Distribution of extraterrestrial chromite in Middle Ordovician Komstad Limestone in the Killeröd quarry, Scania, Sweden

THERESE HÄGGSTRÖM & BIRGER SCHMITZ

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Sediment-dispersed extraterrestrial chromite grains (63–355 μm) have been recovered in a section across the Arenig-Llanvirn transition in the Killeröd quarry in southeastern Scania. Previous studies of the same stratigraphic interval in the Orthoceratite Limestone at Kinnekulle, ca. 350 km to the north in Västergötland, have shown a two orders of magnitude increase in extraterrestrial chromite beginning close to the Arenig-Llanvirn boundary. The stratigraphic distribution and abundance trends of extraterrestrial chromite are essentially identical at Killeröd and Kinnekulle. In the Killeröd section extraterrestrial chromite grains are extremely rare (2 grains/125 kg of rock) in the Arenig lower 8 m of the section (*Megistaspis simon* to *Asaphus expansus* trilobite zones) and abundant (326 grains/162 kg of rock) in the succeeding ca. 3 m of uppermost Arenig and lower Llanvirn (upper *A. expansus* and *A. raniceps* zones) section. The extraterrestrial chromite grains at Killeröd and Kinnekulle are very similar in chemical composition, including characteristic elevated values and narrow ranges of V_2O_3 (0.6–0.9 wt%) and TiO_2 (2.0–3.5 wt%). At Killeröd there is a small group (<4%) of chromite grains with relatively low TiO_2 (1.5–2.0 wt%), but otherwise typical extraterrestrial compositions. These grains may reflect a somewhat more aggressive diagenetic environment at Killeröd than at Kinnekulle. As in previous studies, rare chrome spinel grains with terrestrial or uncertain origin have also been found in the limestone.

The results of this study support previous suggestions that after the disruption of the L chondrite parent body in the asteroid belt at ca. 470 Ma, the flux of extraterrestrial matter to Earth was enhanced by up to two orders of magnitude compared to the present. This is supported by finds in Sweden of abundant fossil meteorites in uppermost Arenig and lower Llanvirn sediments. Whether these conclusions can be put into a global context awaits further study of Middle Ordovician limestones from other continents.

Keywords: Komstad Limestone, chromite, chrome spinel, Middle Ordovician, Arenig-Llanvirn boundary, L chondrite, meteorite flux, fossil meteorites

Therese Häggström, [therese@gvc.gu.se], Department of Marine Geology, Earth Sciences Centre, Göteborg University, SE-405 30 Göteborg, Sweden. Birger Schmitz [birger.schmitz@geol.lu.se], Department of Geology, Lund University, SE-223 62 Lund, Sweden.

The influx of meteorites to Earth has been estimated to have been up to two orders of magnitude higher compared to the present during part of the Middle Ordovician, based on high concentrations of fossil meteorites and meteoritic chromite grains in a limestone section from Kinnekulle, southern central Sweden (Schmitz *et al.* 2001, 2003). The high influx rates have been proposed to reflect the disruption of the L chondrite parent body in the asteroid belt at ca. 470 Ma (Schmitz *et al.* 2001; Korochantseva *et al.* 2006), an event which is reflected in the flux of meteorites to Earth even today (McConville *et al.* 1988; Keil *et al.* 1994; Bogard 1995). Cosmic-ray exposure ages of chromite grains from fossil meteorites show an increasing trend higher up in the meteorite-bearing limestone strata (Heck *et al.* 2004), which points to a single disruption event. Fossil meteorites can, therefore, be used to trace ancient events in space. The recent systematic searches for fossil meteorites in Ordovician limestone (Schmitz *et al.* 2001) evolved following two early stray finds, the Brunflo meteorite from the Rödbrottet quarry in Jämtland (Thors-

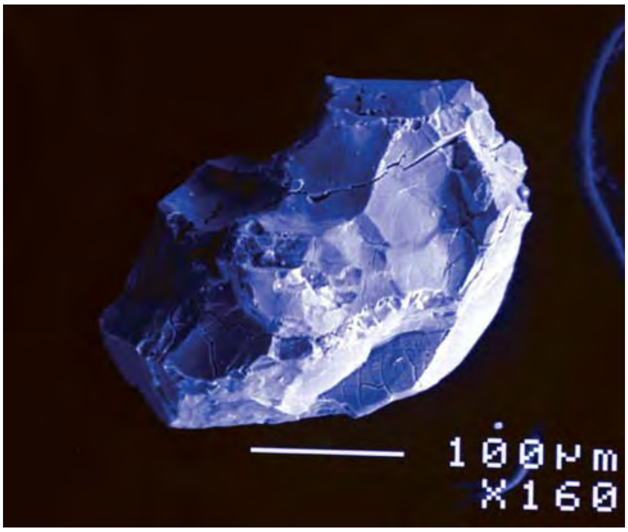

Fig. 1. Extraterrestrial chromite grain recovered from Middle Ordovician Orthoceratite Limestone at Hällekis, Kinnekulle.

lund *et al.* 1984), and Österplana, the first meteorite recovered in the Thorsberg quarry (Nyström *et al.* 1988).

Resistant remnants of sea-floor weathered meteorites, in the form of dispersed microscopic extraterrestrial chromite (EC) grains (Fig. 1), are more readily retrievable from the limestone than fossil meteorites and can also provide estimates of the ancient meteorite influx (Schmitz *et al.* 2003). Following the discovery of abundant sediment-dispersed EC grains associated with the fossil meteorites in the Thorsberg quarry at Kinnekulle, high concentrations of such grains have been discovered in limestone beds of similar age at four other locations in southern and central Sweden (Schmitz *et al.* 2003; Schmitz & Häggström 2006). Fossil meteorites have not been systematically searched for at these localities, but one meteorite was found in the Gullhögen quarry, 35 km southeast of the Thorsberg quarry (Tassinari *et al.* 2004).

The most detailed search for sediment-dispersed extraterrestrial chromite has been performed in a composite Arenig-Llanvirn section of the Thorsberg and Hällekis quarries 4 km apart at Kinnekulle (Schmitz & Häggström 2006). A predominantly red, but occasionally light grey, monotonous and condensed Orthoceratite Limestone sequence is exposed in these quarries. The limestone formed at an average rate of a few mm/1000 years, but sedimentation was frequently interrupted by long periods of non-deposition represented by abundant hard grounds. In the Arenig lower 9 m of the composite section only 5 EC grains were found in 379 kg of limestone. From a level close to the Arenig-Llanvirn boundary EC grain concentrations increase by two orders of magnitude, and remain high through most of the overlying 3 m of section. A total of 276 EC grains were found in 148 kg of limestone from this interval. The change in EC abundance takes place in the upper *Asaphus expansus* trilobite zone, close to the base of the *A. raniceps* Zone (Schmitz & Häggström 2006). The results indicate that the disruption of the L chondrite parent body took place at about this time, which is also supported by the cosmogenic nuclides in chromite grains from the fossil meteorites at Kinnekulle (Heck *et al.* 2004) and ^{40}Ar-^{39}Ar dating of recent L chondrites (Korochantseva *et al.* 2006).

In addition to the EC grains another group of chrome spinel grains has been identified, predominantly in the EC-rich strata at Kinnekulle, and is referred to as „other Cr-rich spinel" (OC) grains (Schmitz & Häggström 2006). Most of these grains

Table 1. Distribution of extraterrestrial chromite (EC) and other Cr-rich spinel (OC) grains in Middle Ordovician limestone from the Killeröd quarry. Depths are relative to the base of the quarry.

Depth (m)	Sample size (kg)	# EC grains	EC grains kg^{-1}	# OC grains	OC grains kg^{-1}
11.25 to 11.40	27.4	17	0.62	2	0.07
10.81 to 10.90	24.1	3	0.12	1	0.04
10.02 to 10.09	23.8	56	2.35	4	0.17
9.88 to 10.02	23.6	74	3.14	57	2.42
9.79 to 9.84	13.5	53	3.93	5	0.37
9.73 to 9.79	17.8	103	5.79	3	0.17
9.71 to 9.73	3.3	12	3.64	1	0.30
8.50 to 8.72	28.4	8	0.28	0	0
7.67 to 7.75	28.4	1	0.04	0	0
6.45 to 6.60	27.2	1	0.04	1	0.04
5.63 to 5.78	16.6	0	0	1	0.06
4.21 to 4.35	24.4	0	0	0	0
2.49 to 2.59	28.4	0	0	0	0

show similarities to terrestrial chrome spinels (Barnes & Roeder 2001), but some may be unusual, as yet unidentified types of extraterrestrial grains. It is enigmatic that OC grains are only abundant in some of the layers that also contain abundant EC grains. This suggests that there may be some causal relationship in the origin of the grains, the significance of which is unclear. Schmitz & Häggström (2006) hypothesize that OC grains are derived from increased weathering of mafic intrusions exposed on the sea floor, possibly related to environmental changes following large impacts on the Baltoscandian shield.

The objective of this study is to perform a detailed search for EC and OC grains across the Arenig-lower Llanvirn condensed limestone section in the Killeröd quarry, one of the southernmost Paleozoic outcrops in Sweden. The results will reveal whether the stratigraphic distribution of EC grains observed at Kinnekulle is reproducible over a distance of 350 km and may also give new perspectives on the relationship between OC and EC grains. The new data presented here adds to the existing database of sediment-dispersed chromite compositions that has been extended continuously since 2000.

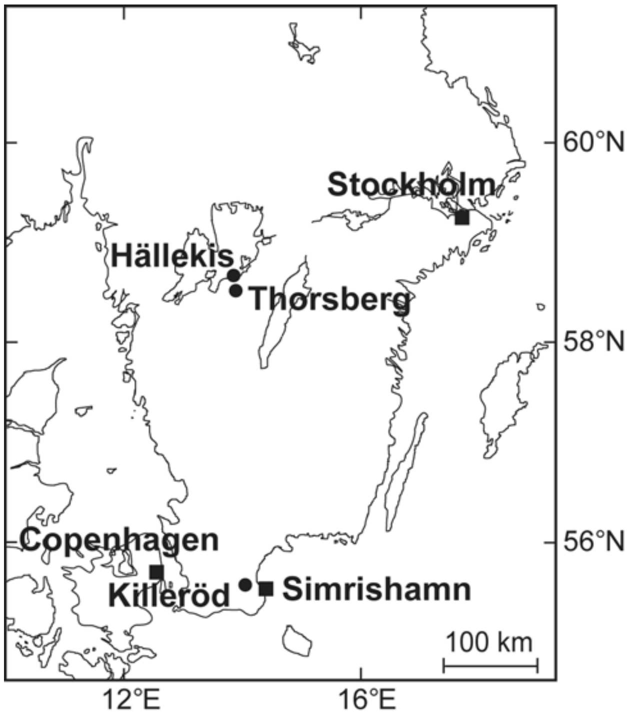

Fig. 2. Locations of the Killeröd, Hällekis and Thorsberg quarries.

Geological setting

The object of study is an abandoned, partly water-filled quarry at Killeröd (55°34′ N, 14°08′E) located 13 km west of the town Simrishamn in Scania, southern Sweden (Figs 2–3). Nielsen (1995, 2004a) established a very detailed trilobite stratigraphy for the limestone in and around the quarry, making correlation with the Orthoceratite Limestone in other parts of southern and central Sweden possible with a high degree of confidence and resolution. In the new global stratigraphic scheme the Killeröd section belongs to the Darriwilian stage in the Middle Ordovician. Following the regional British stratigraphic scheme the section spans the upper Arenig and lowermost Llanvirn series (Nielsen 1995).

The limestone at Killeröd belongs to the Komstad Limestone, which occurs in southern Scania and on Bornholm, and is a dark grey to black variety of the Orthoceratite Limestone. The two types of limestone formed while most of the Baltoscandian shield was covered by a vast epicontinental sea (Lindström 1971). This area includes the East European platform, and a division into so-called confacies belts has been recognized. Five different simultaneous sedimentation environments have been distinguished (Jaanusson 1995; Nielsen 2004b). The Komstad Limestone represents one of the western tongues of the central Baltoscandian Orthoceratite Limestone facies and constitutes the major limestone intercalation in the Scanian Ordovician confacies belt, mainly dominated by graptolite shales (Nielsen 1995). The Komstad Limestone is underlain by lower Arenig Töyen shale and overlain by Llanvirn *Didymograptus* shale (Nielsen 1995). There is a stratigraphic gap towards the overlying shale, representing at the most the upper part of the *D. „bifidus“* and the lower part of the *D. murchisoni* graptolite zones.

The Komstad Limestone has been quarried at many locations since the early Middle Ages, but the last quarry in the area was abandoned in 1986. The type localities for the Komstad Limestone are two quarries at Komstad, but both are now largely water-filled. Nielsen (1995) therefore proposes the more accessible Killeröd quarry, situated 1 km west of the Komstad quarries, as the paratype section.

