SHATSKY RISE EVIDENCES SUPPORT HYPOTHESIS THAT BOTH A BOLIDE (ASTEROID OR COMET) IMPACT (BI) AND DECCAN TRAP FLOODINGS (DT) CAUSED CRETACEOUS/TERTIARY (K/T) EXTINCTIONS AND NOT HYPOTHESIS OF EITHER BI OR DT, ALONE II; R.A. Schmitt[1-4], Y.-G. Liu[1,2], and R.J. Walker[1,3], [1]The Radiation Center and Departments of [2]Chemistry and [3]Geosciences, and [4]College of Oceanography, Oregon State University, Corvallis, Oregon 97331

Interpretation of the data presented in our companion paper [1] suggests that extinction phenomena associated with the Cretaceous/Tertiary (K/T) boundary are the result of both terrestrial volcanism and extraterrestrial impact of either asteroid(s) or comet(s). The identification of eight trace element abundance peaks before, coincident with, and following the now famous Ir peak [2] at the K/T boundary in Shatsky Rise (SR) carbonates (DSDP holes 577 and 577B) suggest that more than one process was operable during this time. The evidence for an extraterrestrial impact is strongly supported at SR and world-wide not only by the anomalous abundance of Ir and the C1-like ratios of nine other siderophile elements at selected K/T sites but also the presence of shocked mineral grains [3] and carbonaceous soot attributed to global wild fires [4], and other evidences [5].

We propose that the bolide impact [2] was important to the K/T extinctions in an ancillary role, within the larger framework of the eruption of the Deccan Trap (DT) continental flood basalts of western India. The trace element peaks, illustrated in [1] at 66.6, 66.4 (K/T), 66.1, and the five peaks between 65.3 and 65.1 Ma represent the chemical signature caused by the periodic eruptions of the Deccan Traps. Rather than depict all ≥26 major and trace elements analyzed [e.g. 6] for each sample in this study, we have selected Al, Hf, Ta, Th, Rb, Cs, Ir, La, and the parameter Ce^{A*} (Ce anomaly) as representative. For the SR carbonate samples, the elements Al, Hf, Ta, Th, Rb, and Cs indicate the detrital clay component; Ir indicates the bolide contribution; while La and Ce^{A*} indicate the rare earth element (REE) content and the pH/P_{CO_2} conditions of the seawater, respectively.

Accompanying the eruption of the Deccan Trap basalts would have been large amounts of CO_2, SO_2, and basaltic ash. The volume of basalt present today suggests that individual eruptions must have expelled tremendous quantities of these "minor" constituents. Their effects on the atmosphere, hydrosphere, and biosphere while very significant cannot be fully appreciated at this point in time. This would presumably include greatly enhanced continental weathering through the effects of acid

Al, Hf, Ta, and Th normalized abundances (Al = 100%) in tholeiitic basalts, composite shales, and Pacific carbonates[a]

	Al(%)	Hf(ppm)	Ta(ppm)	Th(ppm)
N.A.S.C. (North American	(9.0)	(6.3)	(1.1)	(12)
Shale Composite)	≡100	70	12	133
DT (Deccan Trap Basalts)[b]	(8±1) 100	52±13	8±3	26±13
CRB (Columbia River Basalt)	(7) 100	60	10	42±6
S.R. (Shatsky Rise) carbonates[c]				
+ 1.0 Ma	(1.39) 100	48	9	143
+ 3.5	(0.57) 100	49	10	181
+ 4.5	(2.11) 100	51	11	184
+ 59	(0.16) 100	75	13	211
+ 61.1	(0.057) 100	70	-	158
+ 63.1	(0.073) 100	73	16	193
Δ 65.0 (after 5 peaks at +1.2 Ma)	(0.26) 100	70	12	190
Δ 65.2 (avg in 5 peaks at +1.2 Ma)	(0.36) 100	84	13	160
+ 65.2	(0.50) 100	74	6	176
Δ 65.4 (before 5 peaks at +1.2 Ma)	(0.24) 100	52	12	138
+ 65.6	(0.14) 100	85	10	131
+ 65.8	(0.076) 100	89	8	125
+ 66.1	(0.121) 100	60	9	116
Δ 66.1 (+0.3 Ma peak)[d]	-	(0.13) 70	13[e]	183
+ 66.2 (after K/T peak)	(0.068) 100	76	4	101
+ 66.3 (after K/T peak)	(0.058) 100	74	-	47
+ 66.4 (K/T peak)	(0.28) 100	60	10	110
Δ 66.4 (K/T peak)	(0.24) 100	80	12	130
Δ 66.5 (before K/T peak)	(0.085) 100	47	8	71
+ 66.5 (before K/T peak)	(0.081) 100	53	6	74
Δ 66.6 (after -0.2 Ma peak)	(0.16) 100	63	11	116
Δ 66.6 (-0.2 Ma peak)	(0.58) 100	57	13	128
Δ 66.6 (before -0.2 Ma peak)	(0.11) 100	64	7	95
+ 66.6_5	(0.061) 100	70	-	92
+ 66.8_3	(0.063) 100	76	11	102
+ 67.0_0	(0.061) 100	110	7	210
+ 67.1_5	(0.072) 100	53	4	96
Hole 316 carbonates				
70-76	(0.74) 100	51	16	93
55-65	(0.40) 100	41	11	99
<1-35	(0.23) 100	78	6	52
Laytonville limestones				
93-97	(0.13) 100	54	15	60

