Diagenetic uptake of rare earth elements by conodont apatite

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Abstract

The rare earth element (REE) composition of bioapatite has long been used as a proxy for ancient seawater chemistry and paleomarine environmental reconstruction, based on the assumption of preservation of a hydrogenous (seawater-derived) REE signal. Recent work, however, has begun to question the provenance of REEs in conodonts, emphasizing the importance of REEs released by the lithogenous fraction of the sediment and subsequently adsorbed onto conodont apatite in the burial environment. Here, we investigate patterns of REE and trace-element abundance in conodonts and their host sediments from the Early to Late Ordovician Huanghuachang and Chenjiahe sections of Hubei Province, South China. Several lines of evidence indicate that REEs in the conodont samples were acquired mainly from clay minerals in the host sediment during burial diagenesis: (1) REEs in conodonts show a strong positive correlation to Th and other lithogenic elements; (2) conodonts and whole-rock samples show general patterns of REE and trace-element enrichment that are highly similar to each other and bear no resemblance to seawater elemental concentrations; (3) similar patterns are observed in Triassic conodonts and whole-rock samples; and (4) Y/Ho ratios in conodonts are mostly <40 (mean ~33), values that are consistent with derivation of >90% of REEs from lithogenous sources. Conodonts show pronounced middle rare earth element (MREE) enrichment, a pattern that is unambiguously of diagenetic origin owing to its association with lower Y/Ho ratios. With increasing MREE enrichment of conodont samples, U concentrations and La_N/Yb_N ratios shift from high to low, and Mn concentrations from low to high. These patterns suggest that conodont diagenesis was initiated at shallow burial depths under suboxic conditions (i.e., in the zone of Mn(IV) and Fe(III) reduction) but continued at greater burial depths, with most acquisition of secondary REEs at later diagenetic stages. Our findings indicate that (1) conodont apatite frequently does not preserve a recognizable hydrogenous REE signal, and (2) the results of many earlier studies in which REEs in bioapatite were used as a paleo-seawater proxy may need

re-evaluation.

Keywords: REE; Y/Ho; bioapatite; porewater chemistry; diagenesis

1. Introduction

The rare earth element (REE) composition of bioapatite has long been used for reconstruction of paleoceanographic conditions based on Ce anomalies, Nd-isotope ratios, or the shape of normalized REE distributions (e.g., Wright et al., 1984, 1987; Wright et al., 2002; Grandjean et al., 1987; Grandjean-Lécuyer et al., 1993; Laenen et al., 1997; Felitsyn et al., 1998; Lécuyer et al., 1998, 2004; Reynard et al., 1999; Martin and Haley, 2000; Girard and Lécuyer, 2002; Picard et al., 2002; Kemp and Trueman, 2003; Martin et al., 2005; Trotter and Eggins, 2006; Trotter et al., 2007; Chen et al., 2012; Song et al., 2012; Fadel et al., 2015). Over the years, a few studies have concluded that REEs in bioapatite are taken up largely during diagenesis, and that they therefore have questionable utility as a paleoceanographic proxy (e.g., Toyoda and Tokonami, 1990; Bright et al., 2009). In recognition of this concern, recent studies have attempted to make use exclusively of the parts of conodont elements that exhibit lesser degrees of diagenetic alteration, as inferred from the color alteration index (CAI; Epstein et al., 1977; Rejebian et al., 1987). Thus, the albid crown of conodont elements, which is denser and lower in permeability than the basal plate or hyaline crown (Trotter et al., 2007), has become the preferred target of REE analysis (Trotter and Eggins, 2006; Song et al., 2012; Zhao et al., 2013). However, recent studies have shown that diagenetic alteration is probably a pervasive feature of conodont apatite, with all parts of conodont elements being subject to strong post-mortem adsorption of REEs as well as other trace elements from sediment porewaters (Zhao et al., 2013; Chen et al., 2015). Similar conclusions have been reached about the openness of vertebrate fossil bones to prolonged diagenetic alteration (Kocsis et al., 2010; Herwartz et al., 2011, 2013a; Tütken et al., 2011; Kowal-Linka et al., 2014).

Methods of screening conodont samples or sample sets for potential diagenetic influences on REE composition have changed over time. It has long been known that phosphatic tissues *in vivo* contain very low concentrations of REEs (a few ppb) and other trace elements, and that most uptake of non-structural elements occurs post-mortem (Wright et al., 1984; Trueman and Tuross, 2002; Trotter and Eggins, 2006). Studies that have made use of REEs and other trace elements for paleoceanographic analysis generally have argued that such uptake occurred at or close to the sediment-water interface (SWI) and, thus, that the concentrations of these elements in conodont apatite reflected their concentration in contemporaneous seawater (Elderfield and Pagett, 1986; Wright et al., 1987; Grandjean-Lécuyer et al., 1993; Lécuyer et al., 2004). The most widely used approach for putative documentation of the hydrogenous (seawater-derived) origin of REEs relies on $(\text{La}/\text{Sm})_{\text{N}}$ vs $(\text{La}/\text{Yb})_{\text{N}}$ diagrams (e.g. Grandjean-Lécuyer et al., 1993; Laenen et al., 1997; Reynard et al., 1999; Girard and Lécuyer, 2002; Picard et al., 2002; Kemp and Trueman, 2003; Chen et al., 2012; Herwartz et al., 2013a; Kowal-Linka et al., 2014).

89 However, recent studies have inferred that the composition of conodont apatite is
90 extensively altered in the burial environment. Lu-Hf isotopes suggest open-system
91 behavior of bioapatite with REE uptake throughout postmortem diagenesis (Kocsis et
92 al., 2010; Herwartz et al., 2011, 2013b). Y/Ho ratios REEs concentrations suggest that
93 most REEs (frequently >90%) in bioapatite are lithogenously sourced, probably
94 through release from clay minerals in the burial environment (Zhao et al., 2013; Chen
95 et al., 2015).

96 In the present study, we have investigated the REE and trace-element content of
97 conodont apatite and whole-rock samples from the Huanghuachang and Chenjiahe
98 sections in South China in order to (1) determine the provenance of REEs in the study
99 sections, and (2) refine a “toolbox” of general techniques for assessing REE
100 provenance. In the latter regard, this study builds on earlier published work by Zhao et
101 al. (2013) and Chen et al. (2015). The Huanghuachang and Chenjiahe sections are
102 well-suited to a study of this type because it contains abundant conodonts in beds
103 ranging from nearly pure carbonate to marl to shale, thus allowing assessment of
104 lithologic influences on conodont REE content. The results of this study thus have
105 implications not only for Ordovician paleomarine conditions and diagenetic processes
106 but also more generally for evaluation of the provenance of REEs and trace elements
107 in bioapatite of any geologic age.

108 109 **2. Geological setting**

110 The Huanghuachang section is located in Huanghua County, about 22 km
111 northwest of Yichang City, in the Three Gorges area of western Hubei Province, South
112 China (Fig. 1A). It is the Global Stratotype Section and Point (GSSP) of the base of
113 the Middle Ordovician series, with Lower to Upper Ordovician strata well exposed
114 along the major road from Yichang City to Xinsan County. The Chenjiahe section is
115 close to (~5 km distant from) the Huanghuachang section, as both are located on the
116 east limb of the Huangling anticline (Fig. 1B). During the Early to Middle Ordovician,
117 the South China Craton comprised the Yangtze Platform, the Jiangnan Slope, and
118 several marginal uplifts including the Kangdian and Cathaysia oldlands. The Three
119 Gorges area was located on the north-central Yangtze Platform, which accumulated
120 shallow-marine carbonate sediments that graded into argillaceous sands in inner-shelf
121 settings to the northwest and slope facies to the southeast (Fig. 1C) (Zhan and Jin,
122 2007).

123 The Huanghuachang section contains seven formations (from base to top, the
124 Nanjinguan, Fenxiang, Honghuayuan, Dawan, Guniutan, Miaopo, Baota formations)
125 ranging in age from the mid-Early Ordovician to the mid-Late Ordovician (Fig. 2)
126 (Wang et al., 1987; Zhan and Jin, 2007). The upper part of the Chenjiahe section
127 consists of the mid to late Late Ordovician Linxiang and Wufeng formations, which
128 are younger than the Baota Formation (i.e., the top of the Huanghuachang section).
129 We therefore generated a ~85-m-thick composite section consisting of the full ~260 m
130 thickness of the Huanghuachang section as well as the upper ~10 m of the Chenjiahe
131 section. Detailed lithologic descriptions are given in Table 1, and the two study
132 sections are correlated in Figure 2. The entire succession is characterized by a gradual

shift from carbonate platform facies in the Early Ordovician to neritic facies in the Middle Ordovician, reflecting a long-term sea-level rise during this period (Fig. 2; Hu et al., 1996). Deep basinal facies accumulated during a Late Ordovician maximum highstand prior to the Hirnantian glacio-eustatic fall at the end of the Ordovician (Hu et al., 1996; Xiao et al., 1996).

Extensive paleontological and biostratigraphic work has been carried out at Huanghuachang. The succession is highly fossiliferous, and various studies have focused on brachiopods (Chang, 1983; Zhan et al., 2010), acritarchs (Lu, 1987; Yin et al., 1998; Yan and Li, 2010; Li et al., 2011), bryozoan-algal-sponge bioherms (Zhu, 1993; Li et al., 2015), and chitinozoans (Chen et al., 2002). The oldest bryozoan species and bryozoan reefs known in the fossil record are present in the Fenxiang Formation of this region (Xiao et al., 1993; Zhu et al., 1995; Zhu et al., 2006; Liu et al., 1997; Xia et al., 2007; Adachi et al., 2011, 2012). The existing studies of conodonts (Wang et al., 2005, 2009; Wu et al., 2010; Li et al., 2004, 2010a, 2010b) and graptolites (Wang et al., 1987, 1996, 2001, 2003, 2004, 2013; Chen et al., 1995, 2000, 2003) are particularly important in establishing a high-resolution biostratigraphic framework for use in the present study (Fig. 2). The Lower-Middle Ordovician boundary, for which Huanghuachang serves as the GSSP, is defined by the first appearance of the conodont *Baltoniodus? triangularis* in the lower part of the Dawan Formation (Wang et al., 2005, 2009). This level is 0.2 m below the FAD of *Microzarkodina flabellum*, which approximates the boundary between the lower and upper *Azygograptus suecicus* graptolite biozones (Wang et al., 2005, 2009) and is nearly coincident with the base of the *Belonechitina henryi* chitinozoan Biozone (Chen et al., 2009).

3. Material and methods

Large number of samples, each weighing ~3 kg, were collected from all seven formations exposed at Huanghuachang and Chenjiahe sections, providing coverage of the Floian (mid-Early Ordovician) to Katian (mid-Late Ordovician) interval. Weathered surfaces and diagenetic veins were removed, and the remaining sample was cleaned and air-dried. Each sample was crushed and the freshest pieces were selected and powdered with a rock mill to <200 mesh. In order to obtain conodonts, large quantities of sample (~1 to 3 kg) were crushed to a granule size and dissolved in 10% acetic acid for 5 days, after which conodont elements were isolated from the insoluble residue under a binocular microscope. Conodonts in the Huanghuachang and Chenjiahe sections yield color alteration indices (CAI) of 2-3, equivalent to burial temperatures of 60 to 200°C (Epstein et al., 1977).

3.1. Trace elements of whole-rock samples

Measurement of trace-element concentrations was carried out at the State Key Laboratory of Geological Processes and Mineral Resources at the China University of Geosciences-Wuhan using an Aglient 7500a inductively-coupled plasma mass spectrometer (ICP-MS) following the procedure of Liu et al. (2008). About 50 mg of each sample powder were weighed into a Teflon bomb, and 1 mL HNO₃ and 1 mL HF

were added before heating for ~48 h at 190°C in the sealed bomb. After cooling, the contents of the bomb were evaporated at 115°C to incipient dryness, and 1 mL HNO₃ and 1 mL 1-ppm indium (In) laboratory standard were added. The bomb was then resealed and heated to 190°C for another 12 h. The final solution was transferred to a polyethylene bottle and diluted in 2% HNO₃ to about 100 mL for ICP-MS analysis. Results were calibrated using the international standards AGV-2, BHVO-2, BCR-2, RGM-1 and GSR-1 with an average analytical uncertainty better than 2% (RSD). Trace-element data for whole-rock samples are given in Table 2.

3.2. LA-ICP-MS of conodonts

Conodont elements were washed in Milli-Q water, affixed to double-sided adhesive tape, and then placed with a sample cell of a silica glass side. Measurements targeted the albid crown of conodont elements, which has a relatively dense mineral structure and limited permeability, and which therefore is believed to represent the least altered part of conodont tissues (Trotter and Eggins, 2006; Trotter et al., 2007). In this study, the in-situ REE content of single albid crowns was measured using laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) in combination with an ArF excimer laser (Lambda Physik, GeoLas 2005) and a quadrupole ICP-MS (Agilent 7500a) at the State Key Laboratory of Geological Processes and Mineral Resources at the China University of Geosciences-Wuhan. Helium was used as the carrier gas, and argon was used as the make-up gas and mixed with the carrier gas via a T-connector before entering the ICP-MS. The LA-ICP-MS analysis technique makes it possible to acquire reliable chemical compositions in high spatial resolution (32-μm diam.) and continuous compositional depth profiles within a single conodont element. More than 40 elements, typically including Li, B, Na, Mg, Al, Si, K, Ca, Sc, Ti, V, Mn, Fe, Ni, Zn, As, Rb, Sr, Y, Zr, Cd, Sb, Cs, Ba, all REEs (La to Lu), Hf, Pb, Th and U, were measured at each analytical spot. Data collection followed the method described by Trotter and Eggins (2006), using rapid peak-hopping between selected isotopes of each measured element for a period of 100 seconds. Each analysis incorporates an approximately 20 s background acquisition (gas blank) followed by 50 s data acquisition from the sample (Fig. 3). Selection and integration of background and analyte data followed the protocol of Longerich et al. (1996), in which mean background intensities were subtracted. U.S.G.S. reference materials (NIST SRM 610, BHVO-2G, BIR-1G, BCR-2G) were used as calibration standards, and data was calibrated by ICPMSDataCal software according to Liu et al. (2008). The relative deviations between repeat analyses of a glass reference material (BCR-2G) and standard reference values obtained from Gao et al. (2002) indicate that the analytical reproducibility over the course of this study was better than 5%. Data reduction followed the method described by Longerich et al (1996), using mean background corrected intensities and ⁴³Ca as the internal standard to correct for variation in mass ablation yield based on a conodont apatite CaO concentration of 53 wt.%. Trace-element data for conodonts are given in Table 3.

3.3. Elemental calculations

REE concentrations were normalized to the average upper crustal composition (UCC) of McLennan (2001); normalized concentrations are indicated by the subscript “N” (cf. Grandjean et al., 1987; German and Elderfield, 1990). The relative enrichments of the light (La, Ce, Pr, and Nd), middle (Sm, Eu, Gd, Tb, Dy, and Ho), and heavy (Er, Tm, Yb, and Lu) REE fractions are reported as ratios, i.e., LREE/MREE, LREE/HREE, and MREE/HREE, for which La/Sm, La/Yb, and Sm/Yb were used as proxies (cf. Lécuyer et al., 2004). REE distributions were also characterized by the MREE anomaly, expressed as MREE/MREE* and calculated as:

$$\text{MREE} / \text{MREE}^* = \frac{2 \times \text{average}(\text{MREE})}{\text{average}(\text{LREE}) + \text{average}(\text{HREE})} \quad (1)$$

The europium anomaly (Eu/Eu*) was calculated as $2 \times \text{Eu}_N / (\text{Sm}_N + \text{Gd}_N)$ and the cerium anomaly (Ce/Ce*) as $3 \times \text{Ce}_N / (2 \times \text{La}_N + \text{Nd}_N)$. These calculated parameters are given in Tables 2 and 3.

4. Results

Chemostratigraphic profiles for REEs and other geochemical components exhibit little systematic variation (Fig. 4). Whole-rock samples show a lower and slightly fluctuating ΣREE from 8 to 282 ppm (avg. 72 ± 48 ppm) than conodonts from 6 to 3216 ppm (avg. 396 ± 495 ppm). Th in whole-rock samples also exhibit a lower values from 0.5 to 9.9 (avg. 4.6 ± 2.3 ppm) than conodonts from 0.1 to 329.2 ppm (avg. 29.1 ± 49.3 ppm). Whole-rock samples show Y/Ho (avg. 31.1 ± 3.6) close to that of conodonts (avg. 32.8 ± 8.9). Ce/Ce* values of the whole-rock samples range from 0.7 to 1.3 (avg. 0.9 ± 0.1) and conodonts range from 0.6 to 1.8 (avg. 1.0 ± 0.2) in this study. Eu/Eu* values of whole-rock samples show a similar ratios range from 0.9 to 1.1 (avg. 1.0 ± 0.1) than conodonts range from 0.7 to 1.4 (avg. 1.0 ± 0.1).