The stratigraphy of the Komstad Limestone in a section spanning the Killeröd „main“ quarry and the overlying 1.8 m of strata occurring ca. 60 m ESE of the main quarry is illustrated in Fig. 4 (Nielsen 1995). In total the composite section spans 11.4 m. The section is characterized by a sequence of limestone beds with typical thicknesses between 2 and 20 cm, separated by hard grounds or discontinuity surfaces. Some parts of the succession contain marly intercalations reflecting changes in the depositional envi-

Fig. 3. Killeröd „main" quarry in early spring 2006.

ronment and a higher input of clastic material. The limestone contains a substantial fraction of micro-fragments of echinoderms and larger shells of trilobites and cephalopods (Regnéll 1960). From the floor of the main quarry to the top strata the following trilobite zones are recorded: *Megistaspis simon, M. limbata, Asaphus expansus* and *A. raniceps* (Nielsen 1995). The boundary between the *A. expansus* and *A. raniceps* zones is located ca. 1.2 m below the top of the composite section. The lowermost 1.7 m of the section is below the water level. At ca. 3 m above the quarry floor, at the border between the *M. simon* and the *M. limbata* trilobite zones, there is a transition between a lower light grey interval and an upper dark grey to black interval (Nielsen 1995). The upper darker unit, corresponding to the *M. limbata* Zone, has been considered to constitute high quality rock and is the part that has been quarried most extensively. The overlying thin-bedded and impure limestone of the *A. expansus* and *A. raniceps* zones has been considered technically useless (Nielsen 1995).

Except for its black colour the Komstad limestone is essentially very similar in lithology to the red or light grey Orthoceratite Limestone that dominates in Baltoscandia at this time. The black colour reflects depositional anoxic conditions and more stagnant bottom water than in the rest of the epicontinental sea. Judging from the similar thicknesses of the trilobite zones at Kinnekulle and Killeröd (Nielsen 1995; Villumsen *et al.* 2001) the Komstad Limestone formed at approximately the same rate as the Orthoceratite Limestone, i.e. on average a few mm per thousand years (Lindström 1971; Schmitz *et al.* 1996). The upper circa two meters of the composite Killeröd section corresponds to the lower part of the Thorsberg quarry at Kinnekulle where abundant fossil meteorites have been found during quarrying (Schmitz *et al.* 2001).

Materials and methods

In total thirteen limestone samples of typically 5–22 cm thickness and 14–28 kg weight were taken from the Killeröd section. The total mass of analysed limestone was 287 kg. Seven samples were retrieved from the uppermost 1.8 m of rocks exposed in the small hill at the „Killeröd b" site of Nielsen (1995). Six samples were collected in the Killeröd main quarry over the 7.9 m of section exposed above the water level. The material was collected with reference to Nielsen's (1995) lithological log. The positions of the samples are given relative to the base of the Killeröd main quarry (Fig. 4). In order to improve the correlations with Kinnekulle we also studied one sample from the Hällekis quarry section as a complement to the samples studied by Schmitz & Häggström (2006). The new sample, weighing 22.8 kg, was collected from the interval 0.77–0.82 m below the Arkeologen bed.

The samples were split with a sledge hammer into pieces smaller than 8 cm and then crushed further to fragments of <5 mm using a Retsch Jaw Crusher BB 200. The crushed material was decalcified in 6 M hydrochloric acid at room temperature. After sieving the residue at 32 µm, the remaining fraction was leached with 18 M hydrofluoric acid at room temperature with occasional stirring. The residue was recovered with a 32 µm sieve. The acid-insoluble fraction in the size range 63 to 355 µm was searched for opaque minerals under the binocular microscope and grains were picked with a fine brush for element analyses. The grains were first mounted on carbon tape and preliminarily analysed for elemental content in the scanning electron microscope. This preliminary analysis is performed as a precaution in case grains are lost later in the polishing procedure. Tests have shown that the analyses of unpolished grains in most cases give sufficiently good results to discriminate between EC and OC grains. After the initial analyses grains are removed from the carbon tape, washed in ethanol or acetone, and mounted in epoxy resin. Thereafter the mounted grains are polished to a flat surface with wet sandpaper (micro fine 1200 grit), and in some cases further with 1 µm diamond slurry. The acid-leached chromite grains are quite brittle and during the polishing it is important to find

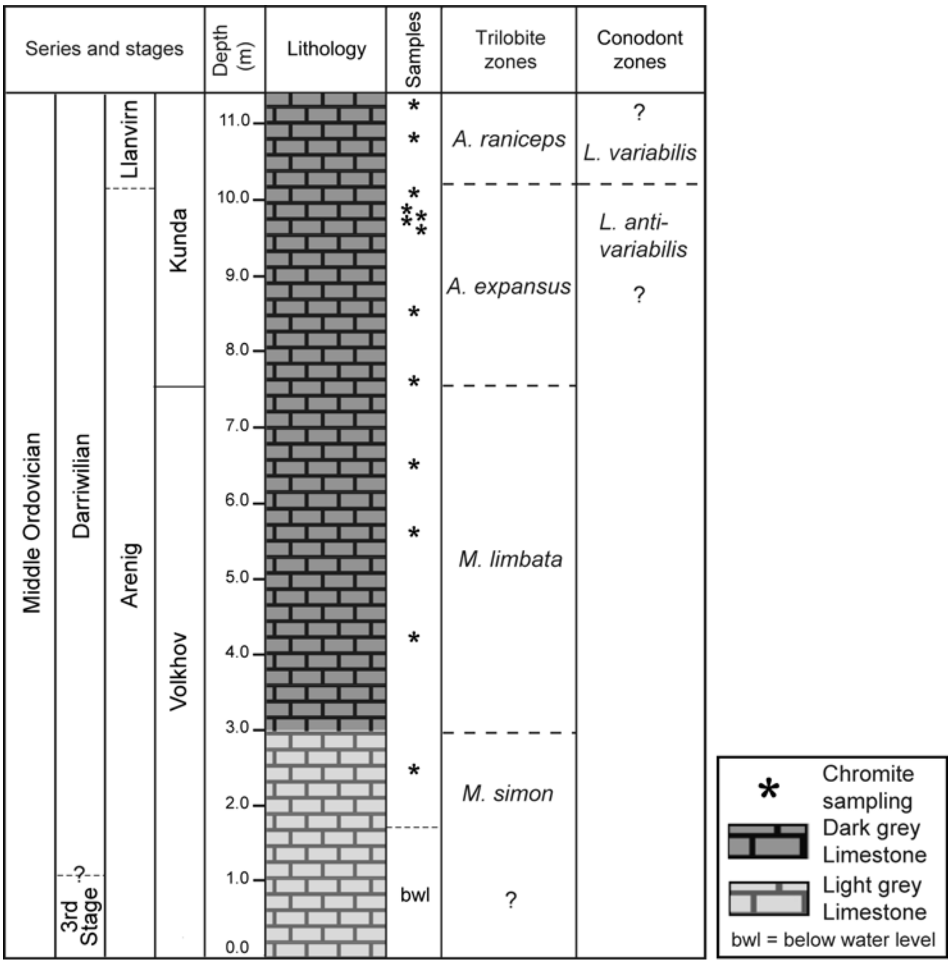

Fig. 4. Stratigraphy of the Komstad Limestone in the Killeröd quarry. Sample levels are indicated by asterisks. Trilobite zonation after Nielsen (1995, 2004a), and preliminary conodont zonation after S. Stouge (personal communication, 2005).

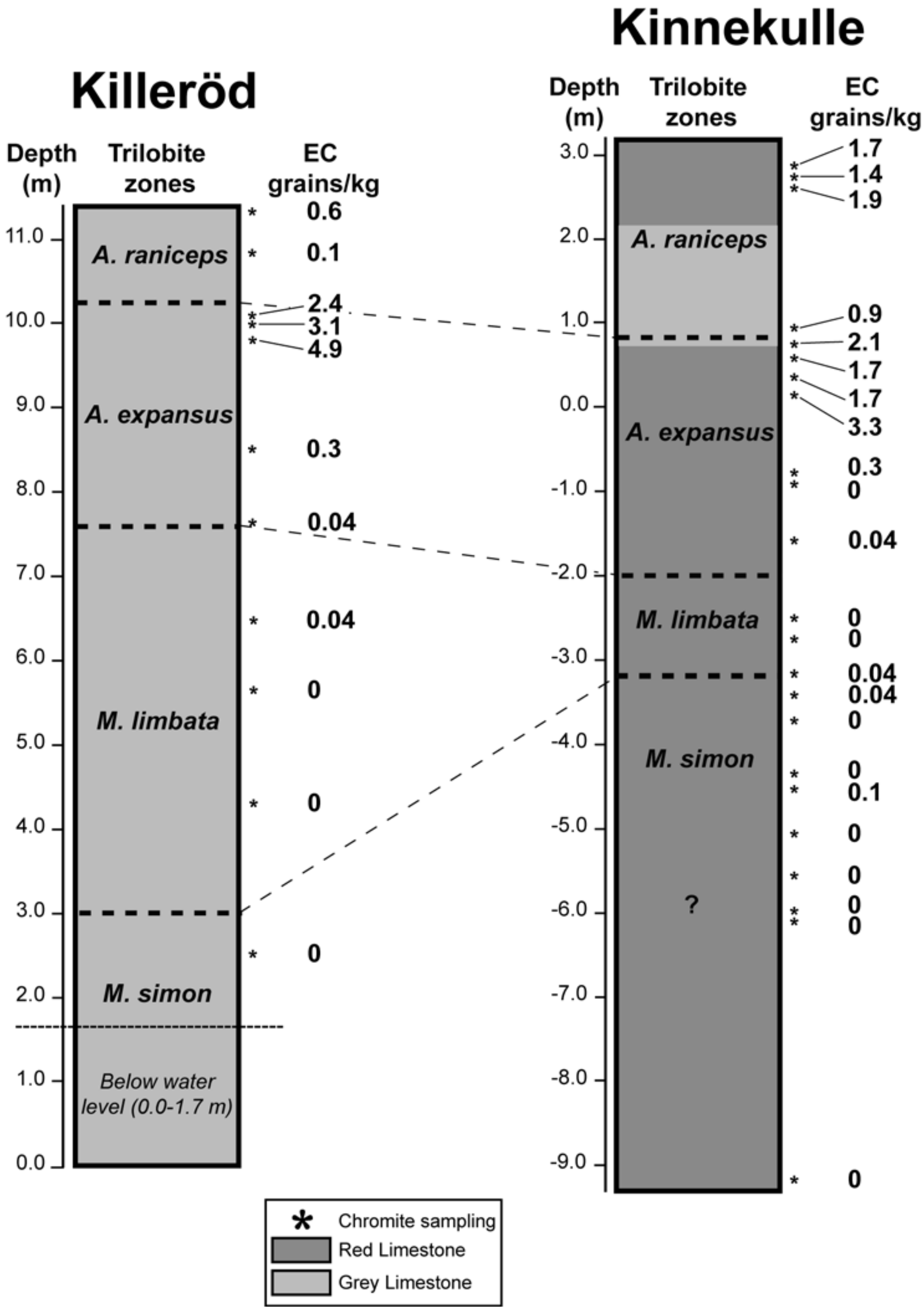

Fig. 5. Comparison of the distribution of sediment-dispersed extraterrestrial chromite (EC) grains in the Killeröd quarry and at Kinnekulle. Trilobite zonation for Killeröd from Nielsen (1995, 2004a), and for Kinnekulle from Villumsen *et al.* (2001) with slight modification of *A. expansus-A. raniceps* boundary according to A.T. Nielsen (personal communication, 2006). Chromite results for Kinnekulle from Schmitz & Häggström (2006) (except one sample, see material and methods section).

the right balance between not losing grains and obtaining a flat surface for accurate elemental analyses. For two of the initial samples in this study almost half of the grains were lost during the polishing and it was decided to reduce the extent of polishing and instead accept a somewhat lower analytical quality compared to the studies by Schmitz *et al.* (2001) and Schmitz & Häggström (2006).

The element analyses were performed with a LINK Oxford energy dispersive spectrometer with a Ge detector, mounted in a Zeiss DSM 940 scanning electron microscope. A cobalt standard linked to simple oxide and metal standards was used to monitor drift of the instrument. Accelerating voltage of 25 kV, sample current about 1 nA and counting live-time of 100 s were used. Precision (reproducibility) of analyses on perfectly flat surfaces was typically better than 1-4%. On irregular surfaces the precision could be much lower. This was particularly a problem for the MgO analyses. Analytical accuracy was controlled by repeated analyses of the USNM 117075 (Smithsonian) chromite reference standard (Jarosewich *et al.* 1980).

Distribution of Cr-rich spinels

The distribution of Cr-rich spinel grains in the studied section at Killeröd is shown in Table 1 and Fig. 5. The grains are divided into two groups, extraterrestrial chromite (EC) grains and „other" Cr-rich spinel (OC) grains. The EC grains have chemical compositions very similar to the dominant type of chromite in equilibrated ordinary chondrites (Bunch *et al.* 1967; Schmitz *et al.* 2001; Wlotzka 2005), whereas the OC grains show a wide compositional range (Tables 2–4). The criteria for chemical identification of EC and OC grains are discussed in detail in Schmitz & Häggström (2006) and in the last section of the present paper.

