Instrumental neutron activation analyses of the most Earth-like meteorites
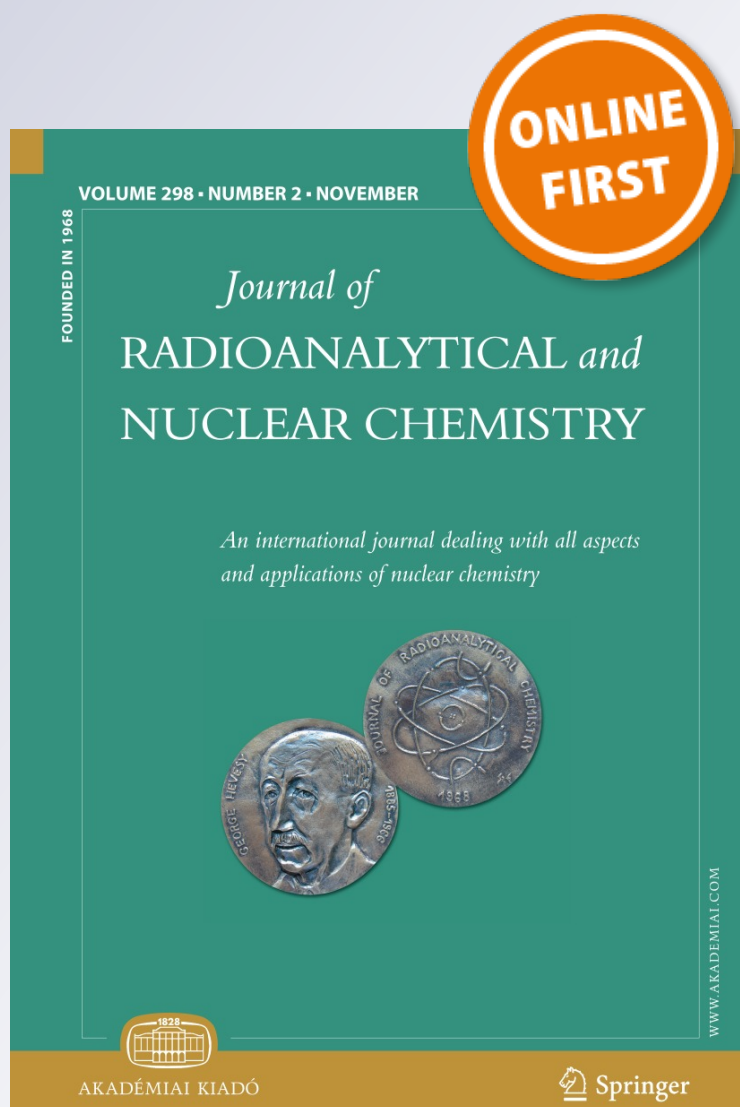
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Abstract C1-carbonaceous chondrites are known to have the highest meteoritic content of volatile elements. Nevertheless, most volatile elements, such as H, He, N and O, are excluded from the accordance with the solar photosphere. In meteoritic material, which condensed closer to the sun, even moderately volatile elements could not completely condense and their C1-normalized concentration ratios with refractory elements are typically depleted. In primitive terrestrial samples these ratios of (lithophile) moderately volatile to refractory elements are even lower. This suggests an accretion of our planet from material, which condensed closer to the sun than all available meteorites surviving in significantly farer distances in the asteroid belt. Evidence to that may come from agreements between most Earth-like meteorites with the depletion pattern of moderately volatile elements in the Earth's mantle or rather related bulk data. Therefore, two samples from Hammadah al Hamra 073 and Sahara 0182, supposed to be further members of the most Earth-like Coolidge-Loongana grouplet, have been analysed by INAA. Together with two earlier analysed samples from the grouplet the results have been used in fingerprint studies with terrestrial data. In spite of internal spreading due to sampling of inhomogeneous material, the results are in accordance with a volatility-dependent model of depletion. Abundance ratios of Fe relative to Mn, Cr, and Si measured from the grouplet-abundances are depleted relative to calculated data from the total Earth, what can be explained with a 30 %-mantle-stripping from an impact of a Mars-sized body.

