Northwest Africa 7034

(Carl Agee, University of New Mexico)

Headline Article

January 30, 2013

New Martian Meteorite is Similar to Typical Martian Crust

--- A newly-identified Martian meteorite from Northwest Africa is not like other Martian meteorites, but has a chemical composition similar to the average Martian crust.

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Carl Agee, Institute of Meteoritics at the University of New Mexico (UNM), led a team with wide scientific expertise from UNM, the University of California at San Diego, and the Carnegie Institution of Washington in examining what turned out to be a unique Martian meteorite, Northwest Africa (NWA) 7034. The ratio of iron to manganese clearly links it to Mars. Yet, its overall chemical composition makes it unique among Martian meteorites: high concentrations of rare earth elements (five times more than the typical Martian meteorite) and H_2O (ten times higher than any other Martian meteorite) and old age of 2.09 billion years (compared to less than 500 million years for the largest group of Martian meteorites, and 1.3 billion years for another group; one sample has an older age of 4.1 billion years). The chemical composition of NWA 7034 is more like that of the Martian crust observed from orbit by the Mars Odyssey Gamma-Ray Spectrometer and on the ground by the Pathfinder and Mars Exploration Rovers. The sample appears to be a volcanic rock with a basaltic composition like most of the crust and formed in the early part of the Amazonian era of Martian geologic history. Small differences in the oxygen isotoptic composition of NWA 7034 compared to other Martian meteorites indicate that rocks on Mars vary somewhat in the proportions of oxygen isotopes.

This unique rock shows the importance of continued searches for meteorites in the hot and cold deserts of Earth to recover additional samples of Mars. The fact that NWA 7034 is the 112th Martian meteorite identified on Earth, also proves the value of persistent searching. More importantly, it also shows us the importance of being able to analyze rocks in terrestrial laboratories with the battery of continuously-improving instruments available to us.

Reference:

- Agee, C. B., Wilson, N. V., McCubbin, F. M., Ziegler, K., Polyak, V. J., Sharp, Z. D., Asmerom, Y., Nunn, M. H., Shaheen, R., Thiemens, M. H., Steele, A., Fogel, M. L., Bowden, R., Glamoclija, M., Zhang, Z., and Elardo, S. M. (2013) Unique Meteorite from Early Amazonian Mars: Water-Rich Basaltic Breccia Northwest Africa 7034, *Sciencexpress*, 3 January 2013, doi: 10.1126/science.1228858.
- **PSRDpresents:** New Martian Meteorite is Similar to Typical Martian Crust --**Short Slide Summary** (with accompanying notes).

Finding a Special Meteorite

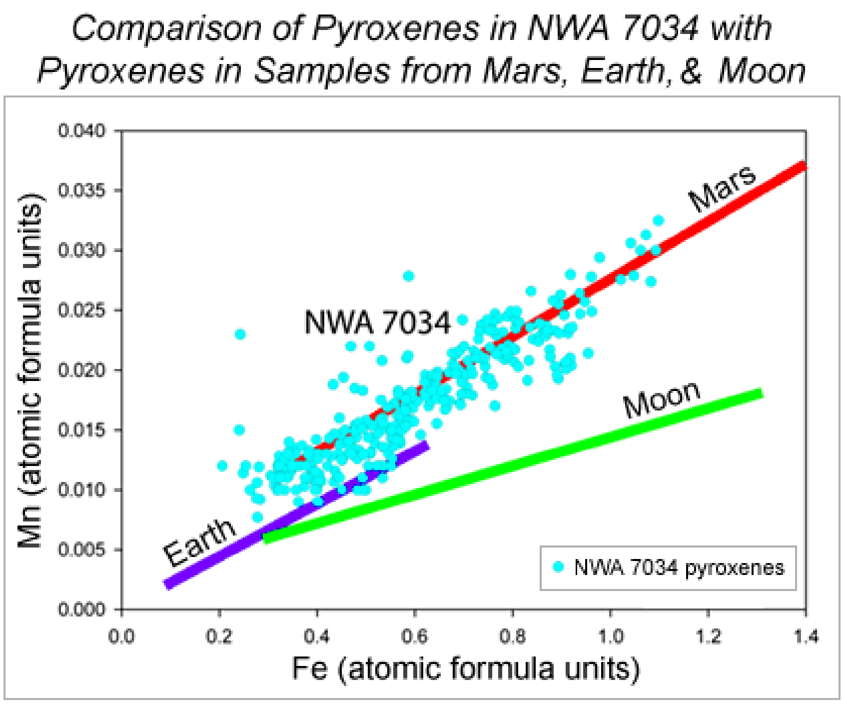
Some meteorites are observed to fall, but most are found. They fall all over, most splashing into the ocean where recovery is unlikely. Many are found by observant people who plow up an unusual rock on their farm or hear a clang when digging in their gardens. In wet climates, fallen meteorites rot practically as soon as they fall, in some cases lasting in the dirt for only a few decades. The best place to preserve them is in dry places, either wet or dry deserts (see **PSRD** article: **Meteorites on Ice**.) These environments do not necessarily perfectly preserve these valuable rocks from the sky, but they do a much better job than do temperate and tropical climates.

