TABULATION OF FURTHER MEASURES OF THE COMPOSITIONS OF DUST PARTICLES RELATED TO THE PROBLEM OF THE IDENTIFICATION OF INTERPLANETARY DUST

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1. NEW ANALYSES

Previous papers (Wright, Hodge, and Langway, 1963; Hodge, Wright, and Langway, 1964, 1967) have presented microprobe analyses of several hundred particles of possible extraterrestrial origin. This paper reports measurements of 140 more particles from a wide variety of sources (Table 1). We find that these new analyses corroborate our previous results and extend somewhat the observed spread in composition of particles of various types. For a discussion of the relevance and possible interpretations of these analyses, refer to our previous papers. Some probable identifications with known laboratory contaminants are noted in the Remarks to Table 1.

Let us comment on the particles from each of the sources, following the order used in Table 1; within each group, the particles are arranged according to decreasing iron.

A. Antarctica. Most of these particles are from the South Pole (collected by H. Bader) and one from about 75°S, 75°W (collected by R. Schmidt). Analyses agree with those of previous studies (Wright and Hodge, 1968). The three stainless-steel wafers are probably from the stainless-steel filters used occasionally in collecting particulates from the South Pole.

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B. Greenland. Particles were collected by Langway from Site 2, Greenland. Analyses corroborate previous findings (Wright et al., 1963; Hodge et al., 1964, 1967). The eight aluminum-rich wafers are probably aluminum foil.

C. Ice Cave. We collected the spherule from an ice cave in the Paradise glacier of Mt. Rainier, Washington. The ice is young, and the particle may be industrial in origin.

D. Stratosphere. Particles were collected by an F-104A aircraft at altitudes averaging 60,000 ft (Hodge and Wright, 1962). A wide variety of composition is shown. No obvious meteoritic dust is present.

E. Deep Sea. Particles were collected in carbonaceous sediments at a depth of 1357 m at 23°50' N, 76°58' W by the Woods Hole Oceanographic Institute. Analyses are given for two spherules found in the sediments, for one spheroid, and for particles from the matrix in which they are embedded. Both spherules seem to be pyrite, and the matrix particles, as expected, are largely calcium and light elements. The red spheroid has a somewhat rock-like composition. It and the spherules are probably unrelated to meteoritic particles.

F. Canyon Diablo. Particles were collected and magnetically separated from the soil surrounding the meteorite crater by J. S. Rinehart in 1956 (see Rinehart, 1958) and by F. W. Wright in 1964. A few similar analyses were reported by Wright and Hodge (1964).

G. Odessa Meteorite Crater. Particles were magnetically separated from the soil in and adjacent to the crater. None contained nickel, and if the particles are derived from the meteorite fall, the nickel must have been lost or segregated to the center, as in the case of some Canyon Diablo particles (Wright and Hodge, 1964).

H. Volcanoes. Many particles from a variety of types of volcanoes were included, and results confirm and extend previous reports (Hodge and Wright, 1964; Wright and Hodge, 1965a; Wright, Hodge, and Allen, 1966). We also include here analyses of some conspicuous (but nonmagnetic) spherules from Kilauea Iki, which are mostly light elements plus aluminum, with some silicon and calcium.

I. Beach Sand. Supplied by C. Kaye from magnetic separations from beach sand at Martha's Vineyard, these large black spherules have compositions similar to those of polar-ice deposits. Mineralogical studies of similar particles are given by Kaye and Mrose (1965) and by Marvin and Einaudi (1967).

J. Artificial Sources. These measurements of artificially produced meteoritic spherules extend those previously reported by Wright and Hodge (1965b).

K. Industrial Source. This particle, collected from the rooftop of a building in the Chicago area, is representative of spherules that are produced in industrial centers.