Introduction

One basic realization of cosmochemistry found in the twentieth century is the starting composition of our solar system. It was concluded from the corresponding composition of C1 carbonaceous chondrites with that of the solar photosphere. In this only highly volatile elements are excluded, such as H, He, N and O, which could only partly condensate even in most primitive C1-meteorites. In the inner part of the solar system the conditions for a complete condensation must have been even worse. There, condensed dust and related gas had a lower opportunity to stay together during the total time of cooling-down. At least the increasing gravity and the stronger solar radiation in the inner solar system were able to remove with time increasing parts of the gas phase around the condensed dust. Therefore, already moderate volatile elements (such as Mg, Si, Cr, Mn) did not completely condense together with the refractory component, similar to what is found in most carbonaceous chondrites relative to the C1-type. However, also other assumptions exist to explain the increasing depletion of moderate volatile elements in this primary material of our solar system (compare e.g. [1]).

The main source of element concentrations in undifferentiated meteorites from so far classified groups as well as ungrouped carbonaceous chondrites is derived from papers of Kallemeyn and other co-workers [2–7]. They analysed comparatively large samples of mostly two replicates of up to 300 mg by instrumental neutron activation analysis and published 25–30 element abundances. Additionally, in the last 30 years other multi-element techniques, especially

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Fig. 1 On refractory elements normalized mass concentrations in different groups of carbonaceous chondrites including the Coolidge-Loongana grouplet are compared with abundances of moderately volatile, lithophile elements in the Earth's mantle. Data are taken from two papers of Kallemeyn et al. [2, 7] and Wänke [10]
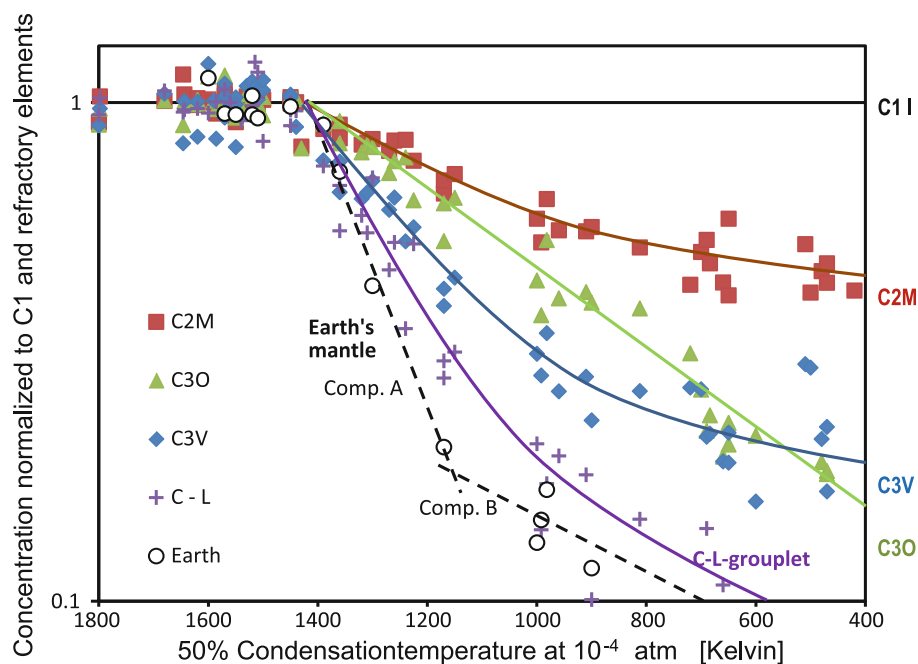
RNAA, XRF and ICP-MS have been used, allowing analyses of totally up to 50 elements in such meteorites [1].

In Fig. 1 refractory normalized element concentrations of the basic carbonaceous chondrite groups mostly from the papers of Kallemeyn et al. [2, 7] are plotted as a function of the 50 % condensation temperatures at 10^{-4} atm [8, 9]. Kallemeyn and Wasson found from similar plots of their analyses that the element abundance pattern in carbonaceous chondrites are in first approximation smooth functions of volatility, but show almost no effects of metal–silicate fractionation as it is known from planetary materials and to some extent also from ordinary chondrites [1]. Furthermore, the found fractionation of moderate volatile elements with volatility in carbonaceous chondrites is smaller than that of primitive terrestrial material. Therefore, the exact composition and origin of the main accretion material of our planet Earth is still controversial. An improved knowledge of this composition would help to understand the genesis and accretion process of our planet.

One way of approach to this question is to find the most Earth-like meteorites. Since we assume a heterogeneous accretion of our planet we concentrate on the early main part of the accretion material, e.g. the component A in Wänke [10], disregarding highly volatile elements, which were derived from later and smaller components. On the other hand, in most meteorites refractory elements are too less fractioned to be specific for an Earth-like composition and so, only the moderate volatile elements or rather their refractory normalized concentrations should be most corresponding with the composition of the most Earth-like meteorites. At least we can look for a compositional trend

in these Earth-like meteorites that can be extrapolated to the terrestrial concentrations. Related primitive concentrations of our planet Earth have been studied since the seventies of the last century (e.g. [11–14]).

