individual fragments (which may once have been clasts in melt units). Most are in the Serenitatis melts, e.g., the dunite 72415, the large norite 77215 (from a meter-sized clast within the melt), and the gabbro in the station 6 boulder. Others occur as smaller clasts within the aphanitic melts, e.g., the norite clast and the granitic fragments in boulder 1, station 2. Among the individual rocks are the troctolites 76335 and 76535, and the samples of shocked and melted norites (78235) that represent a single meter-sized boulder. These pristine igneous rock fragments have produced radiogenic ages mainly in the range of 4.0 to 4.3 Ga, but some may date back to as much as 4.5 Ga. Conspicuously absent (or perhaps just extremely rare) are the ferroan anorthosites common at the Apollo 16 site and present at the Apollo 15 site.

Regolith breccias are uncommon among the massif samples, although some, including glassy breccias, do occur. The sampling bias toward coherent and boulder samples, and the steep slopes working against the production of lithified regolith, may be responsible for this lack. Furthermore, the South Massif landslide would have diluted the uppermost regolith (the source of regolith breccias) with fresher bedrocks, at least at that one location. Mare basalts are rare among the massif samples, even the rake samples, certainly not surprising in view of the downslope movement, including the landslide, at most of sampling sites. The regolith particles tend to reflect the larger rock types, with feldspathic granulites, poikilitic impact melts, and plutonic fragments recognizable. There is little dilution with mare components, and orange glasses are rare. The regolith samples from the North Massif are contaminated with mare basalt or volcanic glass (TiO_2 3% or 4%), but the purest regoliths from the South Massif have little mare contamination. They are only a little more aluminous than the average LKFM "Serenitatis" melt. However, they have only half the abundance of incompatible elements, demonstrating that the soil contains a much lower proportion of the "Serenitatis" or aphanitic melt than might be expected from the relative abundance among the larger rock, rake, and boulder samples. The component underrepresented in the rocks is not particularly anorthositic, but must be low in incompatible elements.

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IMPACT MELT BRECCIAS AT THE APOLLO 17 LANDING SITE.

Graham Ryder, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058-1113, USA.

Impact melt breccias are by far the most common highland rock type collected on the Apollo 17 mission. They tend to be fine grained, with virtually no clast-free impact melt rocks having been identified. All the highland boulders sampled are impact melt breccia, with the possible exception of one South Massif boulder that might have a friable matrix (but nonetheless consists dominantly of impact melt) and a shocked igneous norite boulder from the North Massif. The impact melt breccias were originally described as metaclastic, but their melt origin became apparent as work progressed [1,2]. Chemical compositions appear to allow natural groupings of the impact melt breccias. The present abstract relies in part on some new chemical analyses performed by the author (Fig. 1).

Most of the impact melt breccias are assignable to a single chemical group that is commonly accepted as being produced by the Serenitatis Basin event [1–3]. Most of these samples have crystalline groundmasses with fine- to medium-grained poikilitic matrixes. They dominate the rake samples and the boulders. Most of the remaining impact melt breccias are similar in chemistry to the dominant crystalline melts, but have distinctly higher Al_2O_3 and much lower TiO_2 [4–6]. Their compositions are not as uniform as the "Serenitatis" melts, and have some differences both within and among samples. They are also distinct in having aphanitic melt groundmasses and a greater abundance and diversity of lithic and mineral clasts. These aphanitic melts have been found only among samples from the South Massif.

Three other melt compositions are represented only by single samples: (1) 76055, more magnesian than the "Serenitatis" melts, and with lower incompatible element abundances [7,8]; (2) 72735, a high-K impact melt [9,10]; (3) a poikilitic clast in aphanitic melt 72255, similar to the "Serenitatis" melts but with higher alumina and lower incompatible element abundances [11].

