Chemical Composition and Accretion History of Terrestrial Planets

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Chemical composition and accretion history of terrestrial planets

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The high concentrations of moderately siderophile elements (Ni, Co, etc.) in the Earth's mantle and the similarity of their CI normalized abundances to those of moderately volatile elements (F, Na, K, Rb) and some elements such as In, which under solar nebula conditions are highly volatile, are striking. To account for the observed abundances, inhomogeneous accretion of the Earth from two components has been proposed. In this model accretion started with the highly reduced component A devoid of all elements more volatile than Na, followed by accretion of more and more oxidized material (component B), containing all elements in CI abundances. Recent observations have brought almost conclusive evidence that SNC meteorites are martian surface rocks ejected by huge impacts. By assuming that Mars is indeed the parent body of SNC meteorites, the bulk composition of Mars is estimated. The data on the composition of Mars obtained in this way clearly show that the two-component model is also valid for Mars. The striking depletion of all elements with chalcophile character in the martian mantle indicates that, contrary to the Earth, Mars accreted almost homogeneously (H. Wänke, *Phil. Trans. R. Soc. Lond.* A **303**, 287 (1981)).

CHEMISTRY OF THE EARTH

The composition of the Earth's mantle is well known from investigations on mantle xenoliths which are frequently brought to the surface by volcanic eruptions as well as from investigations of komatiites and other mantle-derived rocks (Sun 1982). Except for the most incompatible elements for which the contribution of the crust becomes important, the mantle determines the chemistry of the Earth for all lithophile elements. The following discussions on the mantle abundances are exclusively based on the analyses of primitive and uncontaminated spinel–lherzolite xenoliths (Jagoutz *et al.* 1979, 1980). However, as seen from table 1, abundance data of the Earth's mantle by other investigators differ only slightly. From figure 1, the following abundance trends can be recognized (table 2).

Relative to Si and CI, all lithophile refractory elements including Mg have abundances of about 1.3. Corresponding to its slightly lower refractory behaviour, Mg is somewhat less enriched. The enrichment of refractory elements might reflect a fractionation according to volatility. However, a uniform enrichment could also be interpreted in terms of a corresponding Si deficiency. The missing Si might have entered the core in metallic form (Ringwood 1958; Wänke 1981). Alternatively the observed Si deficiency in the upper mantle could be compensated by a higher Si abundance in the lower mantle (Liu 1979).

The depletion of V, Cr and Mn, first noted by Ringwood (1966), is striking. Depletion due to volatility could be expected for Mn, the most volatile of these three elements. Under solar-nebula conditions, Cr is only slightly more volatile than Si, whereas V is considerably less volatile than Si. The eucrite parent body, which is highly depleted in moderately volatile elements such as Na and K, shows no depletion of V, Cr and Mn. The same holds for the parent

TABLE 1. BULK COMPOSITION OF THE EARTH

	Ringwood (1977*b*), Ringwood & Kesson (1977)	Morgan & Anders (1980)	Sun (1982)	Wänke *et al.* (1984)	relative to Si and CI
mantle + crust					
MgO (%)	38.1	34.1	38.0	36.85	1.18
Al_2O_3	3.9	4.1	4.3	4.20	1.35
SiO_2	45.9	47.9	44.5	45.95	1.00
CaO	3.2	3.2	3.5	3.54	1.40
TiO_2	0.3	0.20	0.22	0.23	1.53
FeO	8.1	8.9	8.36	7.58	0.16
Na_2O	0.1	0.25	0.39	0.39	0.29
P_2O_5	—	—	0.021	0.015	0.032
Cr_2O_3	0.3	0.9	0.44	0.44	0.56
MnO	0.14	0.11	0.11	0.13	0.28
K (p.p.m.)[a]	129	200	230	231	0.22
Rb	—	0.68	0.66	0.74	0.18
Cs	—	0.02	0.008–0.017	—	—
F	68	20	26	19.4	0.18
Cl	59	29	21–38	12	0.0087
Br (p.p.b.)[b]	—	157	60–90	46	0.0090
I	—	20	—	13	0.012
La (p.p.m.)	—	0.56	—	0.52	1.06
Co (p.p.m.)	98	—	110	105	0.10
Ni	1694	—	2000	2108	0.097
Cu	34	46	30	28	0.13
Zn	50	109	56	49	0.070
Ga	6	5	4.8	3.8	0.21
W (p.p.b.)	—	—	(21)	24.1	0.13
Th	75	76	—	—	—
U	21	21	—	21	1.27
core					
Fe (%)	86.2	84.5	—	80.27	—
Ni	4.8	5.6	—	5.46	—
Co	—	—	—	0.27	—
S	1.0	9.0	—	—	—
O	8.0	—	—	—	—
Si, Mn, Cr	—	—	—	14.00	—
core mass (%)	31.2	32.4	—	33.5	—

[a] In this paper p.p.m. and p.p.b. represent mass ratios.
[b] In this paper one billion is used to represent 10^{12}.