The motivation for a renewed study of compositional correspondence of Earth and meteorites is the establishment of a small group of undifferentiated meteorites, which may fit in this consideration of a most Earth-like meteoritic correlate. First ideas based on the carbonaceous chondrite Coolidge in the 80s [15] have been extended by Kallemeyn and Rubin [7] and Weckwerth and Weber [16] after with Loongana 001 and Hammadah al Hamra 073 two new members of an assumed grouplet around Coolidge were found in the nineties. More recently with Sahara 00182 possibly a fourth member of the grouplet was studied by Choe et al. [17]. Beside these 4 meteorites there are a few other candidates in the meteoritic bulletin data base [18], which are recently classified as ungrouped carbonaceous chondrites with a C3 or C4 petrologic characteristic, but with no or only little chemical analyses so far.

Beside the main carbonaceous chondrite groups in Fig. 1 also mean, C1 and refractory normalized element abundances from samples of the Coolidge-Loongana grouplet are plotted. To see the close relationship with our planet Earth also similar normalized, representative concentrations of lithophile elements from the Earth's mantle (+crust) are added [10].

In addition to the basic carbonaceous chondrites groups in the last decades, a few other groups have been found and described. With more than 200 members the Karoondites are most significant and among the carbonaceous chondrites that

group with the highest petrologic types (4, 5, 6). Similar to the ordinary chondrites the Karoondites show an additional depletion with the petrologic type (C3K → C6K) of highly or almost highly volatile elements, but not of the moderately volatile elements [6]. According to Fig. 1 the fractionation of moderate volatile elements proceeds beyond C3V-chondrites in meteorites of the Coolidge-Loongana grouplet [7]. These meteorites continue the trend of increasing volatility fractionation from CI to CV-meteorites including with Mg already least volatile elements. Additionally, petrologic characteristics exist, in which these different types of carbonaceous chondrites are suitable to distinguish, such as equilibrated olivines and pyroxenes, with significant higher fayallite and ferrosilit concentrations (>25 %) in CK and higher proportions of chondrules (>50 %) in the Coolidge-Loongana grouplet [7, 16].

While Karoondites have almost no metal (<0.1 %) the reduced CV-chondrites have 1–5 % of metal [2, 6]. The members of the Coolidge-Loogana grouplet have only a small trend to higher metal abundances presumably up to 10 % Fe–Ni-metal. But, due to terrestrial weathering in Coolidge 70 % and in the case of Loongana up to 90 % is oxidized, mostly as limonite rims around the metal grains [7]. Furthermore, the C-L-grouplet is also distinguishable from CH to CB meteorites. They have typically much higher amounts of metal (>20, or >50 %), but petrologic and chemical similarities to the group of carbonaceous chondrites [18]. Due to high metal amounts a parallel enrichment of siderophile elements relative to lithophile elements can be observed (a factor of 2 in CHs, up to a factor of 6 in CBs). According to their carbonaceous characteristic, these chondrites show also a volatility dependent fractionation already between Mg and Mn (respectively between Ir and Au for siderophile elements). In the case of Bencubbin [19] this trend of increasing depletion is lower than in CV meteorites, and partly much stronger below Mn. Although, this is in contrast to the terrestrial accretion material, accompanied by a significant metal-silicate fractionation, CB is the only group among the carbonaceous chondrites that shows a higher metal content than that of our planet, at least one significant Earth-like property.

Nevertheless, the volatility dependent fractionation of the moderate volatile elements may be the signature that provides the most significant multiple finger-print, hardly to produce with different types of developments. Such ratios between refractory and moderate volatile elements may have survived even the accretion process of Earth and Moon. For both a similar, but more than 50 % stronger volatility dependent fractionation than in all carbonaceous chondrites has been found.

If we assume again that this kind of fractionation becomes stronger with the distance to the sun, the terrestrial component A is probably among all sufficiently analysed materials so far that, which condensed last and in closest distance to the sun. Then, this is probably also valid for the members of the Coolidge-Loongana grouplet among all available meteorites and in this sense a next step closer to Earth's main accretion material. This preferential position may be supported also from isotopic evidences like differences in the ^{26}Mg anomaly of Coolidge [20] or other indications on a radial fractionation in the early solar nebula. In O-Isotopes Coolidge and HH073 overlap with the field of CV and CK-meteorites [17].

