both the soil and the capping lava were hydrothermally altered. The soil was hydrothermally enriched in Fe, Mn, and Si. The SWa-1 sample was collected from within the altered zone, suggesting it formed through alteration of paleosol clays by addition of Fe. Similar environments are widespread in the CRB, particularly at the plateau margins, suggesting that altered clays may occur frequently at lava-sediment contacts. Such environments are likely to occur wherever basalt flows are emplaced under warm, wet conditions promoting weathering—such as Mars >3.5 Ga before the present, when clay minerals were forming at its surface. This information has important implications for the use of clay compositions to inform clay formation environments on Mars.

Keywords: Nontronite, Mars, clay minerals, Columbia River Basalts, SWa-1

INTRODUCTION

Studies of martian meteorites first demonstrated the presence of clay minerals—likely of martian origin—in these samples beginning in the 1980s (Gooding et al. 1991; Bridges and Grady 2000; Bridges et al. 2001). However, major occurrences of clays on Mars were not confirmed until their detection by remote sensing (Poulet et al. 2005). Further studies showed that clay minerals are widespread in ancient martian rocks (Bibring et al. 2005, 2006; Mustard et al. 2008). These observations had dramatic implications for the climatic history on Mars, for they showed that ancient (>3.5 Ga) Mars must almost certainly have experienced periods of the warm, wet climatic conditions that promote rock weathering to clays. Some of the observed clays, particularly Fe-Mg smectites, may have formed by fluid alteration in the subsurface rather than at the surface, so the observed clay mineralogy may have implications for martian hydrologic cycling as well (Ehlmann et al. 2011a).

The types and compositions of clay minerals observed in ancient martian deposits vary, as do their potential environments of formation (Bishop et al. 2008; Ehlmann et al. 2008, 2011a, 2011b, 2013; Wray et al. 2008; McKeown et al. 2009; Murchie et al. 2009; Noe Dobrea et al. 2010; Bristow and Milliken 2011). Outcroppings of Fe-Mg smectites are widespread across the planet. More aluminous smectites also occur, as does kaolinite. At some localities, stratigraphic relationships are observed between clays of different compositions, suggesting the strata formed in specific types of environments. For example, layering of kaolinite or Al-smectites above Fe-Mg smectites could potentially indicate in situ clay development by basalt alteration in a pedogenic environment (Loizeau et al. 2007; Bishop et al. 2008; Mustard et al. 2008; Wray et al. 2008; McKeown et al. 2009; Murchie et al. 2009; Ehlmann et al. 2011b; Carter et al. 2015), whereas clays in obviously sedimentary deposits such as deltas suggest possible sedimentary transport and redeposition (Loizeau et al. 2007; Michalski and Noe Dobrea 2007; Ehlmann et al. 2008; Mustard et al. 2008; McKeown et al. 2009; Milliken and Bish 2010).

The crystal chemistry of martian clays is critical to these interpretations. For example, where weathering in pedogenic environments is proposed, this is based upon a model of progressive alteration of a mafic parent rock in which early weathering produces ferromagnesian smectites, and progressive leaching at the surface removes soluble components until only relatively aluminous phases remain. Application of this to a martian context requires a full understanding of terrestrial weathering and clay formation. As the surface of Mars is largely basaltic in composition, basalt weathering systems on Earth have been targeted as potential Mars analogs (Michalski et al. 2006; Ehlmann et al. 2012; Greenberger et al. 2012, 2015; Thomson et al. 2014; Yesavage et al. 2015).