[a] Absolute abundances in ( ) are given for N.A.S.C. for Al, Hf, Ta, and Th; absolute abundances in ( ) are given for Al in other sample groups; i.e. wt% of Al in bulk samples.
[b] Estimated avg abundances in six basaltic regions (A.V. Murali, priv. comm., 1990.)
[c] + values are from Hole 577; Δ values are from Hole 577B; they are ~60 m apart.
[d] Al was not measured in +0.3 Ma peak carbonates. Observed avg Hf abundances of 0.13 ppm were normalized to 70, the normalized value in N.A.S.C. relative to Al.
[e] Higher average Ta abundances of 0.061±0.028 ppb in three peak carbonates from Hole 577A were ignored because of possible Ta contamination from the drill coring. Lower and consistent Ta abundances of 0.024±0.003 ppb were founed in three peak carbonates from Hole 577B. The latter average Ta was considered "least" contaminated.

rain and disrupted atmospheric patterns due to the presence of voluminous volcanic gases and ash. We interpret the trace element peaks in the SR carbonates as evidence for these events.

Acidic conditions resulting from the elevated CO_2 and SO_2 concentrations in the atmosphere would have accelerated the weathering of continental materials and increased the dissolved load of fluvial systems world wide. The enhanced abundance of La (representative of the other REE) in the peaks suggests that the REE content of seawater was higher than during normal conditions. In conjunction with a more dynamic weathering environment, the elevated abundances of Al, Hf, Ta, Th, (Rb, and Cs) support the hypothesis that atmospheric conditions were such that increased amounts of N.A.S.C.-like fine detrital material from the continents was transported to the central portions of the oceans by eolian processes. The S.R. at K/T was at ~12°N and ~170°W in the central Pacific ocean [7].

The single Ir peak at K/T [2] suggests that the bolide(s) impact was coincidental with the volcanic events. Further support may be found in the lack of Ir anomalies associated with other Phanerozoic extinctions [e.g. 8] and D.T. flood basalts [9]. The chemical evidence at S.R. is equivocal with regard to the trace element peak at the K/T boundary. Clearly the lack of an Ir peak associated with the trace element peaks at 66.6, 66.1, and the five peaks in the broad region from 65.3 to 65.1 Ma suggests that these peaks were not caused by impacts. Assuming a sedimentation rate of $10m/10^6a$ before K/T [10], we calculate that the enrichments of Ir in the sedimentary carbonates at K/T (66.4 Ma) occurred ~30 ka before the enrichments of Th. It seems more probable that a bolide impact triggered an eruption of the DTs at K/T than that the Ir peak was simply overprinted upon an eruptive episode. Assuming a 10-km diameter asteroid impact on the earth every 50 Ma [11], a significant probability of 0.02 is obtained for such a random bolide impact at K/T time between the natural DT eruptions at -0.2 Ma (66.6 Ma) and +1.2 Ma (65.2 Ma). The extremely low Ir abundance of ~0.007 ppb in the DTs rules out the DTs as the source for Ir in the K/T peak [9].

We [12] have demonstrated the correlation of the Ce^{A*} with changes in seawater pH and by extrapolation global P_{CO_2} changes. The rise in the Ce^{A*} associated with the individual trace element peaks supports the conclusion that emissions of CO_2 and SO_2 associated with DT eruptions created more acidic conditions in the atmosphere and hydrosphere. The broad elevated plateau of the Ce^{A*} from 65.5 to 64.7 Ma suggests that this time period may have been the main eruptive stage of the DTs. This is indirectly supported by $^{40}Ar/^{39}Ar$ dating of DT basalts (72-59 Ma) at various stratigraphic levels [9].

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