There are two incredibly important search areas for desert meteorites. One is Antarctica, where national agencies manage organized searches each Antarctic summer using teams of meteorite hunters in cold-weather garb to look for promising rocks atop the ice sheet. The other area is in northwest Africa, with more free-wheeling, privately-funded search efforts. That is where NWA 7034 [**Data link** from the Meteoritical Bulletin] came from. It traveled from the desert of Morocco to the desert of New Mexico via the plains of Indiana. The meteorite's terrestrial trip began when it was found in 2011 by Aziz Habibi, a Moroccan meteorite dealer. Mr. Habibi sold it in 2011 to American meteorite collector Jay Piatek, a medical doctor who runs the Piatek Institute in Indianapolis, Indiana. Dr. Piatek has a large meteorite collection and like many collectors shares his samples with meteorite researchers. He has worked with the group at the UNM Institute of Meteoritics before. Although the rock's shiny, black fusion crust clearly showed it was a meteorite, Dr. Piatek was puzzled about what kind of meteorite it was. So was Carl Agee when he received the sample from Dr. Piatek and pondered it for a month before sawing off a slice to reveal a dark-grey almost black breccia, unlike any **achondrite** he had seen. Once Agee and his colleagues did a bulk analysis of a small piece of NWA 7034, which had not yet received its official, certified name from the Nomenclature Committee of the Meteoritical Society [**MetSoc link**], they realized what had been sitting on Carl Agee's shelf: a piece of Mars. Dr. Piatek generously donated a slice of the valuable (scientifically and financially) sample to the UNM Institute of Meteoritics.

Three pieces of NWA 7034 (cube is 1 centimeter on a side). Note how dark and smooth the surfaces are, typical of the fusion crust of a fresh, unweathered meteorite. The striking dark color led Carl Agee and his colleagues to nickname the rock "Black Beauty."

