WHAT ARE THE P-TYPE ASTEROIDS MADE OF? T. Hiroi[1], C. M. Pieters[1], M. J. Rutherford[1], M. E. Zolensky[2], S. Sasaki[3], Y. Ueda[3], and M. Miyamoto[3], [1]Dept. of Geological Sci., Brown University, Providence, RI 02912 (takahiro_hiroi@brown.edu), [2]SN2, NASA Johnson Space Center, Houston, TX 77058, [3]Dept. of Earth & Planetary Sci., University of Tokyo, Tokyo 113, Japan.

Introduction: The P-type asteroids [1], together with the D asteroids, had been believed to be one of the most primitive asteroid classes having surface materials rich in carbon and/or organics [2]. Upon a fall of a new type of meteorite, Tagish Lake in 2000, we came to have a possible sample of the D (and/or T) asteroids [3]. In both spectrally and distance from the sun, the P asteroids are located in between the C/G/B/F asteroids and the D asteroids. Because it is believed that the former group are similar to (thermally metamorphosed) CI/CM chondrites [4] and the latter the Tagish Lake meteorite [3], the surface material of the P asteroids may be understood in combination of those two meteorite groups. Taking that direction, this paper presents possibly the first quantitative characterization of the P asteroids in terms of carbonaceous chondrites and their experimental derivatives.

Experimental and Data Acquisition: Fragments of relatively unaltered portion of the Tagish Lake meteorite were put in a vacuum sealed glass with an oxygen eater and heated at 100°C for one week to simulate thermal metamorphism in the parent body. They were then ground into a powder sample of <125 µm in particle size. Another powder sample of the Tagish Lake meteorite (<125 µm) was pressed into a pellet of diameter 1 cm and thickness 0.5 mm and irradiated with pulse-laser at 5 mJ energy level to simulate space weathering in the same way as in [5]. Bidirectional reflectance spectra of these samples together with the untreated Tagish Lake meteorite sample were measured at 30° incidence and 0° emergence angles from 0.3 to 2.5 µm using the Relab facility at Brown University. Reflectance spectra of heated Murchison (CM) meteorite samples [4] and Vicuña (CI) meteorite samples [6] were taken from the Relab Database. Visible and near-IR reflectance spectra [7, 8] and the IRAS albedo data [9] of five P-type asteroids are compiled here.

Comparison of Reflectance Spectra: Shown in Fig. 1 are telescopic reflectance spectra [7, 8] of five P asteroids studied in this paper. After scaling them to the IRAS albedo [9] at 0.55 µm, their average spectrum was calculated with some binning treatment of close wavelength bands. While they are similarly feature-poor, the continuum redness varies among them, and 153 Hilda has a unique, near-flat spectrum in the shorter visible range (0.34-0.55 µm).

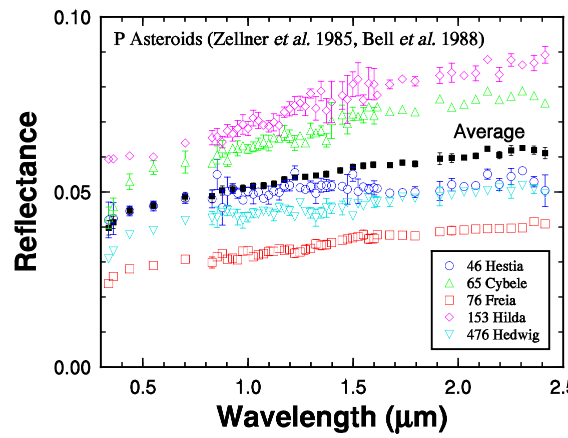

Fig. 1. Telescopic reflectance spectra [7, 8] of five P-type asteroids 46 Hestia, 65 Cybele, 76 Freia, 153 Hilda, and 476 Hedwig (open symbols), and their average spectrum (filled square). They are scaled to match the IRAS albedo [9] at 0.55 µm.

Shown in Fig. 2 are the P asteroid average reflectance spectrum and laboratory reflectance spectra of samples of Murchison (CM) meteorite including the heated ones at 400-1000°C [4], samples of Ivuna (CI) meteorite including the heated ones at 100-600°C [6], and samples of Tagish Lake meteorite including the ones heated at 100°C and irradiated with pulse laser.

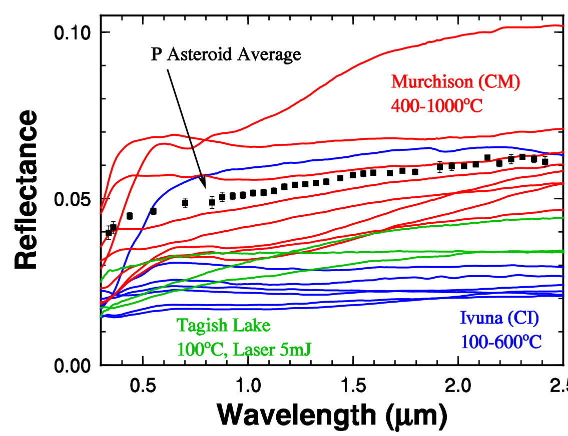

Fig. 2. Laboratory reflectance spectra of Muchison (CM) meteorite samples including heated ones (red lines), Ivuna (CI) meteorite samples including heated ones (blue lines), and Tagish Lake meteorite samples including heated and laser-irradiated ones (green lines), together with the average P asteroid spectrum (filled square).