TABLE 2

	abundances relative to Si and CI
refractory oxyphile elements (Al, Ca, Ti, Sc and most refractory trace elements) and Mg enriched	× (1.3 ± 0.15)
V, Cr, Mn depleted	× (0.25–0.7)
Fe and moderately siderophile (Ga, Cu, W, Co, Ni) depleted	× (0.1–0.2)
moderately volatile (Na, K, Rb, F, Zn) and the highly volatile element In depleted	× (0.1–0.2)
highly siderophile (Ir, Os, Re, Au) strongly depleted	× (0.002)
highly volatile (Cd, Ag, I, Br, Cl, Te, Se, H_2O, CO_2, etc.) strongly depleted	× (10^{-2}–10^{-4})

body of the SNC meteorites (see next section). Hence, Dreibus & Wänke (1979) argued that removal of these elements into the Earth's core be more likely as their depletion due to volatility. Vanadium, Cr and Mn might have partly entered the core either in reduced form as metals or sulphides or as oxides.

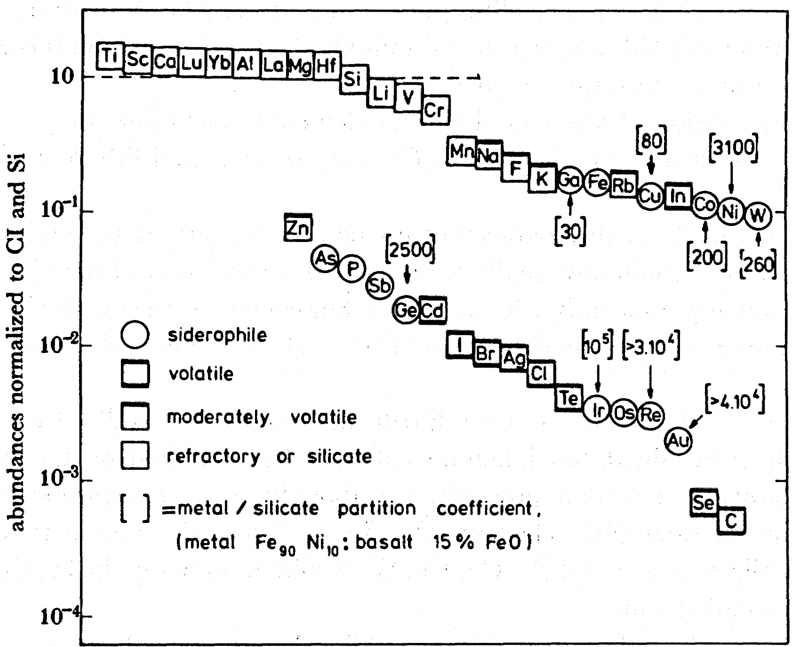

FIGURE 1. Composition of the primitive Earth's mantle (mantle plus crust) as obtained from the chemical analyses of primitive unaltered spinel–lherzolites (Jagoutz *et al.* 1979; Wänke *et al.* 1984).

For Cr, segregation into the core had been suggested by Hutchison (1974). If the Earth's core contains large amounts of dissolved FeO as proposed by Ringwood (1977*a*), V, Cr and Mn, like FeO, might have partly entered the core in form of oxides.

The abundances of the moderately siderophile elements Ga, Cu, W, Co and Ni are only slightly lower than that of Fe. The abundances of these elements in the Earth's mantle are incompatible with all models requiring a chemical equilibrium of the Earth's mantle with a pure FeNi metal phase. The very similar abundances not only require reduction of the metal–silicate partition coefficient of Ni (the most siderophile element of this group) by about a factor of 30, but conditions that make the metal-silicate partition coefficient of these elements almost equal.

The moderately volatile elements K, Rb, Cs and F and even some elements such as In, which under solar nebula conditions are highly volatile, show similar depletion factors. Their abundances fall within the range of the moderately siderophile elements.

Both the highly siderophile and the highly volatile elements are strongly depleted in the Earth's mantle. Also the highly siderophile elements are far too abundant compared with the concentrations to be expected from their metal-silicate partition coefficients. However, relative to each other, Au, Ir, Re and Os are present in almost chondritic abundance ratios.

ACCRETION OF THE EARTH

To explain the observed elemental abundance pattern of the Earth's mantle an inhomogeneous accretion model has been proposed by Wänke (1981). In this model the Earth is thought to be formed from two chemically different components.

Component A. This is highly reduced and free of all elements with equal or higher volatility than Na, but containing all other elements in CI abundance ratios. Iron and all siderophile elements are present as metals, and even Si is present in part as metal. Vanadium, Cr and Mn are present as metals or sulphides. It is assumed that the degree of reduction is comparable or higher to that observed for enstatite chondrites.