The five lowest samples from the composite section spanning the Killeröd quarry only yielded two EC grains, even though 125 kg of limestone were studied. The sample at 8.5 m above the quarry floor gave 8 EC grains in 28.4 kg of limestone, representing intermediate concentrations of EC grains, 0.28 grains per kg. At the base of the overlying 1.8 m thick section at the „Killeröd b" site, in the three lowermost samples (9.71-9.84 m), 168 EC grains were found in ca. 35 kg of limestone, i.e. almost 5 EC grains per kg rock. The middle 6 cm of the interval contain almost 6 EC grains per kg rock, the highest concentration of sediment-dispersed EC grains ever recorded in our studies (cf. Schmitz *et al.* 2003; Schmitz & Häggström 2006). The EC grains are abundant, 2.4-5.8 grains per kg, throughout the interval from 9.71 to 10.09 m. In the two samples representing the top of the section, at 10.90 and 11.25 m, EC grain concentrations are lower, in the range 0.12 to 0.62 grain per kg limestone. In the single sample analysed in this study from the Hällekis section at Kinnekulle, ca. 0.8 m below the base of the Arkeologen bed, 6 EC grains were found, corresponding to 0.26 EC grains per kg (Table 5).

Throughout the studied Killeröd composite section the OC grains are very rare except in one sample at 9.88 m. In this sample 57 OC grains were found compared to 74 EC grains. Not considering this single OC-rich sample only 18 OC grains were found in 263 kg of rock, i.e. on average 0.07 grain per kg. Some of these OC grains may be meteoritic grains that have been diagenetically altered or with unusual compositions.

Correlation with Kinnekulle and other sites

The distribution of EC grains across the Arenig-Llanvirn transition is very similar at Killeröd and Kinnekulle (Fig. 5). All data for Kinnekulle, except for one sample (see materials and methods section), are from Schmitz & Häggström (2006). In both sections the limestone in the Arenig part, represented by the *M. simon, M. limbata* and lower to middle *A. expansus* trilobite zones, is practically devoid of EC grains. Then in the middle *A. expansus* Zone at both localities there is an interval with intermediate levels of EC grains, 0.3 grain per kg. This interval is then followed upward by very EC-rich beds. At Kinnekulle abundant EC grains first appear near the base of the ca. 60 cm thick so called Arkeologen bed, 9 m above the base of the section studied (Schmitz & Häggström 2006). The Arkeologen bed contains about 3 EC grains per kg rock, which represents a two orders of magnitude enrichment compared to the strata below. The Arkeologen bed is also extremely rich in fossil meteorites (Schmitz *et al.* 2001). The base of the Arkeologen bed occurs about 70 cm below the *A. expansus - A. raniceps* boundary at Kinnekulle (according to A. T. Nielsen, personal communication, 2006, based on reinterpretation of data in Villumsen *et al.* 2001). The lowest sample with abundant EC grains at Killeröd, at 9.71 m above the base of the section, occurs 50 cm below the *A. expansus – A. raniceps* boundary according to Nielsen (1995, 2004a). This similarity strongly indicates that an increase in the influx of EC grains at Killeröd and Kinnekulle began at about the same time. Concentrations of EC grains at Kinnekulle remain high from the base of the Arkeologen bed up to the middle part of the prominent grey interval (Fig. 5). The middle grey interval has never yielded any fossil meteorites although being quarried extensively (Schmitz *et al.* 2001). This more clayey interval was probably deposited much more rapidly than the surrounding purer red and transitional red-grey limestones. Tentative studies of the interval indicate that EC grains are rare (Schmitz & Häggström 2006). In the red limestone of the one-meter interval directly above the grey interval at Kinnekulle, EC grains and fossil meteorites are again roughly as abundant as in the one-meter interval below the grey interval. The two stratigraphically highest samples at Killeröd show a decrease in concentration of EC grains to about 0.1 to 0.6 grains per kg. Judging from trilobite stratigraphy, these levels may correspond to the grey interval at Kinnekulle, and more rapid deposition may explain the lower EC concentrations. Further studies of the upward extension of the strata else-

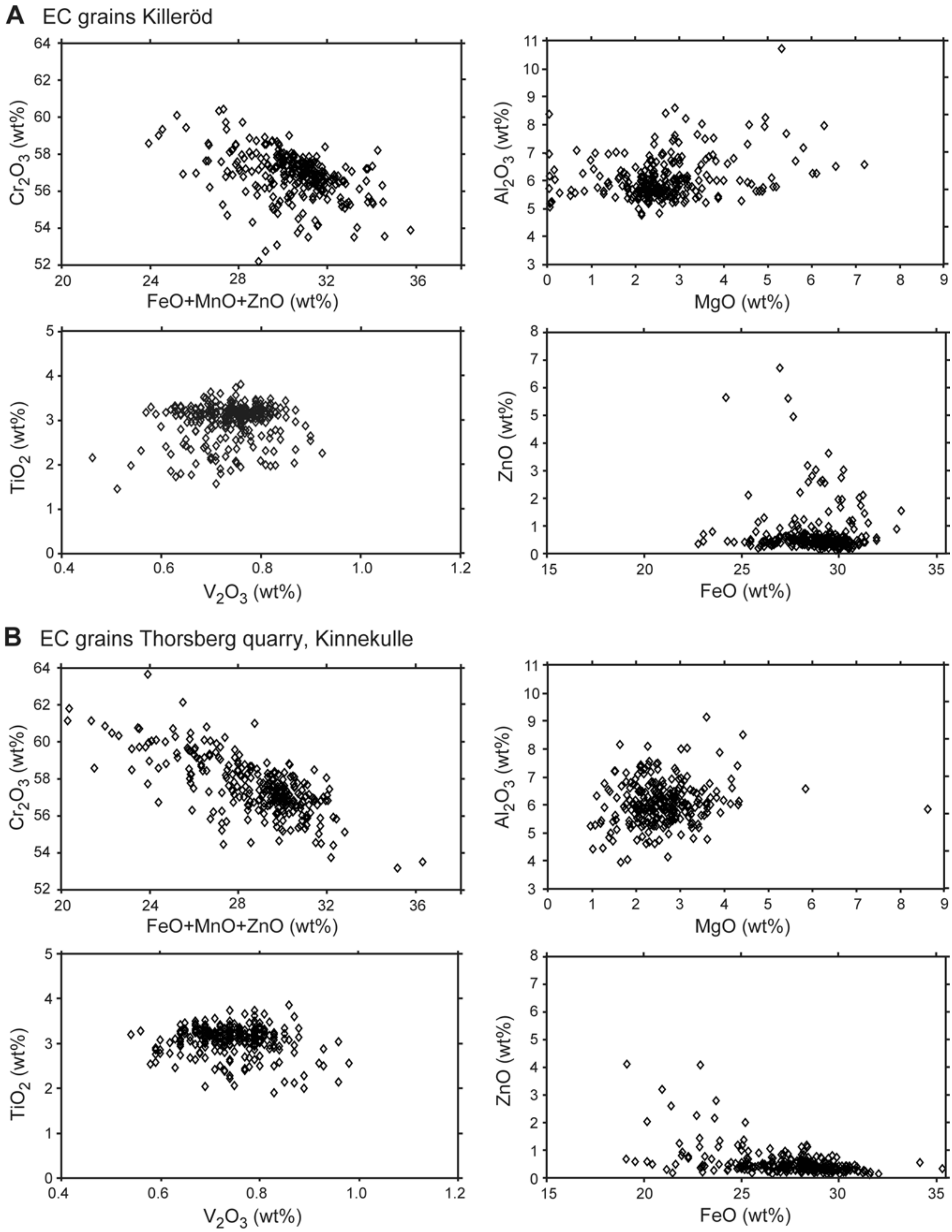
A EC grains Killeröd
Cr2O3 (wt%)
FeO+MnO+ZnO (wt%)
Al2O3 (wt%)
MgO (wt%)
TiO2 (wt%)
V2O3 (wt%)
ZnO (wt%)
FeO (wt%)
B EC grains Thorsberg quarry, Kinnekulle
Cr2O3 (wt%)
FeO+MnO+ZnO (wt%)
Al2O3 (wt%)
MgO (wt%)
TiO2 (wt%)
V2O3 (wt%)
ZnO (wt%)
FeO (wt%)

Table 2. Average element concentrations (wt% and standard deviation) of extraterrestrial chromite (EC) grains, sediment-dispersed and in recent and fossil meteorites.

Locality and depth	# EC grains[1]	Cr_2O_3	Al_2O_3	MgO	TiO_2	V_2O_3	FeO	MnO	ZnO	Total
Sediment-dispersed grains										
Killeröd quarry, Scania[2]										
11.25 to 11.40 m	17	57.25±0.80	5.77±0.40	2.93±1.81	3.00±0.41	0.73±0.07	28.00±1.97	1.30±0.70	0.66±0.70	99.65
10.81 to 10.90 m	3	56.93±1.47	5.58±0.29	3.39±0.90	3.17±0.20	0.77±0.10	28.15±2.48	0.85±0.17	0.35±0.04	99.18
10.02 to 10.09 m	41 (56)	57.12±1.64	6.05±0.78	2.57±0.98	2.85±0.54	0.72±0.07	28.96±1.57	0.83±0.16	0.41±0.24	99.51
9.88 to 10.02 m	37 (74)	56.86±0.73	5.85±0.38	2.18±0.55	3.00±0.36	0.74±0.05	29.97±0.85	0.85±0.13	0.59±0.84	100.04
9.79 to 9.84 m	53	56.15±1.65	6.57±0.99	3.02±1.48	2.92±0.51	0.73±0.07	28.16±2.23	0.79±0.13	1.06±1.26	99.18
9.73 to 9.79 m	103	57.20±0.90	5.91±0.56	2.68±0.86	3.01±0.37	0.75±0.07	28.87±1.32	0.87±0.13	0.68±0.76	99.93
9.71 to 9.73 m	12	56.07±1.10	6.64±1.01	3.05±1.24	2.64±0.50	0.70±0.06	28.60±1.92	0.85±0.20	0.77±0.39	99.32
8.50 to 8.72 m	8	58.60±1.89	6.30±0.23	2.54±0.66	2.78±0.54	0.75±0.09	26.12±2.23	0.88±0.15	1.04±0.39	99.01
Total # of grains and average composition.	274	56.93±1.29	6.08±0.73	2.69±1.10	2.95±0.44	0.74±0.07	28.74±1.72	0.87±0.25	0.71±0.84	99.71
Thorsberg quarry, Kinnekulle[3]										
Sextummen 2.50 to 2.83 m	67	57.52±2.00	6.09±0.98	2.34±1.11	3.03±0.32	0.73±0.08	26.58±3.13	0.70±0.16	0.42±0.30	97.42
Botten 0.87 to 1.05 m	23	56.42±0.94	5.93±0.59	2.53±0.38	3.13±0.16	0.73±0.06	30.05±0.91	0.79±0.09	0.31±0.08	99.89
Golvsten 0.77 to 0.87 m	28	57.52±1.34	5.80±0.62	2.63±0.52	3.06±0.38	0.74±0.05	28.61±1.27	0.85±0.08	0.37±0.14	99.57
Golvsten 0.62 to 0.77 m	30	57.96±1.50	6.04±0.76	2.61±0.55	2.97±0.42	0.78±0.09	27.01±2.36	0.95±0.34	0.74±0.62	99.06
Arkeologen 0.08 to 0.56 m	128	57.82±1.37	6.15±0.66	2.71±0.70	3.16±0.30	0.75±0.07	27.08±2.46	0.77±0.18	0.61±0.61	99.05
Total # of grains and average composition.	276	57.61±1.58	6.07±0.76	2.58±0.79	3.09±0.33	0.75±0.07	27.36±2.63	0.78±0.20	0.53±0.50	98.77
Fossil and recent meteorites[4]										
Fossil meteorites (n=26) from Thorsberg quarry		57.6±1.3	5.53±0.29	2.57±0.83	2.73±0.40	0.73±0.03	26.94±3.89	1.01±0.33	1.86±2.43	98.97
Recent H5/L6 chondrites (n=11)		56.7±0.3	6.45±0.14	3.03±0.14	2.17±0.16	0.72±0.02	29.12±0.42	1.02±0.04	0.33±0.05	99.54
Recent L5/L6 chondrites (n=10)		56.0±0.7	5.86±0.36	2.73±0.64	2.73±0.42	0.75±0.02	30.16±1.18	0.84±0.10	0.31±0.04	99.38

[1] Only polished grains used for average compositions. [2] Depth relative to quarry floor. [3] Depth relative to base of Arkeologen bed. [4] From Schmitz *et al.* (2001).

where may provide evidence for a return to high EC grain concentrations.

Including this study, altogether six different Middle Ordovician limestone sections in southern and central Sweden have been shown to contain very high concentrations of EC grains in an interval at or close to the Arenig-Llanvirn boundary (Schmitz *et al.* 2003). The EC enrichment has been found at Kinnekulle (Thorsberg and Hällekis) and Billingen (Gullhögen) in Västergötland, in the Siljan area in Dalarna and Degerhamn at Öland. In total this represents an area of about 250,000 square kilometres. Schmitz *et al.* (2003) suggested that the dispersed EC grains primarily represent small weathered meteorites that were originally in the size range 0.1 to 1 cm in diameter. About 85-90% of the meteorites that fell on the sea floor during the formation of the Arkeologen bed appear to have disintegrated and are today represented by dispersed EC grains rather than fossil meteorites.

