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## Report

# The Roosevelt County 079–090 meteorites

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**Abstract**–We have classified 12 new, moderately to severely weathered meteorites from Roosevelt County, New Mexico (RC 079–090) that were recovered between 1969 and 1993. They include nine H chondrites and three L chondrites of petrologic types 4 to 6 and shock classification S1 to S4. Among these are a flight-oriented specimen of an H5 chondrite, an L4 chondrite with a porphyritic impact-melt rock clast, an H5 fragmental breccia with an unusual weathering assemblage (probably a Ca sulfate), and an H4 chondrite with unequilibrated pyroxenes.

## INTRODUCTION

We have examined 12 new meteorites from Roosevelt County, New Mexico. Eleven of these were recovered or acquired by J. Warnica of Portales, New Mexico, between 1969 and 1993. Some of these meteorites (RC 081–084) are among the first that were found in blowouts in Roosevelt County, New Mexico, after the recognition that these deflation surfaces make ideal sites for meteorite recovery. Recovery of numerous meteorites by J. Warnica was first mentioned by Huss and Wilson (1973) in one of the earliest publications on meteorites from Roosevelt County. The 12th meteorite (RC 079) was recovered by I. E. Wilson in 1993. Unfortunately, records on some of the details of the recoveries of the Warnica meteorites are incomplete. Portions of RC 082, 083 and 085–087 were traded by J. Warnica with the late J. M. DuPont. While the masses of the pieces retained by J. Warnica are known (Table 1), the original masses of RC 082 and 085 were never recorded. In addition, the masses of the pieces held by the estate of J. M. DuPont are also unknown. P. Sipiera, curator of the DuPont collection, pointed out to us that DuPont's portions of the Warnica meteorites were never studied scientifically. Nevertheless, they should be known by the same numbers as those described here. All of the meteorites studied here except RC 085 were found in Roosevelt County, New Mexico. RC 085 was found in adjacent Curry County, New Mexico, but is given a Roosevelt County number following the precedence set by Scott *et al.* (1986a).

## METHODS AND ANALYTICAL TECHNIQUES

Hand samples were studied under a low-magnification binocular microscope. Polished thin sections were prepared from each meteorite and are retained in the collection of the Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa. Polished thin sections were studied in transmitted and reflected light with an optical microscope. Mineral compositions were determined using a Cameca SX-50 electron microprobe operated at an accelerating voltage of 15 keV and a beam current of 20 nA with a beam size of 1 μm. Well-known minerals were used as standards, and the data were corrected using a ZAF routine. Criteria for meteorite classification follow Gomes and Keil (1980) for chemical group; Van Schmus and Wood (1967) and Scott *et al.* (1986b) for petrologic type; Stöffler *et al.* (1991) for shock stage; and Wlotzka (1993) for weathering degree. Modal analyses of at least 1000 points were conducted using the method of Keil (1962). The unusual feature in RC 089 was studied in detail using a Zeiss DSM 962 scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS) and operated at a beam energy of 20 keV and a beam current of 5 μA.

## RESULTS

### Classification, Weathering and Pairing

Classification of Roosevelt County meteorites RC 079–090 into chemical groups, petrologic types, shock stages and weathering degrees are given in Table 2. Most of these meteorites are typical run-of-the-mill ordinary chondrites, and, thus, detailed descriptions

TABLE 1. Recovery information for Roosevelt County 079–090.

| Meteorite | Original Wt. (g) | Date of Find | Finder | Coordinates: Geographic | Coordinates: Map | Hand Sample Mass: Mass (g) | Hand Sample Mass: Owner |
|---|---|---|---|---|---|---|---|
| RC 079 | 30.2 | 4/1993 | I. E. Wilson | 34°6'N, 103°35'W | T2S, R32E, Sec. 28 | 30.2 | I. E. Wilson |
| RC 080 | 727.8 | 1968 | J. Warnica | 34°3'N, 103°30'W | T3S, R33E, Sec. 17 | 727.8 | J. Warnica |
| RC 081 | 522.2 | 1969 | J. Warnica | 33°38'N, 103°10'W | T8S, R37E, Sec. 8 | 522.2 | J. Warnica |
| RC 082 | ? | 1969 | J. Warnica | 34°5'N, 103°34'W | T3S, R32E, Sec. 3 | 136.7 | J. Warnica |
| RC 083 | 14.8 | 1969 | J. Warnica | 33°40'N, 103°25'W | T7S, R34E, Sec. 36 | 7.5 | J. Warnica |
| RC 084 | 69.6 | 1969 | J. Warnica | 34°12'N, 103°14'W | T1S, R35E, Sec. 23 | 69.6 | J. Warnica |
| RC 085 | ? | 1969 | J. Warnica | 34°19'N, 103°23'W | T1N, R34E, Sec. 16[1] | 140.5 | J. Warnica |
| RC 086 | 9 | 1974 | J. Warnica | 34°17'N, 103°17'W | T1N, R35E, Sec. 28 | 3.4 | J. Warnica |
| RC 087 | 8.2 | 1977 | J. Warnica | 34°4'N, 103°31'W | T3S, R33E, Sec. 6 | 4.9 | J. Warnica |
| RC 088 | 7.5 | 1978 | J. Warnica | 33°53'N, 103°34'W | T5S, R32E, Sec. 10 | 7.5 | J. Warnica |
| RC 089 | 1615 | 1980's | N. Widener | 34°8'N, 103°32'W | T2S, R32E, Sec. 13 | 1615 | J. Warnica |
| RC 090 | 6.4 | 1993 | J. Warnica | 34°17'N, 103°31'W | T1N, R33E, Sec. 30 | 6.4 | J. Warnica |

