and second) showed a significant decline in looking from the first to the second exposure in both age groups [$F(1,30) = 51.0$, $P < 0.001$, older group; $F(1,30) = 32.6$, $P < 0.001$, younger group] but no effect of the kind of sequence [$F(1,15) = 0.05$, $P > 0.1$ and $F(1,15) = 0.04$, $P > 0.1$, respectively] nor a significant interaction. The mean score for looking at the BDR sequence for the older group was 53.78 (SD = 15.95) and for the younger 47.45 (SD = 12.90). The respective scores for the RDB sequence were 53.17 (SD = 18.02) and 48.08 (SD = 13.84). Recovery scores were calculated as in experiment 1. Planned comparisons of these scores showed that the older children did not differentially dishabituate to the role reversals of the BDR and RDB sequences [$t(13) = 0.466$, $P > 0.1$]. The recovery scores were 6.45 (SD = 5.94, $n = 9$) and 7.99 (SD = 6.79, $n = 6$). In contrast, the younger age group showed significantly more dishabituation to the reversed roles of the BDR sequence than to the role reversals of the RDB sequence [$t(20) = 2.497$, $P = 0.01$, one-tailed]. The recovery scores were 5.37 (SD = 8.58, $n = 11$) and 3.61 (SD = 8.28, $n = 11$). The latter result is confirmed on an individual basis: eight of the nine younger subjects who habituated in both their sessions dishabituated more to the experimental role reversal than to the control role reversal ($P < 0.05$, binomial test, one-tailed). Such a comparison is not possible for the older children because only two subjects habituated in both sessions.

The difference in the outcome for the young and older children parallels a comparable difference in children's reactions to picture stories presented in and out of order. Older children respond in the same way to both orders, evidently able mentally to restore the disordered case, but young children do not (*5*). They are flummoxed by the disordered sequence. In particular, the intentionality they normally attribute to the characters, for example, "he's afraid of him because he hit him," is replaced by static descriptions, such as "he's here and he's over there" (*ibid.*). Our data appear to duplicate this outcome: the older children appear to perceive intention in both BDR and RDB, because they need only the appropriate elements, and can order them themselves. By contrast, younger children can perceive intention only in the properly ordered case.

Can we say that what the child perceives when he looks at an appropriate case of BDR is intention? Spontaneous comments, though infrequent, tend to comply with the intentional interpretation. We reserve formal treatment of the verbal approach for later and turn now to a consideration of the alternatives.

The habituation-dishabituation results established that the several tokens of BDR all produced a common perception. If that perception is not intention, what is it? Did the child perceive the experimental sequences as causal, the control as noncausal? We need to distinguish between two senses of causal. Causal in the physical sense can be eliminated. The stringent conditions that Michotte (*1*) showed to be needed for the perception of physical causality were not contained in either kind of sequence. Moreover, suppose such patterns were present; they would have been equally present in both the BDR and RDB cases. Thus, the children would have had either to perceive causality in both cases or noncausality, and neither outcome could account for the difference between the BDR and RDB results.

There is, however, a second sense of causal. Ball L hit ball S *because* S made it angry; S rushed back to L *because* it was afraid; and so on. "Because" in these constructions does not refer to physical causality, defined by the temporal-spatial contiguity of two appropriate actions; but to psychological causality, defined by an inferred change in the internal state of one object brought about by either an inferred change in the internal state of another object, the action of another object, or both. This sense of causality is what we mean by intention, and is the sense that we believe distinguished the experimental and control sequences. Animate/inanimate can be eliminated as a possible alternative for intentional/nonintentional. The movement of the individual balls in the experimental and the control conditions did not differ. In the first experiment, the two cases differed only in synchrony, and in the second, not even in synchrony but only in the order of the BDR pattern.

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6. Supported by postdoctoral fellowship grants to V.D. from the Swiss National Science Foundation and to I.U. from the University of Cophenhagen, and by a grant from the McDonnell Foundation to D.P.

30 August 1988; accepted 18 November 1988

Composition of the Earth

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New estimates of solar composition, compared to earlier measurements, are enriched in Fe and Ca relative to Mg, Al, and Si. The Fe/Si and Ca/Al atomic ratios are 30 to 40 percent higher than chondritic values. These changes necessitate a revision in the cosmic abundances and in the composition of the nebula from which the planets accreted (which have been based on chondritic values). These new values imply that the mantle could contain about 15 weight percent FeO and more $CaMgSi_2O_6$ than has been supposed. Geophysical data are consistent with a dense, FeO-rich lower mantle and a $CaMgSi_2O_6$ (diopside)-rich transition region. FeO contents of 13 to 18 weight percent appear to be typical of the mantles of bodies in the inner solar system. The oldest komatiites (high-temperature MgO-rich magmas) have a similar chemistry to the derived mantle. These results favor a chemically zoned mantle.

