# Site of asteroid impact changed the history of life on Earth: the low probability of mass extinction: Supplementary information

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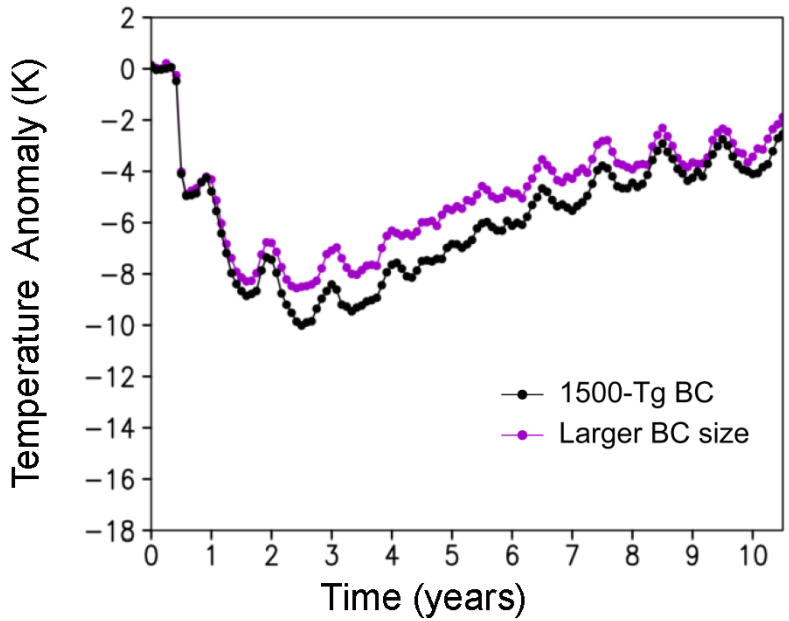
We referred to the literature[55–97] in Supplemental Table 2 in removing the Cenozoic sedimentary rock thickness data from the total calculated thickness of the sedimentary rocks of the continental crust in areas of high hydrocarbon content (orange and magenta areas in Figure 4).




**Supplemental Figure 1: Model sensitivity experiments for the surface air temperature changes for the 1500-Tg BC Chicxulub case.** Changes in the global averages of surface air temperature for the 1500-Tg BC case (black) and the experiment with a larger BC particle size distribution (purple) calculated by the climate model. Monthly anomalies from the control experiment (no ejection case) are shown. See the text (Methods) for details.

**Supplemental Table 1: Summary of maximum global mean surface air temperature anomalies due to soot and sulfate, presence or absence of mass extinctions in various target areas, and occupancy of each area**

