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DATA REPOSITORY ITEM 1: ADDITIONAL INFORMATION ON MATERIAL AND METHODS

Maiolica stratigraphy and sedimentology

Pelagic calcareous ooze dating back to the Jurassic covers large areas of the present sea floor, but cannot be used for our purposes, because spinel extraction would destroy large amounts of precious core material without yielding a statistically significant number of spinel grains. We are therefore restricted to studying pelagic carbonates exposed in outcrop. Probably the best place in the world to find exposures of rocks of this kind is in the Umbria-Marche Apennines of central Italy, with pelagic carbonates (limestones, dolomites, and marls) representing most of the 165-Myr interval from the Pliensbachian to the Oligocene. These rocks are exposed in bands on the flanks of sub-parallel anticlines over a roughly square area almost 100 km on a side. Earth-history studies of many kinds have been carried out on these rocks beginning with Renz (1936), and a recent compilation is given by Menichetti et al. (2016).

In the Umbria-Marche sequence, the first four stages of the Lower Cretaceous (Berriasian-Barremian, ~145-125 Ma) are represented by the Maiolica formation, a pure white pelagic limestone having a fine-grained texture reminiscent of majolica pottery, with abundant beds and nodules of chert, mostly black or dark grey, and rare partings of black clay. This unit, ~400 m thick in basinal settings and ~100 m thick on fault-block seamounts, has proven difficult to correlate, date, and study because of the near-absence of distinctive marker beds, the lack of distal volcanic ashes and thus of datable contemporaneous mineral grains, the absence of planktic foraminifera, which had not yet evolved, the rarity of ammonites and other macrofossils, and the presence of slump units in the basins and probably of corresponding hiatuses on structural highs.

However, for our purposes the Maiolica is ideal, easily dissolving with small residues from which refractory spinel grains can be collected.

All but one of our samples from the Maiolica Formation come from the 240-m-thick Monte Acuto section, extending from 43° 27.830'N, 12° 40.270'E to 43° 27.842'N, 12° 40.745'E, in cuts along the road from Chiaserna to the pass between Monte Acuto and Monte Catria. Here the Maiolica is well exposed as steeply-dipping beds, with the exception of the covered uppermost part of the formation. In the Monte Acuto section, Channell et al. (1995) determined the M-sequence geomagnetic polarity zonation and tied it to nannofossils events and ammonite zones for the Hauterivian and the uppermost Valanginian. Faraoni et al. (1997) in a painstaking study, recovered many ammonites and presented an ammonite zonation for all of the Valanginian and small portions of the underlying Berriasian and the overlying Hauterivian. Moreover, Sprovieri et al. (2006) studied the cyclostratigraphy of the Monte Acuto section using carbon isotopes, tying this record to the known biozonation and magnetostratigraphy. The average sedimentation rate for the Maiolica limestone in the Monte Acuto section is about 25 m/Myr, based on a measured thickness of 137 m of sediments representing the 5.5 Myr Valanginian Stage. It is likely that the bedding in the section reflects precession cycles. The entire late Berriasian to early Hauterivian section at Monte Acuto corresponds to ca. 9.4 Myr (ca. 141.2 -131.8 Ma) and comprises 453 beds, giving an average of 20.75 kyr/bed.

The oldest (ca. 145 Ma) of our Maiolica Formation samples was collected ca. 3 m above the Maiolica-Diaspri formational contact, i.e. close to the Jurassic-Cretaceous boundary, in the Bosso River section along the Pianello-Cagli road, 12 km northwest of Monte Acuto (Kudielka et al., 2002).

Oxygen isotope analyses

Polished epoxy mounts were prepared with all Cr-spinels found together with a centrally mounted analytical standard UWCr-3 (Heck et al., 2010). The same mounts were used for the elemental analyses, see below. A Bruker 3D microscope was used to verify that grain-to-epoxy topography was kept below 3 µm (on average 2 µm) after polishing to minimize mass-dependent isotope fractionation effects during SIMS analysis. Isotopes of $^{16}O^{-}$, $^{17}O^{-}$ and $^{18}O^{-}$ were analyzed with a Cameca IMS 1280 SIMS at the WiscSIMS laboratory. Analyses were performed in three separate sessions with the procedures similar to Heck et al. (2010, 2016, 2017), but with different primary beam sizes (12 µm to 19 µm) to accommodate different grain sizes. This procedure includes analysis and correction for the hydride tailing interference on $^{17}O^{-}$ and bracketing with our analytical standard UWCr-3. We determine parts per thousand deviations from VSMOW as $\delta^{18}O$, $\delta^{17}O$ and from the terrestrial mass-fraction line as $\Delta^{17}O$ ($=\delta^{17}O - 0.52 \times \delta^{18}O$), the latter being the main indicator for an extraterrestrial origin. The external reproducibility (spot-to-spot, 2SD) of $\Delta^{17}O$ measurements of standards was 0.2-0.3‰ during the analyses of the unknowns. We obtained valid results from a total of 86 sediment-dispersed chromite and chrome-spinel grains (of which 77 grains are 32-63 µm large, and 9 grains >63 µm).

Oxygen isotope data of 63 extraterrestrial chrome-spinel grains are shown in Figure DR1. A striking feature in this figure is the tight clustering of grains classified as equilibrated ordinary chondritic grains in three-oxygen isotope space. The “OC-V” grains, which comprise unequilibrated ordinary chondritic grains, HED meteoritic grains, primitive, ungrouped and anomalous achondrites, show a larger range in $\delta^{18}O$ values. For classification of grains we primarily rely on $\Delta^{17}O$ values in conjunction with TiO_2 contents (Fig. 2) and use $\delta^{18}O$ as a secondary classification criterion.

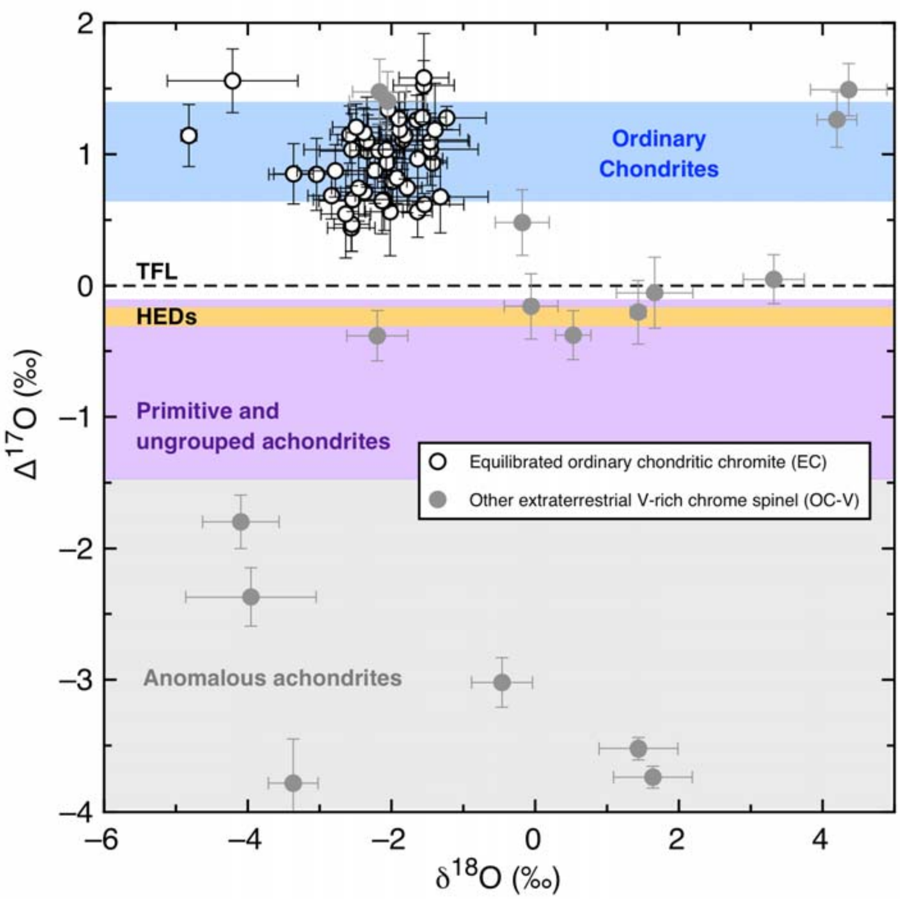

Figure DR1 caption: Oxygen isotopic composition of 63 out of a total 108 extraterrestrial chrome spinel grains recovered from the Maiolica Formation. TFL = terrestrial fraction line; HED = howardite, eucrite and diogenite meteorites, with origin from asteroid 4 Vesta. Error bars are 2σ.

Elemental analyses

The recovered chrome-spinel grains were mounted in epoxy resin, and polished flat using 1 μm diamond paste. These are the same mounts then used for three-oxygen isotope analyses. Element concentrations were analyzed quantitatively at Lund University using standard procedures with a calibrated Oxford-Link energy-dispersive spectrometer (with a Si-detector) mounted on a Hitachi scanning electron microscope

(SEM/EDS) (Schmitz et al., 2009). Cobalt was used to monitor drift of the instrument. An accelerating voltage of 15 kV at high vacuum mode, a sample current ~1-2 nA, and a counting live-time of 80 s (i.e., approximately 250,000 counts) were used. The results of each individual chrome spinel grain represents the average of three separate spot analyses, ensuring better statistics and reproducible data. Precision of analyses was typically better than 1-4 rel%. Analytical accuracy has also been controlled by analyses of the USNM 117075 (Smithsonian) chromite standard (Jarosewich et al., 1980), the UWCr-3 standard (Heck et al., 2010) and internally produced chrome-spinel standards.

The interpretations in the present paper are dependent on precise and reproducible analyses of in particular the TiO_2 and V_2O_3 concentrations in chrome spinels. In order to assess the quality of our analyses we have analyzed the same chrome-spinel grains with our SEM/EDS setup in Lund and a JEOL JXA 8530-F electron microprobe at the Vienna Natural History Museum. In Vienna the grains were analyzed in sessions together with chromite standards earlier analyzed with wet chemistry at the U.S. Geological Survey ("Chromit 53-IN-8" and "Chromit 55-G-23"). The full results of these comparisons will be described elsewhere. Here we only present the results for TiO_2 and V_2O_3, see below. Peak overlaps, e.g. of Ti K-beta with V K-alpha, are compensated for in the software, which is manifested in the results by absence of correlation between Ti and V concentrations. The detection limit for V_2O_3 with our SEM/EDS approach lies at ~0.2 to 0.3 wt%. Accuracy and precision errors get successively higher the closer to this level the V_2O_3 content is (see comparison data below). This has no bearing on our interpretations because we only use V_2O_3 analyses to locate grains with concentrations higher than ~0.5 wt%.

