Camp, *Nature (London)* **263**, 551 (1976); B. C. Hunt, in *Climatic Change and Variability: A Southern Perspective*, A. B. Pittock, Ed. (Cambridge Univ. Press, London, in press).
3. J. R. Bray, *Nature (London)* **252**, 679 (1974).
4. ______, *ibid.* **248**, 42 (1974).
5. ______, *ibid.* **260**, 414 (1976), *ibid.* **262**, 330 (1976).
6. H. Wexler, *Tellus* **8**, 480 (1956).
7. H. Flohn, *Quat. Res. (N.Y.)* **4**, 385 (1974).
8. J. D. Ives, J. T. Andrews, R. G. Berry, *Naturwissenschaften* **62**, 118 (1974).
9. H. B. S. Cooke, *Quat. Res. (N.Y.)* **3**, 206 (1973).
10. W. F. Ruddiman, *Geol. Soc. Am. Bull.* **82**, 283 (1971).
11. L. A. Frakes, paper presented at the Australasian Conference on Climate and Climatic Change, 9 December 1975, Melbourne.
12. N. Calder, *Nature (London)* **252**, 216 (1974).
13. J. D. Hays, J. Imbrie, N. J. Shackleton, *Science* **194**, 1121 (1976).
14. J. D. Hays and D. Ninkovich, *Geol. Soc. Am. Mem. 126* (1970), p. 263.
15. J. R. Kennett and R. C. Thunell, *Science* **187**, 497 (1975).
16. D. Ninkovich and W. L. Donn, *ibid.* **194**, 899 (1976).
17. J. D. Boellstorff, *INQUA (Int. Quat. Assoc.) Abstr.* (1973), p. 33.
18. G. P. Eaton *et al.*, *Science* **188**, 787 (1975).
19. R. K. Matthews, *Earth Planet. Sci. Lett.* **5**, 459 (1969).
20. F. H. Chamalaun and I. McDougall, *Nature (London)* **210**, 1212 (1966).
21. H. Pichler and W. Friedrich, *ibid.* **262**, 373 (1976).
22. S. Nishimura and T. Yokoyama, *Proc. Jpn. Acad.* **49**, 615 (1973).
23. J. F. Evernden and G. H. Curtis, *Curr. Anthropol.* **6**, 343 (1965).
24. J. Frechen and H. J. Lippolt, *Eiszeitalter Ggw.* **16**, 5 (1965).
25. C. W. Naeser, G. A. Izett, R. E. Wilcox, *Geology* **1**, 187 (1973).
26. S. Ishida, K. Maenaka, T. Yokoyama, *Chishitsugaku Zasshi* **75**, 183 (1969).
27. G. A. Izett, R. E. Wilcox, G. A. Borchardt, *Quat. Res. (N.Y.)* **2**, 554 (1972).

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Asteroid Families: Observational Evidence for Common Origins

Abstract. *Colors of minor planets in the* UBV *system indicate compositions quite distinct from those of the field population in each of three Hirayama families. The Eos and Koronis families apparently originated from the collisional fragmentation of undifferentiated silicate bodies, and the Nysa group from a geochemically differentiated parent body.*

The recent availability of reflection spectroscopy (*1*), polarimetry (*2*), and thermal radiometry (*3*, *4*), leading to the compositional classification of a large number of minor planets (*5*), has revitalized the question of the significance of the dynamical families first recognized by Hirayama (*6*–*8*).

The dynamical families, which appear as clusterings in the orbital parameters semimajor axis, proper eccentricity, and proper inclination, are generally thought to represent fragments from the collisional breakup of discrete parent bodies (*9*). Thus the members of a single family should show identical compositions if the parent body was homogeneous, or else compositions belonging to some geochemically plausible stratigraphy if the parent body had geochemically evolved or had accreted in distinct layers (*10*). In the latter case we would now have access to the interior of a differentiated body in a way not possible for the major planets and planetary satellites.

