1995Metic..30...42S

Meteoritics 30, 42–46 (1995)

Axtell, a new CV3 chondrite find from Texas

S. B. SIMON[1], L. GROSSMAN[1, 2], I. CASANOVA[1, 3], S. SYMES[4], P. BENOIT[4], D. W. G. SEARS[4], AND J. F. WACKER[5]

[1]Department of the Geophysical Sciences, University of Chicago, 5734 S. Ellis Ave., Chicago, Illinois 60637, USA
[2]Enrico Fermi Institute, University of Chicago, 5640 S. Ellis Ave., Chicago, Illinois 60637, USA
[3]Department of Geology, Field Museum of Natural History, Chicago, Illinois 60605, USA
[4]Cosmochemistry Group, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, Arkansas 72701, USA
[5]Battelle, Pacific Northwest Laboratories, Richland, Washington 99352, USA

(Received 1994 August 9; accepted in revised form 1994 November 7)

Abstract–We describe a previously unreported meteorite found in Axtell, Texas, in 1943. Based on the mineralogical composition and texture of its matrix and the sizes and abundance of chondrules, we classify it as a CV3 carbonaceous chondrite. The dominant opaque phase in the chondrules is magnetite, and that in refractory inclusions is Ni-rich NiFe metal (awaruite). Axtell, therefore, belongs to the oxidized subgroup of CV3 chondrites, although unlike Allende it escaped strong sulfidation. The meteorite bears a strong textural resemblance to Allende, and its chondrule population and matrix appear to be quite similar to those of Allende, but its refractory inclusions, thermoluminescence properties, and cosmogenic ^{60}Co abundances are not. Our data are consistent with a terrestrial age for Axtell of ~100 years and a metamorphic grade slightly lower than that of Allende.

INTRODUCTION

A new CV3 chondrite, weighing 6.2 kg, has recently become available for study. The name Axtell was approved by the Meteorite Nomenclature Committee of the Meteoritical Society at its meeting in Prague in 1994 July (Wlotzka, 1994). The meteorite was found near Axtell, Texas (31°42′N, 96°49′W) in 1943 by the late Roy Parrish. It remained in the possession of his family for over 50 years and was sold to a meteorite collector in the fall of 1993. Several kg were acquired by the Field Museum soon thereafter. Because the texture of Axtell is quite similar to that of Allende, part of our early efforts were directed toward making sure it is not a piece of Allende that had been exposed to the elements for a quarter century longer than other specimens. Results from a variety of techniques, including petrographic examination, electron probe analysis, oxygen isotopic analysis, measurement of cosmogenic radio-nuclides, and thermoluminescence measurement, are reported here. Some preliminary results of this study were reported by Simon *et al.* (1994).

CIRCUMSTANCES OF FIND AND SUBSEQUENT HISTORY

According to Tommy Wilson, in late May or early June, 1943, his uncle, Roy Parrish, struck the meteorite, breaking off a small piece, with a plow blade during cultivation of a cotton field three miles south of Axtell, Texas. This was the second plowing of the field that year; the meteorite was not encountered during the first plowing, earlier that spring. Some time thereafter, perhaps as much as a couple of years later, the specimen was taken to Baylor University, examined by someone in either the geology department or the Strecker Museum, and identified as a meteorite. Mr. Parrish left the chipped piece at Baylor and took the rest of the meteorite home, where it was kept outside on the back porch of his house and used as a doorstop for as long as Mr. Wilson (born 1939) can remember. Mr. Parrish died in 1963, but the specimen remained in the family until after his wife died in the spring of 1993. Later that year, it was sold to a meteorite collector, Blaine Reed, who sold parts of it to two other collectors, Jim Schwade and Marlin Cilz. The latter cut the specimen into slabs, five of which were traded by Schwade to the Field Museum of Natural History in the fall of 1993.

We have attempted to verify the early part of this sequence of events but have been unable to do so. There are no records of such a sample being brought to Baylor in the 1940s, no one who was there at the time recalls examining a meteorite, and no sample of Axtell can be found there. Nor has Mr. Wilson been able to provide us with a photograph of the meteorite taken prior to 1969, the year Allende fell. We, therefore, turned to scientific methods to attempt to distinguish this meteorite from Allende.

