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The CI Carbonaceous Chondrites as the Missing Old Meteorites of Mars and Implications for Early Mars Biology

J.E. Brandenburg
Orbital Technologies Corporation
Madison Wisconsin

Abstract

An array of data argues that the CI carbonaceous meteorites are samples of early Mars regolith which is now preserved in the Southern highlands. Oxygen isotopes match well with aqueous altered materials from recognized meteorites as do anhydrous grains from the CI when compared to Martian lavas. Chromium isotopes also match well as do Nitrogen when compared to the CI's recognized Martian contemporary, ALH84001. Igneous grains found in CI's fall on the same high Nickel and Ca-Fe mixing lines as recognized Mars meteorites. The aqueously altered clay and siderite materials match well with Mars soil analyses and similar minerals found in ALH84001. The absence of hypervelocity impact material, together with the inclusion of solar flare tracked grains, argues that the CI formed as a regolith in a velocity buffered environment that also supported abundant liquid water, conditions most easily achieved under a planetary atmosphere. The fact that CI are 2% organic matter and are isotopicaly and chemically Martian has profound implications for early Mars biology and supports arguments for life signs found in ALH84001.

I. Introduction: The Mars Age Paradox

The absence of meteorites dating from early Mars, except for ALH84001, is a continuing riddle. However, it now seems possible that the missing old MMs (Mars meteorites) may actually be already in human possession, but have not been recognized as Martian. The CI carbonaceous chondrites have been advanced as candidates for the missing old MMs (Brandenburg , 1996). These meteorites are, like ALH84001, 4.5Gyr in age. If they are from Mars they represent important probes of early Mars surface conditions. The identification of these meteorites as Martian has been proposed based on their detailed isotopic and chemical similarity to the known MMs, particularly their contemporary ALH84001. The CI are 2% organic matter, suggesting a picture of early Mars that was warm, wet, and rich in organics, and strongly supports the finding of life signatures in ALH84001 (Mckay et al. 1996) particularly in light reports of micro-fossils in the CI themselves (Hoover, 2011).

The CI are composed of clays and other water altered or soluble minerals and thus resemble not the recognized MMs, which are lavas, but rather strongly resemble the soil found at the Mars landing sites. This similarity of chemistry between CI material and the Viking soils was first noted by the investigators the Viking Mars lander soil analysis team (Toulmin et al., 1977).

This possible identification of the CI as Martian was late in coming because the CI were, for a long time, thought to represent relics of the primordial solar nebula, and to be from a parent body in the asteroid belt. However, it was also recognized that their heavily aqueously altered state and absence of chondrules or any other evidence of hypervelocity impact argued for their origin in a unique planetary-like environment. Petrographic connections with the body of recognized MMs are certainly present: CI contain small grains which appear to be derived from a large lava melt similar to Martian lavas, and some MMs contain water altered materials similar to those found in the CI.

Despite the discovery of the one 4.5 Gyr aged ALH84001 by Middlefehldt (1994) the rest of the MMs are young <1.2Gyr. The crustal dichotomy of Mars, with a young north and ancient south, would seem to require an approximately equal number of old to young meteorites in our collections. The process of ejection to earth of ALH84001 was similar to the other MMs so ejection physics in South is the same as in North and no reason for a North-South anisotropy in meteoritic bombardment has ever been suggested. Thus, some of our MMs are missing. Therefore, the absence of a large number of ancient meteorite material from the MMs collection is conspicuous and suggested that we may have unrecognized members of the MM collection in our possession. Do we then have MMs in our meteorite collections that, like ALH84001 initially, we do not recognize as Martian? The suggestion that the CIs might represent that group of missing MMs of sedimentary mineralogy, with origins in the southern portion of Mars was first made by Franchii et al. (1997). However, they noted what they believed to be a significant difference in oxygen isotopic composition between the CI and MMs, with CI materials being slightly higher than MM materials in $\Delta^{17}O$. In a full data set however, Martian aqueous materials were also found to have higher $\Delta^{17}O$ than MM lavas. Thus the perceived gap in oxygen isotope signatures between CI and MM materials has disappeared and with it the last substantive objections to the CI Mars connection.

II. Hypothesis

The CI-MM Hypothesis is that the CI carbonaceous chondrites are the missing old meteorites of Mars and are fragments of a sedimentary, water-altered, post-accretion "veneer" that formed on Mars during the Early Intense Bombardment period of Martian history, as was suggested by Anders and Owen (1977) to explain the noble gas isotopics found in the Mars atmosphere. That is, they are formed from the "left-overs" of the formation of Mars from the solar nebula that rained down upon the newly formed surface of that planet and formed a veneer. This veneer, arriving late, never participated in the melt differentiation of Mars. This veneer is preserved in the Noachian South of Mars based on its old surface age but not in the North where resurfacing occurred late in Mars history. Fragments of the water altered veneer were ejected from Mars surface by recent impacts and conveyed to Earth and became the CIs (Brandenburg (1996). The CI material never melt-differentiated but was aqueously altered on Mars surface and sampled its environment.

If this CI-MM hypothesis is correct the CI and Mars should share the same isotopes and while never being melted they should be the same age as the primordial MM ALH84001. ALH84001 and CI are the same age ~ 4.5Gyr, if they are both from Mars then they sampled the same primordial environment and this should be reflected isotopically, chemically and morphologically. New data from ALH84001 supports this connection. Oxygen isotopic data for aqueously altered ALH84001 minerals (carbonates) is identical to CI aqueously altered silicates $\Delta^{17}O = 0.8$ found by Farquahar et al. (1998) and Baker et al. (1998). Nitrogen and Nobel gases closely matches CI isotopic composition for trapped gases in ALH84001 in 3g/cc mineral separates found by Murty and Mohpatra (1997).

In the remainder of this article, the full range of data isotopic, chemical, petro- morphological will be summarized as it relates to the MM-CI connection. The Implications of the MM-CI connection will be discussed, in particular the confirmation of organic matter on Mars and reports of bio-relics in Mars meteorites.

III. Isotopic Data Relating to a Mars-CI Connection

Oxygen isotope data provides strongest connection between Mars and the CI. Oxygen is the third most abundant element in the Sun and is found in all rocks, thus oxygen isotope analysis, comparing the relative abundance of ^{17}O and ^{18}O normalized to the more abundant ^{16}O, is a valuable tool for differentiating meteorite samples, as shown in Figure 1. It is now apparent that the oxygen isotope signature of Mars is richer and more diverse than that of earth, due to the fact that the hydro-sphere of Mars and its lithosphere are out isotopic equilibrium. The water of Mars is more enriched in the light isotope ^{17}O relative to its rock (Karlsson et al., 1992), this fact being attributed to the lack of plate tectonics on Mars. Tectonics is the major mechanism for isotopic equilibration on Earth because it brings subducted rock into contact with water under heat and pressure. Because of this dis-equilibrium of the anhydrous and hydrous minerals oxygen isotopic data in MM and CI materials must be compared in detail. It requires the comparison of anhydrous CI material with anhydrous MM material and likewise the comparison of aqueously altered materials between the two meteorite families.

For the CI the bulk of the material is aqueously altered, so the problem is to find aqueously deposited materials in the otherwise lava derived MMs. When this done comparison can be made between water deposited carbonates found in ALH84001 and other similar materials and the CI clay. When this is done, as shown in Figure 2, it is seen that corresponding CI and MM aqueously altered materials are indistinguishable.

In CI only small amounts of anhydrous materials are found, these consist of olivine and pyroxene grains imbedded in the clay matrix. The oxygen isotope data from the anhydrous mineral olivine and pyroxene grains from the CI (Watson, et al., 1996) can be seen to be indistinguishable from a representative MM olivine (Figure 3).

Thus oxygen isotope data, the most fundamental differentiator between meteorites, has demonstrated a strong link exists between CI and MM s.