The Tagish Lake sample heated at 100°C shows a brighter and redder spectrum, and the laser-irradiated sample shows an brighter and flatter spectrum. While the mechanism of the spectral change in the case of the heated sample is not clear, the reason why the laser-irradiated sample became a brighter and flatter spectrum is supposedly due to the loss of carbon and dehydration of the component minerals. In fact, the spectrum of the laser-irradiated sample resembles some of the C/G/B/F asteroids, which contains many thermally metamorphosed carbonaceous chondrites materials [4]. Although these three Tagish Lake spectra may be sufficient in approximating the average P asteroid spectrum, we have increased the base by adding Murchison (CM) and Ivuna (CI) chondrite spectra to understand the nature of the five P asteroids better.

Mixing Analysis for the Best Spectral Fit: We have performed an intimate mixing calculations for the best spectral fits of these P asteroids with these meteorite samples using Hiroi's Isograin model [10] for opaque minerals [11]. The asteroid reflectances at 0.55 μm are also optimized.

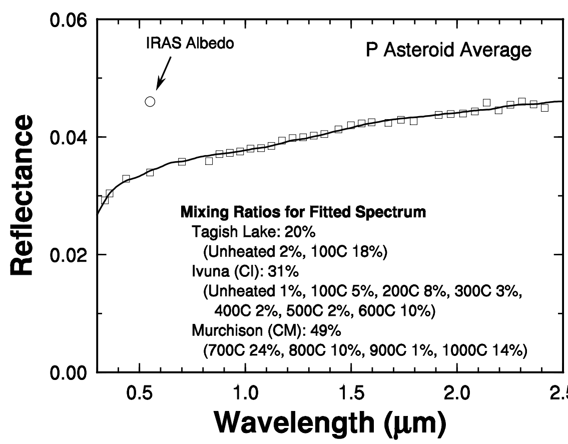

Fig. 3. A spectral mixing calculation for the best fit (solid line) of the average P asteroid spectrum [open square] using the spectra of meteorite samples. The reflectance at 0.55 μm is also optimized for the best fit. The IRAS albedo (open circle) of the average P asteroid is also plotted for comparison.

Shown in Fig. 3 is the result of such a spectral fitting analysis for the average P asteroid spectrum. It indicates that the average P asteroid spectrum is consistent with a surface material made of 20% Tagish Lake-derived materials, 31% Ivuna-derived materials, and 49% Murchison-derived materials, where the majority is altered materials. Of course, it is supposed that the solution is not unique due to the featureless nature of the P-type spectrum and relatively low wavelength resolution and data quality. The optimized reflectance at 0.55 μm is close to but somewhat lower than the IRAS albedo. This is reasonable considering the viewing geometry difference between the IRAS observation and laboratory measurements.

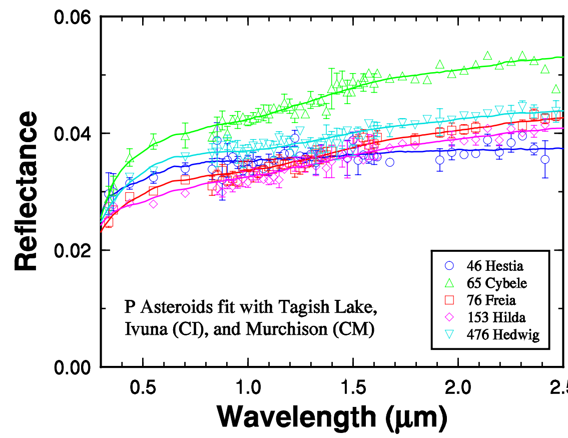

Fig. 4. Spectral mixing calculations for the best fits (solid line) of five P asteroid spectra [open symbols] using the spectra of meteorite samples. The reflectances at 0.55 μm are optimized for the best fits.

Shown in Fig. 4 are the results of same calculations performed for the five P asteroids. Their overall continuum shapes as well as various shapes in the visible region are well reproduced in these calculations. Three asteroids 46, 65, and 476 were represented as containing Tagish Lake-derived materials by 50-80%, while 76 and 153 containing more Murchison and/or Ivuna-derived materials. Majority of the component materials were altered samples.

Summary and Discussion: We have successfully reproduced currently-available, wide-range, visible-NIR reflectance spectra of the P-type asteroids in terms of CI, CM, and Tagish Lake meteorite samples and their experimental derivatives. These results suggest that the surface regolith of the P asteroids may be made of intermediate materials of the CI/CM and Tagish Lake meteorites which went through thermal metamorphism and/or space weathering. In fact, Kaidun meteorite does contain all three of these materials, in addition to others [12].

Acknowledgment: This research was supported by NASA grant NAG5-12847 to TH. Laboratory reflectance spectra were measured at RELAB, a multiuser facility operated under NASA grant NAG5-13609. Authors appreciate technical assistance by Dr. S. Sugita and Mr. S. Ohno.

References: [1] Tholen D. J. (1984) Ph.D. thesis, Univ. Arizona. [2] Vilas F., Smith B. A., *Icarus 64*, 503 (1985). [3] Hiroi T. et al. (2001) *Science*, *293*, 2234. [4] Hiroi T. et al. (1993) *Science 261*, 1016. [5] Yamada M. et al. (1999) *Earth Planets Space 51*, 1255. [6] Hiroi T. et al. (1996) *Lunar Planet. Sci 27*, 551. [7] Zellner B. et al. (1985) *Icarus*, *61*, 335. [8] Bell J. F. et al. (1989) *Lunar Planet. Sci.*, *19*, 57. [9] Tedesco E. F. (1989) In *Asteroids II*, Univ. Arizona Press, 1090. [10] Hiroi T. and Pieters C. M. (1992) *Proc. Lunar Planet. Sci. 22*, 313. [11] Hiroi T. et al. (1994) *Proc. NIPR Symp. Antarct. Meteorites 7*, 230. [12] Zolensky M. E. and Ivanov A. (2003) *Chemie deErde 63*, 185.