THE ASTROPHYSICAL JOURNAL, 197:781–790, 1975 May 1

© 1975. The American Astronomical Society. All rights reserved. Printed in U.S.A.

ASTEROIDS: SPECTRAL REFLECTANCE AND COLOR CHARACTERISTICS. II.

THOMAS B. MCCORD*
Planetary Astronomy Laboratory, Massachusetts Institute of Technology
AND
CLARK R. CHAPMAN*
Planetary Science Institute, Tucson, Arizona

Received 1974 October 29

ABSTRACT

We present new spectrophotometry for 31 asteroids, and improved data for nine previously observed, raising our total sample to 98. Several important new spectral types have been found. Asteroid 349 Dembowska is the first large main-belt asteroid found to resemble ordinary chondritic meteorites in spectral properties (it is similar to LL6 chondrites in pyroxene/olivine content). The first two measured Trojan asteroids show unusual spectra *not* compatible with carbonaceous chondrites or other known meteorites. The spectrum of Mars-crosser 887 Alinda is compatible with unequilibrated chondrites. Most fainter asteroids (especially those in the outer half of the belt) have flat spectra indicating probable carbonaceous composition. Compositional heterogeneity of Hirayama families is common among the 16 families studied to date. But individual asteroids seem to have remarkably uniform surface compositions, indicated by the usual lack of spectral changes with rotation. Spectra of a preliminary sample of proposed meteorite source-bodies are consistent with derivation of meteorites by proposed mechanisms, but further observations are needed.

Subject headings: abundances — asteroids — meteorites, meteors — spectrophotometry

I. INTRODUCTION

Spectrophotometry of minor planets in the visible and near-infrared has revealed a diversity of asteroid compositions with significant implications for the early history of the solar system. In a series of papers (the latest being McCord and Chapman 1975), we have presented spectral reflectance curves for 67 asteroids. These observations have been interpreted and related to meteorites in another group of articles, the more recent ones being Chapman and Salisbury (1973), McCord and Gaffey (1974), Gaffey (1975), Gaffey and McCord (1975), Chapman, Morrison, and Zellner (1975), and Chapman (1974, 1975).

We report here further spectrophotometric observations of nine asteroids previously observed and of 31 additional asteroids. The total number of asteroids observed by this technique is now 98. The new data were obtained at Kitt Peak National Observatory on the 1.3-m reflector during two observing runs: 1973 September 24–30 and 1974 February 11–14.

The new asteroids include the first two Trojans to be observed in our program, another Earth-approaching asteroid (887 Alinda), and a variety of additional Hirayama family members including the brightest member of the large Eos family. As we will describe below, several asteroids we observed have unusual and important spectra. In particular, 349 Dembowska has an absorption band as deep as that of Vesta, but appears to closely resemble type LL6 ordinary chondrites in spectral reflectance characteristics. More than a third of the new asteroids studied have spectra resembling laboratory spectra of type 2 carbonaceous chondrites; several of these have also been found by Zellner, Gehrels, and Gradie (1974) to have very low albedos. It now appears that this dark, carbonaceous compositional class is the dominant one in the asteroid belt.

II. THE OBSERVATIONS

The instrumentation, observing procedures, and data reduction techniques are similar to those described in previous papers (McCord and Chapman 1975; Chapman, McCord, and Johnson 1973*a*), except for the following modifications: The narrow-band interference filter set was augmented so as to improve our spectral resolution in the near-infrared. The effective wavelengths of the filters are listed in table 1. S-1 and S-20 detectors were used during both observing runs. Also, during the September run we frequently used an RCA gallium-indium-arsenide *B* photomultiplier, sensitive from 0.3 μ to about 0.95 μ. Usually the S-1 data were taken in the last 10 filters in a sequential mode of 45-second integrations per filter. These data were scaled to unity at 0.56 μ by matching to the overlapping S-20 or gallium-arsenide observations.

The spectral reflectance data for the 31 new asteroids are presented in figure 1. They are scaled to unity at 0.56 μ. The lines are eye fits to the data. The error bars were determined from the internal consistency of individual runs, except that they are never reduced to less than ± 0.03 in order to reflect our estimates of

---

* Visiting Astronomer, Kitt Peak National Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1975ApJ...197..781M

