Mineralogic and Temperature-Induced Spectral Investigations of A-type Asteroids 246 Asporina and 446 Aeternitas. V. Reddy[1,3], P. S. Hardersen[1,3], M. J. Gaffey[1,3], and P. A. Abell[2,3], [1]Department of Space Studies, Box 9008, University of North Dakota, Grand Forks, North Dakota 58202, vishnu.kanupuru@und.nodak.edu; [2]NASA Johnson Space Center, Astromaterials and Exploration Science, Mail Code KR, Houston, Texas 77058; [3]Visiting Astronomer at the Infrared Telescope Facility, which is operated by the University of Hawai'i under contract from the National Aeronautics and Space Administration, Mauna Kea, Hawai'i 96720.

Introduction: A-type asteroids are a relatively rare taxonomic class with no more than 17 known objects [1,2,3]. They were first identified as a separate group of R-type asteroids based on broadband spectrophotometry by [4], and were later classified based on ECAS data by Tholen (1984) [1]. These asteroids have moderately high albedos (0.13-0.39), extremely reddish slopes shortward of 0.7 µm and a strong absorption feature centered at ~1.05 µm [5]. More recent surveys like the Small Main-Belt Asteroid Spectroscopic Survey (SMASS) [2] and SMASS II [3] have expanded the taxonomic classes including the A-type, adding 12 new asteroids to the original five from [1].

Observing 246 Asporina and 289 Nenetta, [6] were the first to identify A-type asteroids as nearly pure olivine assemblages based on their spectral characteristics. These asteroids display a single broad absorption feature centered at 1.06 µm (Band I) without any significant pyroxene feature at ~2.0 µm (Band II).

The discovery of olivine-rich asteroids is of considerable interest because large masses of pure olivine forms only due to magmatic differentiation and because olivine is a major constituent of the mantles of differentiated bodies. This indicates that at least some objects in the asteroid belt experienced high temperatures that led to partial to full melting and differentiation. Another interesting aspect is that in order for the mantle to be exposed, the parent body must be fragmented or its deep interior exposed by large impacts. Based on the number of iron meteorites in terrestrial collections, it is estimated that at least 80 asteroid parent bodies should have experienced heating and differentiation prior to disruption [7]. However, only a handful of A-type objects were discovered during the taxonomic surveys, assuming that all A-type asteroids are olivine-rich. The study of A-type asteroids may help solve the "missing mantle problem" in the asteroid belt.

[8] observed subtle differences between A-type asteroid spectra and laboratory spectra of olivines; these differences were attributed to changes in temperature. [9], [10], and [11] showed that the 1-µm olivine feature narrows with decreasing temperature and broadens at longer wavelengths with increasing temperature. While [8] compared the spectrum of 446 Aeternitas with spectra of olivine at low-temperatures, no direct measurements of temperature-induced spectral effects on A-type asteroids have yet been made. In this work, we present the preliminary results of our attempt to identify temperature-induced spectral effects on A-type asteroid 446 Aeternitas based on observations at different heliocentric distances. We also derive the olivine mineralogy of A-type asteroids, 246 Asporina and 446 Aeternitas based on the calibration work by [12].

Observations and data reduction: 446 Aeternitas was initially observed by M. J. Gaffey between December 12-15, 1988, using the UH Double-CVF (D-CVF) instrument at the NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawai'i. It was reobserved on January 20, 2004, using the SpeX near-infrared spectrograph [13] at the IRTF along with another A-type asteroid, 246 Asporina. The D-CVF observation of 446 Aeternitas was made at a heliocentric distance of 2.92 A.U. and the SpeX at 3.12 A.U. All SpeX data were subsequently reduced using IRAF and the PC-based SpecPR spectral processing program [14]. Data from the D-CVF instrument was converted to SpecPR format for analysis. SMASS data [2] was spliced together with the D-CVF data to obtain the short wavelength roll-over of the 1-µm feature. Isolation of the Band I and II absorption features, and the band area ratios were accomplished using SpecPR.

Calculating Surface Temperature: Asteroid surface temperatures for each set of observations were computed using a standard thermal model [15]. The models were calculated using the ThermFlux code and assumed an emissivity of 0.9, an infrared beaming factor of 1.0, and instantaneous thermal equilibrium. The temperature of the subsolar point on each body (rather than some integrated temperature) was used for purpose of inter-comparison, since the band width parameter of olivine varies nearly linearly with temperature [8,9].

Results: A summary of the observations along with the spectral parameters is presented in Table 1. The 52-channel survey spectral parameters were also calculated using the D-CVF data from [16,17] and are included for comparison. The agreement between the spectral parameters using data from two different instruments made at three different oppositions, but using the same data reduction method is very apparent. Band I and II centers, and Band Area Ratios (BAR) for the three data sets are within the calculated uncertainties — a strong testament to the robustness of the data reduction methods employed.