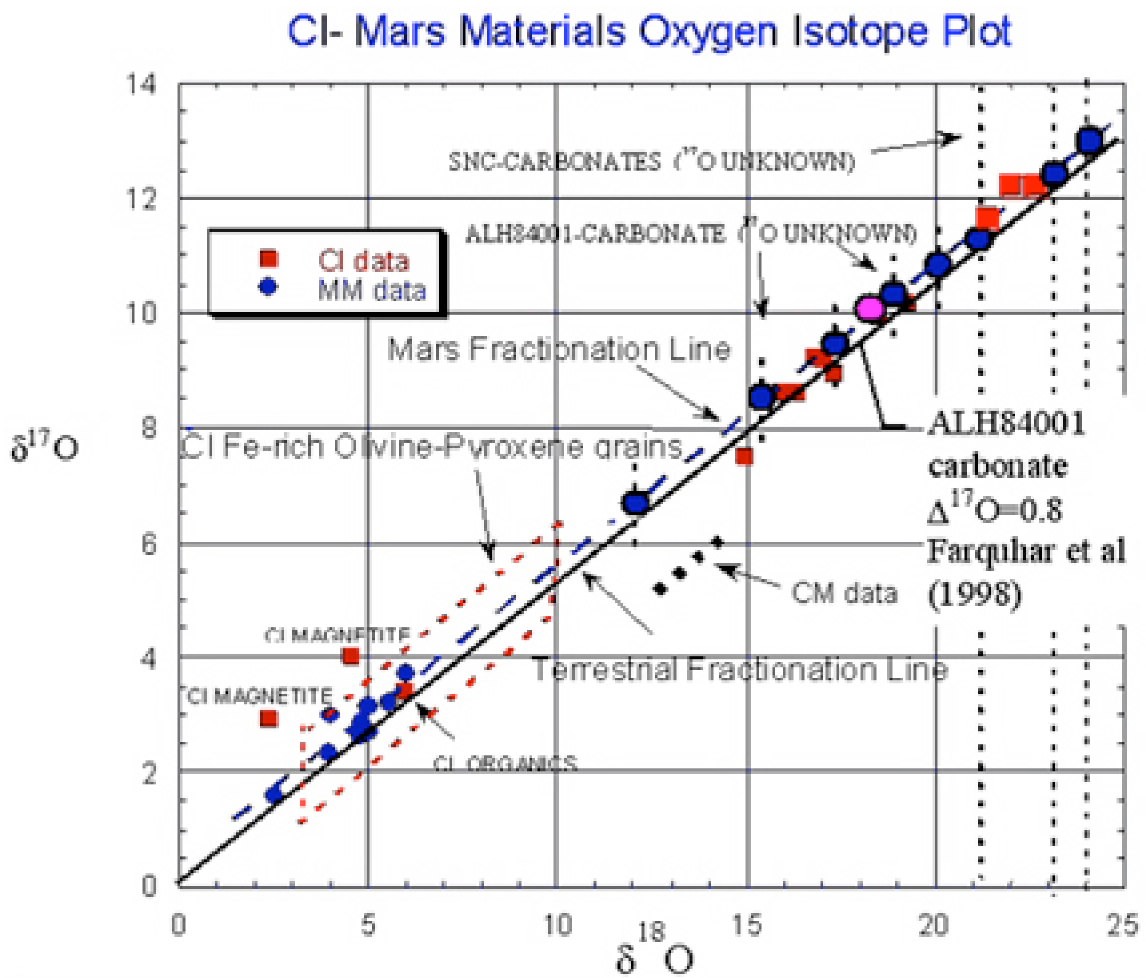
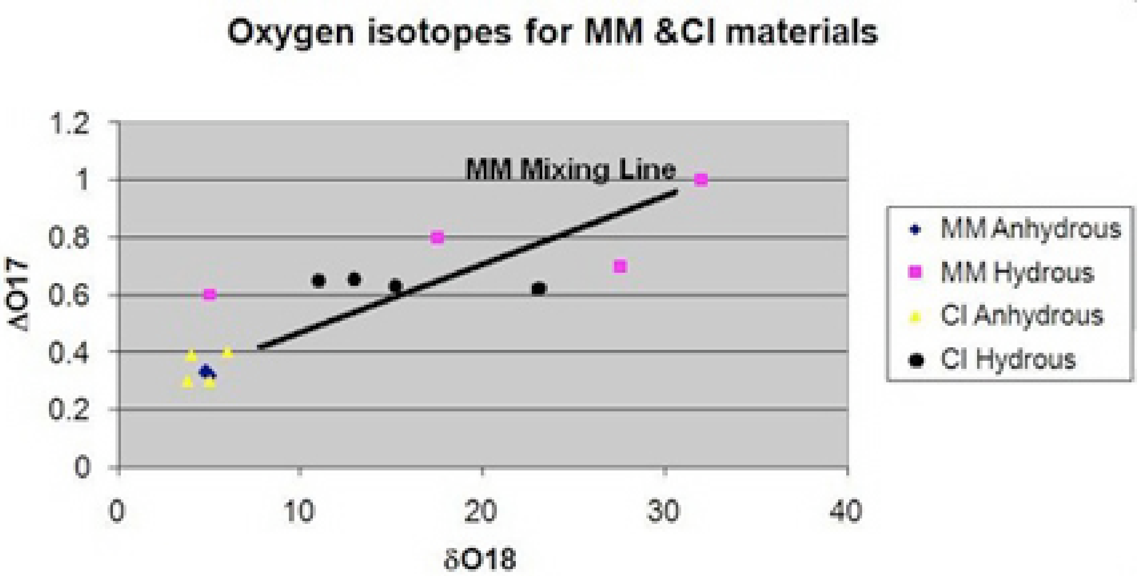


Figure 1. Oxygen isotopic data for Meteorites. MM meteorites are Nakhla and Lafayette. Solid line is the terrestrial fractionation line where terrestrial and lunar materials are found, dashed line is that for Martian materials

Figure 2 (Bottom Next Page). A comparison of oxygen isotopic data for aqueous and anhydrous minerals from both MMs and CIs, is shown. They are compared using the $\Delta^{17}O$ versus $\delta^{18}O$ which measures difference in parts per mil from the terrestrial fractionation line and parts per mil difference from terrestrial ocean water. An approximate MM mixing line has been drawn, showing that CI materials lie on this line and within the bounds of MM materials.


Oxygen isotopes for MM &CI materials
MM Mixing Line
ΔO17
δO18
1.2
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
MM Anhydrous
MM Hydrous
CI Anhydrous
CI Hydrous