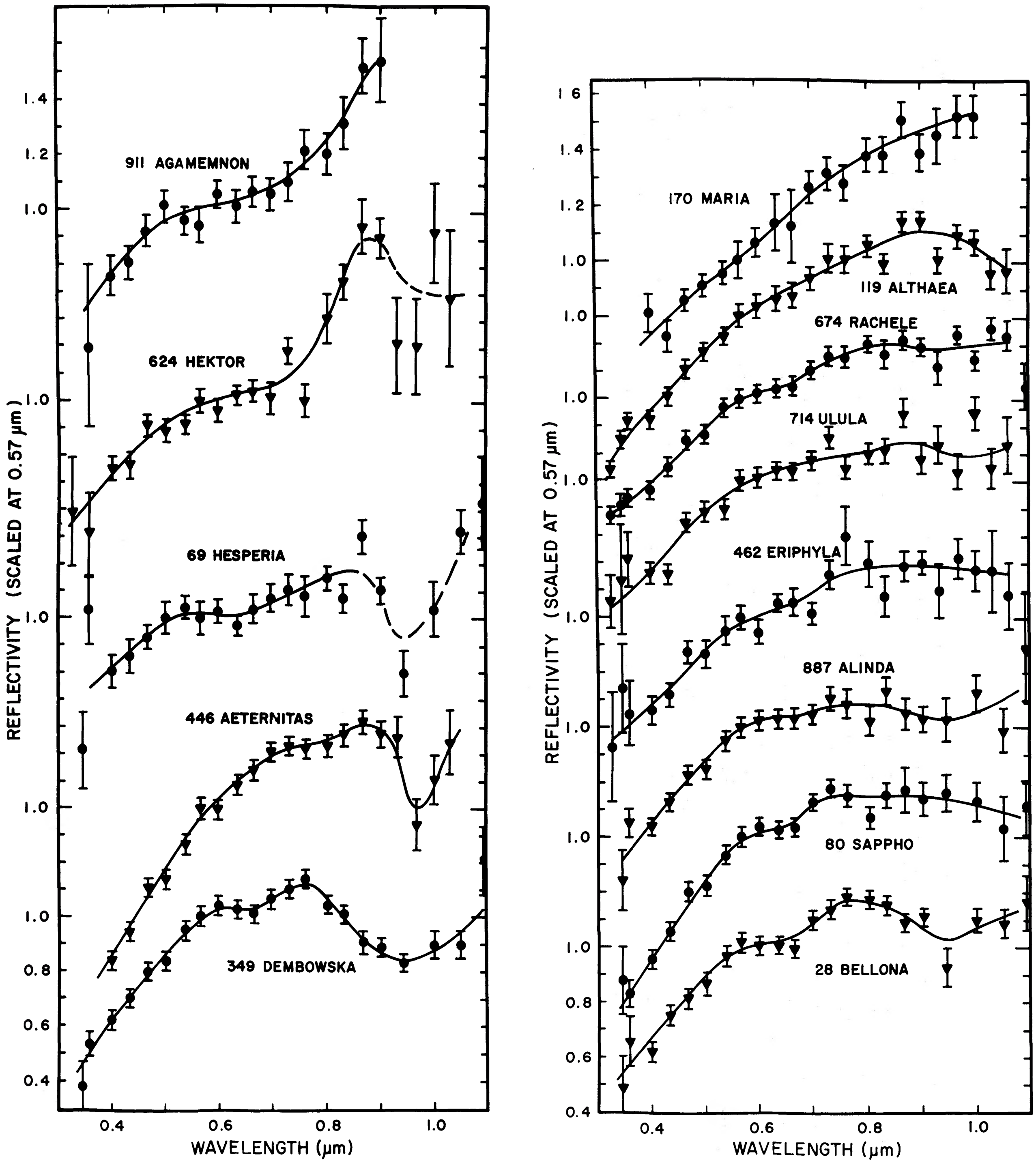

FIG. 1*a*

FIG. 1*b*

FIG. 1.—Spectral reflectance curves for 31 asteroids, scaled to unity at 0.57 μ. Error bars are derived from the internal consistency of the data (see text). The lines are eye fits to the data.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

