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RARE GAS EVIDENCE FOR TWO PAIRED METEORITE FALLS

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Rare Gas Evidence for Two Paired Meteorite Falls

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Abstract. Rare gas contents were determined by mass-spectrometry in meteorites of two so-called paired falls: Accalana-Artracoona-Carraweena and La Lande-Melrose-Taiban. The results show that Accalana and Carraweena are identical, whereas Artracoona appears to be an independent fall. The "La Lande" group includes at least one independent fall: Taiban. A comparison of terrestrial meteorite ages to meteorite fall frequencies shows, that the survival of coincidences of octahedrites and ordinary chondrites, is quite likely.

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Among the thousands of meteorite finds on Earth, there are several instances in which chemically and structurally similar meteorites were recovered from the same area. Such a situation arises for instance when a meteorite shower occurs; the famous L'Aigle shower of 1803 deposited 2000-3000 stones in an area of approximately 12 x 4 km (Heide, 1964). While showers of this magnitude are exceptional, it is nevertheless true that a majority of stone meteorites break up during their fall through the atmosphere so that the fall of a single stone is about as rare an event as the occurence of a shower. The fall of several fragments from one meteoroid is by no means restricted to stones, but has been observed for irons as well (e.g. Sikhote Alin).

Considering the fact that more than half of all the known meteorites were not seen to fall, but are finds, it comes as no surprise that two or more chemically and structurally similar meteorites were discovered as finds in the same area. In particular, the extensive searches of H.H. Nininger and his associates have turned up several such cases. The collector is faced with the following dilemma. Did the fragments come from the same meteoroid, i.e. are they identical, or did they fall at different times in the past, i.e. are they independent? Depending on the judgment of the investigator it has been either suggested that such meteorites are identical or that they are independent.*)

This category of meteorites was listed by Prior and Hey (1953) as paired falls or paired meteorites: "those pairs or groups of falls which it has been suggested are possibly or

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*) A few finds of compositionally different meteorites at close locations are well known, e.g. the chondrite Coon Butte and the octahedrite Canyon Diablo at Arizona Meteor Crater. Such coincidences are commonly considered independent falls.

probably identical." The authors added: "no opinion is implied as to the probability of these identities."

The assignment of meteorites to a paired or to an independent fall can be strengthened by rare gas studies. There are at least three lines of evidence. First, meteorites contain cosmogenic He, Ne, and Ar isotopes, which were produced *in situ* during the cosmic-ray exposure era, when the meteorites existed as relatively small entities in space. Fragments that broke off from a single parent object when it fell through the atmosphere were all irradiated for the same length of time. While one expects to find similar cosmogenic rare gas contents in all fragments, the actual values are not necessarily equal because each fragment could have come from a different depth in the parent object and thus have been subjected to different degrees of shielding. In iron meteorites, substantial variations have been observed; e.g. in Canyon Diablo I found variations by four orders of magnitude (*Heymann et al*, 1965), but this is undoubtedly an extreme case. Shielding effects in stone meteorites are much smaller, owing to the fact that stones are systematically smaller than irons. The range of production rates in stones can be inferred from Al^{26} measurements by *Rowe et al* (1963), which indicate that variations of 20-50% in a single chondrite are not uncommon.

Second, the decay of U, Th, and K has produced radiogenic He^4_r and Ar^{40}_r *). Among different chondrites of the same class, in particular among hypersthenes, one finds variations of these gases by one order of magnitude; He^4_r for instance ranges from about 100 to 2000 x 10^{-8} ccSTP/g. Relatively little is known about variations within a single chondrite; in one case a variation by as much as 50% was found by Zähringer (1965). Nevertheless, the radiogenic components may provide important clues.

Third, several chondrites contain primordial rare gases, the most common component being argon. For the great majority of ordinary chondrites, Ar^{36}_p varies from 0 to 1.5 x 10^{-8} ccSTP/g (e.g. this is the case in 80% of the hypersthene chondrites). Since the probability that two chondrites have similar Ar^{36}_p values outside this range is quite low, such a coincidence strengthens a pairing.

The meteorite catalogue of Prior and Hey (1953) lists 32 paired falls. In the course of my studies of rare gases in hypersthene chondrites, I have determined He, Ne, and Ar isotopes by mass-spectrometry in members of two such multiplets: Accalana-Artracoona-Carraweena and La Lande-Melrose-Taiban. The exper-

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*) I use the subscripts c, r, and p to identify cosmogenic, radiogenic, and primordial components.

imental technique has been described in detail elsewhere (Heymann, 1965). The results together with data previously obtained by others are listed in Table 1.

