Supplementary Materials for

Organic Matter and Water from Asteroid Itokawa

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Supplementary Materials

Supplementary Figures

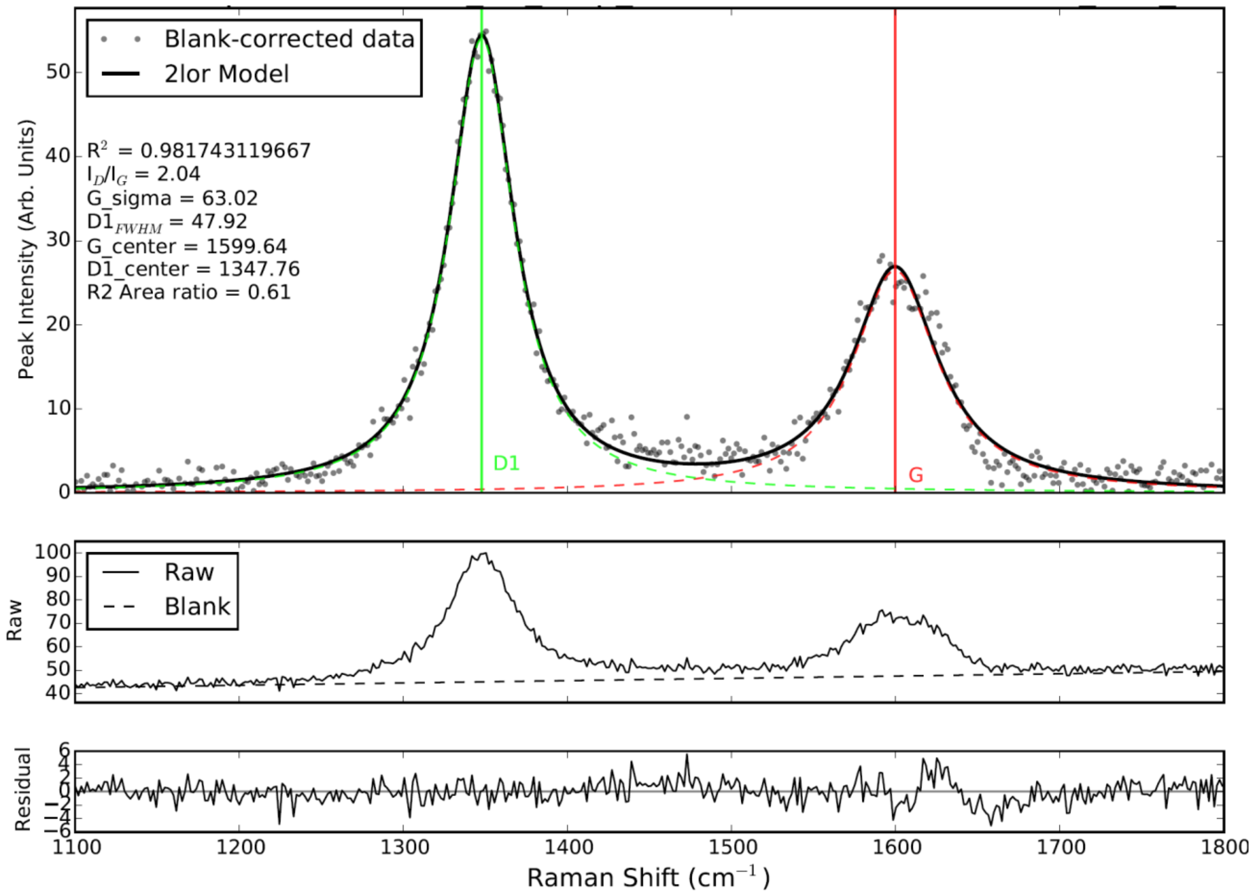

Fig. S1

Example of a two-Lorentzian fit performed on the Raman spectrum of the mature organic material in Amazon. The middle plot shows that the fluorescence background has been subtracted from the raw spectrum assuming a linear baseline. Minimal misfit was observed as displayed by the residual spectrum.