[1] Location in Curry County, New Mexico, but given Roosevelt County number following the precedence of Scott *et al.* (1986a).

of each meteorite are not given beyond the pertinent data in Table 2. We discuss here the weathering and pairing of these meteorites and, in a later section, dwell in more detail on a number of specific meteorites with interesting and noteworthy features.

Many of the meteorites are so extensively weathered that the modal analyses are not reliable indicators of their chemical groups, and we have therefore not carried out modal analyses on meteorites that exhibit weathering of silicates (W5, W6). In examining these meteorites, we find that the weathering scheme of Wlotzka (1993) may not be entirely valid at high degrees of weathering. He suggests that weathering of metal and troilite proceed to completion (stage W4) before weathering of silicates along cracks (W5) and massive replacement of silicates (W6) take place. In these small Roosevelt County meteorites, however, we often note a gradation of weathering effects from the outsides of the stones to their cores, and, thus, assignment of such a chondrite to a single weathering stage is not possible. In these cases, we assign a dual weathering stage (*e.g.*, W5-6) to those specimens. More importantly, we often see weathering of silicates along cracks and even massive replacement of silicates before complete oxidation of sulfides. In RC 084, troilite grains with unweathered regions ≤50 μm in diameter still exist amid completely altered silicates. We suggest that assigned weathering stages based on metal and sulfide abundances can differ from that based on degree of silicate weathering. Where these differ, the higher weathering stage should be assigned to the meteorite as a whole.

Pairing has not been attempted for these meteorites, since most of them have no special petrologic or chemical features that would allow us to distinguish them reliably from other Roosevelt County meteorites.

### Meteorites with Interesting Features

**Roosevelt County 081**–This meteorite weighs 522 g and has an irregular, conical shape, with the front side of the cone being ~10 cm across and the distance between the apex and the front side of the cone being ~5 cm. It is a beautiful example of a flight-oriented specimen. The front surface displays an overall curvature with threadlines formed by flowing molten silicates radiating away from the nose ("Brustseite"). The central point of these threadlines is somewhat offset from the center of this curved surface. No pitting is observed on the front surface. The front and back surfaces are separated by a thin lip at the edge of the meteorite. The rear surface is concave at the edge leading to a central peak, which is opposite the nose on the front surface. Threadlines are seen in some cases to radiate away from the nose, over the lip and towards the central peak on the back. This same effect is documented by Nininger (1981) in the Pricetown meteorite and attributed to streaming of air closing in behind the meteorite. The shape of the rear side suggests that RC 081 was originally irregularly shaped and, during atmospheric flight, did not completely modify this shape to form the domal or conical shape and flat rear side typical of perfectly-oriented specimens (*e.g.*, Lafayette).

**Roosevelt County 084**–This meteorite is "pancake-shaped" and measures 7 × 5 × 1.5 cm. One surface is covered with caliche, whereas the other is brown and has many spherical indentations. We suggest that the unusual shape and markedly different weathering on the two sides suggest that this meteorite is a fragment spalled from the surface of a much larger stone. The caliche-coated side represents the original surface of the meteorite, whereas the other side is a weathering fracture parallel to the surface along which the stone fractured.