Alfvén (*11*) and Trulsen (*12*) have suggested an alternative possibility for producing dynamical families—namely, that they are formed by the collisional focusing of unrelated field asteroids. For such an origin we would expect to find only the pattern of compositions characteristic of that region of the asteroid belt.

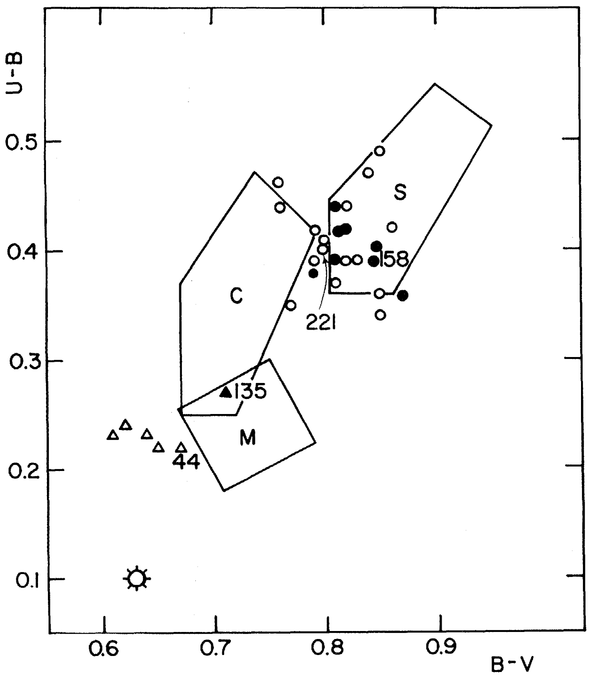

Fig. 1. Ultraviolet-minus-blue versus blue-minus-visual color indices for minor planets in the dynamical families associated with 221 Eos (○), 158 Koronis (●), and 44 Nysa (△). The M-type object 135 Hertha associated with the Nysa family is indicated by (▲). Solar colors of $B - V = 0.63$ and $U - B = 0.10$ are indicated. Family memberships are as assigned by Williams (*8*). Domains indicating the colors of the common C, S, and M asteroid types are adapted from work by Bowell (*15*) and Zellner *et al.* (*16*).

For the hundred or so brighter asteroids, attempts to reconstruct the progenitors of families have generally been disappointing. Chapman (*13*) has noted, for example, that there is no attractive way to reconstruct a single parent body from the S object 15 Eunomia and the C objects 85 Io and 141 Lumen. A statistical study by Hansen (*14*) based on published compositional identifications of the brighter asteroids gave rather inconclusive results. Chance orbital similarities between objects of different provenance are, of course, possible, but if such heterogeneous mixtures turn out to be the rule, then the view of families as fragmentation products is in serious jeopardy.

Figure 1 illustrates *UBV* colors for three families which show strong evidence of consanguinity. The data are preliminary results from continuing photometric surveys at the Lowell Observatory (*15*) and the University of Arizona (*16*). While *UBV* photometry is a coarse tool for elucidating compositional differences between asteroids, the ultraviolet-minus-blue ($U - B$) and blue-minus-visual ($B - V$) color indices are generally sufficient to distinguish the principal C, S, and M types and to recognize objects belonging to rarer or unknown types (*16*). Broadband colorimetry is, moreover, the only technique with which it is possible to reach almost any numbered asteroid with telescopes of modest size.

The 44 Nysa family at a mean semimajor axis, *a*, of 2.43 A.U. contains Nysa itself, a rather large, irregularly shaped object (66 by 102 km) of the very rare E type, which may be identifiable with any bright, colorless, refined silicate such as plagioclase or forsterite, but quite likely corresponds to the iron-free enstatite achondrites (*17*). The family also contains the M or metallic-type object 135 Hertha of diameter about 80 km, and a dozen numbered asteroids in the 10-km size range (*18*). At least four of the smaller objects are seen in Fig. 1 to resemble 44 Nysa closely, with colors entirely atypical of the predominant asteroid population.