Table 1. Chemical composition of particles (percent of element by weight)*

Designation	Size (μ)	Source	Mg	Al	Si	Ca	Ti	Cr	Mn	Fe	Co	Ni	Remarks
						A. Antarctica							
24-16	30 × 20	SP			8-10	<0.5			~0.5	70-75			+Zn(5-6) irregular
21-20	90	SP						20-25	1-2	60-65		8-9	Thin, fragile wafer; stainless steel?
21-24	100 × 50	SP						20-25	1-2	60-65		8-9	Thin, fragile wafer; stainless steel?
22-15a	170 × 150	SP						20-25	1-2	58-63		8-9	Thin, fragile wafer; stainless steel? +Zn (~1)
26-8	18 × 12	SP		12-14	20-25	6-8	4-5		1-2	16-18			Irregular
24-17	30 × 25	SP	45-50		3-4	~0.5			~0.5	6-7			Shiny; irregular
26-7	39 × 37	SP		3-5	12-14	1-2	0.5-1.0	2-3		4-5			+S(2-3) irregular +K(1-2) spheroid
26-5	12	SP			7-9	0.1-0.5		0.5-1.0		2-3			+S(1-2) spheroid
24-18	22 × 20	SP	25-30		30-35	<0.5				2-3			Dark brown irregular spheroid
22-15b	~50	SP		1-2	6-7	9-10	~0.5			2-3			+K(~1) +S(6-7) irregular
21-25	70 × 70	SP								1-2	~1	35-40	Fragile, irregular wafer +Cd(6-8)
26-1	36 × 24 42 × 21	SP			10-12		0.1-0.5			1-2			+S(1-2) 2 attached irregular particles
26-9	45 × 30	SP			2-3	0.1-0.5							+S(1-2) +K(1-2) golden, irregular; appendages
22-20	226 × 220	SP								0.5-1.0	0.5-1.0	10-15	+Cu(65-70) +Cl(3-4) +Cd(3) layered wafer
22-6	30	Antarctic											+S(2-3) spherule
						B. Greenland							
22-22	190 × 80	Site 2, Greenland						<0.5	1-2	95-99			Thin, irregular wafer
22-24	80 × 50	Site 2, Greenland							0.5-1.0	95-99			+K(~1) dark, silvery wafer
24-23a	27 × 18	Site 2, Greenland							~0.5	70-75			Interior of 27-μ spherule — broken
24-24a	27 × 18	Site 2, Greenland							~0.5	70-75			Part of preceding spherule
24-24b	27 × 18	Site 2, Greenland			3-4	<0.5			~0.5	70-75			Part of same spherule
26-14	21	Site 2, Greenland							0.1-0.5	70-75			Spherule

*The table gives the data as reported by Advanced Metals Research Corporation, but the accuracy is good only to about 10 percent.

Table 1 (Cont.)

