been found at diverse Apollo sites and exhibit nonequilibrium textures and mineralogy that clearly result from rapid cooling conditions in the lunar vacuum environment.

- A particularly diagnostic spectral feature of lunar impact melt products is the 600 nm absorption feature associated with microcrystalline ilmenite set in a transparent host (typically as inclusions in plagioclase). The presence of this ilmenite feature is indicative of the impact event and cooling history and is not directly associated with the target composition.

These data represent the first systematic, laboratory measurements of impact melt spectra. The two suites of samples exhibit a consistency in spectral properties that appear to be linked to cooling rate and (consequently) glass abundance and texture. The interrelationship of observed spectral features documented here can be examined directly in remote spectra that contain the necessary spectral range and resolution. These laboratory data provide a foundation for more detailed modeling of complex mixtures on the lunar surface (e.g., Wilcox et al. 2006). It is anticipated that the capabilities of advanced spectroscopic sensors currently being flown to the Moon will enable a new era of geologic analyses and allow major impact events and their associated products to be studied in unprecedented detail in the natural environment.

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REFERENCES

Adams J. B. and Goulland L. H. 1978. Plagioclase feldspars: Visible and near infrared diffuse reflectance spectra as applied to remote sensing. Proceedings, 9th Lunar and Planetary Science Conference. pp. 2901–2909.

Adams J. B., Pieters C., and McCord T. B. 1974. Orange glass: Evidence for regional deposits of pyroclastic origin on the Moon. Proceedings, 5th Lunar Science Conference. pp. 171–186.

Adams J. B., Horz F., and Gibbons R. V. 1979. Effects of shock-loading on the reflectance spectra of plagioclase, pyroxene, and glass (abstract). 10th Lunar and Planetary Science Conference. pp. 1–3.

Bell P. M., Mao H. K., and Weeks R. A. 1976. Optical spectra and electron paramagnetic resonance of lunar and synthetic glasses: A study of the effects of controlled atmosphere, composition, and temperature. Proceedings, 7th Lunar Science Conference, pp. 2543–2559.

Belton M. J. S., Greeley R., Greenberg R., McEwen A., Klaasen K. P., Head J. W., Pieters C. M., Neukum G., Chapman C. R., Geissler P., Haffernan C., Breneman H., Anger C., Carr M. H., Davies M. E., Fanale F. P., Gierasch P. J., Ingersoll A. P., Johnson T. V., Pilcher C. B., Thompson R., Veverka J., and Sagan C. 1993. Galileo multispectral imaging of the North Polar and Eastern Limb regions of the Moon. *Science* 264:1112–1115.

Burns R. G. 1993. *Mineralogical applications of crystal field theory*, 2nd ed. New York: Cambridge University Press. 551 p.

Christensen P. R., Bandfield L., Hamilton V. E., Howard D. A., Lane M. D., Piatek J. L., Ruff S. W., and Stefanov W. L. 2000. A thermal emission spectral library of rock-forming minerals. *Journal of Geophysical Research—Planets* 105:9735–9739.

Cintala M. J. and Grieve R. A. F. 1994. The effects of differential scaling of impact melt and crater dimensions on lunar and terrestrial craters: Some brief examples. In *Large meteorite impacts and planetary evolution*, edited by Dressler B. O., Grieve R. A. F., and Sharpton V. L. Boulder, CO: Geological Society of America. pp. 51–59.

Cloutis E. A. 2010. Basalt-ilmenite mixtures: Spectral reflectance changes as a function of grain size and ilmenite abundance (abstract #1139). 41st Lunar and Planetary Science Conference. CD-ROM.

Cloutis E. A., McCormack K. A., Bell J. F., Hendrix A. R., Bailey D. T., Craig M. A., Mertzman S. A., Robinson M. S., and Riner M. A. 2008. Ultraviolet spectral reflectance properties of common planetary minerals. *Icarus* 197:321–347.

Crown D. A. and Pieters C. M. 1987. Spectral properties of plagioclase and pyroxene mixtures and the interpretation of lunar soil spectra. *Icarus* 72:492–506.

Gillis-Davis J. J., Lucey P. G., Hammer J. E., and Wilcox B. B. 2007. Syntheses and reflectance analyses of lunar red glass compositions: Information to improve understanding of remotely sensed spectral data (abstract #1443). 38th Lunar and Planetary Science Conference. CD-ROM.

Gillis-Davis J. J., Lucey P. G., Hammer J. E., and Denevi B. B. 2008. Syntheses and reflectance analyses of lunar green glass compositions: Information to improve understanding of remotely sensed spectral data (abstract #1535). 39th Lunar and Planetary Science Conference. CD-ROM.

Grieve R. A. F., Dence M. R., and Robertson P. B. 1977a. Cratering processes: As interpreted from the occurrence of impact melts. In *Impact and explosion cratering*, edited by Roddy D. J., Pepin R. O., and Merrill R. B. New York: Pergamon Press. pp. 791–814.

Grieve R. A. F., Dence M. R., and Robertson P. B. 1977b.Terrestrial impact structures: Principal characteristics and energy considerations. In *Impact and explosion cratering*, edited by Roddy D. J., Pepin R. O., and Merrill R. B. New York: Pergamon Press. pp. 247–276.

Hapke B. 1981. Bidirectional reflectance spectroscopy, 1. Theory. *Journal of Geophysical Research* 86:3039–3054.