The geochemical implications of the Nysa-Hertha family are more closely examined elsewhere (*19*). The configuration is strongly suggestive of the remnants of a melted, geochemically differentiated body of initially chondritic composition; 135 Hertha provides the nickel-iron core and 44 Nysa is the largest surviving fragment of a stony mantle.

The Eos and Koronis families are among the best-defined groups (*8*), but unlike the Nysa group, the Eos family at a = 3.01 A.U. and the Koronis family at a = 2.87 A.U. consist not of one or two large objects plus assorted small chips but rather of a continuum of sizes with the five or ten largest objects having comparable diameters. Both families fall in the outer parts of the belt where the field population, at least for diameters > 50 km, is 85 to 90 percent of type C (*5*). Neither group seems to contain any classical C objects with $B - V \sim 0.7$ and $U - B \sim 0.3$. The eight measured Koronis members seem to be of the S type, whereas the Eos objects cluster about a point intermediate between the domains of the typical C and S populations. The dispersion in the colors is partially attributable to observational scatter for such faint objects.

The Eos and Koronis family members are generally too small and distant to have been picked up in bright-asteroid surveys. For 208 Lacrimosa in the Koronis family, Morrison (*3*) has derived, by the method of thermal radiometry, a geometric albedo of 0.14, which puts it firmly in the S class. For 221 Eos itself McCord and Chapman (*1*) have reported a reflection spectrum of unusual type, showing the ultraviolet dropoff characteristic of ferrous silicates and a weak absorption band near 0.97 μm probably attributable to pyroxene, but without the overall spectral redness that is a signature of free iron in the typical S objects. Apparently Eos consists of a mixture of silicates yet to be specifically identified, probably rather close to chondritic in elemental composition but with no exact analog among known meteorite types.

In any case, both the Eos and Koronis families clearly resulted from the fragmentation of discrete undifferentiated parent bodies and not from random collections of the C-dominated populations in their vicinities.

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References and Notes

1. T. B. McCord and C. R. Chapman, *Astrophys. J.* **197**, 781 (1975).
2. B. Zellner and J. Gradie, *Astron. J.* **81**, 262 (1976).
3. D. Morrison, *Astrophys. J.* **194**, 203 (1974); *Icarus*, in press.
4. O. Hansen, *Astron. J.* **81**, 74 (1976).
5. C. R. Chapman, D. Morrison, B. Zellner, *Icarus* **25**, 104 (1975); B. Zellner and E. Bowell, in *The Interrelated Origin of Comets, Asteroids, and Meteorites*, A. H. Delsemme, Ed. (Univ. of Toledo Publications, Toledo, Ohio, in press). The principal types are designated C or carbonaceous, identifiable with carbonaceous chondrites and accounting for ~ 76 percent of the population; S or silicaceous (16 percent), consisting of ferromagnesian silicates plus iron, and identifiable probably with H chondrites or stony-iron achondrites; and M or metallic (5 percent), identifiable with nickel-iron meteorites or possibly the metal-rich enstatite chondrites.
6. K. Hirayama, *Astron. J.* **31**, 185 (1918); *Jpn. J. Astron. Geophys.* **5**, 137 (1928).
7. D. Brouwer, *Astron. J.* **56**, 9 (1951); J. Arnold, *ibid.* **74**, 1235 (1969). The so-called proper orbital elements are corrected for periodic perturbations due to secular variations in the orbits of the major planets.
8. J. Williams, in preparation.
9. E. Anders, *Icarus* **4**, 399 (1965).
10. Some likely internal structures for geochemically differentiated asteroids have been proposed by C. R. Chapman [*Sci. Am.* **232**, 24 (1975)]. Since a bullet/target mass ratio < 1 percent is adequate for explosive fragmentation of the target body (*13*), we do not expect to find pieces of the bullet among the major fragments.
11. H. Alfvén, *Astrophys. Space Sci.* **6**, 161 (1969).
12. J. Trulsen, *NASA Spec. Publ. SP-267* (1971), p. 327.
13. C. R. Chapman, *Geochim. Cosmochim. Acta* **40**, 701 (1976).
14. O. Hansen, *Icarus*, in press.
15. E. Bowell, in preparation.
16. B. Zellner, W. Wisniewski, L. Andersson, E. Bowell, *Astron. J.* **80**, 986 (1975); B. Zellner, L. Andersson, J. Gradie, *Icarus*, in press.
17. B. Zellner, *Astrophys. J.* **198**, L45 (1975).
18. Williams (*8*) prefers to regard Nysa and Hertha as belonging to two contiguous families, slightly separated in orbital inclination. The reality of the division is debatable.
19. B. Zellner, M. Leake, D. Morrison, J. Williams, *Geochim. Cosmochim. Acta*, in press.
20. Supported by the National Aeronautics and Space Administration.