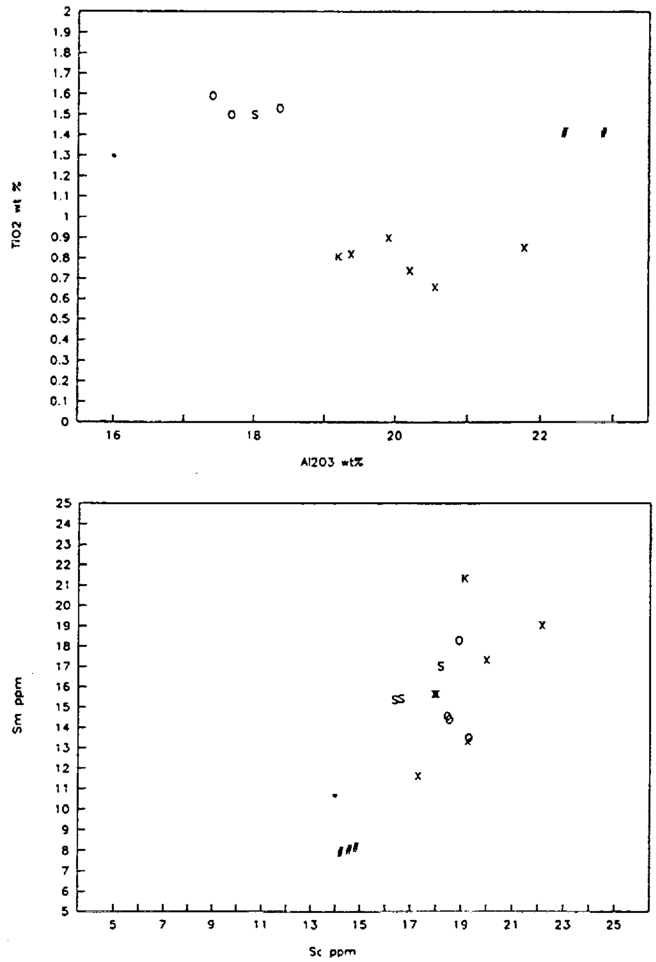

Fig. 1. Chemical analyses (TiO_2 v. Al_2O_3; Sm v. Sc) of impact melt rocks acquired in 1992 by the author, using INAA and fused beads (except 76055 = *, data of [8]). O = "Serenitatis" melt rocks, previously analysed. S = Serenitatis melt rocks, previouslyt analyzed but reanalyzed by INAA. X = 72255 aphanitic melt phase. # = 72255 poikilitic clast. K = 72735 high-K melt rock.

The only other impact melt samples from the Apollo 17 highlands (apart from glass formed by shallow-level recent impacts) are probably the troctolitic basalts found as clasts in some of the aphanitic rocks [e.g., 4]. A second high-K impact melt breccia proposed by [9] was not confirmed in the present analyses; instead, sample 72558 appears to be a typical "Serenitatis" melt.

A discussion of the origin of the aphanitic melt rocks and the "Serenitatis" poikilitic melt rocks was given by [3]. The poikilitic rocks have a lithic clast population limited almost entirely to plutonic igneous rocks such as norites and feldspathic granulites. The aphanitic rocks were faster-cooled, and contain a greater proportion and variety of lithic clasts; these clasts include surficial types such as impact melt and basalts, and felsite or granite clasts are common. The aphanitic rocks have accretionary and "bomb" characteristics; they are consistent with derivation from a much shallower target than the "Serenitatis" melts. Nonetheless, the targets were similar except that the shallower one was more aluminous and less titanian. The two groups could have been formed in the Serenitatis event, but in that case intermediate compositions might have been expected as well. Neither formed in a significant melt sheet, as they all contain conspicuous clasts and have fine-grained groundmasses. Even in the coarser melts, the clasts have not well equilibrated with the groundmass, even for argon [12]. Indeed, the aphanitic melt rocks do not show argon plateaus; their age is based on degassing of felsite/granitic clasts and is close to 3.86 or 3.87 Ga [13,14]. Clasts in the poikilitic rocks also compromise the melt age, although the best examples again suggest 3.87 Ga, presumably the age of the Serenitatis event [15,16]. Melt rocks with a composition very similar to either the "Serenitatis" melts or the aphanitic melts have not been found among Apollo 15 samples on the opposite side of the Serenitatis basin [17].