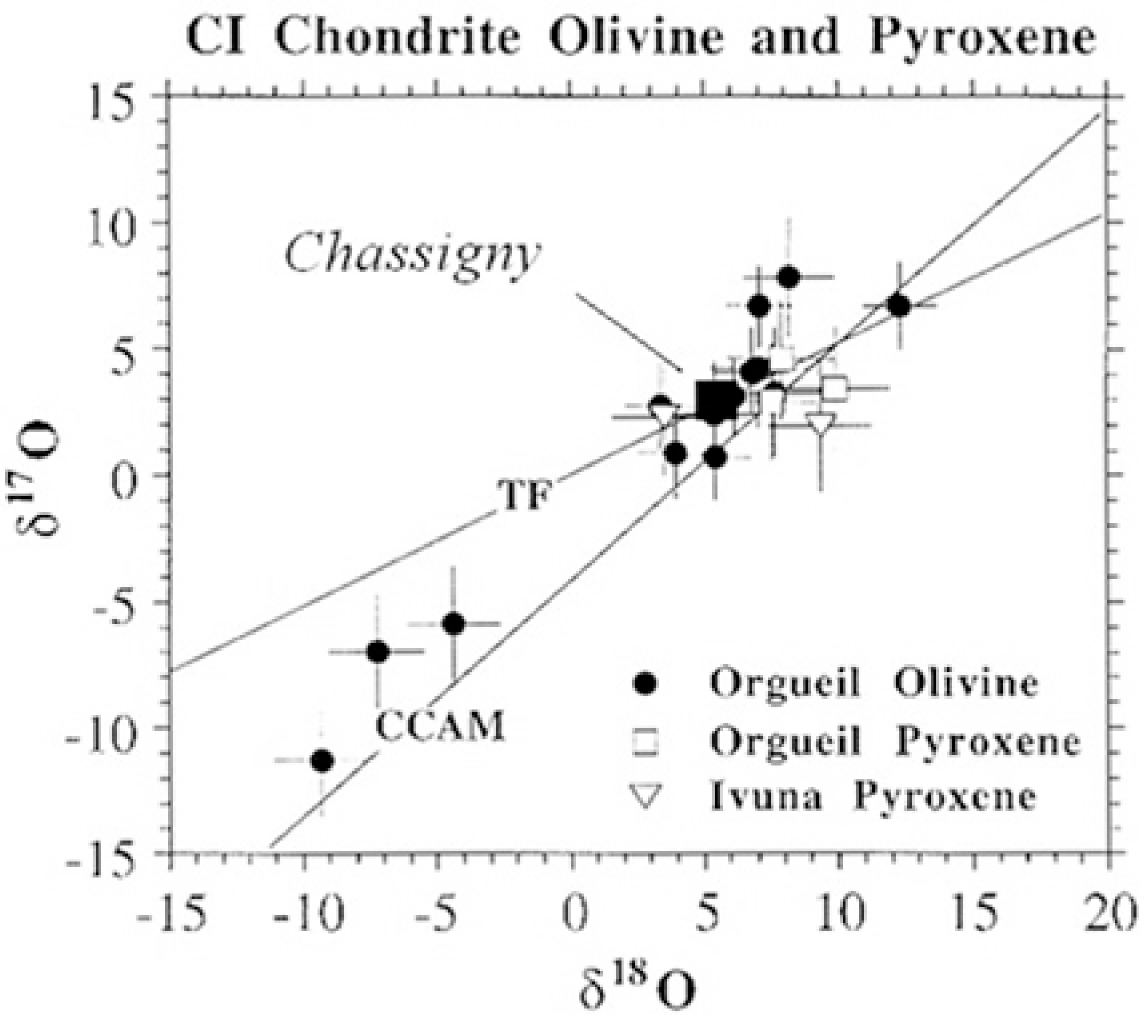

CI Chondrite Olivine and Pyroxene
Chassigny
TF
CCAM
δ17O
δ18O
15
10
5
0
-5
-10
-15
-15
-10
-5
0
5
10
15
20
Orgueil Olivine
Orgueil Pyroxene
Ivuna Pyroxene

Figure 3. A graph of oxygen isotopes for CI olivine and pyroxene grains compared to a representative MM olivine from the recognized MM Chassigny.

Light and Nobel Gas Isotopes

The measurement of another isotopic system D/H in water from both the MM and CI group is consistent with a common water reservoir for both groups. Measurement of the D/H ratio by ion microprobe in hydrous materials for three younger members of the MM group Chassigny, Shergotty, and Zagami, showed a wide range of values from δD = +4000 %o, which is the present Martian atmospheric value (Bjoraker et al. 1989) to +512%o, in water found in glass enclosed inclusions (Watson et al. 1994a). The range of D/ H values was interested to reflect the intense fractionation of mars hydrogen in time by the mechanism of water escape to space. The enclosed water of low δD was interpreted been the oldest water since it had been the most completely isolated from the atmosphere, where hydrogen is continually being fractionated. Measurements of D/H in water released by stepped heating, in the very ancient Martian meteorite, which formed contemporaneously with the CI Orgueil: ALH84001, which at 4.6 Gyr old (Jagoutz 1994) and was, showed also a 350C water release δD component of +33 %o and a 1000C release of + 700 %o (Watson et al 1994b), Watson et al. 1996, Boctor et al. 1998) showing lower D/H overall than other MMs (except for Chassigny, which gave almost terrestrial values using this method). This would appear reasonable, given ALH84001's greater age than other MMs. The values of δD measured in CI water samples released at 180C and above are + 170 to +235 %o inj Orgueil and + 180 to + 300 %o in Ivuna (Yang Epstein, 1982 and Boato, 1954). The D/H ratio data for water in CI materials are thus consistent with exposure to water on Mars contemporaneously with ALH84001, with Mars water less fractionated.

Measurements of carbon isotopes in CI carbonates gave a $\delta^{13}C_{PDB}$ of +70.2 ‰ for Orguiel and +65.8 ‰ for Ivuna. These constitute the heaviest C measured in any meteoritic carbonate (Pillinger, 1984). These can be compared with $\delta^{13}C_{PDB}$ of +9 to +15 ‰ obtained from carbonates in two MMs : Nakhala and EETA 79001 (Wright et al. 1989) with ages of 1.3 Gyr or younger, and from ALH84001 +40.9 ‰ was obtained (Watson et al. 1994a), which has the heaviest carbon of any MM. This is consistent with a picture of an early Mars where fractionation of carbon was lessening in time and would again be consistent with CI carbonate formation on Mars contemporaneously with those found in ALH84001.

The CIs are remarkable in that they contain organic matter in greater abundance than any other meteoritic type (Nagy 1975). Because of this, a martian orgin for the CIs coupled with their great age, would mean evidence for primordial organo-synthesis on Mars and perhaps even primitive biology. However, this degree of organic matter content is is marked contrast to the apparent complete lack of detectable (1ppb) organic matter in the Martian soil at the Viking landing sites (Bieman and Lavoie, 1979) and the apparent hostility of the Martian Surface Environment to organic matter, due to solar UV and the presence of possible oxidizing agents in the Martian soil (Oyama and Berdahl, 1977). Thus the, the CI material would have to be material buried at depths of at least meters below the Martian surface to be preserved over geologic time, out of contact with the UV environment at the surface, but shallow enough to permit ejection. Organic matter has been reported in some MMs and can be compared with that in CIs. The isotopic makeup of the solvent soluable organic carbon in the CI Ivuna is $\delta^{13}C_{PDB}$ = -18.0 ‰ (Pillinger 1984) which compares well with measured acid resistant residue carbon in MMs $\delta^{13}C_{PDH}$ =-28.0 ‰ for Nahkala and δ13CPDH =-33‰ for EETA 79001 (Wright et al. 1989). Careful study of any identified primordial MM organics and comparison with CI organics could provide a good test of the hypothesis that the CI come from Mars, since under this hypothesis organic molecular species should be similar between the two.

Measurement of trapped noble gases and nitrogen in MM materials has provided important evidence for establishing the parent body of the MMs (McSween 1994, Bogard et al., 1984) Extensive analysis has revealed two components: a shock implanted "atmospheric " component matching the modern Mars atmospheric pattern of noble gases and nitrogen isotopic abundance and and a "solar" component thought to rpresent the dissolved gases in the Martian mantle (Swindle et al. 1986). These components appear mixed in several MM lithologies and thus Mars appears to present a rich spectrum of trapped gas isotopic signatures rather than a single one. In contrast, CI trapped gases follow a pattern of isotopic abundance belonging to a broad class called "planetary". At the heavier end of the isotope mass spectrum, Kr and Xe, the CI gases follow a nearly solar pattern called AVCC (Average Carboneacous Chondrites).

Amoung the Kr and Xe isotopes Swindle et al. have identified what appears to be a highly fractionated AVCC component in Shergotites (Swindle et al. 1986) and Drake et al. (1991) more recently has identified in MM trapped gases two mixing lines in the space of $^{86}Kr/^{132}Xe$ and $^{129}Xe/^{132}Xe$ abundance ratios. Both mixing lines have the data from Chassigny as an endpoint, indicating that it represents an important trapped gas component in these isotopes. The data from Chassigny, $^{86}Kr/^{132}Xe$= 1.14 and $^{129}Xe/ ^{132}Xe$ =1.03, compares very favorably with data taken from Eugster et al. (1967) which gives $^{86}Kr/^{132}Xe$ = .98 and $^{129}Xe/^{132}Xe$ = 1.05 for Orgueil indicating that the CI and the MM Chassigny shared this same component. Orgueil magnetites have $^{129}Xe/^{132}Xe$ = 1.02 where this can have a contribution from the decay of ^{129}I. The Martian atmosphere has $^{129}Xe/^{132}Xe$ =2.5. These results seem consistent with the idea, suggested by Peppin (1992), that the early Martian atmosphere received a substantial contribution from CI like material.

Trapped nitrogen, released from the organic portion of the Orgueil meteorite, gives a $\delta^{15}N_{air}$ = +43 (Pillinger 1984) whereas nitrogen from EETA79001 glasses ranges from $+90 < \delta^{15}N_{air} < +225$ (McSween 1985). Since Mars atmosphere is believed to have undergone fractionation in time and the cI are primordial in age, this slightly fractionated nitrogen in CI's is consistent with primordial Martian atmosphere.

This supported strongly by the discover of an end member nitrogen component in ALH84001, (Murty and Mohapatra 1997) which has of $\delta^{15}N_{air}$ = +46. They also found a pattern of Xe isotopes that seems to be AVCC, they also found a Kr component in ALH84001 that has an isotopic signature of AVCC Kr (Figure 4).

In the lighter isotopes, gases trapped in Orgueil organic residues released above 900C, give average, $^{20}Ne/^{22}Ne$ = 8.5 and $^{38}Ar/^{36}Ar$= 0.19 (Frick and Monoit 1977) These can be compared with values obtained the Martian meteorite LEW 88516 released at 1600C which are: $^{20}Ne/^{22}Ne$ =0.92, $^{38}Ar/^{36}Ar$ =0.56, (Treiman et al. 1994). Corresponding values fro Sherggotite lithologies are in ranges $1 < {}^{20}Ne/^{22}Ne < 10$ and $0.19 < {}^{38}Ar/^{36}Ar < 1.0$ (Bogard et al. 1984). Atmospheric values for Mars Argon is $^{38}Ar/^{36}Ar$=0.18 Therefore, in a limited analysis presented here, trapped gas data would appear to be consistent with a common origin for both MM and CI noble gases and nitrogen, as well as oxygen.