ANALYTICAL TECHNIQUES

From the five slabs available, chips were taken for oxygen isotopic analysis by R. N. Clayton and for measurement of cosmogenic ^{60}Co. After examination of the 10 slab surfaces, a variety of fine-grained and coarse-grained refractory inclusions and two dark inclusions were selected for further study. These objects were removed from the slabs with a rock saw and microtrimmer. A total of 24 polished thin sections were made, most of which sample selected refractory inclusions. Two others were intended to be general, representative sections. All sections were examined with a petrographic microscope, and some were studied with a JEOL JSM-35 scanning electron microscope (SEM). Wavelength-dispersive mineral analyses were performed with a fully automated Cameca SX-50 electron microprobe operated at 15 kV and 25 nA. Cosmogenic ^{60}Co was measured in two slabs of Axtell, one 102 g and the other 194 g, and in a slab of Allende (161 g) using a high efficiency multiparameter γ spectrometer. This spectrometer detects multiple γ rays in coincidence using two 30-cm-diameter NaI (Tl) crystals. Coincidence counting allows measurement of weak activities of those radionuclides, such as ^{60}Co, that emit multiple γ rays, by enhancing peak/background ratios and lowering detection limits. Further details on instrumentation and the methods used are given by Perkins *et al.* (1970) and Evans and Reeves (1987). Natural and induced thermoluminescence (TL) measurements were performed using methods and equipment similar to those of Sears *et al.* (1991), including the use of the Dhajala meteorite as a standard for monitoring results and for normalization of induced TL measurements. Three chips, weighing 109, 275, and 515 mg, respectively, were sampled for analysis by TL. About 100 mg of each chip were crushed to 100 mesh, and three aliquots (~4 mg each) were taken from each of the homogenized powders. The induced and natural TL of each aliquot were measured, and the results averaged for each chip. Samples of Allende, subjected to the same processing, were analyzed at the same time for comparison. About 50 mg of the residual powders of two chips were subjected to acid washing (Benoit *et al.*, 1991) to determine possible weathering effects on the Axtell TL data. A sample of Allende was also acid washed using the same procedures, for comparison.

RESULTS

Macroscopic Description

Prior to being sold and subdivided, the specimen was a complete, rounded stone, except for the small piece that was presumably broken off by the plow and left at Baylor University. It has a thin, weathered fusion crust through which chondrules and inclusions can be seen. The slab surfaces (*e.g.*, Fig. 1) reveal abundant chondrules and inclusions in a black matrix. Most chondrules show Fe-oxide staining, but, despite the weathering, the meteorite is not friable. No foliation is visible. Except for the effects of weathering, the texture of this meteorite closely resembles that of Allende.

Petrography and Mineral Chemistry

The thin sections reveal well-defined, about mm-sized chondrules and slightly larger inclusions in a dark brown to opaque matrix. Observation with the SEM shows that the matrix of Axtell is dominated by 1–10 μm olivine grains, mostly in the form of plates and blocky grains, as is typical of CV3 chondrites (*e.g.*, Peck, 1983a; Scott *et al.*, 1988). In Axtell, some of the blocky grains have holes in their centers, similar to the "doughnut-shaped" grains observed in Allende by MacPherson *et al.* (1985).

Most of our efforts have been directed toward petrographically distinguishing Axtell from Allende. Matrix abundances were determined in two Axtell and two Allende thin sections by optically point-counting between 1066 and 1286 points per section, covering ~5 cm^2 of each meteorite. The results were similar: 42 and 55 vol% matrix in Axtell *vs.* 45 and 56 vol% matrix in Allende, indicating very similar ranges. We measured the diameters of ~120 chondrules in each meteorite, and the results for chondrules up to 2000 μm across are illustrated in Fig. 2. The two populations are quite similar to each other. Allende chondrules were found to range from 150 to 1980 μm with only one chondrule >2000 μm across. Axtell chondrules are mostly between 125 and 1980 μm; we found four that are >2000 μm across. In neither meteorite is there a strong peak for a given size range, although, in both meteorites, most chondrules are between 300 and 1100 μm across.