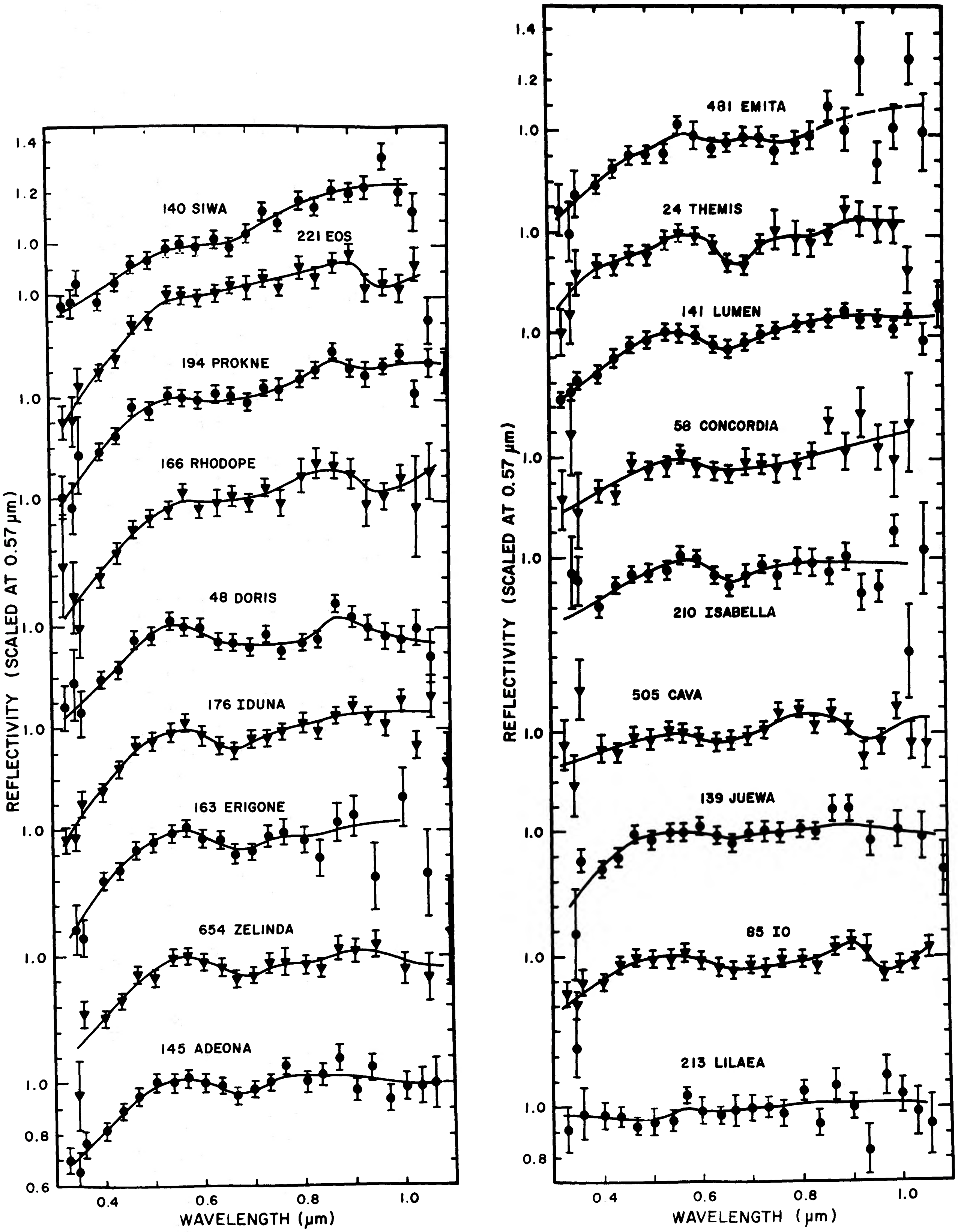

Fig. 1c

Fig. 1d

Fig. 1.—*Continued*

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1975ApJ...197..781M

TABLE 1

EFFECTIVE FILTER WAVELENGTHS (μ)

1973 September Observations			1974 February Observations	
S-1	S-20	Ga-In-As	S-1	S-20
0.331	0.331	0.329	...	...
0.343	0.343	0.342	0.343	0.342
0.363	0.363	0.363	0.360	0.361
0.405	0.406	0.406	0.403	0.404
0.438	0.438	0.438	0.435	0.435
0.472	0.472	0.472	0.469	0.469
0.503	0.503	0.503	0.500	0.500
0.538	0.538	0.538	0.534	0.533
0.566	0.565	0.566	0.566	0.566
0.605	0.604	0.605	0.599	0.599
0.637	0.637	0.637	0.633	0.632
0.670	0.669	0.670	0.665	0.665
0.701	0.700	0.701	0.699	0.699
0.735	0.733	0.735	0.730	0.729
0.768	0.767	0.768	0.764	0.763
0.800	0.798	0.800	0.800	0.798
0.835	0.832	0.835	0.835	0.832
0.868	...	0.868	0.868	...
0.902	...	0.889	0.905	...
0.933	...	0.922	0.947	...
0.967	...	...	1.002	...
0.998	...	...	1.052	...
1.030	...	...	1.098	...
1.063	...	...	...	...
1.098	...	...	...	...

the systematic biases potentially existing in our calibration.

A possible example of such a calibration problem is the slight absorption feature near 0.65 μ which exists to some degree in the spectra of nearly all asteroids we have measured. The presence of this feature in the spectra of asteroids of obviously different mineralogy, and its absence in the laboratory spectra of most meteorites and rocks, suggests that it is partly a spurious feature. On the other hand, some asteroids show the feature much more strongly than others, especially those that otherwise resemble C2 meteorites. C2 meteorites usually do show (Gaffey 1975) a weak feature at that wavelength. Thus the 0.65 μ feature is probably partly real, but the extent to which its presence in the spectra of most asteroids is spurious cannot be reliably judged until a reanalysis of our calibrations, currently under way, is complete.

The spectral reflectance data for the new observations of nine asteroids previously observed are presented in figure 2. In this figure, the data points and error bars are for the new data only, but the lines are fits to appropriately weighted averages of the new data *and* the previous data, and thus represent the best available reflectance curves for those asteroids.

III. SPECTRAL CHARACTERISTICS

In our previous paper (McCord and Chapman 1975) we defined nine spectral parameters that can be measured from spectral reflectance curves that are compositionally significant or that empirically distinguish among asteroid spectra. We tabulated the four best-determined parameters: R/B (reflectance at 0.7 μ divided by that at 0.4 μ); "Bend" (a measure of positive curvature of the visible part of the spectrum); "IR" (an infrared slope parameter sensitive to olivine); and a pyroxene absorption band depth parameter. In table 2 we tabulate the same parameters for our new sample of asteroids. Asterisks indicate asteroids previously observed; the tabulated values are improved values based on the lines in figure 2.