Therefore the light, stable isotopic data for water and lithologies are consistent with MM and CI materials having a common origin.

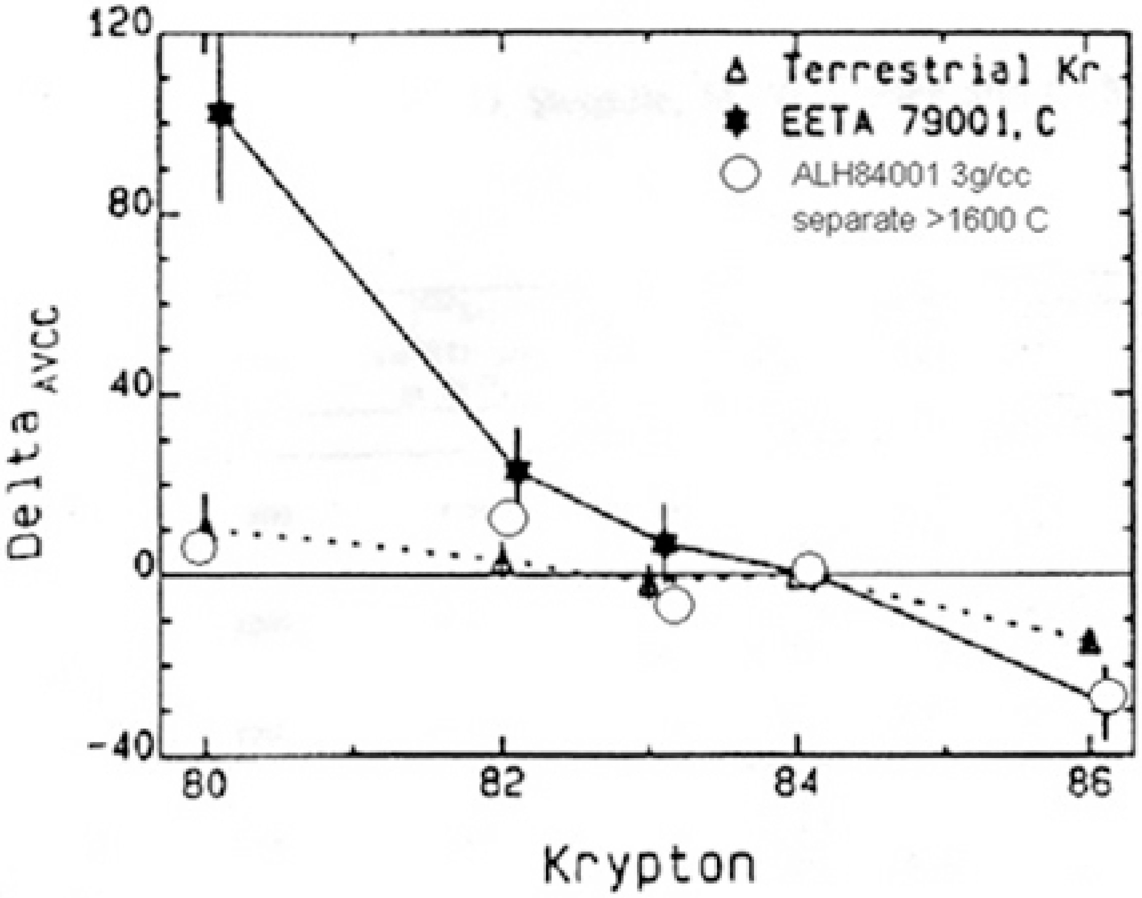


Figure 4. CI versus Martian Kr (graph adapted from Swindle, T. D. , Caffee, M. W., and Hohenberg, C. M., (1986))

Tungsten and Chromium

Recent isotopic studies of MM meteorite have revealed a chromium and tungsten signature for MMs. For Chromium the comparison between recognized Mars Meteorites is informed again by the fact that the MMs represent rock from a chemically differentiated lava melt whereas the CI represent an aqueously processed mixture of materials from a planetary nebula, that simply arrived on Mars too late to be part of the melt. The CI have long been recognized as being composed of a range of materials whose Cr isotopes are individually quite different from those characteristic of Mars or Earth but whose range subsumes those values. A major component of the CI chromium does in fact lie on the Mars value (Endress et al., 1996).

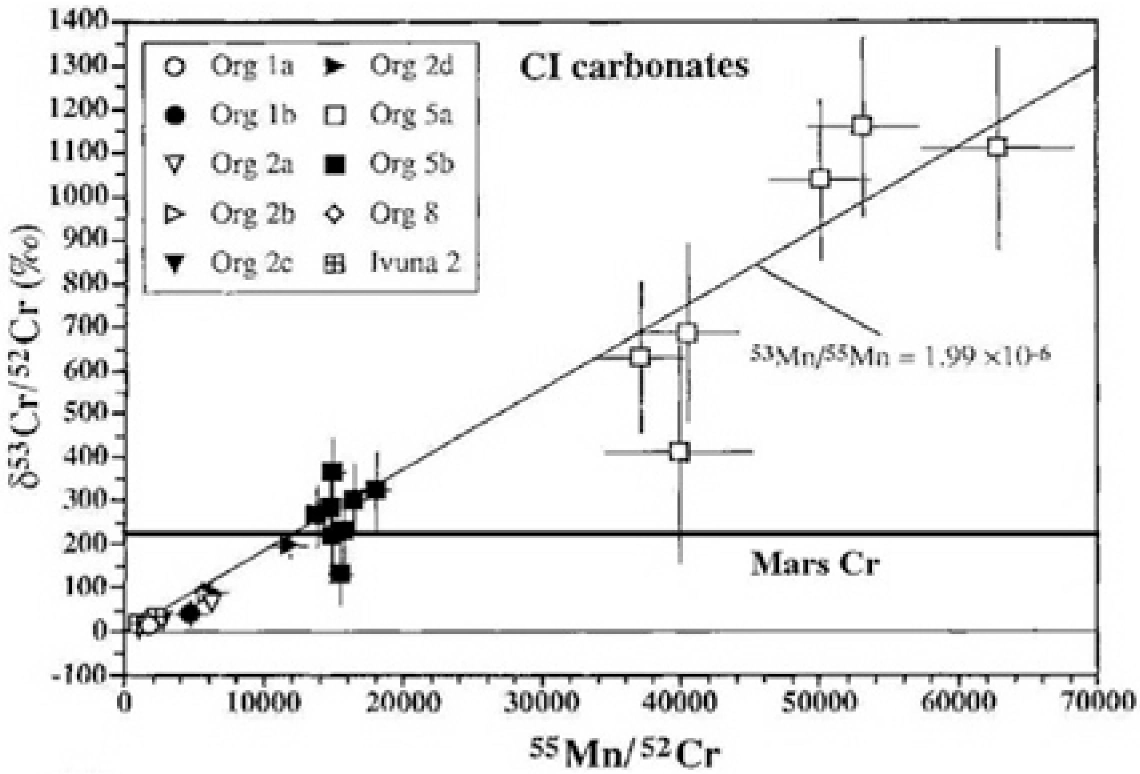


Figure 5. A comparison of $^{53}Cr/^{52}Cr$ for CI materials also showing the recently identified MM signature value. Graph adapted from Endress et al. (1996)

For tungsten the signature relates the time of molten core differentiation to the time of decay of short lived isotopes (Foley C.N. et al. (2003). The agreement in other isotopes with a gap between the range of tungsten isotopic values and those for the CI is consistent with the CI being a late accretion veneer on Mars that did not participate in melt differentiation. Thus, unlike the MMs who formed from a large lava melt and chemically differentiated while the short lived ^{182}Hf was still "live", the CI remained in their undifferentiated state and preserved primordial ratios of isotopes.

