close to the A+ direction obtained from the margin of the Kaap Valley pluton tonalite and reflects overprinting of the Moodies shale during pluton emplacement.

Zircon from a dike from the Clutha Mine (Fig. 1) that crosscuts the folded Moodies sediments has a single-grain Pb-Pb age of 3224.5 ± 0.4 Ma (Table 3), indicating that the Moodies was folded before this time. Because the A magnetization was acquired after folding, it is therefore only constrained to be younger than 3224 Ma and may coincide with the hornblende age of 3214 Ma.

Our paleomagnetic study of the Kaap Valley pluton shows two distinct magnetic directions. One is positive inclination that corresponds to an overprint direction caused by the intrusion of presumed early Proterozoic dikes and is seen in both the interior and margin of the pluton. The other direction is characterized by a negative inclination in the interior of the pluton (which is absent from the pluton margin) and an antipodal positive inclination in the margin of the pluton and in sediments adjacent to the pluton (which is present to a lesser degree in the pluton interior). This direction is significantly different from the present-day magnetic field direction and cannot be correlated with the timing of later thermal events that could have caused a magnetic overprinting. We believe this is a primary magnetization, acquired during cooling of the pluton at 3214 Ma. The data suggest that a reversal of Earth's magnetic field is preserved in the Kaap Valley pluton, making it the oldest observed reversal and implying that the reversing geomagnetic dynamo has been operating since the early Archean.

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Spectral Properties of Near-Earth Asteroids: Evidence for Sources of Ordinary Chondrite Meteorites

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Although ordinary chondrite (OC) meteorites dominate observed falls, the identification of near-Earth and main-belt asteroid sources has remained elusive. Telescopic measurements of 35 near-Earth asteroids (~3 kilometers in diameter) revealed six that have visible wavelength spectra similar to laboratory spectra of OC meteorites. Near-Earth asteroids were found to have spectral properties that span the range between the previously separated domains of OC meteorites and the most common (S class) asteroids, suggesting a link. This range of spectral properties could arise through a diversity of mineralogies and regolith particle sizes, as well as through a time-dependent surface weathering process.

Of the meteorites falling to Earth, 80% are stones consisting of olivine and pyroxene, which are classified as ordinary chondrites (OCs). They are thought to represent samples of the primitive solar nebula that have undergone modest thermal evolution over the age of the solar system (*1*). The most immediate sources for meteorites are likely to be near-Earth asteroids (*2*), which in turn are derived predominantly from the main asteroid belt (*3*). Relatively few spectroscopic observations of near-Earth asteroids have been obtained because of their small sizes, faint apparent magnitudes, and limited intervals of visibility. Of these measured asteroids, only one (1862 Apollo) has spectral properties widely recognized as similar to the laboratory spectral properties of OC meteorites (*4–6*). We now report the results of a survey of the visible-wavelength spectral properties of near-Earth asteroids: we find many that appear to have spectra similar to OC meteorites.

There has also been a long-standing debate over whether the most commonly observed (S class) asteroids are related to the most common meteorites, in spite of a mismatch in their red spectral slopes and absorption band depths. One hypothesis for this spectral mismatch is that some "space weathering" process is responsible for altering the spectral properties of OC asteroids (*7*). Another hypothesis is that Apollo-like OC asteroids (the Q class) exist as a population of small objects distinct from the S-class asteroids (*8*). Our observations do not reveal a distinct population of Q-class objects among small near-Earth asteroids.

We made spectroscopic measurements of 35 near-Earth asteroids, which we have obtained as target-of-opportunity observations over 1991 through 1996. In making these observations, we used a low-resolution spectrograph and solid-state charge-coupled device (CCD) detectors attached to the 2.4-m Hiltner telescope of the Michigan–Dartmouth–Massachusetts Institute of Technology (MDM) Observatory at Kitt Peak, Arizona (*9*). Our spectra cover the visible-wavelength range from 0.45 to 0.95 μm. Over these wavelengths, most of the asteroids categorized within the S class and most of the near-Earth asteroids we measured display spectra with a moderate absorption band near 1 μm, which arises owing to the presence of olivine and pyroxene (*10, 11*). However, six of the near-Earth asteroids we measured have spectra that display unusually deep 1-μm absorption bands (Fig. 1). Over our measured wavelength range, the spectra of these near-Earth asteroids do not resemble 4 Vesta (Fig. 1A), but they do appear similar to the spectra of 349 Dembowska and 1862 Apollo (Fig. 1B) (*12, 13*). Although Dembowska and Apollo clearly have distinguishable near-infrared spectra (*14*), such measurements for our set of faint near-Earth asteroids are not yet available. We make an inference for the spectra of our set of near-Earth asteroids by considering the mineralogies (based on near-infrared measurements) and meteorite analogs for Dembowska and Apollo. Dembowska is considered to be a pyroxene-olivine assem-

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blage with little or no metal (*14*). Apollo is interpreted to have a metal, olivine, and pyroxene mineralogy similar to that of OC meteorites (*5*). Given that Dembowska is an outer main-belt asteroid with no known dynamical link to the inner solar system and that no Dembowska-like meteorites are present in our collections (*15*), we infer that six of our sampled near-Earth objects are much more likely to be analogous to the OC-like near-Earth asteroid 1862 Apollo.