Below follow compilations showing comparisons of analyses performed in Lund and Vienna as outlined in this section:

Sediment-dispersed chromite grains from Massignano section, Italy (Lund Mount 74)

	TiO_2 (wt%)	V_2O_3 (wt%)
Grain 2		
Vienna	2.03	0.70
Lund	2.10	0.69
Grain 3		
Vienna	1.79	0.68
Lund	1.76	0.71
Grain 4		
Vienna	2.01	0.73
Lund	2.04	0.78
Grain 5		
Vienna	1.86	0.62
Lund	1.85	0.72
Grain 6		
Vienna	1.13	0.69
Lund	1.11	0.71

Chrome spinel grains from Winona meteorite (Lund Mount 9)

	TiO_2 (wt%)	V_2O_3 (wt%)
Grain 4		
Vienna	0.42	0.27
Lund	0.38	0.38
Grain 6		
Vienna	0.42	0.23
Lund	0.37	0.32
Grain 10		
Vienna	0.43	0.23
Lund	0.37	0.35
Grain 12		
Vienna	0.43	0.21
Lund	0.45	0.34
Grain 13		
Vienna	0.59	0.25
Lund	0.56	0.34

Chrome spinel grains from fossil meteorite Österplana 065 (Lund Mount 6)

	TiO_2 (wt%)	V_2O_3 (wt%)
Grain 1		
Vienna	0.64	0.43
Lund	0.61	0.57
Grain 2		
Vienna	0.57	0.30
Lund	0.51	0.34
Grain 3		
Vienna	0.44	0.45
Lund	0.45	0.60
Grain 4		
Vienna	0.44	0.43
Lund	0.45	0.51
Grain 5		
Vienna	0.45	0.52
Lund	0.43	0.62

Chrome spinel grains from meteorite NWA 725 (Lund Mount 10)

	TiO_2 (wt%)	V_2O_3 (wt%)
Grain 1		
Vienna	1.03	0.53
Lund	1.01	0.68
Grain 2		
Vienna	1.01	0.45
Lund	0.96	0.66
Grain 3		
Vienna	0.80	0.52
Lund	0.80	0.60
Grain 5		
Vienna	0.89	0.55
Lund	0.92	0.58
Grain 7		
Vienna	0.99	0.48
Lund	0.99	0.59

Analyses of chrome spinel standards in Vienna compared to recommended values

	TiO_2 (wt%)	V_2O_3 (wt%)
55G23		
US Geol. Sur.	0.76	0.19
Vienna	0.66	0.21
53IN8		
US Geol. Sur.	1.60	1.10
Vienna	1.63	0.93

Additional chemical separation steps

For some samples chemical separation methods in addition to HCl and HF leaching were used. For each method we have tested that spinel grains are not affected in a significant way.

Potassium hydroxide leaching/disintegration technique: To leach radiolarian spicules common in some samples as well as disintegrate clay aggregates, samples are treated with a saturated solution of potassium hydroxide for 24 hours prior to HF treatment. Samples are then neutralized and sieved an additional time before the HF leaching.

Nitric acid leaching technique: To leach pyrite, samples are submerged in 68 % HNO_3 for 24 hours with occasional stirring. The samples are neutralized by means of repeated water decanting and subsequently sieved through a 32 µm mesh before picking of grains of interest.

Sulfuric acid leaching technique: To leach barite, fluorite and terrestrial hydroxide minerals insoluble in HCl and HF, samples are submerged in 98% H_2SO_4 for 24 hours with occasional stirring. Due to the high density of the acid, the acid is diluted with water before neutralization by means of repeated water decanting. The neutralized samples are then sieved through a 32 µm mesh before picking of grains of interest.

Lithium heteropolytungstates (LST) heavy liquid separation technique: To separate organic material and low density minerals from the heavy mineral fraction (which includes the spinel grains), a water solution of lithium heteropolytungstates (LST) with a density of 2.9 g/ml is mixed with the sample in a glass vial. The mixture is thoroughly stirred and treated in an ultra-sonic bath to untangle organic material from heavy mineral grains. After 24 hours the light fraction floating on the surface of the LST liquid is removed by means of freezing the bottom of the vial with liquid nitrogen and dispense the liquid LST on top. The frozen LST with the heavy minerals at the bottom of the vial is thawed with water and then sieved through a 32 µm mesh.

Samples for which H_2SO_4 and HNO_3 were used:

H_2SO_4: MMA 36, MMA 40, MMA 39+42, MMA 335; HNO_3: MMA 335

References

Channell, J.E.T., Cecca, F., Erba, E., 1995, Correlations of Hauterivian and Barremian (Early Cretaceous) stage boundaries to polarity chrons: Earth and Planetary Science Letters, v. 118, p. 145-166.

Faraoni, P., Flore, D., Marini, A., Pallini, G., and Pezzoni, N., 1997, Valanginian and early Hauterivian ammonite successions in the Mt Catria group (Central Apennines) and the Lessini Mts (Southern Alps), Italy: Palaeopelagos, v. 7, p. 59-100.

Heck, P.R., Ushikubo, T., Schmitz, B., Kita, N.T., Spicuzza, M.J., and Valley, J.W., 2010, A single asteroidal source for extraterrestrial Ordovician chromite grains from Sweden and China: High-precision oxygen three-isotope SIMS analysis: Geochimica et Cosmochimica Acta, v. 74, p. 497-509.

Heck, P.R., Schmitz, B., Rout, S.S., Tenner, T., Villalon, K., Cronholm, A., Terfelt, F., and Kita, N.T., 2016, A search for H-chondritic chromite grains in sediments that formed immediately after the breakup of the L-chondrite parent body 470 Ma ago: Geochimica et Cosmochimica Acta, v. 177, p. 120-129.

Heck, P.R., Schmitz, B., Bottke, W.F., Rout, S.S., Kita, N.T., Cronholm, A., Defouilloy, C., Dronov, A., and Terfelt, F., 2017, Rare meteorites common in the Ordovician period: Nature Astronomy, v. 1, doi:10.1038/s41550-016-0035.

Jarosewich, E., Nelen, J.A., Norberg, J.A., 1980, Reference samples for electron microprobe analysis: Geostandards Newsletters v. 4, p. 43-47.

Kudielka, G., Koeberl, C., Montanari, A., Newton, J., and Reimold, W.U., 2002, Stable-isotope and trace element stratigraphy of the Jurassic/Cretaceous boundary, Bosso River Gorge, Italy, *in* Buffetaut, E., and Koeberl, C., eds., Geological and Biological Effects of Impact Events: Springer Verlag Berlin Heidelberg, p. 25-68.

Menichetti, M., Coccioni, R., and Montanari, A., eds., 2016, The stratigraphic record of Gubbio: Integrated Stratigraphy of the Late Cretaceous-Paleogene Umbria-Marche Pelagic Basin: Geological Society of America Special Paper, v. 524, 175 p.

Renz, O., 1936, Stratigraphische und mikropaläontologische Untersuchungen der Scaglia (Obere Kreide-Tertiär) im zentralen Apennin: Eclogae Geologicae Helvetiae, v. 29, p. 1-149.

Schmitz, B., Cronholm, A., and Montanari, A., 2009, A search for extraterrestrial chromite in the late Eocene Massignano section, central Italy, *in* Koeberl, C., and Montanari, A., eds., The Late Eocene Earth - Hothouse, Icehouse, and Impacts: Geological Society of America Special Paper, v. 452, p. 71-82.

Sprovieri, M., Coccioni, R., Lirer, F., Pelosi, N., and Lozar, F., 2006, Orbital tuning of a lower Cretaceous composite record (Maiolica Formation, central Italy): Paleoceanography, v. 21, PA4212, doi:10.1029/2005PA001224.

TABLE DR1. SUMMARY OF CHROME SPINEL GRAINS RECOVERED

Sample	kg	EC32	EC63	OC-V32	OC32	OC63
Bosso section, basal Berriasian						
BOS 3 m	124.2	8	1	2	10	0
Monte Acuto, Berriasian interval						
MMA 36	209.2	14	0	9	1	0
MMA 40	201.0	18	1	2	1	0
MMA 39 + 42	102.6	3	0	0	1	0
Total	637.0	43	2	13	13	0
Monte Acuto, Late Valanginian - early Hauterivian interval						
MMA 270	105.6	3	0	1	0	2
MMA 285	107.5	4	0	3	3	6
MMA 335	432.8	16	0	7*	26	11
MMA 349	27.0	0	0	0	0	2
MMA 366 + 367	127.8	5	0	0	11	7
MMA 406	110.0	4	0	2	8	3
MMA 415	104.3	4	0	1	4	2
Total	1015.0	36	0	14	52	33
Grand total	**1652.0**	**79**	**2**	**27**	**65**	**33**

Note: EC32 and EC63 = chromite grains from equilibrated ordinary chondrites in 32-63 and >63 µm fractions, respectively; OC-V32 = other chrome spinel grains with V_2O_3 ≥0.45wt%, 32-63 µm large; OC32 and OC63 = other chrome spinel grains with V_2O_3 ≤0.44wt% in 32-63 and >63 µm fractions, respectively.
*Including 2 grains >63 µm.

TABLE DR2. SUMMARY OF RESULTS OF ELEMENTAL AND OXYGEN ISOTOPIC ANALYSES OF SPINEL GRAINS FROM MAIOLICA FORMATION

PUCKS 229 & 230 - BOS 3 (22.8 + 101.4 kg = 124.2 kg)

EC >63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 2:17	2.33	5.87	2.90	0.88	58.75	0.97	27.64	0.67	100.01	-	-

EC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1:2	4.84	5.96	2.42	0.68	59.61	1.07	23.70	1.01	99.28	-	-
Cr 1:3	2.49	6.35	2.37	0.73	59.44	0.92	20.82	6.91	100.04	-	-
Cr 2:1	2.86	6.47	2.36	0.70	59.39	1.09	27.18	0.36	100.41	-	-
Cr 2:4	2.59	5.00	2.94	0.65	59.18	0.99	28.50	0.40	100.25	-	-
Cr 2:5	3.27	5.46	3.82	0.70	57.16	0.76	28.49	0.42	100.07	-	-
Cr 2:9	2.69	6.79	1.60	0.76	62.10	1.07	24.69	0.34	100.03	-	-
Cr 2:13	3.03	6.10	1.52	0.69	60.76	1.27	25.07	1.28	99.73	-	-
Cr 2:15	3.35	5.41	1.67	0.66	61.55	1.66	25.47	n.d.	99.78	-	-

OC-V 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 2:11	6.98	5.35	n.d.	0.50	67.48	1.03	16.25	3.33	100.92	-	-
Cr 2:12	4.54	17.25	0.45	0.45	46.76	n.d.	30.61	n.d.	100.06	-	-

OC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1:1	16.65	37.42	n.d.	0.25	29.75	n.d.	15.59	n.d.	99.66	-	-
Cr 1:4	13.20	22.00	n.d.	n.d.	47.24	n.d.	17.14	n.d.	99.59	-	-
Cr 2:2	14.19	30.48	0.41	0.32	38.80	n.d.	15.22	n.d.	99.44	-	-
Cr 2:3	12.69	19.92	n.d.	n.d.	52.02	n.d.	15.69	n.d.	100.32	-	-
Cr 2:6	14.12	28.23	0.67	0.22	36.33	n.d.	20.50	n.d.	100.07	-	-
Cr 2:7	14.24	34.50	0.39	n.d.	31.30	0.39	18.40	n.d.	99.22	-	-
Cr 2:8	8.12	19.70	1.23	0.35	30.18	0.38	39.03	n.d.	99.00	-	-
Cr 2:10	0.24	12.42	1.61	n.d.	50.42	2.08	29.1	3.66	99.53	-	-
Cr 2:14	14.07	31.26	0.64	0.29	34.11	0.32	19.11	n.d.	99.80	-	-
Cr 2:16	12.88	27.51	n.d.	0.27	42.04	n.d.	17.53	n.d.	100.24	-	-

