LUNAR MINERAL MODAL ABUNDANCES FROM DIGITAL PETROGRAPHIC THIN SECTIONS. S.E. Braden[1] and M.S. Robinson[1], [1]Northwestern Univ., Center for Planetary Sciences, 1850 Campus Drive, Evanston IL, 60208.

Introduction: Typical methods of estimating mineral modal abundances from Apollo rock samples include optical point counting, electron microprobe techniques, and X-ray fluorescence [1]. Optical point counting directly estimates modal mineral abundances from thin sections. Electron microprobe analysis (EMPA) and X-ray fluorescence (XRF) measure chemical composition. The wt% oxides of the analysis are then fed into CIPW normative calculations to indirectly estimate mineral abundances.

Ideally, all existing lunar sample material would be thoroughly characterized and geospatially located to maximize their scientific utility. The Apollo samples are used by petrologic, cosmochemical, engineering, and remote sensing communities (among others) for a wide variety of investigations. Development of fast and accurate methods of obtaining mineral modal abundances, compositional, and grain size information would thus serve a broad range of scientists.

We are investigating the efficacy of controlled threshholding techniques from digital 3-color (RGB) scans of thin section photomicrographs to derive mineral modal abundances (Table 1) from which we derive oxide abundances (specifically TiO_2). To build confidence in this technique we examined thin sections from samples previously characterized by traditional techniques, allowing us to place error bounds on our estimates. Initially we are focusing on opaque minerals (assumed to be ilmenite) from Apollo 17 basalts. Also, we estimated the average opaque grain size of each rock sample by measuring the longest diameter of approximately 150-200 opaque grains in each photomicrograph. The largest diameter serves as a proxy for the average grain size because grains are typically randomly oriented within a sample. The grain size estimates are precise to ±10 microns within a single slide view and ±40 microns between multiple views of the same section. A portion of the imprecision may be due to natural grain size variation within a sample.

Methods: We scanned more than 6000 lunar thin section photomicrographs (35-mm Kodachrome originals prepared by H. Wilshire USGS) and created a searchable online database to aid the rapid identification and distribution of the digital image files. Slides were scanned at a resolution of 2,400 pixels/inch (Nikon Super Coolscan 4000) and 16-bits per color (RGB). The photomicrograph collection [2] contains plane and polarized light images of samples from all the Apollo sites and the Soviet Luna 16 site.

Grains (opaques, pyroxene, olivine, glasses, and plagioclase) were identified manually, and the boundary of each grain was automatically identified using controlled thresholding on the three RGB components of a plane polarized light image; cross-polarized light images were used to confirm mineral identifications. In the case where multiple photomicrographs exist from the same rock, the area percents for each photomicrograph were averaged as an estimate for the whole rock. TiO_2 wt% was estimated from area percent by: 1) assuming that opaque minerals are all ilmenite, 2) ilmenite is approximately 47.3% FeO and 52.7% TiO_2 (from atomic weights), 3) that area percent serves as an accurate estimator of volume percent, and 4) using a range of estimated mineral densities (densities in g/cc: TiO_2 4.26, FeO 5.7, pyroxene 3.2 - 4.0, plagioclase 3.6 – 3.8, olivine 3.2 – 4.4, glass is <1%). The "volume" percent multiplied by the estimated densities for each mineral (or oxide in the case of ilmenite) yielded the weight. Then the wt% of TiO_2 = (wt of TiO_2) / (total wt of minerals in the thin section).

Results: For typical samples our TiO_2 estimates from the digital slides match the analytical TiO_2 values published in [3] (EMPA, XRF) to within 2 wt% (average difference 1 wt%, standard deviation 0.7, n=12). In many cases the analytical TiO_2 values have a range that varies ±2 wt%, which, if we assume the analytical measurements have very small error, can be attributed to natural variation in the rock.

Repeat measurements of the same slide indicate that the mineral modal estimates have a reproducibility of one percent.

Four of our TiO_2 estimates have significantly higher values than the laboratory values (Table 2). These four samples each have relatively small average grain sizes (32-100 microns), since opaques completely block light, a thin opaque grain can block out all other grains above or below it in the thin section, resulting in an overestimate of volume.

