L14 The terrae < anorthosite, 4.3-4.5 Ga >

It's been a long way, but were here. [In spite of himself, his tears flowed.]
—Al Shepard of *Apollo 14* stepped off *Antares*' footpad, February 5, 1971.[1]

... that we would begin traveling to the Moon – and then stop. —Arthur C. Clarke, 1997.[2]

The terrae are Moon's highly cratered highlands of primordial lunar crust, 65-100 km thick as first measured using the seismic array placed on Moon's surface by *Apollo* mission astronauts (moonquakes due to Earth caused tides are often to Richter 5.5)[3] and again by analysis of gravity and topographic data collected in 1994 by the *Clementine* spacecraft that gave a measure everywhere of its thickness. The terrae rock is a compacted regolith of basalt breccia (formed at a time of heavy meteorite bombardment of the original lunar crust). Terrae rock samples are found in the majority to be composed almost entirely of the mineral anorthosite feldspar. Lunar anorthosite plagioclase is more calcic (>An90) than is the composition of this mineral in most terrestrial (Earth) anorthosites (An60-An40). Interstitial minerals are manganic olivine, manganic pyroxene, and chromic spinel.

Lunar petrologists picture Moon originating with an outer molten layer of basaltic composition. The lunar anorthositic crust is hypothesized to be coalescences of "rockbergs" (ferroan anorthosite) of mostly fractionally crystallized calcic plagioclase that, being less dense than the liquid, floated in the cooling "Lunar Magma Ocean."[4] But how precisely did the plagioclase originate? Bowen, to squelch a long held idea that magma differentiates originate as immiscible liquid fractions in a cooling magma, showed in 1928 that such do occur in some representative systems but at temperatures too high for natural of these systems in Earth's crust.[5] Thereafter, petrologists preferred to apply Bowen's fractional crystallization theory to sort out the origins of igneous rocks of various compositions on Earth.[6] However, in 1951, Edwin Roedder discovered a low-temperature immisciblity field in the fayalite-leucite-silica reactive system.[7] Basalts of plagioclase and pyroxene and no olivine (called *tholiites*), during crystallization, produce pairs of immiscible liquids as globules of one in the other (***Figure L14.1***). In amount, these liquids are a few percent in primitive mid-ocean ridge basalts to approximately 30% in iron-rich basalts. In 1979, Roedder found immisciblity of magma fractionation in many returned lunar samples.[8]

Radiometric dating of terrae samples, variously: anorthosite, olivine-plagioclase cumulate rock (troctolite), and norite; show these to have crystallized 4.3 - 4.5 Ga. In 2005, Hf-W (hafnium-tungsten) chronometry on lunar metals that are free of ^{181}Ta (which can be converted to cosmogenic ^{182}W) pins lunar magma ocean crystallization to 4.527 ± 0.010 Ga (an age consistent with giant impact hypothesis of Moon's origin (*see* Topic ***L15***) and, if so, the completion of the major stage of Earth's accretion).[9] ❑

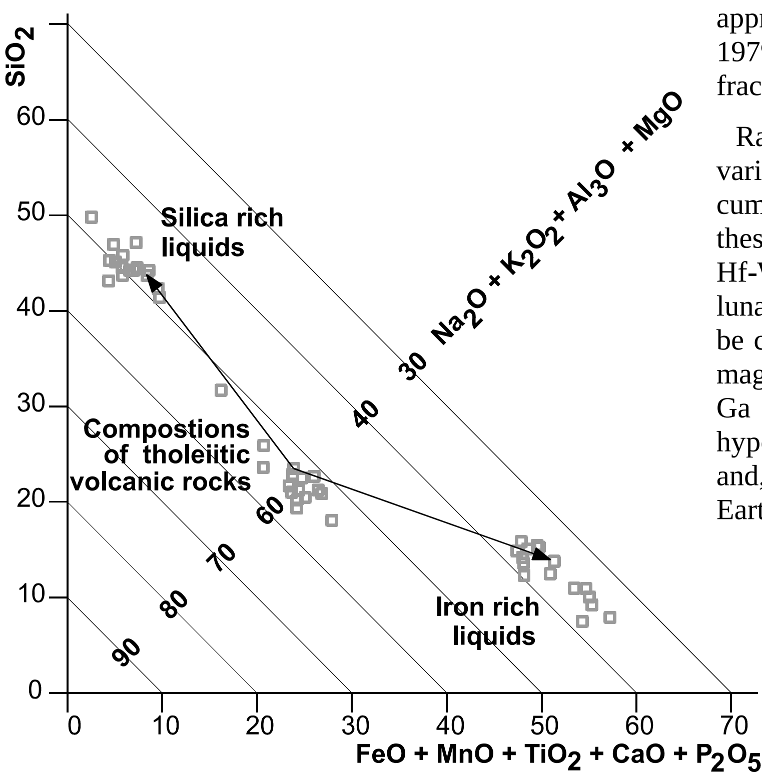

Figure L14.1 [10] Each of the 15 rocks plotted have glassy inclusions that preserve the composition of immiscible liquid pairs (as the arrows indicate for one).