The spectra of these six near-Earth asteroids are similar to the laboratory spectra of OC meteorites (Fig. 2). There is considerable variation in measured band depths among H, L, and LL chondrites and for metamorphic grades within each of these OC categories (*16*). We find that the average for H6 chondrites (a subclass of OC meteorites) provides the most consistent match to our observations as a whole, but given our spectral coverage, we are not able to distinguish among H, L, or LL chondrite analogs for these near-Earth asteroids.

In addition to identifying six potential OC-like near-Earth asteroids (Fig. 2), we found 29 that have spectral properties intermediate between those of S asteroids and those of OC meteorites (Fig. 3, A and B).

These 29 near-Earth asteroids display a continuum of 1-μm band depths spanning the range between S asteroids and OC meteorites (Fig. 3B). Because the spectral distribution is continuous rather than discrete, our results argue against Apollo-like (Q-class) asteroids existing as a group distinct from the S class (*8*). However, our observations do not reveal the nature of the factors that give rise to this apparent continuum of spectral properties.

Most of the observed near-Earth asteroids have estimated diameters of ≤3 km; these objects are thus the smallest asteroids that have been spectrally measured to date (*17*). One possibility for the continuum of spectral properties is that asteroids in this size range are more likely than are larger asteroids to be composed of distinct lithologic units derived from larger asteroids, thereby giving rise to a greater diversity of mineralogies and spectral properties. For example, larger S asteroids may be composed of heterogeneous units for which hemispherically averaged spectra obtained by telescopic techniques cannot reveal the presence of distinct units (*10, 18*). For this scenario, only among a suite of smaller asteroids that individually may be composed of discrete units would a continuum of lithologies be possible. Another factor is that, for a given mineralogy, variations in regolith particle sizes and in the abundance

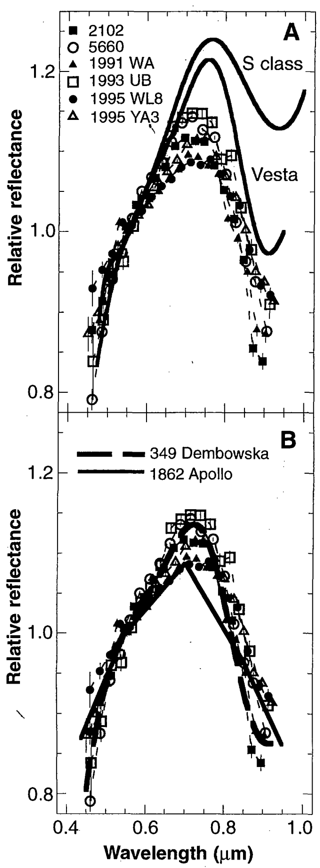

Fig. 1. (**A** and **B**) Comparison between the spectra of six near-Earth asteroids (points) having deep 1-μm absorption bands and the spectra of possibly analogous asteroid types (bold lines). The S asteroid and Dembowska spectra are from (*9*), where the former represents an average of several hundred asteroids. The Vesta-like spectrum is that of the main-belt Vesta fragment 2590 Mourao (*13*). The data for 1862 Apollo (*21*) have a lower resolution, which gives rise to the poorer match in curvature at 0.8 μm. All spectra are normalized to unity at 0.55 μm (*22*).

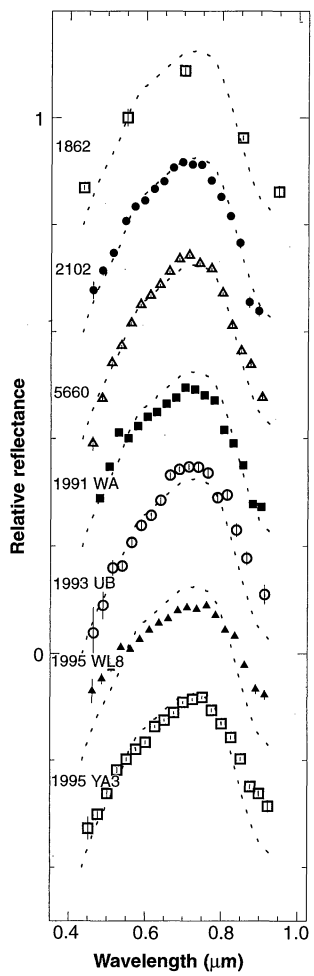

Fig. 2. Visible-wavelength reflectance spectra for six recently observed near-Earth asteroids (plus 1862 Apollo) compared with laboratory measurements for OC meteorites. Superimposed on each asteroid spectrum (points) is an OC meteorite spectrum (dashed lines) represented by the average for H6 chondrites (*16*). All spectra are normalized to unity at 0.55 μm and are offset vertically by 0.2 for clarity. Data for 1862 Apollo are from (*21*).