Designation	Size (μ)	Source	Mg	Al	Si	Ca	Ti	Cr	Mn	Fe	Co	Ni	Remarks
						B. Greenland (Cont.)							
27-1	15	Site 2, Greenland			1-2	1-2				70-75			Spherule
27-2	18	Site 2, Greenland							0.5-1.0	70-75			Spherule
27-4	16	Site 2, Greenland			3-4	0.1-0.5		0.5-1.0	0.5-1.0	70-75			Spherule
27-5	36	Site 2, Greenland						1-2	0.5-1.0	70-75			Spherule
27-6	19	Site 2, Greenland							0.5-1.0	70-75			Spherule
27-14	12	Site 2, Greenland						1-2	0.5-1.0	70-75			Spherule
22-1	80 × 60	Site 2, Greenland							0.5-1.0	70-75			Thin, irregular metallic wafer
27-9	23	Site 2, Greenland							0.1-0.5	68-73			Spherule
27-11	12	Site 2, Greenland						1-2	0.5-1.0	68-73			Spherule; irregular on one side
8-6	30	Site 2, Greenland						~1	<0.5	65-70			Spherule surface
		Site 2, Greenland						0.8-1.5	0.5-1.0	68-73			Interior (av.) fairly solid
		Site 2, Greenland		0.11	0.19	X*	<0.01	0.82	0.77	68-73	X	<0.01	Interior (Spot 1)
		Site 2, Greenland		0.10	0.20	X	<0.01	0.84	0.76	68-73	X	<0.01	Interior (Spot 2)
		Site 2, Greenland		0.11	0.23	X	<0.01	0.82	0.74	68-73	X	<0.01	Interior (Spot 3)
		Site 2, Greenland		0.07	0.21	X	<0.01	0.84	0.75	68-73	X	<0.01	Interior (Spot 4)
		Site 2, Greenland		0.08	0.19	X	<0.01	0.79	0.72	68-73	X	<0.01	Interior (Spot 5)
		Site 2, Greenland		0.09	0.15	X	<0.01	0.81	0.74	68-73	X	<0.01	Interior (Spot 6)
24-13a	35	Site 2, Greenland								65-70			Spherule, surface
24-13b	12	Site 2, Greenland								65-70			Piece of 13a
H-4-24	50 × 40	Site 2, Greenland							0.5-0.7	65-70			Irregular, black, metallic
H-4-10	60	Site 2, Greenland							0.5-0.7	60-70			Black spherule in white matrix
H-4-10a†	—	Site 2, Greenland							0.2-0.4	40-45			White matrix of H-4-10
H-4-19	40	Site 2, Greenland			20-25		0.5-1.0			40-45		1-2	Silvery, irregular spheroid
22-21	130 × 120	Site 2, Greenland		4-5	3-4	~0.5	~0.5	~0.5		20-25			Irregular wafer +S(1-2) +Cl(~0.5)
H-4-23	50 × 35	Site 2, Greenland			10-12	7-8		7-9		20-25			Brown particle attached to red particle +Zn(1-2) +Pb(8-10)
H-4-8	1000×1000	Site 2, Greenland		5-7	14-16	2-3	0.3-0.4	8-10		15-20			Orange matrix +K(1-2) +P(2-3)
H-4-21	60 × 30	Site 2, Greenland		2-4	4-6	6-7	0.1-0.2	8-10		15-20			Composite? +K(1-2) +Zn(2-3)
H-4-6	900 × 360	Site 2, Greenland		4-6	10-12	2-3	0.2-0.3			15-20			Metallic, pitted +K(1-2) +P(2-3)

*X = not measured

†Qualitative results

Table 1 (Cont.)

Designation	Size (μ)	Source	Mg	Al	Si	Ca	Ti	Cr	Mn	Fe	Co	Ni	Remarks
B. Greenland (Cont.)													
H-4-2	600 × 450	Site 2, Greenland		3-5	8-10	1-2				10-12			+K(1-2) +P(1-2) +Zn(0.5-1.0) metallic, pitted
H-4-7	240 × 210	Site 2, Greenland		3-5	10-12	1-2	0.1-0.2			10-12			+K(0.5-1.0) +P(1-2) metallic, pitted
H-4-11	360	Site 2, Greenland			2-3	0.5-0.7				5-7			Silvery spherule +K(0.3-0.5) +P(0.4-0.6) +S(0.2-0.4) + light elements
H-4-15	1500×1500	Site 2, Greenland		1-2	4-6	0.6-0.8	0.05-0.1			4-5			Metallic, pitted +K(1-2) +P(1-2)
H-4-14	220 × 150	Site 2, Greenland			1-2	0.1-0.2				1-2			Metallic, curled, smooth, +K(0.3-0.5) +P(4-6)
27-25	15 × 12	Site 2, Greenland		3-4	4-5			0.1-0.5		1-2			+S(5-7) irregular
22-25	120 × 100	Site 2, Greenland		8-10	16-18	~1	<0.5			1-2			Thin, fragile wafer
22-5	70 × 50	Site 2, Greenland		95-99	~0.5	<0.5				1-2			Thin, irregular silvery wafer; probably Al foil
22-19	330 × 220	Site 2, Greenland		95-99						~0.5			Thin, irregular silvery wafer; probably Al foil
22-23	130 × 100	Site 2, Greenland		75-80						~0.5			+S(~0.05) Wafer; probably Al foil
22-4	230 × 110	Site 2, Greenland		65-70						~0.5			Wafer; probably Al foil
22-2	50 × 30	Site 2, Greenland		60-65	~0.5					~0.5			Probably Al foil spheroid
24-21	25 × 20	Site 2, Greenland		2-3	4-5	<0.5				~0.5			Spheroid
H-4-13a	660 × 150	Site 2, Greenland			1-2	0.1-0.2	0.05-0.1			0.6-0.8			Metallic cylinder, smooth +K(1-2) +P(0.2-0.4) +S(0.2-0.4)
24-22	80 × 60	Site 2, Greenland		90-100						<0.5			Probably Al foil
22-10	100 × 80	Site 2, Greenland		50-55						<0.5			Wafer; probably Al foil
H-4-13	540 × 300	Site 2, Greenland			0.5-1.0	0.1-0.2				0.4-0.6			+K(0.1-0.2) +P(0.2-0.4) + light elements metallic, pitted
H-4-3	240 × 120	Site 2, Greenland		1-2	2-3	1-2	0.05-0.1			0.3-0.5			+P(0.5-1.0) +S(0.2-0.4) + light elements smooth globule