Accalana, Artracoona, and Carraweena were found in Australia within distances of less than 13 km (Prior and Hey, 1953). What seemed to speak for a common origin were their chemical and structural similarity. All three are hypersthene chondrites; the fayalite contents of the olivines are the same: 24 mole % (Mason, 1963). But Dr. B. Mason (private communication) brought to my attention that he finds that the pyroxene in Accalana and Carraweena is distinctly different (predominantly clinopyroxene) from that in Artracoona (predominantly orthopyroxene). Mason's observations are strongly supported by the present results in that the rare gas contents of Artracoona are distinctly different from those of Accalana and Carraweena. He_c^3, Ne_c^{21}, and Ar_c^{38}, as well as He_r^4 and Ar_r^{40} in Artracoona are one order of magnitude higher than in the two other meteorites. Furthermore, Ar_r^{36} in Artracoona is only 0.7×10^{-8} ccSTP/g as against 4.0 and 3.0×10^{-8} ccSTP/g in Accalana and Carraweena.

As for Accalana and Carraweena themselves, the data are not inconsistent with a paired fall assignment. First, the He_c^3/Ne_c^{21} ratios are unusually low in both meteorites, suggesting extensive diffussion loss of both He_c^3 and He_r^4. He_c^3/Ne_c^{21} ratios below 3.0 are relatively uncommon, having been found only in 8% of the hypersthene chondrites, dated thus far. The diffusion loss could well have caused the difference in the He^{4}_{r} contents of the two meteorites. Second, the Ar^{40}_{r} contents are very similar. Third, Ar^{36}_{p} values are similar and outside the range of most hypersthene chondrites. Fourth, the cosmogenic gases differ by about 30%, a rather large but not improbable margin. In my opinion, Accalana and Carraweena are identical meteorites, whereas Artracoona is an independent fall.

Nininger (1934) discovered La Lande 42 km W. of the Melrose (New Mexico) fall, and concluded that the two were identical. Later, he proposed that La Lande and Melrose were independent falls, and presented evidence that "La Lande" itself was a composite of two independent falls, which he named La Lande and Taiban. Fayalite contents of the olivines are 23% in Melrose, 24% in La Lande, and 25% in Taiban (Mason, 1963), lending some support to Nininger's later classification.

The rare gas data present a somewhat confused picture in that two different specimens of La Lande have different Ne^{21}_{c} contents of 4.08 and 2.69 x 10^{-8} ccSTP/g, while two Taiban specimens differ in their cosmogenic rare gas contents by a factor of two. For the purpose of comparison, I have labeled these specimens La Lande I and II, and Taiban I and II. It appears that this paired fall included at least two independent falls since Taiban II is quite distinctly different from the others.

The difference between Taiban I and Taiban II substantiates earlier reports (Prior and Hey, 1953) that several meteorites of this paired fall were either misnamed or mislabeled.

I have repeated the rare gas analysis of Taiban I, a sample of which was made available for this purpose by Dr. H. Wänke. My results confirm the earlier measurement in that the cosmogenic rare gas content of Taiban I is about twice as low as that of Taiban II. This difference is large indeed, but perhaps not quite large enough to all but exclude the possibility that Taiban I was more effectively shielded than Taiban II, both individuals coming from the same parent object. To test this possibility, I have determined the Al^{26} activity in Taiban I (Taiban II was too small for such a measurement) by γ-γ coincidence spectroscopy. The result, 64±9 dpm/kg, points strongly to a different origin of Taiban I and II because the shielding hypothesis requires that Taiban II had an Al^{26} activity of ~130 dpm/kg. This is very unlikely because the Al^{26} contents of ordinary chondrites seem to have an upper limit near 60-70 dpm/kg (Anders, 1962, Rowe et al, 1963).

He^3_c contents of La Lande I, La Lande II, Melrose, and Taiban I are not inconsistent with a pairing of these meteorites. However, the Ne^{21}_c values fall into two groups, one at about 4.0, the other at about 2.7 x 10^{-8} ccSTP/g. Also He^4_r, Ar^{40}_r, and Ar^{36}_p provide no clear-cut evidence for pairing. At this time, the question seems to be unsolved; the four meteorites could be either identical or belong to two independent falls. Perhaps further studies of a larger number of La Lande, Melrose and Taiban specimens could provide the answer.

One conclusion that can be drawn is that geographic proximity and chemical or structural similarities do not always represent sufficient evidence for the pairing of meteorites, as illustrated by the cases of Artracoona and Taiban II. On the other hand, there exist undoubtedly genuine pairs of which Accalana and Carraweena, Canyon Diablo I, II, and III, (Heymann, 1964), and perhaps La Lande, Melrose, and Taiban I are examples. In this connection, it is interesting to speculate on the chance that independent falls of meteorites of the same class occur in a relatively small area on Earth, and on the probability that this coincidence will survive the weathering processes, which will sooner or later destroy its record.