Martian Origin for NWA 7034

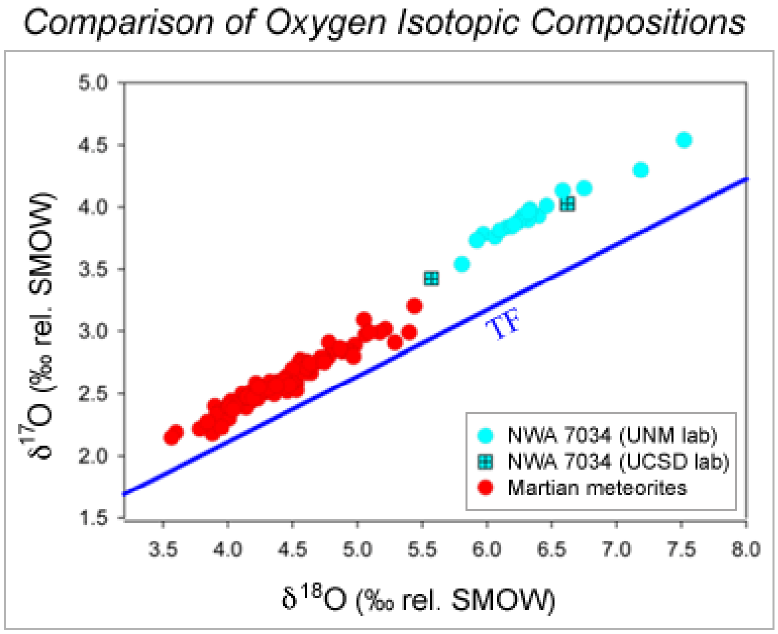
Certain chemical, mineralogical, and textural features about space rocks are so distinctive that cosmochemists can make startlingly quick decisions that a rock is asteroidal, lunar, Martian, or just some kind of Earth rock. Sometimes we can tell just looking at the sample. Other times we need to look at a thin slice of it in an optical microscope. Still other times, and to be sure, we need to determine some key chemical parameters, such as the ratio of iron (Fe) to manganese (Mn), or oxygen **isotopic** composition. Identifying the original home of Black Beauty required some chemistry. The ratio of Fe/Mn is useful because these two elements behave quite similarly during melting and crystallization (within some geochemical limits), so their concentration ratio reflects their ratio in the planetary body in which they formed. The diagram below shows the Mn and Fe concentrations in the mineral pyroxene in NWA 7034, compared to Martian meteorites, Earth rocks, and lunar rocks.



(From Agee, *et al.*, (2013) *Sciencexpress*, doi: 10.1126/science.1228858.)

Concentrations of manganese (Mn) and iron (Fe) in pyroxene crystals in NWA 7034. The units are atomic formula units, often used for minerals, which show the relative abundances of atoms of ions making up a mineral. The blue dots are data from NWA 7034; the lines show the trends for Martian meteorites (red line labeled "Mars"), Earth rocks (purple), and lunar samples (green). The dots fall along the Mars line.

One of the most definitive measures of planetary heritage is the oxygen isotopic composition. (Oxygen has three isotopes with masses of 16, 17, and 18.) Although some types of meteorites overlap in oxygen isotopic composition, most do not. The mix of oxygen isotopes in NWA 7034 is different from all other meteorite types and the Earth (and Moon, which is indistinguishable from Earth). NWA 7034 is slightly different from the other Martian meteorites (see diagram below), but not so different to lead Carl Agee and his colleagues to conclude that the rock did not come from Mars. Instead, they suspect that the slight difference reflects some inherent variation in the oxygen isotopic composition of the Martian interior. Another possibility is that oxygen isotopic abundances were modified by interaction with the Martian atmosphere, which is thought to be higher than the meteorites in $\Delta^{17}O$ (the vertical displacement of any point from the terrestrial fractionation line on the plot shown below). A third, more speculative, possibility is that an exotic cometary or carbonaceous chondrite component was added to the rock through impact processes on Mars.



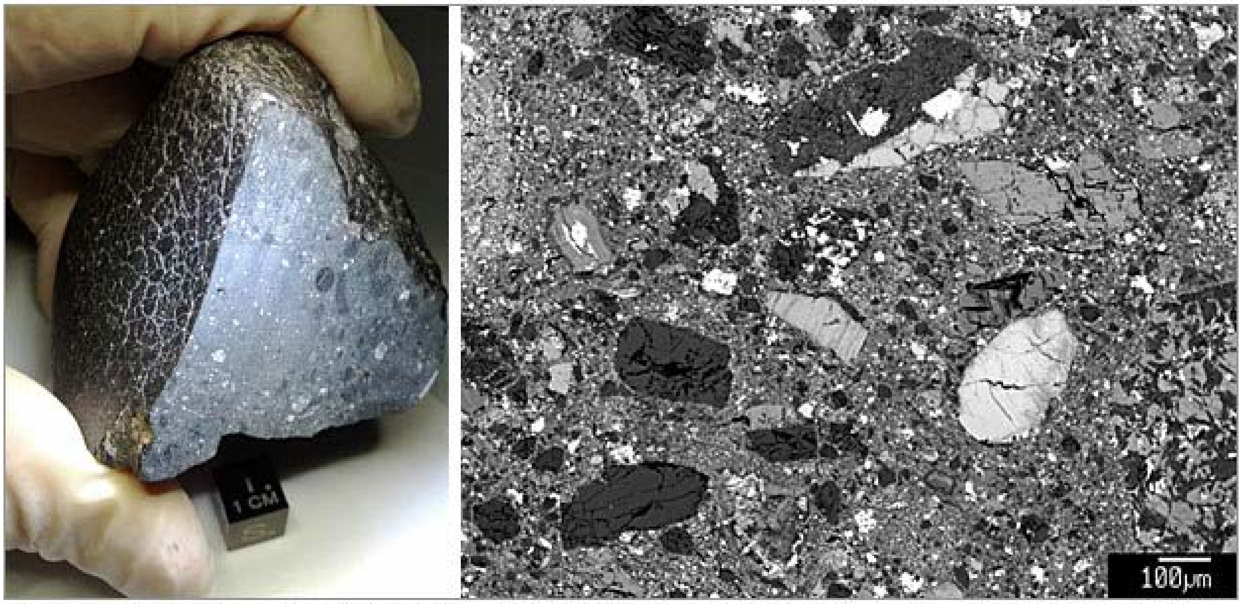
(From Agee, *et al.*, (2013) *Sciencexpress*, doi: 10.1126/science.1228858.)