The aim of instrumental neutron activation analyses on possibly members of the Coolidge-Loongana grouplet was to find and to establish compositional fingerprints, which give further evidence for a membership of meteorites in that so far not classified grouplet and for a possible relationship with the terrestrial accretion material. Increased significance of Earth-like meteorites may help to find further evidence on aspects of the terrestrial accretion history.

Techniques

With the exception of a few main elements done by RFA, all presented bulk concentrations had been carried out with Instrumental neutron activation analysis (INAA). For the preparation single pieces of the meteorites between 100–300 mg were separately enclosed in cylindrical polyethylene containers. Together with two Zr-standards, which were used for flux-determination at the top and the bottom, the samples were filled upon each other in a polyethylene cylinder. This was irradiated for 6 h in the "Karussell" (carousel), a ring-shaped irradiation facility around the core of a small research reactor (TRIGA) operated by the Institute for Nuclear Chemistry at the Johannes-Gutenberg-University in Mainz. The 40 positions for containers in the "Karussell" can be slowly rotated, so that all receive almost the same flux of 7×10^{11} n/cm^{-2} s^{-1} thermal neutrons and 7.5×10^{10} n/cm^{-2} s^{-1} fast neutrons. The exact flux is controlled (independently with ^{95}Zr for thermal and ^{97}Zr for epithermal neutrons) by the Zr-flux monitors and decreases ~ 0.22 % mm^{-1} with height inside the container.

After transfer to Cologne by a company specializing in the transportation of dangerous goods the irradiated samples were measured several times on two high purity Germanium-detectors in a controlled area at the nuclear chemistry division of the Cologne University. Both measuring stations are surrounded with a wall of 10 cm lead, which suppresses the disturbing natural radiation up to the 100th part. The detectors are arranged with a cryostat on Dewar vessels with liquid nitrogen, which are needed for cooling the Ge-crystal to avoid thermal noise in its measurement signal. With a pre- and a main-amplifier the

Table 1 With INAA analyzable elements and their cosmochemical characteristics

	σ ≤ 10 %	σ ≤ 20 %	σ ≤ 30 %
Refractory elements	Sc, W, Ir, Sm, Eu,	Ca, Ru, Hf, Os La, Dy, Yb, Lu	Mo, Ce, Nd, Tb, Re, Pt, U
Moderately volatile	Mn, Cr, Fe, Co, Ni, As, Au	Cu,	
(Highly) volatile	Na, K, Br	(Cl), Zn, Ga, Se	(In), Sb, Hg,

detector signals are shaped for an analog to digital converter (ADC), which gives the input to a multichannel software that displays the measured γ-spectra.

With at least 3–5 measurements suitable selected in distance and time of measurement, about 30 elements could be determined by γ-ray spectrometry. The results were elaborated with special peak evaluation software, which provides an optimal background determination. The count rates received from the peak areas have been calculated back to the end of irradiation and divided by standard values from an INAA-database for the 250 most prominent γ-lines. These have been earlier measured with single element standards under precisely controlled conditions (e.g. the three distances 5, 40 and 140 mm) and recalculated for the detectors used in Cologne with well-determined, energy-dependent efficiency functions.

The statistical errors calculated by the evaluation program have been extended to the indicated accuracy, considering among others, an error of the standard value of up to 2 %. This is in accordance with the minimum of mean variations found for the recalculated efficiencies and observed in results with lowest statistical errors from multiple analyses of rock standard materials. Evaluations have been completed with partly required, but mostly sufficiently calculable corrections (e.g. γ-absorption, flux variations, peak overlapping from different isotopes and background, competing processes with production of the same isotopes and others).

For samples of more than 100 mg and compositions similar to carbonaceous chondrites the described method provides under suitable measuring conditions the analysis of about 30 elements with errors (σ) less than 30 % (compare Table 1).

A supplement of significant elements can be received from short time irradiation with direct measurement at the used neutron source (e.g. in the analysis of Kallemeyn) or by X-ray analysis (Al, Ti, V, Mg, Si). For further details of the techniques see [21] and Jochum et al. [22] for the quality control verified with a ring analysis. Some additional cognition has been received from single element scans on a microprobe (e.g. the portion and composition of metal and Al–Ca-rich inclusions).