Table 1 (Cont.)

Designation	Size (μ)	Source	Mg	Al	Si	Ca	Ti	Cr	Mn	Fe	Co	Ni	Remarks
						B. Greenland (Cont.)							
H-4-5	1050 × 60	Site 2, Greenland			1-2					0.3-0.5			Metallic branched cylinder, smooth +K(0.2-0.3) +light elements
27-8	12	Site 2, Greenland			3-4					0.1-0.5			White material?
27-16	29 × 27	Site 2, Greenland		3-4	4-6	0.1-0.5				0.1-0.5			Irregular
H-4-22	100 × 50	Site 2, Greenland				0.1-0.2				0.1-0.2			+P(0.4-0.6) +Ba(4-6) +light elements irregular surface
H-4-4	330 × 120	Site 2, Greenland								0.05-0.1			Metallic, smooth; mainly light elements
2-8	17	Site 2, Greenland		p* ?	35	2	15						Specularite appearing
2-21	10	Site 2, Greenland		p	1.6	25							Black spherule attached to matrix. Matrix was probed?
2-25	76	Site 2, Greenland											Only Au; gold in color
26-13	15	Site 2, Greenland			3-4	0.1-0.5							+S(1-2) spherule
27-3	24	Site 2, Greenland			1-2	0.1-0.5							+S(0.5-1.0) irregular
H-4-18	40 × 30	Site 2, Greenland		1-2	45-50		0.4-0.5						Black, pitted
27-12	36 × 33	Site 2, Greenland		6-8	10-12	0.1-0.5	0.1-0.5						+S(0.5-1.0) golden color
						C. Ice Cave							
1-17	6	Mt. Rainier		p	<0.5								Spherule?
						D. Stratosphere							
3-7	18 × 16	F-104A		p	7	2	1.5			1.0			Irregular
1-21	9 × 9	F-104A		p	<0.5								
1-25	6	F-104A		p		15					1.0		Spherule
27-20	7	F-104A				5-6	0.1-0.5						Dark inclusion in white material +S(1-2) +K(1-2) +Cl(2-3)
1-2	12 × 6	F-104A		p?		~60							
						E. Deep Sea							
11-1	190 × 180					40-45							Globigerina shell
11-2	180 × 150					35-40							Cluster of 4, as above

*p = present

Table 1 (Cont.)