PUCK 163 - MMA 36 (77.2 + 102.0 + 30.0 kg = 209.2 kg)

EC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1	4.90	6.52	1.72	0.75	60.54	1.11	24.92	0.63	101.08	0.87	±0.20
Cr 5	4.12	5.86	2.68	0.64	59.31	0.66	27.12	0.21	100.61	-	-
Cr 6	2.06	6.14	3.21	0.71	60.34	n.d.	25.73	0.64	98.84	1.14	±0.33
Cr 8	3.31	6.15	1.95	0.61	60.68	1.17	26.65	0.53	101.06	0.96	±0.33
Cr 9	2.78	5.61	2.79	0.62	61.31	0.51	24.40	0.96	99.00	1.58	±0.34
Cr 12	2.54	5.78	2.93	0.70	58.43	0.75	28.36	n.d.	99.49	1.10	±0.33
Cr 13	3.83	5.71	3.24	0.73	59.16	0.95	23.91	1.29	98.83	1.19	±0.35
Cr 14	2.59	6.20	2.65	0.81	58.43	0.96	25.42	1.99	99.06	-	-
Cr 15	6.35	7.55	1.66	0.72	60.54	0.95	22.48	0.67	100.93	-	-
Cr 17	3.43	6.32	2.17	0.68	58.88	1.05	26.43	0.69	99.66	0.56	±0.34
Cr 18	2.53	6.44	2.06	0.69	60.04	1.06	25.86	0.80	99.47	0.55	±0.33
Cr 20	7.38	6.67	1.68	0.70	59.43	0.92	22.62	0.35	99.73	0.65	±0.22
Cr 21	2.26	4.54	2.66	0.65	59.18	0.84	28.76	0.78	99.66	1.56	±0.24
Cr 22	1.94	5.59	3.15	0.74	58.73	0.79	27.52	n.d.	98.46	1.11	±0.22

OC-V 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 2	8.78	15.64	0.59	0.54	50.76	0.44	23.11	n.d.	99.87	1.49	±0.20
Cr 3	3.53	10.98	0.42	0.72	57.18	n.d.	26.53	n.d.	99.35	-1.80	±0.20
Cr 4	4.61	11.13	0.84	0.66	57.52	0.72	23.63	0.90	100.02	-	-
Cr 7	10.54	5.27	2.42	0.76	60.03	n.d.	18.90	n.d.	97.91	1.40	±0.23
Cr 10	7.20	17.85	0.76	0.77	49.32	n.d.	23.44	n.d.	99.34	-3.78	±0.33
Cr 11	7.24	9.54	1.59	1.00	54.82	0.63	24.00	n.d.	98.81	-	-
Cr 16	4.40	6.97	0.81	0.58	58.72	0.70	26.02	0.73	98.93	-	-
Cr 19	5.82	14.35	0.45	0.56	52.07	n.d.	26.24	n.d.	99.48	-2.37	±0.22
Cr 23	6.04	11.67	0.45	0.54	55.14	0.64	24.60	0.25	99.33	-	-

OC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 24	10.80	25.26	n.d.	0.29	46.24	n.d.	17.71	n.d.	100.29	0.05	±0.25

PUCKS 162 & 172- MMA 40 (103.0 + 98.0 kg = 201.0 kg)

EC >63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1	2.52	6.00	3.18	0.68	59.62	0.66	27.47	0.36	100.49	1.04	±0.27

EC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 2	2.43	5.51	3.31	0.69	58.32	1.00	27.67	0.70	99.62	1.02	±0.27
Cr 3	1.67	5.56	4.22	0.67	56.46	0.50	29.72	0.31	99.10	-	-
Cr 4	7.25	6.27	1.98	0.67	61.32	1.01	21.91	n.d.	100.41	0.68	±0.27
Cr 5	3.78	6.19	2.05	0.72	60.14	1.09	24.53	0.57	99.06	1.04	±0.28
Cr 6	2.29	5.78	2.18	0.77	59.94	1.14	27.74	0.75	100.58	0.85	±0.27
Cr 7	4.79	6.62	3.03	0.63	59.35	0.84	24.48	n.d.	99.74	0.62	±0.08
Cr 8	3.33	5.65	3.38	0.71	58.72	0.73	27.89	n.d.	100.40	1.28	±0.09
Cr 11	3.82	6.70	2.16	0.68	59.09	1.02	26.53	0.44	100.44	0.66	±0.09
Cr 12	5.20	6.57	2.14	0.72	59.38	0.96	24.27	n.d.	99.24	-	-
Cr 13	1.83	5.71	3.90	0.76	56.97	0.71	28.85	n.d.	98.73	1.34	±0.10
Cr 14	2.76	6.04	2.87	0.77	57.74	0.97	25.73	1.55	98.41	1.10	±0.14
Cr 2-1	1.81	5.46	4.35	0.76	57.11	0.59	29.84	0.50	100.41	0.93	±0.21
Cr 2-2	2.66	5.86	3.01	0.74	57.57	0.89	28.31	0.54	99.58	-	-
Cr 2-3	4.38	5.12	3.11	0.78	59.01	0.66	27.15	0.43	100.64	0.74	±0.19
Cr 2-4	2.28	5.61	3.23	0.57	58.56	0.99	28.82	0.48	100.54	0.79	±0.19
Cr 2-5	1.81	5.90	3.27	0.69	56.58	0.64	29.67	0.38	98.95	-	-
Cr 2-7	6.25	6.09	2.20	0.74	61.02	0.92	24.09	n.d.	101.31	0.56	±0.20
Cr 2-8	2.14	4.03	2.79	0.85	62.12	0.88	28.00	n.d.	100.81	-	-

OC-V 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 9	4.16	16.33	5.16	0.79	41.81	n.d.	31.95	n.d.	100.21	-3.52	±0.08
Cr 10	5.21	15.55	5.49	0.59	41.92	0.50	30.76	n.d.	100.01	-3.74	±0.08

OC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 2-6	12.59	26.30	n.d.	n.d.	43.05	n.d.	18.51	n.d.	100.44	-	-

PUCK 183 - MMA 39 & 42 (102.6 kg)

EC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1	1.51	5.25	4.30	0.76	55.80	0.65	30.97	n.d.	99.24	-	-
Cr 3	4.06	5.53	3.46	0.63	58.71	0.83	26.96	n.d.	100.18	-	-
Cr 4	4.24	5.84	2.60	0.57	61.09	0.98	24.60	0.52	100.44	-	-

OC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 2	10.17	17.71	0.49	n.d.	45.14	0.42	26.62	n.d.	100.55	-	-

PUCKS 195 & 196 - MMA 270 (105.6 kg)

EC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1-1	2.22	5.05	4.24	0.77	56.57	0.79	29.42	0.42	99.48	1.03	±0.20
Cr 1-4	3.05	7.16	2.26	0.72	60.02	1.20	26.30	0.44	101.15	0.47	±0.21
Cr 1-5	2.48	6.15	1.92	0.77	60.18	1.09	27.67	0.43	100.68	1.16	±0.19

OC-V 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1-3	3.38	9.92	0.93	0.82	54.37	0.45	29.46	n.d.	99.33	-0.38	±0.19

OC >63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 2-1	11.79	17.41	n.d.	0.28	53.23	n.d.	18.58	n.d.	101.29	-	-
Cr 2-2	12.68	21.87	0.51	0.43	44.41	n.d.	21.56	n.d.	101.45	-	-

OC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1-2*	4.17	6.77	n.d.	n.d.	74.73	0.70	12.64	1.72	100.72	-	-

*contamination?

PUCK 211 - MMA 285 (107.5 kg)

EC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 8	3.51	6.54	2.35	0.68	58.13	1.07	26.36	0.56	99.20	0.65	±0.25
Cr 10	3.18	6.29	2.29	0.63	59.15	1.16	27.53	n.d.	100.22	0.88	±0.25
Cr 14	2.12	5.66	3.38	0.67	57.15	0.85	28.49	0.40	98.73	-	-
Cr 17	3.36	6.63	2.34	0.66	58.11	1.00	27.40	n.d.	99.50	0.74	±0.25

OC-V 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 11	3.40	3.53	1.28	0.70	63.68	1.12	25.55	0.63	99.89	1.47	±0.25
Cr 12	5.22	10.44	0.49	0.49	56.28	n.d.	26.76	n.d.	99.69	-0.16	±0.25
Cr 16	7.04	9.43	0.81	0.61	60.00	0.68	21.65	n.d.	100.20	0.48	±0.25

OC >63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1	14.40	23.74	n.d.	0.28	47.23	n.d.	14.54	n.d.	100.18	-0.11	±0.25
Cr 2	12.81	19.73	n.d.	0.34	49.38	n.d.	18.00	n.d.	100.26	0.04	±0.25
Cr 4	11.06	21.44	n.d.	n.d.	47.15	n.d.	19.73	n.d.	99.38	-	-
Cr 5	3.96	2.42	0.45	0.42	57.21	0.56	30.60	n.d.	95.63	-	-
Cr 6	11.70	19.26	0.52	0.37	46.00	0.45	20.93	n.d.	99.49	-	-
Cr 7	4.09	2.60	0.38	0.41	58.93	0.57	31.60	n.d.	98.58	-	-

OC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 9	11.98	14.69	n.d.	n.d.	56.43	n.d.	17.53	n.d.	100.62	-	-
Cr 13	7.99	13.27	n.d.	n.d.	55.39	n.d.	23.44	n.d.	100.08	-	-
Cr 15	11.88	19.11	0.26	n.d.	48.64	0.52	18.96	n.d.	99.37	-	-

PUCKS 161, 164, 195, 196, 212 & 228 - MMA 335 (28.0 + 102.5 + 98.7 + 104.9 + 98.7 kg = 432.8 kg)

EC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 2-1	2.78	6.22	1.84	0.64	58.92	1.00	27.02	0.61	99.03	0.44	±0.18
Cr 2-4	2.59	5.69	1.89	0.60	59.09	1.23	27.48	0.48	99.04	0.69	±0.18
Cr 2-5	1.62	5.39	4.30	0.75	57.03	0.70	30.70	0.26	100.74	1.21	±0.18
Cr 2-9	3.14	6.01	2.48	0.57	59.87	0.98	27.21	n.d.	100.27	0.71	±0.18
Cr 2-10	3.29	4.57	3.09	0.63	60.51	0.76	27.93	n.d.	100.78	1.28	+0.18
Cr 3-1	2.30	5.96	2.66	0.72	58.24	1.02	29.36	0.37	100.63	1.03	±0.19
Cr 3-8	3.50	5.53	2.15	0.65	60.22	0.98	26.67	n.d.	99.69	0.94	±0.19
Cr 3-11	3.69	6.71	2.49	0.66	60.31	1.04	26.07	0.52	101.49	-	-
Cr 5-4	3.56	6.69	2.16	0.77	58.51	1.12	26.41	0.49	99.72	0.82	±0.19
Cr 5-5	3.77	4.85	2.19	0.69	61.26	1.21	25.98	n.d.	98.68	1.52	±0.19
Cr 6-3	2.29	5.38	3.16	0.75	58.33	0.90	28.52	0.45	99.78	1.27	±0.20
Cr 6-4	3.85	5.94	3.47	0.69	57.13	0.80	26.99	0.40	99.28	1.26	±0.19
Cr 6-7	1.77	6.53	3.32	0.69	54.15	0.71	31.34	0.39	98.91	-	-
Cr 6-8	1.33	2.94	2.03	0.62	51.98	1.02	22.54	n.d.	82.44	-	-
Cr 6-12	3.57	5.80	1.99	0.72	60.62	1.28	25.70	n.d.	99.68	-	-
Cr 7-1	1.79	5.74	4.44	0.64	54.81	0.71	30.96	0.46	99.54	-	-

