INSTRUMENTAL REQUIREMENTS AND OBSERVATIONAL STRATEGIES FOR SPECTROPHOTOMETRIC DATA ACQUISITION DURING A CRAF-TYPE ASTEROID FLYBY. Michael J. Gaffey, Department of Geology, Rensselaer Polytechnic Institute, Troy, New York 12181.

Axiom: The history of the asteroid is written in its rocks and minerals.
Corollary: Unless you measure the appropriate mineralogic and petrologic properties, that history cannot be read.

The scientific return from a CRAF-type asteroid flyby mission is critically dependent upon the capabilities and performance of the visible and near-infrared (VNIR) reflectance spectrometer. Other instrumentation - either singly or in concert - can provide powerful insights into the body's shape, surface morphology and cratering history; its mass, volume, and bulk density; and its near-surface thermal properties. But only instrumentation which makes sophisticated determinations of surface lithology (mineral presence, composition, and abundance; petrographic relationships; spatial heterogeneity; etc.) can provide the data base for understanding the physico-chemical processes of the asteroid's history.

The detailed mineralogy and petrology of a rock, whether it be terrestrial or extra-terrestrial, constitutes a decipherable record of the history of that rock. This is exemplified metamorphic geology by the facies concept, which states: the assemblage of minerals in a rock unit are characteristic of the conditions of formation of that unit. The concept of facies is defined in terms of pressure and temperature, and is independent of bulk composition.

The suite of minerals present in any initial asteroidal lithology (e.g. ordinary chondritic, carbonaceous chondritic, etc.) subjected to metamorphism will be altered to the characteristic suite of minerals for that particular metamorphic grade (P/T). The bulk composition may - and often does - remain unchanged. An analogous facies concept applies aqueous alteration or weathering processes and to igneous processes of magma generation by partial melting or fractional crystallization. The mineral suite in a rock provides a record of its history and evolution. Much of meteoritics, lunar sample studies, and terrestrial geology is based on these principles.

The analysis and interpretation of asteroid encounter VNIR spectral data sets is therefore primarily a geologic problem, rather than an astronomical, physics, or engineering exercise. The geosciences have developed the techniques and provide the expertise to decipher that rock record. But this is only possible if the spacecraft instrument is capable of making - and does make - the appropriate spectral measurements.

In a combined asteroid-comet mission, the VNIR spectral requirements to carry out the asteroid study are much more stringent than those for the comet. Schedules, budgetary constraints, and the strong cometary focus the CRAF mission will create pressures to downgrade the actual performance characteristics of the VNIR spectrometer requested and flown. Unless the more strict asteroidal (geologic) requirements are recognized, explicitly defined, and included in the design criteria during the crucial early stages of instrument definition, the final instrument capabilities will probably be inadequate to carry out significant spectral measurements of the asteroid. Given the present lack of sophistication in the area of spectral studies of geologic and meteoritic materials - both in general and on the CRAF-VIMS team - the capabilities necessary to a sophisticated asteroid effort may well be traded away without even being recognized.

Without appropriate spectral measurements, much of the potential of a CRAF-type mission for asteroid science will be lost. The possibility of a meaningful and sophisticated geologic investigation of the asteroid may well vanish before the mission is even launched. Such a failure could easily constitute a negative heritage propagated forward into other asteroid encounter missions.

The instrumental performance requirements - especially in the areas of photometric precision and calibration accuracy - for VNIR spectroscopy of the cometary nucleus are much less stringent than in the case of the asteroid measurements. Given the strong cometary focus of CRAF, this could lead to a relaxation of instrumental performance requirements below those sufficient to carry out the asteroid portion the mission. The less strict performance requirements for the cometary nucleus studies derive from: 1) the rendezvous nature of the encounter, and 2) the environment in which the comet resides. Longer integration times and repeated measurements of the same surface areas.are possible for the cometary rendesvous, but not during the asteroid flyby. Moreover, for the cometary rendezvous, data from a much larger suite of instruments - including the penetrator - can be combined to characterize the nucleus, making the VNIR spectrometer less critical.

The nature of the cometary environment provides a potent argument for relaxing the performance requirements of the spectral instrumentation. For an asteroid, the sun is the sole source of VNIR illumination, and the illumination geometry (phase) of any surface element is uniquely determined by the orientation of the local topography to the incident sunlight. This is definitely not the case for spacecraft measurements of a cometary nucleus. The nucleus is located within a coma of dust and gas, a nebulosity with significant temporal and spatial heterogeneity. This severely limits the attainable photometric precision and accuracy of spectral reflectance measurements of the nucleus.

The illuminating solar spectral flux onto the cometary nucleus is modified during its passage through the coma, as is the spectral flux from the surface to the detector. These two paths will generally be different, so that two different (and poorly constrained) corrections are required. Additionally, the coma contributes a large non-solar (the solar spectral flux modified by the scattering and reflectance properties of the dust and gas) illumination to all parts of the nucleus, exceeding that directly from the sun over much of the surface. And finally, the dust and gas along the line of sight between the nucleus and the spacecraft scatter a non-solar spectral flux to the detector.

An examination of the Comet Halley images from the Giotto spacecraft show the problems encountered in getting a clear view of a nucleus in a coma. The problems of obtaining high precision, calibrated VNIR spectra are significantly greater. A reflectance spectrum can be derived from such nucleus measurements, but the corrections for each of these four temporally-varying factors introduces additional uncertainty in the data set. For a moderately active nucleus, it is unlikely that spectrophotometric precisions and accuracies better than about 5-10% can be obtained. This would suffice for identification and general characterization of the strong ice absorption features (in clean ice, longwards of 1.4um) and the intense bound water features near 3um. With a strong cometary focus to the CRAF mission, there will be pressure to lower instrumental performance to a corresponding level.

Most of the potentially attainable compositional information for an asteroid cannot be obtained at such low levels of photometric precision. The strong 3um feature in a C-type asteroid could be characterized. But, as a half century of work shows rather clearly [1], this feature is not especially diagnostic of detailed mineralogy, particularly in complex mixtures. It provides little information beyond showing the presence of water-bearing species and providing some general discrimination of the major types. It provides no significant information on mineral chemistry, nor petrographic relationships.

Using such a C-type asteroid as an example, high precision (S/N>200; calibration uncertainty < 0.5%; spectral resolution $\leq$ 1%) spectroscopy in the 0.4-1.5um spectral interval permits identification of the clay mineral species present, quantification of their iron contents, and determination of their oxidation state [2,3]. Based on meteoritic studies, such mineralogic variations represent the effects of post-accretionary aqueous alteration in the CI-CM parent bodies [4-6]. The determination of the spatial variability of such parameters across an asteroidal surface would greatly increment our understanding of the of the evolution of C-type bodies and of the nature of post-accretionary alteration. The specific wavelength resolution, spectrophotometric precision and accuracy requirements, and the most significant spectral intervals will vary with the type of target asteroid. But beyond the general observation that these are more stringent than in the cometary case, such requirements are presently poorly defined. Effort should be focused on specifically defining these requirements for the most probable types of asteroidal flyby targets.

But in any case, obtaining the required spectral measurements during a flyby encounter will require a high performance instrument. An informed and sophisticated geologic/meteoritical spectroscopy input is required at the earliest possible time to the decision processes which formulate the actual CRAF-VIMS performance requirements. It may be decided that such requirements cannot be met for any of a variety of fiscal or technical grounds. But the decision should be made with a clear knowledge of the trade-offs, and not in ignorance of the consequences for the asteroid science return. History is likely to judge us less by how well we succeed, than by how cleverly we try. The choice is ours.

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