Component B. This is oxidized and containing all elements – including the volatiles – in CI abundances. Iron and all siderophile (Co, Ni, Cu, Ga, W, etc.) and lithophile elements are present as oxides.

Accretion started with the highly reduced component A. Because of the high temperature reached during accretion (Safranov 1978; Kaula 1979), segregation of metal, i.e. core formation will occur contemporaneously with accretion (Solomon *et al.* 1981). The silicate mantle of the growing mantle will be almost free of FeO and siderophile elements during this stage.

After accretion of about two thirds of the Earth more and more oxidized material (component B) is thought to be added. Small amounts of metal from component A, still present but in decreasing amounts as accretion proceeds, are thought to be responsible for complete extraction of the highly siderophile elements (Ir, Au, etc.) into the core at that stage. The moderately siderophile elements (Ni, Co, Ga, Cu, W) would accompany the highly siderophile elements only to a small extent.

The conveyance of H_2O and Fe^{3+} from component B is thought to be the reason that metallic Fe finally became unstable towards the very end of accretion. Hence, the highly siderophile elements contained in the last 0.2% of the mass added to the Earth remained in the mantle in chondritic abundance ratios. Dreibus & Wänke (1987) have pointed out that the Earth's inventory of H_2O comes close to the amount supplied by this last 0.44% of matter assuming a CI abundance of H_2O.

Mixing of the originally FeO-free mantle with component B added later on does not pose much of a problem considering the energy released during accretion. The accretional energy retained amounts to about 1.8×10^{31} J for the whole Earth (Kaula 1979). Depending on the accretion scenario, the energy released during core formation is in the same order of magnitude as the energy produced during 4.55×10 Ga by the decay of K, Th and U (1.2×10^{31} J), i.e. more than 50% of the total energy is released during accretion. Accretion time estimates are less than 1% (Wetherill 1978) of the age of the Earth and, hence, the energy output during accretion was more than two orders of magnitude higher than the mean energy output by the decay of long-lived radioactive elements. Today the turnover time of the Earth's mantle by convection is in the order of 10^8 years. Hence, the turnover time during accretion could be on the order of 10^6 years, a value small relative to the accretion time of about 30 Ma. Hence, if the proposed scenario is correct component B would have been added to a vigorously convecting mantle and a nearly perfect homogenization of the original FeO-free mantle with component B would result.

Ringwood (1977*a*, 1979) has previously proposed a model to build the inner planets from a reduced volatile-free and an oxidized volatile-containing component. However, he assumed homogeneous accretion. As outlined above, the observed chemical composition of the Earth's mantle can be explained in a more straightforward way by an accretion scenario in which the oxidized component containing FeO and moderately siderophile elements (NiO, CoO, etc.) is added to the mantle only after accretion of about two thirds of the Earth's mass and after segregation of the metal phase, i.e. after core formation.

Chemistry of Mars

Direct information on the bulk chemistry of Mars is very limited. However, within the past few years a number of observations have been made that indicate that in all likelihood we have martian rocks in our meteorite collections in form of the SNC meteorites.

The SNC meteorites (four Shergottites, three Nakhlites and Chassigny), according to their oxygen isotope ratios (Clayton & Mayeda 1983) and various trace element ratios (McSween *et al.* 1979; Burghele *et al.* 1983) form a distinct group of eight achondrites. Their young crystallization ages and their fractionated REE pattern, which exclude an asteroidal origin, were the first observations that pointed toward Mars as the parent body of these meteorites (Nyquist *et al.* 1979; Wasson & Wetherill 1979; Dreibus *et al.* 1981). Additional and very conclusive evidence came from the discovery of a trapped rare gas and nitrogen component with element and isotope ratios very different to those observed in any other meteorites, but closely matching the highly characteristic element ratios of the atmosphere of Mars (e.g. $^{40}Ar/^{36}Ar$; $^{14}N/^{15}N$; $^{14}N/^{40}Ar$ and $^{129}Xe/^{132}Xe$) in shock glasses of shergottite EETA 79001 (Bogard & Johnson 1983; Becker & Pepin 1984; Pepin 1985).

Whereas all other differentiated meteorites have crystallization ages close to 4.5 Ga, the SNC meteorites are much younger. Jagoutz & Wänke (1986) determined for Shergotty a crystallization age of 360 ± 16 Ma. For another shergottite (ALHA 77005), recently Jagoutz (1988) found a crystallization age of only 154 ± 6 Ma. For the same meteorite he found a shock age of 15 ± 15 Ma, which agrees with the cosmic ray exposure age of this meteorite of 2.7 Ma (Nishiizumi *et al.* 1986) and, hence, obviously dates the ejection of this meteorite from its parent body.

