AGU PUBLICATIONS

AGU Advances

Supporting Information for

The Chicxulub Impact Produced a Powerful Global Tsunami

Molly M. Range[*1], Brian K. Arbic[1,2,3], Brandon C. Johnson[4,5], Theodore C. Moore[1], Vasily Titov[6], Alistair J. Adcroft[7], Joseph K. Ansong[1,8], Christopher J. Hollis[9], Jeroen Ritsema[1], Christopher R. Scotese[10], and He Wang[1,11,12]

[1]Department of Earth and Environmental Sciences, University of Michigan, Ann Arbor, MI, USA
[2]Institut des Géosciences de L'Environnement (IGE, Recently on sabbatical), Grenoble, France
[3]Laboratoire des Etudes en Géophysique et Océanographie Spatiale (LEGOS, Recently on sabbatical), Toulouse, France
[4]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN, USA
[5]Department of Physics and Astronomy, Purdue University, West Lafayette, IN, USA
[6]National Oceanic and Atmospheric Administration, Pacific Marine Environmental Lab, Seattle, WA, USA
[7]Atmospheric and Oceanic Sciences Program, Princeton University, Princeton, NJ, USA
[8]Department of Mathematics, University of Ghana, Legon, Accra, Ghana
[9]School of Geography, Environment and Earth Sciences, Victoria University of Wellington, New Zealand
[10]PALEOMAP Project, Evanston, IL, USA
[11]National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA
[12]University Corporation for Atmospheric Research, Boulder, CO, USA

Contents of this file

Additional Supporting Information (Files uploaded separately)

Tables S5 and S6
Movies S1-S4

Introduction

In this file and in related Supporting Information, we include results of the hydrocode simulation and the shallow water ocean model simulations run with parameters different from those of the 'fiducial' runs. For instance, we display results from MOM6 simulations with coarser grid spacing (1/5°) than the 1/10° grid spacing in the fiducial run, and discuss sensitivities to handoff times and other parameters of our coupled hydrocode/shallow-water code simulations. We also include descriptions of the construction of paleo-bathymetries, the paleobathymetry near the impact site, the importance of vaporization in hydrocode modeling, the procedure for blending hydrocode results with the paleo-bathymetry to produce initial conditions for the shallow-water model, the sensitivities of the shallow-water model to different aspects of the handoff from the hydrocode (e.g., the presence or absence of a rim wave, amongst other aspects), and the comparison of energies in the impact tsunami with energies in recent historical tsunamis. Finally, we include four movies: two of the iSALE hydrocode simulation over the first ten minutes of the impact, and one animation each of the MOM6 and MOST shallow-water simulation showing the tsunami propagation throughout the global ocean.

Text S1.

Development of paleobathymetry and initial conditions

The paleobathymetry was created by merging two datasets. Müller et al. (2008) uses a basin-age depth relation to create a deep-ocean bathymetric product. Basin age-depth relationship (Schroeder, 1984; Smith & Sandwell, 1997) refers to the relationship of the depth of the oceanic crust to the age of the oceanic crust. As the oceanic plate moves away from the divergent boundary, it cools and sinks. This relationship can then be used to construct bathymetries. The second dataset, from Scotese (PALEOMAP), is reconstructed through "backtracking" the formation of existing seafloor and lithospheric plate movement. When there is no modern sea floor that can be used to reconstruct the paleobathymetry, the PALEOMAP dataset sets a static water level. Because of this incomplete PALEOMAP bathymetry, in particular the lack of mid-ocean ridge positions in pre-modern static seafloor areas provided by PALEOMAP, we needed a supplemental dataset. We used mid-ocean ridge information from Müller et al. (2008) to supplement the PALEOMAP data, and used the shelf bathymetry from Scotese. A Blackman filter was used to smooth the combined bathymetries, thus preventing large bathymetric discontinuities. The paleobathymetry near the impact site is displayed in Figure S1.

Our iSALE setup is described in Table S1. The model setup is the same as in Collins et al. (2008), but with higher resolution and larger model extent. The grid spacing of 100 m is the same grid spacing used by Bahlburg et al. (2010) to simulate the formation of the Chixculub crater in a 1 km deep ocean. The simulations of Bahlburg et al. (2010) were focused on whether the crater rim would inhibit flow back into the recently formed Chicxulub crater. Thus, the high-resolution zone of Bahlburg et al. (2010) had a horizontal extent of less than 100 km. Because our simulations are focused on formation and evolution of the rim wave, the high-resolution zone in our baseline simulation has a horizontal extent of 250 km.

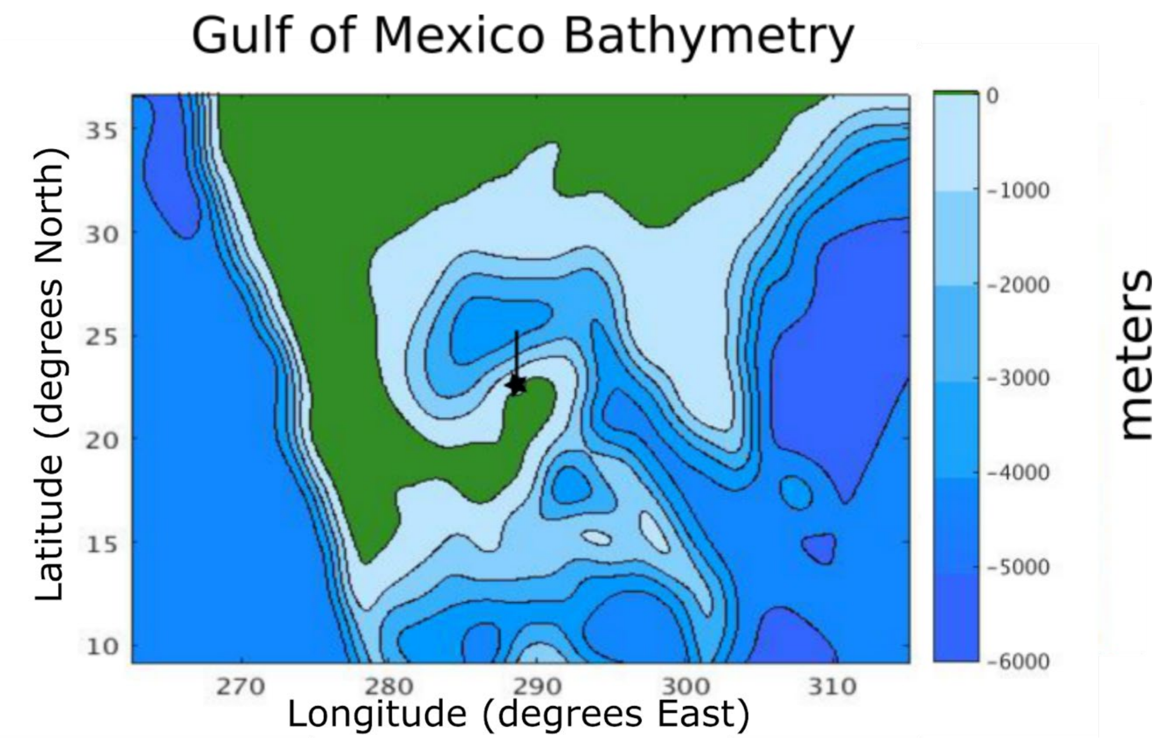
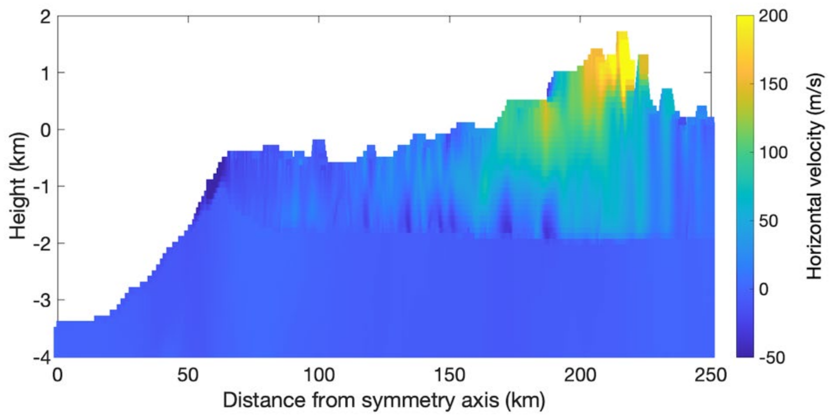


Figure S1. Pre-impact K/Pg bathymetry of Gulf of Mexico in meters. The impact occurred in shallow water of 100-200 m depth, at the location indicated by a star. At >50 km from the impact, the Gulf of Mexico seafloor depth is > 1 km, the depth used in the hydrocode simulation shown in Figure 1. The black line shown above has a length of 250 km, the length of the domain used in the hydrocode simulation.