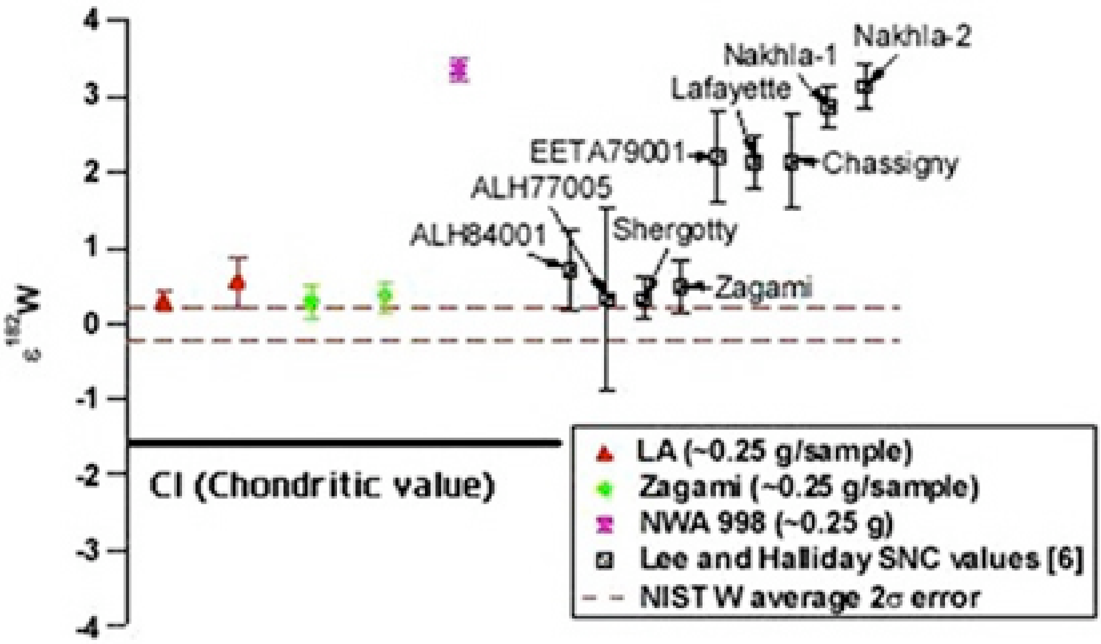


Figure 6. A comparison of Mars and Terrestrial Tungsten isotopes with those of CI. Graph adapted from Foley et al (2003)

Space Exposure Ages

Like all meteorites, the CI are believed to have been buried on the surface of some larger parent body, where they were protected from cosmic rays, when they are ejected by some other impact they are then exposed to cosmic rays which create "spallation" product isotopes. The isotopic composition of light noble gases such as helium and neon, products of cosmic ray spallation, is an important indicator of exposure time to interplanetary space. Estimates of the space exposure times of MM and CI meteorites are shown in Figure 7 and can thus be compared. They appear to be comparable.

Therefore, it is apparent that the CI and MM meteorites came from the same distinct reservoir of isotopes. However, the same can be said for both lunar and terrestrial samples, so that the question then becomes, did the MM and CIs sample the same geo-chemical conditions? This can be answered by comparing the minerals found in them.

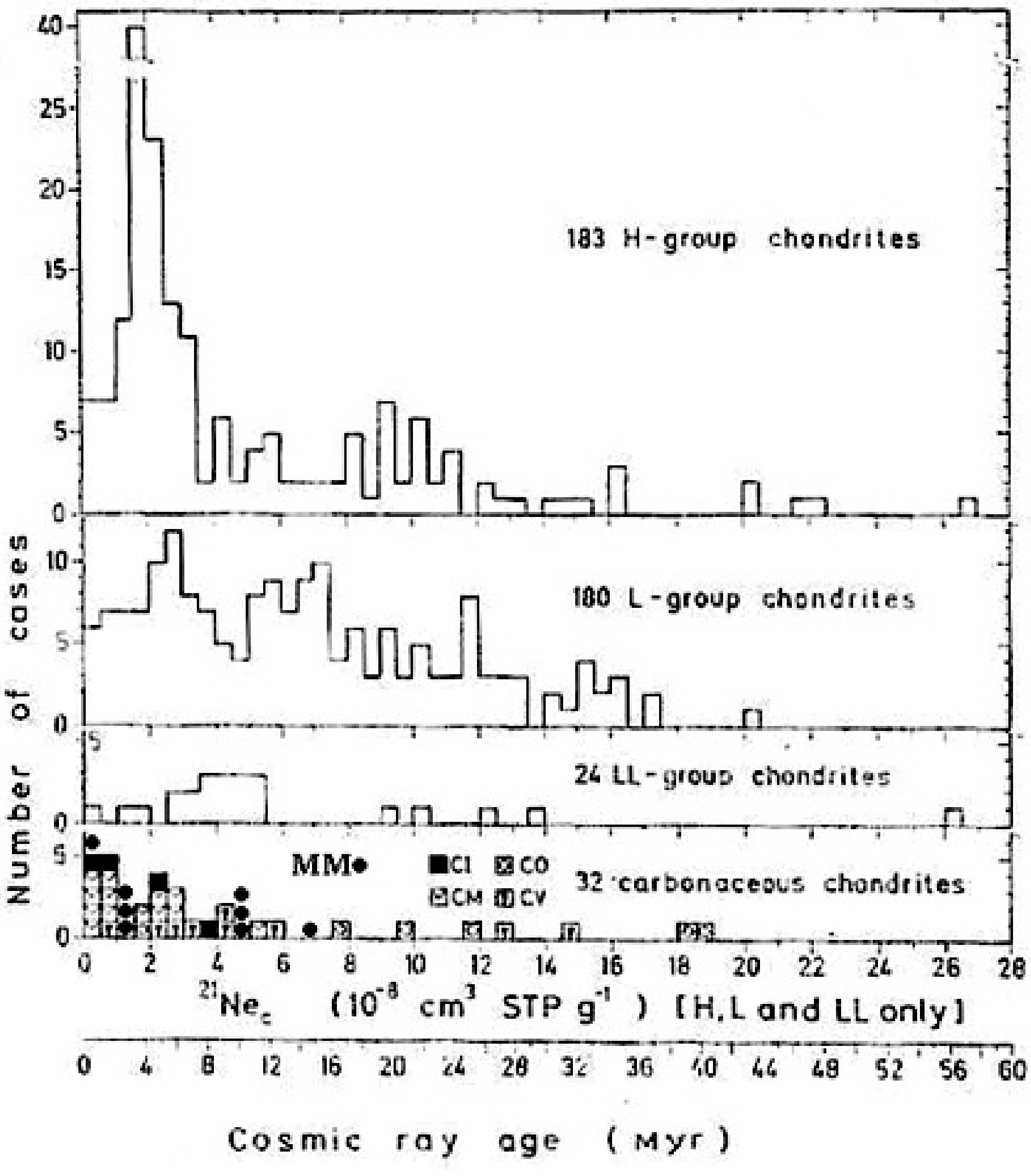


Figure 7. a comparison of cosmic ray exposure ages for CI and presently recognized MMs as well as other meteorite types. Graph adapted from Asteroids, ed. T. Gerhels The University of Arizona Press, Tucson & London pp. 544.

IV. Mineralogical and Chemical Comparisons between CI and MM groups.

Despite the fact that the MMs are overwhelmingly igneous rock and the CI are water formed clay, comparisons can be made between the groups and between the approximately known Martian soils from the landing sites. Igneous rock also appears in the CI in the form of small pyroxene and olivine grains.

Olivine grains are found in carbonaceous chondrites generally, being a component of the dust of the early planetary nebula. However, the olivines found in the CI are unique for those found in carbonaceous chondrites and these unique properties suggest their origin from a planetary sized parent body. The olivine grains found in the CI are unique for those found in carbonaceous chondrites in that the iron rich grains follow a mixing line in Calcium and Magnesium (Kerridge, J. F. and MacDougall J.D., 1976). This is considered remarkable since calcium rich and magnesium rich minerals have very different melting and condensation points and thus the grain cannot be formed directly from a solar nebula. Instead the grains appear to have been formed as droplets, splattered out of a lava melt on a large body. The olivines appear to fall on the same mixing line as Chassigny, the Martian olivine.

In addition, the iron rich olivine grains from CI are rich in nickel. This is considered important because nickel enrichment of olivines is considered to occur only on large bodies, due to the expulsion of nickel from the iron rich molten cores. It can be seen that the olivines from CI fall on the same mixing line as Martian olivines (see Figure 9).

CI can be said to resemble Martian landing site soils in that they are also water formed clays. The similarity between CI and Martian soil composition was striking and was noted at the first landings, to the extent that a Martian origin for CI material was then actively considered (Toulmin et al. 1979). However, since at the time no meteorite was known to have Mars as a parent body, and the CI material was so fragile, this possibility was immediately discounted (Klause Kyle, Private communication).