Oxygen isotopic abundances in NWA 7034 compared to Martian meteorites and the line representing Earth rocks (TF, for Terrestrial Fractionation line). The plot shows the $^{17}O/^{16}O$ and $^{18}O/^{16}O$ ratios in the meteorite samples in parts per thousand, also called per mil (‰). Data have been standardized to standard mean ocean water (SMOW) and plotted as deviations from that value. The important points are that the NWA 7034 data are similar to, yet slightly different from, those of Martian meteorites and they are distinctly different from the terrestrial line and (though not shown) from any other meteorite type. Note that the oxygen isotope measurements were made in two different laboratories, one at the University of California, San Diego (UCSD) and one at the University of New Mexico (UNM).

Unique Martian Meteorite—But Maybe a Run-of-the-Mill Martian Rock

Any expert on Martian meteorites would not immediately shout, "Hey, this is a Martian meteorite!" NWA 7034 does not look like any of the Martian meteorites we already know about. It is a breccia, with rock and mineral fragments distributed in a fine-grained, glassy matrix. The texture can be seen even when looking at a freshly cut surface and in both optical and scanning electron microscopes. But unlike familiar impact melt breccias found in the lunar highlands, Agee and his colleagues conclude that this one is probably a volcanic breccia. Such rocks form in forceful eruptions that bust up pre-existing rock beneath or in the volcano, and spew out a mixture of magma and rock fragments.

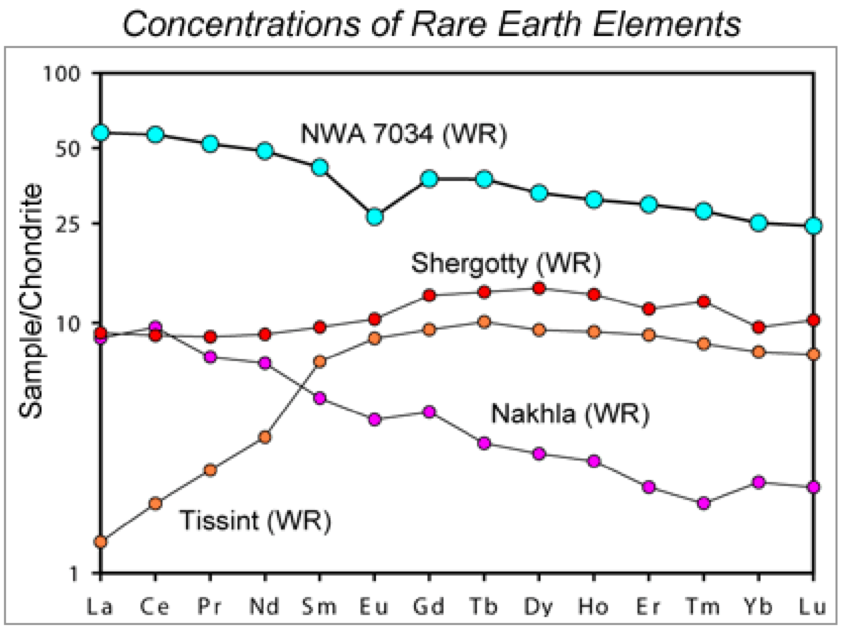
Martian Meteorite: Northwest Africa 7034



(Courtesy of Carl Agee, Univ. of New Mexico.) (From Agee, *et al.*, (2013) *Sciencexpress*, doi: 10.1126/science.1228858.)