We also ran an iSALE simulation, out to 1100 s, with the horizontal mesh extending to 300 km, to test sensitivity to handoff time. In particular, the longer run allows us to ensure that the wave is done with active plunging breaking, the process that cannot be modeled with the shallow water wave models, once the handoff occurs. However, the wave has clearly reached a virtually steady-state phase of propagation as a bore-like wave. Bore-like waves are processes that can be modeled with the nonlinear shallow water wave approximation well, as the hydrocode simulation that runs out to 1100 s shows. In this longer hydrocode run we also limited the vertical extent of the domain to 50 km above the impact point. Ejecta leaving the mesh is therefore removed from the simulation. This choice removes the discontinuous clumps of ejecta seen in Figure 1b. The clumps landing ahead of the rim wave producing transient waves in the water make it unclear if the wave is experiencing strong plunging breaking or simply interacting with these lower amplitude waves. Movie S2 shows the results of this simulation. Out to about 200 s the simulation is nearly identical to the simulation shown in Figure 1. Without the added 'clumps' of ejecta landing ahead of the rim wave it is clear the wave is done with plunging breaking by ~600 s. At 600 s, the wave is more energetic in the case that includes the discontinuous ejecta, but this wave dissipates more quickly than the case that ignores the discontinuous ejecta (Figure S4). Figure S4 also shows that handoffs to MOM6 at 600 s vs. 850 s yield nearly identical results, as quantified by globally integrated energies. The simulation with vertical extent of the mesh limited to 50 km produces a wave that is 1.2 km high at 600 s, whereas the wave shown in Figure 1 has an amplitude of 1.4 km at 600 s. Therefore, the height of the rim wave is not overly sensitive to the presence of late-arriving ejecta.



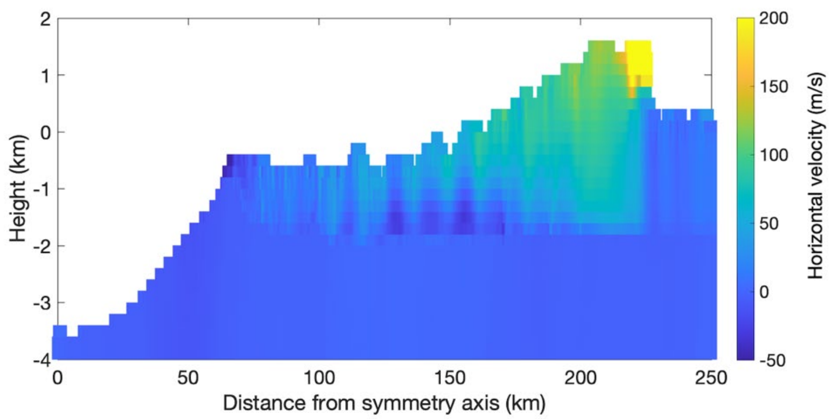


Figure S2. iSALE resolution test. Material is colored according to horizontal velocity as indicated by the color scale. Both frames are plotted 600 s after an impact into a target with a 2 km thick ocean layer. The top frame has a resolution of 100 meters while the bottom frame has a resolution of 200 meters. Resting sea level is represented by a y-axis value of "0".

Figure S2 shows that the waveform produced in a 200 m grid spacing iSALE simulation is very similar to that produced in a 100 m simulation. This similarity provides confidence that resolving the ocean depth by at least 10 cells is sufficient to capture the initial generation of the impact tsunami.

The importance of vaporization in hydrocode modeling

Gisler et al. (2011) pointed out the importance of accounting for vaporization of water when considering impact-generated tsunamis. We expect in simulations where the crater is much deeper than the ocean the effect of ocean vaporization will have a modest effect compared to impacts where the transient crater size is much smaller than the ocean depth. To accurately track the response of material to an impact, shock physics codes must include equations of state and accurately track the thermal state of materials including the effect of vaporization. To limit computational expense, vaporized material is removed from the mesh when densities drop below

10 kg/m^3. This is why no vapor plume appears in Figure 1. In addition to producing an airblast, expansion of the vapor plume may also produce Lamb waves as observed in the recent Tonga event. The Lamb waves would likely enhance the impact-generated tsunami.

Importing hydrocode outputs to the tsunami model

The hydrocode outputs two quantities that will be used in the initial conditions for elevation in our shallow-water models; sea surface elevation perturbations, and perturbations to the seafloor depth. Because our impact simulations are axisymmetric, we write the output of the hydrocode in terms of a radial distance from the impact point to a target point of interest. Let the distance from our target point to the impact origin be r. Then $\eta_{hydrocode}(r)$ is the perturbation (positive upwards) to resting sea level given by the hydrocode, in columns where water exists. Of course, in columns near the impact, there is no water at the end of the hydrocode simulation (600-1100 seconds post-impact). Let $H_{hydrocode}(r)$ be the vertical distance between the seafloor prior to impact and the seafloor at the hand-off from the hydrocode simulation. Again, we take positive values of $H_{hydrocode}(r)$ to denote a deepening of the seafloor. We note that the seafloor can be either sediment or crystalline basement.

For the fiducial "Half Crater" case, we impose the simulated crater on the pre-impact bathymetry only at cells that were initially water (in other words, the crater was not imposed on points that were land in the pre-impact bathymetry). More precisely, if $H_{before}(x,y) + H_{hydrocode}(r) > 0$, then we declare the point (x,y) as being water, with resting depth $H_{before}(x,y) + H_{hydrocode}(r)$, where H_{before} is the pre-impact bathymetry, discussed in more detail below. Negative values of this sum imply that the target point is land.

For the rim wave, the water was only added onto cells that had water, such that the rim wave is not emplaced on land.

For the post-impact points that are water, including those in the crater region, the new water column thickness is $H_{before}(x,y) + H_{hydrocode}(r) + \eta_{hydrocode}(r)$. In water points in the crater region, the initial water column thickness just after impact may be zero. This water is given the depth averaged velocity according to iSALE.

In all regions where there was water, the water column velocity was vertically averaged and also placed in each grid cell. The velocities (as well as sea surface heights and crater depths) are then interpolated to a 1/10th degree resolution and smoothed. For the 'Crater Only' simulation water was vacated from the crater, but no rim wave was initialized. Initial water velocities were zero. For the 'Full Crater' simulation the crater was imposed on the bathymetry including cells that were previously land.

Table S1. Model setup for fiducial iSALE simulation

Description	**Value**
Size of high-resolution cell	100 m
Number of high-resolution cells, horizontal direction	2500
Number of high-resolution cells, vertical direction	600
Physical dimension of entire mesh, horizontal direction	0 to 344.3 km
Physical dimension of entire mesh, vertical direction	-505.1 to 142.9 km
Adaptive time step	0.78 to 2.7 ms

Table S2. Setup for MOM6 1/10th degree simulations

Description	**Value**
Spatial resolution	1/10 degree
North wall boundary	82.05° N
South wall boundary	86.05° S
Temporal resolution	10 seconds

Table S3. MOST model setup

Description	**Value**
Spatial resolution	1/10 degree
North wall boundary	82.05° N
South wall boundary	86.05° S
Temporal resolution	6 seconds

Initial Seafloor Topography

Because the fiducial hydrocode simulation covers points within 250 km of the impact origin, all such points will be part of the initial condition, set by the outputs of the hydrocode, for the shallow-water model. Let the coordinates of a target point, within 250 km of the impact origin, be (x,y). Let $H_{before}(x,y)$ be the topography (resting water depth) of the target point before impact (defined by the merging of the Scotese and Müller datasets, described earlier). The sign of H_{before} informs us about whether the target point was land (negative H_{before} value) or ocean (positive H_{before} value) prior to impact.

Shallow-water model results and sensitivities

The sea surface height perturbation field four hours after handoff from the hydrocode in a MOM6 simulation with 1/5° grid spacing are quite similar to the sea surface height perturbation field four hours after the handoff in the fiducial 1/10° MOM6 run (Figure S3). This similarity indicates that the shallow water grid spacing of 1/10° is reasonably robust for our purposes.

In the 'Half Crater' simulation, the crater is only on grid cells that were originally water before impact. When the crater is placed over the pre-impact bathymetry, there are portions of the crater in water cells, and portions that are on the Yucatan Peninsula. When placing the crater into the model, two initial conditions were made. The 'Full Crater' replaces these land cells on the Yucatan Peninsula with water to a depth of the post-impact crater. The 'Half Crater' initial condition leaves the land cells as land. In the 'Crater Only' simulation, a full crater is made over the land and water cells, but the rim wave is removed, such that the tsunami is due only to water rushing inwards to fill the impact crater.

The ratios of the energies of different MOM6 simulations of the impact tsunami, relative to the 2004 Indian Ocean tsunami (as simulated in Smith et al., 2005) and plotted as a function of time into the shallow-water simulations, are given in Figure S4. The total energy of the Chicxulub tsunami and of three historical tsunamis is provided in Table S4, which also displays the energy of the tsunami source (e.g., Chicxulub asteroid impact in the case of the impact tsunami, and earthquake energies in the case of the 2004 Indian Ocean tsunami and 2011 Tohoku tsunami).

