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Organic Matter on Asteroid 130 Elektra

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Infrared absorption spectra of a low-albedo water-rich asteroid appear to show a weak 3.4-micrometer carbon-hydrogen stretching mode band, which suggests the presence of hydrocarbons on asteroid 130 Elektra. The organic extract from the primitive carbonaceous chondritic Murchison meteorite shows similar spectral bands.

THE CARBONACEOUS CHONDRITIC meteorites are known to contain organic matter. Aliphatic and aromatic polymers constitute about 6% of the mass of the volatile-rich CI chondrites, which are among the most primitive samples of matter in the solar system. These meteorites represent a low-temperature condensate from the solar nebula and contain all of the stable elements in solar proportions except for the highly volatile major elements hydrogen, carbon, nitrogen, and oxygen, and the noble gases (*1–3*). The parent body or bodies of the CI carbonaceous chondrites have been affected by liquid water, as evidenced by the clays and other aqueous alteration products found in the meteorites.

Several investigations have shown the apparent connections between various kinds of meteorites and certain classes of asteroids (*4–6*) in the main belt, and more recently the connection has been drawn even closer by finding meteorite analogs among the planet-crossing asteroids (*7, 8*). This latter step is important in understanding the details of transport of material from apparently stable asteroid orbits to Earth (*9, 10*).

Although the carbonaceous chondrite parent bodies are presumed to exist among the outer asteroids, the evidence is based on their mutual low albedos and, in some cases, reddish color. Lebofsky *et al.* (*11*) have shown that some, but not all, low-albedo C-type asteroids have a broad absorption in their spectra at 3 μm that is attributable to bound water in the mineral lattices. This finding is consistent with the bound water in the CI and CM carbonaceous chondrites. The strength of the ultraviolet absorption, attributed to charge-transfer transitions in iron and titanium, is related to the amount of water represented by the 3-μm absorption (*12*).

In the primitive carbonaceous chondrites, such as Orgueil (CI), Murray (CM), and Murchison (CM), a complex of very shallow bands at 3.4 μm is superimposed on the 3-μm bound-water band seen in diffuse reflectance. These features are caused by the C–H stretching mode and are common to all organic matter, although the exact positions and band shapes vary among compounds. Other classes of carbonaceous chondrites, such as Allende (CV), do not show the C–H band clearly, nor do they have significant bound water evident in their reflectance spectra.

We have sought to carry the connection between the most primitive carbonaceous chondrites and the asteroids further by searching for the C–H organic band in asteroid spectra. In August 1986, we used the cooled-grating array spectrometer (CGAS) at the NASA Infrared Telescope Facility at Mauna Kea, Hawaii, to obtain spectra of asteroid 130 Elektra. Figure 1 shows the asteroid spectrum in the region of the 3.4-μm band. In Fig. 1, curve b, the spectrum is shown as the simple ratio to the spectrum of a solar-type star (Fig. 1, curve e) (*13*). For comparison, the laboratory reflectance spectrum of the insoluble organic extract from the Murchison C1 carbonaceous chondrite is shown (Fig. 1, curve a). The complex of bands at 3.4 μm in the meteorite sample is due to the C–H stretching mode in the organic compounds in the extract. The spectrum of the bulk Murchison meteorite also shows the C–H band, as well as the 3-μm bound-water absorption. Depending on the particle size and packing of the laboratory samples, the band strengths in the bulk meteorite can appear as strong as those in the concentrated organic residue (*14*). Figure 1, curves c and d, shows the same two spectra, but with the continua removed computationally by means of a cubic spline fit to points on the spectrum that were assumed to represent the local