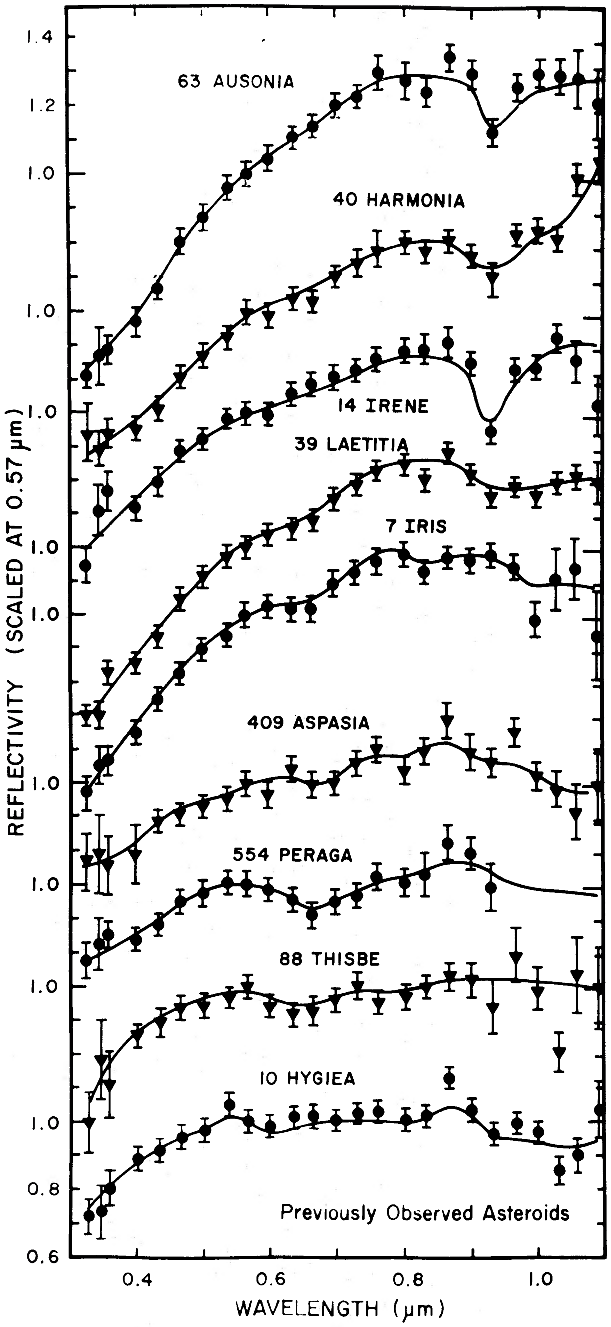

FIG. 2.—New spectral reflectance data for nine asteroids previously observed. Here the lines are fits to weighted means of these new data with previously published data.

1975ApJ...197..781M

TABLE 2

Asteroid Spectral Reflectance Parameters

Number	Asteroid	R/B	Bend	IR	Infrared Band Depth
*7	Iris	1.639	0.170	−0.045	~1
*10	Hygiea	1.143	0.120	−0.080	?
*14	Irene	1.470	0.133	0.093	0.830
24	Themis	1.041	0.175	(0.100)	~1
28	Bellona	1.639	0.175	0.010	(0.877)
*39	Laetitia	1.742	0.160	0.010	0.933
*40	Harmonia	1.652	0.155	0.150	0.934
48	Doris	1.200	0.295	0.015	~1
58	Concordia	1.103	0.155	(0.145)	~1
*63	Ausonia	2.069	0.180	0.045	0.892
69	Hesperia	1.309	0.130	(0.170)	(0.791)
80	Sappho	2.036	0.270	−0.060	~1
85	Io	1.056	0.145	0.070	0.900
*88	Thisbe	1.135	0.135	(0.020)	~1
119	Althaea	1.735	0.145	0.015	~1
139	Juewa	1.152	0.150	0.000	~1
140	Siwa	1.290	0.080	(0.140)	~1
141	Lumen	1.155	0.165	0.080	~1
145	Adeona	1.189	0.200	0.000	~1
163	Erigone	1.192	0.260	(0.080)	~1
166	Rhodope	1.443	0.265	(0.080)	(0.929)
170	Maria	1.697	−0.010	(0.245)	~1
176	Iduna	1.258	0.265	(0.100)	~1
194	Prokne	1.282	0.200	0.125	~1
210	Isabella	1.101	0.200	...	...
213	Lilaea	1.036	0.030	(0.010)	~1
221	Eos	1.500	0.225	(0.045)	0.912
349	Dembowska	1.718	0.260	−0.150	0.75
*409	Aspasia	1.245	0.105	−0.070	~1
446	Aeternitas	2.644	0.250	(0.07)	(0.774)
462	Eriphyla	1.615	0.140	(0.025)	~1
481	Emita	1.241	0.215	(0.135)	~1
505	Cava	1.076	0.045	(0.045)	0.907
*554	Peraga	1.120	0.167	(0.010)	~1
624	Hektor	1.448	0.150	(0.305)	?
654	Zelinda	1.225	0.289	0.010	~1
674	Rachele	1.625	0.170	(0.070)	~1
714	Ulula	1.629	0.215	(0.035)	?
887	Alinda	1.631	0.265	(0.025)	(0.954)
911	Agamemnon	1.437	0.120	...	...

* These values are improved by incorporating new data with previous data.

All nine parameters can be employed to define apparent groupings of spectral curves in a nine-dimensional classification space. Such spectral types may indicate distinctive mineralogy or perhaps different mixtures of several fundamental components. Approximately 27 significantly different types were recognized by McCord and Chapman (1975), although assignment of an individual asteroid to a type was not always deemed significant. The new asteroid sample has yielded nine additional spectral types. Also, eight of the original ones have been augmented, and much-improved observation of one previously observed asteroid (14 Irene) has shifted it to a different type. Let us first describe the nine new spectral types, since several of these are of great importance.