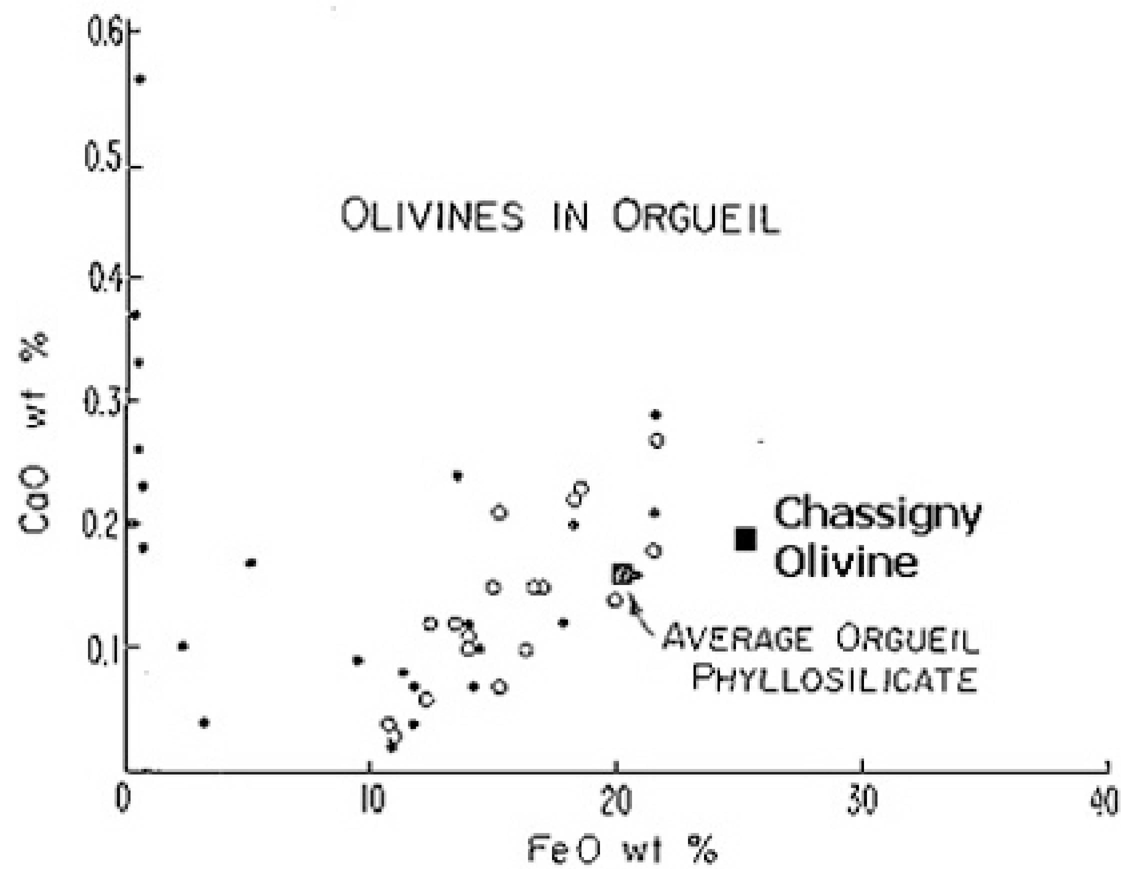


Figure 8. CI Olivines versus Martian Olivines Ca-Fe mixing Line (adapted from Kerridge, J. F. and MacDougall J.D. 1976)

One aqueously formed mineral found in CI and MMs is quite distinct in both groups and is not found in other meteorite types. Ferrous magnesite, also called brunnerite, is found in only two meteoritic types in any abundance: MMs and CIs. The composition of CI brunnerite closely matches that found that ALH84001.(Figure 10)

Therefore, it appears that MM and CI meteorites formed not only from the same pot of isotopes but were formed under the same chemical conditions. The simplest hypothesis then becomes that they both originated on the same planetary body.

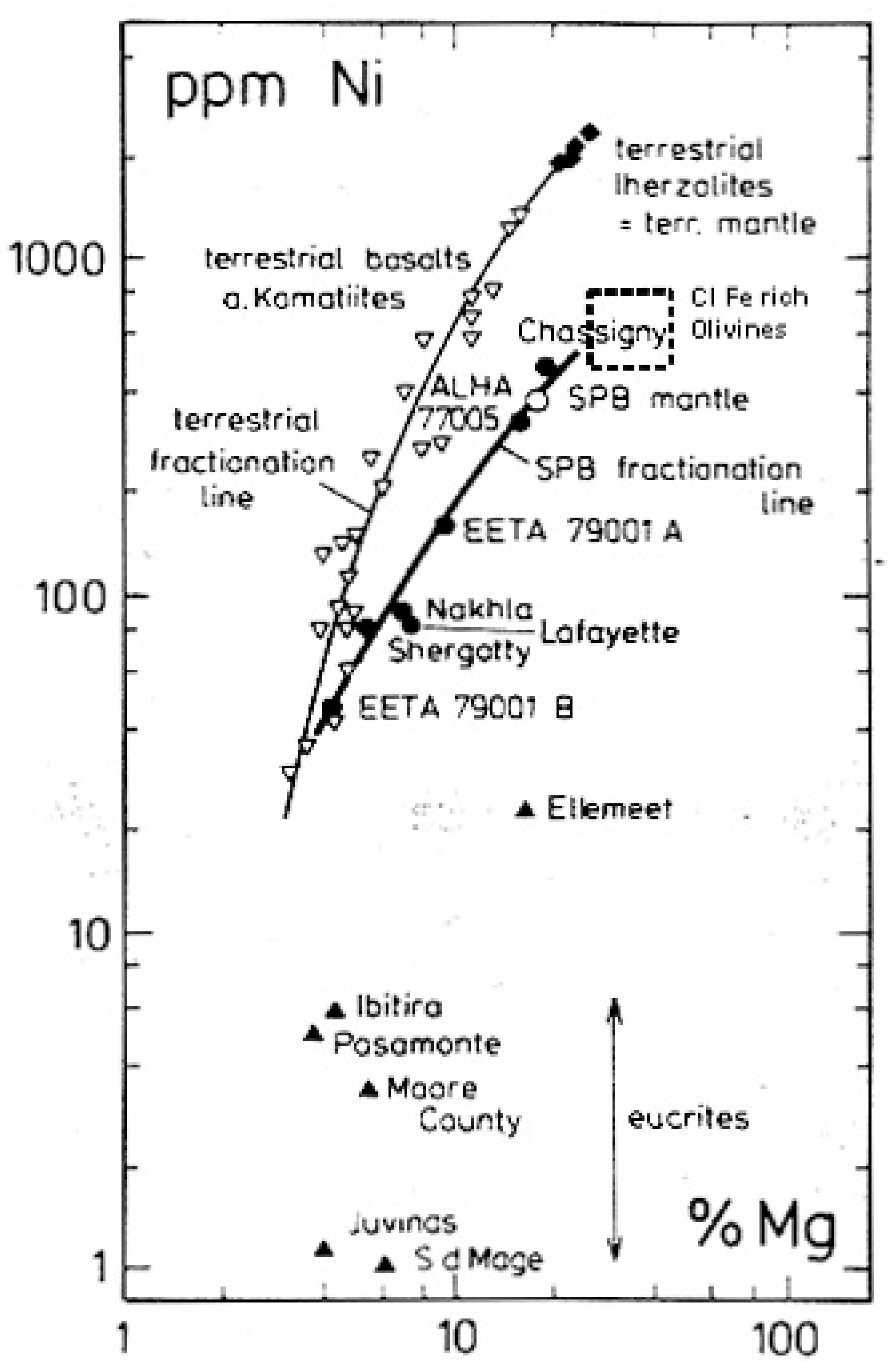


Figure 9. Nickel content of iron rich CI Olivines versus Martian Olivines. (adapted from Kerridge, J. F. and MacDougall J.D. 1976)