Designation	Size (μ)	Source	Mg	Al	Si	Ca	Ti	Cr	Mn	Fe	Co	Ni	Remarks
						E. Deep Sea (Cont.)							
11-3	100 × 70					35-40							Globigerina ooze
14-9	20	Globigerina Ooze			~0.5	~0.5				50-55			+S(45-50) +K(<0.5) spherule from ooze
14-25	20	Globigerina Ooze			~0.5	5-6				50-55			+S(45-50) +K(~0.5) spherule from ooze
14-24	40	Globigerina Ooze			1-2	20-25				<0.5			+S(3-4) +K(<0.5) +Cl(~1) red spheroid from ooze
						F. Canyon Diablo							
		From soil around Arizona Meteorite Crater											
26-12	36 × 27	1964			2-3	1-2	8-10		0.5-1.0	55-60			Irregular spheroid
25-25	112 × 92	1964			3-4	3-4	2-3			45-50			Rough spheroid
26-16	36 × 33	1964			6-8	5-7	7-8		0.1-0.5	40-45			+Cl(0.1-0.5) rough surface
10-17	45 × 36	1956		6-8	8-10	~1	8-10		2-3	35-40			+K(~1) pitted spheroid
10-18	50 × 40	1956			4-6	~0.5	8-10		~0.5	35-40			Pitted spheroid
10-19	54 × 48	1956					<0.5			35-40			Pitted spheroid
26-25	18 × 12	1964		15-20	14-16	2-4	3-4	1-2	1-2	35-40			+K(3-5) +Cl(1-2) dark inclusion
26-20	16	1964			3-4	2-3	4-5		0.1-0.5	30-35			Dark inclusion
12-18	22	1956		10-12	30-35	9-10	1-2		~0.5	25-30			Smaller spheroid, attached to large piece
25-24	20	1964				1-2	0.1-0.5		0.1-0.5	25-30			Red spheroid
26-24	24 × 21	1964		15-20	2-4	2-4		10-12		23-28			+K(0.5-1.0) +Cl(1-2) dark inclusion
26-11	60 × 45	1964			4-6	9-11	3-4		0.1-0.5	20-25			Very irregular surface
12-20	250 × 220	1956		10-12	15-20	4-5	<0.5		<0.5	15-20		~0.5	+K(~1) spheroid
26-21	40 × 27	1964		12-14	20-25	0.1-0.5	4-5	0.1-0.5		14-16			+K(5-7) +Cl(0.5-1.0)
25-23	112 × 99	1964		8-10	20-25	8-10	1-2		0.1-0.5	8-10			+K(1-2) very irregular

Table 1 (Cont.)

Description	Size (μ)	Source	Mg	Al	Si	Ca	Ti	Cr	Mn	Fe	Co	Ni	Remarks
						F. Canyon Diablo (Cont.)							
26-18	60 × 48	1964			1-2	0.5-1.0	22-24		0.1-0.5	8-10			
26-17	40 × 36	1964				0.5-1.0	25-28		0.1-0.5	7-9			Teardrop
26-23	30 × 24	1964			12-14	10-12	0.5-1.0			6-7			+Cl(0.5-1.0) Irregular surface
26-22	45	1964		3-5	12-14	9-11	0.1-0.5			2-3			+K(1-2) +Cl(4-6) +S(4-6) golden spheroid
26-19	21	1964			5-7	9-11				0.5-1.0			+K(1-2) +Cl(2-3) +S(3-5) dark inclusion
26-6	57 × 54	1964			2-3	.5-1.0				0.1-0.5			+K(1-2) +S(8-10)
12-24	55	1956			1-2					<0.5			+K(~0.5) +S(6-8) +light elements spherule?
						G. Odessa Meteorite Crater							
b-11	50	From meteorite craters, Texas					8-10		0.5-1.0	55-60			Polished interior;rough spherule
b-14	35 × 40	From meteorite craters, Texas					18-20		1-2	45-50			Polished interior
b-19	40	From meteorite craters, Texas					20-25		1-2	45-50			Polished interior; spherule
b-7	120	From meteorite craters, Texas					20-25		0.1-0.5	40-45			Polished interior; spheroid
b-10	40 × 55	From meteorite craters, Texas					20-25		1-2	35-40			Polished interior; irregular
						H. Volcanoes							
27-15	75	Kuh-e Taftan Lava		8-10	14-16	1-2	3-4		0.1-0.5	40-45		0.1-0.5	Spheroid;rough surface
13-4	240 × 60	Mt. Mazama (near crater rim)			1-2	1-2	20-25		<0.5	40-45			Irregular

Table 1 (Cont.)

