PIERCING THE CLOUDS: THE STRATIGRAPHY OF MARE NUBIUM. Danielle E. Rose, Dept. of Geology, Southern Oregon University, Ashland, OR 97520, bronzemongoose@moriah.com; Paul D. Spudis, Lunar and Planetary Institute, Houston, TX 77058, spudis@lpi.usra.edu

Even before samples were returned to Earth, geologists had correctly concluded that the smooth, flat surfaces of the lunar maria were the result of fluid, basaltic lava flows [1]. Determining the sequence, duration, and composition of lava flows in the maria allow us to reconstruct the volcanic history of the Moon. Such studies are important for understanding lunar thermal history and planetary bulk composition. Mare Nubium is located in the south-central region of the near side. An area from 0-30° S and 0-30° W was examined using the multispectral data obtained by the Clementine mission in 1994. We have mapped the stratigraphy of Mare Nubium using these and other data to reconstruct the volcanic history of this region of the Moon.

METHOD Clementine data is processed using ISIS software from the USGS [9]. Mosaics are constructed in three spectral bands at the 950, 750 and 415 nm wavelengths. These images are used to make color composites that permit unit mapping. In addition, we mapped iron and titanium content using the techniques of the Hawaiian group [2, 3]; this processing removes the maturation effects that interfere with the compositional dependence of spectral reflectance, and, in conjunction with data from sampled sites on the Moon, permits iron and titanium mapping of regional areas at full resolution (200 m/pixel).

RESULTS Mare basalt flows were mapped on the basis of color and titanium differences (Figure 1). Because the Apollo samples were remarkable for their relatively high titanium content and variation [8], and because titanium can be determined by spectral reflectance [3], mare basalts are arbitrarily broken down into categories by titanium content. All of the flows in Mare Nubium fall into the low-Ti category, and are further subdivided into “low” and “medium” titanium flows. We have identified five compositionally distinct units (Table 1) in Mare Nubium. In some areas the mare surface was obscured by prominent ejecta and rays from large, post-mare craters. For each mapped flow, cumulative crater densities (D > 500 m) were measured on Lunar Orbiter IV photos. These densities were compared to those of the Apollo sites, where we have dated samples from which to estimate their absolute ages (Table 1). On the basis of estimates from these dated Apollo samples, the Nubium flows range in age from about 3.0-3.7 Ga.

To determine the lava flow thickness, each flow was examined for craters that have ejecta lower in iron than the surrounding lava. Such ejecta indicates that the crater has “punched through” the high-iron lava and into the low-iron, anorthositic highland material below [8]. We used a simple cylindrical model of the crater excavation cavity in which the depth of excavation equals 1/10 the observed diameter, values in accordance with those estimated from various cratering studies [8]. The fraction of a high-iron component seen in each crater ejecta blanket is converted into an equivalent thickness of lava at each target site. These data were contoured into an isopach map to show basalt thickness variation and to represent the topography of the underlying Nubium basin floor. From this map, we computed the volume of mare lava by finding the area (or combination of multiple areas, in this case) enclosed by each isopach, and multiplying that area by the 0.1 km interval to produce the volume in cubic kilometers. (This procedure subtracted the scattered islands of highland material within the basin.) Once the volume of each interval was tabulated, the overall volume of the mare was calculated. Mare Nubium consists of approximately 111,000 km^3 of lava. For the entire region, the volume of crust (based on an average 60 km crustal thickness) is ~48×10^6 km^3. Thus, although Mare Nubium covers 45% of the area studied, it represents only 0.2% of volume of the crust in the area. Such a small fraction is consistent with volumes estimated for mare basalt in the crust globally [4].

The eruptions in the Nubium basin lasted about 700 Ma, yielding a magma production rate of 1.6×10^{-4} km^3/a; rates for whole Moon during the late Imbrian is estimated at 150×10^{-4} km^3/a [4]. Either Mare Nubium was unusually quiescent or the estimates of [4] are anomalously high. For comparison, the current magma eruption rate for the individual terrestrial volcano Kilauea is 1.7×10^{-2} km^3/a [4].

CONCLUSIONS Mare Nubium has undergone a prolonged and complex volcanic evolution. Multiple flows of different age and composition have resurfaced the basin floor, and although the flows in Nubium are prominent, they are thin, in accordance with a variety of previous studies [5, 6, 7]. On the basis of the age and volume estimates presented here, the Moon, while volcanically "active" more than 3 billion years ago, was orders of magnitude below the levels of geological "activity" observed on Earth. Vast periods separate each mare flow in Nubium and the picture of lunar volcanism derived from this work suggests rapid, effusive eruptions of high volume flows, possibly lasting only a few weeks or months, followed by extended periods of dormancy. The techniques and approaches followed here can be profitably applied to other lunar maria, allowing us to decipher the complex story of lunar volcanic history on a global basis.

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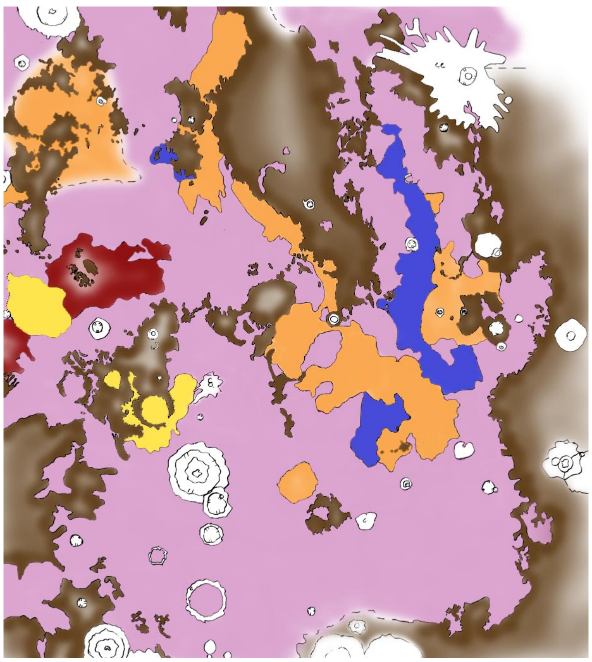

FIGURE 1 – Geologic map of Mare Nubium. Browns are highlands, outlined or white areas are craters and ejecta. L_1 and L_2 flows are in orange, M_1 is yellow, M_2 is blue, M_3 is deep red and M_4 is the light purple that covers most of the region See Table 1 for unit properties.

TABLE 1: Mare Nubium Flow Data

UNIT	CRATER DENSITY	AGE*	COMPOSITION		THICKNESS (m)			EXPOSED AREA
	N/km^2 (10^{-2})	*Ga*	*FeO*	*TiO$_2$*	*Min.*	*Max.*	*Avg.*	*km^2*
L_1	7.6 ± .28	3.7	22%	3.5%	70	460	260	41,000
M_1	6.6 ± .26	3.5	22%	5%	200	630	380	10,000
M_2	6.5 ± .25	3.5	23%	6.5%	130	295	230	20,000
M_3	6.4 ± .25	3.5	23%	6%	360	840	480	12,500
L_2	5.4 ± .23	3.4	22%	3%	400	430	415	2,000
M_4	3.8 ± .19	3.0	22%	5%	70	1340	380	275,000

* Ages interpolated from known Apollo sample dates: Apollo 11, 3.7 Ga with a crater density (N/km^2) of 8.0 x 10^{-2}; Apollo 15, 3.3 Ga with a crater density of 5.0 x 10^{-2}; Apollo 12, 3.1 Ga with a crater density of 4.5 x 10^{-2}.