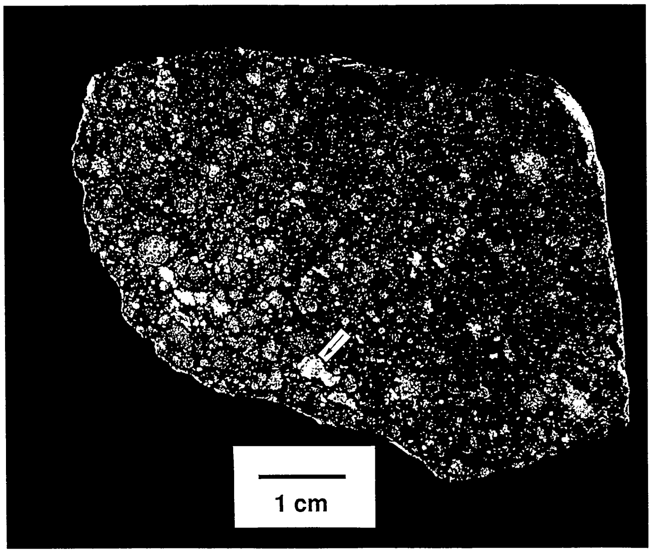

FIG. 1. View of slab surface of Axtell. Note the abundance of chondrules and inclusions and the lack of foliation. The large CAI (arrow) visible at bottom center of the slab is AX-1, a compact Type A inclusion described by Simon *et al.* (1994).

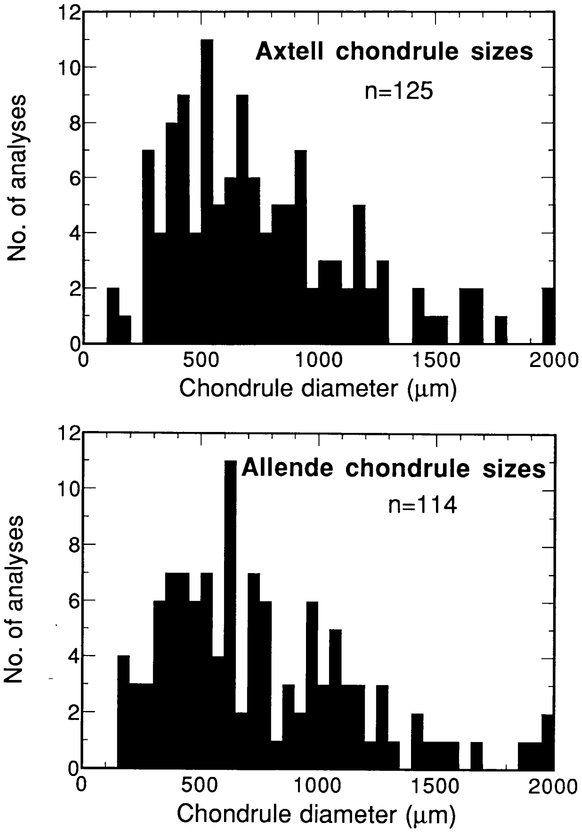

FIG. 2. Histograms of sizes of chondrules in Axtell and Allende. The populations exhibit similar ranges and distributions. Each column represents a range of 50 μm.

The range of chondrule sizes observed in Axtell is much closer to that of Vigarano-type C3 chondrites, 500–2000 μm, than it is to that of Ornans-type C3s, in which the chondrules are generally <500 μm across (Van Schmus and Hayes, 1974). From the chondrule population and the matrix texture, we classify Axtell as a CV3 chondrite.