Description	Size (μ)	Source	Mg	Al	Si	Ca	Ti	Cr	Mn	Fe	Co	Ni	Remarks
						H. Volcanoes (Cont.)							
b-1	555	Kilauea Iki	2-3	4-6	12-14	8-10	0.5-1.0	0.1-0.5	0.1-0.5	10-12		0.1-0.5	+K(0.5-1.0) polished interior (av.), nonmagnetic spherule
		Kilauea Iki		6.1	14.0	X*	0.84	<0.01	0.05	6.2	X	0.03	Interior (Spot 1)
		Kilauea Iki		5.2	11.8	X	1.05	<0.01	0.04	7.2	X	0.03	Interior (Spot 2)
		Kilauea Iki		<0.01	8.3	X	~0	<0.01	0.08	10.7	X	0.20	Interior (Spot 3)
		Kilauea Iki		6.6	11.3	X	1.02	<0.01	0.05	6.7	X	0.03	Interior (Spot 4)
		Kilauea Iki		3.5	10.6	X	1.05	<0.01	0.07	6.9	X	0.04	Interior (Spot 5)
		Kilauea Iki		6.3	12.1	X	0.93	<0.01	0.03	5.8	X	0.03	Interior (Spot 6)
b-2	680	Kilauea Iki		5-6	12-14	8-10	1-2		0.1-0.5	4-6			Nonmagnetic spherule; polished interior (av.)
		Kilauea Iki		6.4	13.4	X	1.00	<0.01	0.04	5.3	X	0.02	Interior (Spot 1)
		Kilauea Iki		7.1	11.0	X	0.97	<0.01	0.04	5.3	X	0.02	Interior (Spot 2)
		Kilauea Iki		7.7	9.9	X	0.93	<0.01	0.04	5.9	X	0.02	Interior (Spot 3)
		Kilauea Iki		6.3	12.0	X	0.92	<0.01	0.03	5.9	X	0.02	Interior (Spot 4)
		Kilauea Iki		6.2	10.2	X	0.93	<0.01	0.04	6.3	X	0.02	Interior (Spot 5)
		Kilauea Iki		5.1	9.6	X	0.85	<0.01	0.03	6.5	X	0.03	Interior (Spot 6)
14-13	140 × 80	Lava Butte (rim of cinder cone)			4-5	2-3	~0.5			4-5			+light elements orange irregular
13-14	230 × 170	Mt. Mazama (near crater rim)			5-6	<0.5	<0.5			3-4			+K(~0.5) +light elements irregular
27-17	80 × 70	Kuh-e Taftan Lava		12-14	20-25	3-4	0.1-0.5			1-2			+K(4-5); irregular
13-3	338	Mt. Mazama (near crater rim)		4-6	14-16	~0.5				<0.5			+K(~1) light, transparent shell
13-22	30	Mt. Mazama (near crater rim)			~1	5-6				<0.5			+S(2-4) +light elements irregular
13-25	50	Mt. Mazama (near crater rim)			1-2	~1				<0.5			+S(6-8): spheroid +light elements
14-4	650	Lava Butte (lava flow)		18-20	5-7	4-5			~0.5	<0.5			From dust on lava flow; spheroid; nonmagnetic; + light elements
14-10	300	Lava Butte (lava flow)		4-6	1-2	2-3			<0.5	<0.5			Similar to 14-4, spheroid; nonmagnetic
14-5a	520	Lava Butte (lava flow)		10-15	4-6	4-5				<0.5			Inner point. + light elements
14-5b				15-20	6-8	4-5			<0.5	<0.5			+S(~0.5), outer point same nonmagnetic spherule
27-21	34	Kuh-e Taftan Lava		12-14	30-35	1-2	3-4	0.1-0.5	0.1-0.5				+K(3-4): spheroid

*X = not measured

Table 1 (Cont.)