OC-V >63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 5-1	3.08	9.30	3.34	0.70	53.95	0.81	27.29	n.d.	98.46	-0.38	±0.19
Cr 5-2	9.29	16.52	1.36	0.63	42.63	0.42	28.84	n.d.	99.67	0.05	±0.19

OC-V 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 2-15	2.99	4.39	n.d.	0.46	54.04	0.73	34.68	n.d.	97.29	-	-
Cr 1-1	5.25	14.16	0.95	0.49	54.32	0.77	25.36	n.d.	101.30	-	-
Cr3-3a*	3.52	7.83	n.d.	0.45	53.62	0.95	32.16	0.53	99.07	-	-
Cr3-3b*	6.72	20.16	n.d.	n.d.	45.90	0.66	25.50	0.47	99.41	-	-
Cr 3-4	3.10	6.77	n.d.	0.57	55.52	0.96	33.75	0.49	101.16	-	-
Cr 6-6	8.62	20.50	1.18	0.61	46.65	n.d.	22.13	n.d.	99.69	-3.02	±0.19

* Grain has two phases

OC >63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 2-16	11.09	19.86	0.25	0.26	48.52	n.d.	19.56	n.d.	99.53	0.07	±0.18
Cr 2-17	13.29	24.24	n.d.	n.d.	44.96	n.d.	16.24	n.d.	98.73	0.05	±0.18
Cr 2-18	8.54	17.48	0.57	0.33	51.82	n.d.	20.82	n.d.	99.56	-	-

Cr 4-1	9.04	13.19	n.d.	n.d.	53.91	0.50	23.08	n.d.	99.72	-	-
Cr 4-2	12.05	22.11	n.d.	n.d.	43.88	0.36	20.20	n.d.	98.61	-	-
Cr 4-3	12.83	22.55	n.d.	n.d.	46.13	n.d.	17.07	n.d.	98.58	-	-
Cr 4-4	9.78	13.84	n.d.	n.d.	53.85	n.d.	22.74	n.d.	100.21	-	-
Cr 4-5	10.63	18.61	n.d.	n.d.	49.39	0.46	21.58	n.d.	100.67	-	-
Cr 5-3	8.10	13.03	n.d.	0.30	55.10	n.d.	22.79	n.d.	99.33	-	-
Cr 6-1	11.80	18.00	0.26	n.d.	49.25	n.d.	20.40	n.d.	99.71	-	-
Cr 6-2	13.33	23.81	n.d.	n.d.	44.03	0.44	17.55	n.d.	99.15	-	-

OC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 2-2	9.96	18.39	1.00	0.44	44.71	n.d.	24.08	n.d.	98.58	0.08	±0.18
Cr 2-3	9.90	18.09	0.91	0.38	44.78	n.d.	24.36	n.d.	98.42	-0.05	±0.18
Cr 2-6	13.43	24.53	n.d.	0.28	44.11	n.d.	16.50	n.d.	98.85	0.07	±0.17
Cr 2-7	9.94	15.08	n.d.	0.34	49.91	n.d.	23.78	n.d.	99.05	-0.31	±0.18
Cr 2-8	11.78	23.95	n.d.	0.34	44.83	n.d.	19.90	n.d.	100.81	-	-
Cr 2-11	12.86	25.58	0.41	0.29	41.51	n.d.	19.39	n.d.	100.03	-0.12	±0.17
Cr 2-12	10.09	15.22	n.d.	0.22	53.83	n.d.	20.98	n.d.	100.35	-0.18	±0.18
Cr 2-13	8.94	9.55	n.d.	n.d.	61.05	n.d.	20.30	n.d.	99.85	-0.15	±0.19
Cr 2-14	14.58	24.79	n.d.	0.26	45.02	0.48	14.88	n.d.	99.99	-	-
Cr 3-2	12.86	24.48	n.d.	n.d.	45.94	0.43	15.74	n.d.	99.45	-	-
Cr 3-5	6.78	14.53	1.45	0.44	44.66	0.67	31.99	n.d.	100.52	-0.23	±0.19
Cr 3-6	9.93	24.60	0.41	0.30	41.91	n.d.	23.34	0.44	100.93	0.01	±0.18
Cr 3-7	9.67	23.75	0.40	0.28	42.92	n.d.	23.18	0.44	100.65	-	-
Cr 3-9	5.38	10.58	n.d.	0.25	52.87	0.59	30.15	n.d.	99.83	-	-
Cr 3-10	6.38	16.69	n.d.	0.29	48.11	0.85	27.40	n.d.	99.71	-	-
Cr 5-6	13.92	25.19	n.d.	n.d.	43.59	n.d.	15.97	n.d.	98.68	-	-
Cr 5-7	9.36	22.24	0.64	0.30	40.53	0.42	25.26	n.d.	98.75	0.08	±0.19
Cr 6-5	9.33	13.08	n.d.	n.d.	54.67	0.42	21.57	n.d.	99.07	-	-
Cr 6-9	11.69	25.77	n.d.	n.d.	42.96	n.d.	19.24	n.d.	99.66	-	-
Cr 6-10	12.55	23.03	0.25	n.d.	47.00	n.d.	17.65	n.d.	100.50	-	-
Cr 6-11	9.59	18.29	0.91	0.38	42.29	n.d.	29.05	n.d.	100.51	-0.14	±0.19
Cr 6-13	9.54	17.57	n.d.	0.29	51.03	n.d.	20.89	n.d.	99.31	-0.02	±0.19
Cr 7-2	9.20	13.21	n.d.	n.d.	56.22	n.d.	21.59	n.d.	100.21	-	-
Cr 8-1	7.96	23.71	n.d.	n.d.	37.74	n.d.	30.82	n.d.	100.23	-	-
Cr 8-2	8.03	17.06	0.88	0.39	45.44	n.d.	27.82	n.d.	99.63	-	-
Cr 8-3	6.65	5.89	0.53	n.d.	55.47	n.d.	31.49	n.d.	100.02	-	-

PUCK 161 - MMA 349 (27.0 kg)

OC >63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1	13.98	26.30	n.d.	n.d.	43.76	0.36	15.84	n.d.	100.23	-	-
Cr 2	10.87	19.15	n.d.	n.d.	48.92	n.d.	21.01	n.d.	99.95	-	-

PUCKS 165 & 161- MMA 366 (102.2 kg) + MMA 367 (25.6 kg) (= 127.8 kg)

EC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1-2	2.94	6.04	2.90	0.75	59.70	0.94	26.87	0.79	100.92	-	-
Cr 1-3	2.34	6.09	3.04	0.70	59.01	0.68	28.57	0.41	100.85	-	-
Cr 1-11	3.68	5.41	2.05	0.70	59.86	1.08	25.07	0.53	98.38	-	-
Cr 2-1	2.61	5.74	3.02	0.71	59.46	0.73	27.71	n.d.	99.98	-	-
Cr 2-3	3.59	6.90	1.88	0.74	59.84	1.09	26.82	n.d.	100.85	-	-

OC >63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1-14	13.27	25.39	n.d.	0.24	43.88	n.d.	17.28	n.d.	100.05	-	-
Cr 1-15	13.14	21.72	n.d	n.d.	48.01	0.49	16.22	n.d.	99.58	-	-
Cr 1-16	3.18	12.66	0.58	0.36	47.69	0.53	35.40	0.78	101.18	-	-
Cr 1-17	9.37	18.86	1.00	0.41	44.08	0.39	26.84	n.d.	100.94	-	-
Cr 1-18	13.42	23.56	n.d	n.d.	46.21	0.41	16.30	n.d.	99.91	-	-
Cr 1-19	12.49	21.96	0.29	0.36	45.39	n.d.	18.85	n.d.	99.34	-	-
Cr 1-20	8.95	17.04	n.d.	n.d.	47.87	n.d.	25.72	n.d.	99.58	-	-

OC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1-1	14.62	22.87	n.d.	n.d.	47.95	n.d.	15.39	n.d.	100.84	-	-
Cr 1-4	8.83	21.69	n.d.	n.d.	46.09	n.d.	22.37	0.42	99.41	-	-
Cr 1-5	11.92	19.01	0.34	0.20	48.23	0.46	19.63	n.d.	99.77	-	-
Cr 1-6	12.17	23.14	n.d.	0.27	45.79	0.39	17.94	n.d.	99.70	-	-
Cr 1-7	10.47	20.90	n.d.	n.d.	48.00	n.d.	20.87	n.d.	100.24	-	-
Cr 1-8	9.90	19.69	0.62	0.38	43.19	n.d.	25.20	n.d.	98.99	-	-
Cr 1-9	10.15	13.37	n.d.	n.d.	56.22	n.d.	19.65	n.d.	99.39	-	-
Cr 1-10	6.25	14.03	0.36	n.d.	49.62	n.d.	30.92	n.d.	101.18	-	-
Cr 1-12	9.55	22.68	n.d.	n.d.	44.44	0.75	22.14	0.45	100.00	-	-
Cr 1-13	8.92	17.78	0.69	n.d.	42.43	0.41	29.22	0.14	99.58	-	-
Cr 2-2	10.22	16.96	1.07	0.39	42.27	n.d.	28.47	n.d.	99.39	-	-

PUCK 189 - MMA 406 (110.0 kg)

EC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1	2.07	5.97	2.83	0.76	57.66	0.91	28.44	0.41	99.05	-	-
Cr 7	7.94	4.80	4.15	0.70	59.50	0.57	22.69	0.38	100.72	-	-
Cr 14	2.46	5.81	1.55	0.77	64.41	1.55	24.19	0.47	101.21	1.14	±0.24
Cr 15	3.69	5.21	2.69	0.80	61.08	0.74	26.08	0.49	100.77	-	-

OC-V 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 16	6.70	14.61	1.34	0.63	40.86	0.46	34.12	n.d.	98.73	-0.05	±0.27
Cr 17	6.92	15.14	1.38	0.64	41.33	n.d.	34.72	n.d.	100.14	-0.20	±0.24

OC >63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 10	13.31	24.42	n.d.	n.d.	45.45	n.d.	17.16	n.d.	100.34	-	-
Cr 11	10.30	18.54	0.44	0.37	44.08	0.47	27.04	n.d.	101.24	-0.07	±0.24
Cr 12	9.90	19.71	0.48	n.d.	46.24	0.53	24.10	n.d.	100.97	-	-

OC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 2	11.28	21.44	0.20	0.32	45.54	n.d.	20.30	n.d.	99.07	-	-
Cr 3	10.33	14.39	n.d.	n.d.	56.90	n.d.	19.24	n.d.	100.86	-	-
Cr 4	6.72	10.37	n.d.	0.30	58.44	0.58	23.25	n.d.	99.67	-	-
Cr 5	9.26	10.96	3.60	n.d.	41.97	0.47	33.78	n.d.	100.03	-	-
Cr 6	11.20	19.30	n.d.	n.d.	51.45	0.47	17.87	n.d.	100.28	-	-
Cr 8	4.07	25.86	0.50	n.d.	41.98	1.19	23.47	1.94	99.00	-	-
Cr 9	12.36	16.57	n.d.	0.32	53.97	n.d.	16.94	n.d.	100.17	-	-
Cr 13	14.19	25.99	n.d.	n.d.	44.58	n.d.	16.54	n.d.	101.31	-	-