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Enhancement of Photochemical Smog by *N,N'*-Diethylhydroxylamine in Polluted Ambient Air

Abstract. *A recent proposal for controlling photochemical smog by the addition to ambient air of 0.03 to 0.05 part per million of diethylhydroxylamine (DEHA) is shown to be invalid. The addition of DEHA in the range of 0.05 to 0.5 part per million to ambient air irradiated with sunlight in a dual outdoor environmental chamber caused marked increases in the rates of formation and concentrations of ozone, peroxyacetyl nitrate, and light-scattering particles.*

Photochemical smog, formed by the action of solar ultraviolet radiation on polluted ambient air containing hydrocarbons (HC) and oxides of nitrogen (NO_x), is characterized by such undesirable phenomena as the conversion of NO to NO_2 and the production of O_3, peroxyacetyl nitrate (PAN), and light-scattering particles (*1*). Although strategies for smog control have focused almost exclusively on reducing the emissions of reactive HC and NO_x (for example, automobile control devices), the possibility of suppressing photochemical smog by introducing into the atmosphere chemicals known to be free radical "traps" (or smog inhibitors) has been discussed for at least 15 years (*2*).

The possible use of *N,N'*-diethylhydroxylamine $[(C_2H_5)_2NOH]$, or DEHA] as an inhibitor has been investigated by Heicklen and his co-workers (*3, 4*); they recently recommended that DEHA be introduced into polluted urban air at concentrations of about 0.03 to 0.05 part per million (ppm) (5–7). This proposal was based on laboratory experiments conducted with DEHA, NO_x, and two olefinic hydrocarbons, ethylene and propylene, at concentrations of several parts per million in O_2; in these experiments DEHA inhibited the conversion of NO to NO_2 and the formation of O_3 (*3, 4*).

According to Heicklen, the advantages of adding DEHA to urban atmospheres rather than using automobile control devices are numerous: DEHA controls stationary as well as mobile source emissions; the method is projected to be cheaper by at least a factor of 100 than automobile control devices and can provide for the immediate elimination of photochemical smog, whereas it will take at least 10 years to equip all cars with emission control devices (*5, 7*). For these reasons, this proposal has received attention not only from air pollution control officials and atmospheric scientists (*8–10*) but also from the general public (*11*).

Two major questions arise from the proposal to add DEHA to polluted urban atmospheres (*7*): the possible toxicity of DEHA and its reaction products in ambient air (*1, 8*), and the validity of extrapolating laboratory results to "real" urban atmospheres. Thus it has been suggested that, even though DEHA might delay the formation of photochemical smog, this would transfer the problem downwind (*1, 8*).

The question of the possible toxicity of DEHA and its reaction products has been raised (*1, 4–10*), but will not be addressed here. We report here on tests of the effectiveness of DEHA as an inhibitor of photochemical smog under closely simulated atmospheric conditions. Our study was conducted in an 80-m^3 dual outdoor environmental chamber constructed from 2-mil FEP Teflon film (*12*). Two types of experiments were conducted: in three cases we used morning Riverside ambient air and either 0.1