[LEFT] Photograph of gloved hand holding a piece of NWA 7034 showing the interior after a slice was taken for analysis. Note the light and dark fragments in a medium gray matrix, the typical texture of a breccia. The exterior has a black fusion crust. [RIGHT] This backscatter electron image of NWA 7034 shows compositional variations and texture of a region about 1 millimeter across. The large dark fragments are feldspar crystals, lighter ones are pyroxene. Fragments with both light and dark areas are rock fragments. (Backscatter images are bright when the average atomic number is high for a crystal, as in minerals containing iron, such as pyroxene, and dark when the atomic number is low, as in feldspar, which contains little iron.)

NWA 7034 is compositionally distinct from other Martian meteorites. This is exemplified by its abundances of the rare earth elements. These elements, the series in the periodic table from lanthanum (La) on the left to lutetium (Lu) on the right, are useful indicators of the geochemical history of a rock. In particular, they help us discover differences in the compositions of the regions of the mantle in which different magmas form. This knowledge is important to understanding the bulk chemical composition of a planet (in this case Mars), how it differentiated into core, mantle, and primary crust, and subsequent magmatic activity that produce most of the crust we observe today. The rare earth element pattern (see diagram below) of NWA 0734 is distinct from those of other Martian meteorites. This almost certainly indicates that it formed in a region of the mantle different from those giving rise to the other Martian meteorites.