Asteroid 349 Dembowska shows a striking spectral reflectance curve, so far unique among our sample of 98 asteroids. It exhibits an infrared absorption band fully as deep as that of Vesta. However, the center of the absorption band is at a longer wavelength than that of Vesta, and the shape of the curve in the visible is dramatically different. In the important respects, Dembowska's spectral reflectance is identical to that of laboratory measurements of highly metamorphosed ordinary chondritic meteorites (e.g., Gaffey 1975; Chapman and Salisbury 1973). The shape and position of the absorption band suggests a high olivine content with a pyroxene/olivine proportion most similar to that of type LL6 chondrites in the Van Schmus and Wood (1967) classification. L-type chondrites cannot be ruled out, but H-types are excluded. One slightly discrepant characteristic of the Dembowska reflection spectrum is the slight dip near 0.65 μ; this may be a stellar calibration artifact, as suggested in the previous section. Dembowska is only the second asteroid to be identified as having surface mineralogy similar to that of the most common meteorites, the ordinary chondrites. The other is 1685 Toro (Chapman, McCord, and Pieters 1973*b*), which most closely resembles type L5 chondrites but has a somewhat lower albedo than is typical for these meteorites. Unlike Toro, which is a small Apollo asteroid, Dembowska is a large object (>150 km diameter) located in the outer part of the main asteroid belt near 2.92 AU.

The two Trojan asteroids 624 Hektor and 911 Agamemnon are the first asteroids we have measured that lie beyond the main asteroid belt. Both objects were very faint, so we were unable to obtain adequate infrared data, but the ultraviolet and visual data suffice to show that both objects share the same unusual spectral characteristics. Although these objects are almost neutral in color in the visible, they are somewhat darker in the ultraviolet and show striking increases in reflectivity in the red and near-infrared. This spectral signature may be potentially identifiable; Gaffey (1974) suggests it is due to a "CT-CF" material (charge transfer–crystal field), and he rules out a carbon-rich mineral assemblage. In any case, it is significant that these two objects, trapped together in the same Jovian Lagrangian point perhaps from the earliest solar-system epochs, have similar spectra.

Asteroid 887 Alinda made a close approach to the Earth in early 1974. Alinda's spectral reflectance curve is significantly different from most reddish asteroid spectra in one important respect: the degree to which the spectrum changes from a reddish slope in the ultraviolet and blue to a horizontal slope in the red and infrared (large value of "Bend"). This is a common property of laboratory measurements of silicate-rich meteorites, but is unusual among asteroids. In all respects, Alinda's spectrum matches that of laboratory spectra of the relatively unequilibrated ordinary chondrites such as Bremervörde (type H3). But due to poor observing weather, the quality of the data is only marginally sufficient to demonstrate the presence of the weak pyroxene absorption feature characteristic of these meteorites, and is insufficient to specify the band position which would be necessary to yield a definitive interpretation of the type of pyroxene and proportion of olivine present on the asteroid surface.

Asteroid 80 Sappho is a fairly small object located

© American Astronomical Society • Provided by the NASA Astrophysics Data System

near the inner edge of the main asteroid belt. Its spectrum is similar to Alinda's in many respects. However, Sappho is slightly redder than Alinda, shows no evidence of an absorption feature, and probably has a lower albedo (Matson 1972) than Alinda (Zellner *et al.* 1974; Morrison 1974). One meteorite measured by Hunt and Salisbury (1975) is a reasonable match to Sappho; it is Lancé, a type C3O. But it is a somewhat atypical example of such meteorites, and Sappho's spectrum must be regarded as undiagnostic, although resembling some relatively metamorphosed carbonaceous chondrites.

Asteroid 446 Aeternitas, in Ceres' Hirayama family (Williams 1975), has the reddest asteroid spectrum ever measured. 170 Maria has a steeply sloping, reddish spectrum, virtually identical to those of some lunar maria soils. 69 Hesperia has some spectral characteristics of some achondritic meteorites, but further data are needed. Other new spectral types consist of: 48; 213; and 166, 194, and 221.

Improved observations of 14 Irene show a moderately deep but narrow infrared absorption feature, and an overall spectrum similar to spectral characteristics for 89 Julia. Therefore, we assign it to the same spectral type as Julia, and list the one other asteroid with which it had been grouped (79 Eurynome) as a Juno type. One new asteroid also has a spectrum similar to that of Juno: 28 Bellona.

Other types previously defined that have been augmented by the new asteroid sample are: the 12 Victoria type (119); the 9 Metis type (462, 674, and 714); the 51 Nemausa type (145, 163, 176, and 654); the 324 Bamberga type (141, 58, 210, 481, 24, and 505); the 10 Hygiea type (85); and the 511 Davida type (139 Juewa).

A particularly striking characteristic of the new sample is that such a large percentage of the new asteroids are of the Nemausa and Bamberga types. These asteroids have spectral characteristics previously likened to laboratory measurements of primitive carbonaceous chondrites (type C2). Radiometric or polarimetric data show that observed asteroids of these types are dark or extremely dark (Chapman *et al.* 1975). These types, which comprise the left-hand mode of the bimodal R/B histogram (fig. 3), clearly predominate in the belt, since they are biased against in samples of bright asteroids. They are already more numerous than the Juno-type asteroids, a major component of the right-hand mode in figure 3, which were most common in our initial sample (Chapman *et al.* 1973*a*).

The question of how many additional spectral types may exist in the asteroid belt can be examined from our sampling statistics. We previously noted (McCord and Chapman 1975) that fainter main-belt asteroids were falling predominantly into spectral types already recognized, and that most new spectral types were arising from the dwindling number of unobserved bright asteroids. The new sample presented in this paper shows the same overall trend, but not so strongly as before. In addition to the non-belt asteroids which we anticipated might be spectrally different (and were: the Trojans and 887 Alinda), several of the new spectral types are due to 13th magnitude objects (170 Maria, 446 Aeternitas, and 213 Lilaea). Thus the total number of spectral types in the asteroid belt probably exceeds somewhat our earlier estimate of 40 to 50.