Trace elements (e.g., Mn, U, Cr) in conodonts vary over larger ranges than whole-rock samples (Tables 2 and 3). Mn, U and Cr range from 99 to 6116 ppm (avg. 1870 ± 1567 ppm), 0.3 to 10 ppm (avg. 1.5 ± 2.0 ppm) and 2.5 to 58 ppm (avg. 16 ± 11 ppm), respectively, in whole-rock samples, and 2.9 to 144 (avg. 36 ± 27 ppm), 0.1 to 105 (avg. 12 ± 22 ppm) and 0.2 to 8.8 (avg. 1.6 ± 1.8 ppm), respectively, in conodonts. Sr in conodonts show a higher value 13004 ± 8166 ppm than 286 ± 62 ppm in whole-rock samples.

The distributions of UCC-normalized REEs show characteristic patterns for both whole-rock and conodont samples. Whole-rock samples show patterns ranging from nearly flat to moderately MREE-enriched, with La_N/Sm_N ratios ranging from 0.53 to 1.11, Sm_N/Yb_N ratios ranging from 1.00 to 1.67, and La_N/Yb_N ratios ranging from 0.70 to 1.31 (Table 2; Fig. 5A). In contrast, all conodonts exhibit strong MREE enrichment, with La_N/Sm_N ratios ranging from 0.06 to 1.21, Sm_N/Yb_N ratios ranging from 1.21 to 29.15 and La_N/Yb_N ratios ranging from 0.53 to 11.14 (Table 3; Fig. 5B). M/M* ratios are significantly higher in conodonts (1.3-6.3; mean 2.7 ± 1.0) than in whole-rock samples (1.1-1.5; mean 1.2 ± 0.1).

5. Discussion

5.1. Lithogenous versus hydrogenous REE sources

Certain lithologies are capable of recording a hydrogenous (seawater-sourced) REE signature. Corals and other massive biogenic carbonates (examples) and bulk marine carbonates that contain little or no siliciclastic material can preserve primary seawater signals, which are characterized by low Σ REE (in ppb range) and strong LREE depletion (Webb and Kamber, 2000; Nothdurft et al., 2004; Webb et al., 2009). However, many carbonate marine sediments contain substantial admixture of terrigenous material (e.g., clays), characterized by high Σ REE and strong MREE enrichment. In the latter situation, hydrogenous REE signals are likely to be obscured by secondary REE fractions acquired from clay-derived REEs released to sediment porewaters (Zhao et al., 2013; Chen et al., 2015).

The study sections consist largely of marls with a few interbeds of shale and nearly pure limestone. The percent clay content of whole-rock samples was estimated as $\text{Th}/\text{Th}^* \times 100$, where Th^* is the concentration in average upper continental crust (UCC), which is 10.7 ppm (McLennan, 2001). Their average clay content is 42.9($\pm$ 20.4)% with a range of 4.6-92.8% ($n = 65$) (Table 2). The Σ REE content of the whole-rock samples exhibits a strong positive correlation to clay content (as proxied by Th concentration), yielding $r = +0.93$ ($p(\alpha) < 0.001$, $n = 65$; Fig. 6). This demonstrates that REEs are strongly associated with the siliciclastic (probably clay-mineral) fraction of the sediment. The Σ REE content of the conodont samples also exhibits a strong positive correlation to Th concentration, with $r = +0.87$ ($p(\alpha) < 0.001$, $n = 83$; Fig. 6). REEs in the conodonts are, for the most part, not resident in clay minerals. However, the nearly collinear relationships of Σ REE to Th in both the whole-rock and conodont samples implies that the REE inventory of the latter was ultimately derived from the former, through release of REEs from detrital clay minerals in the sample matrix to sediment porewaters, followed by adsorption of these REEs by conodont apatite.

Many other trace elements in the study sections show a relationship to the clay fraction similar to that shown by Σ REE. Since the whole-rock samples consist of just two main components (i.e., clays and carbonate), most elements exhibit a pronounced positive or negative correlation with the clay fraction, representing an affinity with clays or carbonate, respectively. Correlation coefficients can be used to rapidly assess affinity with the clay fraction of the sample (as proxied by Th concentration). Elements with a strong positive affinity for clays ($r > +0.70$) include all lithogenic elements (Li, Sc, Ti, Rb, Y, Zr, etc.), many trace metals (V, Cr, Co, Ni, Zn, Sn, etc.), and all REEs (Table 4; Fig. 7A). However, none of the REE ratios (i.e., Ce/Ce*, Eu/Eu*, and M/M*) shows a significant relationship to clay content. The elements with the strongest negative affinity for clays (or positive affinity for carbonates) are Sr ($r = -0.51$) and Mo ($r = -0.35$) (Table 4; Fig. 7A). Mo is normally hosted by organic or sulfide phases rather than carbonates, so this relationship may indicate that TOC and/or pyrite concentrations are higher in the carbonate-rich beds. Some elements show no affinity for either sediment component (e.g., Mn, Cu, and U), probably owing to their presence in several mineral or organic phases.

Correlations among elements are generally somewhat weaker for the conodont

307 samples compared to the whole-rock samples, although mostly similar patterns are
308 evident. For conodonts, the correlation with Th is $> +0.50$ for most lithogenic
309 elements (Al, Si, Sc, Ti, Rb, Y, Nb) and $+0.77$ to $+0.89$ for REEs (Table 4; Fig. 7B).
310 Trace metals show a correlation with Th that is either weakly positive ($+0.30 < r <$
311 $+0.50$), as for Cr, Co, Ni, Cu and Pb, or non-significant, as for Mn, U, V and Zn.
312 (Note that Al, Si, and K concentrations were generated for the conodont but not for
313 the whole-rock samples). These elements prove to be even better predictors than Th of
314 enrichments in trace metals, with $r > +0.50$ for Cr, Co, Ni and Cu, and $r = +0.45 \pm 0.07$
315 for Mo (Table 4). However, correlations of REEs to these elements are weaker ($r =$
316 $+0.48 \pm 0.07$) than to Th. Nonetheless, these relationships suggest that most trace
317 elements in the conodont samples were derived mainly from the clay-mineral fraction
318 of the host rock. A negative correlation is observed with respect to P ($r = -0.42 \pm 0.02$),
319 suggesting that P enrichments were favored in siliciclastic-poor samples.

320 The relationship of the trace metal content of the conodont samples to that of the
321 whole-rock samples can be investigated further by cross-plotting their average
322 concentrations. For the present study samples, this yields a strong positive correlation
323 ($r = +0.71$, $p(\alpha) < 0.01$, $n = 41$; Fig. 8A). The overall strong positive correlation is
324 further evidence that the trace-metal content of conodonts derives mainly from the
325 host rock, although variation around the correlation line may reflect differences in
326 affinity of specific trace metals for conodont apatite. For example, all REEs, Th, and
327 Sr plot above it, suggesting that these elements are strongly adsorbed onto bioapatite
328 or (in the case of Sr) a structural component of the conodont mineral matrix. On the
329 other hand, many transition metals (including V, Ni, Cr, Cu, Co, and Mn) and some
330 lithogenic elements (e.g., Rb, Zr, Nb, and Ti) plot below it, suggesting weak
331 adsorption onto bioapatite. However, these inferences assume that there is a direct
332 relationship between the concentrations of a given trace element in the host sediment
333 and in the sediment porewater, from which adsorption onto bioapatite occurs. In fact,
334 much of the observed variation (Fig. 8A) may be due to differential release of
335 elements from host sediment to porewaters (cf. Chen et al., 2015). REEs are present in
336 siliciclastic sediments mainly adsorbed onto clay minerals (Li and Schoonmaker,
337 2003; Zhao et al., 2013), facilitating their release to porewaters. In contrast, many
338 transition metals form organic ligands that are somewhat resistant to dissolution in the
339 diagenetic environment (Crabtree, 2005), reducing their relative abundance in
340 porewaters. Thus, some combination of differential release to porewaters and
341 differential uptake by conodont apatite accounts for the deviations from linearity
342 observed in Figure 8A.

343 A nearly identical pattern of elemental relationships between conodonts and
344 whole-rock samples is exhibited by Triassic marine units (Fig. 8B; data from Chen et
345 al., 2015). The Triassic units also show a broadly positive correlation, with mostly the
346 same elements plotting above the correlation line (e.g., REEs, Th, and Sr) or below it
347 (e.g., Co, Ni, Pb, and Rb). The shared pattern of elemental behavior is convincingly
348 demonstrated by crossplotting conodont/whole-rock elemental ratios for the
349 Ordovician versus Triassic units (Fig. 9). In this figure, higher values represent
350 elements more readily taken up by conodont apatite, of which Sr (which is a minor

structural component of the mineral matrix) and REEs (which are strongly adsorbed) are the most important. Among the REEs, middle REEs (e.g., Sm, Gd, Eu) show much stronger enrichments than light or heavy REEs, a pattern that is discussed below. Lesser degrees of enrichment in conodont apatite are shown by transition metals (e.g., Co, Ni, and Pb) and lithogenic elements (e.g., Rb and Ba). The correlation of all elements shared by both datasets yields $r = +0.93$ ($p(\alpha) < 0.001$, $n = 24$) with a regression line close to 1:1 equality (dashed line, Fig. 9). The strong positive correlation of elemental abundances in Ordovician and Triassic samples is evidence that the trace-metal content of conodonts in both marine units derives mainly from clay minerals in the host rock.

If, on the other hand, the trace-metal content of conodonts were derived mainly from seawater, then there should be a good correlation between average elemental concentrations in conodonts and seawater. However, the elemental compositions of neither the Ordovician (Fig. 8C) nor the Triassic conodonts (Fig. 8D) show any relationship to seawater elemental concentrations. Since the latter comparisons make use of modern seawater chemistry (because paleoseawater chemistry is basically unknown), the possibility that the trace-metal compositions of Ordovician and Triassic seawater were completely different from that of modern seawater must be noted. Nonetheless, these observations strongly suggest that (1) the trace-metal content of conodonts is generally clay-derived and not hydrogenous in origin, and (2) the relationships exhibited by the Ordovician-age study units are not unique but, rather, common and possibly universal (although investigations of marine units of other ages will be needed for confirmation).

Apart from the broad elemental patterns discussed above, the Y/Ho proxy is quite useful in distinguishing hydrogenous versus lithogenic sources of REEs. Y and Ho have similar ionic radii and show similar vertical distribution profiles in the modern ocean (Zhang et al., 1994), but Ho is scavenged by particulates or ionic species approximately twice as rapidly as Y from the water column (Bau, 1996; Zhang and Nozaki, 1996; Nozaki et al., 1997). Thus, lithogenic sources of REEs are characterized by relatively uniform, low Y/Ho ratios, e.g., 26-28 for chondrite and igneous rocks (Nozaki et al., 1997; Kamber and Webb, 2001) and ~25-30 for average upper continental crust and shales (McLennan, 2001), whereas seawater exhibits variable but generally higher Y/Ho ratios, commonly 60-70 (Kamber and Webb, 2001). For the present study units, most whole-rock and conodont samples yield Y/Ho ratios of <40 , with only four conodonts yielding higher values (45-50; Tables 2 and 3). A crossplot of Y/Ho versus $\sum\text{REE}$ for the present study units shows that Y/Ho decreases somewhat with increasing $\sum\text{REE}$, as would be expected if a hydrogenous REE component were progressively overprinted by lithogenically sourced REEs (Fig. 10). A mixing trend between a hypothetical seawater endmember (Y/Ho = 60) and a lithogenic endmember with average UCC composition (Y/Ho = 27.5) suggests that most samples contain $<30\%$ seawater-derived REEs, with a mean seawater-derived fraction of $\sim 10(\pm 10)\%$ for the full sample set (Fig. 10).

5.2. Diagenetic uptake of REEs by conodonts

Diagenetic redistribution of REEs in marine sediments has been inferred in earlier studies (Elderfield and Pagett, 1986; Grandjean et al., 1987; Kidder et al., 2003; Trotter and Eggins, 2006; Bright et al., 2009). Redistribution is largely a function of adsorption/desorption processes, which can preferentially release or sequester a specific fraction of REEs (e.g., the light, middle, or heavy REE fraction) (Haley et al., 2004; Kim et al., 2012; Chen et al., 2015). The MREE-enriched pattern common in phosphorites is considered to be due to long-term diagenetic enrichment (McArthur and Walsh, 1984). It is mediated by the redox conditions of sediment porewaters, which vary as a function of burial depth, organic matter content, and the availability of specific electron acceptors (e.g. O_2 , NO_2 , NO_3^- , MnO_2 , $FeOOH$, SO_4^{2-} , and CH_2O) (Canfield and Thamdrup, 2009). The REE distributions of porewaters and sediments evolve in conjunction with burial and exposure to different redox zones (Chen et al., 2015).

Diagenesis leads to an increase in the total REE content of conodont apatite (i.e., higher ΣREE). Increasing ΣREE is associated with lower Y/Ho ratios, i.e., ~25-30 (Fig. 10), indicating that diagenetic additions of REEs are related to their release from lithogenous materials, probably mainly clay minerals. This increase occurs in direct proportion to increases in certain other trace elements, e.g., Th, generating a $\Sigma REE/Th$ ratio with a slope close to 1.0 (Fig. 6). This pattern indicates that REEs and Th are released at the same rate in proportion to their concentrations in the lithogenous fraction of the sediment, and that they are subsequently taken up by conodont apatite at the same rate from porewater. Many transition metals and lithogenic elements exhibit strong covariation with ΣREE , although commonly with slopes $\ll 1.0$. For example, Co, Cr, Mn, Ni, Rb, and Nb exhibit slopes of 0.01-0.1 (not shown), indicating either slower uptake of these elements by bioapatite relative to REEs or lower concentrations in porewaters as a result of more limited release from mineral and organic phases of the host sediment (see above).

Diagenetic alteration of the trace-element composition of conodonts is a long-term process that begins in the early diagenetic environment and continues with burial (Chen et al., 2015). In the study units, burial uptake of trace elements was strong in most samples, yielding a lithogenous geochemical signature that is reflected in high ΣREE and trace-element concentrations, low Y/Ho ratios, and high MREE/MREE* ratios (see Section 5.1). However, a small number of samples preserve a dominant early diagenetic signature, indicating minimal later-stage burial alteration. These samples are most readily recognized by Y/Ho ratios of >45 ($n = 4$; Fig. 10), suggesting that $>50\%$ of their REE content was hydrogenously sourced (i.e., from seawater). These samples show other conspicuous features that provide insight into the nature of the early diagenetic conditions under which they formed. Specifically, they show low MREE/MREE* ratios (<2 ; Fig. 11), high U concentrations (>60 ppm; Fig. 12), and high La/Yb ratios (>5 ; Fig. 13).

Most of the conodont samples of this study show a “MREE bulge” or “hat-shaped” distribution (Fig. 5B), as seen in many paleomarine units (e.g., Lécuyer et al., 1998; Girard and Lécuyer, 2002; Bright et al., 2009; Chen et al., 2015). Whole-rock samples also tend to show a slight MREE enrichment (Fig. 5A), although

it is unclear whether this pattern reflects the REE composition of clay minerals or just that admixed conodonts (Chen et al., 2015). The origin of this pattern is not known with certainty and several different ideas have been proposed, including (1) acquisition from contemporaneous seawater (Grandjean et al., 1987; Girard and Lécuyer, 2002; Picard et al., 2002; Lécuyer et al., 2004), and (2) preferential adsorption in the suboxic zone of LREEs and HREEs by Mn-oxyhydroxides and Fe-oxyhydroxides, respectively, enriching porewaters in MREEs (Haley et al., 2004; Kim et al., 2012; Prakash et al., 2012; Abbott et al., 2015). In the present study, the subset of conodont samples yielding hydrogenous REE signatures shows low MREE/MREE* ratios (<2 ; Fig. 11), so the MREE-bulge pattern is unambiguously not a primary feature. Increasing MREE/MREE* ratios with declining Y/Ho ratios shows that the pattern is associated with progressive diagenetic alteration of the conodont samples (Fig. 11). Further, it indicates that the MREE bulge pattern was not acquired during early diagenesis in the suboxic zone (see below) but, rather, at greater burial depths, presumably within or below the zone of sulfate reduction. However, it does not exclude the possibility that modification of porewater REE chemistry began in the suboxic zone.

High uranium (U) concentrations are an indication of elemental uptake within the “suboxic zone”, i.e., the zone of Fe(III) and Mn(IV) reduction (Canfield and Thamdrup, 2009). This zone is often located a few centimeters below the sediment-water interface, depths at which sediment permeability remains high and seawater U can be readily drawn downward along a concentration gradient as it is sequestered by the sediment (Zheng et al., 2002; Morford et al., 2009). At greater depths, the porewater system becomes closed to exchange with overlying seawater, limiting the potential for authigenic U enrichment. In the study units, enrichment of conodonts to >50 ppm U (Fig. 12) is an indication of strong diagenetic uptake of U at shallow burial depths. The lack of significant U enrichment in most samples with higher MREE/MREE* ratios (>3) indicates that these samples experienced only limited early diagenesis and, therefore, were potentially more susceptible to later acquisition of burial REE signatures.