Results

In Table 2 the recent results of two pieces from Hammadah al Hamra 073 and Sahara 00182 are supplemented by earlier, with the same method received results [16] of pieces from Coolidge and a second sample from Hammadah al Hamra 073. Comparison with INAA-results from other samples of the meteorites [17] showed for most elements variations, which can be explained by INAA-statistics and typical variations within the meteorites or the grouplet, respectively. Due to the inhomogeneity of the meteorites in this grouplet (mixture of matrix, chondrules, metal and CAIs) single measurements of pieces up to 1 g show some statistical variation caused by selection effects, in particular for refractory, siderophile and chalcophile elements [24]. Especially, the variations within samples of the same meteorite are often as high, as between samples of different meteorites from the grouplet. Similar variations were already found between two samples of Loongana measured by Kallemeyn et al. [7] as well as by Spettel et al. [23].

Figure 2 shows C1-normalized abundances of the 4 measured samples (Table 2) together with earlier measured samples of Coolidge and Loongana 001 from Kallemeyn et al. [3, 7] plotted versus the 50 % condensation temperature of the analysed elements. The high accordance of the volatility dependent pattern of all samples from the Coolidge-Loongana-grouplet in spite of statistical spreading can be easily checked with exponential trend lines, as offered by the excel-software. For comparison plotted mean values from the classified carbonaceous chondrite groups CI, CM, CO and CV (small symbols) have trend lines with increasing slopes, but some small systematic deviations (slightly curved). The trend lines of the samples from the Coolidge-Loongana-grouplet are significantly steeper. Also, the new sample of Hammadah al Hamra 073 (HH73n) now fits perfectly to the dashed, average trend line of the grouplet in contrast to the earlier sample (HH73), which shows an average slope in between the trend lines of CV meteorites and that of samples from Coolidge and Loongana [16].

Strongest deviations from the trend lines in our measurements are visible in several very low results of strongly refractory elements such as Sc, Ir and Os, which are partly less than their mean values of the CV-meteorites. Since Sc- and Ir-results have small statistical errors of less than 3 % the parallel deviation of both elements could have a real background, may be in connection with the distribution and kind of the Ca–Al-inclusions in the measured pieces.

Main distinguishing feature of samples from the grouplet are their lower concentration ratios between volatile and refractory elements. A significant example, which in all samples causes clearly separated values to other groups

Table 2 INAA-results of two recent and two earlier measured samples [16] of the Coolidge-Loongana grouplet; XRF-data of the earlier samples in italics

Element	[dim] method [mass]	HH073n 203.97 mg	SAH0182 126.5 mg	Accuracy	Coolidge 103.2 mg	HH073 105.5 mg	Accuracy
Mg	[%] XRF				*14.82*	*13.48*	±1 %
Al	[%] XRF				*1.50*	*1.49*	±1 %
Si	[%] XRF				*15.67*	*15.5*	±1 %
Ca	[%] INAA, *XRF*	2	2	±25 %	*1.47*	*1.82*	±2 %
Ti	[%] XRF				*0.085*	*0.08*	±2 %
Fe	[%] INAA, *XRF*	18.3	18.2	±5 %	*21.02*	*22.88*	±1 %
V	[ppm] XRF				*91*	*88*	±2 %
Na	[ppm] INAA	3200	2150	±3 %	1750	3760	±3 %
K	[ppm]	310	270	±15 %	300	330	±15 %
Sc	[ppm]	8.8	8.5	±5 %	9.4	11	±5 %
Cr	[ppm]	2700	3200	±3 %	2950	3500	±3 %
Mn	[ppm]	980	1050	±5 %	1050	1280	±5 %
Co	[ppm]	520	500	±5 %	550	650	±5 %
Ni	[ppm]	12,000	11,000	±10 %	12,000	14,000	±10 %
Zn	[ppm]	20	50	±10 %	33	63	±20 %
Ga	[ppm]	4.8	3.3	±15 %	3.3	4.8	±15 %
As	[ppm]	1.5	2.2	±8 %	2.26	1.55	±8 %
Se	[ppm]	5	7	±10 %	3.2	4.5	±20 %
Br	[ppm]	0.6	0.6	±20 %	1	0.8	±20 %
Ru	[ppm]	1.1	1.1	±20 %	2	1.4	±20 %
Sb	[ppm]	0.07	0.9	±20 %	0.063	0.05	±30 %
La	[ppm]	0.55	0.5	±15 %	0.89	0.55	±15 %
Sm	[ppm]	0.32	0.35	±5 %	0.34	0.35	±5 %
Eu	[ppm]	0.11	0.1	±10 %	0.12	0.13	±10 %
Yb	[ppm]	0.33	0.27	±20 %	0.3	0.31	±20 %
Lu	[ppm]	0.06	0.06	±25 %	0.04	0.045	±25 %
Hf	[ppm]	0.17	0.18	±20 %	0.25	0.18	±20 %
Re	[ppm]				0.078	0.07	±20 %
Os	[ppm]	0.64	0.74	±15 %	0.8	0.8	±15 %
Ir	[ppm]	0.64	0.67	±5 %	0.7	0.84	±5 %
Au	[ppm]	0.11	0.093	±8 %	0.116	0.14	±8 %
Hg	[ppm]				0.45	0.77	±30 %
U	[ppm]				0.02	0.027	±30 %