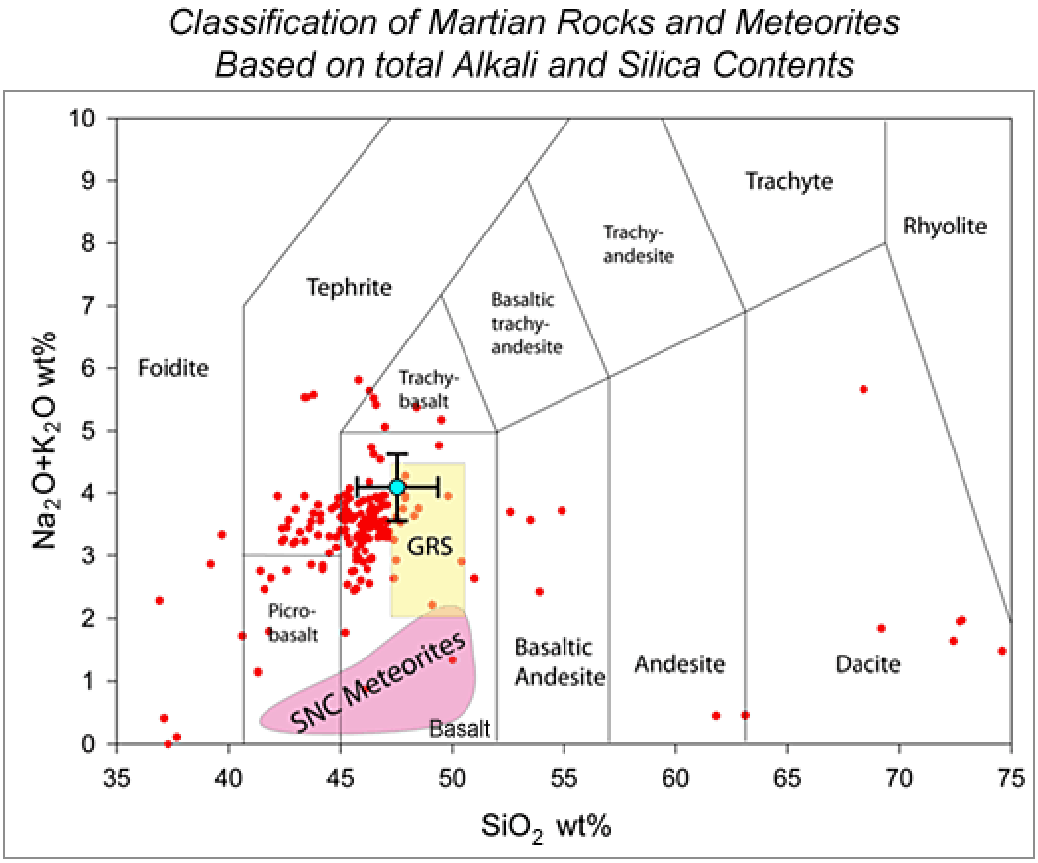


(From Agee, *et al.*, (2013) *Sciencexpress*, Fig. S10, doi: 1126/science.1228858.)

Concentrations of rare earth elements in distinctive Martian rock types. The concentrations are divided by those in carbonaceous chondrites (thought to represent primitive solar system materials) in order to make the patterns smoother. Without this normalization, the pattern for each rock would have zigs and zags because elements with even atomic numbers are more abundant than those with odd atomic numbers. Note that the three representatives of the previously-known Martian meteorites plotted, Shergotty, Tissint, and Nakhla, are quite distinct from each other. NWA 7034 has higher concentrations of the rare earths (and other elements, too) and has a pattern that slopes downward from La to Lu. WR stands for "whole rock," meaning that these analyses were done on representative chips of the meteorites.

The oxygen isotope diagram shown above reinforces the idea that distinctive chemical reservoirs exist inside Mars. Agee and colleagues point out that both the enrichment in ^{18}O (NWA 7034 data are shifted to the right on the diagram compared to other Martian meteorites) and the slight elevation of the data above the line defined by the other Martian meteorites suggest fundamental differences in the source region in the Martian mantle that produced the NWA 7034 magma compared to those that produced the other Martian meteorites.

So, this rock is not like the other Martian meteorites. But it is a lot like rocks on the surface of Mars as analyzed from orbit and on the ground by the series of rovers, such as Spirit and Opportunity. The diagram below is a standard way to classify terrestrial igneous rocks. Note that the analysis for NWA 7034 plots with the cluster of rocks and soils from the Gusev landing site and within the box defined by orbital chemical analyses. It appears to be typical Martian crust. The rest of the Martian meteorites, though extremely valuable, must represent less common areas of the crust.