The chance of recovery depends on the rate of fall of meteorites to the Earth and on their survival times. The fall frequency of all classes was estimated by Brown (1961): one meteorite/10^6 years/km^2. I have assumed that the fall frequency was constant to at least 10^7 years ago and calculated the fall rate on a 10 x 10 km area for meteorites of 8 different classes. In Table II, I have also listed the highest terrestrial ages, reported for octahedrites, pallasites, bronzites, and hypersthenes.

Terrestrial ages depend among others on climatic conditions and composition. The highest terrestrial ages in Table II may well be exceptional, since stones have been reported to weather and disintegrate within a few months, while irons are known to corrode rather quickly when lawrencite is present. Still, it is remarkable that the highest octahedrite age, $>1.5 \times 10^6$ years, compares favorably to the average time between two hits of 2×10^5 years. Similarly, the highest hypersthene age of 2.1×10^4 years is of the same order as the expected average time between two hits of 2×10^4 years.

The lower fall frequency of irons (about 0.1 of that of stones) is probably more than compensated by their greater durability. One would expect irons to be the most likely candidates among surviving coincidences.

The 32 paired falls of Prior and Hey (1953) include 18 "iron pairs." Two of those are associated with massive, crater-forming meteorites (Canyon Diablo and Wabar), one is a hexahedrite pair (the Chilean hexahedrite group), two are pallasites (Baquedano and Malyi Altai), and one is a Ni-poor ataxite (Barraba). These might be genuine pairs, except for the hexahedrites (Signer and Nier, 1962). On the other hand, it is quite conceivable that several of the remaining octahedrite pairs include independent meteorites.

As for stones, the highest terrestrial age of 21,000 years was reported for Potter, a strongly weathered, black chondrite. These chondrites are heavily shocked, quite compact stones, 80 per cent of which are finds, as against only 30 per cent of all chondrites. It is very likely that heavily brecciated or black chondrites are among the most durable stones, and are good candidates for surviving coincidences. In this connection it is interesting to note that both Artracoona and Taiban are classified as black chondrites.*)

Even if the terrestrial age of a stone is one order of magnitude below the age of Potter, the area in which a coincidence is likely to survive is still only 30 x 30 km. Six chondrites show terrestrial ages of 2000-6700 years (Goel and Kohman, 1962). Perhaps the survival of two independent falls of chondrites of the same class within several tens of kilometers should be considered a serious alternative to a pairing of the two falls. This opinion is further strengthened by an observed coincidence: the amphoterites Manbhoom and Vishnupur, which are almost identical in chemistry and structure, fell in India in 1863 and 1906, the places of fall being 80 km apart. If such coincidences occur in the present, why should they not have happened in the past?

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*) My sample of Artracoona is strongly weathered and its appearance is unlike that of a typical black chondrite such as McKinney. Taiban I as well as Taiban II appear to be genuine black chondrites.

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References

Anders E. (1962) Two meteorites of unusually short cosmic-ray exposure age, Science 138, 431-433.

Brown H. (1961) The density and mass distribution of meteoritic bodies in the neighborhood of the Earth's orbit. J. Geophys. Res. 66, 1316-1317.

Goel P.S. and Kohman T.P. (1962) Terrestrial ages of meteorites from cosmogenic C^{14}. Proceedings of the symposium on radioactive dating, Athens. IAEA, Vienna, 1963, 395 pp.

Heide F. (1964) Meteorites. The University of Chicago Press, Chicago, p. 27.

Heymann D. (1964) Origin of the Canyon Diablo No. 2 and No. 3 meteorites. Nature 204, 819-821.

Heymann D., Lipschutz M.E., Nielsen B. and Anders E. (1965) Canyon Diablo Meteorite: Metallographic and mass-spectrometric study of 56 fragments. Submitted to J. Geophys. Res.

Heymann D. (1965) Cosmogenic and radiogenic He, Ne, and Ar in amphoteric chondrites. J. Geophys. Res. (in press).

Hintenberger H., König H., Schultz H. and Wänke H. (1964) Radiogene, spallogene und primordiale Edelgase in Steinmeteoriten. Z. Naturforsch. 19a, 327-340.

Mason B. (1963) Olivine composition in chondrites. Geochim. et Cosmochim. Acta 27, 1011-1023.