We analyzed 63 matrix olivine grains in Axtell. Compositions range from Fa_{34} to Fa_{56}, as illustrated in Fig. 3. This range is slightly wider than that reported for Allende by Peck (1983b), similar to those reported for Allende, Grosnaja and Vigarano by Scott *et al.* (1988), and much narrower than the ranges observed for similar numbers of analyses in Mokoia and Kaba (Peck, 1983b;

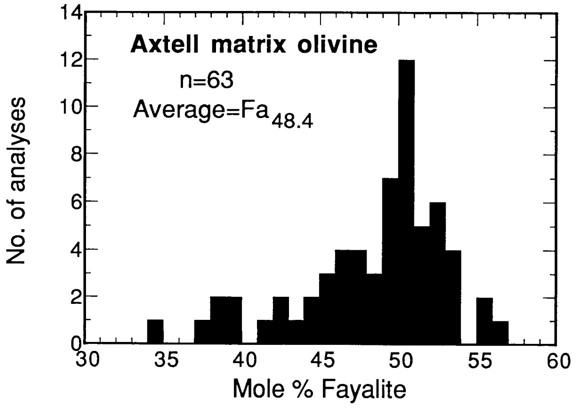

FIG. 3. Histogram of matrix olivine compositions in Axtell, determined by electron microprobe.

Scott *et al.*, 1988). The average fayalite content of Axtell matrix olivine is 48.4 ± 4.7 mol% (1 σ), within 1 σ of the fayalite contents calculated for the average matrix olivine compositions in Allende, Grosnaja and Vigarano (Scott *et al.*, 1988) of 47.6, 48.4 and 50.3 mol%, respectively. Some large, isolated, forsteritic ($Fa_{\sim 4}$) olivine grains in Axtell have rims of relatively fayalitic ($Fa_{\sim 40}$) olivine, a very common feature of Allende (Peck and Wood, 1987; Weinbruch *et al.*, 1990). In Axtell, as in Allende (Weinbruch *et al.*, 1990), the rim olivine is also enriched in MnO relative to the host.

We also analyzed olivine in Axtell and Allende chondrules, and those results are summarized in Fig. 4. The populations are remarkably similar, with average fayalite contents of 6.7 mol% in Axtell and 7.6 in Allende, and peaks at Fa_1. These results for Allende, however, differ slightly from the previous results of Grossman and Steele (1976) and Simon and Haggerty (1979), who observed peaks at Fa_0 and averages of $Fa_{3.6}$ and $Fa_{5.9}$, respectively.

A survey of over 40 opaque assemblages in 20 Axtell chondrules shows that magnetite is the most abundant opaque phase. Like the magnetite in Allende (Haggerty and McMahon, 1979; Rubin, 1991), that in Axtell is virtually NiO-free and contains ~1 wt% Al_2O_3 and ~1.5–3 wt% Cr_2O_3. Sulfides and metal are also present but are much less abundant than magnetite. Two Ni-rich (~70 and 44 wt% Ni) metal grains were found. Most of the S-bearing material contains Ni and may have originally been pentlandite, but it appears to have been affected by terrestrial weathering, and stoichiometric analyses could not be obtained.

Refractory Inclusions

Among the calcium-, aluminum-rich inclusions (CAIs), fine-grained ones appear to be more abundant than coarse-grained ones on the slab surfaces we examined. The fine-grained inclusions are up to 9 mm across and have highly irregular shapes, whereas the coarse-grained inclusions tend to be rounded. Like Allende CAIs, those in Axtell typically contain moderate to large amounts of secondary alteration products. The eight CAIs studied by Simon *et al.* (1994) include one unlike any previously described: a compact Type A (melilite-rich) inclusion with a spinel-perovskite core and an outer zone dominated by melilite laths. Other Axtell CAIs described by Simon *et al.* (1994) that are unusual in some way in their textures or silicate mineralogy compared to those in Allende include (a) a compact Type A (CTA) that contains an unnamed Ca-, Ti-rich silicate previously found in only two other CTAs—one in Allende (Floss *et al.*, 1992), and one in Efremovka (El Goresy and Zinner, 1994); (b) two "fluffy" Type A inclusions (MacPherson and Grossman, 1984) with abundant palisade bodies—Wark and Lovering (1982) found no palisades in Type A inclusions; and (c) two B1s (coarse-grained inclusions with pyroxene-rich cores and melilite mantles), which contain fine-grained (~10 μm) spinel in their cores and mantles rather than coarse-grained spinel (up to ~100 μm) concentrated in the cores and nearly absent from the mantles. Caillet (1994) also found a very unusual refractory inclusion in Axtell: a silicate-free inclusion containing ferroan spinel in its core, intergrown with TiO_2-rich hibonite.