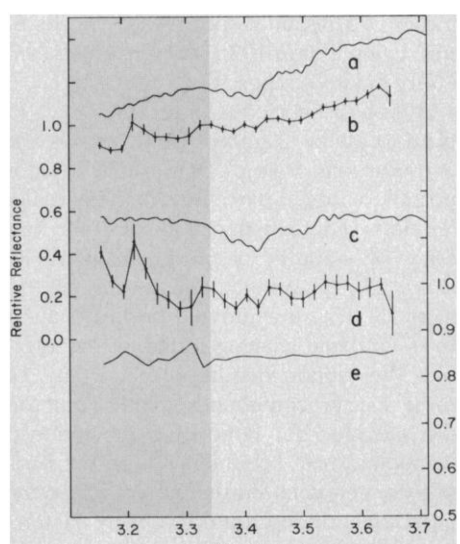

Fig. 1. Reflectance spectra of asteroid 130 Elektra and an organic extract from the Murchison carbonaceous chondrite meteorite. Curve a is the spectrum of Murchison with two times vertical exaggeration to emphasize the weak features between 3.35 and 3.55 μm. Curve b is the telescopic spectrum of 130 Elektra (no exaggeration) with error bars (1σ) as shown. This spectrum is the ratio of the asteroid to the spectrum of the standard star. Curve c is the Murchison spectrum with the continuum slope removed computationally, and curve d is the Elektra spectrum similarly flattened (and with two times vertical exaggeration). Curve e is the standard star spectrum (corrected for extinction). At wavelengths shorter than 3.35 μm, atmospheric extinction is very strong and cannot be entirely removed, as shown in the star spectrum (curve e). The portions of the spectra in the hatched area are, therefore unreliable. At wavelengths longer than 3.35 μm, as seen in the very clean stellar spectrum, correction for atmospheric extinction is very good, and spectral features in the asteroid data can be judged on the basis of their correspondence with similar features in the laboratory spectrum of the meteorite sample. The ordinate scale on the left pertains to spectrum b, whereas that on the right pertains to spectrum d. The other spectra have been offset vertically for clarity.

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continuum. Removal of the continua aids in assessing the similarity and coincidence of the absorption features in the laboratory and asteroid spectra (*15*).

Error bars on the individual points in the asteroid spectrum are $\pm 1\sigma$, and are collected in the coaddition of 14 individual 5-second integrations. The point-to-point dispersion in the data is less than the error bars would suggest, and in comparing the two data sets the main features of the C–H band in Murchison appear to be repeated in the spectrum of 130 Elektra, though the precise strengths and the shapes are distorted by the lower sampling frequency (resolution) and statistical noise. Note that the C–H band is broader than the spectral resolution of the spectrometer, so that the postulation that there is a C–H band in the asteroid rests mainly on the general correspondence of its spectrum to that of Murchison and not on individual data points. Note also that the band is at best very weak: in concentrated organic material from Murchison it amounts to only about 5% absorption strength. Because the band strength depends on particle size and packing as well as the mass fraction of organics, it could be as strong or stronger in the asteroid spectrum as in the laboratory concentrate from the meteorite. The maximum absorption depth in the 130 Elektra spectrum is about 4%.

Asteroid 130 Elektra was chosen for this measurement because it is classified as a "wet" C type on the basis of its deep ultraviolet absorption band (*16*). The 3-μm spectral region has not been investigated for the study of the bound water on Elektra, but its presence is inferred on the basis of the ultraviolet absorption (*12*). Most of the candidate asteroids with deep bound-water bands are not sufficiently bright to study by means of reflectance spectroscopy in the 3-μm region, but in 1986 130 Elektra reached a very favorable apparition.

Although a detection of the 3.4-μm C–H band would be diagnostic of the presence of hydrocarbons, from this band alone it is not possible to determine just what molecules are involved. Murchison contains a vast array of complex organics, including alkanes, alkenes, purines, amino acids, and so forth (*3, 17*), any and all of which exhibit the C–H band we have found on the asteroid. We cannot identify which, if any, of these specific compounds might occur on the asteroid, but none of the mentioned compounds can be eliminated on the basis of these new data. Furthermore, because the band strength depends on so many parameters (*14*), it is not possible from these data alone to estimate the carbon content of the asteroid surface.

The presence of the C–H band on an asteroid does not alone prove that all of the primitive carbonaceous chondrites originate from this or any other asteroid, for comets are known to have this spectral signature as well. Most recently, the organic signature at 3.4 μm has been found in the spectrum of the nucleus and coma of comet P/Halley (*18, 19*). With the detection of the 3.4-μm signature on a low-albedo asteroid, we have shown that bodies of this type are a plausible source of at least one class of carbonaceous chondrites.