IV. DISCUSSION

We now comment briefly on several kinds of ramifications of our new results in order to augment similar discussions in our earlier data papers (Chapman *et al.* 1973*a*; McCord and Chapman 1975). More comprehensive analyses are given in other papers noted in our Introduction.

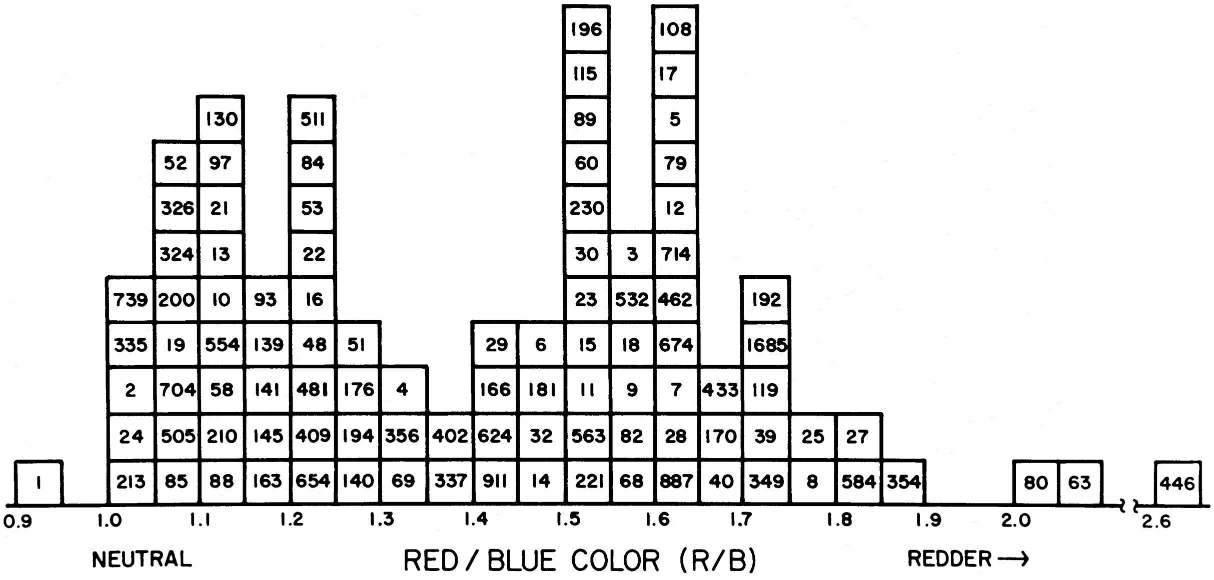

FIG. 3.—Frequency histogram for R/B color parameter

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1975ApJ...197..781M

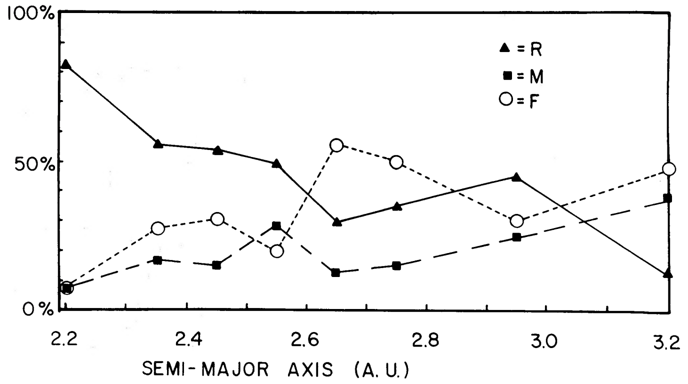

FIG. 4.—Percentage distribution of R, M, and F color groups as a function of semimajor axis

a) Correlation of Spectral Parameters with Orbital Elements

Reliable approximate colors (R = red, M = medium, F = flat spectrum) can be derived for 147 asteroids using the R/B parameter for the 98 asteroids we have observed, and other colorimetry as given in table 9 of Chapman *et al.* (1973*a*) and augmented by the *UBV* photometry of Dunlap (1974) and Howes and Gehrels (1973). As shown in figure 4, reddish asteroids predominate inside 2.3 AU and are very rare beyond 3.0 AU. Flat spectra tend to be common in the outer half of the asteroid belt where low-albedo carbonaceous material is believed to have condensed (Lewis 1972). However the color/semimajor axis relationship is seriously affected by sampling biases. A nearly complete sample is the largest 28 asteroids (diameters calculated by the radiometric or polarimetric methods, or inferred through the color albedo correlation by Chapman *et al.* 1975); only 5 to 20 percent of large asteroids beyond 2.7 AU are R, while perhaps 30 to 50 percent of those within 2.5 AU are R. Thus the dominant surface compositions of asteroids are carbonaceous, especially in the outer half of the belt (see Chapman *et al.* 1975 for a more detailed analysis).