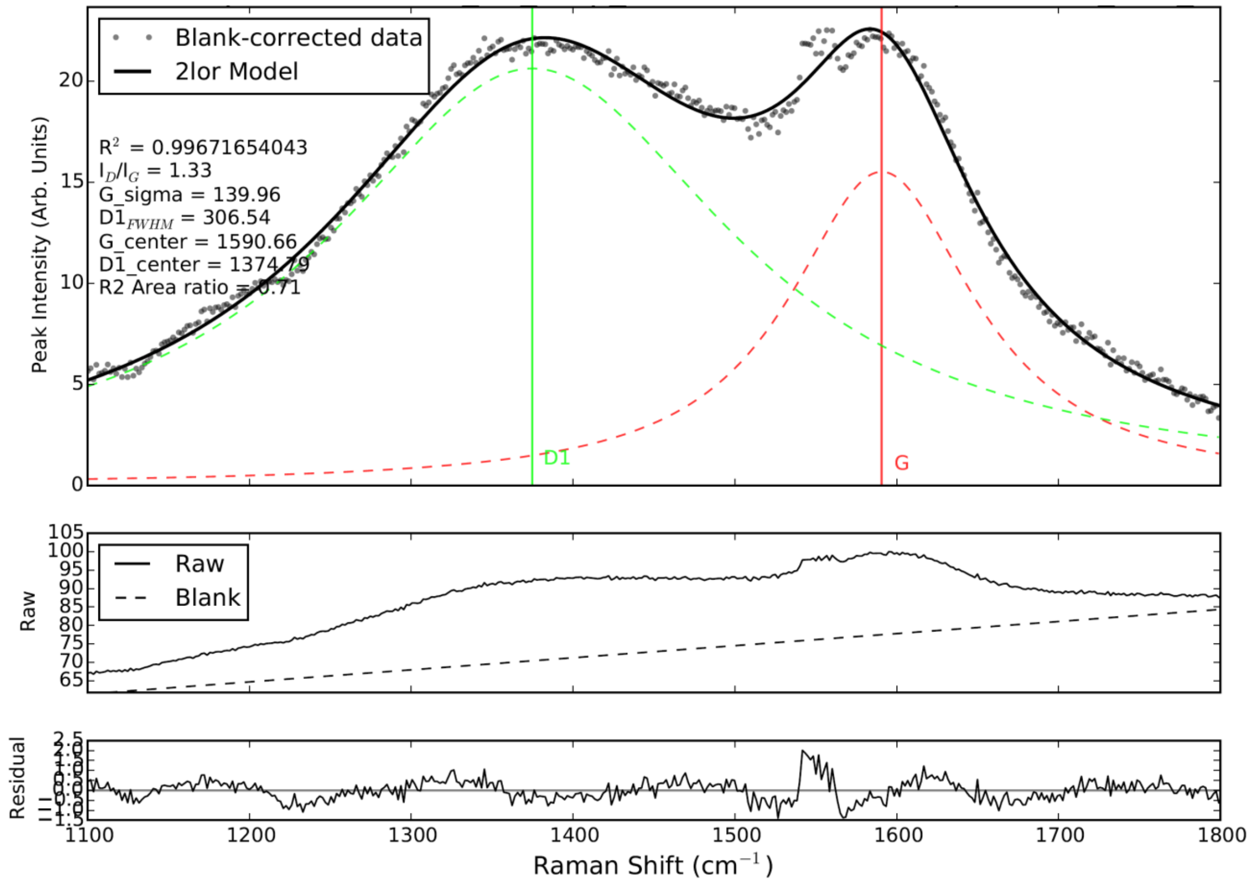

Fig. S2

Example of a two-Lorentzian fit performed on the Raman spectrum of the primitive organic material in Amazon. The middle plot shows that the fluorescence background has been subtracted from the raw spectrum assuming a linear baseline. Minimal misfit was observed as displayed by the residual spectrum.