Finally, the subset of conodont samples yielding a hydrogenous REE signature is characterized by high $\text{La}_\text{N}/\text{Yb}_\text{N}$ ratios (>5) and low Mn concentrations (<10 ppm; Fig. 13). Mn is low in these samples because their chemical composition was determined within the suboxic zone, in which Mn(IV) was actively reduced and lost from the sediment through diffusion (see above). The initially high $\text{La}_\text{N}/\text{Yb}_\text{N}$ ratios of conodonts were probably due to preferential scavenging of LREEs onto apatite during early diagenesis (Chen et al., 2015). With increasing diagenetic alteration, conodonts exhibit progressively lower $\text{La}_\text{N}/\text{Yb}_\text{N}$ ratios, eventually converging on the $\text{La}_\text{N}/\text{Yb}_\text{N}$ ratio of UCC (1.0; Fig. 13). Mn concentrations increase at the same time although only to 50-100 ppm rather than the 500 ppm characteristic of UCC. The higher Mn concentrations of these samples reflect the closed nature of the porewater system during later diagenesis, when Mn that is reductively dissolved into porewaters is available for uptake by conodont apatite. $\text{La}_\text{N}/\text{Yb}_\text{N}$ ratios declined at the same time owing to acquisition of large quantities of REEs from lithogenous sources, effectively

swamping the early diagenetic hydrogenous signal.

5.3. Implications for use of conodont REEs in paleoceanographic research

The REE composition of bioapatite has long been used for reconstruction of paleoceanographic conditions based on Ce anomalies, Nd-isotope ratios, and the shape of normalized REE distributions (e.g., Wright et al., 1984, 1987; Grandjean et al., 1987; Grandjean-Lécuyer et al., 1993; Laenen et al., 1997; Felitsyn et al., 1998; Lécuyer et al., 1998, 2004; Reynard et al., 1999; Martin and Haley, 2000; Girard and Lécuyer, 2002; Picard et al., 2002; Kemp and Trueman, 2003; Martin et al., 2005; Trotter and Eggins, 2006; Bright et al., 2009; Chen et al., 2012; Song et al., 2012; Fadel et al., 2015). However, mounting evidence suggests that any hydrogenous signal present in conodont fossils is generally completely overwhelmed by diagenetic overprints related to release of lithogenous REEs from clay minerals in the host sediment and their subsequent uptake by conodont apatite (Bright et al., 2009; Kocsis et al., 2010; Herwartz et al., 2011, 2013a; Zhao et al., 2013; Chen et al., 2015; this study).

Several recent studies, including Zhao et al. (2013), Chen et al. (2015), and the present one, have developed a “toolbox” of techniques for testing REE datasets to determine the degree to which they represent hydrogenous versus lithogenous signals. Key to these analyses are the generation of (1) REE data for both conodonts and the host sediment (“whole rock”) from which the conodonts are extracted, and (2) concentration data for many other trace elements in addition to REEs. These datasets are useful in allowing specific comparisons between the chemical composition of conodont apatite and their host sediments. We recommend a full comparison of average elemental concentrations in conodont versus whole-rock samples (e.g., Fig. 8) to establish (dis)similarity in enrichment patterns. However, a rapid assessment of REE sources can be made on the basis of Th-vs- Σ REE and Y/Ho-vs- Σ REE crossplots (Figs. 6 and 10). Because strong MREE enrichment is unambiguously a diagenetic feature of all formations that we have examined, crossplots of MREE/MREE* versus other proxies (e.g., Σ REE or Y/Ho) may also be useful in establishing patterns of elemental enrichment associated with progressive diagenetic alteration (Fig. 11). Finally, crossplots of any of these basic proxies versus concentrations for any specific element can provide information about diagenetic enrichment patterns and processes (cf. Chen et al., 2015).

As a consequence of these improvements in data analysis, virtually all of the older REE literature will need to be re-assessed to determine whether the reported signals are truly hydrogenous (as often inferred). In many cases, the original studies provided concentration data only for REEs in conodonts, with little or no other elemental data and no data whatsoever for the sediment hosting the conodonts (e.g., Wright et al., 1987; Reynard et al., 1999; Girard and Lécuyer, 2002; Lécuyer et al., 2004; Song et al., 2012). For these studies, the originally reported data are almost certainly inadequate for reassessment of REE provenance, and, therefore, the conclusions of these studies must be regarded as uncertain until further work has been undertaken on the original samples or new samples collected from the original study

formations. We strongly recommend that all future studies of bioapatite REEs be designed to generate datasets adequate for testing of REE provenance following the techniques developed by Zhao et al. (2013), Chen et al. (2015), and the present study.

6. Conclusions

The widely held view of conodont apatite as a reliable seawater proxy has been re-evaluated in the present study, in which the behavior of REEs and other trace elements (e.g., U, Mn) during diagenesis is considered based on conodont and whole-rock samples from two Ordovician sections in South China. Whole-rock samples show a nearly flat REE distribution with slight MREE enrichment, while conodonts show a typical “MREE bulge” distribution as previously reported. Both whole-rock samples and conodonts in the present study show a primarily lithogenous REE signature based on strong correlation between ΣREE and Th and on Y/Ho ratios of <40 . In addition to REEs, other trace elements (e.g. Si, Al, Ni) from primarily lithogenous sources (i.e., clay minerals in the host rock) were absorbed by conodonts during burial. With increasing diagenetic alteration, conodonts exhibit greater MREE enrichment. A subset of samples characterized by low ΣREE and high Y/Ho ratios (>40) may record predominantly hydrogenous (seawater) influence. These samples also exhibit limited MREE enrichment, high U and low Mn concentrations, and elevated $\text{La}_\text{N}/\text{Yb}_\text{N}$ ratios, signatures that were acquired during early diagenesis in the suboxic zone (i.e., zone of Mn(IV) and Fe(III) reduction). Our findings indicate that conodonts are highly susceptible to diagenetic alteration of their REE and trace-element compositions in both the early and late burial environments, and that many, and possibly most, conodont fossils are incapable of yielding a hydrogenous (seawater-derived) REE signal. In view of the insufficient evaluation of diagenetic influences on the REE composition of conodont apatite in many earlier studies, all claims of for hydrogenous REE signals must be regarded skeptically until a full evaluation of REE provenance, as developed in the present study, has been undertaken.

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Figures and figure captions

Fig. 1. (A) Geographic map of the Three Gorges area, southern Hubei Province, South China. The inset map of China in the upper left shows the location of map A, and the blue rectangle in the main map shows area of map B. (B) Geological map of Yichang area, showing the locations of the Huanghuachang and Chenjiahe sections. Z = Sinian, € = Cambrian, O = Ordovician, S = Silurian, D = Devonian, P = Permian, K = Cretaceous. (C) Early to Middle Ordovician paleogeography of the South China Craton (after Zhan and Jin, 2007).

Fig. 2. Biozonation and correlation of the Huanghuachang and Chenjiahe study sections. Graptolite zones after Wang et al. (1987, 1996, 2001, 2003) and Chen et al. (1995, 2000, 2003). Conodont zones were modified from Wang et al. (2005, 2009), Wu et al. (2010), and Li et al. (2004, 2010a, 2010b). The geological timescale is from the ChronostratChart of Cohen et al. (2014). The sea-level curve is from Xiao et al. (1996); note that the Chenjiahe section extends only to the base of the Hirnantian and does not show the large sea-level fall due to Hirnantian glaciation. Fm. = Formation; M. = Miaopo; W. = Wufeng.

Fig. 3. Representative laser ablation profile plotting the trend of REEs and other selected chemical species in conodont albid crown (sample Hg-22). Scale bar = 100 μm .

Fig. 4. REE profiles for the Huanghuachang and Chenjiahe sections. Black and red lines show conodont and whole-rock data, respectively. Fm. = Formation; S. = Sandbian; H. = Honghuayuan; M. = Miaopo; B. = Baota; L. = Lingxiang; W. = Wufeng.

Fig. 5. REE spidergram distributions for conodonts (A) and whole-rock samples (B) from the Huanghuachang and Chenjiahe sections. Most conodonts show strong MREE enrichment, whereas whole-rock samples show nearly flat distributions with minor MREE enrichment.

Fig. 6. ΣREE vs. Th of whole-rock samples and conodonts from the study section. For whole-rock samples, positive covariation reflects a dilution control in this mixed carbonate-shale succession. For conodonts, higher concentrations of Th and ΣREE are due to diagenetic uptake; $\Sigma\text{REE}/\text{Th}$ ratios similar to those of whole-rock samples imply a lithogenous source for conodont REEs. Also shown are the ΣREE and Th concentrations of average UCC (146 ppm and 10.7 ppm, respectively; McLennan, 2001) and modern seawater ($\sim 1.7 \times 10^{-5}$ ppm, 1.7×10^{-8} to 1.4×10^{-5} ppm, respectively; Guo et al., 1995; Nozaki, 2001). Thus, seawater exhibits a very different $\Sigma\text{REE}/\text{Th}$ ratio (~ 120 to 990) from that of average UCC (13.7) or the study samples (16.3 for whole rocks and 29.8 for conodonts).

Fig. 7. Pearson correlation coefficients (r) between various elements and Th, which is a proxy for clay content, in whole rock (A) and conodont samples (B).

932

933 Fig. 8. Average concentrations of trace elements in conodont versus whole-rock
 934 samples for Ordovician (A) and Triassic (B) marine sediments, and between
 935 conodonts and seawater for the Ordovician (C) and Triassic (D). Data for Triassic
 936 samples are from Chen et al. (2015). Seawater elemental concentrations are for the
 937 Recent as the composition of paleo-seawater is unknown. The dashed lines represent
 938 1:1 relationships.

940

941 Fig. 9. Elemental concentration ratios (conodont/whole rock) for the Ordovician
942 versus the Triassic. The measured elements yield a correlation of $r = +0.93$ with a
943 slope of 1.24 ± 0.11 ; the dashed line represents a 1:1 relationship. Data for Triassic
944 samples are from Chen et al. (2015).

945

Fig. 10. Y/Ho versus ΣREE for conodonts and whole-rock samples from the Huanghuachang and Chenjiahe study sections. The red curve represents a mixing trend between a hypothetical hydrogenous endmember and a terrigenous endmember with average UCC composition (McLennan, 2001); percentages represent the fraction of the hydrogenous endmember. The majority of REEs in both conodonts and whole-rock samples (>90%) are derived from terrigenous siliciclastic sources.

Fig. 11. Y/Ho versus MREE/MREE* for conodonts and whole-rock samples from the Huanghuachang and Chenjiahe study sections. Samples with high Y/Ho (>40) also exhibit low MREE/MREE* (<2).

Fig. 12. [U] versus MREE/MREE* ratios for whole-rock samples and conodonts from the Huanghuachang and Chenjiahe study sections. Some conodonts showing weak diagenetic influence have high [U], whereas conodonts showing strong diagenetic influence yield low [U]. High [U] is probably an indication of early diagenetic uptake of uranium, when suboxic sediment porewaters were in contact with the overlying water column, permitting accumulation of larger amounts of uranium.

Fig. 13. La_N/Yb_N versus Mn for whole-rock and conodont samples from the Huanghuachang and Chenjiahe study sections. Average La_N/Yb_N for whole-rock samples (1.05) is similar to that for UCC (1.0). Mn concentrations are highest for low La_N/Yb_N , reflecting a diagenetic trend.

Table 1. Ordovician stratigraphy of the Three Gorges area, South China

Stage		Age (Ma) ¹	Formation ²	Thickness (m)	Lithology ³
Upper Ordovician	Hirnantian	445.2 ±1.4	Wufeng	4.5	(Lower) Dark gray siliceous bands and carbonaceous shales; (upper) marl and claystone
	Katian	453.0 ±0.7	Linxiang	4.1	Nodular muddy limestone
			Baota	8	Mainly thick limestone beds
	Sandbian	458.4 ±0.9	Miaopo	3.6	Black silty shale with limestone lenses
			Guniutan	19	Argillaceous limestone
Middle Ordovician	Darriwilian	467.3 ±1.1	Dawan	42.2	Alternating argillaceous limestone and shale
	Dapingian	470.0 ±1.4	Honghuayuan	24.4	Bioclastic limestone
Lower Ordovician	Floian	477.7 ±1.4	Fenxiang	68	Thick limestone beds with interspersed mudstone layers
			Nanjinguan	99	Mainly limestone and dolomite with some siliceous bands
	Tremadocian	485.4 ±1.9			

¹Geological timescale is from the ChronostratChart of Cohen et al. (2014), representing the age of the base of each stage. ²The gray fields represent units in the present study. ³Lithologic descriptions are modified from Wang et al. (1987).

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Table 2. REE and trace-element concentrations of whole-rock samples

NO.	Lithology	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	U	Th	Y	Mn	Cr	Sr
CO3L-12	N. L.	16.87	35.29	3.69	14.14	2.87	0.55	2.52	0.38	2.24	0.42	1.22	0.18	1.18	0.16	0.65	5.61	14.4	749	19	203
CO3L-11	N. L.	15.77	34.12	3.42	13.10	2.59	0.51	2.30	0.35	2.00	0.39	1.12	0.18	0.97	0.15	0.55	5.00	13.4	671	16	206
CO3L-10	N. L.	24.53	48.23	5.44	20.63	4.28	0.83	3.74	0.58	3.36	0.63	1.74	0.27	1.55	0.24	1.15	7.96	19.9	726	28	179
CO3L-9	N. L.	24.05	45.72	5.24	19.86	3.98	0.78	3.60	0.54	3.15	0.60	1.70	0.25	1.60	0.24	1.15	7.67	19.1	700	27	180
CO3L-7	N. L.	23.47	47.30	5.25	19.75	4.08	0.79	3.74	0.55	3.23	0.59	1.75	0.25	1.53	0.24	1.07	8.04	18.6	696	27	177
CO3L-5	N. L.	36.27	51.35	7.50	29.48	6.10	1.13	5.70	0.83	4.65	0.87	2.42	0.34	2.11	0.30	1.04	8.99	30.2	831	30	165
CO3L-3	N. L.	22.21	43.29	4.72	17.75	3.44	0.69	3.18	0.46	2.69	0.52	1.49	0.22	1.42	0.21	0.88	7.69	17.0	903	26	186
CO3L-1*	M.	26.22	50.65	5.40	19.79	3.59	0.68	3.23	0.46	2.78	0.52	1.54	0.24	1.47	0.22	1.06	9.88	16.7	726	34	183
O3b-30	L.	16.47	32.01	3.66	14.09	2.87	0.53	2.68	0.38	2.18	0.41	1.21	0.18	1.03	0.16	0.61	5.32	14.3	728	21	245
O3b-28	L.	13.94	26.62	3.10	11.65	2.31	0.45	2.11	0.33	1.84	0.34	0.96	0.15	0.88	0.13	0.56	4.47	12.5	532	17	257
O3b-26	L.	10.95	20.20	2.38	9.00	1.81	0.40	1.74	0.26	1.45	0.29	0.81	0.13	0.68	0.10	0.38	3.54	10.4	464	13	268
O3b-24	L.	12.01	21.88	2.69	10.55	2.16	0.47	1.95	0.32	1.71	0.33	0.95	0.13	0.80	0.11	0.33	3.35	12.2	517	13	253
O3b-22*	L.	4.83	9.28	1.06	4.06	0.85	0.16	0.77	0.12	0.67	0.14	0.36	0.06	0.34	0.05	2.11	1.49	4.4	287	7	343
O3b-20	L.	13.42	24.35	3.00	11.59	2.31	0.54	2.27	0.35	1.91	0.36	1.07	0.15	0.88	0.13	0.38	3.70	13.4	473	14	285
O3b-18	L.	10.97	19.60	2.47	9.62	1.99	0.43	1.77	0.28	1.49	0.29	0.80	0.12	0.69	0.10	0.38	3.19	10.8	439	12	249
O3b-16	L.	16.01	30.35	3.59	13.71	2.78	0.58	2.53	0.38	2.22	0.44	1.21	0.19	1.07	0.16	0.47	5.17	14.5	488	16	290
O3b-14	L.	12.32	21.09	2.75	10.68	2.10	0.46	1.99	0.30	1.71	0.32	0.89	0.14	0.79	0.12	0.41	3.87	11.7	455	14	237
O3b-9	L.	11.20	19.33	2.41	9.20	1.79	0.40	1.78	0.28	1.54	0.28	0.81	0.12	0.74	0.11	0.37	3.61	11.0	519	14	287
O3b-4	L.	12.88	27.03	2.86	10.88	2.07	0.46	2.02	0.30	1.66	0.32	0.87	0.13	0.80	0.12	0.43	4.49	11.0	401	15	241
O3m-10	L.	17.88	29.33	4.03	15.30	3.09	0.70	2.84	0.42	2.39	0.45	1.22	0.18	1.10	0.16	8.24	6.32	16.4	6116	25	325
CO2g-15	M. L.	14.72	29.55	3.44	12.86	2.54	0.47	2.22	0.35	1.91	0.37	1.07	0.17	1.02	0.15	0.50	5.60	12.2	603	20	260
CO2g-11	M. L.	13.69	27.96	3.15	12.15	2.45	0.46	2.19	0.33	1.85	0.36	0.96	0.15	0.92	0.13	0.45	5.02	11.5	568	17	256
O2g-8	M. L.	13.33	21.74	2.92	11.09	2.13	0.41	1.89	0.26	1.60	0.30	0.88	0.13	0.83	0.12	0.53	5.71	11.1	398	22	389
CO2g-7	M. L.	21.25	41.15	4.30	15.50	2.86	0.55	2.61	0.38	2.19	0.42	1.24	0.18	1.20	0.17	0.62	8.71	14.2	573	29	206
CO2g-3	M. L.	12.36	25.28	2.85	10.24	2.05	0.38	1.80	0.27	1.64	0.31	0.91	0.14	0.86	0.14	0.39	4.97	10.0	824	17	269
O2g-18	M. L.	12.31	24.43	2.82	10.53	2.19	0.41	1.99	0.30	1.70	0.32	0.91	0.14	0.92	0.13	0.36	4.53	11.4	755	12	329
O2g-16	M. L.	12.55	22.88	2.86	11.03	2.33	0.43	2.04	0.32	1.87	0.38	1.03	0.16	0.94	0.14	0.37	4.66	12.6	638	11	354
O2g-11	M. L.	11.73	21.21	2.63	10.17	2.10	0.41	1.92	0.29	1.68	0.34	0.98	0.14	0.91	0.14	0.36	4.14	12.2	790	10	337
O2g-1	M. L.	17.23	28.56	4.04	15.57	3.03	0.61	2.87	0.43	2.41	0.45	1.26	0.19	1.16	0.18	10.30	6.42	15.7	1258	18	388
O2d-62	M. L.	18.97	39.21	4.55	16.95	3.66	0.70	3.20	0.51	2.94	0.56	1.59	0.24	1.41	0.20	2.23	5.59	15.8	2498	25	296

