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Express Letter

Extraterrestrial component associated with Australasian microtektites in a core from ODP Site 758B

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ABSTRACT

Major and trace element analyses of 30 sediment samples from ODP Core 758B across the Brunhes–Matuyama geomagnetic polarity reversal and the Australasian microtektite-bearing layer show a small but significant anomaly in the elemental abundances of Ir, Co and Ni. The maximum of the anomaly between 10.89 and 11.00 m below seafloor correlates with the maximum abundance of microtektites. Iridium abundances, which show the most significant anomaly, reach 0.16 ppb, which is evidence for an extraterrestrial component.

1. Introduction

Tektites are natural glasses found within four distinct strewn fields on Earth [1]: the North American (34 Ma old), the Central European (15 Ma), the Ivory Coast (1.1 Ma) and the Australasian (0.76 Ma [2]) strewn field. In addition, microtektites also occur in deep-sea cores of three of the four strewn fields [3,4]. Microtektites are generally < 1 mm in diameter and have an average composition close to that of large tektites. Microtektites are important for determining the extent of the strewn fields (Fig. 1), to constrain the stratigraphic age of tektites, and provide evidence regarding the location of possible source craters.

It is now generally accepted that tektites form by melting of terrestrial continental rocks during the hypervelocity impact of an extraterrestrial object [1,5]. The Central European strewn field has been linked to the Ries crater, Germany, and the Ivory Coast strewn field to the Bosumtwi crater, Ghana. For the Australasian field, no 0.76 Ma old crater has yet been identified in the vicinity of the strewn field, although many pro-

posals for possible source craters were made and later discounted (e.g., lower Mekong [6] and off-shore Vietnam [7]). The geographic distribution of Australasian tektites and microtektites shows radial and concentric patterns, and there are zones that do not contain microtektite-bearing deep-sea cores [6,8,9]. Hartung [10] proposed that Lake Tonle Sap in Cambodia was created by the Australasian tektite event; however, no proof for impact has yet been found. Recently, Glass and Wu [9] reported that several microtektite-bearing layers in cores from the Australasian strewn field contain shocked minerals (quartz and feldspar), vesicular impact glass, coesite and stishovite. This discovery provides another direct link with an impact event. The quantity of both impact debris and microtektites in cores all over the Australasian strewn field increase towards Indochina [9], supporting the crater locations proposed by [6] and [10].

Apart from shocked minerals, enrichments of siderophile elements, especially the platinum-group element (PGE) Ir, are thought to be indicative of an impact origin. An Ir anomaly is associated with the North American clinopyrox-

TABLE 1

Major and trace element abundances in 30 sediment samples from ODP drill core 758B. Major element data in weight percent; trace element data in ppm, except as noted