Mg-Al spinel 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
MgAl 1	28.05	69.83	0.22	n.d.	0.13	n.d.	1.18	0.49	99.90	-	-

PUCK 160 - MMA 415 (104.3 kg)

EC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 6	2.31	5.77	3.14	0.70	57.81	0.74	29.48	n.d.	99.95	1.19	±0.21
Cr 7	2.39	6.14	2.99	0.69	58.55	0.96	27.96	0.50	100.19	-	-
Cr 9	5.49	7.04	1.86	0.74	60.09	0.78	23.15	0.40	99.56	0.85	±0.23
Cr 11	2.14	5.84	2.71	0.68	59.05	0.97	28.75	0.42	100.55	1.15	±0.22

OC-V 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 8	6.08	13.50	0.56	0.64	52.57	n.d.	25.12	n.d.	98.46	1.26	±0.21

OC >63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 1	8.48	18.26	0.72	0.37	45.49	n.d.	26.42	n.d.	99.74	0.04	±0.21
Cr 2	11.58	19.62	n.d.	n.d.	46.61	n.d.	16.18	n.d.	93.99	-	-

OC 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total	$\Delta^{17}O$	2SD
Cr 3	9.74	15.06	n.d.	0.35	54.76	0.44	20.49	n.d.	100.84	-0.14	±0.22
Cr 4	13.15	25.71	n.d.	0.26	43.69	n.d.	16.93	0.29	100.03	0.06	±0.21
Cr 5	10.42	20.40	0.49	0.32	43.52	n.d.	25.69	n.d.	100.85	0.07	±0.21
Cr 10	12.48	26.83	n.d.	n.d.	41.54	n.d.	17.67	0.39	98.92	0.34	±0.21

TABLE DR3. DIVISION OF ORDINARY CHONDRITIC GRAINS USING TiO_2 AND/OR $\Delta^{17}O$

Below we evaluate TiO_2 and $\Delta^{17}O$ in equilibrated ordinary chondritic chromite grains for dividing grains into the three groups, H, L, and LL. We show that both methods give similar results. We note also that there is no indication that a grain lying in the tail of the TiO_2 distribution lies in the corresponding tail of the $\Delta^{17}O$ distribution. Rare grains may have H-chondritic $\Delta^{17}O$, but LL-chondritic TiO_2 and vice versa.

(1) Division of equilibrated ordinary chondritic grains using TiO_2 vs. $\Delta^{17}O$

	H	**L**	**LL**
TiO_2	**≤2.50%**	**2.51-3.39%**	**≥3.40%**
Early Cretaceous (n=46)[1]	23	18	5
%	*50*	*39*	*11*
Early Cretaceous (n=81)[2]	36	34	10
%	*44*	*42*	*14*
Mid-Ordovician, post-LCPB (n=119)[3]	10	102	7
%	*8*	*86*	*6*
Mid-Ordovician, pre-LCPB (n=23)[4]	6	8	9
%	*26*	*35*	*39*
$\Delta^{17}O$	**≤0.80**	**0.81-1.24**	**≥1.25**
Early Cretaceous (n=46)[1]	15	23	8
%	*33*	*50*	*17*
Mid-Ordovician, post-LCPB (n=119)[3]	7	106	6
%	*6*	*89*	*5*
Mid-Ordovician, pre-LCPB (n=23)[4]	5	11	7
%	*22*	*48*	*30*

[1]This study, EC grains analyzed for both TiO_2 and $\Delta^{17}O$, [2]This study, all EC grains. [3]Heck et al. (2016), [4]Heck et al. (2017)

(2) Division of equilibrated ordinary chondritic grains using TiO_2 & $\Delta^{17}O$

	H	H/L	L	L/LL	LL	H/LL
Early Cretaceous (n=46)[1]	12	13	10	8	2	1
%	*26*	*28*	*22*	*17*	*4*	*2*
Mid-Ordovician, post-LCPB (n=119)[2]	1	13	92	11	0	2
%	*1*	*11*	*77*	*9*	*0*	*2*
Mid-Ordovician, pre-LCPB (n=23)[3]	4	3	5	6	5	0
%	*17*	*13*	*22*	*26*	*22*	*0*

[1]This study, [2]Heck et al. (2016), [3]Heck et al. (2017)

TABLE DR4. SUMMARY OF RESULTS OF ELEMENTAL ANALYSES OF EQUILIBRATED ORDINARY CHONDRITIC GRAINS FROM BED GAP7 IN MID-ORDOVICIAN. LYNNA RIVER SECTION IN RUSSIA.

Material and methods

The table contains the SEM/EDS results for EC grains from bed GAP7 from the Lynna section east of St.. Petersburg in Russia. The results for grains >63 µm are from Heck et al. (2017), whereas the 32-63 µm grains were analyzed for the present study. For details on analyses and stratigraphy, see Heck et al. (2017). Results from Lindskog et al. (2012) are also included. "Puck" is Swedish for "Epoxy mount". Grains from four samples have been analysed (102.4, 107.5, 62.3 and 13.0 kg).

Colored TiO_2 results refer to inferred petrographic type, red = H, black = L, blue = LL, see main text.

PUCK 105 - GAP7 - 102.4 kg - >63 µm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total
Cr 1	2.29	6.91	3.87	0.76	59.08	0.56	27.25	0.57	101.29
Cr 2	1.92	6.01	3.77	0.72	57.97	n.d.	30.34	n.d.	100.72
Cr 6	2.85	6.21	2.19	0.86	59.21	0.89	27.35	1.33	100.88
Cr 10	2.05	5.61	4.81	0.81	58.41	0.65	27.83	n.d.	100.16
Cr 12	6.74	5.83	2.27	0.69	60.30	0.78	23.44	n.d.	100.06
Cr 13	3.36	6.82	1.62	0.65	59.28	0.93	27.70	n.d.	100.37
Cr 14	2.93	6.53	3.23	0.73	57.36	0.80	27.74	0.38	99.71

PUCK 218 - GAP7 - 102.4 kg - 32-63 µm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total
Cr 10	2.09	5.41	2.43	0.72	59.78	0.94	27.96	1.08	100.40
Cr 11	2.95	6.76	2.05	0.78	60.46	1.05	26.77	0.55	101.36
Cr 13	8.83	6.32	2.11	0.75	60.83	0.84	19.68	n.d	99.37
Cr 19	1.56	5.49	2.90	0.79	59.33	0.71	29.23	n.d.	100.00
Cr 22	2.28	5.49	4.01	0.76	57.45	0.76	29.34	0.44	100.52
Cr 25	3.80	5.62	3.42	0.73	58.92	0.98	27.01	n.d.	100.49
Cr 28	3.00	6.43	3.19	0.83	60.08	0.77	26.55	0.40	101.25
Cr 31	3.69	5.35	3.57	0.77	57.01	0.74	28.15	0.52	99.81
Cr 33	2.35	6.01	2.50	0.87	60.02	0.78	28.05	0.46	101.03

Cr 34	2.75	5.48	3.26	0.75	58.22	0.75	28.59	0.64	100.45
Cr 35	6.50	5.58	3.11	0.72	57.84	0.70	24.53	n.d.	98.97
Cr 37	3.03	6.89	2.15	0.77	59.31	1.20	26.86	0.53	100.72
Cr 38	3.83	6.32	2.40	0.68	59.51	0.78	27.06	0.54	101.12

PUCK 219 - GAP7 - 102.4 kg - 32-63 µm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total
Cr 1	1.93	4.80	2.16	0.73	61.38	0.93	28.15	0.68	100.77
Cr 2	2.51	6.74	2.26	0.81	59.19	1.02	28.05	n.d.	100.58
Cr 4	7.14	4.62	2.41	0.71	59.20	0.70	24.60	n.d.	99.38
Cr 6	3.35	6.46	2.30	0.75	58.97	0.99	26.38	n.d.	99.20
Cr 8	2.80	4.49	2.36	0.70	61.05	0.67	27.18	0.54	99.79
Cr 9	1.69	5.87	4.61	0.85	55.64	0.61	30.85	0.47	100.59
Cr 10	2.00	5.45	3.59	0.70	57.70	0.67	28.53	n.d.	98.64
Cr 11	2.43	5.97	2.65	0.78	59.61	0.82	27.66	0.56	100.48
Cr 12	6.30	6.20	2.13	0.67	60.02	1.01	23.63	0.49	100.46
Cr 15	2.73	6.05	2.79	0.63	58.74	0.89	27.80	n.d.	99.62
Cr 17	1.99	6.29	3.60	0.75	58.18	0.79	28.50	0.33	100.43
Cr 18	2.97	6.91	2.22	0.62	59.80	1.05	24.59	1.84	100.00
Cr 23	6.66	7.26	2.59	0.64	60.39	1.01	22.13	n.d.	100.69
Cr 24	2.07	4.72	2.60	0.77	60.20	0.93	29.02	0.55	100.88
Cr 27	4.61	5.55	1.20	0.77	61.66	n.d.	23.31	2.18	99.28
Cr 29	2.15	6.01	3.36	0.74	57.26	0.72	29.67	0.50	100.42
Cr 30	1.64	5.57	2.75	0.76	58.31	0.95	29.86	0.64	100.48
Cr 31	2.21	5.74	3.33	0.77	57.56	0.79	28.84	0.53	99.76
Cr 32	2.17	6.21	2.89	0.74	58.58	0.61	29.24	0.41	100.85
Cr 35	2.49	4.79	3.39	0.79	59.17	0.71	28.51	0.56	100.40
Cr 36	2.03	6.31	3.64	0.72	56.61	0.72	30.04	0.42	100.48
Cr 37	3.81	6.24	3.72	0.76	55.31	0.62	28.66	0.50	99.62

PUCK 220 - GAP7 - 102.4 kg - 32-63 µm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total
Cr 1	2.97	6.18	3.35	0.79	57.54	0.90	27.64	0.47	99.84
Cr 3	3.17	5.89	3.46	0.82	57.78	0.57	28.08	n.d.	99.76
Cr 4	4.40	6.62	2.26	0.70	59.49	1.00	26.12	n.d.	100.58
Cr 5	2.39	5.74	3.52	0.68	58.20	0.97	28.91	0.51	100.91
Cr 6	4.16	4.61	3.19	0.79	60.02	0.92	26.52	0.51	100.72
Cr 10	3.31	7.08	2.22	0.75	59.74	1.13	26.65	0.56	101.44
Cr 12	1.98	5.51	4.25	0.86	57.11	0.92	28.97	n.d.	99.62
Cr 13	6.23	5.82	2.57	0.75	60.04	0.92	23.19	n.d.	99.52