O2d-61	M. L.	22.71	48.76	5.46	21.45	4.49	0.83	4.17	0.65	3.72	0.72	2.07	0.32	1.96	0.28	2.24	4.04	21.6	4378	20	309
O2d-60	M. L.	20.90	42.48	4.81	18.20	3.97	0.81	3.60	0.58	3.31	0.66	1.85	0.30	1.80	0.26	1.05	5.29	19.2	3321	27	294
O2d-57	M. L.	12.94	28.81	3.07	11.33	2.43	0.45	1.99	0.33	1.84	0.38	1.04	0.18	1.14	0.16	0.96	4.93	10.6	3498	18	428
O2d-56	M. L.	12.97	29.58	2.97	11.12	2.35	0.43	2.17	0.34	1.98	0.39	1.16	0.19	1.15	0.16	0.82	4.63	10.7	5538	19	275
O2d-55	M. L.	8.88	20.31	2.19	8.54	1.80	0.36	1.61	0.24	1.39	0.30	0.83	0.13	0.80	0.12	0.98	3.51	8.1	5935	11	421
O2d-52	M. L.	13.63	27.38	3.09	11.62	2.27	0.44	1.83	0.28	1.55	0.32	0.93	0.15	0.94	0.14	0.41	5.79	8.6	3619	20	330
O2d-51	M. L.	8.88	18.81	2.23	8.84	1.73	0.34	1.55	0.26	1.42	0.28	0.77	0.11	0.70	0.11	0.55	3.16	7.9	2624	9	372
O2d-50	M. L.	10.69	22.75	2.58	9.30	1.97	0.37	1.63	0.26	1.42	0.31	0.87	0.14	0.80	0.13	0.69	4.72	8.1	3013	14	341
O2d-49	M. L.	14.66	31.80	3.64	13.90	2.97	0.55	2.53	0.39	2.21	0.43	1.20	0.19	1.09	0.17	1.80	5.15	11.6	3454	19	297
O2d-48*	M. L.	10.42	22.74	2.37	8.76	1.81	0.35	1.51	0.25	1.33	0.28	0.76	0.12	0.83	0.12	0.55	4.57	7.5	2831	16	289
O2d-45	M. L.	31.10	65.17	8.15	32.77	7.25	1.36	6.10	0.95	5.20	0.96	2.60	0.37	2.12	0.30	2.67	8.45	27.7	1573	42	190
O2d-44	M. L.	15.34	29.16	3.47	13.06	2.77	0.53	2.36	0.36	2.12	0.42	1.22	0.19	1.20	0.17	0.58	6.20	11.8	1435	23	279
O2d-43	M. L.	13.28	24.25	3.03	11.26	2.21	0.46	2.00	0.32	1.80	0.35	0.96	0.15	0.92	0.16	0.42	5.02	9.5	1564	17	266
O2d-42*	M. L.	10.30	20.32	2.41	9.13	1.92	0.38	1.68	0.25	1.46	0.28	0.79	0.12	0.78	0.12	1.01	3.18	8.3	2906	11	345
O2d-40	M. L.	11.18	22.75	2.85	10.98	2.28	0.45	1.99	0.31	1.65	0.31	0.85	0.13	0.84	0.11	1.09	3.03	9.2	2854	12	308
O2d-30	M. L.	22.07	45.94	5.39	20.64	4.37	0.83	3.70	0.57	3.18	0.64	1.71	0.26	1.55	0.23	2.89	5.26	17.6	4329	25	216
O2d-20	M. L.	16.64	36.04	4.46	18.04	4.04	0.74	3.54	0.52	2.99	0.59	1.59	0.23	1.39	0.19	1.91	4.19	16.8	3083	14	316
O2d-10	M.	54.52	111.01	13.38	54.07	12.57	2.35	11.25	1.69	9.15	1.74	4.70	0.70	4.16	0.54	4.16	9.92	50.1	2105	58	198
O2d-1	M. L.	11.11	22.63	2.90	11.40	2.48	0.49	2.18	0.33	1.77	0.35	1.00	0.14	0.83	0.14	1.43	2.54	10.3	2171	8	262
O1d-68	M. L.	12.90	25.27	3.13	12.00	2.56	0.49	2.19	0.34	1.82	0.36	1.00	0.16	0.93	0.13	0.72	3.99	10.1	2330	14	294
O1d-48	M. L.	19.74	41.05	4.88	18.60	3.87	0.71	3.22	0.46	2.75	0.51	1.38	0.19	1.17	0.19	3.66	5.45	13.9	3559	17	365
O1d-38	M. L.	10.70	19.97	2.32	8.84	1.73	0.36	1.45	0.25	1.33	0.26	0.81	0.12	0.73	0.12	1.82	3.38	7.6	3384	12	295
O1d-28	M. L.	15.61	30.73	3.50	13.29	2.73	0.50	2.39	0.37	2.09	0.38	1.11	0.16	0.98	0.15	3.09	3.33	11.0	3169	13	297
O1d-18	M. L.	11.40	21.89	2.55	9.82	1.92	0.39	1.75	0.27	1.59	0.29	0.80	0.13	0.76	0.11	2.69	2.33	8.5	3204	8	334
O1d-12	M. L.	12.52	26.99	3.09	11.67	2.43	0.47	2.11	0.32	1.81	0.32	0.93	0.13	0.84	0.13	3.21	3.27	9.4	3483	11	336
O1d-9	M. L.	7.36	15.39	1.83	7.27	1.42	0.30	1.36	0.20	1.20	0.21	0.54	0.09	0.56	0.08	1.96	1.55	6.3	2504	4	255
O1d-7*	M. L.	10.58	21.05	2.61	10.25	2.22	0.45	1.98	0.30	1.68	0.32	0.84	0.12	0.76	0.11	1.11	3.32	8.7	1588	5	299
O1d-3	M. L.	11.30	27.79	2.75	10.74	2.36	0.48	2.09	0.33	1.82	0.35	1.00	0.14	0.92	0.13	2.58	3.88	9.2	1686	7	319
O1h-15*	L.	15.74	50.25	4.40	18.21	4.45	0.95	4.29	0.66	3.64	0.69	1.93	0.28	1.65	0.23	0.94	4.65	17.8	2110	4	326
O1h-13	L.	3.44	6.48	0.73	2.78	0.53	0.11	0.53	0.08	0.52	0.10	0.28	0.04	0.25	0.03	1.28	0.49	3.0	756	3	270
O1h-11	L.	6.39	12.89	1.56	5.72	1.18	0.20	1.02	0.16	0.90	0.18	0.53	0.08	0.53	0.08	1.91	2.36	5.2	670	10	328
O1h-9	L.	2.91	5.16	0.59	2.25	0.42	0.08	0.38	0.07	0.36	0.08	0.22	0.03	0.19	0.03	1.88	0.62	2.3	901	3	296
O1h-7	L.	3.10	6.23	0.70	2.71	0.52	0.11	0.47	0.07	0.41	0.09	0.23	0.04	0.23	0.03	0.97	0.52	2.3	925	3	266

O1h-4	L.	1.81	3.31	0.39	1.44	0.30	0.06	0.27	0.04	0.24	0.05	0.14	0.02	0.12	0.02	1.21	0.54	1.4	165	3	408
O1h-3	L.	1.78	3.43	0.38	1.41	0.30	0.06	0.28	0.04	0.26	0.04	0.14	0.02	0.13	0.02	1.41	0.57	1.5	296	4	302

NO.	Σ REE	Ce/Ce*	Eu/Eu*	M/M*	(La/Sm) _N	(La/Yb) _N	(Sm/Yb) _N	Y/Ho	Σ REE/Th	log Σ REE	logTh	log[Σ REE/Th]	%clays	%carb
CO3L-12	82	1.0	1.0	1.2	0.88	1.05	1.19	34.4	14.6	1.9	0.7	1.2	52.4	47.6
CO3L-11	77	1.0	1.0	1.2	0.91	1.20	1.31	34.2	15.4	1.9	0.7	1.2	46.7	53.3
CO3L-10	116	0.9	1.0	1.2	0.86	1.16	1.35	31.4	14.6	2.1	0.9	1.2	74.4	25.6
CO3L-9	111	0.9	1.0	1.2	0.91	1.10	1.22	31.8	14.5	2.0	0.9	1.2	71.7	28.3
CO3L-7	113	1.0	1.0	1.2	0.86	1.12	1.30	31.2	14.0	2.1	0.9	1.1	75.1	24.9
CO3L-5	149	0.7	0.9	1.3	0.89	1.26	1.41	34.8	16.6	2.2	1.0	1.2	84.1	15.9
CO3L-3	102	0.9	1.0	1.2	0.97	1.15	1.18	32.4	13.3	2.0	0.9	1.1	71.9	28.1
CO3L-1*	117	0.9	0.9	1.1	1.09	1.31	1.19	31.9	11.8	2.1	1.0	1.1	92.4	7.6
O3b-30	78	0.9	0.9	1.2	0.86	1.17	1.36	34.6	14.6	1.9	0.7	1.2	49.8	50.2
O3b-28	65	0.9	1.0	1.2	0.90	1.17	1.29	36.2	14.5	1.8	0.7	1.2	41.8	58.2
O3b-26	50	0.9	1.0	1.3	0.91	1.18	1.30	36.1	14.2	1.7	0.5	1.2	33.1	66.9
O3b-24	56	0.9	1.1	1.3	0.83	1.10	1.31	36.4	16.7	1.7	0.5	1.2	31.3	68.7
O3b-22*	23	0.9	0.9	1.2	0.85	1.05	1.23	32.2	15.2	1.4	0.2	1.2	14.0	86.0
O3b-20	62	0.9	1.1	1.3	0.87	1.11	1.28	36.8	16.8	1.8	0.6	1.2	34.6	65.4
O3b-18	51	0.8	1.1	1.3	0.83	1.16	1.41	37.9	15.9	1.7	0.5	1.2	29.8	70.2
O3b-16	75	0.9	1.0	1.2	0.87	1.10	1.27	33.0	14.6	1.9	0.7	1.2	48.3	51.7
O3b-14	56	0.8	1.1	1.3	0.88	1.15	1.30	36.4	14.4	1.7	0.6	1.2	36.1	63.9
O3b-9	50	0.8	1.0	1.3	0.94	1.12	1.19	39.6	13.8	1.7	0.6	1.1	33.8	66.2
O3b-4	62	1.0	1.0	1.2	0.93	1.18	1.27	34.6	13.9	1.8	0.7	1.1	41.9	58.1
O3m-10	79	0.8	1.1	1.3	0.87	1.19	1.37	36.2	12.5	1.9	0.8	1.1	59.0	41.0
CO2g-15	71	0.9	0.9	1.2	0.87	1.06	1.21	32.7	12.7	1.9	0.7	1.1	52.3	47.7
CO2g-11	67	0.9	0.9	1.2	0.84	1.10	1.31	32.1	13.3	1.8	0.7	1.1	46.9	53.1
O2g-8	58	0.8	1.0	1.2	0.94	1.18	1.26	36.8	10.1	1.8	0.8	1.0	53.3	46.7
CO2g-7	94	1.0	0.9	1.1	1.11	1.30	1.17	33.5	10.8	2.0	0.9	1.0	81.4	18.6
CO2g-3	59	1.0	0.9	1.1	0.90	1.05	1.17	32.0	11.9	1.8	0.7	1.1	46.5	53.5
O2g-18	59	0.9	0.9	1.2	0.84	0.99	1.17	35.4	13.0	1.8	0.7	1.1	42.4	57.6
O2g-16	59	0.9	0.9	1.2	0.81	0.98	1.21	33.4	12.6	1.8	0.7	1.1	43.6	56.4
O2g-11	55	0.8	1.0	1.2	0.84	0.94	1.13	36.0	13.2	1.7	0.6	1.1	38.7	61.3

O2g-1	78	0.8	1.0	1.3	0.85	1.09	1.28	34.9	12.2	1.9	0.8	1.1	60.0	40.0
O2d-62	95	1.0	1.0	1.2	0.78	0.99	1.27	28.4	16.9	2.0	0.7	1.2	52.2	47.8
O2d-61	118	1.0	0.9	1.2	0.76	0.85	1.12	29.9	29.1	2.1	0.6	1.5	37.7	62.3
O2d-60	104	1.0	1.0	1.2	0.79	0.85	1.08	29.0	19.6	2.0	0.7	1.3	49.4	50.6
O2d-57	66	1.0	1.0	1.1	0.80	0.84	1.05	28.0	13.4	1.8	0.7	1.1	46.1	53.9
O2d-56	67	1.1	0.9	1.1	0.83	0.83	1.00	27.5	14.5	1.8	0.7	1.2	43.3	56.7
O2d-55	48	1.0	1.0	1.2	0.74	0.81	1.10	27.2	13.5	1.7	0.5	1.1	32.8	67.2
O2d-52	65	0.9	1.0	1.1	0.90	1.06	1.18	26.6	11.1	1.8	0.8	1.0	54.1	45.9
O2d-51	46	0.9	1.0	1.2	0.77	0.93	1.21	28.7	14.5	1.7	0.5	1.2	29.6	70.4
O2d-50	53	1.0	1.0	1.1	0.82	0.98	1.20	26.4	11.3	1.7	0.7	1.1	44.1	55.9
O2d-49	76	1.0	0.9	1.2	0.74	0.99	1.34	27.2	14.7	1.9	0.7	1.2	48.1	51.9
O2d-48*	52	1.0	1.0	1.1	0.86	0.92	1.06	27.2	11.3	1.7	0.7	1.1	42.7	57.3
O2d-45	164	0.9	1.0	1.4	0.64	1.08	1.67	28.9	19.5	2.2	0.9	1.3	79.0	21.0
O2d-44	72	0.9	1.0	1.2	0.83	0.94	1.13	28.1	11.7	1.9	0.8	1.1	57.9	42.1
O2d-43	61	0.9	1.0	1.2	0.90	1.06	1.18	27.3	12.2	1.8	0.7	1.1	46.9	53.1
O2d-42*	50	0.9	1.0	1.2	0.80	0.97	1.20	29.2	15.7	1.7	0.5	1.2	29.8	70.2
O2d-40	57	0.9	1.0	1.3	0.74	0.98	1.33	29.6	18.7	1.8	0.5	1.3	28.3	71.7
O2d-30	111	1.0	1.0	1.3	0.76	1.04	1.38	27.6	21.1	2.0	0.7	1.3	49.1	50.9
O2d-20	91	0.9	0.9	1.4	0.62	0.88	1.42	28.5	21.7	2.0	0.6	1.3	39.2	60.8
O2d-10	282	0.9	0.9	1.5	0.65	0.96	1.48	28.7	28.4	2.4	1.0	1.5	92.8	7.2
O2d-1	58	0.9	1.0	1.4	0.67	0.98	1.47	29.4	22.7	1.8	0.4	1.4	23.7	76.3
O1d-68	63	0.9	1.0	1.3	0.76	1.02	1.35	28.2	15.9	1.8	0.6	1.2	37.3	62.7
O1d-48	99	0.9	0.9	1.3	0.76	1.24	1.62	27.0	18.1	2.0	0.7	1.3	50.9	49.1
O1d-38	49	0.9	1.1	1.1	0.93	1.08	1.16	29.5	14.5	1.7	0.5	1.2	31.6	68.4
O1d-28	74	0.9	0.9	1.2	0.86	1.17	1.37	28.8	22.2	1.9	0.5	1.3	31.1	68.9
O1d-18	54	0.9	1.0	1.2	0.89	1.10	1.23	29.0	23.1	1.7	0.4	1.4	21.8	78.2
O1d-12	64	1.0	1.0	1.3	0.77	1.09	1.41	29.2	19.5	1.8	0.5	1.3	30.6	69.4
O1d-9	38	0.9	1.0	1.3	0.78	0.97	1.24	30.7	24.4	1.6	0.2	1.4	14.5	85.5
O1d-7*	53	0.9	1.0	1.4	0.72	1.02	1.43	27.0	16.0	1.7	0.5	1.2	31.0	69.0
O1d-3	62	1.1	1.0	1.3	0.72	0.90	1.26	26.4	16.0	1.8	0.6	1.2	36.3	63.7
O1h-15*	107	1.3	1.0	1.5	0.53	0.70	1.31	25.9	23.1	2.0	0.7	1.4	43.4	56.6
O1h-13	16	0.9	1.0	1.1	0.97	1.01	1.04	29.8	32.1	1.2	-0.3	1.5	4.6	95.4
O1h-11	31	0.9	0.9	1.1	0.82	0.89	1.09	27.9	13.3	1.5	0.4	1.1	22.1	77.9