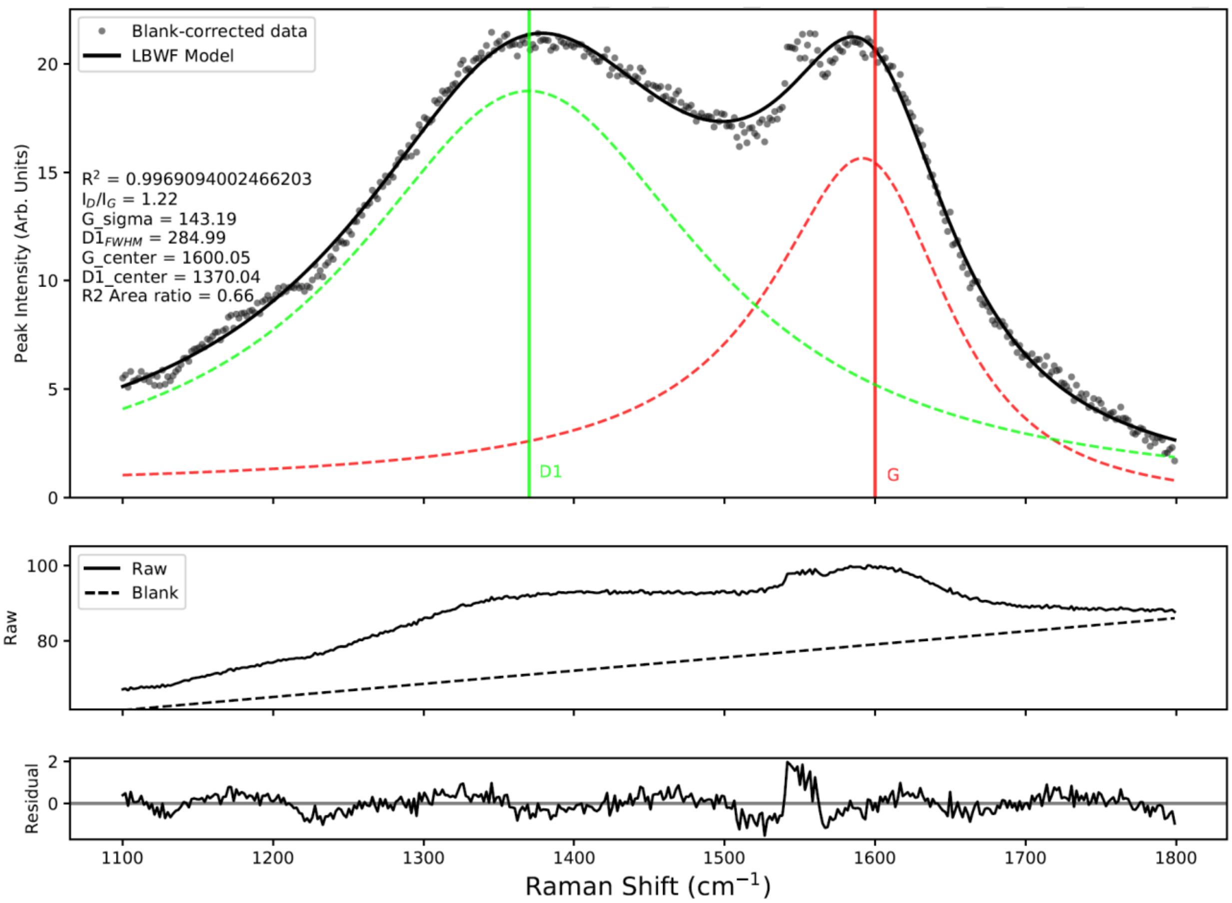

Fig. S3

Example of a two-peak Lorentzian and Breit–Wigner–Fano (LBWF) model fitting performed on the Raman spectrum of the primitive organic material in Amazon. The middle plot shows that the fluorescence background has been subtracted from the raw spectrum assuming a linear baseline. Minimal misfit was observed as displayed by the residual spectrum.

