THE POROSITY OF METEORITES AND ASTEROIDS: RESULTS FROM THE VATICAN COLLECTION OF METEORITES. D. T. Britt[1] and G. J. Consolmagno S.J.[2], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721, [2]Vatican Observatory Research Group, Steward Observatory, University of Arizona, Tucson AZ 85721

Spacecraft determined densities exist for Ida (2.6 ±0.5), Phobos (1.53 ±0.1), and Deimos-(1.34 ± 0.83). These data have been used to suggest possible candidate compositions for these bodies and asteroids in general. We have begun a systematic measurement of densities and porosities of meteorites, including types never before measured, starting with 40 meteorites from the Vatican Observatory collection. Our technique utilizes a modified Archimedean method (non-contaminating 40 micron glass spheres substituting for a fluid) to determine bulk density and a custom helium pycnometer to determine grain density and thus porosity. Our results have significantly increased the meager knowledge of meteorite density and porosity.

Our measurement of Orgueil (CI) produced the lowest bulk density of any meteorite at 1.6 g/cm^3.The bulk density of Orgueil (CI) is 1.6 g/cm^3 and the grain density comes in at 2.1 g/cm^3, for a porosity of 25% (the full set of data obtained at the Vatican Collection is summarized in **Table 1**). This is about 0.5 g/cm^3 lower than the previous lowest meteorite bulk density measurement. Since the sample was relatively small we did twice the usual number of measurements to be sure of getting good data. This is a very fragile rock (more like a dried dirt clod or a piece of charcoal than a stone). Interestingly, the bulk density is coincident with recent estimates of the bulk density of Phobos. The porosity of individual carbonaceous chondrites can vary significantly from sample to sample. Other carbonaceous chondrites measured include Ornans (CO3), bulk density 2.36 ± 0.03; Allende (CV3), bulk density 2.92 ± 0.01, porosity 21 ± 2%; and Vigarano, (CV3) bulk density 3.18 ± 0.04. Porosities of ordinary chondrites rarely exceed 15%, and show a systematic decrease with weathering. There appears to be no correlation between porosity and petrographic type. Mesosiderite bulk densities range from 4 to 4.5, and pallasites cluster around 5.0, in the limited sample measured to date.

Densities vary from sample to sample of the same meteorite, on a scale of several hundred grams. Some samples such as Agen are very homogeneous while others like McKinney or Morristown are clearly not. In iron meteorites the variation in grain and bulk densities are probably due to the presence or absence of sulfide or other inclusions. In ordinary chondrites this probably indicates variations in porosity and/or metal content.

The porosity/bulk density of ordinary chondrites types fall along predicable trend lines. For ordinary chondrites the bulk density and the petrologic type can be used as a predictor of the porosity. Since the petrologic type is a function of mineralogy the types fall along trend lines that have a zero porosity at the average grain density and have a Y-intercept at 100% porosity. For asteroid missions if the composition and bulk density are known from remote spacecraft measurements (i.e. XRF or IR-spectra for composition, orbital tracking and shape models for bulk density), then we can estimate the porosity (and thus its internal structure) from where the bulk density plots on the appropriate trend line.

There appears to be no correlation between metamorphic grade and porosity. This conclusion holds true whether you sort merely by metamorphic grade, or pre-sort by chondrite class. If the metamorphic grade represents the meteorite's depth of burial inside the original parent body, it appears that the burial did not significantly effect the porosity.

Most meteorites are substantially denser than the few asteroid bulk density measurements. Most asteroids must have significant macro-porosity. The three asteroid-like bodies with the best measured bulk densities are Ida (2.6 0.5 g/cm3), Phobos (1.53 0.1 g/cm3), and Deimos (1.34 0.83 g/cm3). All these bulk densities are significantly below the range for their suggested meteorite analogues. The exception is our new measurement of Orgueil which brings the range of carbonaceous chondrites much closer to the values for Phobos. The implication is that most asteroids much have significant macro-porosity (porosity in large fractures or voids) and regolith porosity. What we measure in meteorites is micro-porosity which are voids and cracks on the scale of 10's of microns. Asteroidal macro-porosity may be on the order of >20% and indicates that many of these bodies are loosely packed rubble piles. The implication is that bulk density by itself cannot be used as a diagnostic tool to characterize the composition of asteroids.

Terrestrial weathering reduces porosity without changing bulk density. We measured four ordinary chondrite finds: Hermitage Plains (L6), Kermichel (L6), Ness County (L6), and McKinney (L4). Their bulk and grain densities were almost identical giving near zero porosity. Interestingly, their grain densities are below the average for L-chondrites while the bulk densities are about average for the group. This suggests that the process of terrestrial weathering fills-in the pore space of the meteorite with less dense weathering products like iron oxides and clays.