Nininger H.H. (1934) A gold-bearing stony meteorite from Melrose, New Mexico. Amer. Min. 19, 370-374.

Prior G.T. (1953) Catalogue of Meteorites. Second edition, revised by M.H. Hey, British Museum, London, 2 pp.

Rowe M.W., Van Dilla M.A. and Anderson E.C. (1963) On the radioactivity of stone meteorites. Geochim. et Cosmochim. Acta 27, 983-1001.

Signer P. and Nier A.C. (1962) Rare gases in iron meteorites. Researches on Meteorites (Editor: Carleton B. Moore), John Wiley and Sons, Inc., New York and London, 7 pp.

Stauffer H. (1961) Cosmogenic neon and argon in stone meteorites. J. Geophys. Res. 66, 1513-1521.

Vilcsek E. and Wänke H. (1962) Cosmic-ray exposure and terrestrial ages of meteorites. Proceedings of the Symposium on radioactive dating, Athens. IAEA, Vienna, 1963, 381 pp.

Zähringer J. (1965) Chronology of chondrites with rare gas isotopes. Meteoritika (in press).

Table 1

Rare Gases in Two Paired Meteorite Falls

Meteorite	Rare Gas Content, Units 10^{-8} cc STP/g [1]						Ratios		References	Source of Sample
	He^3	Ne^{21}	Ar^{38}_c	He^4_{rad}	Ar^{40}_{rad}	Ar^{36}_{prim}	He^3/Ne^{21}	Ne^{21}/Ar^{38}_c		
Accalana	4.5	2.0	0.29[2]	150[3]	440	4.0[4]	2.3	6.9	This work	Prof. A.R. Alderman[5]
Carraweena	6.1	2.7	0.44	110	410	3.0	2.3	6.1	This work	Prof. A.R. Alderman
Artracoona	64	13.3	1.88	1430	5300	0.7	4.3	7.1	This work	Prof. A.R. Alderman
La Lande I	--	4.08	0.40	--	930	3.2	--	10.2	Stauffer(1961)	Unknown
La Lande II	15.7	2.69	--	191	--	--	5.35	--	Hintenberger et al (1964)	AML[6] N^o 464.245
Melrose	19	4.30	0.51	220	408	0.43	4.4	8.5	Zähringer (1965)	MNHC[7]
Taiban I	14.1	2.79	--	136	--	--	5.11	--	Hintenberger et al (1964)	AML N^o 541.4
Taiban I	12.0	3.6	0.41	138	260	0.59	3.3	8.9	This work	Dr. H. Wänke[8]
Taiban II	32	7.8	1.11	142	230	0.32	4.0	7.0	This work	ASU[9] N^o 541.1

Notes: 1) All isotopes were determined by the method of peak comparison: duplicate analyses were made, from these the errors are estimated 7-10%;

2) $Ar^{38}_c = \frac{5.67\ Ar^{38} - Ar^{36}}{5.02}$, cosmogenic Ar^{38}; 3) $He^4_{rad} = He^4 - 4\ He^3$, radiogenic He^4 ;

4) $Ar^{36}_{prim} = Ar^{36} - 0.65\ Ar^{38}_c$, primordial Ar^{36} ; 5) The University of Adelaide, Adelaide, South Australia;

6) American Meteorite Laboratory; 7) Museum of Natural History, Chicago; 8) Max Planck Institut für Chemie, Mainz,Germany;

9) Arizona State University.

Table II

Comparison of meteorite fall frequency to terrestrial meteorite ages.

Class	Estimated rate*, falls/year/km^2	Average time between hits on 10 x 10 km area, years	Highest reported terrestrial age, years	References to ages
Irons				
Octahedrites	4×10^{-8}	2×10^{5}	$>1.5 \times 10^{6}$	Vilcsek and Wänke 1962
Hexahedrites	6×10^{-9}	2×10^{6}		Goel and Kohman 1962
Ni-poor Ataxites	2×10^{-9}	5×10^{6}		
Ni-rich Ataxites	5×10^{-9}	2×10^{6}		
Stony-Irons				
Pallasites	5×10^{-9}	2×10^{6}	11,000	Goel and Kohman 1962
Stones				
Bronzite Chondrites	3×10^{-7}	3×10^{4}	4,700	Goel and Kohman 1962
Hypersthene Chondrites	4×10^{-7}	2×10^{4}	≥21,000	Goel and Kohman 1962
Achondrites	7×10^{-8}	1×10^{5}		

Notes: *) Based on an estimated rate of 1 meteorite/10^6 years/km^2 (Brown 1961) and estimated percentages of each class as seen to fall to the Earth (Wood 1964). Only one significant figure is given.