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Fig. 6. A) Chemical composition of EC grains at Killeröd (all polished grains from samples above 9.71 m; results from Table 3). B) For comparison, results for the 51 EC grains found in two samples (Botten and upper Golvsten beds) from the grey interval in the Thorsberg quarry, Kinnekulle (Schmitz & Häggström 2006). Note the larger spread in MgO concentrations in the Killeröd results.

Chemical composition of EC and OC grains

We use here, with some minor modification, the same definitions of EC and OC grains as in Schmitz & Häggström (2006) and refer to this paper for a more detailed discussion. Following Schmitz & Häggström (2006) the EC grains are characterized by high Cr_2O_3 contents in the range ca. 55-60 wt%, ca. 25-30 wt% FeO, ca. 5-8 wt% Al_2O_3 and ca. 1.5-4 wt% MgO (Tables 2-5). The most discriminative feature is that the composition should also plot within a narrow field of ca. 0.6-0.9 wt% V_2O_3 and ca. 2.0-3.5 wt% TiO_2. In

Table 2 elemental results for 274 polished EC grains from the Killeröd section are summarized and compared with the results for sediment-dispersed and meteorite-enclosed EC grains from Kinnekulle, as well as results for recent equilibrated H and L chondrites. The average compositions of the sediment-dispersed EC grains from Killeröd and Kinnekulle, respectively, are almost indistinguishable. Small differences in composition compared with chromite from recent meteorites are readily explained by minor diagenetic modifications. An example of the effects of diagenesis is the slightly higher FeO content of the Killeröd grains (28.7 wt% FeO) compared to the Kinnekulle grains (27.4 wt% FeO). This feature is developed also within the Kinnekulle section, where the EC grains from a few grey, more reduced beds show ca. 1–2% higher FeO contents than EC grains from the red oxidized beds (Table 2). The Killeröd section is grey to black and reduced throughout, and chromites from all the beds show similar FeO contents to the grey beds at Kinnekulle. Although EC grain average compositions are very similar at Kinnekulle and Killeröd, we note some marginal differences (Fig. 6; Table 2). The MgO concentrations at Killeröd are more scattered, with several grains having compositions a few percent outside the accepted ranges specified in Schmitz & Häggström (2006). We know from analyzing a large number of unpolished grains that surface irregularities have a much larger effect on the analytical results for MgO than for the other elements. The larger scatter in the MgO results in this study may, to some extent, be related to the different polishing approach compared to previous studies (see material and methods section), however, differences in diagenesis may also have played a significant role. The fact that we here accept some grains as EC, despite too high or low MgO values, has no bearing on any of the central conclusions. Another marginal difference compared to the Kinnekulle study is that we found 13 grains at Killeröd with typical EC grain composition for all elements, but TiO_2 concentrations in the range 0.8–2.0 wt% rather than the „accepted" 2.0–3.5 wt% range of Schmitz & Häggström (2006). Of the 13 grains, 10 have TiO_2 concentrations between 1.5–2.0 wt% and these have been classified as EC grains here. Grains with this composition were not found at Kinnekulle, but since TiO_2 concentrations in this range do sometimes occur in chromites from recent, equilibrated L chondrites, an EC classification is reasonable (Schmitz *et al.* 2001; Wlotzka 2005).

In contrast to the small compositional range of EC grains, OC grains from the Killeröd quarry show a wide scatter (Fig. 7). Element ranges are 28–66 wt% Cr_2O_3, 15–33 wt% FeO, 3.3–31 wt% Al_2O_3, 2.4–14 wt% MgO, <0.1–4.0 wt% TiO_2 and 0.1–1.1 wt% V_2O_3. Most of the OC grains are of terrestrial origin (Barnes & Roeder 2001), but some may be of extraterrestrial origin but with more unusual compositions than the typical common chromite of equilibrated chondrites, here referred to as EC. Some of the OC grains may represent common extraterrestrial chromite grains that have undergone extensive diagenetic alteration.

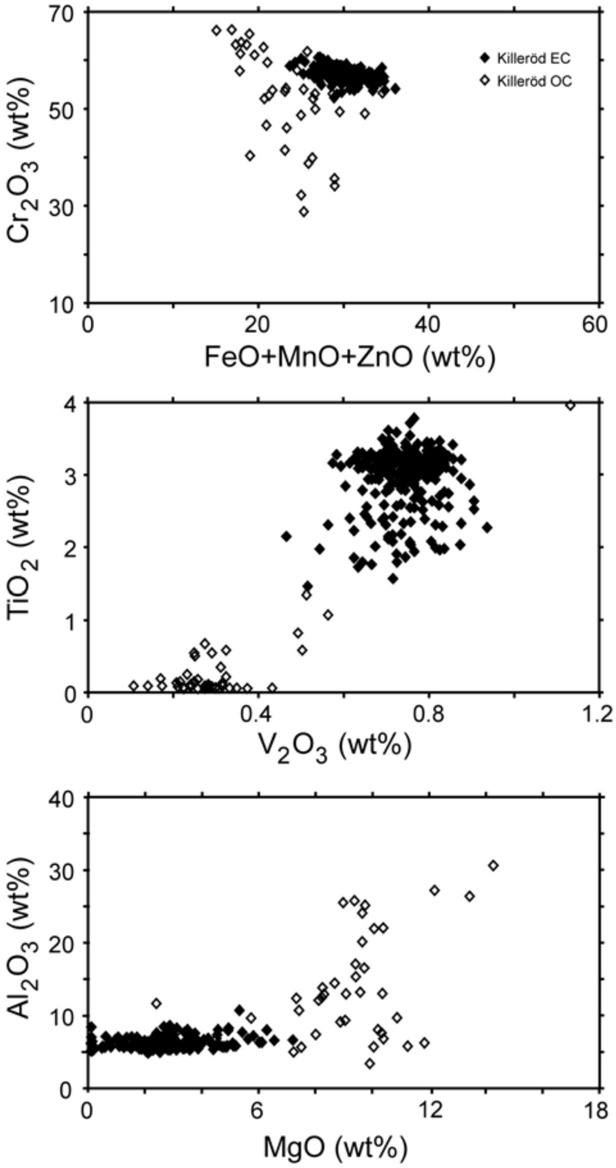

Fig. 7. Comparison of chemical composition of EC and OC grains recovered in the Killeröd quarry. The definition of an EC grain is that it has a composition within the defined ranges for all elements analysed (see text for details). There may be overlaps between OC and EC grains for single elements, but not for the full range of elements.

The approach here is to under-estimate rather than over-estimate the flux of extraterrestrial detritus. In recent chondritic meteorites, up to a few percent of the chrome-rich spinel grains may have compositions that would place them in the OC rather than the EC categories defined here. However, expanding the accepted ranges for our EC grains would create a greater and more complex overlap with terrestrial chromites. At Killeröd only one sample contains any significant amounts of OC grains, and the ratio OC/EC grain in this sample is 0.8, compared to ratios of 0.03–0.1 for most of the section. When OC/EC ratios are higher than 0.1, the majority of the OC grains are most likely of terrestrial origin, and may reflect synchronous ultramafic volcanism or exposure of terrestrial Cr-spinel rich rocks to sea-floor weathering and erosion. At Kinnekulle three samples of 24 studied are rich in OC grains and these samples, similarly to the OC-rich sample at Killeröd, all occur in the upper EC-rich part of the section. The occurrence of the anomalous grey, clay-rich interval in the OC- and EC-rich part of the section indicates on-going terrestrial environmental perturbations, including sea-level changes and exposure of previously buried rocks to weathering. The environmental perturbations may have been triggered by an increased flux of large L chondritic impactors, a proposal that finds some support in an over-representation of mid-Ordovician impact craters in recent compilations of craters on Earth (Schmitz *et al.* 2001).

Conclusions

The distribution trends for EC grains across the upper Arenig and lowermost Llanvirn are essentially identical in limestone sections from Killeröd and Kinnekulle, 350 km apart. The onset of a two-orders-of-magnitude enrichment in EC grains close to the Arenig-Llanvirn boundary at both sites most likely reflects an increased flux of ordinary chondritic micrometeorites and meteorites to Earth, following the disruption of the L chondrite parent body in the asteroid belt at about this time. Further studies of sections on other continents are required to further test the validity of this scenario.

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References

Barnes, S.J. & Roeder, P.L. 2001: The range of spinel compositions in terrestrial mafic and ultramafic rocks. Journal of Petrology 42, 2279-2302.

Bogard, D.D. 1995: Impact ages of meteorites: A synthesis. Meteoritics 30, 244-268.

Bunch, T.E., Keil, K. & Snetsinger, K.G. 1967: Chromite composition in relation to chemistry and texture of ordinary chondrites. Geochimica et Cosmochimica Acta 31, 1569-1582.

Heck, P.R., Schmitz, B., Baur, H., Halliday, A.N. & Wieler, R. 2004: Fast delivery of meteorites to Earth after a major asteroid collision. Nature 430, 323-325.

Jaanusson, V. 1995: Confacies differentiation and upper Middle Ordovician correlation in the Baltoscandian Basin. Eesti Teaduste Akadeemia Toimetised, Geologia 44, 73-86.

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

Keil, K., Haack, H. & Scott, E.R.D. 1994: Catastrophic fragmentation of asteroids: evidence from meteorites. Planetary and Space Science 42, 1109-1122.

Korochantseva, E.V., Trieloff, M., Buikin, A.I., Lorenz, C.A., Ivanova, M.A., Schwarz, W. H., Hopp, J. & Jessberger, E.K. 2006: L chondrite asteroid breakup tied to Ordovician meteorite shower by multiple isochron ^{40}Ar-^{39}Ar dating. Meteoritics & Planetary Science 41, A99.

Lindström, M. 1971: Vom Anfang, Hochstand und Ende eines Epikontinentalmeeres. Geologische Rundschau 60, 419-438.

McConville, P., Kelley, S. & Turner, G. 1988: Laser probe ^{40}Ar-^{39}Ar studies of the Peace River shocked L6 chondrite. Geochimica et Cosmochimica Acta 52, 2487-2499.

Nielsen., A.T. 1995: Trilobite systematics, biostratigraphy and palaeoecology of the Lower Ordovician Komstad Limestone and Huk Formations, Southern Scandinavia. Fossils and Strata 38, 1-374.

Nielsen, A.T. 2004a: New data on the Komstad Limestone of SE Scania, Sweden: Volkhov-Kunda bio- and ecostratigraphy. In: Hints, O. & Ainsaar, L. (eds): WOGOGOB-2004. Working Group on the Ordovician Geology of Baltoscandia, Abstracts, 72.

Nielsen, A.T. 2004b: Ordovician sea-level changes – a Baltoscandian perspective. In: Webby, B.D., Paris, F., Droser, M.L. & Percival, I.G. (eds): The Great Ordovician Biodiversification Event, 84-93. Columbia University Press.

Nyström, J.O., Lindström, M. & Wickman F.E. 1988: Discovery of a second Ordovician meteorite using chromite as a tracer. Nature 336, 572-574.

Regnéll, G. 1960: The lower Palaeozoic of Scania. In: Regnéll, G. & Hede, I.E. (eds): The Lower Palaeozoic of Scania, the Silurian of Gotland. Guide to Excursions Nos. A22 and C17, 3-43. 21st International Geological Congress, Norden 1960. Copenhagen.

Schmitz, B. & Häggström, T. 2006: Extraterrestrial chromite in Middle Ordovician marine limestone at Kinnekulle, southern Sweden – Traces of a major asteroid break-up event. Meteoritics & Planetary Science 41, 455-466.

Schmitz, B., Lindström, M., Asaro, F. & Tassinari, M. 1996: Geochemistry of meteorite-rich marine limestone strata and fossil meteorites from the lower Ordovician at Kinnekulle, Sweden. Earth and Planetary Science Letters 145, 31-48.

Schmitz, B., Tassinari, M. & Peucker-Ehrenbrink, B. 2001: A rain of ordinary chondritic meteorites in the early Ordovician. Earth and Planetary Science Letters 194, 1-15.

Schmitz, B., Häggström, T. & Tassinari, M. 2003: Sediment-dispersed extraterrestrial chromite traces a major asteroid disruption event. Science 300, 961-964.

Tassinari, M., Schmitz, B. & Löfgren, A. 2004: The first fossil meteorite from the mid-Ordovician of the Gullhögen quarry, Billingen, southern Sweden. GFF 126, 321–324.

Thorslund, P., Wickman, F. E. & Nyström J. O. 1984: The Ordovician chondrite from Brunflo, central Sweden. I. General description and primary minerals. Lithos 17, 87-100.

Villumsen, J., Nielsen, A.T. & Stouge, S. 2001: The trilobite and conodont biostratigraphy of the upper Volkhov-lower Kunda deposits at Hällekis quarry, Västergötland, Sweden. In: Harper, D.A.T. & Stouge, S. (eds): WOGOGOB-2001. Working Group on the Ordovician Geology of Baltoscandia, Abstracts, 30-31.

Wlotzka, F. 2005: Cr spinel and chromite as petrogenetic indicators in ordinary chondrites: Equilibration temperatures of petrologic types 3.7 to 6. Meteoritics & Planetary Science 40, 1673-1702.