Cr 14	3.04	6.61	1.74	0.79	59.45	0.88	25.43	1.18	99.12
Cr 21	3.56	5.37	2.50	0.70	59.49	0.78	27.51	0.37	100.27
Cr 22	2.33	6.33	2.38	0.68	58.60	0.97	28.16	0.26	99.71
Cr 23	2.31	5.50	2.67	0.78	57.41	0.89	28.68	0.56	98.79
Cr 24	2.48	5.63	3.32	0.79	56.25	0.77	28.85	0.41	98.48
Cr 25	2.28	5.50	3.39	0.68	58.91	1.02	28.73	0.41	100.93
Cr 27	3.09	6.78	2.41	0.78	58.55	0.97	26.80	n.d.	99.38
Cr 28	3.03	6.59	2.18	0.75	59.81	1.02	26.74	n.d.	100.13
Cr 29	3.02	6.70	2.37	0.67	59.89	0.95	27.25	n.d.	100.86
Cr 30	4.04	6.82	2.12	0.74	60.52	0.99	24.14	n.d.	99.37
Cr 32	1.98	5.70	3.69	0.74	56.81	0.66	28.16	0.58	98.32
Cr 33	2.14	5.82	3.38	0.77	59.96	0.68	24.98	1.19	98.91
Cr 34	2.85	6.35	3.00	0.72	58.42	0.99	27.34	n.d.	99.66
Cr 35	6.26	6.12	3.12	0.82	58.25	0.61	24.03	0.40	99.62

PUCK 221 - GAP7 - 102.4 kg - 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total
Cr 2	2.79	5.24	4.58	0.62	56.64	0.63	30.10	n.d.	100.60
Cr 4	3.46	5.81	3.39	0.79	58.12	0.70	28.08	n.d.	100.35
Cr 7	7.13	6.77	2.85	0.85	60.38	0.44	20.69	1.60	100.71
Cr 8	3.18	6.73	2.51	0.67	59.25	0.91	24.72	2.64	100.61
Cr 9	2.56	6.12	4.14	0.78	57.10	0.66	28.19	0.60	100.15
Cr 10	2.90	6.29	2.92	0.92	60.07	0.69	27.35	n.d.	101.13
Cr 12	5.86	5.98	2.20	0.80	60.35	0.92	23.93	n.d.	100.05
Cr 13	3.14	6.48	2.26	0.78	59.96	1.06	26.66	0.39	100.73
Cr 17	3.00	6.79	2.21	0.84	60.27	0.91	26.52	0.45	100.99
Cr 18	1.94	5.70	2.49	0.87	61.08	0.86	26.23	0.55	99.73
Cr 20	4.34	6.10	3.15	0.72	57.55	0.81	27.49	n.d.	100.16
Cr 21	5.07	5.86	3.51	0.80	59.57	0.52	26.15	n.d.	101.49
Cr 22	1.90	5.89	4.16	0.84	58.73	0.74	28.83	n.d.	101.09
Cr 23	2.92	5.34	3.71	0.71	58.57	0.81	27.18	0.27	99.50
Cr 24	2.71	5.20	3.94	0.67	57.73	0.90	28.43	0.51	100.09
Cr 25	4.19	6.51	2.15	0.67	58.88	1.02	26.59	0.51	100.52
Cr 26	1.57	5.91	4.03	0.70	55.84	0.64	31.31	n.d.	100.00
Cr 27	3.63	5.51	1.99	0.81	60.34	1.02	26.84	0.74	100.87
Cr 28	5.56	6.21	2.20	0.79	60.77	0.92	24.17	0.30	100.92
Cr 30	6.93	8.69	1.57	0.63	60.95	0.89	20.83	n.d.	100.49
Cr 36	1.91	6.53	2.55	0.74	62.90	0.67	23.01	1.11	99.41
Cr 37	1.88	6.19	2.03	0.78	59.45	0.58	25.41	2.87	99.18

PUCK 222 - GAP7 - 102.4 kg - 32-63 µm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total
Cr 1	2.47	5.57	3.54	0.72	57.70	1.04	27.55	1.80	100.40
Cr 2	2.43	6.43	2.74	0.81	58.92	0.77	27.32	0.63	100.04
Cr 3	2.25	6.28	3.19	0.82	57.92	0.85	29.11	0.35	100.78
Cr 4	2.06	5.62	3.30	0.68	60.29	0.58	25.23	1.47	99.24
Cr 8	8.33	4.96	2.94	0.60	59.30	0.69	22.21	n.d.	99.02
Cr 9	1.81	5.18	3.56	0.77	59.52	0.66	29.47	0.37	101.33
Cr 10	3.02	9.78	1.40	0.53	57.64	0.79	26.94	n.d.	100.11
Cr 11	2.45	5.58	3.79	0.74	57.35	0.93	28.74	n.d.	99.57
Cr 12	2.89	5.44	2.75	0.75	59.04	1.14	27.98	0.71	100.68
Cr 14	3.36	5.98	2.89	0.83	58.02	0.76	27.88	n.d.	99.71
Cr 16	2.12	6.58	2.62	0.75	58.57	0.97	28.81	0.47	100.89
Cr 17	3.33	6.72	2.26	0.69	59.18	0.94	26.57	0.54	100.24
Cr 18	5.73	6.18	3.09	0.73	57.63	0.67	25.13	0.42	99.59
Cr 19	3.53	7.02	1.86	0.72	59.47	1.05	26.07	n.d.	99.72
Cr 20	2.74	6.26	3.48	0.76	55.66	0.62	29.66	n.d.	99.18
Cr 26	2.41	5.77	3.18	0.63	58.65	1.04	29.27	0.48	101.42
Cr 29	5.78	4.62	1.41	0.84	63.92	0.95	22.74	n.d.	100.27
Cr 32	2.26	6.10	2.21	0.67	58.57	0.77	28.60	n.d.	99.18
Cr 33	1.72	6.59	3.05	0.77	56.62	0.74	30.37	0.44	100.29
Cr 36	2.78	6.71	2.40	0.74	60.85	0.65	25.31	0.86	100.29
Cr 37	6.08	6.35	2.39	0.66	61.43	0.85	22.30	n.d.	100.06

PUCK 84 - GAP7 - 107.5 kg - >63 µm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total
Cr 2	5.29	6.67	2.38	0.69	58.13	0.98	24.58	0.30	99.02
Cr 3	3.25	5.51	3.11	0.80	59.26	0.93	26.77	0.59	100.22
Cr 5	3.40	6.83	2.37	0.74	57.95	0.92	26.27	0.49	98.97
Cr 7	2.49	6.57	3.40	0.70	56.93	0.74	27.98	n.d.	98.81
Cr 10	3.14	6.25	2.32	0.61	59.78	0.89	26.15	0.84	99.98
Cr 11	2.55	6.02	3.46	0.87	60.40	0.78	26.02	0.58	100.69
Cr 12	2.05	6.94	3.37	0.82	56.99	0.71	28.39	0.41	99.68
Cr 13	3.10	6.52	2.61	0.59	59.80	0.99	26.82	0.46	100.89
Cr 15	1.91	5.59	4.28	0.80	57.67	0.89	29.00	0.31	100.46
Cr 16	3.77	5.11	3.26	0.67	59.00	1.03	25.26	1.53	99.63
Cr 17	2.83	5.23	3.06	0.77	60.04	n.d.	28.42	0.76	101.11
Cr 21	6.13	6.37	2.78	0.77	60.00	0.78	23.03	0.43	100.28
Cr 22	3.25	6.29	3.71	0.83	57.77	0.68	26.16	0.65	99.34

PUCK 103 - GAP7 - 107.5 kg - 32-63 µm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total
Cr 1	2.11	5.66	3.58	0.57	57.76	0.47	29.64	0.43	100.22
Cr 3	2.81	5.01	4.47	0.62	55.78	0.40	29.81	0.14	99.03
Cr 4	1.83	3.91	3.57	0.73	59.03	0.46	29.33	0.48	99.35
Cr 5	3.36	5.31	3.62	0.61	57.21	0.41	29.32	0.20	100.04
Cr 7	1.98	6.25	2.60	0.71	58.52	0.51	28.90	0.67	100.13
Cr 11	4.34	5.66	2.94	0.69	58.92	0.39	26.97	0.29	100.20
Cr 12	3.86	6.82	1.93	0.69	59.26	0.61	27.05	0.33	100.54
Cr 13	5.27	5.10	3.22	0.64	59.42	0.35	26.40	0.15	100.56
Cr 15	3.87	6.01	2.74	0.72	59.76	0.48	26.70	0.23	100.51
Cr 16	3.90	6.24	2.32	0.66	59.09	0.57	27.23	0.31	100.34
Cr 18	3.40	5.78	1.81	0.62	61.64	0.73	27.18	0.36	101.52
Cr 19	2.14	5.83	2.80	0.66	58.08	0.50	28.82	0.34	99.18
Cr 21	2.09	7.44	1.80	0.68	61.85	0.58	23.84	0.38	98.66
Cr 24	4.88	6.01	2.39	0.55	60.23	0.59	24.60	0.05	99.30
Cr 25	3.33	6.33	2.26	0.69	59.06	0.73	26.78	0.59	99.77
Cr 27	2.00	5.76	3.50	0.72	57.28	0.53	30.15	0.23	100.17
Cr 30	3.27	6.59	2.24	0.70	59.54	0.62	26.53	0.24	99.73
Cr 31	1.53	5.16	3.01	0.62	59.90	0.42	26.98	0.69	98.31
Cr 34	1.63	5.57	4.23	0.57	56.81	0.28	27.93	0.54	97.56
Cr 36	1.99	5.13	3.04	0.74	58.36	0.41	28.98	0.45	99.10
Cr 41	2.12	6.27	2.55	0.71	58.64	0.55	27.84	0.35	99.03
Cr 44	1.75	5.64	2.24	0.73	60.41	0.41	27.09	0.37	98.64
Cr 46	2.14	4.44	2.92	0.64	60.75	0.44	24.88	2.69	98.92
Cr 47	2.07	5.88	2.41	0.74	58.63	0.56	28.84	0.35	99.49
Cr 51	2.16	6.32	2.27	0.69	58.50	0.63	28.22	0.58	99.36
Cr 53	2.11	6.21	2.57	0.69	57.38	0.40	29.01	0.48	98.86
Cr 54	3.47	5.72	2.22	0.59	59.18	0.38	26.47	0.16	98.19
Cr 55	3.55	5.30	2.51	0.63	57.92	0.46	28.45	0.29	99.11
Cr 56	4.97	6.51	2.31	0.67	59.11	0.69	24.27	1.02	99.54
Cr 57	2.39	5.97	2.29	0.56	59.90	0.75	26.61	1.45	99.92
Cr 58	1.81	6.76	2.89	0.68	55.87	0.37	30.88	0.32	99.58
Cr 60	2.17	4.98	3.42	0.68	57.98	0.49	29.81	0.30	99.83
Cr 62	2.90	5.43	4.48	0.33	63.46	0.72	22.72	0.06	100.09
Cr 64	2.42	5.49	3.45	0.72	57.51	0.43	29.23	0.21	99.46
Cr 67	4.08	5.23	3.75	0.67	57.68	0.43	27.44	0.44	99.72
Cr 68	3.35	6.45	2.46	0.65	59.01	0.67	26.44	0.54	99.58
Cr 70	2.23	5.90	2.30	0.64	58.72	0.60	28.48	0.35	99.22
Cr 71	3.32	4.84	2.37	0.63	59.85	0.45	27.58	0.35	99.40