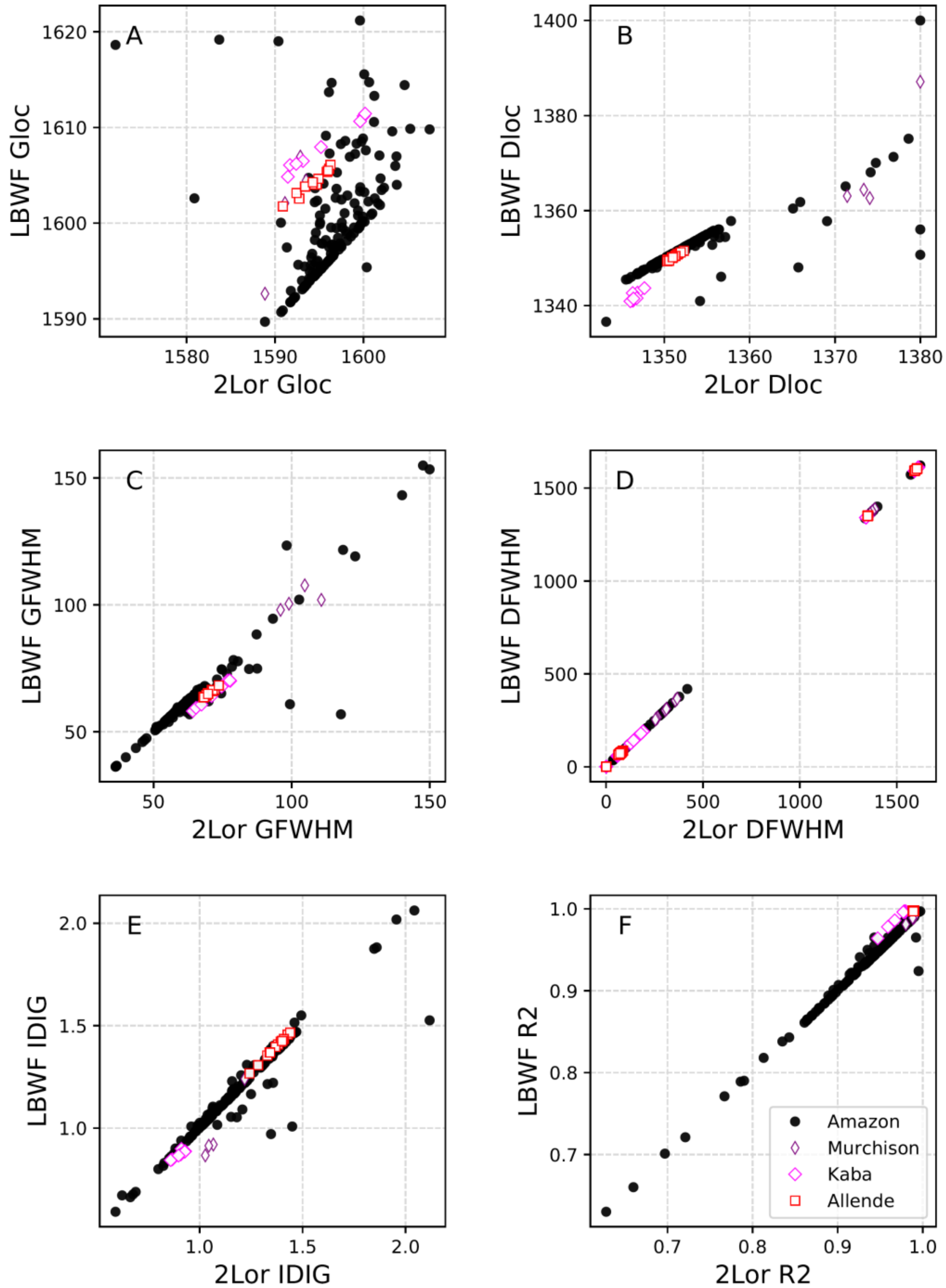

Fig. S4

Comparison between the Raman band parameters **(A)** G band location, **(B)** D band location, **(C)** G band full width at half maximum (FWHM), **(D)** D band FWHM, **(E)** intensity ratio between the D and G bands, **(F)** R^2 values of the results, obtained from peak-fitting using 2-peak Lorentzian and 2-peak Lorentzian and Breit–Wigner–Fano (LBWF) models.

Supplementary Tables

Table S1

The H_2O contents (ppm) and δD values (‰) of standards used for SIMS calibration of water content and for determining the instrumental mass fractionation (IMF) factor.