O1h-9	13	0.9	1.0	1.1	1.04	1.11	1.07	30.1	20.7	1.1	-0.2	1.3	5.8	94.2
O1h-7	15	0.9	1.1	1.2	0.89	0.99	1.11	26.7	29.0	1.2	-0.3	1.5	4.8	95.2
O1h-4	8	0.9	1.0	1.2	0.90	1.08	1.19	30.0	15.3	0.9	-0.3	1.2	5.0	95.0
O1h-3	8	0.9	0.9	1.1	0.90	0.97	1.08	33.7	14.6	0.9	-0.2	1.2	5.3	94.7

NO.	Li	Be	Sc	Ti	V	Co	Ni	Cu	Zn	Ga	Rb	Zr	Nb	Mo	Sn	Cs	Ba	Hf	Ta	Tl	Pb	U
CO3L-12	14.5	0.80	5.30	1343	33.7	8.10	17.4	21.3	32.4	5.84	45.7	44.0	5.51	0.10	1.17	1.92	257	1.21	0.38	0.20	13.1	0.65
CO3L-11	12.3	0.74	4.86	1193	31.4	5.67	16.7	20.1	29.4	5.56	42.0	39.6	4.84	0.06	1.01	1.87	303	1.04	0.33	0.18	11.0	0.55
CO3L-10	20.5	1.18	7.72	1954	53.1	8.55	25.4	9.86	39.2	9.07	71.4	65.8	8.05	0.12	1.76	3.24	329	1.66	0.52	0.31	14.9	1.15
CO3L-9	20.7	1.24	7.65	1820	54.3	9.96	24.7	10.5	40.0	8.85	71.6	61.7	7.16	0.16	1.65	3.28	310	1.58	0.50	0.32	23.5	1.15
CO3L-7	20.1	1.17	7.94	1831	49.5	8.63	25.0	8.26	38.6	8.64	68.6	60.1	7.47	0.12	1.56	3.13	331	1.61	0.51	0.31	14.2	1.07
CO3L-5	19.8	1.30	10.1	1974	54.3	8.57	29.1	8.85	42.5	9.44	72.8	68.1	8.20	0.17	1.74	3.59	339	1.71	0.57	0.32	27.3	1.04
CO3L-3	17.7	1.16	7.64	1820	37.2	10.1	24.5	6.24	37.0	8.46	63.8	62.8	8.38	0.42	1.44	3.16	317	1.49	0.54	0.30	12.5	0.88
CO3L-1*	23.1	1.35	8.61	2332	77.7	11.5	29.8	11.6	40.2	10.1	82.8	74.8	10.5	0.10	2.03	4.22	414	1.89	0.69	0.38	8.36	1.06
O3b-30	15.6	0.81	5.14	1546	38.5	6.88	19.4	4.27	33.1	5.90	40.0	42.7	6.61	0.16	1.09	1.66	259	1.15	0.45	0.20	9.36	0.61
O3b-28	11.3	0.72	4.48	1252	40.4	6.26	15.4	46.4	26.3	4.83	33.2	33.8	5.28	0.41	0.86	1.21	229	0.84	0.36	0.16	7.62	0.56
O3b-26	10.3	0.52	3.53	1108	16.3	5.40	13.7	3.31	25.0	3.59	23.4	27.6	4.89	0.07	0.72	0.86	186	0.74	0.32	0.11	10.1	0.38
O3b-24	11.0	0.51	3.51	1169	15.5	5.04	13.2	2.59	21.9	3.46	23.2	29.3	5.57	0.07	0.68	1.08	325	0.75	0.35	0.11	9.48	0.33
O3b-22*	3.99	0.29	1.54	338	11.3	3.64	7.08	3.47	13.1	1.81	13.3	11.5	1.26	1.13	0.28	0.63	87.9	0.31	0.09	0.15	3.67	2.11
O3b-20	12.7	0.62	3.98	1383	21.6	5.15	14.7	8.32	66.0	3.79	25.0	33.4	6.20	0.07	0.75	1.04	219	0.83	0.39	0.12	8.22	0.38
O3b-18	10.8	0.55	3.14	1113	18.7	5.47	11.5	2.73	22.0	3.20	22.0	29.2	5.48	0.08	0.62	1.03	189	0.72	0.35	0.12	5.53	0.38
O3b-16	13.2	0.74	5.50	1524	30.7	8.34	16.2	10.8	27.6	5.17	37.8	38.5	6.79	0.07	0.99	1.38	292	1.02	0.44	0.17	7.02	0.47
O3b-14	12.5	0.57	3.58	1198	25.0	5.78	13.4	6.10	27.6	3.93	27.9	31.5	5.17	0.10	0.87	1.23	419	0.83	0.33	0.15	7.06	0.41
O3b-9	11.0	0.55	3.51	1079	16.1	4.94	11.8	8.90	21.7	3.60	24.0	31.7	5.43	0.21	0.74	1.11	192	0.76	0.35	0.13	6.11	0.37
O3b-4	13.8	0.72	4.05	1410	28.5	4.51	13.7	3.42	28.4	4.29	31.0	37.3	6.56	0.38	0.95	1.41	229	0.97	0.44	0.15	10.2	0.43
O3m-10	12.9	0.74	3.86	1212	20.6	3.70	12.1	5.30	20.9	5.41	40.8	38.4	5.04	0.31	1.15	2.03	577	1.03	0.39	0.24	6.72	8.24
CO2g-15	12.7	0.96	4.62	1186	21.0	6.90	14.4	2.20	27.2	5.95	52.3	41.8	4.69	0.24	1.21	2.72	230	1.16	0.35	0.26	11.7	0.50
CO2g-11	9.25	0.83	4.17	987	15.7	6.57	12.2	4.00	20.4	5.10	46.9	36.6	3.99	0.10	1.10	2.64	188	0.99	0.30	0.21	11.3	0.45
O2g-8	14.0	0.54	3.83	917	16.4	4.44	9.86	11.6	17.3	3.85	24.9	28.2	4.27	0.06	0.82	1.11	248	0.75	0.27	0.12	4.41	0.53
CO2g-7	10.8	1.37	6.69	1737	32.2	10.6	18.7	5.08	36.9	8.88	85.2	61.4	6.90	0.15	1.79	4.97	319	1.63	0.50	0.43	13.9	0.62
CO2g-3	8.05	0.78	4.54	1033	19.4	6.12	14.5	4.49	22.5	5.24	46.7	31.2	4.14	0.38	1.06	2.57	200	0.88	0.29	0.22	10.1	0.39

O2g-18	10.3	0.61	3.76	815	13.2	5.12	10.8	3.91	19.6	3.65	25.0	28.1	3.41	0.08	0.88	1.15	199	0.76	0.24	0.13	7.39	0.36
O2g-16	7.85	0.50	3.42	787	11.8	3.51	8.89	5.87	26.5	3.41	20.7	27.4	3.58	0.09	0.75	0.75	163	0.76	0.25	0.11	14.5	0.37
O2g-11	9.22	0.47	3.46	714	13.0	7.83	10.0	1.67	23.1	3.11	20.5	27.2	3.18	0.10	0.67	1.03	140	0.73	0.21	0.11	12.4	0.36
O2g-1	10.9	0.64	4.27	1059	23.7	7.66	14.7	7.01	35.5	4.74	34.8	32.7	4.47	1.37	1.03	1.58	317	0.87	0.33	0.27	9.27	10.3
O2d-62	12.2	1.18	6.19	1250	28.3	9.07	16.0	6.26	32.9	6.99	53.3	36.7	5.03	0.35	1.08	2.53	289	1.06	0.35	0.22	21.3	2.23
O2d-61	10.4	1.13	6.71	883	24.4	7.53	12.0	9.99	30.9	5.65	38.1	25.1	3.45	0.28	0.82	1.86	574	0.71	0.26	0.16	20.4	2.24
O2d-60	14.0	1.28	7.26	1275	29.2	5.99	16.4	18.1	30.6	7.60	60.2	31.3	4.82	0.09	0.99	2.99	262	0.89	0.32	0.26	10.1	1.05
O2d-57	13.2	0.88	4.64	972	20.5	7.33	19.2	2.11	30.5	5.04	35.8	31.6	3.73	0.10	0.83	1.91	187	0.95	0.26	0.16	9.88	0.96
O2d-56	11.5	0.91	5.00	891	19.9	10.4	20.3	8.30	27.3	5.42	40.2	26.4	3.47	0.16	0.80	2.34	341	0.71	0.24	0.18	11.0	0.82
O2d-55	7.68	0.55	2.96	613	14.1	6.05	12.5	65.2	19.0	2.90	18.1	23.6	2.46	0.21	0.49	0.99	256	0.64	0.16	0.10	16.9	0.98
O2d-52	9.37	0.93	4.70	1163	15.6	9.07	21.3	0.88	24.6	5.90	51.7	40.7	4.36	0.08	0.92	2.77	301	1.17	0.34	0.23	14.2	0.41
O2d-51	6.45	0.46	2.33	529	18.1	5.98	12.1	40.2	17.8	2.76	16.2	23.0	2.18	0.12	0.42	0.91	452	0.63	0.16	0.09	24.1	0.55
O2d-50	8.62	0.65	3.17	849	20.8	7.17	14.8	0.95	21.6	3.96	26.6	34.1	3.29	0.16	0.68	1.59	500	0.91	0.22	0.13	15.0	0.69
O2d-49	8.51	0.87	4.69	1138	20.6	6.47	12.5	1.65	23.1	5.22	39.6	32.1	4.36	0.05	0.83	2.38	179	0.89	0.32	0.18	9.51	1.80
O2d-48*	8.20	0.67	3.39	887	19.1	7.20	15.9	0.83	23.7	4.32	31.7	32.1	3.32	0.08	0.77	1.79	145	0.93	0.24	0.13	11.3	0.55
O2d-45	12.4	1.78	10.5	1678	46.3	11.5	22.6	2.18	42.7	11.5	103	36.8	6.39	0.10	1.46	6.63	347	1.06	0.47	0.35	13.9	2.67
O2d-44	9.21	0.98	5.49	1238	23.2	6.87	13.4	32.9	28.5	6.35	59.4	41.5	4.55	0.07	1.02	3.56	190	1.18	0.33	0.25	6.29	0.58
O2d-43	10.8	0.63	4.29	1058	18.0	9.13	15.7	0.88	30.0	5.24	44.6	33.6	3.95	0.08	0.81	2.50	177	0.89	0.29	0.19	5.62	0.42
O2d-42*	6.98	0.62	3.26	672	13.7	4.51	9.21	8.29	19.8	3.31	25.6	20.6	2.46	0.05	0.49	1.52	331	0.63	0.17	0.11	12.3	1.01
O2d-40	5.95	0.53	3.23	519	12.3	4.10	7.70	1.44	16.6	3.04	25.0	14.7	1.87	0.20	0.41	1.68	116	0.42	0.14	0.10	7.03	1.09
O2d-30	9.77	1.03	7.18	1060	27.0	7.13	15.7	2.73	27.9	6.63	58.0	26.1	3.88	0.10	0.89	3.40	239	0.74	0.29	0.20	10.5	2.89
O2d-20	7.72	0.62	4.25	715	15.3	5.59	9.71	2.66	18.9	3.73	29.0	27.4	2.57	0.19	0.58	1.74	166	0.82	0.20	0.12	17.1	1.91
O2d-10	17.2	2.12	15.5	2215	63.5	13.1	26.6	12.5	56.4	15.4	135	40.5	8.36	0.11	1.96	7.97	477	1.18	0.60	0.44	10.3	4.16
O2d-1	5.41	0.41	3.08	337	10.7	3.26	5.73	11.4	11.9	2.24	17.3	9.02	1.30	0.03	0.71	1.11	69.8	0.25	0.10	0.08	7.54	1.43
O1d-68	8.44	0.65	3.96	576	15.3	5.51	10.6	40.3	20.0	3.78	29.8	15.1	2.21	0.04	0.55	1.88	299	0.44	0.15	0.12	7.54	0.72
O1d-48	10.4	0.77	4.86	772	18.2	5.57	10.8	10.3	19.8	4.44	33.9	24.2	2.75	0.09	0.61	2.17	168	0.68	0.20	0.14	10.8	3.66
O1d-38	6.95	0.56	2.98	531	12.4	4.80	8.71	7.18	17.5	3.24	23.2	16.6	2.10	0.15	0.43	1.52	175	0.49	0.15	0.11	10.5	1.82
O1d-28	7.70	0.65	4.20	531	15.3	4.77	8.27	6.84	17.8	3.56	25.8	16.7	1.99	0.10	0.49	1.58	235	0.46	0.14	0.10	17.6	3.09
O1d-18	6.51	0.46	2.56	289	8.76	3.65	5.85	7.38	12.5	2.07	13.3	8.18	1.06	0.05	0.28	0.73	247	0.24	0.08	0.05	5.34	2.69
O1d-12	6.60	0.53	3.06	381	11.6	4.48	7.14	6.34	12.6	2.71	18.6	11.9	1.37	0.08	0.34	1.19	94.2	0.35	0.11	0.08	20.9	3.21
O1d-9	3.16	0.20	1.28	165	5.01	2.78	3.99	1.92	7.49	1.08	6.48	5.90	0.64	0.07	0.14	0.40	517	0.16	0.05	0.05	4.77	1.96
O1d-7*	3.60	0.31	2.05	218	7.06	2.45	3.69	0.90	25.1	1.53	11.1	5.84	0.87	0.05	0.20	0.69	73.5	0.18	0.06	0.04	6.03	1.11
O1d-3	7.80	0.41	2.48	306	8.15	5.42	6.00	3.63	16.3	2.04	13.5	9.66	1.17	0.26	0.26	0.82	82.7	0.28	0.08	0.10	6.79	2.58

O1h-15*	13.1	0.50	1.89	166	4.25	3.83	4.10	1.98	5.63	1.34	5.20	3.47	0.73	0.24	0.13	0.15	62.7	0.09	0.06	0.05	4.93	0.94
O1h-13	2.31	0.18	0.70	91.4	4.95	2.03	3.87	3.76	5.51	0.68	4.74	1.89	0.33	0.41	0.11	0.29	39.2	0.04	0.03	0.05	2.23	1.28
O1h-11	6.22	0.48	2.26	627	15.8	4.98	7.26	7.82	14.9	2.79	19.2	28.4	2.14	0.64	0.47	1.04	114	0.74	0.15	0.13	4.08	1.91
O1h-9	2.29	0.18	0.63	128	6.00	2.53	4.90	3.47	6.69	0.71	4.58	4.33	0.47	1.67	0.14	0.25	55.5	0.12	0.04	0.10	3.07	1.88
O1h-7	1.84	0.21	0.89	117	4.67	2.04	3.43	3.16	5.30	0.80	5.72	2.05	0.38	0.29	0.13	0.38	39.5	0.06	0.03	0.05	1.56	0.97
O1h-4	1.77	0.15	0.57	138	7.12	3.09	5.67	3.55	4.96	0.76	3.76	3.46	0.60	1.14	0.14	0.17	62.1	0.09	0.05	0.07	2.71	1.21
O1h-3	2.52	0.14	0.67	139	6.74	2.33	3.99	2.06	7.30	0.85	4.96	3.18	0.51	1.09	0.18	0.22	418	0.09	0.04	0.13	1.78	1.41

Notes: * Replicate samples. Analytical reproducibility is better than 5% on average. All elemental concentrations are in ppm. L. = Limestone; N. L. = Nodular limestone; M. L. = Muddy limestone; M. = Mudstone.