| ~9 km asteroid Carbon and sulfur Impact target area & typical thickness of source rocks (mantle) (km) | Occupancy (%) | Surviving soot in the stratosphere (Tg) | Temp anomaly by soot in global (°C) | Temp anomaly by soot on land (°C) | Surviving $SO_4$ in the stratosphere Case 1 (Tg) | Surviving $SO_4$ in the stratosphere Case 2 (Tg) | Temp anomaly by $SO_4$ in global Case 1 (°C) | Temp anomaly by $SO_4$ in global Case 2 (°C) | Mass extinction |
|---|---|---|---|---|---|---|---|---|---|
| Oceanic low hydrocarbon 0.1 – 0.5 (15) | 49.9 | 2 – 12 | 0 – -2 | 0 – -3 | 35 | 210 | -0.5 | -1 – -3 | No |
| Oceanic medium hydrocarbon 0.5 – 2 (15 – 10) | 12.4 | 59 – 230 | -4 – -8 | -6 – -13 | 43 – 65 | 260 – 390 | -0.5 – -1.5 | -1 – -4 | No |
| Oceanic high hydrocarbon 2 – 5 (13 – 10) | 5.2 | 230 – 590 | -8 – -11 | -13 – -17 | 65 – 110 | 390 – 650 | -0.5 – -2 | -1 – -6 | Yes |
| Oceanic very high hydrocarbon 5 – 20 (10 – 0) | 0.8 | 590 – 2300 | -11– <-11 | -17 – <-17 | 110 – 350 | 650 – 2100 | -0.5 – -4 | -2 – -11 | Yes |
| Continental crust low hydrocarbon 0.1 – 0.5 | 17.8 | 12 – 59 | -2 – -4 | -3 – -6 | 2 – 9 | 11 –55 | 0 | 0 – -0.5 | No |
| Continental crust medium hydrocarbon 0.5 – 2 | 7.3 | 59 – 230 | -4 – -8 | -6 – -13 | 9 – 35 | 55 – 210 | 0 – -1 | 0.5 – -3 | No |
| Continental crust high hydrocarbon 2 – 5 | 4.4 | 230 – 590 | -8 – -11 | -13 – -17 | 35 – 91 | 210– 550 | -0.5 – -2 | -1 – -6 | Yes |
| Continental crust very high hydrocarbon 5 – 20 | 1.1 | 590 – 2300 | -11– <-11 | -17 – <-17 | 91 – 350 | 550 – 2100 | -0.5 – -4 | -2 – -11 | Yes |
| High hydrocarbon & high sulfur* 2 – 5 | 0.8 | 230 – 590 | -8 – -11 | -13 – -17 | 300 – 760 | 1800 – 4550 | -1 – -7 | -3 – -13 | Yes |
| High hydrocarbon & high sulfur: K-Pg case* 3 | - | 350 | -10 | -16 | 460 | 2750 | -1 – -5 | -3 – -11 | Yes |
| Very high hydrocarbon & high sulfur* 5 – 20 | 0.2 | 590 – 2300 | -11– <-11 | -17 – <-17 | 760 – 910 | 4550 – 5500 | -2 – -7 | -4 – -14 | Yes |
| Probability of mass extinction | | | | | | | | | ~13% |

Colors in soot and $SO_4$ columns correspond to those in Tables 1 and 2. The color gradient from pale to deep blue indicates the scale of

global mean surface air temperature anomaly. The deepest blue areas correspond to surface air temperature anomaly causing a mass extinction. Temperatures were derived using the K curve for soot and HR (upper case) and LTS (lower case) curves for sulfate in Fig. 5. See the text for case 1 and case 2 details. *continental crust. Temp: surface air temperature.

**Supplemental Table 2: Ratio between pre-Cenozoic sedimentary rock thickness and total thickness or thickness of the Cenozoic sediments to obtain pre-Cenozoic sedimentary rock thickness for orange and magenta areas in Fig. 4.**

| Area of high organic carbon content | Pre-Cenozoic/Total | Thickness of the Cenozoic (km) | Reference |
|---|---|---|---|
| Off eastern Africa | | 0.6 | *55* |
| Off southwestern Africa | 0.7 | 0.1-0.5 | *56-58* |
| Congo | >0.9 | | *59* |
| Off northwestern Africa | 0.3 | | *60* |
| Sahara | 0.8 | | *61* |
| Mediterranean | 0.5 | | *62, 63* |
| Northern Arabia | >0.9 | | *64* |
| Black Sea | 0.8 | | *65, 66* |
| Caspian Sea | 0.8-0.9 | | *67, 68* |
| Northern Europe | >0.9 | | *69* |
| Off Northern Europe | | 0.5 | *70* |
| Europian Arctic | 0.9 | | *71* |
| Western Siberia | >0.9 | | *72* |
| Central Siberia | >0.9 | | *73, 74* |
| Eastern Siberia | >0.9 | | *75* |
| Central China | >0.9 | | *74, 75* |
| Tarim Basin | >0.9 | | *76* |