The following estimates on the chemistry of Mars are based on the rather safe assumption that Mars is indeed the Shergotty parent body (SPB). It is further assumed that all elements more volatile than Na are present in Cl abundances. As we know from the Earth and Moon this assumption holds within an error of about 30%.

Mantle

FeO and MnO. Under normal planetary conditions with ol + op + cpx being the major FeO- and MnO-bearing phases, the liquid–solid partition coefficients of FeO and MnO are only slightly above unity. The absolute concentrations of MnO in SNC meteorites vary between 0.45 and 0.55%. Assuming a CI abundance of MnO in the martian mantle a concentration of 0.46% MnO would be expected. Hence, it is quite clear that contrary to the Earth's mantle Mn is not depleted in the martian mantle but like in the eucrite parent body (EPB, possibly the asteroid Vesta) is present in CI abundance. The FeO/MnO ratio of the four shergottites and Nakhla is 39.1 ± 1.5. Hence, we find compared with the CI FeO/MnO ratio of 100.6 with a CI and Si normalized Mn abundance of 1.00, a FeO abundance of 0.39 for the martian mantle.

Cr. As seen from figure 2, Cr follows Mg in all SNC meteorites. The correlation line indicates a CI Cr/Mg ratio. Hence, as for Mn there is the clear indication that Cr is not depleted in the martian mantle contrary to its quite noticeable depletion in the terrestrial mantle. With the assumption of Mg abundance of 1.00, we find also for Cr an abundance of 1.00 in the martian mantle.

K, Rb and Cs. As for the Moon, the EPB and to a lesser extent for the Earth (Wänke 1981), an excellent correlation of K against La is observed in all SNC meteorites (figure 3), yielding

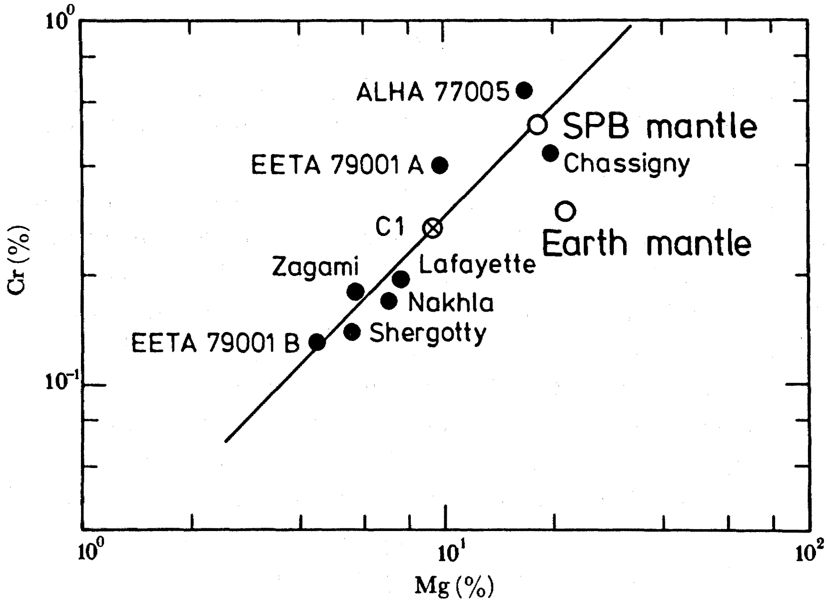

FIGURE 2. Chromium against Mg in SNC meteorites. All SNCs have a chondritic (CI) Mg/Cr ratio.

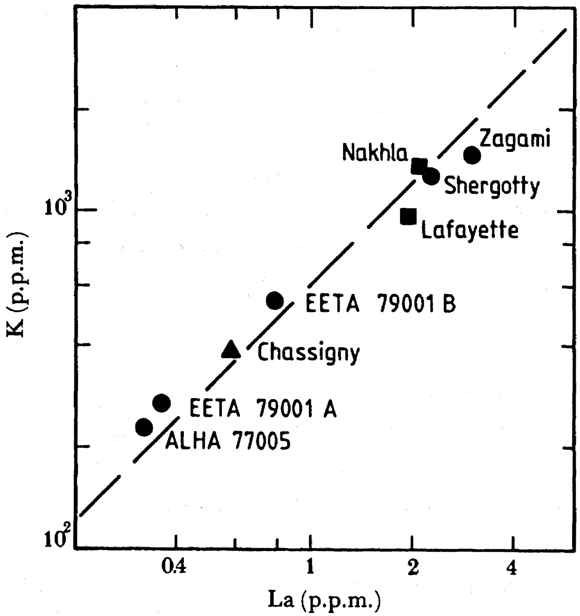

FIGURE 3. Correlation of the moderately volatile element K with the refractory element La in all SNC meteorites.

a K/La ratio of 635 compared with the CI ratio of 2110. If we assume an abundance of 1.00 for the refractory element La, a value of 0.30 is obtained for the abundance of K. Shergottites have a K/Rb ratio of 289 ± 39 and a Rb/Cs ratio of 15.8 ± 0.8, compared with the CI values of these ratios of 251 and 10.8, respectively. Based on the K abundance of 0.30 one finds abundances for Rb of 0.26 and for Cs of 0.20.