A related correlation shows that many asteroids ($\sim 70\%$) with $a < 2.3$ AU have infrared absorption bands, whereas few asteroids ($\sim 10\%$) beyond 3.0 AU have bands. The "IR" parameter, low or negative values of which tend to indicate olivine, shows little variation with a among the 83 asteroids for which the parameter has been measured. But there is a significant tendency for the "Bend" parameter to average lower for $a < 2.5$ AU. McCord and Gaffey (1974) argue that "Bend" increases with increasing proportions of silicates; thus asteroids at small semimajor axes have lower proportions of opaques (metals in the case of R asteroids, carbon in the case of non-R asteroids).

b) Composition of Hirayama Families

The question of compositional homogeneity of Hirayama family members can now be addressed using our sample of 98 asteroid spectra (included within 147 asteroids of known color), since J. G. Williams (1975; also see Hartmann, Chapman, and Williams 1975) has published his final compilation of proper orbital elements and Hirayama family lists. A total of 63 asteroids with known colors (including 36 with measured spectra) represent 43 Hirayama families in the main asteroid belt deemed significant by Williams. To these we add three Trojan asteroids.

In table 3 we compare the spectra and colors of pairs or triplets of asteroids representing 16 families. For asteroids with measured spectra, the color sequence F, MF, M, MR, R, VR, VVR, VVVR, based on the R/B value and defined by McCord and Chapman (1975), is employed. The column indicating identical spectra is based on actual comparisons of the spectra, however, and not just these colors. For comparing other asteroid colors we employ the less precise sequence f, m, mr, vr, applying lowercase letters to designate the four color groups defined by Chapman *et al.* (1973*a*). In cases where colors are very poorly known, "fm" designates f or m, and "r" designates mr or vr. It appears from the table that a majority of the Hirayama families are composed of fragments with different surface compositions.

c) Rotational Variations of Color

It is important to determine the degree to which asteroids have inhomogeneous compositions by measuring their spectral reflectances as they rotate. During one night of the 1973 September observing run, eight different asteroids were kept under periodic surveillance during substantial portions of their probable rotation periods (light curves have not, however, been measured for most of them). Their spectra were measured approximately once every 45 minutes over a duration of 5 or 6 hours. None of the asteroids measured (numbers 141, 63, 119, 554, 674, 140, 176, and 145) showed significant spectral changes during the period. The spectral series have been especially carefully analyzed for asteroids 141, 554, and 674, and none show any significant spectral variation.

These data strengthen the case for general homogeneity of composition for asteroids and imply that the few known cases of minor color changes with rotation (4 Vesta and 6 Hebe; see Chapman *et al.*

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1975ApJ...197..781M

TABLE 3

COMPARISONS OF ASTEROID COLORS IN HIRAYAMA FAMILIES

	SPECTRAL REFLECTANCE SAMPLE			COLORIMETRY ONLY SAMPLE		
FAMILY NUMBER	Asteroid Number	Color	Identical Spectra?	Asteroid Number	Color	Similar Color?
1..........	24	F(f)	...	62	m	two similar, one different
				268	f	
2..........	221	R(mr)	...	1287	vr	two similar, one different
				1291	mr	
3..........	462	R(mr)	...	321	mr	two similar, one different
				658	vr	
4..........	714	R	no			
	170	VR				
67..........	1	F	no			
	39	VR				
	446	VVVR				
132..........	58	MF	yes			
	210	MF				
138..........	145	MF(f)	prob. no	70	fm	70 may be similar to either 145 or 166
	166	MR(m)				
140..........	15	R	no			
	85	MF	prob. yes			
	141	MF				
141..........	...	...	...	77	r	yes
				124	r	
148..........	402	MR(m)	...	510	m	yes
158..........	19	MF?	maybe			
	21	MF				
162..........	...	...	...	20	mr	yes
				182	r	
163..........	115	R	yes			
	584	VVR				
171..........	12	R	no			
	84	M				
189..........	8	VR(vr)	...	341	vr	yes
Trojans......	624	MR(m)	yes	1437	f	no
	911	MR(m)				

1973*a*) and the one suspected case of major change (19 Fortuna; McCord and Chapman 1975) are unusual. This might seem surprising in view of the likelihood of frequent asteroid collisions and the fact that Hirayama family members show considerable compositional heterogeneity, but it may be compatible with the model for asteroid collisional evolution proposed by Chapman (1975).

d) *Spectral Sampling of Proposed Meteorite Source Bodies*

Two dynamical modes for deriving meteorites from the main asteroid belt have been proposed recently (see review by Wetherill 1974). Zimmerman and Wetherill (1973) show that fragments knocked off certain asteroids into the nearby 2:1 Jupiter resonance at 3.27 AU will be perturbed by Jupiter and converted to Earth-crossing orbits of the appropriate type to account for meteorites. The second mode, proposed by Williams (1973), is analogous to the first, but involves secular resonances rather than the 2:1 Jupiter commensurability. Secular resonances are zones in *a-e-i* space; if fragments from asteroids located near these resonances approach the resonance, they will also be accelerated into Earth-crossing orbits.

Although the yield of meteorites on Earth has been predicted only approximately for the first mode, and not at all for the second, we can expect suitable candidate meteorite parents to be located as close as possible to these resonances or the 2:1 commensurability. Presumably the yield will be higher for larger objects which have a greater collisional cross section. But until quantitative calculations are made, we cannot be sure of the degree to which the sporadic nature of collisional events may sample these objects nonrepresentatively.

