WHAT ARE S-CLASS ASTEROIDS MADE OF? (AND WILL GASPRA TELL US?)

Jeffrey F. Bell (Dept. of Geology and Geophysics, SOEST, Univ. of Hawaii, Honolulu HI 96822)

The longest running argument in asteroid science concerns the mineral composition and meteoritical association of the asteroids assigned to taxonomic type S. Over the past 20 years this controversy has occupied an immense number of abstracts, funding proposals, telescope time requests, progress reports, workshop preceedings, Arizona "Blue Book" chapters, NASA SPs, CPs, TMs, JPL internal documents, and occasionally even refereed journal articles. The approaching flyby of the S-type asteroid Gaspra by the Galileo spacecraft will drag an even larger section of the space science community into this turgid debate. This review is intended to introduce these unfortunate newcomers to the basics of the problem. Below are summarized the various proposed S asteroid surface compositions in roughly the order in which they appeared.

A) ORDINARY CHONDRITES: It was known long before asteroid spectroscopy began that ordinary chondrites (OCs) make up more than 75% of observed meteorite falls. Some (but not all) meteoriticists of the 1960s came to believe that these fall statistics must reflect the proportions of meteorite parent bodies in the asteroid belt. Thus when the first asteroid colors and albedos were obtained in the early 1970s there was a strong expectation that many asteroids would resemble OCs. Indeed, the spectral class "S" originally was intended to stand for "silicaceous" as "M=metal" and "C=carbonaceous" (1). Thus the original 3 asteroid types neatly accounted for ordinary chondrites, irons, and carbonaceous chondrites. For a short time everyone was happy.

B) STONY-IRONS: Later, when spectra of ordinary chondrites were measured in the lab (2) it became apparent that they actually had little similarity to S asteroids other than having olivine and pyroxene absorption bands. The asteroids have a steep red continuum totally unlike that of the OCs, and the details of the silicate bands vary wildly, implying mineralogies usually far outside the OC range. To explain these facts it was suggested that most S-type surfaces are differentiated assemblages of metal, orthopyroxene, and olivine, similar to stony-iron meteorites such as pallasites, lodranites, and siderophyres. This material would be the product of melting in the deep interiors of the asteroid parent bodies, subsequently exposed by the collisional disruption. Advocates of this hypothesis have proposed various alternate source bodies for OCs. Probably the least objectionable of these is the Q-class asteroids, which conveniently are all tiny Earth-crossing asteroids with low-quality spectra. But current collisional models of the asteroids require that this population be constantly replenished from a reservoir in the main belt, where no Q-types have been found.

C) WEATHERED ORDINARY CHONDRITES: Upon discovery of the continnuum slope problem, advocates of interpretation A) proposed that the red continuum of S asteroids is created by some "space weathering" process which alters the spectrum of the uppermost regolith. Usually they propose that this is associated with the metal component of chondrites, because it is obvious that pure-silicate asteroids of classes V, R, A, and E do not have any reddening. This proposal has inspired investigations of both synthetic metal-rich regoliths derived from OCs (3) and natural OC parent body regolith material preserved in some meteorite breccias (4). All these studies demonstrate that "weathered" OC material does not redden, but rather becomes spectrally flatter and in extreme cases approximates a C-type spectrum, never an S-type. In fact this similarity leads some to propose that the OCs actually come from C-type asteroids (5).

D) CARBONLESS CARBONACEOUS CHONDRITES: When the first near-IR spectra of S asteroids revealed that most had higher ol/pyx than any OC, it was proposed (6) that they represented unknown types of chondrites, specifically material with the silicate composition of carbonaceous chondrites but no carbon. But since no such meteorites have ever fallen on Earth, this hypothesis requires its advocates to abandon the very fall-statistics argument that had originally inspired the chondritic interpretation of S-types in the first place. Furthermore, the asteroid Flora which was cited in (6) as the most OC-like of the S-types was later shown to have large variations in silicate mineralogy between different regions of its surface, far outside the range of OCs (7). As a result, this theory is almost forgotten, except by die-hard supporters of interpretation A) above who mistakenly cite (6) as supporting them.

E) EVERYTHING: The mounting spectral evidence for wild variations in composition between different S asteroids and even across the surface of individual ones leads some workers (7) to wonder if both schools might be right. It is impossible to rule out some chondritic areas on the surfaces of S asteroids with the current data, if one allows the other areas to be made of extreme differentiated mineralogies (e.g. pure metal or pure olivine). Since we observe an entire "hemisphere" at once with Earth-based telescopes the chondritic areas could not be separated from the differentiated areas. Current ideas about asteroid differentiation lean toward such a complex pattern of heating. The fatal objection to this theory is that the actual OC breccias do not contain differentiated clasts, which would be sure to exist in the regolith of a "patchwork asteroid".

F) NOTHING: Alternatively one may take the wide variety of S spectra to indicate that there is really no such thing as a unified "S-type asteroid", but a variety of different objects with different origins and histories which we have not yet properly distinguished. For instance, the Eos asteroid family contains objects formally classified S in most systems, but with IR spectra that closely match those of CO or CV chondrites. A new class "K" was recently created to contain these objects (8). But this probably does not herald the beginning of the end for Class S. There does seem to be a hard core of well observed objects with classical S properties that will always remain even if some of the fainter objects which have only incomplete spectral data later turn out to be something else.

THE CURRENT POSITION: At present almost all scientists actively involved in research on asteroid composition appear to hold some version of interpretation B. In fact, no full journal article defending any other view has appeared for at least 10 years (the closest approximation being (9)). Yet some of them (especially C) continue to be defended vigorously in less formal situations. None can be rigourously excluded on the basis of current data, and very little new data is being collected due to funding and personnel shortages.

GASPRA: ROSETTA STONE OF THE ASTEROID BELT? Will the Galileo flyby of Gaspra end the Great Debate? Most attention has focused on spectral observations to be made by the NIMS IR spectrometer and SSI camera. But the spectral studies to be performed by these instuments will be essentially the same as those already being done from Earth. The whole debate outlined above has been between those who accept the fundamental usefulness of mineral spectroscopy, and those who reject it in favor of meteorite fall statistics. More spectral data is unlikely to convince the second group, who have been remarkably ingenious in proposing reasons why the hundreds of existing S-type asteroid spectra don't really mean what they obviously do. Alternatively, it is possible that some striking morphological evidence of a metal-rich composition will apppear in the images of Gaspra. For instance, impact experiments in nickel-iron targets produce craters with rigid, "frozen" ejecta flaps, usually with many sharp prongs of metal visible. If similar structures were seen on Gaspra, they would strongly suggest that the bedrock was dominated by metal. Probably the least ambiguous datum would be an accurate density for Gaspra. Any density significantly above 3.8 would rule out a chondritic composition. The stony-iron model implies a density between 4.0 and 7.8. This determination is independent of any quibbles about spectral interpretation and would sense the entire body of the asteroid rather than a superficial layer. Obtaining accurate values for the mass and volume of Gaspra should be the highest priority during the flyby.

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