W. The excellent correlation of La against W yields a W abundance of 0.60.

Mo. Similar to W, Mo behaves in oxidized form as incompatible element following Nd.

From the measured Mo/Nd ratio in Shergotty, EETA 79001 and ALHA 77005 a mantle concentration of 0.118 p.p.m. Mo is obtained which corresponds to a Mo abundance of 0.066 (Laul *et al.* 1985).

P. Phosphorus correlates best with the heavy rare-earth elements yielding a P abundance of 0.35 (Weckwerth 1983).

F. A weak correlation of F is found with Li, yielding a rough estimate of 0.31 for F, assuming a Li abundance of 1.00.

Na, Ga and Al. The three elements Na, Ga and Al correlate well with each other in all shergottites (figure 4). The mean ratio of the two moderately volatile elements in shergottites Na/Ga = 525 comes very close to the CI ratio of 551. Again assuming an Al abundance of 1.00, the mean ratios Na/Al and Ga/Al of 0.235 ± 0.007, respectively $(4.13 \pm 0.22) \times 10^{-4}$ yields abundance values of Na = 0.38 and Ga = 0.37.

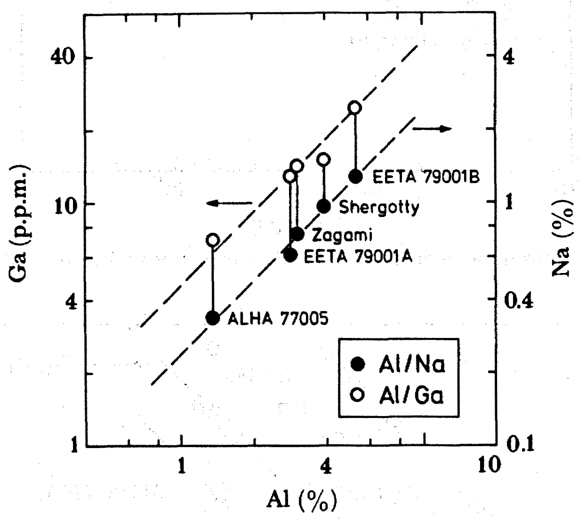

FIGURE 4. Correlation of the moderately volatile element Na and the moderately siderophile element Ga with the refractory element Al in shergottites.

Cl, Br and I. As observed for mid-ocean ridge basalt glasses by Shilling *et al.* (1980), Cl and Br behave in magmatic processes as highly incompatible elements and, hence, correlate well with other highly incompatible elements like La. Similar good correlations are found for all SNC meteorites for which halogen data are available (figure 5). The mean values for their Cl/La and Br/La ratios of 54 respectively 309, yield abundances for Cl = 0.020 and for Br = 0.029.

The measured Cl and I concentrations in SNCs may be influenced by antarctic contamination, as two of the four shergottites were found in Antarctica and high contaminations in many antarctic meteorites were observed for I and Cl (Dreibus & Wänke 1985). However, in the non-antarctic shergottites iodine is depleted relative to Cl halogen ratios (Dreibus & Wänke 1987). As on Earth, Cl, Br and I are observed in CI abundance ratios Dreibus & Wänke (1985, 1987) have assumed for Mars CI abundances for Cl and I relative to Br.

Co. As in terrestrial and lunar basalts, the Co concentrations in shergottites are proportional to their mafic portions expressed by the sum MgO + FeO (figure 6). For the martian mantle MgO + FeO = 48.1 % (table 2), corresponding to an abundance of Co = 0.070.

Ni. Assuming a CI abundance of Mg, the Ni/Mg fractionation line (figure 7) yields Ni