To quantify the magnitude of TiO_2 abundance error due to small grain sizes, we modeled a thin section with a thickness of 30 microns, grain size of 6 microns (cubic grain), and a volume percent of 10%. We found the resulting apparent area percent to be ~40%. This small grain size effect results in overestimation of TiO_2 wt% in rock samples with grain sizes smaller than the thickness of the slide (30 microns). As grain sizes increase above 30 microns this error decreases.

Three (70215, 74275, and 76136) of the four noted rock samples have 15%-62% of grains smaller than 20 microns. The fourth sample (74235) has only <1% of the grains < 20 microns. Thus, small opaque grain size cannot be held responsible for this discrepency. This sample does have an anomalously low pyroxene (26%) content compared to the rest of the basalts, which range from 42-57% pyroxene. It is possible (probable) that this section does not represent the bulk mineralogy of the rock.

Conclusions: Digital analysis of high quality scans of lunar petrographic thin sections return useful mineral modal, compositional, and grain size estimates. Our initial work with the Apollo 17 thin sections indicates that the TiO_2 abundance estimates are accurate to about 1 wt% for rocks with grain sizes greater than ~60 microns.

Although the majority of the larger lunar rocks have been geochemically characterized, future geochemical studies could benefit from detailed analysis of TiO_2 wt% variations within a single rock specimen (from multiple thin sections) as well as smaller uncharacterized rocks. There is a paucity of modal analyses of lunar rocks and an abundance of readily available digital thin sections, thus future petrographic studies could benefit from digital modal analyses. Finally, only a few studies report average mineral grain sizes for lunar rocks - digital image analyses could easily and rapidly provide such estimates. Next we will apply digital modal analysis to photomicrograph digital scans from Apollo 11 and 15 rocks to increase confidence. Apollo 11 basalts are high in TiO_2 like the Apollo 17 basalts, but more compositionally diverse, and the Apollo 15 basalts have intermediate to low TiO_2 levels, so if the method remains accurate with these rocks, then it will be shown to be applicable to a large range of basalt types.

Rock sample	opq	plag	px	ol
70017	20%	19%	53%	1%
70035	21%	19%	53%	0%
70135	20%	18%	48%	0.50%
70149	23%	20%	48%	2%
70215	34%	10%	43%	6%
70275	19%	19%	44%	4%
72135	27%	4%	42%	6%

Table 1. Modal mineral abundances of seven rock samples derived with digital modal analysis (glass is <1%)

References: [1] Heikin et al. (1991) *Lunar Sourcebook*, Cambridge Press;
[2] http://cps.earth.northwestern.edu [3] Catalog of Apollo 17 Rocks, JSC Publication 26088.

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Rock sample	# of views	# of sections	opaque area %	TiO_2 wt% (digital slide analysis)	TiO_2 wt% range from [4]	Δ TiO_2	opaque grain size* (microns)
70017	8	7	20%	12%-14%	12% - 14%	0	200
70035	12	4	21%	13%-15%	13%	1	220
70135	1	1	20%	13%-15%	13% - 14%	0.5	223
70149	10	1	23%	14%-16%	N/A	N/A	217
70275	1	1	19%	13%-14%	12%	1.5	208
71055	1	1	19%	12%-14%	12% - 14%	0	246
71135	1	1	21%	12%-14%	11%	2	264
71569	2	1	17%	11%-13%	12% - 13%	0	78
74255	3	1	15%	10%-12%	12% - 13%	-1.5	96
75035	1	1	15%	9%-11%	9% - 10%	-1	217
75055	7	2	17%	11%-12%	10%	1.5	214
75075	2	1	23%	13%-15%	13%	1	140
78505	6	2	19%	12%-14%	12%	1	244
79155	3	1	23%	14%-16%	13%	2	N/A
70215	*9*	*1*	*34%*	*20%-22%*	*13%*	*8*	*32*
74275	*2*	*1*	*29%*	*17%-19%*	*9% - 13%*	*7*	*70*
76136	*4*	*1*	*27%*	*17%-19%*	*13%*	*5*	*100*
74235	*2*	*1*	*27%*	*18%-21%*	*12%*	*7.5*	*100*

Table 2. Summary of results, multiple *views* of the same *section* are common within the Wilshire collection. Italicized samples have lowest accuracy in derived TiO_2, and are discussed in the text.