**Roosevelt County 085**–RC 085 contains an impact-melt rock clast that is readily identifiable in hand specimen and thin section, because it is visibly lighter in color than the chondritic host. The clast is truncated by the edge of the meteorite, has an elongate, semicircular outline in thin section with dimensions of ~1 × 2 cm, and the clast-host boundary is not very distinct microscopically. Its texture and composition are typical of many similar melt-rock clasts described from ordinary chondrites (*e.g.*, Rubin, 1985). It consists of large (≤1 mm) euhedral to subhedral olivines set in a fine-grained groundmass (Fig. 1). The composition of the large, porphyritic olivines ($Fa_{24.6 \pm 0.3}$, N = 21) is in the range of L chondrites and is similar to those in the host ($Fa_{24.5 \pm 0.2}$). The groundmass is composed of ≤100 μm equant to elongate mafic silicates, which backscattered electron imaging and quantitative electron microprobe analyses show to be dominated by low-Ca pyroxene. A single, reliable analysis of this pyroxene ($Fs_{21.3}Wo_{1.4}$) indicates that it is also typical of L chondrites. Between the

TABLE 2. Chemical, petrologic, shock and weathering data for Roosevelt County 079–090.

| Meteorite | UH PTS Number | Olivine Fa Avg. | Olivine Fa 1σ | Olivine N | Low-Ca Pyroxene Fs Avg. | Fs 1σ | Wo Avg. | Wo 1σ | Low-Ca Pyroxene N | Chemical Group | Petrologic Type | Shock Stage | Modes (wt%) WP[1] | Modes (wt%) Fe,Ni | Modes (wt%) FeS | Weathering Stage | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RC 079 | 227 | 18.6 | 0.2 | 20 | 17.1 | 0.4 | 1.3 | 0.3 | 15 | H | 4 | S1 | Tr | 3.2 | 29.4 | W3 | |
| RC 080 | 235 | 19.4 | 0.3 | 15 | 17.7 | 0.3 | 1.3 | 0.2 | 15 | H | 6 | S1 | 13.6 | 6.1 | 2.9 | W2 | |
| RC 081 | 236 | 18.5 | 0.6 | 20 | 16.0 | 0.4 | 1.3 | 0.1 | 23 | H | 5 | S2 | 11.3 | 5.9 | 11.1 | W3 | |
| RC 082 | 237 | 17.8 | 0.2 | 15 | 16.4 | 0.2 | 1.2 | 0.5 | 15 | H | 4 | S2 | 0.9 | 2.6 | 23.5 | W3 | |
| RC 083 | 241 | 18.5 | 0.3 | 16 | 16.8 | 0.2 | 1.3 | 0.1 | 19 | H | 5 | S2 | – | – | – | W5 | |
| RC 084 | 238 | 24.1 | 0.6 | 16 | 20.9 | 0.6 | 1.1 | 0.8 | 15 | L | 4 | S3 | – | – | – | W5-6 | |
| RC 085 | 249 | 24.5 | 0.2 | 20 | 21.8 | 0.8 | 1.6 | 0.3 | 19 | L | 4 | S4 | 5.6 | 6.3 | 3.6 | W2 | Host |
| | | 24.6 | 0.3 | 21 | 21.3 | – | 1.4 | – | 1 | L | – | S3 | – | – | – | W2 | Impact-melt Clast |
| RC 086 | 242 | 24.6 | 0.3 | 15 | 21.1 | 0.3 | 1.7 | 0.2 | 16 | L | 6 | S3 | – | – | – | W5-6 | |
| RC 087 | 243 | 18.3 | 0.2 | 20 | 16.7 | 0.2 | 1.5 | 0.2 | 15 | H | 5 | S2 | 2.9 | 4.8 | 19.9 | W3 | |
| RC 088 | 244 | 18.6 | 0.2 | 15 | 16.9 | 0.2 | 1.2 | 0.2 | 15 | H | 4 | S1 | – | – | – | W5 | |
| RC 089 | 229 | 19.6 | 0.3 | 10 | 18.0 | 0.2 | 1.5 | 0.1 | 10 | H | 5 | S3 | 0.4 | 1.5 | 35.8 | W4 | Host |
| | | 19.6 | 0.3 | 10 | 17.8 | 0.3 | 1.5 | 0.2 | 10 | H | 5 | S3 | – | – | – | – | Clast |
| RC 090 | 230 | 17.3 | 0.2 | 20 | 13.2 | 4.3 | 0.6 | 0.5 | 20 | H | 4 | S1 | 0.6 | 0.3 | 34.5 | W4 | |

[1] Weathering products of terrestrial origin.