In tables 4 and 5 we give a shopping list of probable sources for meteorites, tabulated with regard to absolute magnitude g and an approximate measure of the proximity to the relevant resonance. Those asteroids shown in italics have already been sampled spectrophotometrically in our program. We have sampled a reasonable fraction of possible meteorite sources for $g = 7$ and brighter, only. It can be said that these largest potential source objects are *not* dominantly responsible for the meteorites that fall on the Earth.

But do the largest, best-situated objects we have

© American Astronomical Society • Provided by the NASA Astrophysics Data System

1975ApJ...197..781M

TABLE 4

SECULAR RESONANCE SOURCE

g = 5	6	7	8	9	10
		Best			
2		*130*	154	36	304
			386	426	329
				466	501
				772	581
				1317	582
					605
					631
					739
					1390
		Fair			
	6	31	*89*	344	132
			194	683	136
			849	790	186
				814	234
				895	795
					863
					907
					1005
		Possible			
			8	43	183
			13	*80*	270
			18	*115*	345
				176	439
				654	*584*
				1093	694
					733

TABLE 5

KIRKWOOD GAP SOURCE

g = 7	8	9	10
	Best		
		108	325
		122	530
		175	580
		381	581
		895	648
		1317	696
			781
			805
			892
			903
			927
			973
			978
			1109
			1303
			1567
	Fair		
511	154	*176*	
		184	
		469	
		545	
		758	
		760	
	Possible		
31	57	199	
92	94	489	
	106	490	
	488	491	
	702	508	
	849	595	
		618	
		762	
		814	

measured contribute *any* meteorites? One test is to see if the spectral properties of the asteroids in question (2 Pallas, 6 Hebe, 130 Elektra, and 511 Davida) are compatible with *some* known meteorite type. If they were not, then doubt would be cast on the proposed modes. Pallas and Davida have spectra similar to the laboratory spectrum of the very rare Karoonda meteorite, and the general spectral characteristics of these asteroids suggest a carbonaceous composition. Perhaps the reason we get few if any meteorites from these asteroids is that they are so large that their gravitational fields inhibit meteorites from being placed efficiently into the resonances. While the spectrum of 6 Hebe does not match a measured meteorite spectrum, Hebe is probably of stony-iron composition (McCord and Gaffey 1974). 130 Elektra has spectral characteristics similar to C2 meteorites. The other candidate sources that we have sampled probably can be reconciled with known meteorite types as well. Thus the incomplete observational evidence so far obtained does not rule out the proposed mechanisms for bringing asteroidal fragments to Earth.

We thank C. Pieters for assistance during both observing runs, and A. Goldberg during the 1974 February run. We are grateful for discussions with M. Gaffey and G. Wetherill. This work was funded in part by NASA grant NGR 22-009-583 to MIT, and NASA contracts NASW-2521 and NASW-2522 to the Planetary Science Institute. This is MIT Planetary Astronomy Laboratory Contribution No. 117 and Planetary Science Institute Contribution No. 36.

REFERENCES

Chapman, C. R. 1974, *Geophys. Res. Letters*, **1**, 341.

———. 1975, *Geochim. Cosmochim. Acta*, submitted.

Chapman, C. R., McCord, T. B., and Johnson, T. V. 1973*a*, *A.J.*, **78**, 126.

Chapman, C. R., McCord, T. B., and Pieters, C. 1973*b*, *A.J.*, **78**, 502.

Chapman, C. R., Morrison, D., and Zellner, B. 1975, *Icarus*, Vol. **25**, in press.

Chapman, C. R., and Salisbury, J. W. 1973, *Icarus*, **19**, 507.

Dunlap, J. L. 1974, *A.J.*, **79**, 324.

Gaffey, M. J. 1974, private communication.

———. 1975, *J. Geophys. Res.*, in press (also, Ph.D. thesis, MIT).

Gaffey, M. J., and McCord, T. B. 1975, in preparation.

Hartmann, W. K., Chapman, C. R., and Williams, J. G. 1975, *Rev. Geophys.*, submitted.

© American Astronomical Society • Provided by the NASA Astrophysics Data System

Howes, M. L., and Gehrels, T. 1973, *A.J.*, submitted.
Hunt, G., and Salisbury, J. W. 1975, *Mod. Geol.*, in press.
Lewis, J. S. 1972, *Earth Planet. Sci. Letters*, **15**, 286.
Matson, D. L. 1972, Ph.D. thesis, California Institute of Technology.
McCord, T. B., and Chapman, C. R. 1975, *Ap. J.*, **195**, 553.
McCord, T. B., and Gaffey, M. J. 1974, *Science*, **186**, 352.
Morrison, D. 1974, *Ap. J.*, **194**, 203.
Van Schmus, W. R., and Wood, J. A. 1967, *Geochim. Cosmochim. Acta*, **31**, 747.
Wetherill, G. E. 1974, *Ann. Rev. Earth Planet. Sci.*, **2**, 303.
Williams, J. G. 1973, *Eos*, **54**, 233.
———. 1975, in preparation.
Zellner, B., Gehrels, T., and Gradie, J. 1974, *A.J.*, **79**, 1100.
Zimmerman, P. D., and Wetherill, G. W. 1973, *Science*, **182**, 51.

CLARK R. CHAPMAN: Planetary Science Institute, 252 W. Ina Road, Suite D, Tucson, AZ 85704

THOMAS B. MCCORD: Planetary Astronomy Laboratory, Massachusetts Institute of Technology, Bldg. 24, Room 422, Cambridge, MA 02139

© American Astronomical Society • Provided by the NASA Astrophysics Data System