MOST WORKERS HAVE ASSUMED that the sun, planets, and chondritic meteorites are all derived from the solar nebula and that they contain approximately the same ratios of the refractory condensable elements. Carbonaceous chondrite abundances have generally been taken as an appropriate guide to the composition of the condensable material in the solar system and the planets. Chondritic and solar values have both been used in compilations of the cosmic or solar system abundances (*1*). Satisfactory models of Earth can be obtained from these cosmic abundance tables (*2*). The inferred FeO content of the mantle for a chondritic Earth is low because nearly all of the iron resides in the core.

Type 1 carbonaceous chondrites (CI)

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Table 1. Estimates of solar system composition (relative to 1000 atoms of Si). Solar composition is from solar energetic particles (both corona and photosphere) (*3*); cosmic abundances are mainly from chondrites (*1*).

Element or ratio	Solar	Cosmic
Mg	1089 ± 63	1075 ± 41
Al	83.7 ± 4.1	84.9 ± 4.1
Si	1000	1000 ± 44
Ca	82 ± 13	61.1 ± 4.3
Ti	4.9 ± 1.5	2.4 ± 0.12
Fe	1270 ± 160	900 ± 24
Ca/Al	0.98 ± 0.20	0.72 ± 0.09

Table 2. Terrestrial compositions based on chondritic (*2*) and solar abundances compared with average lherzolite (*24*) (weight percent).

Component	Chondritic	Solar	Lherzolite
	Mantle		
MgO	37.7	32.7	42.2
SiO_2	52.5	45.0	44.2
Al_2O_3	3.8	3.2	2.1
CaO	3.0	3.4	1.9
FeO	3.3	15.7	8.3
	Core		
Fe_2O	32.2	32.0	

have generally been considered as representative samples of nebular material because they are volatile-rich, have not suffered any obvious high-temperature events, and generally have nearly solar ratios of the refractory elements. Their compositions can also be measured with much greater precision than can solar abundances. Otherwise, solar values would have been adopted for all elements in the cosmic abundances tables.

Recently, the composition of the corona and photosphere of the sun have been redetermined (*3*). The Fe abundance is about 40% higher than indicated by earlier measurements, and Fe, Ca, and Ti, relative to Si, Al, and Mg, are 30 to 40% higher than chondritic values (Table 1). These new values suggest that chondritic meteorites may be unrepresentative samples of the solar nebula (*4*), and that the terrestrial planets may be richer in Fe, Ca, and Ti than previously supposed. The differences from conventional values are large and major contradictions with geophysical data might be expected. In particular, with these new values, the mantle of Earth would have a higher FeO content and more $CaMgSi_2O_6$, the diopside component of clinopyroxene and an important component of basalt.

The Earth is the largest available sample of condensed refractory material in the solar system. I use chemical and geophysical data to test whether chrondritic or solar abundances are more appropriate for conditions in the part of the nebulae from which the terrestrial planets formed. I have calculated the composition of the terrestrial mantle from the new solar values (Table 2). The procedure is as follows (*2*): The core is assumed to be Fe_2O. This composition is close to the inferred eutectic composition of the Fe-O system at high pressure (*5*) and also has about the right density (*2, 6*). The relative mass of the core is 32.5% (*7*) and this mass is used to determine the total amount of FeO remaining for the mantle. I then assumed that all of the remaining Fe, as FeO in silicates, along with fully oxidized Mg, Si, Al, and Ca, are in the mantle. The inferred FeO content of the mantle is about 15.7 weight percent. This value is much greater than the 8 to 12% of FeO in upper mantle lherzolites and basalts (*2*). The lower mantle represents 70% of the mantle and the implication is that the lower mantle is enriched in FeO compared to samples from the upper mantle (*8*).