Sample No.	2H-1-30	2H-1-40	2H-1-50	2H-1-60	2H-1-70	2H-1-80	2H-1-90	2H-1-100	2H-1-110	2H-1-120	2H-1-129	2H-1-134	2H-1-139	2H-1-144	2H-1-147
Depth (mbsf)	9.80	9.90	10.00	10.10	10.20	10.30	10.40	10.50	10.60	10.70	10.79	10.84	10.89	10.94	10.97
SiO ₂	24.52	18.79	18.29	19.12	18.92	20.21	21.53	24.31	25.52	41.08	69.43	68.93	70.95	20.99	21.76
TiO ₂	0.33	0.26	0.24	0.25	0.25	0.27	0.26	0.29	0.25	0.17	0.09	0.09	0.28	0.30	0.29
Al ₂ O ₃	7.00	5.42	5.08	5.25	5.20	5.79	5.96	6.66	6.43	8.14	12.21	12.94	6.02	6.00	6.08
Fe ₂ O ₃	3.16	2.02	1.93	2.06	1.79	2.24	2.26	2.24	2.24	1.74	0.70	0.70	2.39	2.59	2.53
MnO	0.060	0.053	0.054	0.062	0.052	0.064	0.056	0.059	0.062	0.067	0.070	0.054	0.072	0.057	0.070
MgO	1.99	1.57	1.47	1.46	1.48	1.60	1.59	1.66	1.50	1.00	0.35	0.39	1.76	1.74	1.77
CaO	29.47	35.91	36.65	35.89	36.02	34.51	33.70	30.17	30.17	19.40	1.11	1.42	33.26	33.15	32.67
Na ₂ O	1.38	1.01	1.02	1.06	1.06	1.20	1.29	1.62	1.87	3.15	4.77	4.82	1.37	1.27	1.44
K ₂ O	0.72	0.67	0.68	0.68	0.68	0.74	0.77	0.97	1.09	2.49	5.32	5.30	0.85	0.84	0.80
P ₂ O ₅	0.083	0.083	0.077	0.084	0.082	0.091	0.081	0.084	0.087	0.064	0.052	0.046	0.080	0.072	0.075
L.O.I.	30.90	34.50	34.67	34.51	34.52	33.42	33.02	31.23	30.78	21.88	4.99	4.46	32.88	32.95	32.43
Total	99.61	99.98	100.13	100.38	99.96	100.14	100.51	99.64	100.00	99.19	99.67	100.04	99.90	99.93	99.93
Sc	6.36	6.31	6.04	6.49	5.85	7.35	7.17	7.8	6.57	4.99	2.71	3.57	6.95	7.37	6.87
Cr	36.1	42.8	39.9	40.1	39.1	44.8	41.4	43.3	36.6	25.3	5.1	1.2	49.1	51.6	45.7
Co	15.8	15.1	13.3	16.5	11.7	11.4	10.1	9.54	7.92	9.59	1.79	2.48	12.2	10.1	9.33
Ni	69	67	59	65	58	53	51	51	41	35	7	11	69	75	68
Zn	65.5	74.1	67.3	70.1	66.6	75.7	71.9	72.8	60.5	54.1	37.9	42.6	72.2	67.8	63.9
As	8.5	6.6	20	16.4	7.1	8.9	13.6	6.6	10.1	7.5	9.7	17.0	15	24	16
Cu	3.65	3.54	1.82	2.51	2.12	2.47	3.04	3.99	3.94	6.95	6.95	9.04	2.65	1.98	1.76
Se	1.12	1.23	0.75	0.69	0.64	0.53	0.41	0.51	0.52	0.74	0.99	1.47	0.39	0.42	0.33
Br	16.8	19.6	11.4	30.6	29.1	28.8	33.2	30.7	30.1	25.3	14.1	19.1	29.4	24.4	28.5
Rb	47.5	48.9	46.6	50.7	44.6	52.9	54.4	63.1	65.6	127	268	260	52.8	55.9	50.8
Sr	11.90	12.10	12.20	12.90	11.10	10.70	11.60	10.20	9.98	761	75	92	1070	1110	1030
Zr	64	50	48	48	58	56	62	62	67	86	146	220	57	68	59
Ag	<0.06	<0.06	<0.04	0.023	0.021	0.06	0.043	0.028	0.035	0.053	0.056	0.038	0.032	0.011	0.043