PUCK 104 - GAP7 - 107.5 kg - 32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total
Cr 1	2.16	5.06	2.52	0.74	59.38	0.61	25.41	2.74	98.62
Cr 2	2.07	6.01	2.92	0.67	57.31	0.44	30.31	0.27	100.00
Cr 6	2.58	5.01	2.81	0.70	58.68	0.65	27.39	1.71	99.52
Cr 7	2.85	5.91	2.25	0.69	60.32	0.78	27.31	0.41	100.52
Cr 8	3.62	4.89	3.91	0.71	57.44	0.37	28.92	0.19	100.04
Cr 11	1.95	5.29	3.83	0.58	58.60	0.38	27.75	0.48	98.85
Cr 12	2.10	5.16	3.55	0.58	58.43	0.47	30.23	0.35	100.85
Cr 13	5.31	5.63	3.68	0.63	57.64	0.42	26.64	0.22	100.16
Cr 15	2.88	5.54	3.59	0.69	57.18	0.45	29.25	0.26	99.84
Cr 16	1.90	5.93	3.70	0.68	57.31	0.36	29.31	0.25	99.44
Cr 17	6.26	6.00	2.19	0.65	59.38	0.48	23.05	0.82	98.83
Cr 18	1.58	5.89	3.02	0.68	57.07	0.36	31.45	0.32	100.36
Cr 19	6.55	5.45	3.71	0.72	58.21	0.30	24.10	0.24	99.29
Cr 23	3.15	6.16	2.32	0.67	59.10	0.68	27.04	0.40	99.52
Cr 26	1.45	5.23	1.80	0.74	62.35	0.62	21.97	3.16	97.33
Cr 27	1.31	4.12	2.49	0.67	63.53	0.35	26.65	0.33	99.46
Cr 29	1.80	5.35	3.75	0.76	58.56	0.40	25.76	0.70	97.07
Cr 33	2.66	5.51	3.52	0.61	57.90	0.45	28.93	0.21	99.80
Cr 35	2.45	5.29	3.77	0.58	56.68	0.43	29.70	0.41	99.30
Cr 36	6.07	6.49	1.54	0.66	62.60	0.48	22.03	0.04	99.90
Cr 43	2.79	5.13	3.84	0.58	56.83	0.46	29.81	0.34	99.77
Cr 44	3.06	4.64	3.01	0.75	58.04	0.41	28.83	0.64	99.37
Cr 46	2.34	5.47	3.77	0.76	56.54	0.46	29.70	0.42	99.46
Cr 49	2.85	6.90	1.81	0.75	58.97	0.77	27.74	0.23	100.03
Cr 50	4.08	5.67	3.82	0.70	57.67	0.35	27.88	0.28	100.44
Cr 51	2.64	6.95	2.00	0.65	58.41	0.76	28.54	0.35	100.32
Cr 52	6.29	6.27	2.53	0.83	58.76	0.27	19.96	0.46	95.36
Cr 55	3.35	5.42	1.69	0.67	60.82	0.76	26.95	0.39	100.05
Cr 57	2.36	5.34	4.33	0.61	55.80	0.34	31.18	0.17	100.12
Cr 59	4.47	5.48	1.55	0.59	61.90	0.54	25.45	0.13	100.11
Cr 61	2.77	5.89	2.77	0.77	58.25	0.52	29.04	0.22	100.23
Cr 62	3.10	5.30	3.27	0.59	57.63	0.49	28.94	0.41	99.74
Cr 63	1.36	5.58	3.95	0.74	55.65	0.36	31.63	0.33	99.60
Cr 66	2.04	5.90	3.32	0.71	57.72	0.53	29.42	0.25	99.91
Cr 71	3.17	6.17	2.44	0.63	58.39	0.63	28.25	0.37	100.06
Cr 72	3.02	6.27	2.39	0.62	58.61	0.66	27.62	0.36	99.56
Cr 73	2.82	5.16	2.41	0.61	61.20	0.43	21.90	1.34	95.88
Cr 75	2.24	5.40	3.11	0.58	58.97	0.49	27.82	0.73	99.34
Cr 76	3.32	5.84	1.74	0.69	59.98	0.70	26.33	0.37	98.97
Cr 78	1.79	6.22	3.83	0.69	58.44	0.36	26.33	0.36	98.02

PUCK 106 - GAP7 - 62.3 kg - >63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total
Cr 1	3.23	5.41	3.44	0.67	57.49	0.67	26.94	2.39	100.25
Cr 2	3.42	6.65	2.30	0.78	59.39	1.16	25.79	0.69	100.19
Cr 7	2.01	6.51	2.89	0.88	60.28	0.67	27.95	n.d.	101.19
Cr 15	2.67	5.66	4.01	0.75	58.4	0.54	28.35	n.d.	100.39

FROM LINDSKOG ET AL. (2012) - GAP7- 13.0 kg - >63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total
Cr 1	5.57	5.57	3.86	0.86	58.76	n.d.	26.27	n.d.	100.9
Cr 2	6.24	6.79	1.21	0.63	62.85	0.73	22.36	n.d.	100.8

32-63 μm

	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	MnO	FeO	ZnO	Total
Cr 1	1.88	6.27	3.73	0.81	56.53	0.76	30.37	0.47	100.8
Cr 2	3.00	6.35	2.76	0.88	59.46	0.89	27.71	0.37	101.4
Cr 3	2.37	5.22	3.79	0.81	58.22	0.76	29.45	n.d.	100.6
Cr 4	3.09	6.12	2.20	0.70	60.55	0.89	27.18	n.d.	100.7
Cr 5	2.23	5.70	4.39	0.82	57.94	0.63	29.45	n.d.	101.2
Cr 6	2.44	6.23	3.90	0.69	57.65	0.73	28.95	n.d.	100.6
Cr 7	2.43	6.53	3.80	0.69	58.41	0.63	27.96	n.d.	100.5
Cr 8	1.93	6.53	3.01	0.74	57.30	0.73	29.53	0.57	100.3
Cr 9	3.25	5.98	2.52	0.68	59.77	1.18	26.56	0.28	100.2
Cr 10	2.59	6.75	1.60	0.76	59.73	1.32	27.07	0.47	100.3
Cr 11	1.98	5.77	2.14	0.69	59.89	1.06	28.14	n.d.	99.66

References:

Heck, P.R., Schmitz, B., Bottke, W.F., Rout, S.S., Kita, N.T., Cronholm, A., Defouilloy, C., Dronov, A., and Terfelt, F., 2017, Rare meteorites common in the Ordovician period: Nature Astronomy, v. 1, doi:10.1038/s41550-016-0035.

Lindskog, A., Schmitz, B., Cronholm, A., and Dronov, A., 2012, A Russian record of a Middle Ordovician meteorite shower: extraterrestrial chromite at Lynna River, St. Petersburg region. Meteoritics & Planetary Science 47, 1274-1290.

TABLE DR5. GRAIN ABUNDANCES FROM DIFFERENT METEORITE TYPES OTHER THAN EQUILIBRATED ORDINARY CHONDRITES BASED ON $\Delta^{17}O$

Δ^{17}O of grain	**Before LCPB Ordovician**[1] *% of 18 gr. (% of all 41 gr.)*	**Early Cretaceous**[1] *% of 17 gr. (% of all 108 gr.)*	**Today**[2] *% of non-EC flux*
$\Delta^{17}O$ = 0.35 to 1.6‰ Unequilibrated ordinary chondrites	0 (0)	29 (7)	~35
$\Delta^{17}O$ at TFL within 2SD Primitive or ungrouped achondrites, (HEDs, or unusual terrestrial V-rich grains?)	17 (7)	24 (6)	<1
$\Delta^{17}O$ <0 to -0.49‰ at ~2SD HEDs, primitive or ungrouped achondrites	50 (22)	12 (3)	~60
$\Delta^{17}O$ < -0.50‰ primitive, ungrouped or anomalous achondrites	33 (15)	35 (9)	<1
Lunar, martian, R chondrites	0	0	~5
Total	100 (44)	100 (25)	100

[1]The columns show the division of all extraterrestrial grains analyzed for $\Delta^{17}O$ but with a major element composition different from the chromites of equilibrated ordinary chondrites. In the estimate for the fraction of the total extraterrestrial grain assemblage in the Cretaceous it has been assumed that the 17 OC-V grains that could be analyzed for $\Delta^{17}O$ are representative of all the 27 OC-V grains recovered.

[2]The column shows the approximate fraction of the flux of all achondrites and unequilibrated ordinary chondrites rich in large chrome spinels (Heck et al., 2017). Data for recent falls from Meteoritical Bulletin Database (www.lpi.usra.edu/meteor/).

Table DR6

Analysis #	Mount_grain_sequence/spot number	d18O	d18O 2SE	d17O	d17O 2SE	D17O	D17O 2SE	OH cor.	OH cor. Error	sp fraction (x)
Session 1: Primary beam: 5 nA, 19 µm diameter. 2 sequence of isotope analyses (400s integration) per spot. OH tailing 10 ppm ±25%										
Bracket #353-358, 375-380 (n=6)	**UWCr3: raw mean values and 2SD**	**6.95**	**0.35**	**2.69**	**0.33**	**-0.85**	**0.32**	0.03	0.01	
20160125-359	163_gr06_1st	-1.81	0.35	0.20	0.33	1.14	0.33	0.14	0.04	0.13
20160125-360	163_gr06_2nd							0.12	0.03	
20160125-361	163_gr08_1st	-1.63	0.35	0.12	0.33	0.96	0.33	0.09	0.02	0.15
20160125-362	163_gr08_2nd							0.09	0.02	
20160125-363	163_gr09_1st	-1.55	0.35	0.78	0.33	1.58	0.34	0.17	0.04	0.14
20160125-364	163_gr09_2nd							0.33	0.08	
20160125-365	163_gr10_1st	-3.37	0.35	-5.53	0.33	-3.78	0.33	0.04	0.01	0.35
20160125-366	163_gr10_2nd							0.03	0.01	
20160125-367	163_gr12_1st	-2.34	0.35	-0.12	0.33	1.10	0.33	0.17	0.04	0.13
20160125-368	163_gr12_2nd							0.12	0.03	
20160125-369	163_gr13_1st	-1.39	0.35	0.46	0.33	1.19	0.35	0.39	0.10	0.16
20160125-370	163_gr13_2nd							0.64	0.16	
20160125-371	163_gr17_1st	-2.02	0.35	-0.49	0.33	0.56	0.34	0.13	0.03	0.15
20160125-372	163_gr17_2nd							0.31	0.08	
20160125-373	163_gr18_1st	-2.64	0.35	-0.83	0.33	0.55	0.33	0.18	0.04	0.14
20160125-374	163_gr18_2nd							0.21	0.05	
Bracket #375-380, 197-402 (n=6)	**UWCr3: raw mean values and 2SD**	**6.76**	**0.91**	**2.46**	**0.55**	**-0.97**	**0.20**	0.03	0.01	
20160125-381	163_gr19_1st	-3.96	0.91	-4.43	0.55	-2.37	0.22	0.04	0.01	0.29
20160125-382	163_gr19_2nd							0.05	0.01	
20160125-383	163_gr20_1st	-2.10	0.91	-0.45	0.55	0.65	0.22	0.08	0.02	0.22
20160125-384	163_gr20_2nd							0.10	0.02	
20160125-385	163_gr21_1st	-4.21	0.91	-0.63	0.55	1.56	0.24	0.21	0.05	0.11
20160125-386	163_gr21_2nd							0.54	0.14	
20160125-387	163_gr22_1st	-1.84	0.91	0.15	0.55	1.11	0.22	0.11	0.03	0.12
20160125-388	163_gr22_2nd							0.10	0.03	
20160125-389	163_gr24_1st	4.93	0.91	2.62	0.55	0.05	0.25	0.42	0.11	0.47
20160125-390	163_gr24_2nd							0.50	0.12	
20160125-391	163_gr14_1st	-3.59	0.91	-0.07	0.55	1.79	0.37	1.26	0.32	0.14
20160125-392	163_gr14_2nd							1.11	0.28	
20160125-393	163_gr16_1st	0.22	0.91	1.89	0.55	1.78	0.47	1.72	0.43	0.18
20160125-394	163_gr16_2nd							1.57	0.39	
20160125-395	163_gr23_1st	0.71	0.91	0.53	0.55	0.16	0.27	0.62	0.15	0.26
20160125-396	163_gr23_2nd							0.66	0.16	
Session 2: Primary beam: 3 nA, 16.7 µm diameter. 2 sequence of isotope analyses (400s integration) per spot. OH tailing 15 ppm ±20%										
Bracket #31-36, 40-45 (n=6)	**UWCr3: raw mean values and 2SD**	**5.31**	**0.17**	**1.64**	**0.35**	**-1.05**	**0.25**	0.05	0.01	
2016516-37	Mnt 189 gr16 1/2: 130s	2.17	0.17	1.23	0.35	0.10	0.27	0.06	0.01	0.28