Table 3 (Appendix). Element concentration (wt%) in polished sediment-dispersed extraterrestrial chromite grains (EC) and other Cr-rich spinels (OC) (>63μm) extracted from the Middle Ordovician Komstad Limestone in the Killeröd quarry, southern Sweden.

Sample and depth relative to base of the Killeröd section (quarry floor)	Cr_2O_3	Al_2O_3	MgO	TiO_2	V_2O_3	FeO	MnO	ZnO	Total
EC grains									
6.45 to 6.60 m	57.52	6.55	5.64	2.34	0.69	24.08	0.90	0.60	98.32
7.67 to 7.75 m	58.25	6.51	1.38	2.63	0.67	27.96	0.71	1.05	99.18
8.50 to 8.72 m	58.92	6.26	2.49	3.12	0.85	25.77	0.90	0.71	99.02
	57.20	6.00	3.54	3.07	0.72	26.68	0.89	0.77	98.87
	56.54	6.28	3.27	3.17	0.70	26.48	1.14	0.62	98.20
	57.06	6.14	2.23	1.89	0.64	29.04	0.70	1.35	99.03
	62.27	6.51	1.42	2.64	0.86	21.55	0.80	1.69	97.74
	58.70	6.75	2.15	2.01	0.73	26.88	0.88	1.38	99.48
	57.92	6.30	2.55	3.25	0.64	27.70	0.71	0.99	100.05
	60.15	6.19	2.38	3.08	0.82	24.85	1.04	0.80	99.31
9.71 to 9.73 m	57.21	5.26	0.08*	1.99	0.81	31.13	0.93	1.73	99.14
	56.55	6.60	3.49	1.79	0.72	27.56	0.84	1.05	98.60
	53.49	7.31	2.43	2.11	0.70	31.93	0.70	0.56	99.23
	55.22	7.49	3.59	2.33	0.66	28.76	0.84	0.81	99.70
	56.96	7.95	4.94	3.13	0.59	25.15	0.49	0.41	99.62
	56.89	5.41	2.07	2.75	0.67	30.39	0.63	0.37	99.18
	54.78	8.03	3.52	2.55	0.76	27.72	0.78	1.25	99.39
	56.03	6.88	3.05	2.55	0.75	28.82	0.97	0.69	99.74
	56.42	5.45	2.30	3.13	0.67	29.52	1.29	0.52	99.30
	55.95	6.82	4.24	3.11	0.70	26.91	0.77	0.60	99.10
	57.17	5.51	3.08	3.18	0.76	27.99	0.95	0.60	99.24
	56.21	6.95	3.77	3.09	0.66	27.28	0.96	0.62	99.54
9.73 to 9.79 m	54.02	7.45	2.85	1.97	0.54	31.94	0.91	0.47	100.15
	57.29	5.66	2.73	3.19	0.72	29.74	0.69	0.41	100.43
	57.09	5.30	2.28	3.24	0.66	30.05	0.84	0.49	99.95
	56.50	5.48	2.73	3.35	0.79	29.42	0.80	0.50	99.57
	55.39	6.30	1.74	3.13	0.64	30.08	0.84	1.67	99.79
	55.39	6.75	0.99	3.08	0.66	29.45	0.94	3.61	100.87
	56.93	5.90	2.94	3.22	0.80	29.33	0.87	0.35	100.34
	57.06	5.78	2.47	3.04	0.71	29.93	0.88	0.32	100.19
	57.02	5.54	2.84	3.09	0.76	28.87	0.93	0.56	99.61
	56.86	5.68	2.49	3.16	0.83	28.90	0.77	0.36	99.05
	56.83	5.67	2.58	3.10	0.79	29.59	1.02	0.34	99.92
	57.51	5.63	2.33	3.13	0.69	29.24	0.82	0.32	99.67
	57.28	5.25	2.84	3.26	0.79	28.48	0.92	0.30	99.12
	57.04	5.89	3.18	3.25	0.77	28.60	1.08	0.32	100.13
	57.40	6.97	2.64	3.17	0.76	27.78	0.98	0.54	100.24
	58.50	5.94	2.36	3.28	0.77	28.04	0.73	0.47	100.09
	58.25	5.28	2.30	3.56	0.75	28.15	0.94	0.68	99.91
	58.97	6.53	6.55	2.75	0.84	23.04	0.63	0.69	100.00
	59.01	4.81	2.15	2.53	0.90	28.53	1.24	0.47	99.64
	55.05	7.02	1.56	2.75	0.84	29.98	0.85	1.94	99.99
	57.01	5.80	2.22	3.20	0.80	29.79	0.92	0.35	100.09
	57.88	5.29	3.15	3.37	0.82	28.67	1.05	0.39	100.62
	58.46	5.50	2.97	3.27	0.84	26.67	0.87	0.30	98.88
	57.68	5.56	2.50	3.16	0.80	28.79	0.85	0.38	99.72
	57.93	5.62	2.04	3.29	0.70	27.93	0.92	0.87	99.30
	57.57	5.62	2.74	3.22	0.70	28.86	0.82	0.37	99.90
	57.76	5.62	2.80	3.20	0.77	28.91	1.24	0.47	100.77
	58.45	5.79	5.21	3.25	0.74	25.84	0.62	0.18*	100.08
	57.93	5.80	2.70	3.21	0.75	29.13	0.87	0.17*	100.56
	57.62	5.33	2.23	2.60	0.73	29.54	0.81	0.48	99.34
	57.64	5.23	3.12	3.37	0.75	28.83	0.93	0.50	100.37
	57.83	6.15	2.12	3.20	0.81	28.32	0.87	0.53	99.83
	57.40	6.09	3.11	1.86	0.74	29.01	0.96	0.69	99.86
	56.92	5.45	2.26	3.29	0.64	30.39	0.76	0.41	100.12
	57.06	6.01	2.87	3.14	0.81	29.11	0.80	0.30	100.10
	57.29	5.02	2.08	3.31	0.66	29.64	0.87	0.40	99.27

Table 3 Continued

Sample and depth relative to base of the Killeröd section (quarry floor)	Cr_2O_3	Al_2O_3	MgO	TiO_2	V_2O_3	FeO	MnO	ZnO	Total
	57.89	6.10	3.03	3.00	0.74	27.57	0.75	0.24	99.32
	56.52	5.95	2.97	3.03	0.78	28.38	1.02	0.64	99.29
	56.54	6.18	2.45	2.56	0.65	29.31	0.93	0.67	99.29
	55.63	5.97	1.84	3.10	0.63	30.53	0.86	1.18	99.74
	56.38	6.27	0.80	2.68	0.76	28.80	0.98	3.03	99.70
	56.02	5.44	1.54	3.33	0.72	30.92	0.82	0.46	99.25
	56.32	5.93	2.41	3.20	0.74	29.58	1.13	0.47	99.78
	57.21	8.60	2.90	2.06	0.75	26.17	0.86	1.28	99.83
	57.24	6.62	4.09	1.72	0.63	28.17	0.89	0.56	99.92
	56.74	6.15	2.18	2.79	0.74	28.41	0.86	2.59	100.46
	55.69	5.58	0.29	2.96	0.87	30.12	0.98	2.74	99.23
	57.88	5.50	2.53	2.84	0.70	29.86	0.96	0.32	100.59
	57.50	5.78	2.19	3.14	0.77	29.96	0.85	0.34	100.53
	57.30	5.36	2.61	3.42	0.79	29.30	0.82	0.42	100.02
	57.52	5.43	2.28	3.26	0.67	29.74	0.72	0.33	99.95
	56.11	5.54	1.29	3.07	0.80	31.49	0.82	1.11	100.23
	57.44	5.22	2.62	3.37	0.76	28.37	0.95	0.65	99.38
	57.14	5.47	3.88	3.11	0.64	27.55	0.80	0.53	99.12
	56.14	6.04	3.16	2.41	0.69	29.54	0.67	0.70	99.35
	57.29	6.08	1.79	2.95	0.79	30.24	0.87	0.63	100.64
	56.91	6.65	2.84	2.71	0.82	29.79	0.84	0.40	100.96
	57.45	5.77	2.55	3.03	0.79	29.35	1.00	0.30	100.24
	57.54	6.11	2.41	3.22	0.76	28.81	0.80	0.35	100.00
	57.43	5.47	2.67	3.39	0.74	29.97	0.75	0.53	100.95
	58.66	5.72	1.82	3.28	0.80	28.34	0.64	0.50	99.76
	56.32	5.78	3.18	3.29	0.71	28.62	1.00	0.39	99.29
	56.73	5.87	3.00	2.85	0.60	29.18	0.88	0.49	99.60
	55.78	7.30	4.56	2.42	0.65	27.67	0.68	0.47	99.53
	57.69	5.56	3.14	3.30	0.64	29.28	0.73	0.21	100.55
	56.92	6.02	2.69	2.23	0.62	29.39	0.91	0.54	99.32
	57.24	5.38	3.37	3.22	0.87	28.44	0.72	0.25	99.49
	56.78	5.77	1.83	2.87	0.89	30.34	0.87	0.78	100.13
	58.54	5.86	2.28	3.17	0.78	27.89	0.81	0.46	99.79
	58.72	5.94	2.44	3.23	0.79	27.57	0.72	0.47	99.88
	57.41	5.57	2.75	3.35	0.70	29.98	0.74	0.22	100.72
	57.39	5.56	2.53	3.17	0.74	28.78	0.79	0.36	99.32
	56.24	6.31	2.74	2.93	0.76	29.92	0.99	0.62	100.51
	57.98	6.29	2.31	2.15	0.70	28.57	0.89	0.99	99.88
	57.78	5.77	2.38	3.45	0.80	29.28	0.82	0.23	100.51
	57.41	5.80	3.29	2.64	0.90	27.40	1.25	0.63	99.32
	57.39	5.34	2.90	3.21	0.65	28.77	0.93	0.45	99.64
	58.17	5.73	3.51	3.48	0.82	26.49	0.85	0.32	99.37
	57.06	5.63	3.38	3.25	0.80	28.91	0.69	0.40	100.12
	57.17	5.33	2.53	3.30	0.74	29.69	0.93	0.25	99.94
	56.78	5.74	2.52	3.16	0.82	28.95	0.76	0.35	99.08
	58.03	5.38	3.89	2.52	0.78	27.79	0.72	0.26	99.37
	57.76	6.36	3.42	3.00	0.72	26.96	1.10	0.92	100.24
	56.34	6.08	3.04	3.01	0.73	29.39	0.87	0.27	99.73
	57.34	6.03	2.35	3.07	0.76	29.32	0.72	0.37	99.96
	57.21	6.10	3.19	3.24	0.79	29.30	0.74	0.39	100.96
	56.36	5.83	1.81	3.13	0.81	30.75	0.72	0.87	100.28
	57.46	5.85	3.21	3.13	0.81	29.01	0.91	0.50	100.88
	57.07	5.92	1.37	2.94	0.81	30.15	0.98	1.94	101.18
	58.10	6.21	3.01	2.89	0.76	26.99	0.89	0.59	99.44
	57.85	5.72	2.92	3.13	0.71	28.39	0.98	0.43	100.13
	55.41	5.67	2.05	2.40	0.61	31.37	0.95	0.62	99.08
	57.34	7.39	2.98	2.59	0.69	27.53	0.80	0.69	100.01
	56.52	6.60	2.65	2.77	0.83	29.54	1.06	0.79	100.76
	57.52	6.76	3.00	3.12	0.82	28.21	0.93	0.71	101.07
	58.64	5.89	2.73	2.33	0.87	28.12	0.98	0.59	100.15
	55.40	6.98	0.00*	2.31	0.81	27.39	0.80	5.62	99.31
	56.36	5.34	1.91	3.27	0.76	30.55	0.67	0.37	99.23
	57.67	5.73	2.95	3.36	0.80	28.83	0.78	0.35	100.47
	57.47	6.38	2.43	3.12	0.81	29.83	0.90	0.47	101.41
	57.02	5.70	2.52	3.25	0.79	29.26	0.83	0.29	99.66
	59.30	5.86	2.28	2.89	0.71	25.73	0.90	0.79	98.46
	57.61	6.28	6.03	3.17	0.83	25.45	0.70	0.45	100.52