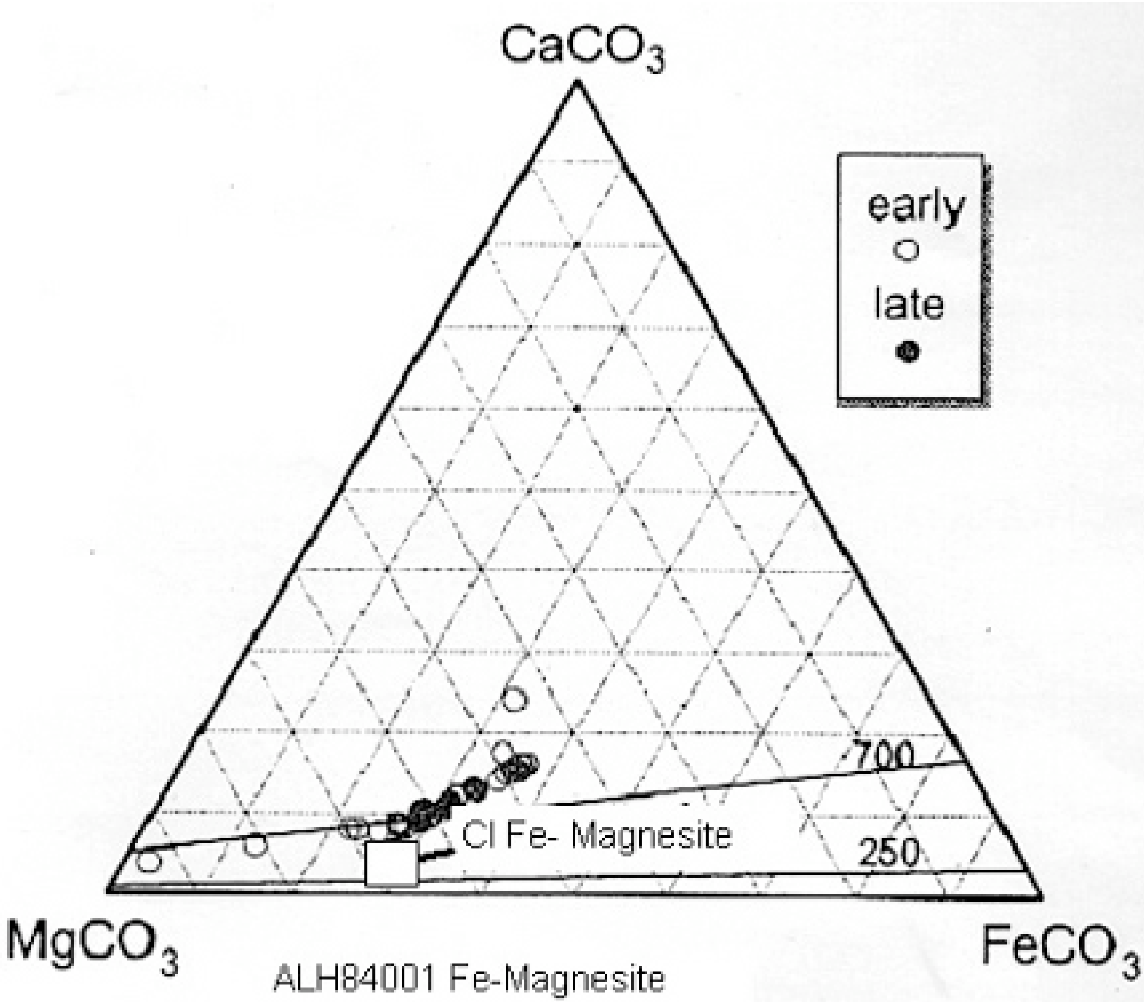


Figure 10. A comparison of the composition of ferroan magnesite found in ALH84001 and that found it CIs. (adapted from Wright I.P., M.M. Grady, and C.T. Pillinger(1992))

Petro-Morphology

The CI, like almost all meteorites, were once buried away from cosmic ray bombardment below the surface of a parent body somewhere in the solar system. This parent body was impacted and then released the CI as secondary fragments that made their way to earth. The morphology of the CI offers constraints on the nature of the parent body.

The CI are described as composed of clay that was brecciated by low velocity impact and with the clasts then cemented back together by water soluble salts, chiefly carbonates, with later sulfate formation. The individual clay clasts have a pronounced lamellar character (Figure 11), suggesting that they formed in a strong gravity field. There is no evidence for hypervelocity impact. In this brecciated mix isolated olivine grains are found, some with solar flare tracks, indicating that they were once in solar space. The olivines contain both a low iron forsteritic branch and a high iron, high nickel, branch. The latter population strongly differentiates the olivine grains from those found in CM chondrites. This is a further differentiation from CM chondrites where there are abundant

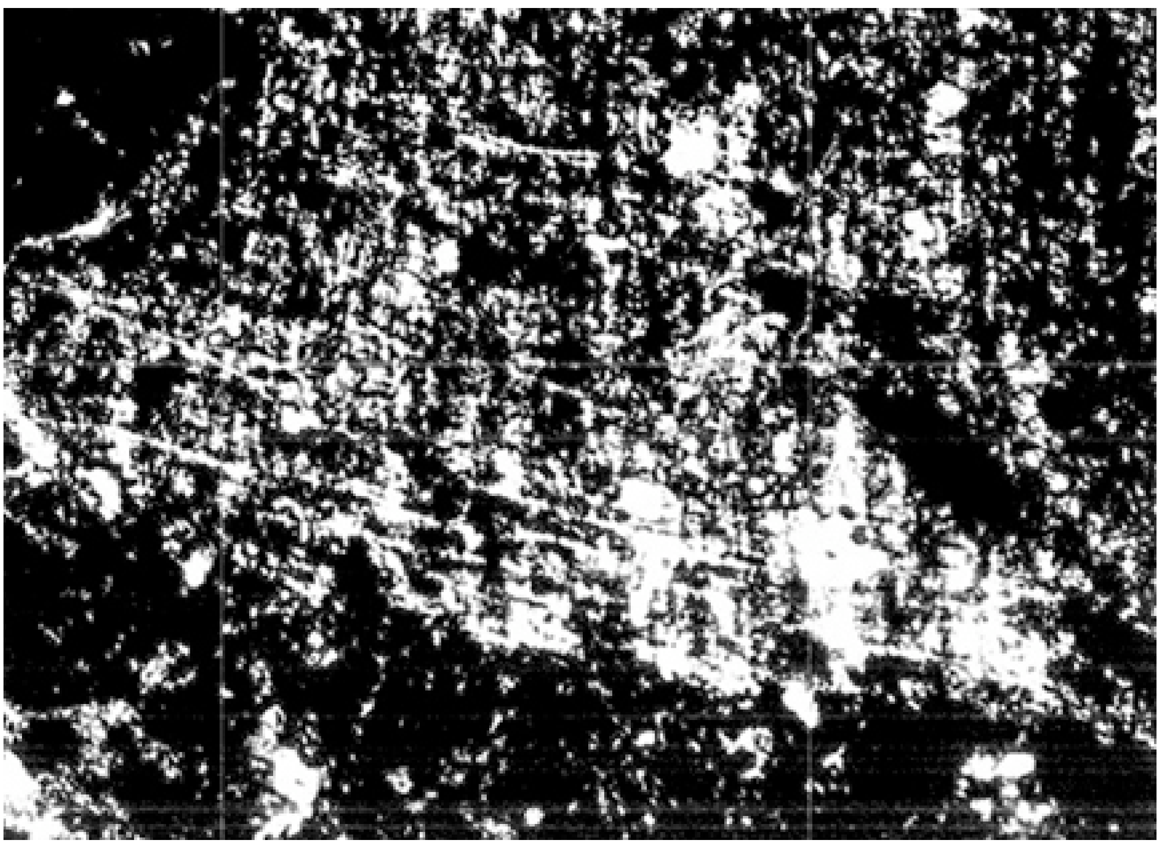


Figure 11 Clast in the CI Chondrite Orgueil, composed mostly of ill defined hydrated silicates, showing pronounced lamellar texture. Width of field of view is 1 mm. (from Kerridge and Bunch, 1979)

chondrites and much evidence for hypervelocity impact. The olivine grains in CI are unique also in that they are often embayed, with embayments concentrated in iron rich portions of the grains.

The CI are also, as a group, remarkably uniform in composition and morphology, indicating a large parent body, capable of enforcing large scale uniformity on its surface.

Based on the presence of tracked olivine grains, the CI clearly formed as regolith on some parent body. However, based on the absence of hypervelocity impact they were formed in velocity buffered environment. The simplest way for this to occur is that the CI formed under an atmosphere, like a rock on earth. The parent body of the CI was thus massive enough to form and hold an atmosphere and support the abundance of water they were exposed to. The gravity of such a body would also easily explain the lamellar character of the clasts.