of carbonaceous chondrites, is the ratio of abundances from the volatile Zn to the refractory Sc. Since two main lines of these elements are very close in their gamma energies, already a cut of 15 keV out of the INAA spectra between 1110 and 1125 keV from any late measurement (>10 d after irradiation) gives a sufficient characterization to recognize and classify a sample from the Coolidge-Loongana grouplet. Therefore, the ratio of the line areas in late measurements of any Ge-detector must be in the area of 1 % to come from a sample of the C-L-grouplet. In CV chondrites the area of the 1115 keV-peak from Zink-65 has between 2 and 3 %, from CM chondrites about 6 % and from CI(C1) chondrites about 10 % of the area of the neighboured 1120 keV-peak from Scandium-46.

Discussion

Similar to the C1 starting composition of the solar system, which became the basis for a big field of research in geo- and cosmochemistry, a more detailed knowledge of the origin and composition of the terrestrial accretion material would help to understand the evolution process in the early solar system and in particular that of our planet Earth. In
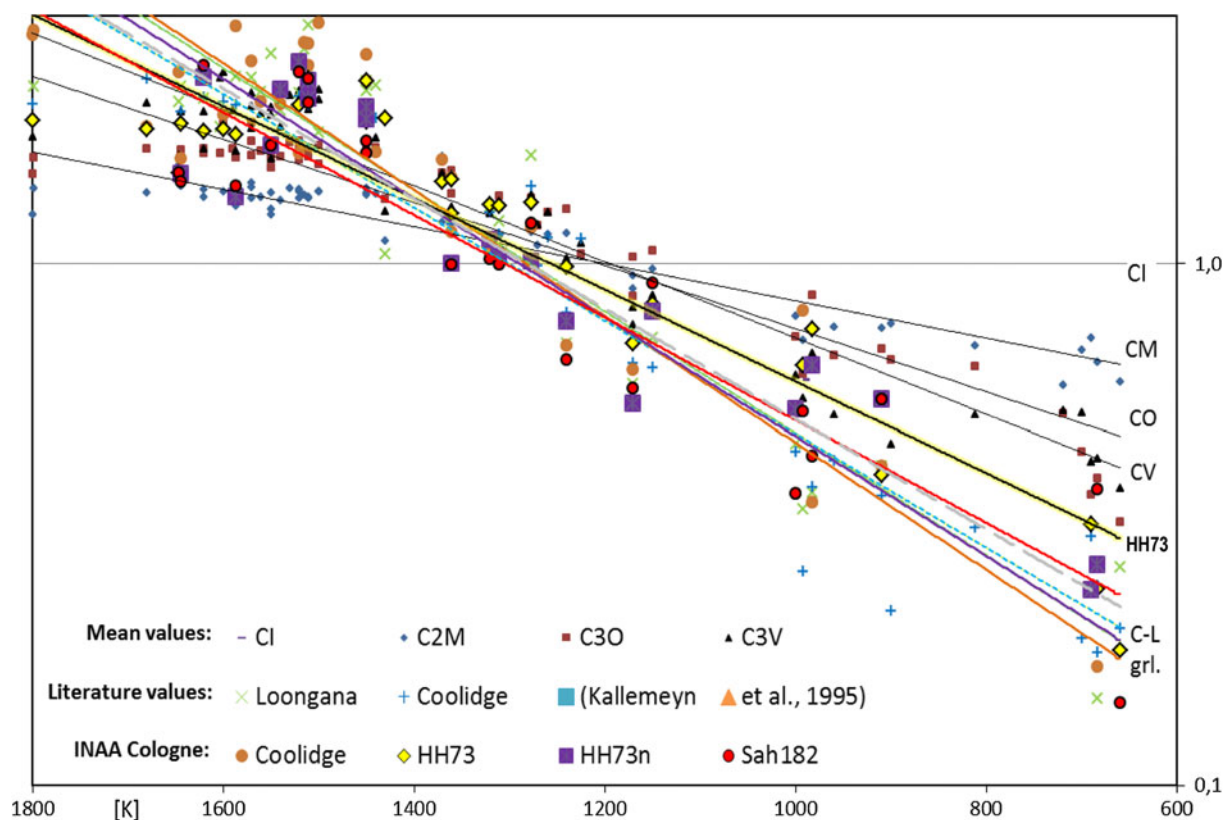
Fig. 2 C1-normalized element concentrations of 6 samples from 4 meteorites of the Coolidge-Loongana-grouplet (*big symbols*) are plotted versus the 50 % condensation temperature of the analysed elements. For comparison mean values of the main groups of carbonaceous chondrites are added with *small symbols*. Only the earlier analysed sample from Hammadah al Hamra 073 shows a trend between CV and the C-L grouplet abundances