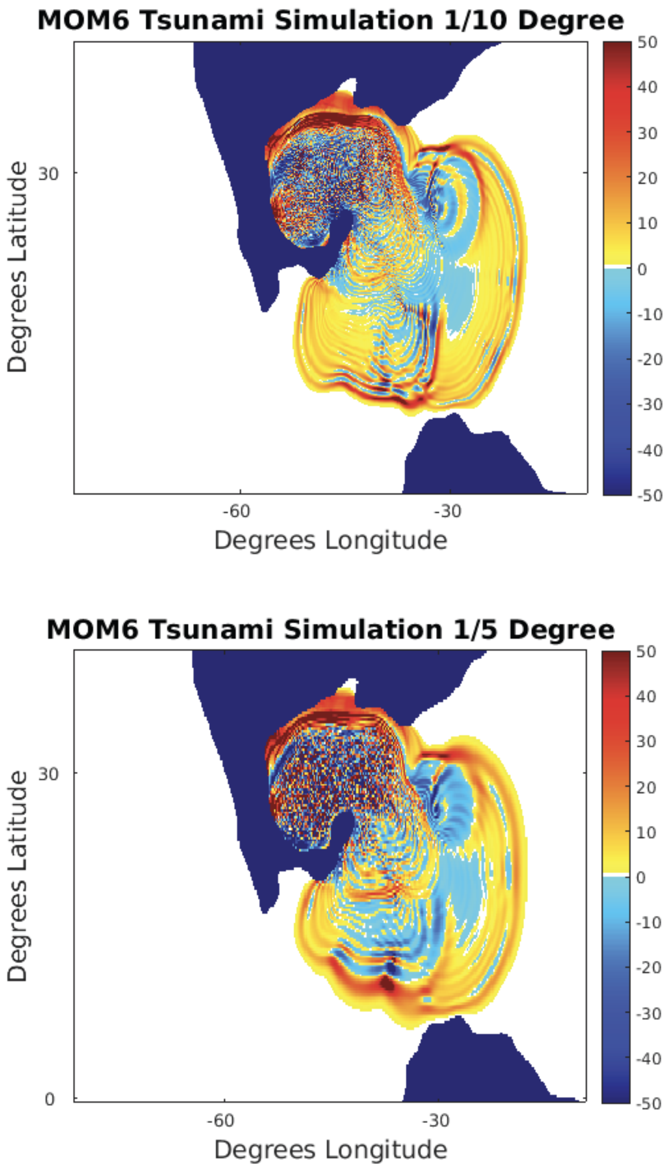


Figure S3. Sea surface height perturbations (m) four hours after handoff from the fiducial hydrocode simulation, in (top) fiducial 1/10° MOM6 simulation and (bottom) 1/5° MOM6 simulation.

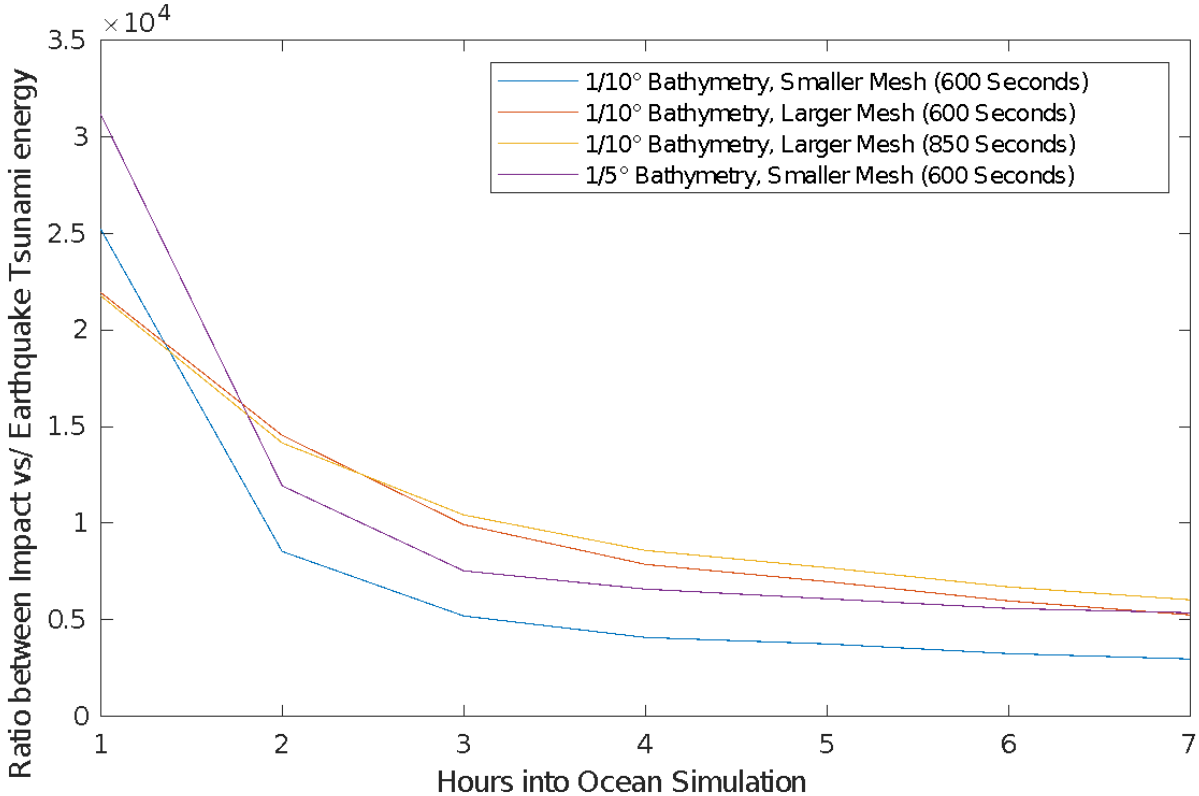


Figure S4. Ratio of Chicxulub impact total (kinetic plus potential) energy to 2004 Indian Ocean earthquake-generated tsunami total energy, as a function of time into the respective shallow-water simulations. In the legend, 'smaller mesh' refers to our fiducial model while the 'larger mesh' refers to models that use our iSALE simulation that was runout to later times, had a larger horizontal extent of the high-resolution zone, and later arriving discontinuous ejecta. The initial energy of the fiducial model (blue curve) is 5.1 x 10^{19} J. For comparison the 2011 Tohoku Tsunami had an initial energy of 3.0 x 10^{15} J and 1.5 x 10^{15} J four hours later (Tang et al., 2012). The 2004 Indian Ocean Tsunami had an initial energy of 1.7 x 10^{16} J and 9.1 x 10^{15} J four hours later. Thus, the impact generated tsunami dissipates more quickly than earthquake generated tsunamis.

Table S4. Maximum energy values of the fiducial Chicxulub impact tsunami model runs compared to the modeled energy of several historical tsunamis

	Tsunami Energy E_T (J)	**Source Energy E_S (J)**	**Ratio E_T/E_S (%)**
Full Crater, with Rim Wave (600 seconds)	5.1×10^{20} (max)	2.7×10^{23}	0.19%
1883 Krakatau Tsunami (Maeno and Imamura, 2011)	~1.2×10^{13} (max)	~1.0×10^{17}	0.01%
2004 Indian Ocean Tsunami (Tang et al., 2012)	1.7×10^{16} (max)	6.2×10^{18}	0.27%
2011 Tohoku Tsunami (Tang et al., 2012)	3.0×10^{15} (max)	2.8×10^{18}	0.11%

Run times and computing hardware

The hydrocode simulations employed here take of order one month on a high-end desktop. The 1/10º MOM6 simulations take of order two days to run on about 60 processors, on the University of Michigan Great Lakes supercomputer system (https://arc.umich.edu/greatlakes/).

Movie Captions

The four movies that we made for this paper are posted with the Supporting Information and can also be found on our data repository https://doi.org/10.7910/DVN/GWOFIO where they are referred to as "SI_Video1.mp4, SI_Video2.mp4, S!_Video3.mp4, SI_Video4.mp4".

Movie S1. Animation of the iSALE hydrocode fiducial simulation for the first 600 s post asteroid impact shown in Figure 1. Time series with material colored according to material type (crustal material is brown, sediments are yellow, and the ocean is blue). The origin marks the point of impact. Black curves mark material interfaces (e.g., sediment-crust interface).

Movie S2. Animation of the iSALE hydrocode model for first 1100 s post asteroid impact. This simulation is the same as the simulation shown in Figure 1 but has vertical extent of mesh limited to 50 km and the high-resolution zone extended to a radial distance of 300 km. Time series with material colored according to material type (crustal material is brown, sediments are yellow, and the ocean is blue). The origin marks the point of impact. Black curves mark material interfaces (e.g., sediment-crust interface).

Movie S3. Animation of the change in sea surface height tsunami propagation over 48 hours from the fiducial MOM6 model. Shown in m at ten-minute increments.

Movie S4. Animation of the change in sea surface height tsunami propagation over 48 hours from the fiducial MOST model. Shown in m at five-minute increments.

References From Supporting Information

Arbic, B.K., Garner, S.T., Hallberg, R.W., & Simmons, H.L. (2004). The accuracy of surface elevations in forward global barotropic and baroclinic tide models. *Deep-Sea Research II,* 51, 3069-3101, https://doi.org/10.1016/j.dsr2.2004.09.014.

Bahlburg, H., Weiss, R., & Wünnemann, K. (2010). Low energy deposition in the Chicxulub crater during the impact to post-impact transition. *Earth and Planetary Science Letters*, 295, 170–176, https://doi.org/10.1016/j.epsl.2010.03.037.

Collins, G.S., Morgan, J., Barton, P., Christeson, G.L., Gulick, S., Urrutia, J., Warner, M., & Wünnemann, K. (2008). Dynamic modeling suggests terrace zone asymmetry in the Chicxulub crater is caused by target heterogeneity. *Earth and Planetary Science Letters*. https://doi.org/10.1016/j.epsl.2008.03.032

Gisler, G., Weaver, R., & Gittings, M. (2011). Calculations of asteroid impacts into deep and shallow water. Pure and Applied Geophysics, 168, 1187-1198, https://doi.org/10.1007/s00024-010-0225-7

Maeno, F. and Imamura, F. (2011). Tsunami generation by a rapid entrance of pyroclastic flow into the sea during the 1883 Krakatau eruption, Indonesia. *Journal of Geophysical Research: Solid Earth*,116, B09205, https://doi.org/10.1029/2011JB008253

Müller, R.D., Sdrolias, M., Gaina, C., Steinberger, B., & Heine, C. (2008). Long-term sea-level fluctuations driven by ocean basin dynamics. *Science* 319, 1357-1362, https://doi.org/10.1126/science.1151540.