Embayments are found on some CI olivine grains (Kerridge, and MacDougall, 1976), coinciding with the lower temperature melting iron rich portions. The presence of such embayments can be explained as being caused by ablation as they fell through an atmosphere (Figure 12). Accordingly, the simplest model for formation of the CI parent minerals was they formed on a massive parent body with an atmosphere. This parent body had large lava melts and these served as sources for olivine grains when impacted, accounting for the calcium-iron mixing line present in the iron rich olivine grains.

Therefore, the morphology of the CI and their complex history of several periods of inundation in water, followed by desiccation, brecciation by mild impact, then re- immersion in water, is most simply explained by their formation in a planetary environment similar to early Mars, rather than some minor body in the solar system.

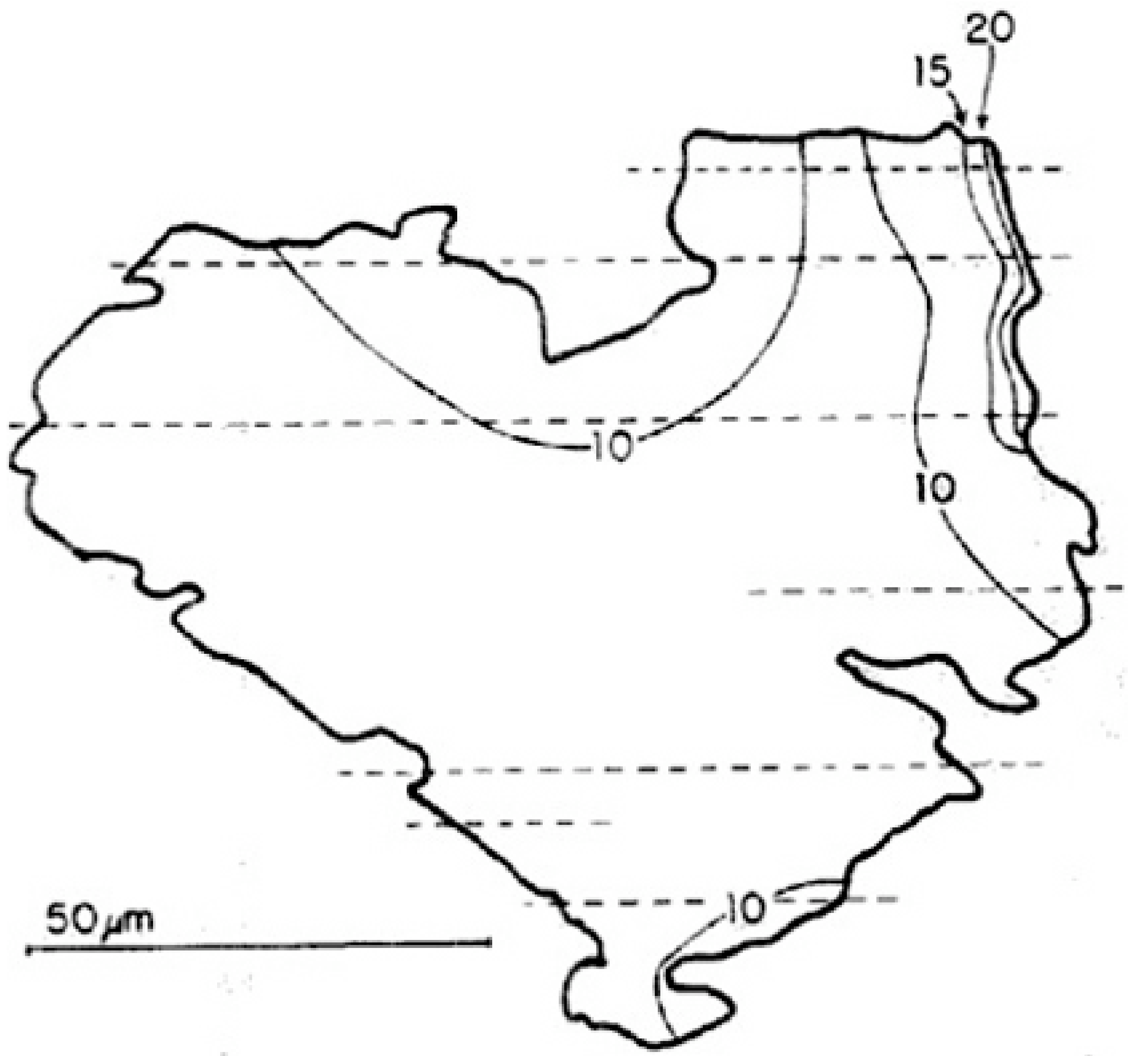


Figure 12 Outline of a zoned olivine grain from Orgueil showing contours of iron (and calcium) enrichment. Valuse give FeO content in wt. % Dashed lines show locations of microprobe traverses. (from Kerridge and MacDougall 1976)

V. Discussion: the CI connection to Mars

Therefore, based on isotopes of oxygen and chromium, and the chemical similarity of CI olivines and olivine-rich Chassigny, and the the chemical similarity the CI and ALH84001 ferroan carbonates, the CI must be considered Martian in origin. Other isotopic and chemical data is consistent with this finding. CI, uniquely, have no chondrules or evidence of hypervelocity impact yet, as evidenced by solar tracked grains, were a regolith material. This is consistent only with formation under atmosphere which stops chondrules but not grains and provides velocity buffering. Additionally, CI grains are uniquely embayed-zoned suggesting ablation in atmosphere. The simplest explanation for this array of features is that the CI formed under an atmosphere on Mars, of the same materials as the rest of Mars.

With the CI-MM connection firmly established the Martian age paradox is solved. Mars surface is actually well-sampled in our meteorite collection when CI and recognized MMs are combined. The CI are the missing old meteorites of Mars and this discovery also practically doubles our amount of Martian material. Thus the south of Mars is very ancient and also heavily water altered and that impacts have supplied us with materials from both hemispheres uniformly. This conclusion also confirms the model of cratering statistics proposed by Nadine Barlow (1988), who proposed that the surface ages of Mars were largely bi-modal, with very ancient terrains in the south of the dichotomy and very young terrains to the north. Mars southern hemisphere has been nearly devoid of aqueous and geological activity since Early Intense Bombardment Era.

Models of Mars accretion from CI like material are supported as is CI veneer on Mars (Pepin 1992, Dreibus and Wanke, 1985). The hypothesis that Mars is parent body of CI carbonaceous chondrites, is a revival of an earlier hypothesis of a planetary seabed origin of CI material made by Urey (1968).

The high levels of organic a material found in the CI argues for an early Martian surface that was warm, wet, and rich in organics. Both Mars and Earth had very similar surface environments at this time and were both enduring the Early Intense Bombardment period, they could easily have swapped significant amounts of material and even shared biology on these exchanged surface materials. Early Mars and early Earth then appear to have possessed almost identical environments and because of Early Intense Bombardment probably exchanged materials to a degree. Thus, biology should be expected on early Mars since it is evident on early Earth. By confirming these life-promoting conditions of early Mars, the origin of CI on Mars therefore, strongly supports the findings of Mckay et al. (1996) in their contention that ALH84001 holds relic-biology.

Controversy still exists over whether the evidence for biology in ALH84001 by itself is convincing. An excellent summary of the state of the ALH84001 centered life debate has been made by Schirber (2010) who mentions recent compelling evidence for biogenic magnetites in ALH84001 (Thomas-Keprta et al. 2009). However, by placing abundant organic materials on a warm, wet, early Mars surface, a CI origin on Mars makes primitive life on early Mars almost automatic, given that such conditions nurtured life on Earth.

The finding of life on early Mars is even more strongly supported by reports of microfossils in the CI themselves by Hoover (2011). Reports of abundant microfossils in meteorites whose parent body was some small object in the asteroid belt would raise immediate questions as to how such a small body could support life for any period. However, if the CI are from Mars and represent probes of early Mars conditions, then such microfossil findings are entirely reasonable, if not expected. Early Mars and Earth were apparently almost identical. If life began in one place, no scientific reason exists to exclude it from the other.

Truly, we are entering an age when exobiology is to be considered one of the most likely explanations considered for any new organic phenomenon seen in the cosmos, rather than the least likely. This is, in effect, a Second Copernican Revolution, where Earth and humanity are now being displaced from being the center of the biological universe, whereas in the Middle Ages we were displaced from its geometric center. However, a terra-centric biologic view is increasingly incompatible with our understanding of both biology on Earth and conditions in the rest of the cosmos, which make Earth seem less and less a unique place for life to thrive. Thus, a change of human viewpoint is inevitable and this finding of the CI-MM connection only hastens it. The CI are from Mars apparently, and this changes our view of Mars somewhat, but it changes our view of the human place in the cosmos profoundly.

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