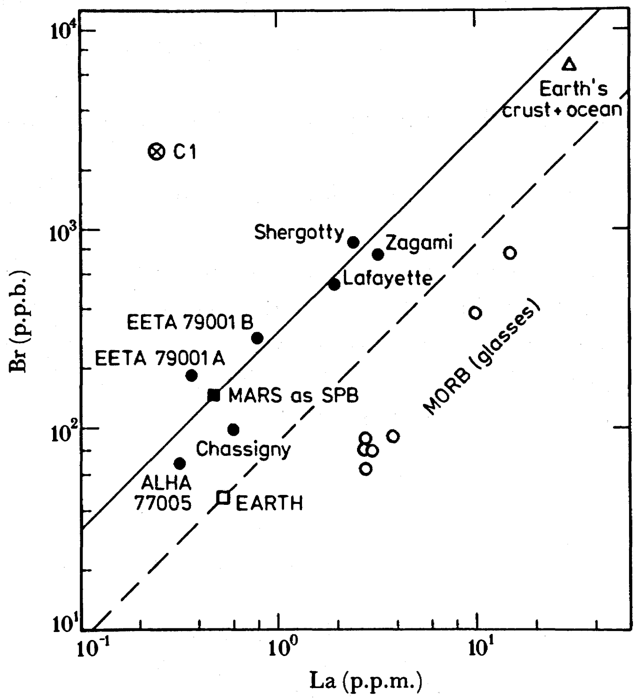

FIGURE 5. Bromine against La in SNC meteorites and terrestrial rocks.

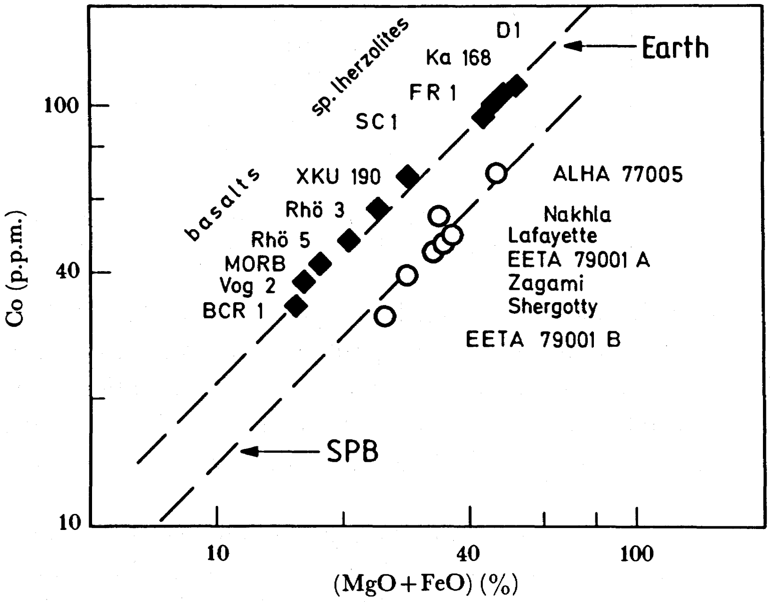

FIGURE 6. Cobalt against MgO + FeO in basalts and upper mantle nodules from the Earth and in shergottites and nakhlites (basalts from SPB).

concentrations of 400 p.p.m. for the mantle of Mars, i.e. considerably lower than the 2108 p.p.m. Ni in the Earth's mantle. An abundance of Ni = 0.019 is calculated for Mars.

Cu and Zn. A rough estimate of the abundance of these two compatible elements in the martian mantle can be obtained by using the concentration observed in ALHA 77005, a MgO-rich rock (MgO = 27.7 %), which for its major and trace element chemistry comes very close

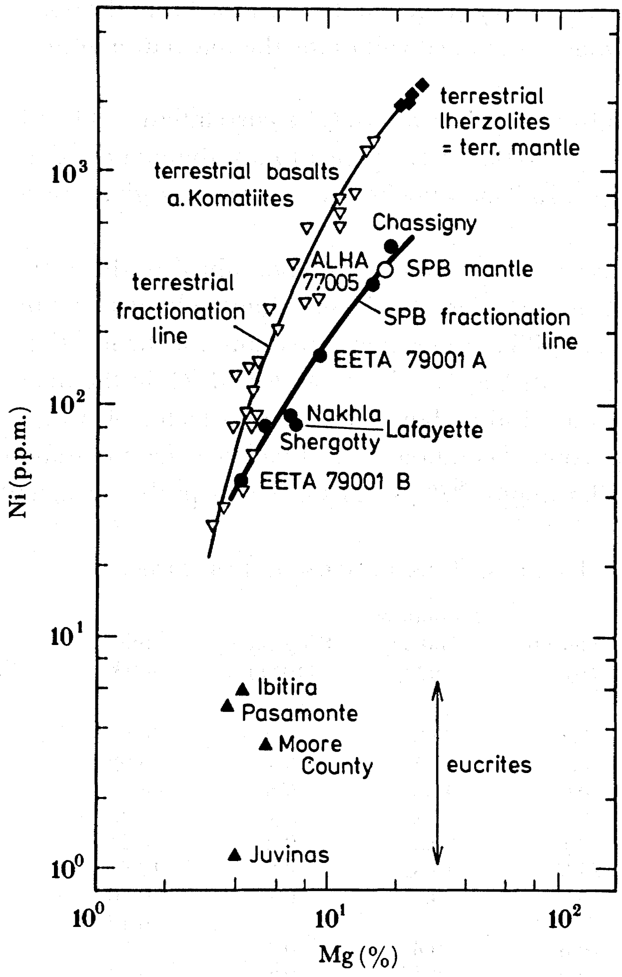

FIGURE 7. Ni/Mg fractionation lines for xenoliths and basalts of the Earth and the SNC meteorites.