Table 3. REE and trace-element concentrations of conodont samples

NO.	Lithology*	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	U	Th	Y	Mn	Cr	Sr
HP-32-2	N. L.	16.38	63.87	8.41	37.51	8.15	1.54	7.97	1.04	5.46	0.89	1.75	0.15	0.88	0.10	1.60	9.5	27.6	69.2		3396
HP-32-3	N. L.	5.82	20.58	2.61	10.85	3.25	0.62	3.01	0.42	2.17	0.44	1.02	0.08	0.47	0.05	0.97	0.6	14.0	58.2	1.1	5632
HP-32-4	N. L.	5.58	21.96	3.16	15.96	4.63	1.07	5.32	0.64	3.32	0.48	1.17	0.11	0.55	0.05	1.12	0.4	17.0	58.3	1.6	5466
HP-31	N. L.	118.06	488.61	69.53	335.27	88.77	18.02	83.56	8.57	42.98	6.08	13.64	1.01	4.97	0.56	7.15	143.3	195.2	43.2	8.0	8719
HL-30	N. L.	91.39	248.38	41.90	184.11	40.97	8.53	41.04	4.95	25.56	4.07	10.16	0.89	5.21	0.52	4.82	70.7	139.7	56.3	2.0	4139
HP-27	N. L.	70.90	229.10	41.00	193.82	47.32	10.19	45.32	4.64	23.52	3.58	7.63	0.50	3.49	0.28	5.31	69.7	111.4	22.0	2.5	9715
HP-13	L.	7.53	46.28	7.91	44.39	13.05	3.53	13.00	1.36	5.83	0.83	1.61	0.14	0.78	0.06	0.12	2.6	31.9	7.2	1.8	1442
HP-12	L.	4.76	26.76	2.50	11.98	2.28	0.44	2.00	0.25	1.04	0.14	0.51	0.03	0.28	0.01	0.27	3.4	6.7	115.8	2.6	8788
HP-11	L.	2.25	10.42	1.80	9.10	3.26	0.63	3.40	0.34	1.54	0.23	0.49	0.04	0.16	0.02	0.73	0.5	8.1	67.7		3017
HP-10	L.	23.27	106.86	14.17	67.39	18.79	4.25	17.84	1.97	10.62	1.52	3.38	0.28	1.44	0.17	0.74	22.4	48.0	70.1	0.5	8227
HP-9	L.	8.72	28.82	4.39	19.30	4.90	1.23	4.43	0.54	2.68	0.38	0.74	0.07	0.56	0.07	0.44	6.1	13.1	98.6		5328
HP-7	L.	27.10	115.68	15.76	75.87	18.54	3.78	16.37	1.66	7.08	1.16	2.17	0.18	0.74	0.10	0.97	23.6	36.4	26.5		9282
HP-5	L.	56.84	284.39	29.26	137.02	34.13	8.00	35.72	4.03	20.58	3.38	7.52	0.61	3.72	0.36	1.44	49.9	112.0	42.3	4.9	9953
HP-4	L.	23.11	141.59	12.20	57.03	14.80	3.39	15.84	1.84	8.60	1.31	3.25	0.24	1.83	0.11	0.37	16.4	48.1	36.4	3.2	9564
HPP-1'	L.	9.03	67.31	8.27	40.40	9.96	2.17	9.84	1.00	4.55	0.59	1.30	0.10	0.56	0.05	0.34	18.7	17.8	44.1	1.1	5371
Hm-7	L.	1.49	4.47	0.65	4.00	1.80	0.48	1.74	0.16	0.91	0.14	0.25	0.02	0.05	0.00	0.60	3.1	3.7	13.8		13935
Hm-6	L.	112.60	401.56	92.99	531.46	207.93	65.59	237.99	25.06	112.98	15.40	29.87	2.12	10.92	1.03	22.31	232.0	451.6	44.7	7.0	2321
Hm-5	L.	23.47	82.98	18.06	96.87	33.74	8.21	40.52	4.87	24.05	3.30	6.93	0.58	2.71	0.28	8.94	32.4	99.8	24.0	2.1	20109
Hm-1	L.	12.72	46.42	11.29	69.16	26.98	4.69	27.53	2.58	10.92	1.25	2.06	0.15	0.46	0.08	8.01	19.4	33.8	12.5	8.8	18590
Hg-42	M. L.	9.79	24.27	5.13	24.07	6.75	1.57	6.38	0.71	4.78	0.71	1.56	0.10	0.69	0.11	5.41	2.8	27.7	41.0		5642
Hg-40-4	M. L.	111.38	359.53	78.44	399.47	110.78	29.38	87.64	8.65	40.38	5.22	10.55	0.84	3.52	0.28	28.50	101.2	154.8	38.9	2.0	13162
Hg-40-3	M. L.	107.16	323.78	69.45	328.40	83.45	20.23	67.08	7.25	31.38	4.08	8.06	0.80	3.26	0.27	30.11	77.5	128.9	34.7	0.3	14965
Hg-40-2	M. L.	80.26	252.69	56.52	282.88	75.69	19.78	64.73	6.64	29.66	3.92	7.47	0.56	2.63	0.24	22.39	69.0	122.7	38.1		14549
Hg-40-1	M. L.	127.63	368.35	73.09	326.57	76.54	17.42	61.16	6.65	32.85	4.70	9.85	0.71	4.59	0.37	39.26	112.0	155.0	35.2	4.8	14812
Hg-33	M. L.	43.54	130.78	23.06	100.85	23.92	4.72	20.40	2.38	11.43	1.70	3.59	0.37	1.35	0.13	0.49	36.0	59.2	54.0	2.2	9414
Hg-31	M. L.	18.91	53.72	11.37	58.76	17.43	3.18	15.73	1.67	8.01	1.13	2.87	0.23	1.21	0.12	0.46	23.4	42.5	44.1	1.2	9850
Hg-25	M. L.	58.52	158.21	27.31	118.04	26.59	5.79	23.62	2.68	15.93	2.08	5.97	0.45	1.94	0.25	0.97	28.0	78.3	54.8	5.2	11846
Hg-22	M. L.	254.69	537.62	132.36	534.05	117.33	21.95	92.69	10.91	53.42	7.98	18.36	1.50	7.70	0.71	5.46	25.3	250.1	9.6	0.2	9279
Hg-21	M. L.	58.08	136.95	30.67	136.61	33.17	6.75	35.21	3.84	21.10	3.27	7.13	0.58	3.39	0.26	0.90	24.5	109.5	24.8	1.6	4127
Hg-18	M. L.	92.90	336.75	50.77	225.26	49.28	10.47	46.79	5.45	27.09	4.32	10.00	0.79	4.25	0.44	7.30	47.8	133.4	22.7	2.6	9133

Hg-17	M. L.	66.32	221.40	32.80	136.24	28.23	5.27	18.57	1.97	10.66	1.44	3.46	0.32	1.98	0.20	2.88	30.2	49.4	27.0	2.8	17606
Hg-16	M. L.	22.46	86.03	14.08	68.78	15.23	2.99	13.46	1.34	6.82	1.01	1.84	0.14	0.65	0.06	1.88	13.3	29.6	18.8		7849
Hg-12	M. L.	23.28	86.84	12.60	52.42	12.31	2.33	10.22	1.25	6.10	0.93	2.19	0.19	0.80	0.09	0.71	16.4	31.3	19.2	0.3	17538
Hg-10	M. L.	72.94	267.43	39.21	154.82	37.06	8.02	35.52	4.69	26.47	3.86	8.76	0.88	4.80	0.47	5.72	20.9	132.7	18.4	4.2	7554
Hg-9	M. L.	20.06	68.72	11.78	51.25	11.64	2.19	10.41	1.20	6.37	0.88	2.34	0.17	0.81	0.10	1.73	19.5	30.7	50.9	1.0	43194
Hg-4	M. L.	69.31	221.58	26.23	103.94	22.40	4.22	18.51	2.65	14.32	2.31	5.88	0.61	4.05	0.51	77.44	11.3	77.2	22.2	0.9	8497
Hg-3	M. L.	98.18	347.32	41.71	183.99	37.14	7.70	34.68	3.98	23.77	3.47	9.13	0.77	4.27	0.41	4.38	46.8	111.9	66.0	1.3	2384
Hg-1	M. L.	367.96	1256.06	193.24	853.44	184.70	34.03	159.33	17.76	91.92	13.40	29.95	2.42	10.79	1.09	12.23	329.2	396.1	64.3	1.6	7017
Hd-64	M. L.	41.74	124.20	17.83	80.24	19.25	4.41	19.79	2.46	13.27	2.12	4.92	0.44	2.01	0.23	7.57	20.6	65.3	81.3	4.5	5715
Hd-59	M. L.	8.72	25.41	3.82	15.72	3.42	0.45	2.53	0.23	1.36	0.24	0.45	0.03	0.06	0.01	1.93	1.5	6.7	82.9		17306
Hd-57	M. L.	9.30	37.91	6.34	31.35	9.05	1.69	7.48	0.90	5.00	0.78	1.93	0.15	1.28	0.12	1.05	4.3	25.4	78.9	0.7	10857
Hd-52	M. L.	14.04	59.49	12.22	58.81	15.24	2.97	14.19	1.52	8.05	1.18	2.40	0.18	0.58	0.05	1.87	13.1	36.2	74.7		12511
Hd-47	M. L.	30.80	126.38	17.70	80.56	16.83	3.38	15.45	1.83	9.53	1.58	3.23	0.23	1.23	0.11	2.56	11.3	44.7	30.7	1.8	16687
Hd-46	M. L.	8.04	38.23	4.95	26.24	7.63	1.78	8.16	0.89	4.46	0.59	1.36	0.12	0.70	0.04	2.17	2.8	18.8	81.5	0.4	8963
Hd-24	M. L.	9.97	48.79	11.85	72.65	23.01	4.58	22.33	2.16	11.56	1.55	3.24	0.19	0.86	0.07	1.68	1.7	47.5	144.5		8050
Hd-21	M. L.	10.36	31.76	6.60	28.39	6.04	1.05	5.27	0.61	3.79	0.51	1.06	0.09	0.58	0.05	1.05	22.0	15.5	48.2	1.0	7906
Hd-18	M. L.	9.91	36.58	5.00	21.82	4.65	1.08	3.95	0.49	3.20	0.48	1.05	0.13	1.10	0.06	0.94	20.7	14.1	55.0		26952
Hd-17	M. L.	5.11	13.56	1.81	9.70	2.46	0.43	2.32	0.22	1.74	0.35	0.75	0.08	0.61	0.09	1.61	1.0	9.7	52.2	2.5	15281
Hd-16	M. L.	7.92	24.71	3.98	17.51	4.34	1.05	3.46	0.36	2.26	0.34	0.60	0.06	0.36	0.03	0.28	4.9	10.2	45.3	0.8	11772
Hd-14	M. L.	128.64	306.03	34.83	128.77	23.02	4.35	21.71	2.68	16.34	2.91	8.08	0.83	5.89	0.66	25.29	8.3	97.2	25.6	2.0	14381
Hd-12	M. L.	26.05	75.82	7.92	29.26	5.38	1.15	5.13	0.64	3.98	0.65	1.56	0.18	1.22	0.12	20.46	3.6	20.7	27.0	0.5	25274
Hd-11	M. L.	21.64	72.60	7.65	29.75	7.29	1.40	6.01	0.89	4.71	0.90	2.09	0.20	1.44	0.22	4.93	2.1	24.8	51.2	0.8	8378
Hd-9A	M. L.	140.72	474.57	58.78	240.11	50.35	9.08	40.03	4.99	24.24	3.86	8.40	0.71	4.14	0.40	24.27	34.3	100.8	28.3	3.3	15041
Hd-7	M. L.	60.21	159.30	23.48	98.12	20.51	4.47	19.15	2.20	11.74	1.95	4.63	0.30	2.08	0.23	7.37	17.5	62.5	20.6	0.8	17594
Hd-5	M. L.	13.54	39.55	5.93	24.78	4.90	1.17	4.30	0.46	2.27	0.38	0.96	0.06	0.32	0.05	8.10	4.0	12.6	38.4	1.1	8198
Hd-4	M. L.	79.61	206.26	28.92	122.41	25.25	5.37	23.31	2.81	15.81	2.42	5.88	0.56	2.96	0.41	13.28	6.2	75.3	7.4	1.1	12186
Hd-2	M. L.	57.97	153.71	19.33	81.83	18.27	4.26	18.68	2.62	17.29	3.15	8.93	1.16	7.35	0.88	8.33	9.3	98.3	42.7	0.4	18579
Hd-1	M. L.	43.58	132.20	16.87	70.94	14.99	3.08	13.24	1.53	8.87	1.37	2.97	0.27	1.44	0.21	7.46	8.1	39.1	13.1	0.2	22414
HH-51	M. L.	21.71	77.09	9.79	44.35	8.72	1.98	8.06	0.91	4.58	0.75	1.63	0.15	0.63	0.07	4.53	3.4	19.2	17.2		15398
HH-50	M. L.	60.47	224.94	30.08	133.59	32.17	6.66	26.95	3.16	15.49	2.28	4.49	0.32	1.52	0.17	6.17	69.1	56.8	12.1	1.2	19734
HH-49	M. L.	1.04	2.70	0.24	1.03	0.23	0.05	0.27	0.04	0.24	0.03	0.08	0.01	0.06	0.01	0.26	0.1	1.2	21.1		35004
HH-48	M. L.	19.55	79.09	9.32	41.82	11.07	1.87	10.60	1.33	5.78	0.91	1.99	0.16	0.88	0.08	2.95	9.8	23.5	20.3	2.1	10217
HH-47-4	M. L.	23.82	91.25	10.74	45.62	11.99	2.42	11.20	1.35	7.68	1.15	2.91	0.22	1.25	0.13	2.44	3.5	35.3	22.6		16650

HH-47-3	M. L.	38.50	144.83	17.40	75.41	19.42	4.23	20.53	2.25	12.27	1.89	4.19	0.30	1.85	0.17	5.79	5.8	58.7	21.8	1.4	15750
HH-47-2	M. L.	48.64	178.53	20.76	94.85	23.19	5.38	24.65	2.71	16.58	2.39	5.21	0.47	2.69	0.21	10.58	13.8	80.0	20.7	1.2	15690
HH-47-1	M. L.	30.80	116.57	13.61	61.83	15.04	3.62	14.71	1.76	10.10	1.63	3.82	0.31	1.63	0.17	6.71	7.6	50.8	20.6	1.8	14564
HH-46	M. L.	9.71	32.31	3.75	16.42	4.05	0.92	4.43	0.50	2.62	0.40	0.91	0.08	0.46	0.04	1.09	3.3	12.3	29.1	0.9	9007
HH-40	L.	4.35	15.31	1.70	7.98	1.80	0.49	2.02	0.26	1.20	0.22	0.42	0.05	0.07	0.03	0.72	0.3	6.6	15.3	1.6	18126
HH-39-4	L.	3.13	7.75	1.07	4.29	0.75	0.16	0.92	0.11	0.65	0.07	0.26	0.04	0.08	0.02	1.07	0.5	2.9	15.0		8509
HH-39-3	L.	5.59	15.03	1.84	8.04	1.21	0.22	1.31	0.19	0.94	0.17	0.54	0.06	0.17	0.06	1.52	0.5	5.3	13.3	0.3	8444
HH-39-2	L.	12.95	36.02	4.19	19.63	3.33	0.89	2.49	0.39	2.02	0.37	1.13	0.14	0.48	0.05	4.21	3.7	10.9	14.5	3.2	8305
HH-39-1	L.	13.88	35.05	4.78	20.63	3.87	1.06	4.47	0.48	2.26	0.57	1.06	0.08	0.53	0.06	5.16	3.4	14.0	17.6	5.7	8158
HH-37	L.	5.47	18.64	2.42	11.69	1.66	0.57	2.06	0.23	0.98	0.15	0.33	0.06	0.05	0.02	1.77	3.0	4.4	2.9	1.1	19795
HH-36	L.	9.37	27.23	3.04	15.59	2.99	0.61	2.81	0.33	1.71	0.29	0.53	0.07	0.23	0.04	6.21	3.9	8.6	9.7	0.7	8520
HH-35	L.	10.32	30.18	3.81	15.92	2.47	0.63	2.79	0.45	2.15	0.31	0.74	0.07	0.46	0.04	7.90	18.1	10.4	7.8		18048
HH-34	L.	11.60	20.61	2.02	8.13	1.44	0.41	1.90	0.22	1.53	0.27	1.09	0.11	0.36	0.07	12.13	3.5	12.5	15.2		24191
HH-33	L.	0.99	2.48	0.30	1.16	0.17	0.04	0.23	0.02	0.13	0.01	0.11	0.00	0.03	0.00	0.52	0.2	0.9	4.9	1.7	17164
HH-32	L.	8.03	26.49	3.41	17.28	4.08	0.79	3.21	0.40	1.54	0.27	0.55	0.01	0.09		10.84	6.2	8.1	3.0	1.1	10146
HH-30	L.	37.93	111.69	14.94	72.13	15.04	3.13	14.59	1.45	7.34	1.14	2.66	0.24	0.81	0.12	97.72	55.5	36.9	3.6		15466
HH-29	L.	48.69	155.28	19.11	88.15	18.77	3.92	17.42	1.92	9.90	1.56	3.19	0.29	1.17	0.11	72.13	66.5	45.1	6.9		7543
HH-28	L.	71.50	196.13	26.21	110.40	23.16	4.63	22.13	2.75	13.41	2.28	5.77	0.55	1.97	0.24	105.15	48.3	69.3	4.7	1.3	21492
HH-27	L.	80.38	278.61	40.56	187.03	39.79	7.59	32.23	3.50	13.94	2.17	4.79	0.41	1.02	0.14	59.92	69.1	60.2	5.7	1.1	50209
HH-26	L.	88.85	249.66	36.52	173.65	35.35	6.74	30.84	2.93	12.80	2.00	4.24	0.36	1.04	0.09	100.96	61.7	60.1	4.5	2.7	17768