Using this high-quality data, we investigated temperature-induced spectral effects on 446 Aeternitas using data taken with the asteroid at two different heliocentric distances. Based on ThermFlux calculations, we estimated the sub-solar temperature of the D-CVF data (2.923 A.U.) to be 221 K and the SpeX data (3.128 A.U.) to be 214 K. The normalized Band I feature from the two data sets is presented in Fig. 1. Within the observed temperature range (7 K), no significant broadening or narrowing of the 1-μm feature was observed. Using the FWHM of Band I as a spectral parameter, we conclude that the 1-μm feature essentially remains unchanged over the observed temperature range. Currently, we are investigating temperature-induced spectral effects on 446 Aeternitas over a larger temperature and heliocentric range.

An average spectrum of 446 Aeternitas is displayed in Fig. 2. Based on calibration work by [12] and the calculated Band I center, we estimate the olivine to be $Fo_{70}\pm_{20}$ for 446 Aeternitas and $Fo_{40}\pm_{20}$ for 246 Asporina. A weak (~5 %) Band II feature is present in the SpeX and 52-channel survey spectrum of 446 Aeternitas, but not in the Dec. 1988 D-CVF data. This could be due to compositional differences on the asteroid's surface at different rotational phases. Based on the Band II position (1.992 μm), we suggest the presence of a minor amount of pyroxene in the assemblage although trace amounts of spinels are known to produce a weak 2-μm features in olivine assemblages [18].

References: [1] Tholen D.J. (1984) Ph.D. thesis, Univ. of Arizona. [2] Xu S. et al. (1995) *Icarus,* 115, 1-35.[3] Bus S.J. and Binzel R.P. (2002) *Icarus,* 158, 146-177. [4] Veeder G.J. et al. (1983) *Icarus,* 55, 177-180. [5] Tholen D.J. and Barucci M.A. (1989) *Asteroids II,* 298-315. [6] Cruikshank D.P. and Hartmann W.K. (1984) *Science,* 223, 281-283. [7] Keil K. (2000) *Planet. Space Sci.,* 48, 887-903. [8] Lucey P.G. et al. (1998) *J. Geophys. Res.* 103, 5865. [9] Roush T.L. (1984) Master's thesis, Univ. of Hawaii. [10] Singer R.B. and Roush T.L. (1985) *J. Geophys. Res.* 90, 12,434-12,444. [11] Roush T.L. and Singer R.B. (1986) *J. Geophys. Res.* 91, 10,301-10,308. [12] King T.V.V. and Ridley W.I. (1987) *J. Geophys. Res.* 92, 11457-11469. [13] Rayner J.T. et al. (2003) *Publ. ASP,* 115 (805), 362-382. [14] Clark R.N. (1980) *Publ. ASP,* 92, 221-224. [15] Lebofsky L.A. and Spencer J.R. (1989) in *Asteroids II,* 128-147. [16] Gaffey M.J. et al. (1993) *Icarus,* 106, 573-602. [17] Bell J. F. (1988) *Lunar Planet. Sci.* 19, 57-58. [18] Pieters C. M. *et al.* (1990) *Lunar Planet. Sci. XXI*, 962-963.

Table 1. Spectral parameters of 446 Aeternitas.

Spectral Parameters	**SpeX (Jan. 2004)**	**D-CVF (Dec. 1988)**	**52-color survey (Nov. 1983)***
Band-I Center	**1.07**	**1.07**	**1.07**
Band-I Area	**0.163**	**0.166**	—
Band-II Center	**1.992**	—	**2.02**
BAR	**0.1**	—	**0.09**
FWHM	**0.47 μm**	**0.47 μm**	—
Heliocentric Dist.	**3.128 A.U.**	**2.923 A.U.**	—
Sub-Solar Temp.	**214 K**	**221 K**	—

*[16]

Figure 1. 446 Aeternitas SpeX/D-CVF Normalized Band I feature.

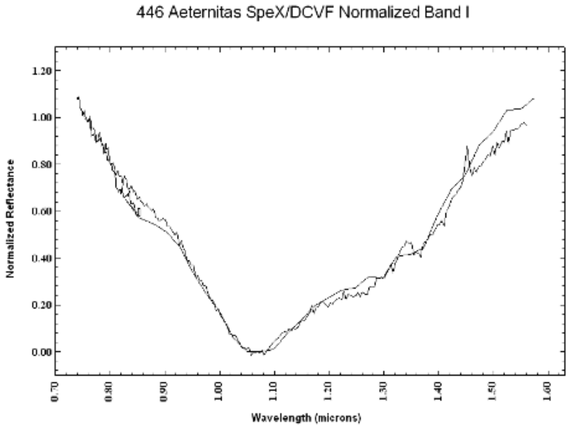

Figure 2. Average spectrum of 446 Aeternitas.