contrast to meteoritic material from Mars and the mother body of the HED meteorites (possibly the asteroid Vesta), primitive material of Earth and Moon show a very similar fractionation trend of moderately volatile elements as it is known between different groups of carbonaceous chondrites. Their mean abundances normalized to C1 and refractory elements versus condensation temperatures as plotted in Fig. 1 allows an overview to find suitable features for an extrapolation of meteoritic trends in direction of the terrestrial composition.

The Coolidge-Loongana grouplet bridges in the chemical view more than halfway of the extrapolation in the direction of a calculated terrestrial accretion material. Therefore, every identified and confirmed new member of the grouplet increases not only the significance of this type of meteorites, it also strengthens the assumption that the extrapolated composition of a possibly further group in this direction really existed and had been the main component in the accretion of our planet as far as the extrapolation fits to a verified terrestrial composition.

The extrapolation should be based on data with statistically sufficient precision and checking the agreement needs well-known terrestrial features. The last factor should be well-controlled fulfilled for abundance ratios of element pairs with similar geochemical behaviour, what means in first approximation with similar compatibility to mantle minerals, e.g. Fe/Mn and Al/Ga mass ratios. These four elements are fairly measurable with INAA and have significant differences in the cosmochemical behaviour. Both can help to raise the precision of the extrapolated trend. In Fig. 3 the mass ratios of Fe/Mn of the discussed groups of meteorites are plotted versus the mass ratios of Al/Ga. Due to the geochemical similarities, terrestrial samples from the mantle [13] have only a small spreading. Since Ga is a little bit more incompatible, the crust has up to a factor of 2 lower mass ratios of Al/Ga, what influences negligibly the precision for the total Earth less than 10 %. While for both elements the influence of the terrestrial core is even lower, this is certainly different for the mass ratios of Fe/Mn. But in this case the Fe-content of the core is with about 80 % sufficiently well-known. Only the Mn needs some assumption to calculate a Fe/Mn mass ratio of the total planet Earth.

While Wänke in [10] assumed that most of the missing Mn in the mantle compared with C1 is in the core, the assumption of a volatility-dependent depletion trend of the

Fig. 3 Abundance ratios of Fe/Mn versus Al/Ga from significant types of undifferentiated meteorites are plotted in comparison to representative terrestrial values. Using a trend of the carbonaceous chondrites, which is extended by the Coolidge-Loongana grouplet, the area of a terrestrial accretion material is extrapolated and drawn together with hints on possibly explanations
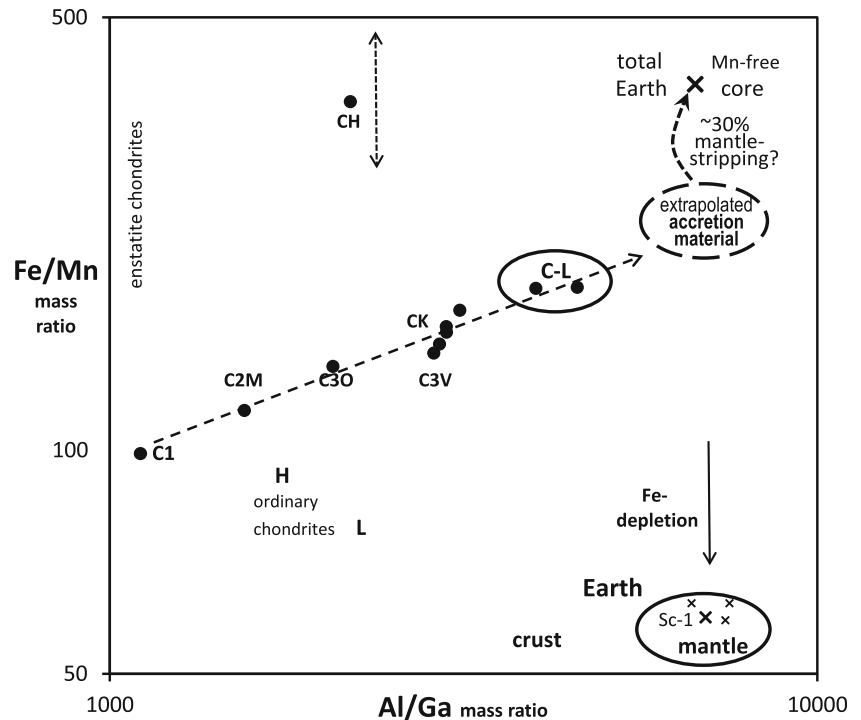
moderate volatile elements in the Earth's mantle believes in an extensively Mn-free core. In this case the Fe/Mn mass ratio of the total Earth is almost 7 times higher than in the mantle. Since the trend of Fe/Mn mass ratios in carbonaceous chondrites extrapolates an almost 2 times lower value (compare Fig. 3), an explanation is necessary.