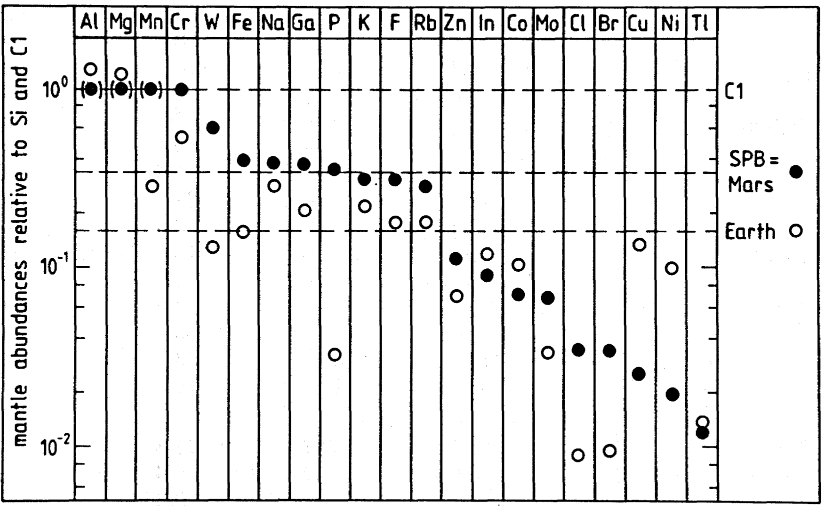

FIGURE 8. Estimated elemental abundances in the mantle of Mars (SPB) together with the respective data for the Earth's mantle. Note that contrary to the Earth's mantle, Mn and Cr are not depleted in the martian mantle, while elements with chalcophile character are more depleted in the martian mantle.

to the above estimates of the chemistry of the mantle of Mars. From the observed concentrations in ALHA 77005 the following abundance values for the martian mantle are obtained: 0.027 for Cu and 0.099 for Zn.

Tl and In. By using data from Smith *et al.* (1984) a correlation of Tl with Br is found for the shergottites. The Tl/Br ratio of 0.024 corresponds to an abundance of Tl = 0.013. A rough estimate for In based on the In/Ga ratio in SNC meteorites gives an abundance of In of 0.090.

The elemental abundances in the martian mantle obtained in this way are summarized in table 3 and plotted in figure 8. As for the Earth, almost identical abundance values for a number of geochemically very different elements are found for the martian mantle. The mean abundance value for the elements Ga, Fe, Na, P, K, F and Rb in the martian mantle is 0.35, and hence, exceeds the terrestrial abundances by about a factor of two.

In estimating the mass portion of component B, it has to be kept in mind that CI chondrites contain beside other volatiles about 20% of H_2O, which probably includes a considerable

TABLE 3. BULK COMPOSITION OF MARS

	Anderson (1972)	Morgan & Anders (1979)	Ringwood (1981)	this work	relative to Si and Cl
mantle + crust					
MgO (%)	27.4	29.8	29.9	30.2	1.00
Al_2O_3	3.1	6.4	3.1	3.02	1.00
SiO_2	40.0	41.6	36.8	44.4	1.00
CaO	2.5	5.2	2.4	2.45	1.00
TiO_2	0.1	0.3	0.2	0.14	1.00
FeO	24.3	15.8	26.8	17.9	0.39
Na_2O	0.8	0.1	0.2	0.50	0.38
P_2O_5	—	—	—	0.16	0.36
Cr_2O_3	0.6	0.6	0.4	0.76	1.00
MnO	0.2	0.15	0.1	0.46	1.00
K (p.p.m.)	573	77	218	305	0.30
Rb	—	0.258	—	1.06	0.26
Cs	—	0.026	—	0.07	0.20
F	—	24	—	32	0.31
Cl	—	0.88	—	38	0.029
Br (p.p.b.)	—	4.7	—	145	0.029
I	—	0.59	—	32	0.029
Co (p.p.m.)	—	—	—	68	0.070
Ni	—	—	—	400	0.019
Cu	—	—	—	5.5	0.027
Zn	—	42	—	62	0.099
Ga	—	2.4	—	6.6	0.37
Mo (p.p.b.)	—	—	—	118	0.066
In	—	0.095	—	14	0.090
Tl	—	0.17	—	3.6	0.013
W	—	—	—	105	0.6
Th	77	113	60	56	1.00
U	17	33	17	16	1.00
core					
Fe (%)	72	88.1	63.7	77.8	—
Ni	9.3	8.0	8.2	7.6	—
Co	—	—	—	0.36	—
S	18.6	3.5	9.3	14.24	—
O	—	—	18.7	—	—
core mass (%)	11.9	19.0	18.2	21.7	—

portion of terrestrial contamination. In any case, assuming component B to be compositionally like CI chondrites only a very small portion of the amounts of H_2O and hydrocarbons added to Mars could have been retained in the planet. Hence on a volatile-free basis we find for Mars a mass portion of component B of about 40%.