Table 3 Continued

Sample and depth relative to base of the Killeröd section (quarry floor)	Cr_2O_3	Al_2O_3	MgO	TiO_2	V_2O_3	FeO	MnO	ZnO	Total
9.79 to 9.84 m	54.16	6.74	2.34	3.12	0.74	30.15	0.80	0.60	98.65
	58.52	6.48	2.35	3.18	0.75	26.44	0.86	0.55	99.13
	56.18	6.02	4.37	2.96	0.73	27.99	0.66	0.50	99.41
	57.07	6.04	3.70	3.06	0.78	27.40	0.75	0.42	99.22
	56.88	6.73	5.64	3.02	0.80	26.54	0.78	0.40	100.79
	53.56	6.18	0.05*	3.63	0.70	32.96	0.71	0.89	98.68
	56.38	6.10	2.93	3.42	0.71	28.16	0.96	0.46	99.12
	56.75	6.36	2.21	2.17	0.71	29.42	0.77	0.64	99.03
	54.52	6.96	1.39	2.63	0.78	24.21	0.83	5.64	96.96
	57.31	6.19	2.66	1.79	0.64	27.87	0.78	1.00	98.24
	56.64	5.48	2.89	3.27	0.68	28.83	0.91	0.55	99.25
	55.42	5.23	0.10*	2.81	0.73	26.97	0.80	6.71	98.77
	55.40	6.04	2.87	3.00	0.68	29.00	0.73	0.50	98.22
	55.65	6.73	3.83	3.23	0.62	28.72	0.90	0.58	100.26
	56.52	7.01	1.09	2.08	0.80	29.46	0.80	1.52	99.28
	57.21	5.22	0.00*	2.08	0.71	31.30	0.99	1.45	98.96
	59.44	6.30	2.39	3.43	0.85	24.62	0.59	0.40	98.02
	55.84	5.78	2.97	3.27	0.73	29.05	0.79	0.41	98.84
	55.27	6.77	3.61	3.29	0.68	28.57	0.62	0.58	99.39
	57.36	5.07	0.00*	1.96	0.82	31.03	0.97	2.01	99.22
	51.97	10.71	5.33	2.31	0.56	27.52	0.86	0.50	99.76
	53.76	7.50	2.89	3.29	0.58	29.54	0.66	0.42	98.64
	53.51	6.70	2.89	3.18	0.70	29.92	0.77	0.43	98.10
	54.41	6.76	2.38	3.18	0.73	30.23	0.78	0.42	98.89
	54.12	6.68	2.47	3.11	0.77	30.34	0.78	0.42	98.69
	53.11	8.01	4.58	2.87	0.73	28.57	0.66	0.49	99.02
	55.26	6.13	5.10	3.09	0.68	26.13	0.68	0.45	97.52
	56.19	8.25	4.95	3.05	0.73	25.46	0.70	0.50	99.83
	55.68	6.35	2.69	3.22	0.75	29.65	0.61	0.65	99.60
	54.71	7.19	5.82	3.14	0.75	26.49	0.54	0.43	99.07
	58.21	5.74	0.00*	1.98	0.83	31.22	0.92	2.10	101.00
	55.44	7.64	2.90	1.94	0.76	28.26	0.85	0.74	98.53
	53.89	6.41	0.16*	3.73	0.75	33.21	0.98	1.54	100.67
	55.15	6.38	1.67	2.07	0.75	31.36	0.87	0.40	98.65
	55.31	8.39	0.00*	2.01	0.67	30.23	0.79	3.01	100.41
	56.90	6.25	2.45	2.27	0.93	29.92	0.88	0.48	100.08
	55.16	8.23	3.14	2.56	0.84	27.72	1.00	0.78	99.43
	55.82	6.35	2.67	3.19	0.75	29.65	0.58	0.61	99.62
	56.81	5.68	0.54	3.03	0.75	29.05	0.83	2.59	99.28
	58.08	6.01	3.45	3.31	0.64	26.56	0.62	0.38	99.05
	57.42	7.02	2.82	3.34	0.79	26.73	0.67	0.46	99.25
	57.41	4.87	2.55	3.17	0.61	29.02	0.87	0.54	99.04
	57.12	5.95	4.55	3.13	0.67	27.00	0.63	0.38	99.43
	56.53	7.10	0.66	2.79	0.64	28.39	1.10	3.19	100.40
	56.57	7.00	1.75	2.18	0.73	28.61	0.72	2.79	100.35
	60.10	7.00	2.62	3.49	0.69	23.51	0.91	0.79	99.11
	57.57	5.45	3.44	3.45	0.74	26.76	0.79	0.37	98.57
	59.34	6.21	3.62	3.31	0.83	23.04	1.05	0.44	97.84
	56.32	6.87	3.68	3.09	0.67	27.21	0.91	0.61	99.36
	56.77	5.89	4.64	3.14	0.68	26.90	0.81	0.47	99.30
	56.79	5.78	4.91	3.31	0.83	26.22	0.72	0.46	99.02
	57.75	6.09	2.88	3.46	0.79	25.34	0.78	2.12	99.21
	56.91	7.97	6.29	2.77	0.77	24.27	0.74	0.45	100.17
9.88 to 10.02 m†	56.43	5.47	2.78	2.57	0.72	31.28	0.80	0.41	100.46
	56.97	5.65	2.58	3.11	0.78	29.90	0.88	0.27	100.14
	56.98	5.67	2.21	3.01	0.70	30.42	0.86	0.38	100.23
	56.68	5.45	2.10	3.07	0.82	30.25	1.04	0.38	99.79
	56.79	5.98	2.12	2.42	0.71	30.30	0.75	0.56	99.63
	57.49	5.84	2.38	3.12	0.68	29.79	0.75	0.27	100.32
	56.07	6.59	2.40	3.02	0.77	30.64	0.86	0.32	100.67
	56.80	6.01	3.85	3.07	0.79	27.77	0.96	0.47	99.72
	55.33	6.19	1.19	3.08	0.79	30.64	1.11	1.08	99.41
	57.49	5.61	2.37	3.08	0.69	29.79	0.89	0.33	100.25
	56.46	5.64	2.24	3.21	0.77	30.53	0.73	0.18*	99.76
	56.32	5.80	2.03	3.24	0.67	30.17	0.95	0.34	99.52

†Additionally 37 EC grains were found and analysed preliminarily as loose grains, but were lost during the polishing (see Table 4).

Table 3 Continued

Sample and depth relative to base of the Killeröd section (quarry floor)	Cr_2O_3	Al_2O_3	MgO	TiO_2	V_2O_3	FeO	MnO	ZnO	Total
	57.13	5.71	2.20	3.27	0.63	29.74	0.80	0.21	99.69
	56.66	5.91	2.20	3.06	0.82	30.46	0.73	0.19*	100.03
	57.01	5.92	2.27	3.26	0.67	29.48	0.70	0.18*	99.49
	55.93	5.62	2.25	3.14	0.65	30.36	0.95	0.56	99.46
	57.51	6.49	2.01	1.56	0.71	29.48	0.92	0.52	99.20
	56.53	6.43	1.05	3.11	0.77	29.28	0.93	2.54	100.64
	56.80	5.69	2.28	2.98	0.77	30.39	0.71	0.29	99.91
	55.55	6.74	2.82	3.02	0.76	30.70	0.90	0.36	100.85
	57.10	5.66	2.51	3.18	0.74	29.97	0.86	0.36	100.38
	56.44	6.58	2.27	2.77	0.78	31.00	0.76	0.33	100.93
	56.92	5.40	2.32	3.44	0.69	30.15	0.77	0.33	100.02
	56.23	5.72	1.94	3.10	0.77	28.98	1.02	1.13	98.89
	56.94	5.36	2.08	2.98	0.70	30.52	0.84	0.41	99.83
	58.39	6.08	1.61	2.03	0.87	30.37	0.96	0.55	100.86
	56.64	6.31	2.13	2.77	0.69	31.17	0.48	0.60	100.79
	56.00	5.73	2.53	3.19	0.69	30.48	0.85	0.36	99.83
	56.55	6.06	0.18*	3.29	0.74	27.67	1.12	4.95	100.56
	58.71	5.75	2.47	3.06	0.85	28.23	0.96	0.31	100.34
	56.01	6.16	2.17	2.70	0.77	30.32	0.74	0.45	99.32
	57.59	5.42	2.08	3.19	0.74	30.05	0.74	0.38	100.19
	57.01	5.65	2.35	3.28	0.80	30.14	0.65	0.34	100.22
	57.96	5.22	2.31	3.13	0.76	29.03	0.83	0.28	99.52
	58.07	5.79	2.13	3.15	0.78	28.70	0.90	0.41	99.93
	57.00	5.37	2.06	3.15	0.75	30.54	0.82	0.47	100.16
	57.51	5.65	2.12	3.11	0.75	30.30	0.89	0.29	100.62
10.02 to 10.09 m†	58.23	6.90	2.32	3.80	0.76	26.55	0.87	0.28	99.71
	57.62	6.26	6.12	2.98	0.76	25.46	0.78	0.28	100.26
†Additionally 15 EC grains were found and analysed preliminarily as loose grains, but were lost during the polishing (see Table 4).	56.65	6.01	2.41	2.94	0.68	30.24	0.91	0.35	100.19
	57.80	5.55	1.86	2.96	0.67	29.98	0.73	0.17*	99.72
	57.46	5.82	1.70	3.22	0.79	29.81	0.77	0.70	100.27
	60.30	5.64	2.25	3.44	0.77	26.17	0.69	0.24	99.50
	59.68	5.64	4.81	2.14	0.70	26.05	0.93	0.42	100.37
	54.33	7.69	5.43	2.15	0.46	27.62	0.61	0.36	98.65
	53.98	8.43	2.69	2.35	0.75	29.68	0.75	0.35	98.98
	56.66	5.77	2.37	3.11	0.79	30.06	0.79	0.20*	99.75
	55.02	7.52	3.78	2.03	0.75	28.72	0.57	0.25*	98.64
	60.39	5.58	2.19	3.60	0.72	26.42	0.54	0.34	99.78
	58.07	5.48	2.82	1.85	0.62	29.24	0.84	0.28	99.20
	54.77	7.56	2.44	2.46	0.64	29.56	0.90	0.40	98.73
	55.70	4.87	2.15	2.99	0.74	28.14	0.76	0.63	95.98
	55.25	5.83	1.40	2.94	0.75	30.71	1.12	1.19	99.19
	56.46	5.80	2.38	2.75	0.67	30.47	0.79	0.25	99.57
	56.17	5.81	2.52	2.38	0.69	28.03	0.78	0.54	96.92
	57.80	6.20	1.81	2.29	0.83	28.21	1.02	1.23	99.39
	59.71	6.16	1.63	3.40	0.74	26.68	1.03	0.46	99.81
	57.40	6.23	2.44	3.10	0.67	30.19	0.58	0.29	100.90
	57.42	5.74	2.62	3.51	0.69	29.63	0.90	0.32	100.83
	56.87	5.52	2.02	2.98	0.80	31.01	0.87	0.40	100.47
	55.52	6.93	2.60	3.16	0.74	30.16	0.87	0.28	100.26
	57.93	5.55	2.14	3.19	0.63	29.07	0.82	0.58	99.91
	58.92	5.94	2.56	3.50	0.70	28.06	0.76	0.34	100.78
	56.99	5.63	0.84	1.90	0.72	29.46	0.99	0.98	97.51
	55.78	5.96	2.17	3.03	0.74	30.18	0.97	0.48	99.31
	56.93	6.02	2.13	2.95	0.66	29.36	1.15	0.28	99.48
	52.74	7.65	3.41	1.45	0.51	28.05	0.79	0.36	94.96
	56.78	5.39	1.83	2.64	0.80	31.05	0.94	0.32	99.75
	57.94	6.83	2.97	2.39	0.79	26.25	1.19	0.68	99.04
	57.88	5.37	2.34	3.35	0.69	30.69	0.63	0.18*	101.13
	58.87	5.24	3.60	2.33	0.74	27.43	0.56	0.47	99.24
	56.35	5.62	2.34	2.81	0.70	30.76	0.80	0.29	99.67
	58.49	5.42	2.42	3.22	0.79	28.36	1.08	0.38	100.16
	57.45	5.57	2.44	3.12	0.77	30.40	0.86	0.32	100.93
	57.57	5.53	2.31	3.25	0.74	29.36	0.70	0.35	99.81
	57.54	5.60	2.43	3.18	0.71	30.20	0.83	0.34	100.83