Sb	0.61	0.48	0.61	0.61	0.66	0.47	0.43	0.51	0.62	0.76	0.84	1.05	0.71	0.66	0.67
Cs	3.43	3.51	3.34	3.68	3.23	3.71	3.76	4.29	3.96	6.09	11.4	10.8	3.78	4.09	3.78
Ba	755	603	901	683	527	583	688	752	799	795	310	235	392	470	400
La	16.1	16.3	15.3	16.4	15.1	19.2	16.9	19.3	18.3	17.8	25.3	33.5	17.8	19.4	19.1
Ce	28.5	29.7	25.9	28.5	27.2	30.3	29.7	32.7	31.3	36.4	54.9	63.9	32.1	33.8	31.1
Nd	14.9	15.9	14.1	14.5	14.7	17.5	18.1	18.2	18.6	17.4	27.6	29.8	16.8	17.5	16.5
Sm	3.16	3.11	3.21	3.44	3.36	3.77	3.53	3.82	3.39	3.38	5.10	6.71	3.48	3.71	3.65
Eu	0.69	0.73	0.64	0.67	0.69	0.81	0.79	0.81	0.67	0.54	0.41	0.51	0.71	0.73	0.68
Gd	3.05	3.22	3.16	3.17	3.52	3.76	3.65	4.05	3.59	3.82	5.75	5.98	2.85	2.92	2.76
Tb	0.48	0.54	0.43	0.49	0.51	0.57	0.58	0.61	0.61	0.68	1.03	1.08	0.51	0.54	0.54
Dy	3.1	3.2	2.7	2.9	2.9	3.3	3.4	3.60	3.60	4.40	6.90	7.6	3.20	3.30	3.1
Y	0.25	0.27	0.19	0.24	0.23	0.27	0.27	0.29	0.30	0.42	0.72	0.72	0.23	0.23	0.23
Yb	1.65	1.77	1.54	1.69	1.63	1.91	1.92	2.14	2.05	2.77	5.35	5.99	1.67	1.75	1.72
Lu	0.24	0.23	0.21	0.24	0.21	0.27	0.26	0.28	0.28	0.41	0.74	0.73	0.23	0.24	0.23
Hf	1.11	1.06	0.97	1.06	0.98	1.18	1.22	1.36	1.25	1.88	4.01	6.56	1.24	1.34	1.25
Ta	0.34	0.32	0.29	0.33	0.29	0.35	0.35	0.37	0.42	0.87	1.89	1.81	0.330	0.340	0.32
W	0.61	0.55	0.48	0.69	0.43	0.72	0.45	0.64	0.79	1.21	2.08	3.12	0.38	0.71	0.84
Ir (ppb)	<0.04	0.062	0.058	0.065	0.065	0.068	0.075	0.068	0.055	<0.04	<0.04	<0.05	0.16	0.15	0.12
Au (ppb)	1.3	0.9	0.8	1.2	1.1	1.6	1.2	1.1	1.4	0.7	0.8	0.5	1.1	1.4	1.4
Hg	0.12	0.11	0.06	0.06	0.05	0.03	0.04	0.05	0.06	0.11	0.14	0.17	0.01	0.01	0.03
Th	6.65	5.84	5.45	6.11	5.38	6.27	6.35	7.71	8.48	18.1	42.1	41.3	6.35	6.41	5.96
U	1.56	1.28	1.92	2.31	1.01	1.14	1.21	1.35	1.51	3.21	7.53	7.74	1.15	1.18	0.98
K/U	6282	7891	5260	4416	8614	9386	9008	9333	8874	7227	6282	6292	10522	10085	11327
Zr/Hf	58	47	49	45	59	47	48	46	54	47	36	34	46	51	47
La/Th	2.42	2.83	2.81	2.68	2.81	3.06	2.98	2.50	2.16	0.98	0.60	0.81	2.80	3.03	3.20
Hf/Ta	3.26	3.31	3.34	3.21	3.38	3.37	3.49	3.68	2.98	2.16	2.12	3.62	3.76	3.94	3.91
Th/U	4.26	4.56	2.84	2.65	5.33	5.50	5.25	5.71	5.62	5.64	5.59	5.54	5.52	5.43	6.08
La ₂ O ₃ /Y ₂ O ₃	6.59	6.30	6.71	6.56	6.26	6.79	6.65	6.09	6.03	4.34	3.20	4.20	7.20	7.49	7.50
Eu/Eu*	0.679	0.705	0.614	0.620	0.613	0.657	0.673	0.629	0.587	0.459	0.231	0.246	0.689	0.678	0.655