NO.	Σ REE	Ce/Ce*	Eu/Eu*	M/M*	(La/Sm) _N	(La/Yb) _N	(Sm/Yb) _N	Y/Ho	Σ REE/Th	log Σ REE	logTh	log(Σ REE/Th)
HP-32-2	154	1.2	0.9	2.4	0.3	1.4	4.5	30.9	16.3	2.2	1.0	1.2
HP-32-3	51	1.2	0.9	2.4	0.3	0.9	3.4	31.5	91.0	1.7	-0.2	2.0
HP-32-4	64	1.0	1.0	3.3	0.2	0.7	4.1	35.0	143.7	1.8	-0.4	2.2
HP-31	1280	1.1	1.0	3.2	0.2	1.7	8.7	32.1	8.9	3.1	2.2	1.0
HL-30	708	0.9	1.0	2.4	0.3	1.3	3.8	34.3	10.0	2.8	1.8	1.0
HP-27	681	0.9	1.0	3.1	0.2	1.5	6.6	31.1	9.8	2.8	1.8	1.0
HP-13	146	1.0	1.3	4.6	0.1	0.7	8.2	38.2	55.9	2.2	0.4	1.7
HP-12	53	1.6	1.0	2.1	0.3	1.3	4.0	46.1	15.6	1.7	0.5	1.2
HP-11	34	1.0	0.9	4.4	0.1	1.0	9.8	34.7	72.8	1.5	-0.3	1.9
HP-10	272	1.2	1.1	3.2	0.2	1.2	6.4	31.5	12.1	2.4	1.4	1.1

HP-9	77	1.0	1.2	2.9	0.3	1.1	4.3	34.6	12.6	1.9	0.8	1.1
HP-7	286	1.1	1.0	3.1	0.2	2.7	12.3	31.4	12.1	2.5	1.4	1.1
HP-5	626	1.5	1.1	2.7	0.2	1.1	4.5	33.1	12.5	2.8	1.7	1.1
HP-4	285	1.8	1.0	2.8	0.2	0.9	3.9	36.6	17.4	2.5	1.2	1.2
HPP-1'	155	1.5	1.0	3.3	0.1	1.2	8.6	30.2	8.3	2.2	1.3	0.9
Hm-7	16	0.8	1.3	5.7	0.1	2.0	16.1	26.8	5.2	1.2	0.5	0.7
Hm-6	1847	0.7	1.4	6.3	0.1	0.8	9.3	29.3	8.0	3.3	2.4	0.9
Hm-5	347	0.7	1.0	4.6	0.1	0.6	6.1	30.2	10.7	2.5	1.5	1.0
Hm-1	216	0.6	0.8	6.3	0.1	2.0	28.5	27.0	11.1	2.3	1.3	1.0
Hg-42	87	0.7	1.1	3.0	0.2	1.0	4.8	39.2	31.0	1.9	0.4	1.5
Hg-40-4	1246	0.7	1.4	4.2	0.2	2.3	15.4	29.7	12.3	3.1	2.0	1.1
Hg-40-3	1055	0.8	1.3	3.6	0.2	2.4	12.5	31.6	13.6	3.0	1.9	1.1
Hg-40-2	884	0.7	1.3	4.1	0.2	2.2	14.1	31.3	12.8	2.9	1.8	1.1
Hg-40-1	1110	0.8	1.2	3.0	0.3	2.0	8.1	33.0	9.9	3.0	2.0	1.0
Hg-33	368	0.9	1.0	2.8	0.3	2.4	8.7	34.9	10.2	2.6	1.6	1.0
Hg-31	194	0.7	0.9	3.5	0.2	1.1	7.0	37.6	8.3	2.3	1.4	0.9
Hg-25	447	0.9	1.1	2.5	0.3	2.2	6.7	37.6	16.0	2.7	1.4	1.2
Hg-22	1791	0.7	1.0	2.5	0.3	2.4	7.5	31.4	70.9	3.3	1.4	1.9
Hg-21	477	0.7	0.9	2.9	0.3	1.3	4.8	33.4	19.5	2.7	1.4	1.3
Hg-18	865	1.1	1.0	2.6	0.3	1.6	5.7	30.9	18.1	2.9	1.7	1.3
Hg-17	529	1.1	1.1	2.1	0.4	2.5	7.0	34.4	17.5	2.7	1.5	1.2
Hg-16	235	1.0	1.0	2.9	0.2	2.5	11.4	29.3	17.6	2.4	1.1	1.2
Hg-12	212	1.1	1.0	2.5	0.3	2.1	7.5	33.5	12.9	2.3	1.2	1.1
Hg-10	665	1.2	1.0	2.4	0.3	1.1	3.8	34.4	31.8	2.8	1.3	1.5
Hg-9	188	1.0	0.9	2.6	0.3	1.8	7.0	34.9	9.6	2.3	1.3	1.0
Hg-4	497	1.2	1.0	1.8	0.5	1.3	2.7	33.5	43.8	2.7	1.1	1.6
Hg-3	797	1.2	1.0	2.1	0.4	1.7	4.3	32.3	17.0	2.9	1.7	1.2
Hg-1	3216	1.0	0.9	2.5	0.3	2.5	8.4	29.6	9.8	3.5	2.5	1.0
Hd-64	333	1.0	1.1	2.6	0.3	1.5	4.7	30.9	16.2	2.5	1.3	1.2
Hd-59	62	1.0	0.7	2.1	0.4	11.1	29.1	27.7	42.9	1.8	0.2	1.6
Hd-57	113	1.0	1.0	2.8	0.2	0.5	3.4	32.6	26.2	2.1	0.6	1.4
Hd-52	191	0.9	0.9	3.5	0.1	1.8	12.7	30.6	14.6	2.3	1.1	1.2
Hd-47	309	1.1	1.0	2.5	0.3	1.8	6.7	28.3	27.4	2.5	1.1	1.4

Hd-46	103	1.2	1.1	3.7	0.2	0.8	5.3	31.8	36.3	2.0	0.5	1.6
Hd-24	213	0.7	0.9	4.8	0.1	0.9	13.1	30.7	124.9	2.3	0.2	2.1
Hd-21	96	0.8	0.9	2.4	0.3	1.3	5.1	30.4	4.4	2.0	1.3	0.6
Hd-18	89	1.1	1.2	2.1	0.3	0.7	2.1	29.6	4.3	2.0	1.3	0.6
Hd-17	39	0.9	0.8	1.8	0.3	0.6	2.0	28.1	39.4	1.6	0.0	1.6
Hd-16	67	1.0	1.3	2.8	0.3	1.6	5.8	29.6	13.6	1.8	0.7	1.1
Hd-14	685	1.1	0.9	1.3	0.8	1.6	1.9	33.4	82.1	2.8	0.9	1.9
Hd-12	159	1.2	1.0	1.5	0.7	1.6	2.2	32.0	44.4	2.2	0.6	1.6
Hd-11	157	1.3	1.0	1.8	0.4	1.1	2.5	27.4	74.0	2.2	0.3	1.9
Hd-9A	1060	1.2	1.0	2.1	0.4	2.5	5.9	26.1	30.9	3.0	1.5	1.5
Hd-7	408	1.0	1.1	2.2	0.4	2.1	4.8	32.0	23.3	2.6	1.2	1.4
Hd-5	99	1.0	1.2	2.3	0.4	3.1	7.4	33.4	25.0	2.0	0.6	1.4
Hd-4	522	1.0	1.0	2.1	0.5	2.0	4.2	31.1	83.8	2.7	0.8	1.9
Hd-2	395	1.0	1.1	1.5	0.5	0.6	1.2	31.2	42.6	2.6	1.0	1.6
Hd-1	312	1.1	1.0	2.1	0.4	2.2	5.1	28.6	38.3	2.5	0.9	1.6
HH-51	180	1.1	1.1	2.3	0.4	2.5	6.8	25.8	52.8	2.3	0.5	1.7
HH-50	542	1.1	1.1	2.8	0.3	2.9	10.3	24.8	7.9	2.7	1.8	0.9
HH-49	6	1.2	1.0	1.8	0.7	1.2	1.7	45.9	44.0	0.8	-0.9	1.6
HH-48	184	1.3	0.8	2.8	0.3	1.6	6.1	25.8	18.8	2.3	1.0	1.3
HH-47-4	212	1.3	1.0	2.5	0.3	1.4	4.7	30.8	61.1	2.3	0.5	1.8
HH-47-3	343	1.2	1.0	2.8	0.3	1.5	5.1	31.1	59.6	2.5	0.8	1.8
HH-47-2	426	1.2	1.0	2.7	0.3	1.3	4.2	33.5	30.8	2.6	1.1	1.5
HH-47-1	276	1.2	1.1	2.6	0.3	1.4	4.5	31.0	36.5	2.4	0.9	1.6
HH-46	77	1.2	1.0	2.6	0.4	1.5	4.3	30.4	23.4	1.9	0.5	1.4
HH-40	36	1.2	1.2	2.7	0.4	4.7	13.0	29.2	129.4	1.6	-0.6	2.1
HH-39-4	19	1.0	0.9	1.7	0.6	2.8	4.4	39.5	38.1	1.3	-0.3	1.6
HH-39-3	35	1.0	0.8	1.4	0.7	2.4	3.4	30.3	78.1	1.5	-0.3	1.9
HH-39-2	84	1.0	1.4	1.7	0.6	2.0	3.4	29.6	22.9	1.9	0.6	1.4
HH-39-1	89	1.0	1.2	2.2	0.5	1.9	3.6	24.6	26.2	1.9	0.5	1.4
HH-37	44	1.1	1.4	2.3	0.5	7.3	14.8	30.2	14.7	1.6	0.5	1.2
HH-36	65	1.0	1.0	2.2	0.5	3.0	6.4	29.9	16.4	1.8	0.6	1.2
HH-35	70	1.1	1.1	1.9	0.6	1.7	2.6	33.2	3.9	1.8	1.3	0.6
HH-34	50	0.9	1.1	1.3	1.2	2.4	2.0	47.1	14.3	1.7	0.5	1.2

HH-33	6	1.1	0.9	1.4	0.9	2.4	2.6	104.2	34.1	0.8	-0.8	1.5
HH-32	66	1.0	1.0	3.1	0.3	6.6	22.5	29.7	10.6	1.8	0.8	1.0
HH-30	283	1.0	1.0	2.5	0.4	3.5	9.1	32.4	5.1	2.5	1.7	0.7
HH-29	369	1.1	1.0	2.4	0.4	3.0	7.8	28.9	5.6	2.6	1.8	0.7
HH-28	481	1.0	1.0	2.1	0.5	2.7	5.7	30.3	10.0	2.7	1.7	1.0
HH-27	692	1.0	1.0	2.6	0.3	5.8	19.0	27.7	10.0	2.8	1.8	1.0
HH-26	645	0.9	1.0	2.5	0.4	6.3	16.6	30.0	10.4	2.8	1.8	1.0

NO.	Li	Be	Sc	Ti	V	Co	Ni	Cu	Zn	Ga	Rb	Zr	Nb	Mo	Sn	Cs	Ba	Hf	Ta	Pb	U
HP-32-2	4.98	0.69	0.28	36	2.13	0.33	0.57	0.9	19.9	0.74	1.05	0.82	0.08	0.04	0.88	0.09	1044	0.03	0.00	17.1	1.60
HP-32-3	5.17	1.82	0.17	22	1.59	0.04		0.5	18.4	0.44	0.13	0.28		0.12	1.49	0.02	531			13.6	0.97
HP-32-4	5.45	1.85	0.24	20	2.17	0.07		0.4	15.3	0.46	0.06	0.27	0.00	0.20	0.80	0.01	583		0.00	15.0	1.12
HP-31	6.25	0.93	2.09	158	5.98	0.81	7.58	11.9	29.4	7.38	15.32	21.15	0.58	0.18	1.43	0.49	485	0.41	0.06	9.5	7.15
HL-30	5.72	1.74	2.12	74	3.01	0.35	0.74	1.1	18.6	3.06	3.89	4.29	0.31	0.11	0.92	0.25	661	0.01	0.05	14.0	4.82
HP-27	4.77	0.55	1.17	134	2.55	0.37	1.64	3.7	19.8	3.40	4.27	4.74	0.39		0.07	0.22	293	0.08	0.02	5.7	5.31
HP-13	2.41	0.07	0.02	17	0.34	0.11	1.00	1.7	41.2	0.77	0.38	0.24	0.02	0.02	1.93	0.03	449			0.9	0.12
HP-12	4.68	1.18	0.52	47	12.68	0.26	7.61	17.8	47.5	0.88	4.08	1.17	0.17	0.33	1.14	0.03	454	0.08	0.02	15.3	0.27
HP-11	3.00	2.18	0.13	15	10.33	0.12	0.38	12.5	43.4	0.52	0.03	0.16	0.01	0.11	1.06	0.01	385	0.00		12.4	0.73
HP-10	4.43	1.16	0.76	58	40.37	0.29	1.04	11.3	21.2	1.59	1.77	1.50	0.19	0.35	1.25	0.08	588	0.01	0.04	12.6	0.74
HP-9	6.00	1.32	0.42	87	9.20	0.36	14.34	13.3	36.1	0.79	5.56	1.71	0.31	0.11	1.61	0.04	538	0.06	0.03	17.2	0.44
HP-7	3.80	0.71	0.54	118	1.99	0.32	0.70	1.0	30.2	1.79	2.69	2.82	0.46	0.02	1.37	0.09	254	0.04	0.02	4.8	0.97
HP-5	4.28	0.97	1.75	185	9.27	0.54	30.48	37.6	59.4	3.74	10.45	5.01	0.48	0.24	2.09	0.17	348	0.17	0.03	21.3	1.44
HP-4	4.33	1.52	1.00	99	5.01	0.28	8.65	12.3	55.2	2.01	4.76	3.33	0.24	0.21	1.45	0.14	319	0.08	0.01	13.9	0.37
HPP-1'	18.64	0.92	0.64	52	16.93	3.16	22.60	14.1	42.7	2.23	2.64	1.80	0.13	0.90	0.84	0.03	481	0.04	0.01	16.0	0.34
Hm-7	7.43	0.44	0.16	33	0.19	0.03	4.20	4.0	29.1	0.48	0.84	0.37	0.10		1.02	0.05	140			0.9	0.60
Hm-6	11.13	1.83	2.39	235	4.68	1.80	26.15	42.4	48.6	5.63	9.48	5.38	0.73	0.57	1.68	0.23	1373	0.15	0.05	10.8	22.31
Hm-5	6.15	0.66	0.38	169	2.06	0.30	5.81	10.9	70.6	1.78	5.06	2.69	0.49	0.06	1.45	0.19	293	0.05	0.04	4.7	8.94
Hm-1	13.94	0.13	0.59	236	4.76	0.52	11.03	19.4	61.8	1.77	11.50	4.24	0.98	1.25	1.48	0.30	85	0.09	0.08	14.3	8.01
Hg-42	4.71	0.95	0.20	17	0.05	0.00	0.99	0.9	14.4	0.44	0.20	0.13	0.01		1.21		292			1.0	5.41
Hg-40-4	7.83	0.70	1.03	229	4.13	0.82	6.81	2.4	51.9	5.59	4.98	2.03	0.78	0.13	1.17	0.27	1997	0.02	0.04	9.7	28.50
Hg-40-3	8.15	0.50	0.59	207	2.44	0.84	12.20	2.7	49.3	5.00	2.94	1.70	0.56	0.14	0.29	0.11	1480	0.07	0.05	7.7	30.11
Hg-40-2	6.41	0.66	0.93	85	1.90	0.71	7.73	2.3	44.2	3.48	3.39	2.12	0.32	0.07	0.35	0.19	2044	0.02	0.04	6.0	22.39