Table 3 Continued

Sample and depth relative to base of the Killeröd section (quarry floor)	Cr_2O_3	Al_2O_3	MgO	TiO_2	V_2O_3	FeO	MnO	ZnO	Total
	56.93	6.06	2.31	2.59	0.82	29.83	0.89	0.12*	99.55
	57.41	5.58	2.34	3.30	0.79	30.09	0.85	0.23*	100.59
10.81 to 10.90 m	58.58	5.29	4.42	3.33	0.81	25.37	0.84	0.39	99.03
	56.46	5.58	2.84	2.95	0.65	30.11	0.68	0.31	99.58
	55.75	5.87	2.90	3.23	0.85	28.98	1.02	0.34	98.94
11.25 to 11.40 m	57.05	5.30	2.29	3.13	0.69	30.26	0.97	0.52	100.21
	56.66	6.01	4.01	3.09	0.79	28.13	0.95	0.31	99.95
	56.44	5.51	2.90	3.44	0.77	29.61	0.76	0.28	99.71
	57.26	5.66	4.74	3.06	0.73	26.84	0.74	0.40	99.43
	57.85	5.26	2.92	3.17	0.70	29.14	1.03	0.28	100.35
	56.28	5.48	0.52	3.24	0.74	29.16	2.65	2.64	100.71
	57.51	6.17	3.19	2.90	0.72	28.96	0.94	0.11*	100.50
	56.48	5.44	1.93	3.06	0.82	30.33	1.05	0.44	99.55
	57.79	5.65	2.57	3.11	0.83	28.05	0.79	0.37	99.16
	58.56	6.60	7.20	2.31	0.69	22.77	0.81	0.34	99.28
	57.07	5.64	4.89	3.25	0.82	26.21	0.86	0.40	99.14
	55.67	6.63	3.01	2.90	0.74	29.81	1.06	0.44	100.26
	57.11	5.65	1.29	3.32	0.63	29.25	1.58	0.53	99.36
	58.11	5.95	1.38	2.85	0.76	27.68	1.59	0.60	98.92
	58.57	5.76	1.14	1.76	0.66	25.84	2.80	1.12	97.65
	57.30	5.59	0.63	3.32	0.82	28.01	2.59	2.20	100.46
	57.58	5.80	5.13	3.17	0.57	25.96	0.98	0.26	99.45
OC grains	*Cr_2O_3*	*Al_2O_3*	*MgO*	*TiO_2*	*V_2O_3*	*FeO*	*MnO*	*ZnO*	*Total*
5.63 to 5.78 m	61.46	7.34	8.30	0.69	0.71	17.95	1.43	1.55	99.42
6.45 to 6.60 m	50.63	17.01	11.92	0.29	0.00*	18.39	0.00*	0.00*	98.24
9.71 to 9.73 m	52.80	10.72	7.42	0.17	0.17	28.04	0.54	0.11*	99.97
9.73 to 9.79 m	28.34	30.82	14.21	0.57	0.50	25.10	0.35	0.04*	99.93
	57.03	5.85	3.39	1.06	0.56	28.61	1.01	0.81	98.32
	56.32	7.77	3.14	1.34	0.51	29.23	0.92	0.97	100.20
9.79 to 9.84 m	33.69	25.93	9.36	0.49	0.25	28.29	0.34	0.31	98.66
	49.12	12.11	8.10	0.33	0.31	28.97	0.38	0.16*	99.49
	60.01	5.62	7.50	0.07*	0.14	27.09	0.30	0.26	100.99
	61.57	4.95	7.23	0.06*	0.21	25.09	0.63	0.16*	99.90
	58.62	7.15	2.88	0.81	0.49	27.16	0.81	1.00	98.92
9.88 to 10.02 m†	31.77	26.53	13.38	0.66	0.27	24.92	0.23	0.06*	97.82
	65.23	3.32	9.89	0.57	0.32	19.12	0.29	0.01*	98.75
	63.03	6.77	10.37	0.00*	0.33	18.31	0.53	0.27	99.61
	51.80	13.84	8.24	0.09*	0.24	26.06	0.41	0.07*	100.75
	39.96	27.36	12.16	0.07*	0.17	18.90	0.33	0.25	99.20
	60.83	9.10	8.86	0.06*	0.24	19.12	0.54	0.31	99.06
	53.57	14.47	8.66	0.06*	0.29	20.81	0.82	0.35	99.03
	57.55	13.03	10.33	0.07*	0.27	17.78	0.40	0.15*	99.58
	48.35	17.13	9.39	0.13	0.21	24.36	0.62	0.19	100.38
	53.77	12.37	7.33	0.03*	0.26	24.61	0.63	0.24	99.24
	53.03	6.83	4.53	0.02*	0.22	33.39	0.57	0.33	98.92
	63.01	8.01	10.18	0.01*	0.27	17.07	0.45	0.36	99.36
	45.75	20.22	9.63	0.12	0.25	23.00	0.42	0.17*	99.56
	63.49	7.57	10.31	0.00*	0.28	17.70	0.58	0.20*	100.13
	52.83	12.50	8.21	0.16	0.26	25.95	0.49	0.29	100.69
	39.50	22.06	10.04	0.13	0.25	25.79	0.38	0.28	98.43
	52.45	15.38	9.40	0.11	0.21	20.94	0.52	0.15*	99.16
	59.35	9.32	9.03	0.04*	0.31	20.47	0.62	0.33	99.47
	62.50	7.34	8.00	0.04*	0.30	20.08	0.52	0.38	99.16
	65.94	6.18	11.80	0.01*	0.37	15.01	0.44	0.28	100.03
	35.19	25.29	9.73	0.07*	0.31	28.28	0.41	0.24	99.52
	53.34	13.02	9.06	0.00*	0.35	22.71	0.38	0.28	99.14
	55.62	9.65	5.74	0.11	0.31	28.14	0.66	0.26	100.49
	53.91	12.95	8.29	0.00*	0.43	22.48	0.74	0.27	99.07

†Additionally 30 OC grains were found and analysed preliminarily as loose grains, but were lost during the polishing (see Table 4).

Table 3 Continued

Sample and depth relative to base of the Killeröd section (quarry floor)	Cr_2O_3	Al_2O_3	MgO	TiO_2	V_2O_3	FeO	MnO	ZnO	Total
	51.81	16.59	9.70	0.09*	0.28	20.40	0.45	0.22	99.54
	66.11	5.73	11.22	0.02*	0.30	17.03	0.27*	0.14*	100.82
	61.16	9.68	10.85	0.07*	0.11*	17.39	0.78	0.23	100.27
10.02 to 10.09 m†	41.14	25.65	8.96	0.53	0.29	22.60	0.54	0.24	99.95
	46.25	22.16	10.36	0.00*	0.22	20.58	0.38	0.34	100.29
†Additionally 1 OC grain was found but lost during polishing (see Table 4)	49.62	13.24	9.56	0.23	0.23	26.03	0.54	0.22	99.67
10.81 to 10.90 m	57.73	5.63	10.03	0.20	0.32	24.27	0.43	0.03*	98.64
11.25 to 11.40 m	38.38	24.20	9.63	0.53	0.25	25.16	0.67	0.18*	99.00
	48.71	11.65	2.43	4.03	1.12	31.87	0.40	0.05*	100.26

Values marked with * are lower than the detection limit (<2 Sigma)

Table 4 (Appendix). Element concentration (wt%) in unpolished sediment-dispersed extraterrestrial chromite grains (EC) and other Cr-rich spinels (OC) (>63µm) extracted from the Middle Ordovician Komstad Limestone in the Killeröd quarry, southern Sweden.

Sample and depth relative to base of the Killeröd section (quarry floor)	Cr_2O_3	Al_2O_3	MgO	TiO_2	V_2O_3	FeO	MnO	ZnO	Total
EC grains (preliminary classification)									
9.88 to 10.02 m	48.62	5.06	2.98	2.02	0.50	31.76	0.95	0.24	92.13
	49.71	9.82	1.79	1.86	0.56	25.35	0.82	2.37	92.28
	52.52	6.07	1.76	2.96	0.55	27.36	0.63	0.41	92.26
	50.75	10.29	2.56	1.98	0.60	27.21	0.90	1.13	95.42
	52.35	7.92	2.66	2.78	0.76	28.82	0.72	0.77	96.78
	51.15	5.97	5.93	2.20	0.64	24.05	0.90	0.22	91.05
	56.99	7.25	3.02	1.49	0.40	28.67	0.93	0.59	99.33
	50.53	7.99	1.42	2.63	0.73	26.20	1.33	2.04	92.87
	55.21	8.53	2.77	1.79	0.48	31.86	0.72	0.30	101.66
	55.75	5.49	3.15	2.82	0.69	29.27	0.95	1.01	99.13
	56.37	5.24	11.70	2.57	0.60	19.89	0.54	0.33	97.25
	51.04	5.46	3.98	2.52	0.60	28.36	0.67	0.17	92.80
	57.26	4.60	2.12	1.72	0.79	28.81	0.87	0.52	96.69
	41.58	0.49	0.09	1.36	0.36	15.90	1.03	0.13	60.94
	51.55	6.03	2.62	2.87	0.61	34.29	0.79	0.17	98.93
	53.79	7.06	2.61	1.92	0.56	28.91	0.94	0.52	96.31
	53.15	3.63	2.29	1.17	0.67	29.83	1.01	0.31	92.06
	58.96	3.90	8.77	2.88	0.64	25.96	0.93	0.36	102.40
	58.56	8.30	2.47	1.68	0.68	28.31	1.35	0.95	102.30
	51.12	6.21	3.51	2.50	0.55	33.64	0.71	0.03	98.27
	46.90	9.29	4.65	1.40	0.49	29.35	0.99	0.44	93.51
	53.97	5.00	2.52	2.75	0.74	26.64	0.72	0.17	92.51
	48.38	8.45	3.90	2.03	0.50	35.03	0.82	0.00	99.11
	56.49	5.04	6.09	3.01	0.64	26.62	0.39	0.00	98.28
	57.09	7.66	1.65	2.60	0.96	29.15	1.16	0.77	101.04
	45.89	4.99	1.45	2.29	0.50	30.79	0.67	0.38	86.96
	54.03	6.33	2.62	2.81	0.64	29.57	0.79	0.24	97.03
	53.91	9.00	3.17	2.60	0.71	29.07	0.81	0.29	99.56
	54.85	7.31	2.47	2.47	0.74	26.46	0.75	0.23	95.28
	45.65	10.08	3.46	2.09	0.40	35.10	0.82	0.21	97.81
	54.95	7.98	3.21	2.90	0.69	29.36	0.89	0.33	100.31
	57.47	6.78	0.90	2.47	0.79	26.59	1.10	4.29	100.39
	57.10	6.00	8.52	2.66	0.74	20.38	0.30	0.32	96.02
	52.07	5.42	6.27	2.63	0.69	24.21	0.55	0.05	91.89

Table 4 Continued

Sample and depth relative to base of the Killeröd section (quarry floor)	Cr_2O_3	Al_2O_3	MgO	TiO_2	V_2O_3	FeO	MnO	ZnO	Total
	53.03	5.36	1.71	3.00	0.70	28.17	0.89	0.49	93.35
	51.90	8.04	1.83	2.68	0.70	29.65	0.79	0.90	96.49
	52.40	6.39	1.28	2.70	0.78	27.74	0.95	1.25	93.49
	49.34	7.55	3.68	2.18	0.50	28.36	0.91	0.31	92.83
	56.67	8.22	3.29	2.01	0.63	29.90	0.81	0.56	102.09
	55.07	4.30	3.21	2.23	0.60	28.48	0.85	0.14	94.88
	51.40	7.00	2.70	2.18	0.55	27.44	1.43	0.55	93.25
	52.84	6.55	2.45	1.24	0.69	25.09	1.26	0.59	90.71
	47.36	4.46	0.15	2.42	0.69	24.95	0.99	3.60	84.62
	49.79	5.99	0.02	2.00	0.62	25.07	1.02	4.52	89.03
	52.74	5.47	3.00	2.70	0.45	33.58	1.14	0.44	99.52
	52.30	5.10	0.26	2.53	0.97	26.28	1.44	2.58	91.46
	55.45	5.83	1.33	2.61	0.89	28.38	0.91	1.31	96.71
	54.47	6.91	3.54	1.21	0.51	29.55	1.13	1.82	99.14
	54.62	6.80	1.10	2.51	0.76	29.60	0.57	1.05	97.01
	48.87	3.30	1.04	1.96	0.68	26.11	0.72	0.37	83.05
	54.57	6.36	0.72	2.91	0.59	27.84	0.81	3.61	97.41
	55.92	5.49	2.51	2.88	0.84	28.05	0.87	0.91	97.47
	54.51	7.12	2.53	2.25	0.66	36.63	0.62	0.06	104.38
	52.12	6.03	2.15	1.80	0.53	31.17	0.99	0.50	95.29
	54.03	7.41	3.17	1.46	0.60	32.61	1.05	0.11	100.44
	53.03	5.57	1.46	2.42	0.60	28.29	0.67	0.64	92.68
	54.60	3.91	0.68	2.80	0.77	22.09	0.81	0.30	85.96
	51.78	6.17	5.82	2.25	0.45	24.18	0.67	0.00	91.32
	54.48	4.19	5.35	0.94	0.50	28.74	0.54	0.12	94.86
	51.77	6.14	4.66	0.93	0.58	32.13	0.98	0.46	97.65
	54.48	6.05	1.70	2.22	0.50	29.31	0.63	0.29	95.18
	55.03	4.98	1.49	1.80	0.64	26.01	1.17	0.50	91.62
	49.15	3.36	0.38	2.58	0.62	23.16	1.06	1.09	81.40
	46.27	5.98	1.45	2.15	0.51	32.82	0.67	0.24	90.09
	55.51	5.38	2.36	2.75	0.40	28.04	0.47	0.00	94.91
	49.48	3.32	1.14	0.82	0.36	24.49	1.22	0.76	81.59
	51.85	6.85	1.59	2.62	0.59	27.13	1.14	1.31	93.08
	49.00	4.63	2.12	2.50	0.55	29.53	0.87	0.06	89.26
	51.63	6.41	3.48	0.76	0.36	27.10	0.95	0.45	91.14
	51.49	7.63	1.93	1.89	0.55	25.08	0.82	0.72	90.11
	45.89	4.18	3.66	1.32	0.43	27.88	0.81	0.29	84.46
	51.59	5.98	2.64	2.49	0.79	27.08	0.86	0.29	91.72
	50.33	4.78	2.89	1.21	0.64	28.46	0.71	0.21	89.23
	49.62	2.83	1.15	0.94	0.44	22.82	0.87	1.27	79.94
Average element concentration (wt% and std. deviation)	52.46±3.38	6.12±1.77	2.79±2.00	2.18±0.61	0.61±0.13	28.00±3.52	0.87±0.23	0.74±0.95	93.78
10.02 to 10.09 m	52.97	6.11	1.48	2.86	0.66	28.86	0.73	0.53	94.20
	42.84	5.25	1.24	1.86	0.46	23.40	0.96	0.91	76.92
	52.24	4.46	3.06	2.30	0.83	28.52	0.00	0.13	91.54
	50.50	6.18	0.83	1.50	0.69	27.31	1.32	3.11	91.44
	47.32	7.70	2.78	1.37	0.61	26.00	0.54	0.25	86.57
	47.84	4.82	2.39	1.65	0.40	26.87	0.58	0.45	85.00
	45.61	3.55	1.81	2.30	0.63	25.53	0.41	0.53	80.37
	49.11	5.28	5.03	1.33	0.50	25.82	0.10	0.33	87.50
	48.48	6.30	3.26	1.14	0.59	25.21	0.84	0.21	86.03
	43.66	2.23	0.37	1.15	0.76	17.28	0.92	0.54	66.91
	46.84	7.48	1.62	2.39	0.64	26.49	0.50	0.89	86.85
	52.06	4.47	1.74	2.77	0.31	27.16	0.54	0.00	89.05
	39.33	0.91	0.30	1.40	0.49	18.11	1.04	0.40	61.98
	51.55	5.51	2.31	2.37	0.36	28.11	0.40	0.69	91.30
	39.98	1.11	0.46	1.76	0.53	23.62	0.46	0.18	68.10
	43.70	2.86	0.57	1.52	0.45	32.20	0.65	0.25	82.20
	48.46	2.99	1.57	1.05	0.50	23.99	0.56	0.27	79.39
	40.13	4.89	1.39	2.33	0.35	38.66	0.45	0.08	88.28
	43.61	6.44	4.67	1.91	0.37	26.01	0.55	0.39	83.95
	45.20	2.37	1.19	2.47	0.20	22.82	0.07	0.95	75.27
	52.28	5.61	2.60	2.90	0.66	28.88	0.54	0.40	93.87