TABLE 1 (continued)

Sample No.	2H-2-0	2H-2-5	2H-2-10	2H-2-15	2H-2-20	2H-2-30	2H-2-40	2H-2-50	2H-2-60	2H-2-70	2H-2-80	2H-2-90	2H-2-100	2H-2-110	2H-2-120
Depth (mbsf)	11.00	11.05	11.10	11.15	11.20	11.30	11.40	11.50	11.60	11.70	11.80	11.90	12.00	12.10	12.20
SiO ₂	22.36	22.63	24.26	20.04	22.15	26.08	22.26	26.43	46.68	18.17	18.73	18.54	17.51	23.07	24.43
TiO ₂	0.29	0.31	0.34	0.31	0.31	0.31	0.24	0.26	0.23	0.24	0.23	0.24	0.21	0.31	0.35
Al ₂ O ₃	6.18	6.50	6.96	5.89	6.27	6.86	5.69	6.59	9.42	4.94	5.19	5.02	4.83	6.58	7.13
Fe ₂ O ₃	2.47	2.49	3.06	2.54	2.67	3.26	2.46	2.09	1.84	2.02	2.17	2.22	1.96	2.75	3.19
MnO	0.069	0.066	0.065	0.059	0.066	0.066	0.066	0.072	0.095	0.081	0.071	0.071	0.065	0.070	0.062
MgO	1.74	1.79	1.87	1.77	1.79	1.83	1.55	1.45	0.95	1.43	1.44	1.46	1.40	1.79	2.03
CaO	32.29	31.79	29.96	33.85	32.94	28.80	33.53	30.38	15.70	37.39	36.47	36.65	37.71	31.33	29.73
Na ₂ O	1.48	1.42	1.81	1.58	1.08	1.68	1.08	1.73	3.53	1.09	1.10	1.16	1.07	1.71	1.77
K ₂ O	1.46	1.61	1.62	1.44	0.88	1.43	0.99	1.51	3.78	1.01	0.86	0.96	0.87	0.87	0.89
P ₂ O ₅	0.079	0.076	0.088	0.061	0.063	0.077	0.077	0.072	0.060	0.083	0.091	0.086	0.073	0.093	0.071
L.O.I.	32.21	31.75	30.82	33.75	32.57	29.80	32.36	29.52	17.66	34.22	33.97	34.08	34.72	31.38	30.34
Total	100.64	100.41	100.84	101.29	100.80	100.18	100.30	100.09	99.93	100.66	100.32	100.48	100.42	99.94	99.99
Sc	6.61	6.88	8.28	7.05	7.83	7.53	6.78	6.38	5.22	6.24	6.65	6.47	5.92	8.09	6.89
Cr	45.2	44.9	57.9	49.1	56.2	46.8	35.1	36.9	27.4	39.9	45.1	41.2	39.8	53.7	43.1
Co	8.71	9.38	10.5	9.98	11.3	13.1	14.1	12.3	5.62	7.21	7.82	7.97	7.28	10.2	8.18
Ni	54	42	60	42	42	40	43	52	28	34	48	36	37	23	34
Zn	62	71.3	77.8	66.4	79.8	60.7	65.5	73.5	61.6	60.1	65.4	63.5	62.8	63.3	66.6
Ga	7.8	8.4	22	8.2	7.2	5.3	5.9	5.9	11.5	12	15	12	6.5	19	11
As	1.16	1.51	2.28	1.91	1.76	2.42	5.54	8.42	4.64	0.65	1.31	1.22	1.09	1.92	2.12
Se	0.38	0.31	0.71	0.43	0.69	0.63	0.69	0.78	0.5	0.45	0.29	0.31	0.32	0.34	0.56
Br	29.2	29.2	34.5	31.3	33.1	30.4	25.6	24.7	25.2	28.3	30.2	32.1	30.3	31.1	29.5
Rb	52.9	56.1	65.4	56.1	61.5	55.1	53.1	62.1	117	44.6	44.7	46.4	42.2	59.1	48.4
Sr	101.0	99.5	110.0	109.0	111.0	91.0	115.0	99.0	61.5	119.0	122.0	126.0	124.0	104.0	114.0
Zr	63	58	88	60	66	66	81	74	100	62	50	55	48	35	39
Ag	0.059	0.061	0.07	0.032	0.044	0.035	0.028	0.015	0.045	0.044	0.06	0.049	0.051	0.06	0.05