Earlier estimates of the terrestrial FeO content fall into two categories. Petrological estimates are based on the compositions of basalts and peridotites and generally fall near 8% FeO. In geophysical estimates, the mass and moment of inertia and periods of free oscillation are used to constrain the density, mineralogy, and chemistry of the Earth's mantle (*7*). Petrologic methods actually are representative only of the uppermost mantle whereas the geophysical estimates are primarily sensitive to the lower mantle. The uncompressed high-temperature density of the lower mantle is about 4.0 g cm^{-3} (*9*). The mineralogy of the lower mantle is primarily $(Mg,Fe)SiO_3$ in the perovskite structure and (Mg,Fe)O in the rock salt structure, with FeO strongly partitioned into the (Mg,Fe)O phase (*10*). If the mean temperature for the uncompressed adiabat is 1700°C and the mean coefficient of thermal expansion is 30×10^{-6} to 40×10^{-6}°C^{-1}, the inferred zero-pressure (metastable) density of the lower mantle is 4.21 to 4.28 g cm^{-3} at standard conditions. A model with about 14% FeO and chondritic or solar ratios of MgO to SiO_2 satisfies the geophysical constraints better than the more olivine-rich and FeO-poor compositions thought to be representative of the upper mantle (*4, 8*). The density of a lower mantle with 15.7 weight percent FeO and solar ratios of the major elements (Table 2) distributed among perovskite (the predominant phase), magnesiowustite, and corundum is 4.26 to 4.28 g cm^{-3}, also in agreement with the inferred zero-pressure density of the lower mantle calculated above from the geophysical data. Thus, the solar value (with 32.5% Fe_2O removed to form the core) is consistent with geophysical data regarding a high FeO content for the average mantle and the lower mantle. The upper mantle and transition region (400 to 650 km depth) may also be enriched in FeO compared to available samples from the shallowest mantle.

This high FeO content is also close to estimates for the lunar and Martian mantles (*11, 12*) (Table 3). Venus may have a composition identical to Earth (*13*). The eucrite parent body has an inferred FeO content of 14.4% (*12*). Thus, silicate mantles of 13 to 18% FeO appear to be typical of the terrestrial planets.

The high Ca/Al ratio for the sun also has interesting implications if it is representative of the mantle. The uncertainties in the solar Ca/Al ratio are such that the ratio may overlap the chondritic value (Table 1) but it is substantially higher than earlier estimates of the terrestrial mantle. The main calcium- and aluminum-bearing phases in the upper mantle are clinopyroxene (cpx) and garnet (gt). A high Ca/Al ratio means a high cpx/gt ratio. The solar Ca/Al value is about 32% greater than in chondrites and 14% greater than in average upper mantle lherzolites. Midocean ridge basalts (MORBs) have Ca/Al ratios close to chondritic and therefore less than lherzolites and the solar value. Lherzolites are olivine- and orthopyroxene-rich rocks, low in Ca and Al, which are generally regarded as either basalt source rocks or residue after basalt extraction. Neither basalts nor lherzolites may be representative of the mantle because partial melting, melt extraction or addition, and magma generation and evolution can change such ratios as Ca to Al. Basalts are derived by partial melting of the cpx and gt fraction of either lherzolite or an olivine eclogite (piclogite) (*14, 15*). Basalts, such as MORB, can have a lower Ca/Al ratio than their source if the source has a high cpx/gt ratio and if some cpx is left behind in the refractory residue, or if the magma cools and cpx crystallizes before eruption of the basalt. Some high temperature magmas (komatiites) have high Ca/Al ratios, as high as and higher than the solar values. The distribution of clinopyroxene is most likely not uniform in a mantle that has experienced partial melting and crystallization.

The high CaO content and Ca/Al ratio indicate that the diopside content and the diopside/gt ratio are higher in a solar mantle than in a chondritic mantle or in pyrolite, a previous contender for average mantle (*16*). This ratio controls the depth of the stability field of diopside. A high diopside/gt ratio has been proposed to account for the high seismic gradient observed for the transition region (*17*).

The magnitude of the seismic velocity jump at the 400 km seismic discontinuity in

Table 3. Estimates of the silicate composition of Earth, moon, and Mars. The first Mars model is based on the composition of SNC (shergottite, nakhlite, and chassignite) meteorites. The second is a multicomponent model.

Component or ratio	This paper	Moon (*29*)	Mars (*12*)	Mars (*30*)
SiO_2	45.0	43.4	44.4	41.6
Al_2O_3	3.2	6.0	3.02	6.4
FeO	15.7	13.0	17.9	15.9
MgO	32.7	32.0	30.2	29.8
CaO	3.4	4.5	2.45	2.4
CaO/Al_2O_3	1.08	0.75	0.81	0.38
MgO/(MgO+FeO)	0.68	0.71	0.63	0.65

Table 4. Estimate of mantle composition and comparison with mantle lherzolites, komatiites, and pyrolite (*15*).