Table 4 Continued

Sample and depth relative to base of the Killeröd section (quarry floor)	Cr_2O_3	Al_2O_3	MgO	TiO_2	V_2O_3	FeO	MnO	ZnO	Total
	45.40	7.66	3.20	2.84	0.55	27.51	0.75	0.75	88.66
	49.32	8.81	3.17	1.93	0.41	27.52	0.41	0.78	92.35
	49.72	2.90	1.44	1.93	0.61	25.50	0.14	1.23	83.47
	50.99	5.80	2.25	2.71	0.27	26.44	0.57	0.32	89.35
	51.63	4.51	0.98	2.74	0.46	25.51	0.96	0.43	87.22
	48.57	6.20	2.29	2.23	0.64	28.43	0.75	0.18	89.29
	44.71	4.86	0.81	2.16	0.50	28.23	0.83	0.28	82.38
	55.17	2.94	3.80	1.69	0.61	18.33	0.68	0.00	83.22
	49.22	5.27	2.41	0.98	0.55	30.60	1.11	0.54	90.68
	56.85	5.49	0.66	3.25	0.62	28.16	0.72	2.35	98.10
	49.21	9.01	4.77	2.99	0.48	26.06	1.13	0.41	94.06
	50.39	5.81	2.90	0.77	0.40	25.81	1.14	0.46	87.68
	46.56	2.61	0.63	2.32	0.53	29.74	1.12	0.23	83.74
	56.68	7.37	2.13	2.18	0.84	31.56	0.45	0.41	101.62
	52.88	5.68	2.68	2.55	0.40	34.13	0.87	0.20	99.39
	52.47	4.47	0.63	2.86	0.40	29.45	0.72	0.31	91.31
	53.72	3.03	0.53	1.05	0.95	23.27	1.29	0.93	84.77
	56.07	6.13	2.03	1.56	0.83	29.12	0.98	0.77	97.49
	53.58	5.21	3.16	2.22	0.73	30.78	0.76	0.15	96.59
	52.34	7.20	4.09	2.75	0.41	33.55	0.81	0.20	101.35
	56.07	3.84	2.55	2.99	0.47	29.89	0.70	0.00	96.51
	53.79	1.99	0.67	2.84	0.64	24.77	0.95	0.45	86.10
	38.96	4.82	2.34	1.38	0.40	28.38	0.50	0.21	76.99
	57.04	5.90	2.99	3.09	0.52	29.62	0.71	0.42	100.29
	57.50	6.57	2.32	3.24	0.70	28.41	0.82	0.47	100.03
	51.88	3.00	1.60	2.31	0.74	32.94	1.11	0.43	94.01
	48.83	3.09	0.89	2.49	0.65	21.70	0.82	0.52	78.99
	56.15	5.78	2.57	2.88	0.65	30.30	0.80	0.51	99.64
	45.23	4.88	1.25	1.05	0.40	29.25	0.83	0.08	82.97
	46.07	4.68	2.06	1.91	0.64	29.13	0.96	0.32	85.77
	50.55	5.97	2.61	1.47	0.73	28.37	0.73	0.11	90.54
	47.36	4.65	4.48	2.05	0.77	25.58	0.67	0.44	86.00
	50.85	8.50	0.93	2.63	0.67	28.01	1.05	3.03	95.67
	54.15	2.91	2.92	1.72	0.69	22.22	0.69	0.27	85.57
	54.72	5.71	2.48	2.53	0.60	30.17	0.86	0.33	98,35
Average element concentration (wt% and std. deviation)	49.61±4.76	5.00±1.86	2.11±1.20	2.12±0.66	0.56±0.16	27.31±3.84	0.72±0.29	0.54±0.61	87.96
OC grains (preliminary classification)	*Cr_2O_3*	*Al_2O_3*	*MgO*	*TiO_2*	*V_2O_3*	*FeO*	*MnO*	*ZnO*	*Total*
9.88 to 10.02 m	50.23	18.22	8.52	0.15	0.26	20.71	0.44	0.10	98.63
	47.30	16.94	7.51	0.38	0.05	15.77	0.32	0.90	89.17
	58.02	3.03	4.00	0.04	0.19	17.89	0.65	0.58	84.40
	48.28	8.45	3.47	0.06	0.12	34.63	0.72	0.18	95.91
	42.53	20.65	9.02	0.23	0.10	23.37	0.59	0.21	96.70
	52.93	13.56	7.70	0.13	0.23	22.52	0.66	0.28	98.01
	54.62	4.33	2.51	0.13	0.09	33.28	0.97	0.28	96.21
	58.45	9.20	7.61	0.08	0.21	16.99	0.50	0.42	93.46
	43.04	22.17	13.57	0.45	0.18	28.40	0.38	0.19	108.38
	40.79	19.74	7.38	0.23	0.12	25.99	0.53	0.13	94.91
	56.39	6.73	5.26	0.08	0.26	24.52	0.42	0.40	94.06
	59.34	3.31	4.65	0.08	0.32	29.00	0.56	0.28	97.54
	32.95	26.69	11.91	0.72	0.47	26.87	0.30	0.04	99.95
	46.28	21.53	9.15	0.14	0.12	25.05	0.21	0.36	102.84
	55.55	14.48	10.04	0.05	0.16	17.99	0.05	0.46	98.78
	62.21	9.63	8.08	0.00	0.29	16.24	0.72	0.83	98.00
	55.83	13.95	9.72	0.13	0.26	16.92	1.16	3.25	101.22
	62.21	3.40	3.72	0.12	0.07	20.52	0.61	0.52	91.17
	37.47	24.95	10.42	0.10	0.25	17.53	0.31	0.25	91.28
	59.45	8.60	8.77	0.07	0.22	18.91	0.26	0.05	96.33
	47.21	17.73	11.84	0.02	0.26	20.18	0.17	0.18	97.59
	56.85	15.86	12.05	0.01	0.29	18.49	0.48	0.86	104.89
	47.73	13.37	5.76	0.00	0.35	16.85	0.43	0.55	85.04
	59.53	7.97	7.53	0.06	0.02	19.83	0.53	3.86	99.33
	47.83	21.59	10.69	0.37	0.16	17.92	0.46	1.07	100.09

Table 4 Continued

Sample and depth relative to base of the Killeröd section (quarry floor)	Cr_2O_3	Al_2O_3	MgO	TiO_2	V_2O_3	FeO	MnO	ZnO	Total
	62.21	7.73	5.27	0.06	0.38	14.48	0.71	4.37	95.21
	59.02	10.67	5.21	0.09	0.21	22.44	0.66	0.62	98.92
	52.73	8.58	5.19	0.66	0.43	27.08	1.09	1.34	97.10
	41.62	15.01	5.71	0.29	0.17	23.15	0.51	0.10	86.56
	48.05	20.86	11.03	0.22	0.39	18.40	0.54	0.55	100.04
	58.24	7.74	4.34	0.09	0.21	21.39	0.55	0.37	92.93
	57.40	10.12	7.78	0.09	0.40	20.23	0.43	0.64	97.09
	56.24	10.21	7.76	0.10	0.32	13.03	0.60	0.50	88.76
	53.90	15.05	8.56	0.08	0.27	17.46	0.61	1.63	97.56
	56.61	9.41	2.85	0.15	0.26	20.47	1.07	2.50	93.32
	60.63	8.25	3.95	0.00	0.41	24.11	0.85	1.14	99.34
	56.73	6.93	5.81	0.06	0.30	19.46	0.60	0.19	90.08
	51.93	15.15	6.91	0.09	0.55	20.70	0.32	1.27	96.92
	59.34	9.71	5.30	0.04	0.19	19.17	0.31	0.29	94.35
	50.94	13.65	6.05	0.02	0.17	20.93	0.36	0.41	92.53
	55.81	10.47	3.47	0.12	0.28	23.71	0.47	0.03	94.36
	39.13	17.70	6.72	0.14	0.07	30.07	0.61	0.14	94.58
	49.25	17.71	8.81	0.22	0.24	23.77	0.32	0.36	100.68
	58.59	12.84	12.36	0.00	0.45	16.96	0.61	0.42	102.23
	54.52	12.17	4.82	0.09	0.34	19.82	0.42	0.46	92.64
	53.30	3.88	2.32	0.05	0.26	27.71	0.35	0.39	88.26
	52.54	15.99	11.83	0.20	0.17	15.41	0.13	0.19	96.46
	57.91	5.27	5.29	0.00	0.18	16.75	0.68	2.87	88.95
	43.23	8.49	4.29	0.04	0.13	23.66	0.55	0.38	80.77
	53.62	8.99	4.44	0.02	0.15	21.57	0.54	0.46	89.79
	44.20	10.32	12.16	0.10	0.16	22.38	0.48	0.13	89.93
	38.05	21.86	10.09	0.52	0.20	19.20	0.36	0.39	90.67
	36.87	18.50	7.16	0.21	0.10	22.17	0.08	0.41	85.50
	49.41	12.75	5.56	0.08	0.20	17.06	0.38	0.25	85.69
	55.02	12.37	8.63	0.02	0.12	16.99	0.27	0.83	94.25
	47.94	20.96	10.80	0.11	0.36	19.26	0.43	0.43	100.29
	31.44	24.57	8.58	0.13	0.10	25.21	0.33	0.19	90.55
10.02 to 10.09 m	56.80	9.79	4.82	0.19	0.14	22.64	0.00	0.50	94.88
	30.12	29.68	9.83	0.22	0.22	19.66	0.64	0.23	90.60
	45.52	25.63	7.58	0.12	0.14	16.53	0.20	0.13	95.85
	54.05	4.30	8.05	0.64	0.33	16.30	0.13	0.41	84.21

Table 5 (Appendix). Element concentration (wt%) in polished sediment-dispersed extraterrestrial chromite (EC) and other Cr-rich spinel (OC) grains (>63µm) extracted from the Middle Ordovician Orthoceratite Limestone in the Hällekis quarry, Kinnekulle, southern Sweden.

Sample and depth relative to base of the Arkeologen bed (see Schmitz & Häggström, 2006)	*Cr_2O_3*	*Al_2O_3*	*MgO*	*TiO_2*	*V_2O_3*	*FeO*	*MnO*	*ZnO*	*Total*
EC grains									
-0.77 to -0.82 m	59.71	6.60	1.77	2.40	0.82	20.57	1.35	5.50	98.72
	(65.39) †	7.08	2.00	3.28	0.85	20.88	n.d.	n.d.	99.49
	57.34	6.21	2.46	3.24	0.78	27.00	0.92	0.80	98.75
	59.54	6.45	2.22	3.15	0.73	27.53	n.d.	n.d.	99.62
	59.85	6.47	2.03	2.91	0.72	27.00	n.d.	n.d.	98.98
	55.98	6.12	2.24	2.20	0.78	24.99	0.96	1.03	94.30
OC grain									
-0.77 to -0.82 m	36.10	15.41	9.53	1.16	n.d.	38.10	n.d.	n.d.	100.30

These grains were analysed at the Lund University, and not at the Göteborg University like all the other grains in this study. An energy dispersive spectrometer (Oxford EDS) with a Si detector linked to a Hitachi S-3400N scanning electron microscope was used. Cobalt was used for standard and the acceleration voltage was 15 kV. Precision (reproducibility) of analyses was typically better than 1-4 %, using a counting live-time of 80 seconds. † = questionable value because of analytical problem; n.d. = not detected. The grains were recovered from a sample of 22.8 kg of limestone.