This explanation may be a mantle stripping of planet Earth, which may happen during an impact of a Mars-sized body, as it is assumed by many other factors, especially to separate and accrete a Moon-sized body in the terrestrial orbit. An enrichment-factor of 2 by removal of a mantle that holds the total Mn would mean to separate more than half of the mantle material from the core. Although, the planet mercury needs to receive its high density (>5 g/cm^3) an even higher factor of mantle stripping (>65 %), this seems not very likely for our planet Earth. A similar comparison of the Fe/Cr mass ratio leads to a similar depletion factor of 2.5 and about 1.5 in the case of the Fe/Si mass ratio. Since in comparison to Mn and Cr, Si has by far the lowest metal/silicate partitioning coefficient ($\sim 10^{-4}$) a separation of 30 % with mantle-stripping as calculated with a Si-free core seems most likely.

In the case of Mn and Cr the stripping factor may be reduced to 30 % by the assumption of a small content of Mn and Cr in the core (0.5 respectively 1 of the abundance level in the mantle). This assumption seems more likely than to explain the total depletion factors of Si, Cr and Mn with a separation to the core, because of the much different metal/silicate partitioning of these elements. In a two-component-model like that of Wänke [10] this problem is certainly reduced. But still it needs additional assumptions to explain the stronger depletion of Mn in the mantle in comparison to the more siderophile element Cr.

Furthermore, the order of increasing depletions of Mg, Si, Cr, Mn, K in the Earth's mantle (compare Fig. 1) looks much more to be volatility-dependent than produced by any kind of metal/silicate differentiation. The high similarity of normalized abundances between the Coolidge-Loongana-grouplet and the terrestrial mantle supports certainly the assumption of an origin from the accretion material. The fact that an exact meteoritic correlate of the main mass in the inner solar system is still not available and the necessary assumption of an unlikely, strong radial fractionation of the solar system that produces very different depletions of the moderate volatile elements between the Earth-Moon-system and the farer from the sun accreted Mars and asteroids (HED) on the other side speaks more against it. Progress on these questions can be expected from further studies of element and isotopic fractionations in meteorites including a full established group around the meteorites Coolidge and Loongana 001. Additionally, a possibly influx from CH meteorites (compare Fig. 3) should be observed. A stronger participation in the accretion material would fairly explain the high Fe-ratios to Mn, Si and Cr without the necessity of a mantle stripping, but would lead according to the Al/Ga mass ratios known so far to a lower fractionation of the moderately volatile

elements, as it can be measured from primitive terrestrial sample.

Conclusions

INAA has been developed in close connection with cosmochemistry mainly in the surroundings of the expected first lunar rocks from Apollo. More than 40 years later the specific advantages and the capability of INAA are still competitive in particular in cosmochemistry, just as the presented work has shown. Beside the non-destruction of rare meteoritic material and the availability for further measurements, the parallel analysis of about 30 elements in the same bulk sample, gives the accuracy for the delivery of trustful ratios between two of these elements. Recent selection of still mainly INAA for measuring precise mass ratios to classify new meteorites or to estimate their connection to the terrestrial accretion material proves this competitiveness and continuing significance of this method. Main conclusions from the recent measurements are the definite belonging of Hammadah al Hamra 073 and Sahara 0182 to the Coolidge-Loongana grouplet from the view of chemical composition. Especially, the low results of (moderately) volatile elements such as Mn, K, Ga and Zn had been unequivocal. The question, whether a total establishment of a group around Coolidge and Loongana or an even closer composition of a meteorite to the terrestrial mantle abundances delivers the complete proof that the depletion of the moderately volatile elements in the Earth's mantle is due to its accretion material remains nevertheless open.

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