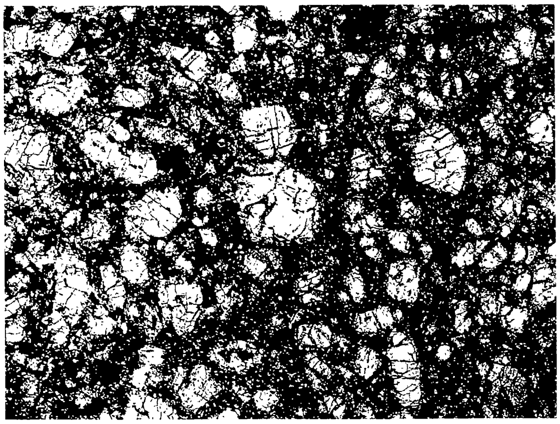

FIG. 1. Transmitted, plane-polarized light view of porphyritic impact-melt rock clast in RC 085. Large (≤1 mm) euhedral to subhedral olivines are embedded in a groundmass of fine-grained (<100 μm) pyroxene with minor olivine, interstitial plagioclase and traces of Fe,Ni metal, troilite and chromite. Field of view = 4 mm.

groundmass mafic silicates occurs microcrystalline plagioclase and 1–3 μm metallic Fe,Ni and troilite blebs, along with minor chromite. The clast is depleted in Fe,Ni relative to the chondritic host and contains a single large troilite grain ~5 mm in diameter.

The melt-rock clast appears to have experienced the same moderate shock and weathering as the host material. Olivines in the melt-rock clast exhibit planar fractures and a weak mosaicism, suggesting shock stage S3. The large troilite grain is polycrystalline and is shock-melted at one end, forming a mixture of shock-melted silicates with troilite blebs 1–200 μm in diameter (Stöffler *et al.*, 1991). These troilite blebs often include 1–5 μm Fe,Ni metal particles. Weathering products in the clast are minor, probably reflecting the original depletion of the clast in Fe,Ni metal. Troilite is essentially unaltered. A large weathering vein near the edge of the specimen cuts across both the clast and host. The clast exhibits a weathering stage of W1.

The clast appears to be an impact melt rock, possibly from an L-group target, as indicated by the mineral compositions. The large size, depletion of metal and approximate whole-rock silicate composition all argue that the clast is not simply a large type II porphyritic olivine chondrule, although the textures are similar (Scott and Taylor, 1983). The depletion of metal suggests that the clast did not form *in situ*, although significant three-dimensional heterogeneity could exist in it. Large troilite particles without associated metal have been observed in other impact-melt rock clasts (*e.g.*, Kinsey *et al.*, 1995), and their presence has been attributed to metal-troilite fractionation during melting or transport, with formation of large troilite nuggets due to immiscibility of the sulfide melt. Because of the similarity in mineral compositions and the equilibrated nature of clast and chondrite host, we conclude that this impact-melt rock formed prior to or during peak metamorphism and was incorporated into the RC 085 host prior to completion of peak metamorphism.

**Roosevelt County 089**–This meteorite is cube-shaped, measures 10 × 12 × 7 cm, and weighs 1.6 kg. It appears to have retained much of its original surface features despite heavy weathering. The surface is quite smooth, regmaglypts are apparent, and an interesting weathering feature was noted and studied in the hand sample. This feature is a large troilite grain (~3.5 mm in diameter) that has weathered during terrestrial residence to form an unusual assemblage (Fig 2). In the center of the troilite grain is a 1.5 mm area of fine-grained weathering products. Qualitative EDS analysis indicates variable concentrations of Ca, Fe, Si, S, Al, Mg, and Ti. The nature and precise source of this material is unknown, although it is probably a mixture of weathering products of the host troilite and surrounding or originally included silicates. In the center occurs a 1000 × 230 μm crystal, which qualitative EDS analysis shows to contain major amounts of Ca and S and minor and variable amounts of Fe. No X-ray diffraction data are available on this crystal, but its qualitative EDS analysis suggests that it may be Ca sulfate and formed as a result of weathering of troilite. The precise source of the Ca is unknown, but it is most likely from groundwater (with the Ca from the caliche, which is found on most of these meteorites). Although sulfate weathering products have previously been reported from an aubrite (*e.g.*, Okada *et al.*, 1981), we are unaware of any similar occurrences of sulfate crystals of this size in other weathered meteorites.