Sb	0.42	0.52	0.75	0.46	0.55	0.39	0.41	0.52	1.07	0.64	0.45	0.32	0.28	0.37	0.41
Cs	3.89	4.01	4.28	3.67	4.12	3.54	3.15	4.03	6.42	3.07	3.55	3.42	3.15	4.18	3.98
Ba	415	403	507	405	420	330	658	735	605	645	790	705	730	610	696
La	17.2	17.2	21.7	17.9	18.6	18.4	18.1	18.5	27.2	16.8	17.2	16.8	13.9	19.8	18.5
Ce	32.1	32.2	37.9	32.4	36.3	32.2	29.9	34.2	50.5	26.2	27.5	27.5	23.1	34.8	31.5
Nd	17.4	19.2	20.7	17.1	19.2	16.4	16.3	17.3	23.8	14.6	19.2	18.1	13.8	19.9	17.8
Sm	3.26	3.57	4.17	3.34	3.24	3.51	3.23	3.24	4.12	2.88	3.28	2.98	2.57	3.68	3.21
Eu	0.68	0.69	0.82	0.73	0.83	0.78	0.75	0.74	0.73	0.73	0.73	0.64	0.58	0.74	0.76
Gd	2.71	2.61	3.07	2.85	3.09	2.92	2.76	2.91	3.76	2.93	2.87	2.83	2.64	2.92	2.86
Tb	0.52	0.45	0.58	0.56	0.58	0.52	0.53	0.53	0.59	0.51	0.48	0.49	0.46	0.48	0.47
Dy	2.1	1.7	2.1	1.2	4.1	1.5	1.6	1.2	1.2	1.1	0.9	3.6	2.4	2.1	1.6
Y	0.26	0.24	0.3	0.25	0.29	0.25	0.28	0.31	3.1	2.8	3.1	3.1	2.9	3.1	3.1
Yb	1.64	1.79	1.97	1.77	2.04	1.85	1.83	1.88	2.31	1.72	1.93	1.84	1.51	1.86	1.72
Lu	0.22	0.23	0.28	0.24	0.27	0.25	0.25	0.27	0.33	0.24	0.27	0.25	0.19	0.28	0.26
Hf	1.25	1.33	1.52	1.25	1.38	1.33	1.21	1.49	2.98	0.95	0.98	1.01	0.85	1.07	0.97
Ta	0.35	0.35	0.41	0.32	0.39	0.29	0.28	0.32	0.51	0.26	0.32	0.31	0.32	0.31	0.29
Th	0.51	0.84	0.39	0.51	0.67	0.43	0.49	0.75	1.61	0.58	0.38	0.41	0.51	0.48	0.45
Ir (ppb)	0.14	0.077	0.086	0.077	0.065	0.06	0.05	0.055	<0.04	<0.04	<0.04	0.068	0.06	0.05	<0.04
Au (ppb)	2.1	1.7	2.1	1.2	4.1	1.5	1.6	1.2	1.2	1.1	0.9	3.6	2.4	2.1	1.6
Hg	<0.001	0.02	0.04	0.03	0.06	0.04	0.03	0.03	0.02	<0.01	<0.1	<0.1	<0.12	<0.06	<0.1
Pb	5.86	5.85	7.11	6.06	6.77	6.45	5.75	8.11	16.9	4.93	5.39	5.37	4.86	6.71	5.76
U	1.13	0.78	0.92	0.91	0.68	0.52	0.99	1.57	2.95	0.78	1.03	1.26	1.28	1.29	1.12
K/U	19115	30513	25543	23736	33088	46731	23838	17070	18780	26026	14078	14841	12578	9380	10536
Zr/Hf	50	44	58	48	51	50	67	50	34	65	51	54	56	33	40
La/Th	2.94	2.94	3.05	2.95	2.75	2.85	3.15	2.28	1.61	3.41	3.19	3.13	2.86	2.95	3.21
Hf/Th	3.57	3.80	3.71	3.91	3.54	4.59	4.32	4.66	5.84	3.65	3.06	3.16	2.74	3.45	3.34
Th/U	5.19	7.50	7.73	6.66	9.96	12.40	5.81	5.17	5.73	6.32	5.23	4.26	3.80	5.20	5.14
La ₂ /Yb ₂	7.09	6.49	7.44	6.83	6.16	6.72	6.68	6.65	7.96	6.60	6.02	6.17	6.22	7.19	7.27
Eu/Eu*	0.699	0.691	0.700	0.723	0.802	0.745	0.768	0.736	0.567	0.768	0.727	0.673	0.680	0.690	0.767