Standard	Type	H_2O (ppm)	δD (‰)	References
San Carlos	Olivine	2	-	[43]
PE [BM.1998.P2 (1780)]	Pyroxene	0 ± 11.4		[44]
KBH-1	Pyroxene	186	−113 ± 4	[43]
116610-15	Pyroxene	441 ± 31	-	[45]
116610-18	Pyroxene	199 ± 13	-	[45]
116610-21	Pyroxene	354 ± 28	-	[45]
116610-26	Pyroxene	237 ± 19	-	[45]
116610-29	Pyroxene	62 ± 4	-	[45]

Table S2

Isotopic compositions of Orgueil IOM standard used for NanoSIMS imaging analysis, and the standard ratios used in the calculation of the isotopic value of Amazon.

Isotopic compositions (‰)	δDSMOW	δ13CPDB		δ15NAir
Orgueil IOM	+972 ± 2	–17.05 ± 0.04		+30.7 ± 0.2
Reference	[4]	[4]		[4]
	D/HSMOW	13C/12CPDB	12C13C/12C12C	15N/14NAir
Standard ratios	0.00015576	0.0112372	0.0224744	0.003676
Reference	[58]	[59]		[60]

IOM: Insoluble organic matter; SMOW: Standard Mean Ocean Water; PDB: Pee Dee Belemnite; Air: atmospheric

Table S3

The raw and IMF-corrected C, N and H isotopic ratios and the delta values.

	Bulk OM	ROI-1	ROI-2
ROIAREA (μm^2)	6.6	0.9	1.4
ROIDIAM (μm^2)	2.9	1.1	1.3
Raw data:			
$^{12}C^{13}C/^{12}C^{12}C$	0.01095 ± 0.00006	0.01103 ± 0.00007	0.01069 ± 0.00012
$^{12}C^{15}N/^{12}C^{14}N$	0.00488 ± 0.00004	0.00650 ± 0.00018	0.00428 ± 0.00005
D/H	0.00045 ± 0.00002	0.00057 ± 0.00007	0.00035 ± 0.00004
IMF-corrected ratios:			
$^{12}C^{13}C/^{12}C^{12}C$	0.01097 ± 0.00006	0.01105 ± 0.00007	0.01071 ± 0.00012
$^{12}C^{15}N/^{12}C^{14}N$	0.00494 ± 0.00007	0.00659 ± 0.00020	0.00434 ± 0.00008
D/H	0.00091 ± 0.00036	0.00118 ± 0.00048	0.00071 ± 0.00029
IMF-corrected delta values (‰):			
$\delta^{13}C$	-23.97 ± 5.22	-16.76 ± 6.39	-46.54 ± 11.02
$\delta^{15}N$	344.32 ± 20.05	791.88 ± 53.44	179.96 ± 20.94
δD	4868.31 ± 2288.13	6542.67 ± 3056.06	3554.41 ± 1837.33

Table S4

The raw $H^-/^{16}O^-$ ratios and background corrected H_2O concentrations, and the raw δD values and those corrected for the IMF and background.

NAMs	D/H	D/H Poisson	$H/^{16}O$	$H/^{16}O$ Poisson	H_2O (ppm)	2SD	δD (‰)	2SD
Olivine	0.000105	5.7	0.00000617	0.065	235	60	-354	104
Albite	0.000128	5.38	0.00002355	0.0589	993	252	-177	128
Pyroxene	0.000223	6.11	0.000477	0.0912	278	14	348	328

Table S5

The C, N and H isotopic compositions for organic material in Amazon, various chondrites, interplanetary dust particles, and nanoglobules presented in Fig. 3 in the main text, and their corresponding data sources.