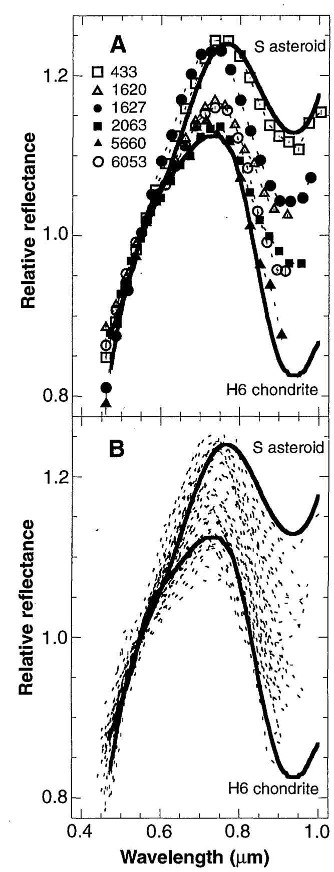

Fig. 3. Visible-wavelength reflection spectra for near-Earth asteroids spanning the gulf separating the spectra of S asteroids (upper solid line) from OC meteorites (lower solid line). (**A**) Spectra for six asteroids are presented to show the range of variations for individual objects. (**B**) Spectra for 35 near-Earth asteroids (*23*) are indicated by dashed lines only. In both (A) and (B), all spectra are normalized to unity at 0.55 μm but are not offset. The S-asteroid spectrum represents an average from main-belt S asteroids (*9*), and the meteorite spectrum is an average for H6 chondrites (*16*).

of opaque materials can give rise to a range of absorption band depths similar to the range observed (*14*).

As a final possibility for interpreting the observed range of spectral properties spanning the divide between S asteroids and OC meteorites, we would suggest that asteroids in the observed size range have the most diverse range of ages of any asteroid population sampled to date. Because significant collisions occur much more frequently for small objects, "young" fragments or "fresh" surfaces are most likely to be found among small asteroids (*19*). However, because collisions are a stochastic process, the sampled population will contain a wide range of surface ages. If a time-dependent weathering process (*7*) is active, as has been proposed to explain surface variations measured in Galileo spacecraft images of 243 Ida (*20*), asteroids most closely resembling OC meteorites would be those with the youngest surfaces. For this scenario, a wide range of surface ages could give rise to a continuum of spectral properties, such as we have observed.

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23. The following near-Earth asteroid spectra are presented in Fig. 3B: 433, 1036, 1620, 1627, 1864, 1866, 2062, 2063, 2102, 4179, 4954, 5143, 5626, 5660, 6053, 6489, 6455, 6569, 1989 VA, 1991 BB, 1991 VK, 1991 WA, 1991 XB, 1992 CC1, 1993 TQ2, 1993 UB, 1993 WD, 1993 XN2, 1994 AB1, 1994 AW1, 1994 EF2, 1994 TW1, 1995 BL2, 1995 WL8, and 1995 YA3.

24. Data reported here were obtained at the MDM Observatory. This work was supported by NASA grants NAGW1450, NAGW3901, and NASW5026 and by a National Science Foundation Presidential Young Investigator Award (R.P.B.). A grant from the Planetary Society provided additional access to the telescope essential for the success of this project. We thank B. G. Marsden, G. V. Williams, and E. L. G. Bowell for assistance with ephemerides for newly discovered objects and M. Gaffey and an anonymous referee for helpful reviews.

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Arabidopsis AUX1 Gene: A Permease-Like Regulator of Root Gravitropism

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The plant hormone auxin regulates various developmental processes including root formation, vascular development, and gravitropism. Mutations within the *AUX1* gene confer an auxin-resistant root growth phenotype and abolish root gravitropic curvature. Polypeptide sequence similarity to amino acid permeases suggests that *AUX1* mediates the transport of an amino acid–like signaling molecule. Indole-3-acetic acid, the major form of auxin in higher plants, is structurally similar to tryptophan and is a likely substrate for the *AUX1* gene product. The cloned *AUX1* gene can restore the auxin-responsiveness of transgenic *aux1* roots. Spatially, *AUX1* is expressed in root apical tissues that regulate root gravitropic curvature.

Auxins regulate many aspects of plant growth and development (*1*). Indole-3-acetic acid (IAA), the major form of auxin in higher plants, is synthesized from an indole precursor of the tryptophan amino acid biosynthetic pathway within shoot apical tissues (*2*). IAA is then redistributed from the shoot apex to other tissues (*3*), where it influences many cellular processes, including elongation growth (*4*). Our knowledge of the cellular machinery that mediates the transport and perception of IAA is limited. Several auxin-binding proteins have been identified, including putative carriers and receptors (*5*), but their physiological importance remains unclear. Molecular genetic approaches in *Arabidopsis thaliana* have provided new opportunities to identify and characterize novel auxin signaling components (*6*). We selected root gravitropism as our genetic model for auxin signaling.

Roots use specialized gravity-sensing columella cells located in the root cap to monitor root orientation. After a gravistimulus, the columella cells direct actively growing

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