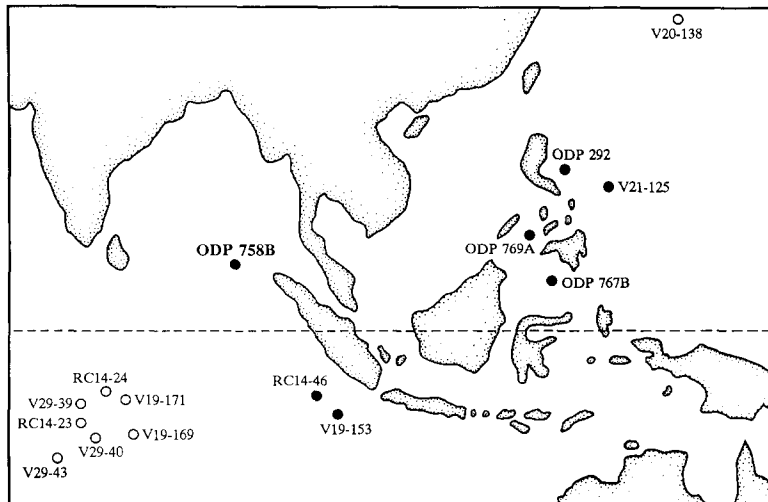


Fig. 1. Locality map of ODP hole 758B. ● = other cores where shocked quartz and coesite have been found to be associated with the microtektite layer (except V21-125 where no microtektites were found); ○ = cores with microtektite layers only (data from [9]). The broken line is the equator.

ene-rich spherule layer [11,12], but not with the microtektite layer. Core samples containing shocked minerals and microtektites from the Australasian strewn field were examined for an extraterrestrial component (see preliminary report in [13]). In the present work, a direct correlation between a siderophile element anomaly and a microtektite layer is made.

2. Samples and methods

Thirty samples from ODP hole 758B covering the Brunhes–Matuyama geomagnetic polarity reversal and the zone enriched in Australasian microtektites [14] were obtained from the ODP Curatorial Facility. ODP hole 758B is located along the crest of the Ninety East Ridge at 05°23′02″N and 90°21′40″E [15] (Fig. 1). Sample depth ranged between 9.80 and 12.20 m below sea floor (mbsf); sample spacings were 10 cm in the top and bottom parts and 5 cm in the zone of the maximum microtektite distribution, which was reported by Smit et al. [14] to be at 10.95 mbsf.

The samples were dried for 24 h at 110°C and then gently homogenized in an agate mortar. About 0.5–0.7 g were used for X-ray fluorescence (XRF) major element analysis. For Na, neutron activation analysis (NAA) values were taken, and for K NAA and XRF values were averaged. 200–

300 mg were used for INAA (for procedures, instrumentation, standards, precision and accuracy, see [16]). For Ir analysis, INAA was followed by a longer irradiation (at a flux of 6.10^{13} n cm^{-2} s^{-1}). After about 2 months the samples were dissolved in diluted HCl and the residues counted for up to 80 h on a 48% efficiency HpGe detector. For the current analyses, the precision of the Ir values is estimated at about ± 0.03 ppb at concentrations below 0.1 ppb, and about ± 0.02 ppb for concentrations > 0.1 ppb.