Samples	Samples	$\delta^{13}C_{PDB}$ (‰)	$\delta^{15}N_{Air}$ (‰)	δD_{SMOW} (‰)	Reference
Bulk OM	Amazon	-23.97	344.32	4868	This study
ROI-1	Amazon	-16.76	791.88	6543	This study
ROI-2	Amazon	-46.54	179.96	3554	This study
Orgueil	CI	-17.05	30.70	972	[4]
Ivuna	CI	-16.97	31.90	978	[4]
Bells	CM	-34.20	415.30	3283	[4]
Kivasvaara	CM	-17.13	2.70	707	[4]
Murchison	CM	-18.91	-1.00	777	[4]
Mighei	CM	-18.33	0.50	803	[4]
Murray	CM	-18.05	7.50	893	[4]
DOM03183	CM	-17.45	-1.90	639	[4]
Cold Bokk	CM	-18.63	-2.00	734	[4]
ALH83100	CM	-17.86	-6.70	723	[4]
MET01070	CM	-18.17	-8.50	693	[4]
LEW85311	CM	-15.62	-0.50	1008	[4]
Y793321	CM	-8.39	35.10	95	[4]
PCA91008	CM	-11.38	26.00	244	[4]
Y86720	CM	-19.86	29.50	496	[4]
MET00426	CR	-20.32	176.80	3054	[4]
QUE99177	CR	-20.83	187.40	3139	[4]
EET92042	CR	-22.19	184.10	3002	[4]
GRA95229	CR	-21.61	153.40	2909	[4]
Al Rais	CR	-24.20	161.80	2619	[4]
GRO95577	CR	-26.58	233.20	2973	[4]
LEW85332	CR	-23.70	309.00	3527	[4]
Kaba	CV	-15.44	-26.20	209	[4]
Mokoia	CV	-15.04	-36.30	341	[4]
MET00430	CV	-18.35	-65.60	62	[4]
Bali	CV	-18.00	-47.50	160	[4]
Allende	CV	-17.03	-51.20	194	[4]
ALH84028	CV	-15.89	-41.40	239	[4]
Leoville	CV	-13.09	-17.50	1361	[4]
Vigarano	CV	-12.05	-21.30	839	[4]

Eframovka	CV	-13.11	-25.70	714	4
MET01017	CV	-6.79	-31.40	-57	4
ALH77307	CO	-8.29	3.00	314	4
Colony	CO	-8.68	17.70	749	4
Y81020	CO	-8.17	3.30	402	4
Kainsaz	CO	-13.92	-16.40	435	4
Y791717	CO	-7.13	-19.40	340	4
ALH77003	CO	-7.72	-27.10	132	4
ALH83108	CO	-4.47	-29.70	417	4
Semarkona	OC	-23.67	26.90	2322	4
QUE97008	OC	-20.35	-0.70	3199	4
MET00526	OC	-15.94	-4.20	4526	4
MET00452	OC	-16.05	-7.20	2678	4
Bishunpur	OC	-16.65	12.10	2749	4
LEW86018	OC	-15.88	36.30	2531	4
GRO95502a	OC	-11.90	-3.70	3297	4
GRO95504a	OC	-10.42	5.30	3174	4
GRO95505a	OC	-15.81	-34.40	4009	4
MET96503b	OC	-13.60	-11.30	3984	4
MET96515b	OC	-13.36	-8.70	3997	4
Krymka	OC	-17.38	-10.70	1917	4
WSG95300	OC	-12.00	-38.50	6181	4
ALH83010	OC	-14.81	-46.90	346	4
Chainpur	OC	-16.86	8.20	2708	4
MET00506	OC	-13.13	-11.30	3908	4
GRO95517	EH	-7.75	27.40	-115	4
PCA91238	EH	-7.14		-160	4
ALH77295	EH	-7.36	32.50	-23	4
EET87746	EH	-7.16	6.90	299	4
Indarch	EH	-8.73	-20.90	-82	4
PCA91020	EL	-8.21	17.80	-119	4
MAC02837	EL	-7.06	14.40	-109	4
G 15-1	Nanoglobule	-47.00	474.00	2589	63
G 15-2	Nanoglobule	-18.00	415.00	2977	63
G 15-3	Nanoglobule	-33.00	477.00	2767	63
G 8-1	Nanoglobule	17.00	1007.00	3097	63
G 8-2	Nanoglobule	-42.00	575.00	8113	63
G 8-3	Nanoglobule	-26.00	448.00	5940	63
G 5-1	Nanoglobule	-47.00	519.00	3509	63
G 5-2	Nanoglobule	-35.00	458.00	1789	63
Lumley 1a	IDP	-22.00	334.00	702	64
Lumley 1b	IDP	17.00	498.00	480	64
Lumley1c	IDP	-14.00	259.00	531	64