Schroeder, W. (1984). The empirical age-depth relation and depth anomalies in the Pacific Ocean Basin. *Journal of Geophysical Research* 89, 9873-9883, https://doi.org/10.1029/JB089iB12p09873.

Scotese, C. R. (1997). *The PALEOMAP Project: paleogeographic atlas and plate tectonic software.* https://cmr.earthdata.nasa.gov/search/concepts/C1214607516-SCIOPS

Smith, W.H.F., & Sandwell, D.T. (1997). Global seafloor topography from satellite altimetry and ship depth soundings. *Science*, 277, 1956-1962. https://doi.org/10.1126/science.277.5334.1956.

Smith, W.H.F., Scharroo, R., Titov, V.V., Arcas, D., & Arbic, B.K. (2005). Satellite Altimeters Measure Tsunami—Early Model Estimates Confirmed. *Oceanography*, *18*(2), 11–13. https://doi.org/10.5670/oceanog.2005.62.

Tang, L., Titov, V.V., Bernard, E N., Wei, Y., Chamberlin, C D., Newman, J.C.,Mofjeld, H.O., Arcas, D., Eble, M.C., Moore, C., Uslu, B., Pells, C., Spillane, M., Wright, L., & Gica, E. (2012). Direct energy estimation of the 2011 Japan tsunami using deep-ocean pressure measurements. *Journal of Geophysical Research*, 117(C8), C08008. https://doi.org/10.1029/2011JC007635

Titov, V.V., & Synolakis, C.E. (1995). Modeling of breaking and nonbreaking long-wave evolution and runup using VTCS–2. *Journal of Waterway, Port, Coastal and Ocean Engineering*, 121, 308-316, https://doi.org/10.1061/(ASCE)0733-950X(1995)121:6(308)

Zhou, H., Wei, Y., & Titov, V.V. (2012): Dispersive modeling of the 2009 Samoa tsunami. *Geophysical Research Letters*, 39(16), L16603, https://doi.org/1029/2012GL053068

References From Supporting Information Table S5 and Table S6

Abramovich, S., Keller, G., Adatte, T., Stinnesbeck, W., Hottinger, L., Stüben, D., Berner, Z., Ramanivosoa,B. & Randriamanantenasoa, A. (2002). Age and paleoenvironment of the Maastrichtian-Paleocene of the Mahajanga Basin, Madagascar: a multidisciplinary approach. *Marine Micropaleontology 47*, 17–70. http://dx.doi.org/10.1016/S0377- 8398(02)00094-4.FIX DOI; should be clickable

Açıkalın, S, Vellekoop, J., Ocakoglu, F., Yılmaz, I.Ö., Smit, J., Altıner, S. Ö., Goderis, S, Vonhof, H., Speijer, R.P., Woelders, L., Fornaciari, E., & Brinkhuis, H. (2015). Geochemical and palaeontological characterization of a new K-Pg Boundary locality from the Northern branch of the Neo-Tethys: Mudurnu e Göynük Basin, NW Turkey: *Cretaceous Research, 52,* 251-267.

Adatte, T., Keller, G., Burns, S., Stoykova, K.H., Ivanov, M.I., Vangelov, D., Kramar, U., & Stüben, D. (2002). Paleoenvironment across the Cretaceous-Tertiary transition in eastern Bulgaria: *Geological Society of America Special Paper 356*, 231-251.

Alegret, L., Kaminski, M.A., & Molina, E. (2004). Paleoenvironmental recovery after the Cretaceous/Paleogene boundary crisis: evidence From the marine Bidart section (SW France). *Palaios, 19,* 574-586.

Alegret, L., Arenillas, I., Diaz, C., Grajales-Nishimura, J., Meléndez, A., Molina, E., Rojas Museo, R., & Soria, A.R. (2005). Cretaceous-Paleogene boundary deposits at Loma Capiro, central Cuba: Evidence for the Chicxulub impact. *Geology, 33* (9), 721-724.

Alegret, L. & Thomas, E., (2005). Cretaceous/Paleogene boundary bathyal paleo-environment in the central North Pacific DSDP Site 465), the Northwestern Atlantic (ODP Site 1049), the Gulf of Mexico and the Tethys: The benthic foraminiferal record. *Earth and Planetary Science Letters*, 224, 53-82

Alegret, L., Thomas, E, & Lohmann, K.C. (2012). End-Cretaceous marine mass extinction not caused by productivity collapse. P*roceedings of the National Academy of Sciences of the United States of America 109*(3), 728-732.

Albertao, G.A., & Martins Jr., P.P. (1996). A possible tsunami deposit at the Cretaceous-Tertiary boundary in Pernambuco, northeastern Brazil. Sedimentary Geology, 104, 189-201.

Alvarez, W. & Lowrie, W. (1978). Upper Cretaceous palaeomagnetic stratigraphy at Moria, Umbrian Apennines, Italy: verification of the Gubbio section: *Geophysical Journal of the Royal Astronomical. Society, 57*, 1-17.

Alvarez, W., Asaro, F. & Montanari, A. (1990). Iridium profile for 10 million years across the Cretaceous-Tertiary Boundary at Gubbio (Italy). *Science, 250*, 1700-1702.

Alvarez, W., Smit, J., Lowrie, W., Asaro, F., Margolis, S.V., Claeys, P., Kastner, M., & Hildebrand, A.R. (1992). Proximal impact deposits at the Cretaceous-Tertiary boundary in the Gulf of Mexico: A restudy of DSDP Leg 77 Sites 536 and 540. *Geology*, 20, 697–700.

Andrews, J.E., Packham, G., et al. (1975). *Initial Reports of the Deep Sea Drilling Project, Volume 30*. Washington DC: U.S. Govt. Printing Office.

Arneth, J.-D, Matzigkeit, U., & Boos, A. (1985). Carbon isotope geochemistry of the Cretaceous-Tertiary section of the Wasserfallgraben, Lattengebirge, southeast Germany. *Earth and Planetary Science Letters, 75*, 50-58.

Askin, R. A. (1985). The palynological record across the Cretaceous/Tertiary transition on Seymour Island, Antarctica. In R.M. Feldmann, M.O. Woodburne, (Eds.), *Geology and paleontology of Seymour Island: Geological Society of America Memoir 169*, (pp. 155-162).

Austin, J. A., Jr., Schlager, W., Palmer, A.A. et al. (1986). *Proceedings of the Ocean Drilling Program, Initial Reports. (Pt. A), 101.* College Station, TX: Ocean Drilling Program.

Barker, P. F., Dalziel, I.W.D., et al. (1976). *Initial Reports of the Deep Sea Drilling Project 36*. Washington DC: U.S. Govt. Printing Office.

Barker, P. F., Carlson, R.L., & Johnson, D.A. (1983). *Initial Reports Deep Sea Drilling Program, 72*. Washington DC: U.S. Govt. Printing Office.

Barker, P. F., Kennett, J.P., et al. (1988). *Proceedings of the Ocean Drilling Program, Initial Reports, 113*. College Station, TX: Ocean Drilling Program.

Barker, P. F, Kennett, J.P., et al. (1990), *Proceedings of the Ocean Drilling Program, Scientific Results, 113*. College Station, TX: Ocean Drilling Program.

Barrera, E. (1994). Global environmental changes preceding the Cretaceous-Tertiary boundary: Early-late Maastrichtian transition: *Geology, 22*, 877-880,

Barron, J., Larsen, B., et al. (1989). *Proceedings of the Ocean Drilling Program, Initial Reports, 119*. College Station, TX: Ocean Drilling Program.

Batenburg, S.J., Sprovieri, M., Gale, A.S., Hilgen, F.J., Hüsing, S., Laskar, J., Liebrand, D, Lirer, F., Orue-Etxebarria, X., Pelosi, N., & Smit, J. (2012). Cyclostratigraphy and astronomical tuning of the Late Maastrichtian at Zumaia (Basque country), Northern Spain. *Earth and Planetary Science Letters*, 359-360,264-278, https://doi.org/10.1016/j.epsl.2012.09.054

Benson, W. E., Sheridan, R. E., et al. (1978). *Initial Reports of the Deep Sea Drilling Project, 44*.Washington DC: U.S. Govt. Printing Office), 1005 pp.

Bleil, U., (1985). The magnetostratigraphy of northwest Pacific sediments, Deep Sea Drilling Project Leg 86.In G. R.Heath, L. H.Burckle et al., *Initial Reports of the Deep Sea Drilling Project, 86*. Washington DC: U.S. Govt. Printing Office.

Boillot, G., Winterer, E.L., Meyer, A.W., et al. (1987). *Proceedings of the Ocean Drilling Program, Initial Reports, (Pt. A) 103*. College Station, TX: Ocean Drilling Program.

Bolli, H. M., Ryan, W.B.F. et al. (1978). *Initial Reports of the Deep Sea Drilling Project, Volume 40*. Washington DC: U.S. Govt. Printing Office.