This meteorite shows no obvious indications for brecciation in hand sample, possibly because the stone is highly weathered, but brecciation is very apparent in thin section. Light-colored clasts are enclosed in a dark, fine-grained matrix, reminiscent of the light-dark structure found in regolith breccias (Fredriksson and Keil, 1963). The thin section examined contains numerous clasts, ranging in size from 1.3 mm to 2.3 cm. Compositions of minerals in the clasts and in the matrix indicate that the meteorite is a breccia of H chondrite composition. Compositions of olivine ($Fa_{19.6 \pm 0.3}$; N = 10) and low-Ca pyroxene ($Wo_{1.5 \pm 0.2}$, $Fs_{17.8 \pm 0.3}$; N = 10) in the largest clast are within standard deviations of those in the matrix ($Fa_{19.6 \pm 0.3}$, N = 10; $Wo_{1.5 \pm 0.1}$, $Fs_{18.0 \pm 0.2}$, N = 10). Olivine compositions measured in other, smaller clasts are also indicative of H classification ($Fa_{19.8}$), and both clasts and matrix are classified as petrologic type 5 and shock stage S3.

Because of its brecciated nature and its superficial resemblance in microscopic texture to regolith breccias, RC 089 was analyzed for noble gases to determine whether it contains solar wind-implanted gases. A bulk sample of 76 mg was analyzed (Table 3), after having been preheated in vacuum for ~24 h at 100 °C. Argon values have somewhat large errors due to a relatively high blank. No solar noble


FIG. 2. Secondary electron image of a large troilite grain (white) on a sawn surface of RC 089. The troilite exhibits complex banding and has a large, central, fine-grained pocket that is composed of weathering products from the troilite and surrounding or included silicates. In the center of this weathered material is a 1000 × 230 μm crystal, which qualitative EDS analysis shows to consist of major Ca and S. Its composition suggests it is a Ca sulfate of weathering origin. Scale bar = 2 mm.

TABLE 3. Noble gas data for Roosevelt County 089.

| | | | | | | | | | | Cosmogenic Fraction | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{3}He$ | $^{4}He$ | $^{20}Ne$ | 20/22 | 22/21 | $^{36}Ar$ | 36/38 | $^{40}Ar$ | $^{84}Kr$ | $^{132}Xe$ | $^{21}Ne$ | $^{38}Ar$ | 22/21 | 3/21 |
| 6.02 | 610 | 1.82 | 0.979 | 1.119 | 0.490 | 1.98 | 4080 | 0.0103 | 0.0066 | 1.66 | 0.176 | 1.100 | 3.63 |
| 0.20 | 24 | 0.07 | 0.010 | 0.006 | 0.040 | 0.10 | 160 | 0.0005 | 0.0003 | 0.07 | 0.010 | 0.008 | 0.08 |

Concentrations in $10^{-8}$ $cm^3$STP/g.
Lower numbers indicate analytical uncertainty.
Sample Mass = 76 mg.
Cosmogenic component calculated by assuming trapped Ne and Ar to be atmospheric.

gases could be detected in the sample: the $^{20}Ne/^{22}Ne$ ratio is close to the value typical for the cosmogenic component of~0.8, and the $^{4}He$ concentration is less than half the typical value for chondrites with good retention of radiogenic $^{4}He$. The absence of solar wind gases indicates that RC 089 is not a regolith but a fragmental breccia. The $^{22}Ne/^{21}Ne$ ratio of the cosmogenic component indicates "average shielding." The shielding-corrected $^{21}Ne$ exposure age calculated according to Eugster (1988) is 5.1 Ma. Krypton and Xe concentrations are typical for ordinary chondrites of higher petrologic types. A considerable part of the Kr and Xe is atmospheric contamination, however, as indicated by the relatively high $^{84}Kr/^{132}Xe$ ratio of 1.56 and the Xe isotopic composition (not given). This contamination by atmospheric heavy noble gases of meteorites found in terrestrial desert regions is common (Loeken *et al.*, 1992).

**Roosevelt County 090**–RC 090 is a somewhat unusual type 4 chondrite in that it contains equilibrated olivines ($\sigma$/mean Fa = 1.2%) but unequilibrated pyroxenes (range of $Fs_{6.5-24.3}$). Other examples of type 4 chondrites with unequilibrated pyroxenes include Bo Xian ($Fs_{3.4-22.9}$; McCoy *et al.*, 1991), and TIL 91700 ($Fs_{15-25}$; Mason, 1993). The coexistence of equilibrated olivines and unequilibrated pyroxenes is consistent with the higher diffusion rates for Fe-Mg in olivine relative to low-Ca pyroxene (*e.g.*, Buening and Buseck, 1973; Huebner and Nord, 1981). This evidence for incomplete silicate equilibration in RC 090 is supported by the sharp chondrule outlines and abundant striated pyroxene.

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