Lumley1d	IDP	-25.00	316.00	575	[64]
Lumley1e	IDP	-4.00	553.00	861	[64]
Lumley1f	IDP	-46.00	236.00	495	[64]
Balmoral1 Spot 1	IDP	-33.00	248.00	1128	[64]
Balmoral1 Spot 2	IDP	-26.00	272.00	498	[64]
Balmoral1 ROI 2	IDP	-44.00	317.00	502	[64]
Balmoral1 ROI 3	IDP	-42.00	352.00	1000	[64]
Midford1bulk	IDP	-17.00	14.20	8146	[57]
Midford2bulk	IDP	-8.00	-1.00	5862	[57]
Bramber1bulk	IDP	-3.00	-167.00	1166	[57]
Bramber2bulk	IDP	-12.00	22.00	642	[57]
Arundel1bulk	IDP	-7.00	-190.00	498	[57]
Arundel3abulk	IDP	-10.00	239.00	988	[57]
Pizarrob	IDP	7.00	390.00	297	[65]
Cortes	IDP	15.00	340.00	560	[65]
Magellan	IDP	14.00	260.00	593	[65]
Columbus	IDP	23.00	400.00	1525	[65]
Polo	IDP	12.00	240.00	862	[65]
Hudson	IDP	22.00	89.00	678	[65]
Raleigh	IDP	16.00	41.00	1787	[65]
Hawkins	IDP	21.00	63.00	599	[65]
Drake	IDP	-1.00	73.00	1141	[65]
Frobisher	IDP	23.00	139.00	651	[65]
L2005 A2a 31	IDP	-4.00	-10.70	600	[66]
L2005 F 31	IDP	-26.00	153.40	20000	[66]
L2005 4 31	IDP	-49.00	161.80	24800	[66]
L2005 3 31	IDP	-31.00	907.25	8000	[66]
L2005 A3 31	IDP	-1.00	481.57	-420	[66]
L2008 B2a 4	IDP	-45.00	450.97	1100	[66]
L2008 310x 5	IDP	-4.00	873.07	71	[66]
L2008 310d 5	IDP	-11.00	1281.99	66	[66]
L2008 310e 5	IDP	33.00	379.05	17	[66]
L2008 310g 5	IDP	-7.00	275.46	-35	[66]
L2008 310L 5	IDP	-23.00	364.30	-55	[66]
L2008 19a 5	IDP	-16.00	681.60	664	[66]
L2008 110 5	IDP	-18.00	159.02	822	[66]
L2009 D9 10	IDP	-52.00	80.82	12000	[66]
L2009 D10 10	IDP	-42.00	80.82	1100	[66]
L2009 D12 13	IDP	-120.00	105.00	4100	[66]
L2009 D1 3	IDP	-52.00	320.00	2100	[66]
L2009 D6 7	IDP	-43.00	140.00	1200	[66]
L2009 D7 8	IDP	-1.00	150.00	1200	[66]
L2011 A1 6	IDP	-38.00	180.00	1200	[66]

L2011 A2 6	IDP	-14.00	100.00	1400	[66]
L2011 A3 7	IDP	-53.00	-93.00	5600	[66]
L2011 A4 7	IDP	-55.00	-10.00	930	[66]
L2011 A5 11	IDP	-27.00	94.00	2900	[66]
L2011 A6 11	IDP	33.00	290.00	2900	[66]
L2011 A7 15	IDP	-76.00	17.00	130	[66]
L2011 A8 15	IDP	-67.00	47.00	3600	[66]
L2011 A10 22	IDP	-41.00	18.00	680	[66]
L2011 4 5	IDP	-24.00	92.00	-350	[66]
L2011 4	IDP	-30.00	234.00	490	[67]
Chocha B 8C	IDP	-30.00	237.00	470	[67]
Chuki 5-4D	IDP	-11.00	6.00	-210	[67]
Chuki 5-4D	IDP	-8.00	34.00	-185	[67]
Chuki 5-4D-1	IDP	2.00	915.00	960	[67]