Listed below are the results of our measurements at the Vatican Collection. The samples are identified by name and type. Where there were multiple individuals of the same meteorite, the data lists the averages of all the individuals. The table lists the grain density (the density of the solid material), the bulk or average density including porosity, and the porosity of the sample.

TABLE 1: Results of Vatican Collection Measurements

Sample Name	Type	Fall/Find	Date	Mass	Grain ρ	+/-	Bulk ρ	+/-	Porosity	+/-
Agen (average of 3)	H5	fall	1814	1660.3	3.74	0.01	3.33	0.01	10.9%	0.4%
Allende	CV3	fall	1969	168.5	3.68	0.08	2.92	0.01	20.8%	2.3%
Augustinovka	Oct IIIB	find	1890	1198.8	7.35	0.09	6.99	0.09	5.0%	1.7%
Bath (average of 2)	H4	fall	1892	633.9	3.63	0.03	3.42	0.01	5.9%	0.9%
Brenham (average of 3)	pall	find	1882	480.92	5.32	0.13	4.97	0.08	6.6%	2.8%
Bur-Gheluai	H5	fall	1919	1286.6	3.65	0.02	3.53	0.01	3.2%	0.6%
Canon Diablo (average of 2)	Oct IA	find	1819	949.5	7.71	0.14	7.38	0.05	4.3%	1.9%
Crab Orchard (average of 3)	meso	find	1887	967.9	4.32	0.03	4.20	0.02	2.7%	0.8%
Farmington (average of 4)	L5	fall	1890	994.9	3.51	0.04	3.32	0.02	5.5%	1.4%
Finmarken	pall	find	1902	321.3	4.98	0.20	4.82	0.08	3.3%	4.4%
Glorieta Mts (average of 5)	Oct	find	1884	1003.5	7.69	0.14	7.59	0.08	1.3%	2.0%
Hermitage Plains	L6	find	1909	498.8	3.34	0.05	3.29	0.02	1.4%	1.5%
Homestead (average of 3)	L6	fall	1875	1936	3.56	0.01	3.35	0.01	6.0%	0.5%
Indian Valley	Hex IIA	find	1887	576.9	8.35	0.23	7.23	0.08	13.4%	2.9%
Juvinas	Euc	fall	1821	212.5	3.37	0.09	3.03	0.01	10.2%	2.8%
Kermichel (average of 2)	L6	find	1911	647.9	3.36	0.03	3.27	0.01	2.9%	1.0%
Knyahinya (average of 3)	L5	fall	1866	597.7	3.40	0.03	3.35	0.01	1.5%	0.9%
Mangwendi	LL6	fall	1934	92.2	3.18	0.19	3.15	0.01	1.0%	5.9%
McKinney (average of 6)	L4	find	1870	1055.1	3.46	0.02	3.45	0.04	0.3%	1.1%
Mincy (average of 2)	meso	find	1857	484.6	4.47	0.07	4.21	0.05	5.9%	1.9%
Mocs (average of 6)	L6	fall	1882	490.2	3.51	0.04	3.14	0.01	10.6%	1.4%
Morristown (average of 3)	meso	find	1887	1318.5	4.24	0.02	4.22	0.02	0.6%	0.7%
Nakhla	SNC	fall	1911	153.5	3.31	0.11	3.10	0.02	6.3%	3.4%
Ness County	L6	find	1894	697.3	3.37	0.03	3.35	0.01	0.5%	0.8%
Ochansk (average of 3)	H4	fall	1887	1419.6	3.70	0.02	3.22	0.01	13.0%	0.6%
Odessa (average of 2)	Oct IA	find	1921	571.7	7.17	0.17	7.15	0.03	0.4%	2.4%
Orgueil	CI	fall	1864	47.2	2.12	0.17	1.58	0.01	25.8%	8.4%
Parnallee	LL3	fall	1857	88.9	3.27	0.21	3.16	0.01	3.3%	6.4%
Pultusk (average of 4)	H5	fall	1868	860.4	3.65	0.03	3.41	0.02	6.6%	0.9%
Santa Cat (average of 6)	Atx	find	1875	668.1	4.80	0.09	4.01	0.03	16.4%	2.0%
Scottsville	Hex IIA	find	1867	489.4	7.72	0.47	7.51	0.04	2.7%	6.1%
Tamentit	Oct IIIA	find	1864	576.8	7.47	0.15	7.54	0.02	-1.0%	2.0%
Torino (average of 2)	H6	fall	1988	201.6	3.97	0.14	3.30	0.01	16.8%	3.7%