The flat TiO_2 pattern in calc-alkaline rocks, reflecting early crystallization of Fe-Ti oxide, is also similar.

[36] The alkali abundances of surface type 1 and 2 are clearly subalkaline (Figure 2), although *Neksavil et al.* [2003] proposed that some SNC magmas were alkaline. Figure 9 shows the compositions of alkaline (anorogenic) lavas from the Nandewar volcano [*Abbott*, 1969; *Stolz*, 1985]. Although the Al_2O_3 and FeO* abundances are similar to calc-alkaline lavas, the Mars surface compositions are clearly distinguished from alkaline rocks by their SiO_2 and TiO_2 contents.

[37] By comparison with terrestrial magmas, it may be difficult to envision how hydrous melting and fractional crystallization could have happened in the absence of plate tectonics. Subduction of hydrated slabs provides the mechanism for adding so much water to the Earth's mantle. At present, Mars is a one-plate planet that convectively translates radioactive heat in the mantle through a stagnant lid [*Schubert et al.*, 2001]. However, some authors have proposed an early period of plate tectonics on Mars to explain various geomorphic features [*Sleep*, 1994; *Baker et al.*, 2002; *Fairen et al.*, 2002] and magnetic lineation patterns detected in parts of the ancient southern highlands [*Connerney et al.*, 1999; *Nimmo and Stevenson*, 2000], although there is little or no supporting evidence [*Pruis and Tanaka*, 1995]. Thermal models suggest that the stagnant lid model operating during the entire Martian evolution can more readily explain the volume and timing of crust formation than can a model of early plate tectonics followed by a stagnant lid [*Hauck and Phillips*, 2002; *Breuer and Spohn*, 2003]. Also, the preservation of early-formed isotopic anomalies in the mantle source regions of SNC meteorites [*Chen and Wasserburg*, 1986; *Borg et al.*, 1997; *Lee and Halliday*, 1997] would have been difficult during plate tectonic convection.

[38] In terrestrial subduction zones, the primary melts are basaltic, not andesitic, and andesites are produced primarily by fractional crystallization and assimilation of overlying silicic crust [*Rudnick*, 1995]. As a consequence, andesitic volcanism on Earth is mostly associated with thick, continental crust. Conversely, on Mars surface type 2 (possibly andesitic) materials overlie thin crust in the northern plains, whereas the thick southern highlands are overlain by surface type 1 (basaltic) materials. *Baker et al.* [2002] suggested that early subduction with attendant hydrous mantle melting on Mars produced a thick andesitic crust in the highlands. Later floods eroded the highlands andesitic crust and delivered these sediments to the lowlands, where they covered thinner oceanic crust. The highlands were subsequently mantled by younger, plume-related basalts. There are several potential problems with this scenario. First, it seems unlikely that large impacts into the highlands would not have excavated significant amounts of andesitic crustal stratigraphy to produce a mixed TES spectral signal. And second, even if surface type 2 is interpreted as weathered basalt (see below), our derived composition of surface type 1 materials in the highlands still suggests hydrous melting, unlike the tholeiitic compositions expected for plume basalts and seen in SNC meteorites.

[39] It is conceivable that hydrous melting of the Martian mantle might somehow have occurred without plate tectonics. There is precedence for this idea: *Rudnick* [1995] argued that the production of a part of the Earth's continental crust in the Archaean required a different mechanism than subduction, although the specific mechanism is unclear. *Lowman* [1989] proposed that an ancient andesitic crust could have formed on Mars through hydrous melting without plate tectonics. In his model, mantle water was thought to be primordial, leading to an early crust of andesite with later dry, basaltic volcanism. Early melts of a wet mantle would presumably scavenge water, leading to the dry mantle source region of younger SNC meteorites, as envisioned by *Waenke and Dreibus* [1988]. *Marsh* [2002] argued that terrestrial bimodal magmatism, leading to the production of siliceous melts from basaltic parent magmas, occurs through the formation of lenses within solidification fronts. However, it is not obvious that such a mechanism could operate on a global scale and produce volumetrically significant amounts of andesite.

4.2. Weathering of Basaltic Rocks

[40] Chemical weathering in the terrestrial environment almost certainly takes place under conditions different from Mars. However, *Nesbitt and Wilson* [1992] indicated that leaching of major elements from weathered volcanic rocks is not greatly influenced by primary mineralogy, bulk chemical composition, or climatic conditions, so it is plausible that tools developed for terrestrial weathering but applied to the Martian regolith may provide useful insights.

[41] Chemical weathering of terrestrial basaltic rocks typically leads to bulk depletion of leachable CaO, Na_2O, K_2O, and to a lesser extent MgO, relative to FeO and Al_2O_3. These depletions are illustrated by arrows in molar ternary diagrams (Figure 10) devised by *Nesbitt and Young* [1984] and *Nesbitt and Wilson* [1992]. The plotted positions of the new compositions from this study (X-boxes), as well as compositions based on previous deconvolutions, suggest that surface type 2 materials could have been produced by chemical weathering of surface type 1 basaltic andesite. Figure 10a shows that surface type 2 materials contain more Al_2O_3 than surface type 1, as appropriate for weathered materials, but they also contain slightly higher proportions of K_2O, the component most readily leached. The relative positions of surface type 1 and 2 materials in Figure 10b are also consistent with weathering. In Figure 10c, surface type 2 compositions are displaced toward higher Al_2O_3 relative to surface type 1, not directly away from the easily leached apex. This displacement might occur if iron was not already oxidized to the ferric state, which is the insoluble form [*Nesbitt and Wilson*, 1992].

[42] Only a modest degree of chemical weathering is required by these diagrams (the displacement is less than the lengths of vectors representing weathered terrestrial basalts in Figure 10; weathered terrestrial basalts commonly are shifted across the feldspar-FeO or feldspar-FeO + MgO joins). Incomplete weathering is in agreement with the limited proportions of clays and other alteration phases (<50%) in the deconvolved surface type 2 spectra of *Wyatt and McSween* [2002]. Alternatively, surface type 2 materials could consist of basaltic sand that has been physically mixed (on TES pixel scale) with chemically weathered materials. The surface type 1 composition might also