Designation	Size (μ)	Source	Mg	Al	Si	Ca	Ti	Cr	Mn	Fe	Co	Ni	Remarks
						I. Beach Sand							
27-23	310	Martha's Vineyard, Massachusetts							0. 1-0. 5	70-75			Spherule
27-24a	250	Martha's Vineyard, Massachusetts							0. 1-0. 5	70-75			Spherule (a) Surface
27-24b							0. 1-0. 5			70-75			(b) Interior
27-22	300	Martha's Vineyard, Massachusetts								70-75			Spheroid
H-4-25 1A	200	Martha's Vineyard, Massachusetts							0. 2-0. 4	68-73			Spherule Surface
									0. 1-0 5	68-73			Interior (av.) small pores; gray needles
				<0. 01	0. 21	X*			0. 24	68-73	X		Interior (Spot 1)
					0. 21	X			0. 24	68-73	X		Interior (Spot 2)
					0. 16	X			0. 26	68-73	X		Interior (Spot 3)
					0. 15	X			0. 22	68-73	X		Interior (Spot 4)
					0. 33	X			0. 24	68-73	X		Interior (Spot 5)
					0. 29	X			0. 22	68-73	X		Interior (Spot 6)
					0. 26	X			0. 22	68-73	X		Interior (Spot 7)
					0. 21	X			0. 25	68-73	X		Interior (Spot 8)
					0. 24	X			0. 25	68-73	X		Interior (Spot 9)
H-4-20	470	Martha's Vineyard, Massachusetts		1-2	1-2	0. 4-0. 6	0. 05-0. 1		0. 3-0. 5	68-73			Spherule Surface rough
						J. Artificial Sources							
17-23	30	Canyon Diablo				1-2				70-75			Spherule: Surfacé
26A		Canyon Diablo							0. 1-0. 5	68-73			Interior (av.) solid
17-2	50	Canyon Diablo								70-75		0. 1-0. 2	Spherule Surface
25A		Canyon Diablo								67-72		0. 5-1. 0	Interior (av.) very porous
17-11	80	Canyon Diablo								68-73	0. 5-1. 0	6-7	Hollow flask
17-15a	90	Canyon Diablo								67-72		0. 2-0 3	Hollow flask
21-5	42	Canyon Diablo								65-70	~0 2	4-5	Spherule Surface
29A		Canyon Diablo								65-70	0. 5-1. 0	4-5	Interior (av) solid
19-17	36	Estherville								68-73	~0 5	7-8	Spherule Surface
28A		Estherville								65-70	0. 5-1 0	6-8	Interior (av.) solid

* X = not measured

Table 1 (Cont.)

Designation	Size (μ)	Source	Mg	Al	Si	Ca	Ti	Cr	Mn	Fe	Co	Ni	Remarks
						J. Artificial Sources (Cont.)							
19-21	63	Estherville			4-6	<0.5				55-60	~0.5	4-5	Spherule Surface rough
14A		Estherville								65-70	0.5-1.0	5-6	Interior (av.) solid
		Estherville		0.01	0.05	X*	<0.01	0.07	<0.01	65-70	X	7.1	Interior (Spot 1)
		Estherville		0.03	0.07	X	<0.01	0.07	<0.01	65-70	X	7.0	Interior (Spot 2)
		Estherville		0.01	0.06	X	<0.01	0.07	<0.01	65-70	X	7.4	Interior (Spot 3)
		Estherville		0.01	0.08	X	<0.01	0.07	<0.01	65-70	X	7.1	Interior (Spot 4)
		Estherville		0.01	0.05	X	<0.01	0.06	<0.01	65-70	X	7.3	Interior (Spot 5)
		Estherville		0.02	0.05	X	<0.01	0.07	<0.01	65-70	X	7.5	Interior (Spot 6)
19-12	43	Estherville			7-8	3-4		<0.5	<0.5	40-45			Spherule Surface
27A				0.5-1.0		4-6	0.1-0.5	0.1-0.5	0.1-0.5	40-45			Interior (av.) solid
19-22	31	Estherville		6-8	20-22	7-8	<0.5	<0.5	<0.5	40-45			Spherule Surface
18A				1-2	8-10	6-8	0.1-0.5	0.1-0.5	0.1-0.5	28-33			Interior (av.) solid
						K. Industrial Source							
20-18	22	Chicago roof		15-16	24-26	~1	0.5-1.0			20-22			Spherule +K(~0.5)

*X = not measured

2. ANALYSES OF TEST PARTICLES

All analyses in the tables were carried out for us by the Advanced Metals Research Corporation, S. H. Moll, laboratory supervisor, with an electron-beam microanalyzer. Most of the analyses in Table 1 are surface analyses made with a 1-μ beam on more or less smooth surfaces. To gain insight into the accuracy of these figures, we sent with the unknowns four test particles of composition known to us but not to the scientists at the Advanced Metals Research Corporation. Table 2 shows the results and confirms the estimated errors, as indicated by the quoted range.