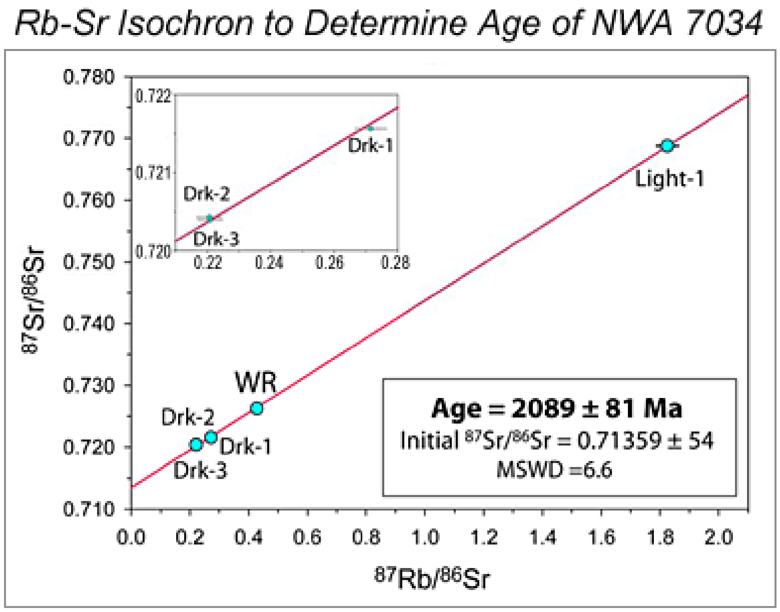


Standard classification diagram for terrestrial igneous rocks. It plots the sum of the main alkali elements (potassium and sodium, expressed as oxides) against the silicon concentrations (expressed as silicon dioxide, SiO_2). The names (some quite unusual!) encompass different ranges of alkali and silica abundances. Note that the Martian meteorites ("SNC" meteorites in the diagram) are distinctly lower than not only the mean value for NWA 7034 (cyan circle with uncertainties shown as a cross), but also almost all soil and rock analyses done by the Spirit rover (red dots) and the mean surface analysis done by the orbiting Mars Odyssey Gamma Ray Spectrometer (GRS, the yellowish rectangle). NWA 7034 is clearly like typical Martian crustal materials, in contrast to other Martian meteorites. See the paper by Hap McSween and coworkers for more details about the Mars orbiter and rover data.

A Middle-Aged Martian Rock

The Martian meteorites are also atypical of the general surface of Mars in that, with the exception of one sample, they are 1.3 billion years old or younger, some down to about 180 million years old. The one exception is ALH 84001, an igneous rock that formed 4.1 billion years ago (see **PSRD** article: **A Younger Age for the Oldest Martian Meteorite**). Geologists have known from careful mapping and crater counting that most of the Martian surface must be older than around 3 billion years, so all those meteorites being so young made everyone wonder "Why?" Was it just luck that an impact or a few impacts that liberated rocks from the surface hit only the youngest terrane? Or did water so alter the older surface areas that the rocks were too weathered to remain coherent when launched by an impact?

NWA 7034 partially fills in the age gap. Rubidium-strontium dating of mineral separates from the rock gives an age of about 2.1 billion years, in the first half of the **Amazonian** era of Martian history (about 3 billion years ago to the present). This is still a relatively dry period in Martian history, but the volcanic-breccia nature of NWA 7034 indicates that water played an important role in its eruption.



(From Agee, *et al.*, (2013) *Sciencexpress*, doi: 10.1126/science.1228858.)

Rubidium (Rb)-Strontium (Sr) isotope plot of a sample of the whole rock (WR) and materials separated magnetically from NWA 7034. The important point is that these different separates (labeled Drk-1 etc. and Light-1) have different Rb/Sr ratios. If they fall on a line on this plot, they define a unique age for the sample based on the known rate of radioactive decay. This unique age for NWA 7034 is 2089 ± 81 million years.

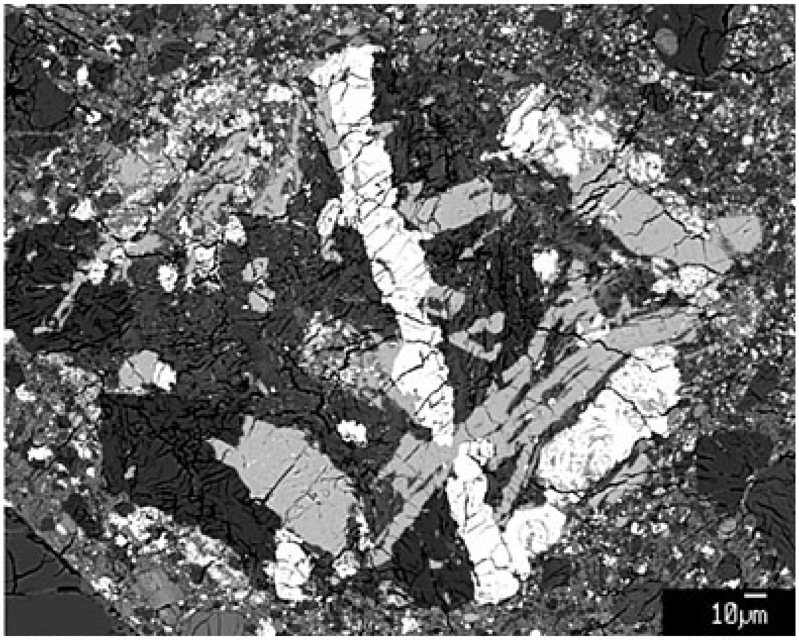
Water

NWA 7034 is one wet rock. It contains about 0.6 wt% H_2O, at least ten times more than any other Martian meteorite. Orbital gamma ray and neutron spectrometer data indicate that the upper half meter or so of the Martian surface between about 50 degrees north and 50 degrees south latitudes contains at least 1 wt% water, so NWA 7034 is more like those regions than are typical Martian meteorites, further emphasizing that NWA 7034 is a lot like the typical crust of Mars.