2016516-38	Mnt 189 gr16 2/2: 130s							0.06	0.01	0.28
2016516-39	Mnt 189 gr16 3/3 : 130s							0.07	0.01	0.28
Bracket #31-36, 40-45 (n=6)	**UWCr3: raw mean values and 2SD**	**5.14**	**0.11**	**1.68**	**0.48**	**-0.94**	**0.22**	0.05	0.01	
2016516-46	Mnt 189 gr16_spot 2 1/2	1.16	0.11	0.39	0.48	-0.21	0.24	0.11	0.02	0.28
2016516-47	Mnt 189 gr16_spot 2 2/2							0.36	0.07	0.28
2016516-48	Mnt 189 gr17_spot 1 1/2	1.43	0.11	0.54	0.48	-0.20	0.24	0.17	0.03	0.29
2016516-49	Mnt 189 gr17_spot 1 2/2							0.49	0.10	0.29
2016516-50	Mnt 189 gr14 1/2	-4.82	0.11	-1.36	0.48	1.14	0.24	0.14	0.03	0.13
2016516-51	Mnt 189 gr14 2/2							0.13	0.03	0.13
2016516-52	Mnt 189 gr11 1/2	3.96	0.11	1.99	0.48	-0.07	0.24	0.07	0.01	0.37
2016516-53	Mnt 189 gr11 2/2							0.09	0.02	0.37
Session 3: Primary beam: 2.5 nA, 12 µm diameter. 1 sequence of isotope analyses (200s integration) per spot. OH tailing 50 ppm ±25%.										
Bracket #60-63, 81-84 (n=8)	**UWCr3: raw mean values and 2SD**	**2.97**	**0.33**	**0.40**	**0.18**	**-1.14**	**0.17**	0.19	0.05	
2016516-64	164_gr01	-2.56	0.33	-0.89	0.18	0.44	0.18	0.21	0.05	0.14
2016516-65	164_gr02	4.36	0.33	2.34	0.18	0.08	0.18	0.21	0.05	0.38
2016516-66	164_gr03	4.40	0.33	2.24	0.18	-0.05	0.18	0.22	0.06	0.38
2016516-67	164_gr04	-2.83	0.33	-0.79	0.18	0.69	0.18	0.22	0.05	0.13
2016516-68	164_gr05	-2.49	0.33	-0.09	0.18	1.21	0.18	0.21	0.05	0.11
2016516-69	164_gr06	6.18	0.33	3.28	0.18	0.07	0.17	0.18	0.05	0.50
2016516-70	164_gr07	3.51	0.33	1.51	0.18	-0.31	0.18	0.22	0.05	0.34
2016516-71	164_gr09	-2.38	0.33	-0.52	0.18	0.71	0.18	0.27	0.07	0.14
2016516-72	164_gr10	-1.57	0.33	0.46	0.18	1.28	0.18	0.22	0.05	0.13
2016516-73	164_gr11	6.06	0.33	3.03	0.18	-0.12	0.17	0.18	0.05	0.49
2016516-74	164_gr12	3.67	0.33	1.73	0.18	-0.18	0.18	0.22	0.06	0.35
2016516-75	164_gr13	2.32	0.33	1.06	0.18	-0.15	0.19	0.38	0.09	0.27
2016516-76	164_gr15	-10.74	0.33	-8.16	0.18	-2.57	0.78	3.05	0.76	0.11
2016516-77	164_gr16	5.56	0.33	2.96	0.18	0.07	0.18	0.23	0.06	0.42
2016516-78	164_gr17	6.45	0.33	3.40	0.18	0.05	0.18	0.19	0.05	0.49
2016516-79	164_gr18	4.92	0.33	1.46	0.18	-1.10	0.47	1.78	0.44	0.36
2016516-80	164_gr15-spot2	-11.03	0.33	-7.92	0.18	-2.18	0.67	2.58	0.65	0.11
Bracket #215-218, 228-231 (n=8)	**UWCr3: raw mean values and 2SD**	**2.83**	**0.20**	**0.47**	**0.16**	**-1.00**	**0.18**	0.22	0.05	
2016516-219	172_gr01	-1.50	0.20	-0.64	0.16	0.14	0.45	1.64	0.41	0.12
2016516-220	172_gr02	-2.01	0.20	-0.41	0.16	0.63	0.23	0.58	0.14	0.14
2016516-221	172_gr03	-1.78	0.20	-0.18	0.16	0.74	0.19	0.24	0.06	0.15
2016516-222	172_gr04	-1.99	0.20	-0.24	0.16	0.79	0.19	0.22	0.05	0.12
2016516-223	172_gr05	-1.82	0.20	-0.35	0.16	0.60	0.25	0.70	0.17	0.12
2016516-224	172_gr06	4.51	0.20	1.81	0.16	-0.54	0.26	0.74	0.19	0.50
2016516-225	172_gr07	-1.64	0.20	-0.29	0.16	0.56	0.20	0.30	0.08	0.19
2016516-226	172_gr08	-3.17	0.20	-1.05	0.16	0.60	0.23	0.54	0.14	0.10
2016516-227	172_gr01 spot 2	-1.43	0.20	0.19	0.16	0.93	0.21	0.47	0.12	0.12
Bracket #227-231, 242-245 (n=8)	**UWCr3: raw mean values and 2SD**	**2.82**	**0.25**	**0.42**	**0.26**	**-1.05**	**0.18**	0.21	0.05	
2016516-232	195_335_2-gr01	-2.08	0.25	-0.05	0.26	1.03	0.19	0.27	0.07	0.13

2016516-233	195_335_2-gr05	2.96	0.25	1.31	0.26	-0.23	0.19	0.22	0.05	0.29
2016516-234	195_335_2-gr06	4.88	0.25	2.55	0.26	0.01	0.18	0.19	0.05	0.45
2016516-235	195_335_2-gr10	-2.13	0.25	-1.27	0.26	-0.16	0.22	0.52	0.13	0.31
2016516-236	195_335_2-gr08	-2.06	0.25	-0.13	0.26	0.94	0.19	0.22	0.05	0.14
2016516-237	195_270_gr01	-2.18	0.25	-0.11	0.26	1.03	0.20	0.37	0.09	0.12
2016516-238	195_270_gr03	0.53	0.25	-0.10	0.26	-0.38	0.19	0.22	0.05	0.20
2016516-239	195_270_gr04	-2.55	0.25	-0.86	0.26	0.47	0.21	0.42	0.11	0.16
2016516-240	195_270_gr05	-2.38	0.25	-0.07	0.26	1.16	0.19	0.26	0.06	0.13
2016516-241	195_335_2-gr11	-2.51	0.25	-0.95	0.26	0.35	0.24	0.65	0.16	0.16
Bracket #360-363, 375-378(n=8)	**UWCr3: raw mean values and 2SD**	**3.01**	**0.37**	**0.37**	**0.32**	**-1.20**	**0.24**	0.21	0.05	
2016516-364	211_gr01	6.29	0.37	3.16	0.32	-0.11	0.25	0.19	0.05	0.50
2016516-365	211_gr02	5.90	0.37	3.11	0.32	0.04	0.25	0.20	0.05	0.43
2016516-366	211_gr05	-13.55	0.37	-7.42	0.32	-0.38	0.31	0.75	0.19	0.10
2016516-367	211_gr10	-2.23	0.37	-0.28	0.32	0.88	0.25	0.22	0.06	0.15
2016516-368	211_gr11	-2.17	0.37	0.35	0.32	1.47	0.25	0.24	0.06	0.11
2016516-369	211_gr12	-0.06	0.37	-0.19	0.32	-0.16	0.25	0.24	0.06	0.23
2016516-370	211_gr14	-2.34	0.37	-0.50	0.32	0.72	0.30	0.71	0.18	0.12
2016516-371	211_gr16	-0.18	0.37	0.39	0.32	0.48	0.25	0.23	0.06	0.25
2016516-372	211_gr17	-2.46	0.37	-0.54	0.32	0.74	0.25	0.26	0.07	0.16
2016516-373	211_gr08	-2.13	0.37	-0.46	0.32	0.65	0.25	0.27	0.07	0.16
2016516-374	211_gr15	5.21	0.37	2.34	0.32	-0.37	0.30	0.71	0.18	0.42
Bracket #375-378, 391-394 (n=8)	**UWCr3: raw mean values and 2SD**	**2.95**	**0.42**	**0.41**	**0.26**	**-1.12**	**0.18**	0.20	0.05	
2016516-379	212_gr_1-01	-2.20	0.42	-1.53	0.26	-0.38	0.19	0.23	0.06	0.19
2016516-380	212_gr_1-02	3.32	0.42	1.77	0.26	0.05	0.19	0.19	0.05	0.34
2016516-381	212_gr_1-04	-1.92	0.42	-0.18	0.26	0.82	0.19	0.24	0.06	0.16
2016516-382	212_gr_1-05	-1.55	0.42	0.72	0.26	1.52	0.19	0.20	0.05	0.14
2016516-383	212_gr_1-07	4.63	0.42	2.49	0.26	0.08	0.19	0.21	0.05	0.41
2016516-384	212_gr_2-03	-1.90	0.42	0.28	0.26	1.27	0.20	0.34	0.09	0.12
2016516-385	212_gr_2-04	-1.65	0.42	0.40	0.26	1.26	0.19	0.21	0.05	0.16
2016516-386	212_gr_2-06	-0.46	0.42	-3.26	0.26	-3.02	0.19	0.19	0.05	0.40
2016516-387	212_gr_2-07	-2.73	0.42	-0.73	0.26	0.69	0.28	0.87	0.22	0.13
2016516-388	212_gr_2-11	4.34	0.42	2.12	0.26	-0.14	0.19	0.20	0.05	0.36
2016516-389	212_gr_2-12	-1.47	0.42	-0.03	0.26	0.73	0.23	0.55	0.14	0.15
2016516-390	212_gr_2-13	4.01	0.42	2.06	0.26	-0.02	0.19	0.19	0.05	0.15