Table 2. Chemical composition of test particles (percent of element by weight)

#316 stainless steel	Mean diameter (μ)	Al	Si	Ti	Cr	Mn	Fe	Ni	Mo	Co
Spherule	70	0	0.5-1.0	0	15-17	1-2	63-68	13-15	3-5	
Spherule	60	0	0.5-1.0	0	15-17	2-4	63-68	9-11	2-3	
Irregular	140 × 100	0	0.5-1.0	0.1-0.5	18-22	2-4	60-65	6-8	0	
Certified and gross analysis		0	0.65	0	17.06	1.68	65.0	13.03	2.30	
#316 stainless steel spherules from SAO probe, January 28, 1969*					17.4 17.4 17.2 16.9	1.1 1.2 1.2 1.0	65.4 63.5 64.8 65.0	13.8 13.5 13.5 13.9		
Laboratory-known cobalt	45									100

*Figures for these four elements only are given for comparison purposes.

After the surface analyses of several hundred of our particles, we sectioned and polished some of them, mostly spherules. Average composition figures were obtained for the interiors of these particles as the beam scanned the flat surfaces. In a few cases we investigated further with a six-point (or more) analysis program to obtain the composition figures at specific points probed in the interiors. These points are listed in Table 1 as "Spots," and composition figures are sometimes given to hundredths of a percent. According to the Advanced Metals Research Corporation, the detectability limit was improved by the use of better crystals at this time, and elements found in the polished particles at the 0.1 level may not have been detected in the earlier analyses.

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REFERENCES

HODGE, P. W., and WRIGHT, F. W.

1962. The space density of atmospheric dust in the altitude range 50,000 to 90,000 feet. Smithsonian Contr. Astrophys., vol. 5, pp. 231-238.

1964. Studies of particles for extraterrestrial origin. 2. A comparison of microscopic spherules of meteoritic and volcanic origin. Journ. Geophys. Res., vol. 69, pp. 2449-2454.

HODGE, P. W., WRIGHT, F. W., and LANGWAY, C. C., Jr.

1964. Studies of particles of extraterrestrial origin. 3. Analyses of dust particles from polar ice deposits. Journ. Geophys. Res., vol. 69, pp. 2919-2931.

1967. Studies of particles for extraterrestrial origin. 5. Compositions of the interiors of spherules from Arctic and Antarctic ice deposits. Journ. Geophys. Res., vol. 72, pp. 1404-1406.

KAYE, C. A., and MROSE, M. E.

1965. Magnetic spherules, colored corundum, and other unusual constituents of a heavy beach sand, Martha's Vineyard, Massachusetts. Geological Survey Prof. Paper 525-D, pp. D37-D43.

MARVIN, U. B., and EINAUDI, M. T.

1967. Black, magnetic spherules from Pleistocene and recent beach sands. Geochim. Cosmochim. Acta, vol. 31, pp. 1871-1884.

RINEHART, J. S.

1958. Distribution of meteoritic debris about the Arizona meteorite crater. Smithsonian Contr. Astrophys., vol. 2, pp. 145-160.

WRIGHT, F. W., and HODGE, P. W.

1964. Compositional studies of extraterrestrial particles. Ann. N.Y. Acad. Sci., vol. 119, pp. 287-297.

1965a. Studies of particles for extraterrestrial origin. 4. Microscopic spherules from recent volcanic eruptions. Journ. Geophys. Res., vol. 70, pp. 3889-3898.

WRIGHT, F. W., and HODGE, P. W.

1965b. Analysis of artificial meteoritic spherules. Smithsonian Astrophys. Obs. Spec. Rep. No. 192, 10 pp.

1968. The question of the origin of the magnetic spherules found in Antarctic ice. Paper presented at International Symposium on Antarctic Glaciological Exploration, Dartmouth College, Hanover, New Hampshire, 3-7 September, to be published by SCAR.

WRIGHT, F. W., HODGE, P. W., and ALLEN, R. V.

1966. Electron-probe analysis of interiors of microscopic spheroids from eruptions of the Mt. Aso, Surtsey, and Kilauea Iki volcanoes. Smithsonian Astrophys. Obs. Spec. Rep. No. 228, 8 pp.

WRIGHT, F. W., HODGE, P. W., and LANGWAY, C. C., Jr.

1963. Studies of particles for extraterrestrial origin. 1. Chemical analyses of 118 particles. Journ. Geophys. Res., vol. 68, pp. 5575-5585.