Big questions remain about the source of the water. It might have been in the magma when it ascended from the interior, in which case it contains important information about the source of water to Mars and perhaps explains why the rock is the product of a strong eruption on Mars. (At even modest depths in planets, magma can have considerable water dissolved in it. At the low pressure near the surface the water leaves solution in the magma, forms bubbles, often so many that the magma shoots out of the volcanic vent explosively. Alternatively, the water might represent liquid water (or ice) already in the crust that was mobilized at some point and altered the pre-existing volcanic rock. Even the younger Martian meteorites have a rich record of such alteration. Additional research is needed to determine whether the water was in the magma or added later.

NWA7034 contains igneous rock fragments containing abundant apatite. This mineral contains water in the form of OH in its crystal structure and because it is igneous, contains important information about the water, including the ratio of deuterium to hydrogen in it. Apatite is altered by water relatively easily, so might record a wet weathering event on Mars, but usually we can see evidence for that, such as tattered margins and compositional changes at those margins. NWA 7034 has excellent igneous apatite in unusual rock fragments, such as the one shown below. The value of determining the OH content of apatite is explained more fully in the PSRD article: **How Much Water is Inside Mars**.

Rock Clast in NWA 7034



(From Agee, *et al.*, (2013) *Sciencexpress*, Fig. S2, doi: 1126/science.1228858.)

Backscatter electron image of a rock clast in NWA 7034 that contains ilmenite (white), apatite (light gray crystals), plagioclase feldspar (gray), and potassium feldspar (dark gray). The OH and deuterium to hydrogen ratio can be measured in the apatite crystals by secondary ion mass spectrometry.

Keep Looking

Martian meteorites continued to be found by national Antarctic programs and private collecting expeditions, such as the one that led from Aziz Habibi to Jay Piatek to Carl Agee. Many of the rocks are similar to those we already have, but the unique properties of NWA 7034 show that continuing to search will yield more than the same old, same old Martian meteorites. It is likely that additional new types will be found eventually. Of course, we could always send spacecraft to fetch samples for us!

Field photograph of the MIL 03346 Martian meteorite collected by the Antarctic Search for Meteorites Program (ANSMET) on an ice field in the Miller Range, Antarctica in 2003. Click for more information. Continued searches for meteorites are likely to yield additional new types of Martian meteorites, and other types of meteorites as well.

Additional Resources

Links open in a new window.

- **PSRDpresents:** New Martian Meteorite is Similar to Typical Martian Crust --**Short Slide Summary** (with accompanying notes).

- **Ancient Water-rich Meteorite Linked to Martian Crust** video from University of New Mexico, with Carl Agee, Karen Ziegler, and Yemane Asmerom.

- Agee, Carl B., Wilson, Nichole V., McCubbin, Francis M., Ziegler, Karen, Polyak, Victor J., Sharp, Zachary D., Asmerom, Yemane, Nunn, Morgan H., Shaheen, Robina, Thiemens, Mark H., Steele, Andrew, Fogel, Marilyn L., Bowden, Roxane, Glamoclija, Mihaela, Zhang, Zhisheng, and Elardo, Stephen M. (2013) Unique Meteorite from Early Amazonian Mars: Water-Rich Basaltic Breccia Northwest Africa 7034, *Sciencexpress*, 3 January 2013, doi: 10.1126/science.1228858. [**abstract**]
- McSween, H. Y., Jr., Taylor, G. J., and Wyatt, M. B. (2009) Elemental Composition of the Martian Crust, *Science*, v. 324, p. 736-749, doi: 10.1126/science.1165871. [**abstract**]

- **NWA 7034 abstracts [pdf file]** from the program of the 44th Lunar and Planetary Science Conference, March 18-22, 2013. These cover additional information about the meteorite, including noble gas data.

2013
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