Component or ratio	Solar	Spinel lherzolite*	Komatiites†		Pyrolite
SiO_2	45.0	44.2	44.9	44.8	45.1
Al_2O_3	3.2	2.0	3.1	3.6	4.6
FeO	15.7	8.3	13.5	12.0	7.8
MgO	32.7	42.3	33.0	34.9	38.1
CaO	3.4	2.1	3.8	3.7	3.1
CaO/Al_2O_3	1.08	1.07	1.21	1.02	0.67
MgO/(MgO+FeO)	0.68	0.84	0.71	0.74	0.83

*Average of 301 continental spinel lherzolites (*24*). †Komatiite, Barberton, South Africa (*27*).

the upper mantle is only about one-half of what is expected for the olivine-spinel phase change (*15, 18*). This difference suggests that there is a neutral mineral in the mantle that does not undergo a pressure-induced phase change near this depth. Clinopyroxene dissolves in gt at high pressure, with a substantial increase in both density and seismic velocity. The depth of the transition increases as the Ca/Al or cpx/gt ratios increase. For a cpx/gt ratio typical of MORBs and CI chondrites, the transition depth is close to 400 km (*19*). However, with a higher Ca/Al ratio the transition is deeper, which would allow both a small magnitude jump at the 400 km discontinuity and a high gradient in seismic velocity below 400 km.

Seismic tomography suggests that the MORB source region may be below 400 km (*20*). Partial melting of a high cpx/gt piclogite (*14*) yields basalt and a cpx-bearing residue, which, because of high temperature and reduction in the amount of the dense phase garnet by the melting process, can be buoyant relative to garnet peridotite or unmelted piclogite. A fertile piclogite transition region, where hot or partially molten, can thereby rise into the shallow mantle.

A high Ca/Al ratio would reverse the problem pointed out by Palme (*21*), who rationalized the high Ca/Al of lherzolites relative to chondrites in terms of garnet extraction from the shallow mantle. We must now explain the lherzolites and basalts by clinopyroxene removal or addition of garnet or plagioclase to the shallow mantle. A gt- and cpx-rich transition region (400 to 650 km depth) with a high cpx/gt ratio is one possibility (*22*). This region could form as a cumulate from a magma ocean or from the sinking of dense melts (*23*). The Ca/Al ratio increases in the order: crust, basalt, peridotites. Density increases in this order, also, at least at low pressure, and Al_2O_3 content decreases, which suggests that there is some chemical stratification in the Ca/Al ratio of the upper mantle. Samples from the shallow mantle may, therefore, not be representative of the whole mantle. Terrestrial basalts and many peridotites, particularly those from oceanic environments, have Ca/Al ratios less than the new solar values but the average continental lherzolite (*24*) has a nearly solar ratio. Earth models based on mixtures of peridotite and basalt, such as pyrolite, have low values of CaO/Al_2O_3 (0.7 for pyrolite compared to 1.08 for solar).

The upper ~150 km of the mantle under ancient (Archean) continental shields appears to have been beneath the continental crust since the crust was formed and is buoyant relative to the underlying mantle and to oceanic mantle (*18, 25, 26*). Although this continental mantle is not primitive material, it is ancient and may therefore have preserved some geochemical characteristics of the early mantle, more so than other samples from the mantle. The CaO and Al_2O_3 contents of continental lithosphere may be representative of those of ancient melts, such as komatiites, or overridden oceanic plates.

Komatiites are dense high-temperature, high-MgO magmas that are characteristic of ancient (Archean) terrains. Some are 3.5 billion years old (*27*). Based on their MgO content, crystallization temperatures, and age, they are the most primitive of magmas and should be more similar to their source chemistry than other magmas are. They are remarkably similar to my estimate of primitive mantle. The similarities include high FeO contents and high CaO/Al_2O_3 ratios.

High-MgO melts, such as komatiites, probably provide the best terrestrial estimate of the CaO/Al_2O_3 ratio of the mantle because they represent large degrees of partial melting and they apparently have experienced little crystal loss before solidifying. The argument is that olivine, $(Mg,Fe)_2SiO_4$, is a dense refractory mineral, and its loss should decrease the MgO content of the residual lower temperature melts such as basalts. If melting in the formation of komatiites was extensive enough to melt olivine, the calcium- and aluminum-bearing phases should have been completely melted and the CaO/Al_2O_3 ratio should reflect that of the source. Even if the source region was secondary, it would have contained nearly the initial ratios of Ca, Al, and the incompatible elements if it resulted from large degrees of partial melting of primitive material.