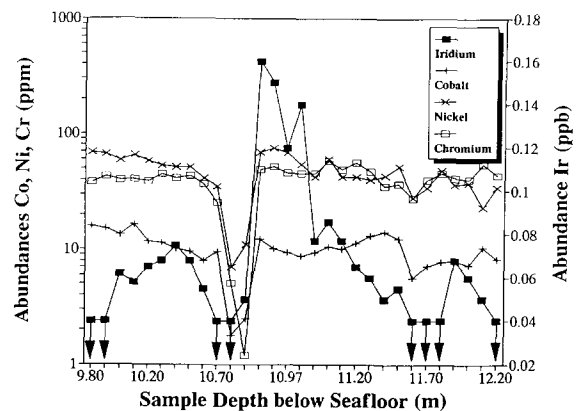


Fig. 2. Abundances of the siderophile elements Ir, Ni and Co, and the chalcophile element Cr, across the sediment samples in ODP core 758B, between 9.80 and 12.20 mbsl (note that the scale is not linear—see Table 1).

3. Results and discussion

The results for 10 major and 35 trace element analyses are given in Table 1. The mineralogical composition of the samples (by XRD) shows only minor changes between different samples. Most samples are dominated by calcite, quartz and some halite; only samples 2H-1-129 and 2H-1-134 show abundant plagioclase. The chemical composition of the sediment samples shows relatively small variations, with the exception of the thick ash layer between about 10.70 and 10.84 mbsf, and another one at around 11.6 mbsf. Within the ash layers, carbonate and some trace element contents (e.g., Sc, Cr, Co, Ni, Zn, Sr and Ba) drop, while Si, Al, Na, K, As, Se, Rb, Zr, Sb, Cs, the REEs, Th and U increased. Some of these elements (As, Se and Sb) are typical of volcanic ashes.

The most important discovery is a significant enrichment in Ir in samples 2H-1-139 to 2H-2-0 (10.89–11.00 mbsl). This is the same interval in which the Australasian microtektites have their peak abundance. Figure 2 shows a plot of the abundances of the siderophile elements Ir, Ni and Co and the chalcophile element Cr. Iridium has an average background abundance of < 0.04–0.06 ppb, but shows a concentration increase of a factor of > 3, with a peak abundance of 0.16 ppb at about 10.90 mbsl. The background concentration of Ir is dominated by influx of extraterrestrial material [17]. The absolute concentration of Ir in the background is a function of the sediment accumulation rate. The Ir anomaly at 10.89–11.00 mbsl cannot be due to any change in accumulation rate because no other chemical parameter (e.g., Ca content) indicates a change [14]. The accumulation rate at ODP 758B is relatively high at around 1.1 cm/ka [15], which produces a more diluted Ir signal in the background, near average continental values of around 0.04–0.06 ppb.

Ni shows a minor anomaly correlating with the Ir maximum; Cr shows no enrichment, and Co shows a minor peak associated with the Ir anomaly. Taking an average Ni background of about 50 ppm, an enrichment of up to 75 ppm correlated with the Ir anomaly seems significant. The other elements show no significant changes. As tektites are derived from terrestrial crustal

rocks, a higher continental chemical signature might have been expected in the microtektite layer. However, the composition of the sediment samples is not sufficiently different from the average crustal sediment composition to allow the resolution of such an additional component.

In conclusion, the findings of a significant Ir and a minor Ni anomaly in samples from ODP hole 758B are evidence for an extraterrestrial signature associated with the microtektite-bearing layer. In addition to microtektites, this layer also contains abundant evidence for an impact-derived component in the form of shocked quartz, coesite and frothy impact glass fragments [9]. The association of a projectile-derived component with tektite debris is significant because of the low abundances of Ir and other platinum group metals in tektite glass, which has made the identification of such a component difficult [18].

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