Core

To estimate the composition and mass of the martian core, it is assumed that the whole planet contains Fe and Ni in abundances equal to 1.00 and a sulphur abundance of 0.35 (mean abundance of elements derived from component B). It is further assumed that the portion of Fe not contained as FeO in the mantle as well as all Ni and S is present in elemental state in the core. In this way a core mass of 21.7% is obtained.

The estimated bulk composition of Mars as listed in table 2 is in excellent agreement with the geophysical data of the planet. In particular the smaller and less denser core and due to its higher FeO content denser mantle agrees well with the measured density and moment of inertia of Mars (Wood *et al.* 1981).

Accretion history of Mars

The similar abundances of several geochemically very different elements in the mantle of Mars is further strong evidence for the formation of the inner planets from two compositionally different components (figure 8). There are, however, a number of elements supposedly derived from component B which in the Earth's mantle have abundances similar to that of Fe, Na, Ga, K, F and Rb, but in the martian mantle have either as for W, a higher abundance or, as for Zn, Co, Ni, Cu and In, a considerably lower abundance. The latter elements all have a rather strong chalcophile character. This depletion of all elements with chalcophile geochemical behaviour is taken to be a strong indication for a homogeneous accretion of Mars. Hence, contrary to what was suggested for the Earth, on Mars the two components had the chance to equilibrate with each other and, hence, were probably supplied almost simultaneously to the growing planet. The high abundance of component B, which supplied large amounts of sulphur, was obviously responsible for FeS becoming a major phase and at its segregation extracting all chalcophile elements according to their sulphide–silicate partition coefficients. On the other hand, the sulphide–silicate partition coefficient is low for W and also low for Cr and Mn. Hence, large portions of W and all of Cr and Mn supplied by component A after oxidation – equilibration with component B – remained in the mantle. We believe that this explains why, contrary to the case of the Earth's mantle, Cr and Mn and probably also V are not depleted in the martian mantle, whereas the abundance of W exceeds that of Fe, Na, Ga, etc. Figure 8 further shows that the high depletion of P in the terrestrial mantle must be a special feature of the Earth as in the mantle of Mars P has similar abundances as the other moderately volatile, respectively siderophile elements. In summary, the abundances of Co, Ni, Cu, Zn and In and in particular those of W, Cr and Mn point towards an almost homogeneous accretion of Mars.

FORMATION OF COMPONENTS A AND B

At this time there does not exist a generally accepted model for the solar nebula and the processes therein, which are relevant to fractionations of chemical elements. All that we can deduce from the chemical composition of the Earth and Mars as outlined above is the following.

Component A obviously formed mainly at and inside the orbit of the Earth whereas component B was probably formed in the region of the asteroidal belt or beyond. Mars located just at the transition of the region dominated by component A and the region dominated by component B was fed from both components simultaneously and in approximately equal proportions. The accretion of the Earth started with material from its neighbourhood, i.e. with component A and so probably did Venus, whereas material of component B was added to Venus and Earth only at a later stage of accretion as the transfer of material from the region outside of the orbit of Mars required additional time. As this transfer was probably accomplished by perturbation of Jupiter it may be coupled with the formation time of Jupiter.

Dreibus & Wänke (1984) have speculated that the required low oxygen fugacity of component A might be achieved by carbon being the reducing agent. They pointed out that, in the absence of a hot solar nebula, the dust and planetesimals that accreted from this dust may be rich in carbon. In the meantime it seems to be established that in the dust of Comet Halley, carbon is present in solar abundances (Jessberger *et al.* 1986). In the absence of H_2O in the inner part of the solar nebula, planetesimals heated possibly by the decay energy of ^{26}Al would become strongly reduced by carbon and may have lost their volatile and moderately volatile elements. The processes involved in such a loss of volatilized elements from planetesimals are far from being understood. It has been suggested that such a loss could occur after disruption of planetesimals containing molten or almost molten material (Wänke *et al.* 1981; Zook 1981). Alternatively, in the midplane of the solar nebula, in the region at and inside the orbit of the Earth, the temperature may have been high enough that the dispersed matter became reduced and depleted in volatile and moderately volatile elements. For planetesimals formed in the region of the asteroidal belt and further out the amount of water accreted in form of ice may have been substantial so that the decay energy of ^{26}Al was mainly used for the evaporation of H_2O. Simultaneously substantial portions of carbon could have been lost in the form of CO and CH_4. It is in this region that component B is thought to have formed.

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