Compositions of some high-MgO rocks that are thought to represent quenched high-temperature melts from the mantle are given in Table 4. Komatiites have variable CaO/Al_2O_3 ratios, but they bracket solar values. They also tend to have higher FeO values than other peridotites. The relatively low FeO content of most mantle rocks requires that the upper mantle had a multistage evolution if the higher FeO abundances are appropriate for primitive mantle. Dense FeO-rich crystals and melts may have settled during accretional melting events and magma ocean evolution.

The notion that CI chondrites represent primitive solar nebula material may not be valid (*28*). The carbonates and sulfates, which contain a large fraction of the calcium in these meteorites, apparently formed by aqueous activity near the surface of the parent body. The sulfates are water soluble. That the Ca/Al ratio is similar in all chondrite types has lent support to the suggestion that the refractory elements occur in chondrites in their original (nebular) ratios. By implication, the sun and the planets should have these same ratios and, lacking precise measurements, have been assumed to do so. However, recent observations indicate that the solar Fe abundance is significantly greater than earlier estimates and greater than in chondritic meteorites. The solar Ca/Al ratio is marginally higher than in chondrites and in earlier estimates of Earth's mantle. If these new solar values are representative of the nebula from which the planets accreted, then the mantles of the terrestrial planets should have higher FeO/MgO and CaO/Al_2O_3 ratios and more diopside than previously supposed. Independent geophysical data support these modifications. In particular, the lower mantle appears to be enriched in FeO and the transition region in clinopyroxene compared to earlier models based on upper mantle petrology. A chemically layered mantle is a distinct possibility.

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31. Supported by NSF grant EAR-85-09350. Contribution No. 4705, Division of Geological and Planetary Sciences.

12 September 1988; accepted 31 October 1988

Direct Observation of Native DNA Structures with the Scanning Tunneling Microscope

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Uncoated double-stranded DNA dissolved in a salt solution was deposited on graphite and imaged in air with the scanning tunneling microscope (STM). The resolution was such that the major and minor grooves could be distinguished. The pitch of the helix varied between 27 and 63 angstroms in the images obtained. Thus the STM can be useful for structural studies of a variety of uncoated and isolated biomolecules.

THE STM HAS BEEN USED TO STUDY the atomic structure of many surfaces other than metals and semiconductors (*1*). Organic, inorganic, and biological molecules have been imaged, both in air and under a variety of other media. These samples include, among others, bacteriophage virus particles (*2*), metal-shadowed recA-DNA complexes (*3, 4*), native closed circular DNA (*4*), and other smaller organic molecules (*5*). These early studies are promising because it was shown that the advantages of the STM [simplicity of operation, low cost, angstrom resolution, both laterally (x and y directions) and normal to the

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Fig. 1. (Facing page) DNA deposited on graphite and imaged in air with the STM. All of the images were obtained at constant tunnel current (topographic images). (**A**) Sample area, 1050 Å by 1050 Å; total height, 49 Å; sample bias, −155 mV; current setpoint, 0.9 nA; gap resistance, 172 MΩ; acquisition time, 210 s, (tip velocity of 1300 Å/s). Postacquisition image processing consisted of digital bandpass filtering with the removal of all Fourier components $>9.72 \times 10^{-2}$ Å^{-1} and $<2.43 \times 10^{-3}$ Å^{-1}. Variation of these values within reasonable ranges caused no significant changes in the images. The image is presented in a projected three-dimensional format with gray scale, as viewed from a perspective 45° above the plane, and 20° clockwise in the plane. (**B**) Magnified view of center of (A), under the same conditions, area 260 Å by 260 Å; total height range 48 Å; viewing perspective is 45° above the plane and 30° counterclockwise in the plane. (**C**) Area 340 Å by 340 Å; total height range, 29 Å; sample bias, −155 mV; current setpoint, 0.8 nA; gap resistance, 194 MΩ; viewing perspective is 45° above the plane and 20° clockwise in the plane. (**D** and **E**) Area 400 Å; total height range, 132 Å; sample bias, −97 mV; current setpoint, 3.3 nA; gap resistance, 29 MΩ; acquisition time 42 s (tip velocity of 2500 Å/s). (D) Raw image. (E) Postacquisition image processing consisted of nine point two-dimensional smoothing applied once, followed by simulated light source shading from a point 15° above the plane. (**F**) Schematic of the DNA structure in (D) and (E).