Bourgeois, J., Hansen, T.A., Wiberg, P.L. & Kauffman, E.G. (1988). A tsunami deposit at the Cretaceous-Tertiary boundary in Texas. *Science*, 241, 567–570.

Bowles, J. (2007). Data report: revised magnetostratigraphy and magnetic mineralogy of sediments from Walvis Ridge, Leg 208 In D. Kroon, D., J.C. Zachos, C. Richter. (Eds.): Proceedings of the Ocean Drilling Program, Scientific Results, 208. (College Station, TX: Ocean Drilling Program), 24 pp. doi:10.2973/odp.proc.sr.208.2007 .

Bowman, V.C., Francis, J.E., Askinb, R.A., Riding, J.B., & Swindles, G.T. (2014). Latest Cretaceous–earliest Paleogene vegetation and climate change at the high southern latitudes: palynological evidence from Seymour Island, Antarctic Peninsula.

Bralower, T.J., & Paull, C.K. (1998) The Cretaceous-Tertiary boundary cocktail: Chicxulub impact triggers margin collapse and extensive sediment gravity flow, Geology, 26(4), 331-334.

Bralower, T.J., Premoli Silva, I., Malone, M.J. et al. (2002a). Proceedings of the Ocean Drilling Program, Initial Reports, (Pt. A), 198. College Station, TX: Ocean Drilling Program. doi:10.2973/odp.proc.ir.198.2002,

Bralower, T.J., Premoli Silva, I., & Malone, M.J. (2002b). Leg 198 synthesis: a remarkable 120 M.Y. record of climate and ceoanography from Shatsky Rise, Northwest Pacific Ocean, In T.J. Bralower, I. Premoli Silva, M.J. Malone, et al. *Proceedings of the Ocean Drilling Program, Initial Reports, 198.* College Station, TX: Ocean Drilling Program. doi:10.2973/odp.proc.ir.198.2002, p. 1-47.

Brinkhuis, H. & Zachariasse, W.J. (1988). Dinoflagellate cysts, sea level changes and planktonic foraminifers across the Cretaceous-Tertiary boundary at El Haria, Northwest Tunisia. *Marine Micropaleontology, 13*, 153-191.

Buffler, R. T., Schlager, W. et al. (1984). *Initial Reports of the Deep Sea Drilling Project, 77*. Washington DC: U.S. Govt. Printing Office.

Burns, R. E., Andrews, J.E. et al. (1973). *Initial Reports of the Deep Sea Drilling Project, 21*. Washington DC: U.S. Govt. Printing Office.

Campbell, C.E., Oboh-Ikuenobe, F.E., Eifert, E.I. (2008). Mega tsunami deposit in Cretaceous- Paleogene boundary interval of southeastern Missouri. *Geological Society of America Special Paper* 437, 189-198.

Canudo, J.I., Keller, G., & Molina, E. (1991). Cretaceous/Tertiary boundary extinction pattern and faunal turnover at Agost and Caravaca, S.E. Spain. *Marine Micropaleontology*, 17, 319-341. https://doi.org/10.1016/0377-8398(91)90019-3

Carter, R.M., McCave, I.N., Richter, C., Carter, L., et al. (2000). Proceedings of the Ocean Drilling Program, Initial Reports, 181 [Online]. doi:10.2973/odp.proc.ir.181.2000, Available from World Wide Web: <http://www-odp.tamu.edu/publications/181_IR/181ir.htm>.

Ciesielski, P. F., Kristoffersen, Y. et al. (1988). *Proceedings of the Ocean Drilling Program, Initial Reports*, *114*. College Station, TX: Ocean Drilling Program.

Clemens, S.C., Kuhnt, W., LeVay, L.J., & the Expedition 353 Scientists. (2015). *Expedition 353 Preliminary Report: Indian Monsoon Rainfall*. International Ocean Discovery Program. http://dx.doi.org/10.14379/iodp.pr.353.2015.

Coffin, M.F., Frey, F.A., Wallace, P.J. et al. (2000). *Proceedings of the Ocean Drilling Program, Initial Reports, 183* [Online]. doi:10.2973/odp.proc.ir.183.2000, Available from World Wide Web: <http://www-odp.tamu.edu/publications/183_IR/183ir.htm>.

Creager, J. S., Scholl, D.W. et al. (1973). *Initial Reports of the Deep Sea Drilling Project.* Washington DC: U.S. Govt. Printing Office), 930 pp.

Davies, T. A., Luyendyk, B.P. et al. (1974). *Initial Reports of the Deep Sea Drilling Project, 26*. Washington DC: U.S. Govt. Printing Office.

Denne, R.A., Scott, E.D., Eickhoff, D.P., Kaiser, J.S., Hill, R.J., & Spaw, J.M. (2013). Massive Cretaceous-Paleogene boundary deposit, deep-water Gulf of Mexico: New evidence for widespread Chicxulub-induced slope failure: *Geology, 42(*9), 983-986, https://doi.org/10.1130/G34503.1

Dinarès-Turell, J., Westerhold, T., Victoriano Pujalte, V., Röhl, U. & Kroon, D. (2013). Settling the Danian astronomical time scale: a prospective global unit stratotype at Zumaia, Basque Basin. In R. Rocha et al., (Eds), *STRATI 2013*. Springer International Publishing Switzerland. doi: 10.1007/978-3-319-04364-7_38

Donovan, A.D., Baum, G.R., Blechschmidt, G.L., Loutit, T.S., Pflum, C.E. & Vail, P.R. (1988). Sequence Stratigraphic Setting of the Cretaceous-Tertiary boundary in central Alabama. In Sea-Level Changes-An Integrated Approach, *SEPM Society for Sedimentary Geology Special Publication* No. 42, 299-307.

Edgar, N. T., Saunders, J.B. et al. (1973). *Initial Reports of the Deep Sea Drilling Project,* *15*.Washington DC: U.S. Govt. Printing Office.

Elliot. D.H., Askin, R.A., Kyte, F.T, & Zinsmeister, W. J. (1994). Iridium and dinocysts at the Cretaceous-Tertiary boundary on Seymour Island, Antarctica: Implications for the K-T event: *Geology, 22,* 675-678.

Erbacher, J., Mosher, D.C., Malone, M.J. et al. (2004). *Proceedings of the Ocean Drilling Program, Initial Reports, 207*. College Station, TX: Ocean Drilling Program. doi:10.2973/odp.proc.ir.207.2004.

Esmeray-Senlet, S., Wright, J.D., Olsson, R.K., Miller, K.G., Browning, J.V. & Quan, T.M. (2015). Evidence for reduced export productivity following the Cretaceous/Paleogene mass extinction: *Paleoceanography, 30*, 718–738. doi:10.1002/2014PA002724.

Exon, N.F., Kennett, J.P., & Malone, M.J. (2004). Leg 189 synthesis: Cretaceous–Holocene history of the Tasmanian Gateway. In N.F. Exon, J.P. Kennett, and M.J. Malone, (Eds.). *Proceedings of the Ocean Drilling Program, Scientific Results, 189*, 1-37. College Station, TX: Ocean Drilling Program. doi:10.2973/odp.proc.sr.189.101.2004

Expedition 342 Scientists. (2012). Paleogene Newfoundland sediment drifts. *Integrated Ocean Drilling Program, Preliminary Report, 342*. https://doi.org/10.2204/iodp.pr.342.2012

Galburn, B. (1992). Magnetostratigraphy of Upper Cretaceous and Lower Tertiary sediments, Sites 761 and 762, Exmouth Plateau, Northwest Australia. In U. von Rad, B.U. Haq, et al. *Proceedings of the Ocean Drilling Program, Scientific. Results, 122*: College Station, TX: Ocean Drilling Program.

Galbrun, B., and Gardin, S. (2004). New chronostratigraphy of the Cretaceous–Paleogene boundary interval at Bidart, France: *Earth and Planetary Science Letters, 224*, 19-32.

Graciansky, P. C. de, Poag, C.W. et al. (1985). *Initial Reports of the Deep Sea Drilling Project, 80*. Washington DC: U.S. Govt. Printing Office.

Hailwood, E.A. & Clement, B.M. (1991). Magnetostratigraphy of Sites 699 and 700, East Georgia Basin. In P. F. Ciesielski, Y. Kristoffersen, et al. *Proceedings of the Ocean Drilling Program, Scientific Results, 114.* College Station, TX: Ocean Drilling Program. 337-357.

Hamilton, N. (1990). Mesozoic magnetostratigraphy of Maud Rise, Antarctica, In P.F.

Barker, J.P. Kennett, et al. *Proceedings of the Ocean Drilling Program, Scientific Results, 113*. College Station, TX: Ocean Drilling Program.

Hamilton, N. & Suzyumov, A. E. (1983). Late Cretaceous magnetostratigraphy of Site 516, Rio Grande Rise, southwestern Atlantic Ocean, Deep Sea Drilling Project, Leg 72. In P.F. Barker, R.L. Carlson, and D.A. Johnson: *Initial Reports of the Deep Sea Drilling Project, 72*. Washington DC: U.S. Govt. Printing Office, 723-730.

Hansen. J. M. (1979). Dinoflagellate zonation around the boundary. In T. Birkelund, & R. G. Bromley, (Eds.). *Cretaceous-Tertiary boundary events. Volume I*. (University of Copenhagen, Denmark), 136-141.