The opaque assemblages in several of the Axtell CAIs we studied are also different from those in Allende (Casanova and Simon, 1994). Unlike Allende, the dominant sulfide phase in Axtell CAIs is troilite, rather than pentlandite, and Axtell CAIs do not contain sulfide veins. In the four CAIs considered by Casanova and Simon (1994), the dominant metallic phase in Axtell is awaruite (approximately Ni_3Fe), however, which is common in Allende (*e.g.*, Haggerty and McMahon, 1979).

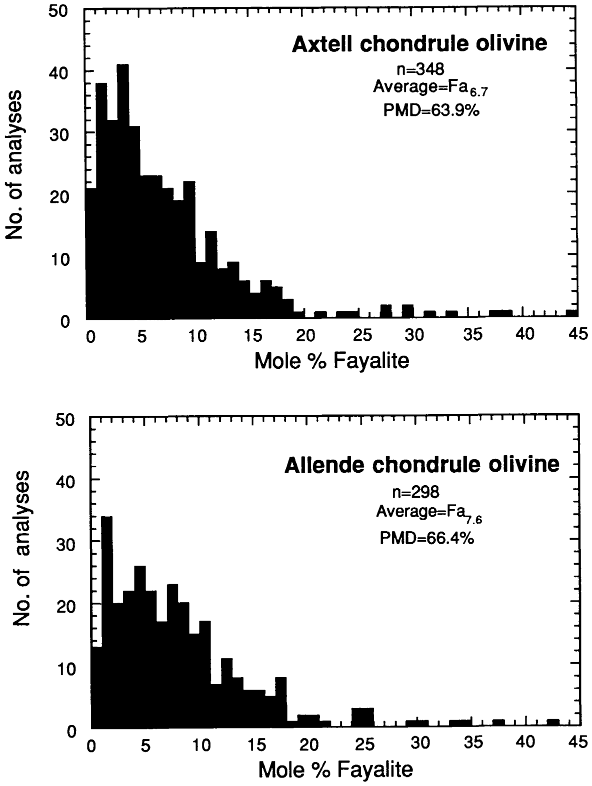

FIG. 4. Histograms of compositions of olivine in Axtell and Allende chondrules, determined by electron microprobe. The two data sets are quite similar. PMD = percent mean deviation.

Oxygen Isotopes

Axtell has an oxygen isotopic composition of $\delta^{18}O$ = +1.61, $\delta^{17}O$ = –2.54 (R. N. Clayton and T. K. Mayeda, pers. comm.), values typical for CV3 chondrites (Clayton, 1993). These are very close to the accepted values for bulk Allende of $\delta^{18}O$ = +1.51, $\delta^{17}O$ = –2.73 (T. K. Mayeda, pers. comm.).

Thermoluminescence

The cosmic radiation that meteorites are exposed to while in space excites electrons, which can be trapped in metastable energy states. If the sample is subsequently heated, the electrons are released, and light is emitted as they return to their normal states. This light is the natural thermoluminescence (TL) of the sample, and it provides a record of a meteorite's exposure history. Meteorites obtain a radiation dose of ~10 rad $year^{-1}$ in space, but only ~0.1 rad $year^{-1}$ once on Earth (Melcher, 1981), allowing the natural TL to decay with time. The level of natural TL, therefore, provides an estimate of the terrestrial age of a meteorite. None of our samples of Axtell have measurable natural TL at any point in their glow curves; taking into account the background TL intensity, this implies that the natural TL level of all our samples of Axtell is <0.5 krad. In contrast, samples of Allende have natural TL levels of about 5 krad and 15 krad at 250 °C and 400 °C in the glow curves, respectively.

After the natural TL has been drained from a sample, a known dose of radiation can be applied, and the sample heated to determine the induced TL sensitivity. This is an indicator of feldspar abundance, which is related to the degree of recrystallization of glass in chondrules and, therefore, metamorphic grade. Both Axtell and Allende have peaks in induced TL sensitivity at 130 °C, but relative to Dhajala, Allende has a value of 0.04 ± 0.01, whereas the three chips of Axtell give values between 0.006 ± 0.001 and 0.002 ± 0.001. Thus, the TL sensitivity of Axtell is about 10% that of Allende. Acid-washing to remove weathering products, which might lower TL sensitivity levels (Benoit *et al.*, 1991), caused no change in either the glow curve shapes or the TL sensitivity values of either Axtell or Allende.