Hg-40-1	7.33	0.39	0.80	165	3.15	0.85	10.41	2.7	48.0	4.68	4.13	16.55	0.58		0.51	0.24	500	0.28	0.05	7.8	39.26
Hg-33	8.33	0.39	0.38	44	7.97	0.83	4.39	7.2	35.0	2.22	1.75	0.68	0.14	0.06	1.55	0.44	285	0.02	0.00	8.2	0.49
Hg-31	5.29	0.43	0.36	48	0.95	0.54	1.50	1.0	72.7	1.28	1.64	0.96	0.10	0.04	1.06	0.10	149	0.01	0.03	5.4	0.46
Hg-25	20.82	0.50	0.60	138	10.81	0.65	5.63	14.1	44.8	2.47	6.71	1.71	0.38	0.28	2.19	0.31	186	0.04	0.05	19.9	0.97
Hg-22	3.23	0.14	0.46	27	0.64	2.53	4.28	7.2	44.5	5.63	0.90	3.77	0.04	0.22	1.64	0.02	17	0.06	0.00	5.9	5.46
Hg-21	6.38	0.93	0.53	36	2.75	0.22	0.49	5.9	25.5	2.08	0.89	1.31	0.04	0.15	1.35	0.15	213		0.01	18.8	0.90
Hg-18	7.14	0.82	0.84	76	3.40	0.51	4.09	3.8	34.2	3.85	5.08	2.05	0.20	0.10	1.17	0.27	241	0.03	0.02	7.1	7.30
Hg-17	8.61	0.68	1.16	54	2.87	0.51	8.85	12.8	24.6	2.43	4.15	13.17	0.16	1.38	0.36	0.11	757	0.20	0.01	15.1	2.88
Hg-16	52.35	0.28	0.21	23	0.28	0.18	0.14	1.1	31.6	1.15	0.41	0.27	0.03	0.11	1.55	0.01	106	0.03	0.00	4.5	1.88
Hg-12	10.21	0.57	0.29	76	0.65	0.11	1.22	3.6	53.6	1.01	0.98	0.43	0.20	0.17	0.73	0.05	185		0.02	6.5	0.71
Hg-10	7.24	0.39	0.68	35	0.61	0.80	6.97	7.3	30.5	2.99	2.23	0.94	0.14	0.13	1.19	0.02	34		0.01	7.2	5.72
Hg-9	8.85	1.89	0.34	31	1.03	0.23	7.10	11.1	55.0	1.10	1.67	0.44	0.03	0.58	1.33	0.04	473	0.02	0.00	14.0	1.73
Hg-4	10.10	0.51	1.32	55	3.96	0.40	4.93	8.3	31.0	2.20	2.90	3.46	0.28	0.24	1.80	0.13	10698	0.03	0.02	8.6	77.44
Hg-3	5.80	1.31	1.06	92	2.67	1.36	10.64	9.4	42.5	3.11	3.52	1.60	0.19	0.63	1.35	0.12	1090	0.03	0.01	22.1	4.38
Hg-1	6.05	0.56	1.87	88	3.15	1.37	11.24	12.1	27.6	11.42	5.50	3.13	0.23		0.52	0.19	1521	0.09	0.02	23.0	12.23
Hd-64	6.57	1.22	0.74	70	4.90	0.82	2.62	16.4	25.3	2.41	6.09	0.91	0.25	0.49	0.97	0.33	561	0.01	0.02	12.5	7.57
Hd-59	4.69	0.63	0.17	14	0.06	0.07	0.59	0.5	51.1	0.59	0.14	0.05		0.05	0.63	0.02	116	0.01		3.3	1.93
Hd-57	5.91	1.10	0.31	34	1.23	0.19	1.19	2.0	17.8	0.69	1.29	0.25	0.11	0.13	1.31	0.03	514	0.01	0.02	4.2	1.05
Hd-52	5.56	0.33	0.15	44	0.96	0.26	1.63	1.8	43.6	1.25	1.94	0.63	0.16	0.09	0.92	0.09	122	0.00	0.03	6.0	1.87
Hd-47	16.06	0.26	0.24	67	2.30	0.44	2.44	2.6	34.1	1.53	2.77	1.04	0.22	0.05	0.85	0.08	95	0.03	0.00	3.1	2.56
Hd-46	6.08	0.81	0.06	18	1.43	0.15	1.75	12.6	27.3	0.63	0.82	0.20	0.01	0.22	0.85	0.03	168		0.01	10.2	2.17
Hd-24	4.74	1.57	0.08	15	0.17	0.07	0.11	0.9	24.2	0.76	0.21	0.15		0.12	0.36	0.04	272			9.2	1.68
Hd-21	7.42	1.21	0.05	23	0.39	0.06	0.64	1.4	26.7	0.52	0.38	0.10	0.01	0.24	1.10	0.01	130	0.02		11.1	1.05
Hd-18	7.19	0.28	0.72	35	0.40	0.13	0.61	0.8	45.1	0.54	0.77	0.41	0.07		0.73	0.05	48			3.7	0.94
Hd-17	6.64	0.72	0.34	15	0.83	0.06	0.27	0.3	14.8	0.38	0.08	0.22		0.16	0.81	0.03	586			9.9	1.61
Hd-16	7.30	0.33	0.26	15	0.46	0.14	0.85	0.8	20.5	0.46	1.18	0.16	0.01		0.92	0.12	61	0.01	0.00	2.4	0.28
Hd-14	9.58	0.15	0.59	36	0.64	0.20	0.98	0.6	96.6	2.67	1.06	0.61	0.06	0.09	1.23	0.05	40	0.01	0.01	1.8	25.29
Hd-12	14.68	0.02	0.33	23	0.39	0.26	0.60	0.6	26.4	0.87	0.37	0.64	0.04	0.01	0.75	0.03	84		0.00	2.0	20.46
Hd-11	5.98	1.15	0.56	14	0.17	0.68	0.32	1.4	24.7	0.69	0.16	0.54	0.00	0.06	0.73	0.01	282	0.02		5.4	4.93
Hd-9A	8.25	0.22	0.54	101	2.98	0.70	1.46	4.2	18.0	4.66	4.75	1.15	0.48	0.07	1.24	0.29	119	0.06	0.07	3.3	24.27
Hd-7	10.36	0.23	0.29	22	0.22	0.12	1.24	2.8	34.5	1.34	0.60	0.40	0.05		1.60	0.02	99	0.01	0.00	2.1	7.37
Hd-5	5.92	0.43	0.02	23	0.12	0.09	1.46	4.4	25.0	0.64	0.68	0.41	0.00	0.02	1.05	0.01	113	0.01	0.01	2.8	8.10
Hd-4	7.72	0.01	0.16	42	0.74	0.42	1.56	6.3	46.7	2.37	1.31	0.42	0.12	0.06	1.04	0.03	122	0.02	0.01	1.5	13.28

Hd-2	5.72	0.97	1.46	30	0.58	4.05	1.76	2.7	14.0	1.41	1.48	1.20	0.13	0.13	1.18	0.05	544	0.01	0.01	7.3	8.33
Hd-1	10.86	0.18	0.14	35	0.20	0.19		8.4	148.4	1.29	0.33	0.27	0.04		0.42	0.03	48		0.01	1.1	7.46
HH-51	6.56	0.22		25	0.14	0.42	0.27	1.1	39.1	0.79	0.14	0.11	0.07	0.02	0.57	0.13	96		0.00	0.6	4.53
HH-50	11.55	0.06	0.28	38	0.27	0.08	0.63	1.4	83.5	2.27	0.62	0.47	0.10	0.04	0.93	0.01	69		0.02	2.9	6.17
HH-49	5.48	0.20	0.10	15	0.01	0.02	0.21	0.1	15.2	0.34	0.02	0.01	0.00		1.45		195			0.3	0.26
HH-48	4.50	0.24	0.15	24	0.13	0.16	4.39	5.6	21.5	1.02	0.65	0.12	0.03	0.03	1.28	0.01	91	0.02		1.0	2.95
HH-47-4	13.48	0.26	0.16	30	0.21	0.08	0.31	0.4	29.7	1.03	0.32	0.25	0.05	0.03	1.21	0.02	72			0.4	2.44
HH-47-3	14.90	0.15	0.25	27	0.21	0.05	0.22	0.3	27.8	1.50	0.20	0.40	0.04	0.03	0.69	0.02	78	0.01		0.4	5.79
HH-47-2	14.12	0.14	0.27	27	0.26		0.35	0.5	26.5	1.46	0.07	0.75	0.04	0.03	0.92	0.02	68	0.02		0.6	10.58
HH-47-1	14.18	0.13	0.35	30	0.29	0.08	0.57	0.5	26.8	1.20	0.14	0.42	0.03	0.07	0.85	0.03	58		0.00	0.7	6.71
HH-46	5.82	0.46	0.21	20	0.03	0.02	0.32	0.5	41.0	0.45	0.09	0.04	0.06		1.24	0.01	164		0.00	0.7	1.09
HH-40	4.77	0.29		11	0.07	0.04	0.26	0.1	48.9	0.33	0.00	0.02			2.72	0.03	63			0.2	0.72
HH-39-4	4.23	1.43	0.06	11	0.14	0.32	0.79	1.5	23.9	0.20	0.12	0.02	0.01	0.10	3.48	0.03	469			2.7	1.07
HH-39-3	4.10	0.97	0.04	10	0.07	0.10	0.50	0.5	22.7	0.47		0.07		0.07	3.49	0.03	491			1.4	1.52
HH-39-2	4.57	0.86	0.24	13	0.29	0.26	1.24	2.5	29.4	0.68	0.29	0.10	0.02	0.34	4.72		443		0.00	3.4	4.21
HH-39-1	4.35	0.76	0.18	15	0.48	0.35	1.46	2.8	35.0	0.81	0.54	0.22	0.05	0.63	9.42	0.06	424		0.01	3.4	5.16
HH-37	11.59	0.05	0.10	14	0.10	0.03		0.2	30.8	0.52	0.10	0.03		0.02	2.61		57		0.00	0.6	1.77
HH-36	6.06	0.81	0.06	10	0.17	0.04	0.27	0.9	33.0	0.58	0.08	0.07	0.00	0.19	2.06	0.01	266		0.00	1.0	6.21
HH-35	7.37	0.14	0.04	12	0.09	0.07	0.33	0.5	21.1	0.56	0.09	0.34	0.00		2.25		75	0.02		1.8	7.90
HH-34	6.25	0.35	0.06	16	0.09	0.02	0.75	0.6	47.6	0.54	0.08	0.16		0.03	3.84		101		0.01	1.3	12.13
HH-33	5.96	0.26		12	0.07	0.01	0.06	0.2	23.1	0.32	0.05				2.56	0.02	109			0.9	0.52
HH-32	7.16	0.26	0.17	11	0.17	0.04	0.10	0.7	30.4	0.54	0.03	0.18		0.02	2.70		34			0.6	10.84
HH-30	6.40	0.95		12	0.91	0.04	0.55	0.6	22.7	1.19	0.12	0.04	0.02		2.22		189	0.01	0.00	1.8	97.72
HH-29	6.25	0.92	0.07	20	0.53	0.04	0.24	0.4	19.6	1.70	0.30	0.30	0.04	0.10	1.37	0.04	248	0.01	0.00	2.8	72.13
HH-28	6.20	1.07	0.38	25	1.05	0.22	0.30	1.6	26.0	1.60	0.47	0.38	0.03	0.33	2.56		334	0.01	0.01	2.7	105.15
HH-27	16.17	0.22	0.17	16	0.53	0.18	5.70	3.7	62.2	2.79	0.66	0.71	0.02	0.08	1.90	0.05	214			3.2	59.92
HH-26	5.06	0.37	0.08	37	0.56	0.07	1.26	1.1	20.0	2.60	0.76	0.30	0.08	0.03	2.07	0.04	189	0.01	0.01	2.2	100.96

Notes: * Lithology of host rocks of conodonts. All elemental concentrations are in ppm. L. = Limestone; N. L. = Nodular limestone; Muddy limestone = M. L.

Table 4. Pearson correlation coefficients of various elements to percent clay content

Whole rock	r	Conodonts	r
Li	0.86	Li	0.00
Be	0.89	Be	0.11
Sc	0.88	B	0.46
Ti	0.89	Na ₂ O	0.12
V	0.84	MgO	0.24
Cr	0.89	Al ₂ O ₃	0.56
Mn	-0.01	SiO ₂	0.56
Co	0.84	P ₂ O ₅	-0.19
Ni	0.87	K ₂ O	0.42
Cu	0.06	CaO	0.00
Zn	0.77	Sc	0.67
Ga	0.92	TiO ₂	0.54
Rb	0.90	V	0.09
Sr	-0.51	Cr	0.35
Y	0.78	MnO	0.04
Zr	0.87	FeO	0.20
Nb	0.84	Co	0.32
Mo	-0.35	Ni	0.48
Sn	0.93	Cu	0.39
Cs	0.84	Zn	0.06
Ba	0.44	Ga	0.87
La	0.86	Ge	0.86
Ce	0.82	Rb	0.53
Pr	0.82	Sr	-0.08
Nd	0.79	Y	0.86
Sm	0.74	Zr	0.46
Eu	0.74	Nb	0.50
Gd	0.74	Mo	0.05
Tb	0.73	Ag	0.36
Dy	0.75	Cd	0.03
Ho	0.74	Sn	-0.15
Er	0.76	Sb	0.11
Tm	0.77	Cs	0.48
Yb	0.78	Ba	0.15
Lu	0.81	La	0.77
∑REE	0.82	Ce	0.84
Hf	0.89	Pr	0.84
Ta	0.87	Nd	0.88
Tl	0.89	Sm	0.89
Pb	0.47	Eu	0.84
Th	1.00	Gd	0.88
clays%	1.00	Tb	0.87
carb%	-1.00	Dy	0.88

U	0.13	Ho	0.87
LREE	0.83	Er	0.86
$\log(\sum \text{REE}/\text{Th})$	-0.34	Tm	0.82
		Yb	0.73
		Lu	0.69
		Hf	0.51
		Ta	0.42
		W	0.36
		Bi	0.00
		Pb	0.34
		Th	1.00
		U	0.27
		$\sum \text{REE}$	0.88
		LREE	0.86
		Ti	0.54

Notes: Percent clay content is proxied by Th/Th^* , where Th^* is the average concentration in the upper continental crust (10.7 ppm; McLennan, 2001).

Table 5. Average elemental concentrations of whole-rock and conodont samples from Ordovician and Triassic rocks, and of modern seawater

	Seawater	Whole rock (Ordovician)	Conodonts (Ordovician)	Conodont / Whole rock (Ordovician)	Whole rock (Triassic)	Conodonts (Triassic)	Conodont / Whole rock (Triassic)
Li	0.18	10.27	6.25	0.61			
Be	6.00E-07	0.73	0.56	0.77			
B	4.4		7.11				
Na ₂ O	1.08		0.6				
MgO	0.129		0.11				
Al ₂ O ₃	4.00E-08		0.05				
SiO ₂	2.00E-04		0.44				
P ₂ O ₅	0.06		40.9				
K ₂ O	0.038		0.04				
CaO	0.0412		53				
Sc	6.00E-07	4.42	0.29	0.07			
TiO ₂	1.00E-07	0.16	0.01	0.03			
V	0.002	22.34	0.65	0.03			
Cr	3.00E-04	16.49	1.1	0.07			
MnO	3.00E-05	0.23	0.0035	0.01			
FeO	5.50E-09		0.08				
Co	3.00E-06	6.2	0.22	0.04	10.26	0.039	0.0038
Ni	4.80E-04	13.33	1.19	0.09	10.54	0.28	0.03
Cu	1.00E-04	9.05	2.33	0.26	11.84		
Zn	5.00E-04	24.55	30.5	1.24	29.41		
Ga	2.00E-06	4.68	1.25	0.27	5.16		
Ge	5.00E-06		0.45				
As	0.002		0				
Rb	0.12	36.1	0.82	0.02	29.2	0.26	0.01
Sr	8	286	10220	35.77	259.6	1467.5	5.65
Y	1.00E-06	12.5	36.4	2.92	15.2	72.7	4.78
Zr	3.00E-05	29.6	0.43	0.01			
Nb	1.00E-05	3.97	0.06	0.02			
Mo	0.01	0.24	0.08	0.32			
Ag	2.00E-06		0.14				
Cd	1.00E-04		0.02				
Sn	6.00E-07	0.81	1.23	1.51			
Sb	2.00E-04		0.09				
Cs	4.00E-04	1.9	0.04	0.02			
Ba	0.02	247.5	240.8	0.97	105.3	22.1	0.21
La	2.79E-07	14.77	23.27	1.58	15.17	15.02	0.99
Ce	2.84E-08	29.35	86.03	2.93	29.74	51.95	1.75
Pr	3.62E-08	3.42	12.22	3.58	3.57	11.69	3.28
Nd	1.65E-07	13.11	61.83	4.72	14.21	80.65	5.68
Sm	3.00E-08	2.72	15.04	5.52	3.33	45.69	13.72
Eu	8.20E-09	0.53	3.18	5.96	0.76	10.79	14.17
Gd	4.34E-08	2.44	14.59	5.99	3.19	50.03	15.71
Tb	7.10E-09	0.37	1.53	4.12	0.47	5.17	11.0517

Dy	5.16E-08	2.1	8.01	3.81	2.56	19.21	7.5
Ho	1.42E-08	0.4	1.16	2.87	0.47	2.48	5.25
Er	4.75E-08	1.13	2.66	2.34	1.25	4.35	3.49
Tm	7.30E-09	0.17	0.2	1.19	0.18	0.3	1.67
Yb	4.84E-08	1.04	1.1	1.06	1.09	1.11	1.02
Lu	8.30E-09	0.15	0.11	0.73	0.15	0.11	0.69
Hf	7.00E-06	0.8	0.01	0.01	1.17		
Ta	2.00E-06	0.28	0.01	0.02	0.36		
W	1.00E-04		0.03				
Tl					0.18		
Bi	2.00E-05		0.01				
Pb	2.00E-06	10.4	4.7	0.45	4.84	1.86	0.38
Th	1.00E-05	4.59	13.07	2.84	3.41	6.86	2.01
U	0.0032	1.46	4.38	3	1.27	1.23	0.97
ΣREE	8.00E-07	71.71	216.3	3.02	76.6	343.6	4.49

Notes: Triassic data are from Chen et al. (2015) and seawater data from Nozaki et al. (2001). Major element oxides are in percent, REEs and trace elements in ppm.