Hansen, H.J., Drobne, K., & Gwozdz, R. (1995). The K/T boundary in Slovenia: Dating by magnetic susceptibility and an iridium anomaly in a debris flow: 4th Int. workshop European Science Network "Impact Cratering and Evolution of Planet Earth",Ancona, May 1995, Abstracts and Field Trips. (Università degli Studi Urbino, Ancona) 84–85.

Haq, B.U., von Rad, U., O'Connell, S. et al., (1990). *Proceedings of the Ocean Drilling Program, Initial Reports, 122.* College Station, T X: Ocean Drilling Program).

Hart, M.B., Feist, S.E., Håkanssonc, E., Heinbergd, C., Price, G.D., Lenge, M.J., & Watkinson, M. P. (2005). The Cretaceous–Palaeogene boundary succession at Stevns Klint, Denmark: Foraminifers and stable isotope stratigraphy: *Palaeogeography, Palaeoclimatology, Palaeoecology*, 224), 6 – 26.

Hay, W. W., Sibuet, J.-C. et al. (1984). *Initial Reports of the Deep Sea Drilling Project,75*. Washington DC: U.S. Govt. Printing Office.

Hayes, D. E., Pimm, A.C. et al. (1972). *Initial Reports of the Deep Sea Drilling Project, 14*. Washington DC: U.S. Government Printing Office.

Hayes, D. E., Frakes, L.A. et al. (1975). *Initial Reports of the Deep Sea Drilling Project, 28.* Washington DC: U.S. Govt. Printing Office.

Heath, G. R., Burckle, L.H. et al. (1985). *Initial Reports of the Deep Sea Drilling Project, 86*. Washington DC: U.S. Govt. Printing Office.

Herbert, T.D. & D'Hondt, S.L. (1990). Precessional climate cyclicity in Late Cretaceous-Early Tertiary marine sediments: a high resolution chronometer of Cretaceous-Tertiary boundary events. Earth and Planetary Science Letters, 99, 263-275.

Hines, B.R., Kulhanek, B.K., Hollis, C.J., Atkins, C.B., & Morgans, H.E.G., (2013). Paleocene–Eocene Stratigraphy and Paleoenvironment at Tora, Southeast Wairarapa, New Zealand, New Zealand Journal of Geology and Geophysics, https://doi.org/10.1080/00288306.2013.836112

Hinz, K., Winterer, E.L. et al. (1984). *Initial Reports of the Deep Sea Drilling Project, 79*. Washington DC: U.S. Govt. Printing Office.

Hollis, C.J. (2002). Biostratigraphy and paleoceanographic significance of Paleocene radiolarians from offshore eastern New Zealand. *Marine Micropaleontology, 46*, 265-316.

Hollis, C. J., Strong, C. P., Rodgers, K. A., & Rogers, K. M. (2003). Paleoenvironmental changes across the Cretaceous/Tertiary boundary at Flaxbourne River and Woodside Creek, eastern Marlborough: New Zealand. *New Zealand Journal of Geology and Geophysics, 46*, 177-197.

Hollister, C. D., Craddock, C. et al. (1976). *Initial Reports of the Deep Sea Drilling Project, 35*. Washington DC: U.S. Government Printing Office.

Hsü, K. J., and LaBrecque, J.L. et al. (1984). *Initial Reports of the Deep Sea Drilling Project, 73*. Washington (U.S. Govt. Printing Office.

Huber, B.T., Liu, C., Olsson, R.K. & Berggren, W.A. (1994). Comment on ''The Cretaceous-Tertiary boundary transition in the Antarctic Ocean and its global implications'', by G. Keller: *Marine Micropaleontology, 24*, 91-99.

Husson, D., Galbrun, B., Laskar, J., Hinnov, l.A., Thibault, N., Gardin, S., and Locklair, R.E. (2011). Astronomical calibration of the Maastrichtian (Late Cretaceous): *Earth and Planetary Science Letters, 128,* 128-340.

Keller, G., & Lindinger, M. (1989). Stable isotope, TOC and CaCO3 record across the Cretaceous/Tertiary boundary at El Kef, Tunisia. Palaeogeography, Palaeoclimatology, Palaeoecology, 73, 243-265.

Keller, G., Adatte, T., Stinnesbeck, W., Stüben, D., Kramar, U., Berner, Z., Li, L., & Perch-Nielsen, K. v. S. (1997). The Cretaceous-Tertiary transition on the shallow Saharan Platform of Southern Tunisia. *Geobios, 30,* 951-975.

Keller, G., Adatte, T., Tantawy, A.A., Berner, Z., Stüben, D. (2007). High stress late Cretaceous to early Danian paleoenvironment in the Neuquen Basin, Argentina. *Cretaceous Research, 28*, 939–960. http://dx.doi.org/10.1016/j.cretres.2007.01.006.

Keller, G., Khozyem, H.M., Adatte, T., Malarkodi, N., Spangenberg, J.E., Stinnesbeck, W. (2013). Chicxulub impact spherules in the North Atlantic and Caribbean: age constraints and Cretaceous-Tertiary boundary hiatus. *Geological Magazine 150*, 885–907. http://dx.doi.org/10.1017/S0016756812001069.

Kroenke, L. W., Berger, W.H., Janecek, T.R. et al. (1991). *Proceedings of the Ocean Drilling Program, Initial Report,130*. College Station, TX: Ocean Drilling Program.

Kyte, F.T., Smit, J. & Wasson, J.T. (1985). Siderophile interelement variations in the Cretaceous-Tertiary boundary sediments from Caravaca, Spain. *Earth and Planetary Science Letters, 73,* 183-195.

Lancelot, Y., Winterer, E.L. (1980). *Initial Reports of the Deep Sea Drilling Project, 50.* Washington DC: U.S. Government Printing Office.

Lancelot, Y., Seibold, E. et al. (1977). *Initial Reports of the Deep Sea Drilling Project, 41.* Washington DC: U.S. Government Printing Office.

Laird, M.G., Bassett, K. N., Schiøler, P., Morgans, H. E. G, Bradshaw, J. D. & Weaver, S.D. (2003). Paleoenvironmental and tectonic changes across the Cretaceous/Tertiary boundary at Tora, southeast Wairarapa, New Zealand: A link between Marlborough and Hawke's Bay. *New New Zealand Journal of Geology and Geophysical, 46,* 275-293.

Landman, N.H., Johnson, R.O., Garb, M.P., Edwards, L.E., & Kyte, F.T. (2007). Tertiary boundary interval on the Atlantic coastal plain, with a description of the highest ammonite zones in North America. Part III. Manasquan River Basin, Monmouth County, New Jersey. *Bulletin of the American Museum Natural History, 30*, 122 pp.

Larson, R.L., Moberly, R. et al. (1975). *Initial Reports of the Deep Sea Drilling Project, 32*. Washington DC: U.S. Government Printing Office.

Latal, C. (2004). The Cretaceous-Paleogene boundary section of Gorgo a Cerbara: an integrated stratigraphical study. *Annals Naturhistorisches Museum Wien, 160A,* 259-279.

Lowrie, W., & Alvarez, W. (1977). Upper Cretaceous-Paleocene magnetic stratigraphy at Gubbio, Italy. III. Upper Cretaceous magnetic stratigraphy. *Geological Society of America Bulletin, 88*, 374-377.

Ludwig, W. J., Krasheninikov, V.A. et al. (1983). *Initial Reports of the Deep Sea Drilling Project, 71*. Washington DC: U.S. Government Printing Office.

MacLeod, K.G. & Keller, G. (1991a). How complete are Cretaceous/Tertiary boundary sections? A chronostratigraphic estimate based on graphic correlation. *Geological Society of America Bulletin, 103*, 1439-1457.

MacLeod, K.G. & Keller, G. (1991b). Hiatus distributions and mass extinctions at the Cretaceous/Tertiary boundary. *Geology, 19,* 497-501.

MacLeod, K.G., Whitney, D.L., Huber, B. T., & Koeberl, C. (2007). Impact and extinction in remarkably complete Cretaceous-Tertiary boundary sections from Demerara Rise, tropical western North Atlantic. *Geological Society of America Bulletin, v.119* (1/2), 101–115;. doi:10.1130/B25955.1.

MacLeod, K.G., Quinton, P.C., Sepúlveda, J. & Negra, M.H. (2018). Postimpact earliest Paleogene warming shown by fish debris oxygen isotopes (El Kef, Tunisia). *Science, 360,* 1467–1469.

Mahoney, J.J., Fitton, J.G., Wallace, P.J. et al. (2001). *Proceedings of the Ocean Drilling Program, Initial Reports 19.* College Station, TX, Ocean Drilling Program. doi.10.2973/odp.proc.ir.192.2001.

Mascle, J., Lohmann, G.P., Clift, P.D. et al. (1996). *Proceedings of the Ocean Drilling Program, Initial Reports, 159.* College Station, TX, Ocean Drilling Program.

Mateo, P., Keller, G., Adatte. T. & Spangenberg., J.E. (2016). Mass wasting and hiatuses during the Cretaceous-Tertiary transition in the North Atlantic: Relationship to the Chicxulub impact. *Palaeogeography, Palaeoclimatology, Palaeoecolology. 441*, 96–115. http://dx.doi.org/10.1016/j.palaeo.2015.01.019

Maurrasse, F. J.-M. R., and Sen, G. (1991). Impacts, tsunamis and the Haitian Cretaceous-Tertiary boundary layer. *Science, 252*, 1690–1693.