| | | | |
|---|---|---|---|
| Turkmenistan | >0.9 | | *77* |
| Himalayas | >0.9 | | *74, 78* |
| Arabian Sea | | >5 | *79* |
| Bay of Bengal | 0.2 | | *80* |
| Off Northwestern Australia | 0.4, 0.8 | | *81, 82* |
| Australia basins | >0.9 | | *83* |
| Off Antarctica | | 1.0 | *84* |
| Andes | >0.9 | | *85* |
| Off Southeastern South America | ~0.6 | 0.4 | *86* |
| Off Northern South America | 0.6 | | *57* |
| Gulf Coast | 0.9 | | *87* |
| Gulf of Mexico | 0.9 | | *88* |
| Yucatan | 0.9 | | *54* |
| Off Eastern North America | | 0.3-1.0 | *89, 90* |
| Rocky Mountains | >0.9 | | *91* |
| Aleutian Basin | | 1.0 | *92, 93* |
| Canadian Arctic | 0.9 | | *94, 95* |
| Off western Greenland | | ~1 | *96* |
| Off eastern Greenland | | 0.9 | *97* |

**Supplemental Table 3: Area ($km^2$) of each region defined by latitude, geography, and amount of organic matter**

| Color in Figure 1 | Area | N60-90 | N30-60 | N0-30 | S0-30 | S30-60 | S60-90 | Total | Occupancy (%) |
|---|---|---|---|---|---|---|---|---|---|
| White | Ocean | 5,291,066 | 37,570,230 | 75,060,124 | 75,630,904 | 52,083,568 | 9,847,780 | 255,483,673 | 49.9 |
| | Shelf | 890,730 | 1,063,014 | 454,537 | 16,582 | 105,627 | - | 2,530,491 | 0.5 |
| | Continent | 5,111,671 | 24,284,360 | 16,487,641 | 23,832,231 | 10,496,692 | 8,184,455 | 88,397,051 | 17.3 |
| White total | | 11,293,468 | 62,917,604 | 92,002,302 | 99,479,718 | 62,685,887 | 18,032,236 | 346,411,214 | 67.7 |
| Olive | Ocean | 6,591,556 | 5,305,688 | 12,490,795 | 12,542,679 | 14,807,865 | 11,456,461 | 63,195,044 | 12.4 |
| | Shelf | 468,236 | 1,657,506 | 283,731 | 109,059 | 2,007,997 | 109,826 | 4,636,355 | 0.9 |
| | Continent | 1,416,107 | 11,028,895 | 6,122,278 | 7,372,063 | 5,233,596 | 1,430,787 | 32,603,727 | 6.4 |
| Olive total | | 8,475,899 | 17,992,090 | 18,896,803 | 20,023,801 | 22,049,459 | 12,997,074 | 100,435,127 | 19.6 |
| Orange | Ocean | 5,810,662 | 2,028,152 | 7,912,811 | 4,540,188 | 4,225,328 | 2,231,690 | 26,748,831 | 5.2 |
| | Shelf | 608,395 | 1,813,977 | 1,056,168 | 299,063 | 1,355,842 | 77,583 | 5,211,027 | 1 |
| | Continent | 5,020,133 | 6,334,041 | 4,620,573 | 2,682,041 | 2,281,019 | 599,636 | 21,537,444 | 4.2 |
| Orange total | | 11,439,189 | 10,176,170 | 13,589,552 | 7,521,292 | 7,862,189 | 2,908,909 | 53,497,302 | 10.5 |
| Magenta | Ocean | 1,651,169 | 250,409 | 1,279,557 | 388,808 | 420,149 | 289,145 | 4,279,237 | 0.8 |
| | Shelf | 272,748 | 872,857 | 1,006,660 | 99,113 | 320,391 | 11,561 | 2,583,329 | 0.5 |
| | Continent | 1,159,586 | 1,575,847 | 1,036,784 | 303,108 | 237,951 | - | 4,313,275 | 0.8 |
| Magenta total | | 3,083,503 | 2,699,113 | 3,323,000 | 791,028 | 978,491 | 300,706 | 11,175,841 | 2.2 |
| Total | | 34,292,059 | 93,784,977 | 127,811,658 | 127,815,840 | 93,576,025 | 34,238,924 | 511,519,483 | |

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