Sample 76055 has an older age, with a plateau that seems reliable at 3.91 Ga [18]. The sample is clast-poor (though not clast-free). The other two samples (72255 clast and high-K 72735) have not yet been dated, but are included in a laser Ar-Ar analysis in progress [17]. Samples of the "Serenitatis" and aphanitic melts are also included in the Ar study in an attempt to confirm and refine the age of Serenitatis and the possible relationships among the impact melt groups, as well as characterize the impact history of the Moon.

The characteristics of impact melt rocks are derived from the melt volume produced by the impact, from the clastic material entrained and picked up as the melt moved away from its source, and by the cooling environment. The characteristics can thus provide information on the lunar crust at and around the target site. Differences in composition of melt rocks can be interpreted as vertical or horizontal (or both) variations in crustal composition. Lithic and mineral clasts can be used to define the source rocks. The Apollo 17 impact melts suggest some variation in targets. The crust may be richer in titanium and poorer in alumina at greater depth. The deeper sampled parts seem to consist of pristine igneous rocks, particularly norites and troctolites, and some feldspathic granulites, whereas the shallower part has a greater complement of granitic/felsitic rocks and near-surface lithologies such as basalts, impact melts, and breccias. The lower part does not seem to consist of mixed megaregolith, but some components of the melt are as yet chemically unexplained.

The melt population sampled by the boulders and rake samples is not representative of the massifs, which contain more alumina and lower abundances of incompatible elements. The soil composition suggests a maximum of 50% of either "Serenitatis" melt or aphanitic melt as a component. There is probably a bias in that coherent material, particularly large boulders, is likely to be a late unit, such as melt produced in Serenitatis; pre-Serenitatis material presumably exists as smaller blocks within the ejecta pile forming the massifs.

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APOLLO 17: ONE GIANT STEP TOWARD UNDERSTANDING THE TECTONIC EVOLUTION OF THE MOON. Virgil L. Sharpton, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058, USA.

The Moon's landscape is dominated by craters and large multiring impact basins that have obliterated any morphological evidence of the surface and interior processes occurring in the first few hundred million years of lunar history. By ~4.0 Ga, the lunar lithosphere was thick enough to support loads imposed by basin formation and mare infilling without complete isostatic compensation [1,2]. Most of the lunar tectonic features developed since that time are local in scale, and are associated with vertical deformation in and around mare basins. These features include (1) tectonic rilles, or graben, located along the margins of major mare basins, such as Serenitatis; (2) wrinkle ridges of compressional origin located primarily within the mare units; and (3) mare topography [3,4] developed via flexure and in part controlled by basin substructure. The relative ages and spatial arrangements of these features are explained by flexure of the lunar lithosphere around mascon basins in response to volcanic loading and global cooling [1].

Our present understanding of the tectonic history of the Moon has been shaped in large measure by the Apollo program, and particularly the Apollo 17 mission. The landing site, in the Taurus-Littrow valley on the southeastern flank of Mare Serenitatis, allowed extensive examination of the tectonic expression within and around the southern portion of Mare Serenitatis from the CSM orbiting overhead. Serenitatis is particularly well suited for understanding the tectonics of basin loading because its volcanic stratigraphy is conspicuous and reasonably simple [e.g., 3], and numerous tectonic features are developed on and around the mare. The Scientific Instrument Module included the Apollo Lunar Sounder Experiment, which was designed to detect layering in the upper few kilometers of the Moon [5,6]; these data have placed important constraints on the size of the volcanic load and the lithospheric response [1,4–6].

Astronauts on the surface in Taurus-Littrow valley made detailed observations of the Lee-Lincoln scarp and other structures encountered along their extensive traverses. They also made gravity measurements and conducted seismic profiling to constrain the geometry of the subfloor basalts [7]. These data, in conjunction with the samples returned to Earth, permit a far clearer understanding of the origin and evolution of this key valley and its relationship to Mare Serenitatis. In this brief paper, I attempt to summarize some of the interpretations that have emerged since Apollo 17, focusing on some of the problems and uncertainties that remain to stimulate future exploration of the Moon.