Cosmogenic Radionuclides

Bombardment of a meteorite by galactic cosmic rays while in the space environment generates a neutron flux that increases with depth within the meteorite and can convert some of its stable atoms into radionuclides, whose production virtually ceases upon the fall of the meteorite to Earth. The activity decreases at a rate determined by the half-lives of the various radionuclides, providing a measure of the terrestrial age of a meteorite. We determined the activities of ^{60}Co ($t_{1/2}$ = 5.27 years) in two slabs of Axtell and in one of Allende. In Axtell, no significant ^{60}Co activity was detected in either sample even when counted for 5000 min, with activities at or below our detection limit of 0.5 dpm kg^{-1}, which is within 2σ of background. Our sample of Allende, analyzed for comparison, shows a ^{60}Co activity of ~2 dpm kg^{-1}, corresponding to ~40 dpm kg^{-1} at the time of fall. Because ^{60}Co results from neutron capture by ^{59}Co, the abundance of ^{60}Co in a meteorite specimen is dependent upon its position in the preatmospheric body and, if samples from different original depths are analyzed, a range of ^{60}Co contents can be expected (Rancitelli *et al.*, 1969). This accounts for the range of activities, 23 to 180 dpm kg^{-1}, reported for 10 samples of Allende analyzed for ^{60}Co in 1969 (Evans *et al.*, 1982), which would correspond to a range of 1–7 dpm kg^{-1} today. Our result for Allende falls within this range, and those for Axtell do not. Samples of Allende with activities of <1 dpm kg^{-1} may exist but, based on data in Rancitelli *et al.* (1969), would have to consist of material from the outermost few cm of the preatmospheric body.

DISCUSSION

Possible Identity With Allende

Several things are clear from the preliminary investigations of Axtell described above. It is remarkably similar to Allende on the basis of texture, oxygen isotopes, and chondrule populations. The CAI populations appear to be somewhat different, but we cannot be sure that such CAIs as have been found in Axtell (Simon *et al.*, 1994; Caillet, 1994) do not exist in Allende. Furthermore, we have been unable to verify the date of the find, as reported by the nephew of the finder, with any photographs or official documentation. The question of identity with Allende comes down to non-petrographic characteristics of the specimens, and here we see measurable differences, both in terms of their TL sensitivities and ^{60}Co activities.

Axtell has a much lower natural TL level than Allende. Although the decay rate of natural TL is not well calibrated for carbonaceous chondrites, if we use ordinary chondrite TL parameters and an assumed storage temperature of 25 °C, then the observed difference between Axtell and Allende indicates a difference in terrestrial ages of at least 100 years. The decay of natural TL of a meteorite is affected by its ambient storage temperature, with decay rates being higher at higher temperatures. If Axtell and Allende fell at the same time, to attribute their natural TL difference to different thermal environments would require that Axtell was ~50–60 °C warmer than Allende for at least 10 years, a highly unlikely scenario. Heating during atmospheric passage is also a highly unlikely explanation of the observed difference in natural TL levels since TL is only drained immediately adjacent to fusion crust (Sears, 1975). All three of the chips sampled for TL were taken from ≥1 cm from apparent fusion crust, from different slabs of the meteorite. The large difference in natural TL levels cannot be attributed to greater shielding depth for Axtell than for Allende unless the former came from the interior of a very large meteoroid body (Benoit *et al.*, 1994). For Axtell to be from the same body as Allende, the cosmogenic ^{60}Co data would require that Axtell came from very near the surface of the preatmospheric body. The natural TL data and the ^{60}Co data, thus, indicate that Axtell and Allende are not portions of the same meteorite and that Axtell has been on Earth significantly longer than Allende.