The occurrence of the organic signature in the asteroids further attests to the widespread distribution of organic matter throughout the solar system and to the fact that complex organic molecules have been transported from remote locations to Earth and other planets. The study of additional asteroids in the context of the organic signature will shed further light on the nature of the solar nebula in the zones of asteroid formation, as well as on the dynamical mixing and chemical evolutionary phenomena that have occurred since condensation of the parent planetesimals.

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10. The identification of meteorite parent bodies among the asteroids is made on the basis of spectral reflectance similarities, usually in the wavelength range 0.3 to 25 μm. Two broad absorption bands of pyroxene centered at 0.95 and 1.8 μm are seen in many of the S-class asteroids and also in eucritic meteorites (*5*). Also, the strong absorption band of olivine centered at 1.05 μm has been found in several A-class asteroids; olivine is characteristic of the pallasites and of Brachina, Chassigney, and other meteorites.
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13. 130 Elektra was observed on 27 August 1986, when the distance from the sun was 2.538 AU and the distance from Earth was 1.543 AU. The asteroid data were taken over an airmass range of 1.223 to 1.317, and the standard star (BS 9002 = 107 Aqr. F2 III + F2 V) over the range 1.279 to 1.380. The standard star was used both for atmospheric extinction correction and as an acceptable approximation to a solar-type standard in this spectral region. With the CGAS, 32 evenly spaced wavelengths are measured simultaneously through the range 3.1 to 3.7 μm, at a resolution of 180. To avoid saturation of the detectors with background radiation, individual integrations (exposure times) had to be limited to 5 seconds. An equal number of integrations were made on the adjacent sky. With frequent interspersed standard star observations and a limited time available for the asteroid, we could not increase the total integration time on 130 Elektra. Attempts to observe on other nights were thwarted by clouds.
14. The organic extract was prepared from the Murchison meteorite by L. Alaerts and is described in L. Alaerts *et al.*, *Geochim. Cosmochim. Acta* **44**, 189 (1980). The spectrum shown here was obtained with a reflectance spectrometer in the laboratory of J. W. Salisbury at the U.S. Geological Survey in Reston, VA, and has a resolution about four times higher than that of the asteroid data. The strength of the spectral feature centered at 3.4 μm in low-albedo meteorite samples depends not only on the concentration of hydrocarbons but on the penetration depth of the incident light from the spectrometer radiation source. The penetration, in turn, depends on the sample particle size and packing density; maximum band strength in these data is obtained when the sample is sifted into the holder to achieve high porosity, and consequently maximum opportunity for photon absorption in the particles. On a natural asteroid surface, particle size and packing will be determined by the object's impact history and its ability to retain small particles against gravitational escape during impact events. Strong mineral absorption bands and sharply peaked photometric phase functions of many asteroids suggest that porous surfaces of fine particles are the norm.
15. In meteorites, the C–H band is located on the slope of a broad and featureless absorption band of bound water. In asteroid 130 Elektra, the true continuum underlying the bound-water band slopes upward toward longer wavelengths because of the increasing contribution of the thermal emission of the asteroid to the total flux, reflected sunlight being the dominant component of the flux at 3.4 μm. To remove the thermal flux component and the bound-water band (which in other asteroids has differing strengths) requires modeling assumptions that are not well constrained. In the present context, we are trying to establish the presence and appearance of one absorption band superimposed on another: fortunately, the underlying band has no fine structure. The cubic spline we used was fit to points in the asteroid spectrum that we assumed represent the local continuum, that is, the smooth wing of the bound-water absorption band. Similarly, the continuum in the spectrum of the meteorite slopes upward because of the bound-water band in Murchison and because of incomplete instrumental cancellation of thermal emission of the specimen at room temperature. The cubic spline was fit to the Murchison data at points outside the C–H band to flatten the local continuum, that is, the smooth slope of the bound-water absorption.
16. D. J. Tholen, thesis, University of Arizona (1984); personal communication. Asteroid 130 Elektra is a rather undistinguished body with an orbital semimajor axis of 3.109 AU, eccentricity 0.22, and inclination 22.9°. The radiometrically determined diameter is 189 ± 13 km, and the geometric albedo is 0.089 ± 0.013, according to the IRAS asteroid survey [D. L. Matson, Ed., *Jet Propulsion Laboratory Document D-3698*, Preprint Version No. 1 (1986)].
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