Margolis, S.V., Mount, J.F. & Doehne, E. (1987). The Cretaceous/Tertiary boundary carbon and oxygen isotope stratigraphy, diagenesis, and paleoceanography at Zumaya, Spain: *Paleoceanography, 2* (4), 361-377.

Maxwell, A.E. et al. (1970). *Initial Reports of the Deep Sea Drilling Project, 3*. Washington DC: U.S. Government Printing Office.

Michel, H.V., Asaro, F., Alvarez, ,W. Z & Alvarez L.W. (1990). Geochemical studies of the Cretaceous-Tertiary boundary in ODP holes 689b and 690c. In P.F. Barker, J.P. Kennett, et al: *Proceedings of the Ocean Drilling Program, Scientific Results, 113*. College Station, TX: Ocean Drilling Program, 159-168.

Miller, K.G., Sugarman, P.J., Browning, J.V. et al. (1998). Bass River Site report. *Scientific results, Ocean Drilling Program, Leg 174AX Supplement*, 5-43. College Station, TX: Ocean Drilling Program. 10.2973/odp.proc.ir.174AX.1998

Miller, K.G., Sugarman, P.J., Browning, J.V. et al. (1999). *Proceedings of the Ocean Drilling Program, Initial Reports , 174AX (Suppl.)*. College Station, TX: Ocean Drilling Program. doi:10.2973/Odp.Proc.Ir.174axs.104.1999.

Moberly, R., Schlanger, S.O. et al. (1986). *Initial Reports of the Deep Sea Drilling Project, 89.* Washington DC: U.S. Government Printing Office.

Molina, E., Alegret, L., Arenillas, I., and Arz, J. A. (2005). The Cretaceous/Paleogene boundary at the Agost section revisited: paleoenvironmental reconstruction and mass extinction pattern: Journal Iberian *Geolology, 31* (I), 135-150.

Molina, E., Alegret1, L., Arenillas1, I., Arz1, J.A., Gallala, N., Hardenbol, J., von Salis, K., Steurbaut5, E., Vandenberghe, N. & Zaghbib-Turki, D. (2006). The Global Boundary Stratotype Section and Point for the base of the Danian Stage (Paleocene, Paleogene, "Tertiary", Cenozoic) at El Kef, Tunisia Original definition and revision. *Episodes, 29*(4), 263-273.

Monechi, S. & Thierstein, H.R. (1985). Late Cretaceous-Eocene nannofossil and magnetostratigraphic correlations near Gubbio, Italy. *Marine Micropaleontology,* 9(5), 419-440, doi.org/10.1016/0377-8398(85)90009-X

Montadert, L.Z., & Roberts, D.G. (1979). *Initial Reports of the Deep Sea Drilling Project, 48*. Washington DC: U.S. Government Printing Office.

Montanari, A., Hay, R.L., Alvarez, W., Asaro, F., Michel, H.V., Alvarez, L.W. & Smit, J. (1983). Spheroids at the Cretaceous-Tertiary boundary are altered impact droplets of basaltic composition: *Geology, 11*, 668-671.

Montanari, A., Claeys, P., Asaro, F., Bermudez, J., & Smit, J. (1994). Preliminary stratigraphy and iridium and other geochemical anomalies across the KT boundary in the Bochil Section (Chiapas, southeastern Mexico), in New developments regarding the K/T event and other catastrophes in Earth history. *Lunar and Planetary Institute Contribution 825*, 84–85.

Moore, T. C, Jr., Rabinowitz, P.D. et al. (1984). *Initial Reports of the Deep Sea Drilling Project, 7.* Washington DC: U.S. Government Printing Office.

Norris, R.D., Kroon, D., Klaus, A., et al. (1998). *Proceedings of the Ocean Drilling Program, Initial Reports, 171B*. College Station, TX: Ocean Drilling Program.

Ogorelec, B, Dolenec, T., & Drobne, K. (2007). Cretaceous–Tertiary boundary problem on shallow carbonate platform: Carbon and oxygen excursions, biota and microfacies at the K/T boundary sections Dolenja Vas and Sopada in SW Slovenia, Adria CP. *Palaeogeography, Palaeoclimatology, Palaeoecology, 255*, 64–76.

Olsson, R.K., Miller, K.G., Browning, J.V., Wright, J.D., & Cramer, B.S. (2002). Sequence stratigraphy and sea level change across the Cretaceous/Tertiary boundary on the New Jersey passive margin. In C. Koeberl and K.G. MacLeod, K.G., (Eds.) Catastrophic Events and Mass Extinctions: Impacts and Beyond, *Geological Society of America Special Paper 356,* 97–108.

Olsson, R.K., Miller, K.G., Browning, J.V., Habib, D., & Sugarman, P.J. (1997). Ejecta layer at the Cretaceous-Tertiary boundary, Bass River, New Jersey (Ocean Drilling Program Leg 174AX). *Geology, 25*(8),759–762.

Pardo, A., Ortiz, N. & Keller, G. (1996). Latest Maastrichtian foraminiferal turnover and its environmental implications at Agost, Spain. In: In N. Macleod & G. Keller (Eds.), *The Cretaceous/Tertiary Boundary Mass Extinction: Biotic and Environmental Events*. (Norton, New York), 139-171.

Peirce, J., Weissel, J. et al. (1989). *Proceedings of the Ocean Drilling Program, Initial Reports,121*. College Station, TX: Ocean Drilling Program.

Perch Nielsen, K., McKenzie, J., Quziang, H.E., Silver, L.T., & Schultz, P.H. (1982). Biostratigraphy and isotope stratigraphy and the "catastrophic" extinction of calcareous nannoplankton at the Cretaceous/Tertiary boundary: *Geological Society of America Special Paper, 190,* 353-371.

Poore, R., Tauxe, L., Percival Jr., S.F., Labrecque, J.L., Wright, R., Petersen, N.Y.P., Smith, C.C., Tucker, P. & Hsu, K.J. (1983). Late Cretaceous-Cenozoic Magnetostratigraphic and biostratigraphic correlations of The South Atlantic Ocean: DSDP Leg 73: *Palaeogeography, Palaeoclimatology, Palaeoecology, 42*, 127-149.

Premoli Silva, I., Haggerty, J., Rack, F. et al. (1993). *Proceedings of the Ocean Drilling Program, Initial Reports, 144*. College Station, TX: Ocean Drilling Program.

Punekar, J., Keller, G., Khozyem, H.M., Adatte, T., Font, E., & Spangenberg, J. (2016). A multi-proxy approach to decode the end-Cretaceous mass extinction: *Palaeogeography, Palaeoclimatology, Palaeoecology, 441*, 116-136.

Rea, D.K., Basov, L.A., Janecek, T.R., Palmer-Julson, A. et al. (1993). *Proceedings of the*

Ocean Drilling Program, Initial Reports, 145. College Station, TX: Ocean Drilling Program.

Robin, E., Boclet, D., Ph. Bonte, Ph., Froget, L., C. Jehanna, C. & Rocchia. R. (1991). The stratigraphic distribution of Ni-rich spinels in Cretaceous-Tertiary boundary rocks at El Kef (Tunisia), Caravaca (Spain) and Hole 761C (Leg 122): *Earth and Planetary Science Letters. V. 107* (3-4), 715-721.

Ruddiman, W., Sarnthein, M., Baldauf, J. et al. (1988). *Proceedings of the Ocean Drilling Program, Initial Reports, 108 (Part A).* College Station, TX: Ocean Drilling Program.

Sager, W.W., Winterer, E.L, Firth, J.V. et al. (1993). *Proceedings of the Ocean Drilling Program, Initial Reports, 14.* College Station, TX, Ocean Drilling Program.

Sanford, J.C., Snedden, J.W., & Gulick, S.P.S. (2016). The Cretaceous-Paleogene boundary deposit in the Gulf of Mexico: Large-scale oceanic basin response to the Chicxulub impact. *Journal of Geophysical Research, Solid Earth, v. 121 (3)*, 1240-1261. https://doi.org/10.1002/2015JB012615

Saito, T., Yamanoi, T., & Kaiho, K. (1986). End-Cretaceous devastation of terrestrial flora in the boreal Far East: *Nature, 323*, 253-255.

Schlanger, S.O., Jackson, E.D. et al. (1976). *Initial Reports of the Deep Sea Drilling Project, 33*. Washington DC, U.S. Government Printing Office.

Schlich, R., Wise, Jr., S.W. et al. (1989). *Proceedings of the Ocean Drilling Program, Initial Reports 120*. College Station, TX, Ocean Drilling Program.

Schmitz, B., Keller, G., & Stenvall, O., (1992). Stable isotope and f oraminiferal changes across the Cretaceous-Tertiary boundary at Stevns Klint, Denmark Arguments for long-term oceanic instability before and after bolide-impact event: *Palaeogeography, Palaeoclimatology, Palaeoecology, 96*, 233-260.

Schulte, P., Speijer, R., Mai, H., & Kontny, A. (2006). The Cretaceous–Paleogene (K–P) boundary at Brazos, Texas: Sequence stratigraphy, depositional events and the Chicxulub 903 impact. *Sedimentary Geology,* 184, 77-109.

Schulte, P., Speijer, P., Brinkhuis, H., Kontny, A., Claeys, P., Galeotti , S., & Smit, J. (2008). Comment on the paper “Chicxulub impact predates K–T boundary: New evidence from Brazos, Texas” by Keller et al., 2008: Earth and Planetary Science Letters, 269, 614-620.