Axtell also has a much lower TL sensitivity than Allende even after acid washing, although their glow curve shapes are fairly similar. The induced TL characteristics of Axtell make it unique among the CV chondrites analyzed to date, but it is most similar to Grosnaja, Arch, and ALHA 81003, which have virtually the same TL sensitivity as Axtell but different peak temperatures. On the basis of the proposed classification scheme for CV chondrites, we tentatively assign Axtell to a petrologic type of 3.0, compared to type 3.2 for Allende (Symes *et al.*, 1993).

Axtell is best classified as a member of the oxidized subgroup of the CV3 chondrites (McSween, 1977) based on the high magnetite:metal ratio in its chondrules and the high Ni content of its metal in chondrules and inclusions. Although not among the original criteria, the presence of fayalitic rims on olivine grains further supports classification of Axtell as an oxidized CV3 (Weinbruch, pers. comm.), and Axtell resembles members of the oxidized subgroup in the degree of alteration of CAIs. Axtell does, however, exhibit some features that are more typical of members of the reduced subgroup than of the oxidized subgroup. First, its CAIs are not strongly sulfidized, and they lack sulfide veins. Second, most of the rare sulfide that is present in Axtell is troilite (Casanova and Simon, 1994), whereas pentlandite tends to be the dominant sulfide in members of the oxidized subgroup (McSween, 1977). Axtell appears to be a member of the oxidized subgroup that, unlike Allende, escaped sulfidation.

Acknowledgments–The authors wish to thank Mr. Tommy Wilson for providing background information about the meteorite. We also thank O. Draughn of the Department of the Geophysical Sciences, University of Chicago, for prompt thin section preparation soon after the receipt of the specimen. Reviews by D. Kring and S. Weinbruch led to improvements in the manuscript. This work was funded by NASA through grants NAGW-3340 and NAGW-2728 (LG), NAG 9-81 (DWGS), and contract NAS9-17538 (JFW), and funding is gratefully acknowledged.

Editorial handling: R. Jones

REFERENCES

BENOIT P .H., SEARS H. AND SEARS D. W. G. (1991) Thermoluminescence survey of 12 meteorites collected by the European Antarctic meteorite expedition to Allan Hills and the importance of acid washing for thermoluminescence sensitivity. *Meteoritics* **26**, 157–160.

BENOIT P. H., CHEN Y. AND SEARS D. W. G. (1994) Natural thermoluminescence profiles in meteorites: Cosmogenic and terrestrial profiles in falls and finds (abstract). *Lunar Planet. Sci.* **25**, 99–100.

CAILLET C. (1994) A new type of Al-rich inclusion in Axtell CV3 chondrite (abstract). *Meteoritics* **29**, 453–454.

Casanova I. and Simon S. B. (1994) Opaque minerals in CAIs, and classification of the Axtell (CV3) chondrite (abstract). *Meteoritics* **29**, 454–455.

Clayton R. N. (1993) Oxygen isotopes in meteorites. *Ann. Rev. Earth Planet. Sci.* **21**, 115–149.

El Goresy A. and Zinner E. K. (1994) Efremovka E49: A compact Type-A CAI containing a partially molten spinel-melilite-diopside xenolith (abstract). *Meteoritics* **29**, 461–462.

Evans J. C. and Reeves J. H. (1987) ^{26}Al survey of Antarctic meteorites. *Earth Planet. Sci. Lett.* **82**, 223–230.

Evans J. C., Reeves J. H., Rancitelli L. A. and Bogard D. D. (1982) Cosmogenic nuclides in recently fallen meteorites: Evidence for galactic cosmic ray variations during the period 1967–1978. *J. Geophys. Res.* **87**, 5577–5591.

Floss C., El Goresy A., Palme H., Spettel B. and Zinner E. (1992) An unusual Ca-Ti-Al silicate in a Type A Allende inclusion (abstract). *Meteoritics* **27**, 220.

Grossman L. and Steele I. M. (1976) Amoeboid olivine aggregates in the Allende meteorite. *Geochim. Cosmochim. Acta* **40**, 149–155.

Haggerty S. E. and McMahon B. M. (1979) Magnetite-sulfide-metal complexes in the Allende meteorite. *Proc. Lunar Planet. Sci. Conf.* **10th,** 851–870.

MacPherson G. J. and Grossman L. (1984) "Fluffy" Type A Ca-, Al-rich inclusions in the Allende meteorite. *Geochim. Cosmochim. Acta* **48**, 29–46.

MacPherson G. J., Hashimoto A. and Grossman L. (1985) Accretionary rims on inclusions in the Allende meteorite. *Geochim. Cosmochim.* Acta **49**, 2267–2279.

McSween H. Y. (1977) Petrographic variations among carbonaceous chondrites of the Vigarano type. *Geochim. Cosmochim. Acta* **41**, 1777–1790.

Melcher C. L. (1981) Thermoluminescence of meteorites and their terrestrial ages. *Geochim. Cosmochim. Acta* **45**, 615–626.

Peck J. A. (1983a) An SEM petrographic study of C3(V) meteorite matrix (abstract). *Lunar Planet. Sci.* **14**, 598–599.

Peck J. A. (1983b) Chemistry of CV3 matrix minerals and Allende chondrule olivine (abstract). *Meteoritics* **18**, 373–374.

Peck J. A. and Wood J. A. (1987) The origin of ferrous zoning in Allende chondrule olivines. *Geochim. Cosmochim. Acta* **51**, 1503–1510.

Perkins R. W., Rancitelli L. A., Cooper J. A., Kaye J. H. and Wogman N. A. (1970) Cosmogenic and primordial radionuclide measurements in Apollo 11 lunar samples by nondestructive analysis. *Proc. Apollo 11 Lunar Sci. Conf.*, 1455–1469.

Rancitelli L. A., Perkins R. W., Cooper J. A., Kaye J. H. and Wogman N. A. (1969) Radionuclide composition of the Allende meteorite from nondestructive gamma-ray spectrometric analysis. *Science* **166**, 1269–1271.

Rubin A. E. (1991) Euhedral awaruite in the Allende meteorite: Implications for the origin of awaruite- and magnetite-bearing nodules in CV3 chondrites. *Am. Min.* **76**, 1356–1362.

Scott E. R. D., Barber D. J., Alexander C. M., Hutchison R. and Peck J. A. (1988) Primitive material surviving in chondrites: Matrix. In *Meteorites and the Early Solar System* (eds. J. F. Kerridge and M. S. Matthews), pp. 718–745. Univ. Arizona Press, Tucson, Arizona.

Sears D. W. G. (1975) Thermoluminescence studies and the preatmospheric shape and mass of the Estacado meteorite. *Earth Planet. Sci. Lett.* **26**, 97–104.

Sears D. W. G., Hasan F. A., Batchelor J. D. and Lu J. (1991) Chemical and physical studies of type 3 chondrites–XI: Metamorphism, pairing, and brecciation of ordinary chondrites. *Proc. Lunar Planet. Sci. Conf.* **21**, 493–512.

Simon S. B. and Haggerty S. E. (1979) Petrography and olivine mineral chemistry of chondrules and inclusions in the Allende meteorite. *Proc. Lunar Planet. Sci. Conf.* **10th,** 871–883.

Simon S. B., Grossman L. and Wacker J. F. (1994) Unusual refractory inclusions from a CV3 chondrite found near Axtell, Texas (abstract). *Lunar Planet. Sci.* **25**, 1275–1276.

Symes S. J. K., Guimon R. K., Benoit P. H. and Sears D. W. G. (1993) Thermoluminescence and metamorphism in CV chondrites (abstract). *Meteoritics* **28**, 446–447.

Van Schmus W. R. and Hayes J. M. (1974) Chemical and petrographic correlations among carbonaceous chondrites. *Geochim. Cosmochim. Acta* **38**, 47–64.

Wark D. A. and Lovering J. F. (1982) Evolution of Ca-Al-rich bodies in the earliest solar system: Growth by incorporation. *Geochim. Cosmochim. Acta* **46**, 2595–2607.

Weinbruch S., Palme H., Müller W. F. and El Goresy A. (1990) FeO-rich rims and veins in Allende forsterite: Evidence for high temperature condensation at oxidizing conditions. *Meteoritics* **25**, 115–125.

Wlotzka F. (1994) The Meteoritical Bulletin, No. 77. *Meteoritics* **29**, 891–897.