Schulte, P., Alegret, L., Arenillas, I., Arz, J. A., Barton, P. J., Bown, P. R., et al. (2010). The Chicxulub asteroid impact and mass extinction at the Cretaceous-Paleogene boundary. *Science (New York, N.Y.)*, *327*(5970), 1214–1218, https://doi.org/10.1126/science.1177265

Sibuet, J.-C, Ryan, W.B.F., et al. (1979). *Initial Reports of the Deep Sea Drilling Project, 47 Part 2*. Washington DC: U.S. Government Printing Office.

Sigurdsson, H., Leckie, R.M., Acton, G.D., et al. (1997) *Proceedings of the Ocean Drilling Program, Initial Reports, 165*. College Sta- tion, TX: Ocean Drilling Program.

Simpson, E.S.W., Schlich, R., et al. (1974). *Initial Reports of the Deep Sea Drilling Project, 25.* Washington DC: U.S. Government Printing Office.

Smit, J. (1999). The global stratigraphy of the Cretaceous-Tertiary boundary impact ejecta. *Annual Review of Earth and Planetary Sciences, 27*, 75−113.

Smit, J. & Romein, A.J.T. (1985). A sequence of events across the Cretaceous-Tertiary boundary: *Earth and Planetary Science Letters, 74*, 55-170.

Smit, J., Montanari, A., Swinburne, N.H.M., Alvarez, w., Hildebrand, A.R., Margolis, S.V., Claeys, Lowrie, W., & Asaro, F. (1992). Tektite-bearing, deep-water clastic unit at the Cretaceous-Tertiary boundary in northeastern Mexico: *Geology, 20,* 99-103.

Smit, J., Roep, T.B., Alvarez, W., Montanari, A., Claeys, P., Grajales-Nishimura, J.M., & Bermudez, J. (1996). Coarse-grained, clastic sandstone complex at the K/T boundary around the Gulf of Mexico: Deposition by tsunami waves induced by the Chicxulub impact. *Geological Society of America Special Paper 307*, 151−182.

Stinnesbeck, W., Keller, G., de la Cruz, J., de León, C., MacLeod, N., & Whittaker, J.E. (1997). The Cretaceous–Tertiary transition in Guatemala: limestone breccia deposits from the South Peten basin. Geologische Rundschau, 86, 686-709.

Storms, M.A., Natland, J.H. et al. (1991). *Proceedings of the Ocean Drilling Program, Initial Reports 132*. College Station, TX: Ocean Drilling Program.

Stott, L.D. & Kennett, J. P. (1990). The paleoceanographic and paleoclimatic signature of the Cretaceous/Paleogene boundary in the Antarctic: stable isotopic results from ODP leg 113. In P.F. Barker, J.P. Kennett, et al. *Proceedings of the Ocean Drilling Program, Scientific Results, 113*. College Station, TX: Ocean Drilling Program.

Stüben, D., Kramar, U., Berner, Z., Stinnesbeck, W.. Keller, G.. & Adatte, T. (2002). Trace elements, stable isotopes, and clay mineralogy of the Elles II K/T boundary section in Tunisia: indications for sea level fuctuations and primary productivity. *Palaeogeography, Palaeoclimatology, Palaeoecology, 178*, 321-345.

Suganuma, Y. & Ogg, J. G. (2006). Campanian through Eocene magnetostratigraphy of Sites 1257–1261, OD Leg 207, Demerara Rise (western equatorial Atlantic). In D.C. Mosher, J. Erbacher, and M.J. Malone, (Eds.), *Proceedings of the Ocean Drilling Program, Scientific Results, 207*(3). College Station, TX: Ocean Drilling Program. doi:10.2973/odp.proc.sr.207.102.2006

Supko, P. R., Perch-Nielsen, K. et al. (1977). *Initial Reports of the Deep Sea Drilling Project, 39.* Washington, DC: U.S. Government Printing Office.

Tada, R., Iturralde-Vinent, M.A., Matsui, T., Tajika, E., Oji, T., Goto, K., Nakano, Y., Takayama, H., Yamamoto, S., Kiyokawa, S., Toyoda, K., Garcıa-Delgado, D., Dıaz-Otero, C., & Rojas-Consuegra, R. (2003). K/T boundary deposits in the Paleo-western Caribbean basin. In C. Bartolini, R. T. Buffler, and J. Blickwede, (Eds.), The Circum-Gulf of Mexico and the Caribbean: Hydrocarbon habitats, basin formation, and plate tectonics. *American Association of Petroleum Geologists Memoir 79,* 582–604.

Tarduno, J.A., Duncan, R.A., Scholl, D.W. et al. (2002). *Proceedings of the Ocean Drilling Program, Initial Reports, 197*. College Station, TX: Ocean Drilling Program. doi:10.2973/odp.proc.ir.197.2002

Taylor, K.W.R., Willumsen, P.S., Hollis, C.J., Pancost, R.D. (2018). South Pacific evidence for the long-term climate impact of the Cretaceous/Paleogene boundary event. *Earth Science Reviews*, 179, 287-302. doi.org/10.1016/j.earscirev.2018.02.012

Thiede, J., Vallier, T. L. et al. (1981). *Initial Reports of the Deep Sea Drilling Project, 62*. Washington, DC: U.S. Government Printing Office.

Tobin, S.T., Ward, P. D., Steig, E.J., Olivero, E.B., Hilburn, I.A., Mitchell, R.N., Diamond, M. R., Raub, T.D., & Kirschvink, J. L. (2012). Extinction patterns, $\delta^{18}O$ trends, and magnetostratigraphy from a southern high-latitude Cretaceous–Paleogene section: Links with Deccan volcanism: *Palaeogeography, Palaeoclimatology, Palaeoecology, v. 350–352*, 180 –188.

Tucholke, B. E., Vogt, P.R. et al. (1979). *Initial Reports of the Deep Sea Drilling Project, 43*. Washington, DC: U.S. Government Printing Office.

Tucholke, B.E., Sibuet, J.-C., Klaus, A. et al. (2004). *Proceedings of the Ocean Drilling Program, Scientific Results, 210*. College Station, TX: Ocean Drilling Program. doi:10.2973/odp.proc.ir.210.2004

van Hinte, J. E., Wise, Jr., S.W. et al. (1987). *Initial Reports of the Deep Sea Drilling Project, 93.* Washington, DC: U.S. Government Printing Office.

Veevers, J. J., Heirtzler, J.R. et al. (1974). *Initial Reports of the Deep Sea Drilling Project, 27.* Washington, DC: U.S. Government Printing Office.

von der Borch, C., Sclater, C.J.G. et al. (1974). *Initial Reports of the Deep Sea Drilling Project, 22.* Washington, DC: U.S. Government Printing Office.

von Rad, U., Ryan, W.B.F. et al. (1979). *Initial Reports of the Deep Sea Drilling Project, 47, Part 1*. Washington, DC: U.S. Government Printing Office.

von Rad, U., Haq, B.U. et al. (1992). *Proceedings of the Ocean Drilling Program, Scientific Results*, *122*. CollegeStation, TX: Ocean Drilling Program.

Weissel, J., Peirce, J., Taylor, E., Alt, J. et al. (1991). *Proceedings of the Ocean Drilling Program, Scientific Results, 121*. College Station, TX: Ocean Drilling Program.

Winterer, E.L., Ewing, J.I. et al. (1973). *Initial Reports of the Deep Sea Drilling Project, 17.* Washington, DC: U.S. Government Printing Office.

Witts, J.D., Whittle, R.J., Wignall, P.B., Crame, J.A., Francis, J.E., Newton, R.J., & Bowman, V. (2016). Macrofossil evidence for a rapid and severe Cretaceous–Paleogene mass extinction in Antarctica. *Nature Communications, 7*, 11738. Doi:10.1038/ncomms11738.

Witts, J.D., Newton, R.J., Mills, B.J.W., Wignall .P.B., Bottrell, S.H., Hall, J.L.O., Francis, J.E. & Crame, J.A. (2018). The impact of the Cretaceous–Paleogene (K–Pg) mass extinction event on the global sulfur cycle: Evidence from Seymour Island, Antarctica. *Geochimica et Cosmochimica Acta*, 230, 17-45. https://doi.org/10.1016/j.gca.2018.02.037

Worzel, J.L., Bryant, W. et al. (1973). *Initial Reports of the Deep Sea Drilling Project, 10.* Washington, DC: U.S. Government Printing Office.

Zachos, J.C., Arthur, M.A., Thunell, R.C., Williams, D.F., & Tappa. E.J. (1985). Stable isotope and trace element geochemistry of carbonate sediments across the Cretaceous/Tertiary boundary at Deep Sea Drilling Project Hole 577, Leg 86. In G.R. Heath, L.H. Burckle, et al., *Initial Reports of the Deep Sea Drilling Project,* *86.*Washington DC: U.S. Government Printing Office, 513-532. doi:10.2973/dsdp.proc.86.120.1985

Zachos, J.C., Arthur, M.A., & Dean, W.E. (1989). Geochemical evidence for suppression of pelagic marine productivity at the Cretaceous/Tertiary boundary: *Nature, 337*, 61–64.

Zachos, J.C., Kroon, D., Blum, P. et al. (2004). *Proceedings of the Ocean Drilling Program, Initial Results 208*. College Station, TX, Ocean Drilling Program. doi:10.2973/odp.proc.ir.208.2004