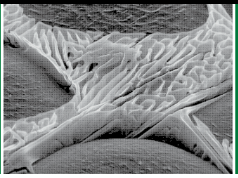
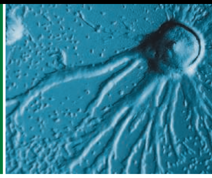




LETTERS

edited by Jennifer Sills

Cretaceous Extinctions: Multiple Causes

IN THE REVIEW "THE CHICXULUB ASTEROID IMPACT AND MASS EXTINCTION AT THE CRETACEOUS-Paleogene boundary" (P. Schulte *et al*., 5 March, p. 1214), the terminal Cretaceous extinctions were confidently attributed to a single event, the environmental consequences of the impact of an extraterrestrial body. The list of 41 authors, although suggesting a consensus, conspicuously lacked the names of researchers in the fields of terrestrial vertebrates, including dinosaurs, as well as freshwater vertebrates and invertebrates. Although we the undersigned differ over the specifics, we have little doubt that an impact played some role in these extinctions. Nevertheless, the simplistic extinction scenario presented in the Review has not stood up to the countless studies of how vertebrates and other terrestrial and marine organisms fared at the end of the Cretaceous (*1*–*4*).

Deccan plateau basalts. Lava from Deccan volcanism formed distinct layering.

Patterns of extinction and survival were varied, pointing to multiple causes at this time—including impact, marine regression, volcanic activity, and changes in global and regional climatic patterns (*5*). It is telling that in all other instances of mass extinction in the past 600 million years, no signature of an extraterrestrial impact has ever been reliably detected, despite extensive searches. Moreover, there are many other known instances of large impacts in the geologic record, with no associated extinctions (*6*). The general importance of impacts to extinction is called into question, as well as the importance of the Cretaceous-Paleogene impact as a single cause (*7*). By contrast, all of the five widely accepted mass extinctions occur during or shortly after times of global marine regression (*8*) and at least three occur during intervals of massive volcanism (*9*).

J. DAVID ARCHIBALD,[1]* W. A. CLEMENS,[2] KEVIN PADIAN,[2] TIMOTHY ROWE,[3] NORMAN MACLEOD,[4] PAUL M. BARRETT,[4] ANDREW GALE,[5] PAT HOLROYD,[6] HANS-DIETER SUES,[7] NAN CRYSTAL ARENS,[8] JOHN R. HORNER,[9] GREGORY P. WILSON,[10] MARK B. GOODWIN,[6] CHRISTOPHER A. BROCHU,[11] DONALD L. LOFGREN,[12] STUART H. HURLBERT,[1] JOSEPH H. HARTMAN,[13] DAVID A. EBERTH,[14] PAUL B. WIGNALL,[15] PHILIP J. CURRIE,[16] ANNE WEIL,[17] GUNTUPALLI V. R. PRASAD,[18] LOWELL DINGUS,[19] VINCENT COURTILLOT,[20] ANGELA MILNER,[4] ANDREW MILNER,[4] SUNIL BAJPAI,[21] DAVID J. WARD,[22] ASHOK SAHNI[23]

[1]Department of Biology, San Diego State University, San Diego, CA 92182–4614, USA. [2]Department of Integrative Biology and Museum of Paleontology, University of California, Berkeley, CA 94720–3140, USA. [3]Jackson School of Geosciences, University of Texas, Austin, TX 78712, USA. [4]Department of Palaeontology, The Natural History Museum, London SW7 5BD, UK. [5]Department of Earth and Enviromental Science, University of Portsmouth, Portsmouth, Hants PO1 3QL, UK. [6]Museum of Paleontology, University of California, Berkeley, CA 94720–4781, USA. [7]Department of Paleobiology, National Museum of Natural History, Washington, DC 20013–7012, USA. [8]Department of Geoscience, Hobart and William Smith Colleges, Geneva, NY 14456, USA. [9]Museum of the Rockies, Montana State University, Bozeman, MT 59717, USA. [10]Department of Biology, University of Washington, Seattle, WA 98195–1800, USA. [11]Department of Geoscience, University of Iowa, Iowa City, IA 52242, USA. [12]Raymond M. Alf Museum of Paleontology, Claremont, CA 91711, USA. [13]Department of Geology and Geological Engineering, University of North Dakota, Grand Forks, ND 58202–8358, USA. [14]Royal Tyrrell Museum, Drumheller, AB T0J 0Y0, Canada. [15]School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK. [16]Department of Biological Sciences, University of Alberta, Edmonton, AB T6G 2E9, Canada. [17]Department of Anatomy and Cell Biology, Oklahoma State University Center for Health Sciences, Tulsa, OK 74107, USA. [18]Department of Geology, University of Delhi, Delhi 110 007, India. [19]InfoQuest Foundation, 160 Cabrini Boulevard, No. 48, New York, NY 10033, USA. [20]Institut de Physique du Globe de Paris, 75251 Paris, France. [21]Department of Earth Sciences, Indian Institute of Technology, Roorkee 247667 (Uttarakhand), India. [22]Department of Earth and Environmental Sciences, Medway Campus, University of Greenwich, Chatham, Kent ME4 4AW, UK. [23]Centre of Advanced Study in Geology, Lucknow University, Lucknow 226001, India.

*To whom correspondence should be addressed. E-mail: darchibald@sunstroke.sdsu.edu

References

1. G. P. Wilson, *J. Mam. Evol*. **12**, 53 (2005).
2. J. D. Archibald, D. E. Fastovsky, in *The Dinosauria*, D. B. Weishampel *et al*., Eds. (Univ. of California Press, Berkeley, CA, 2004), pp. 672–684.
3. N. MacLeod *et al*., *J. Geol. Soc. London* **154**, 265 (1997).
4. P. M. Barrett *et al*., *Proc. R. Soc. London Ser. B* **276**, 2667 (2009).
5. N. MacLeod, in *Evolution on Planet Earth*, L. Rothschild, A. Lister, Eds. (Academic Press, London, 2003), pp. 253–277.
6. C. W. Poag *et al*., in *Deep-Sea Research, Part II*, R. Gersonde *et al*., Eds. (Pergamon, New York, 2002), pp. 1081–1102.
7. N. C. Arens, I. D. West, *Paleobiology* **34**, 456 (2008).
8. S. E. Peters, *Nature* **454**, 626 (2008).
9. P. B. Wignall, *Earth Sci. Rev*. **53**, 1 (2001).

Cretaceous Extinctions: The Volcanic Hypothesis

IN THEIR REVIEW "THE CHICXULUB ASTERoid impact and mass extinction at the Cretaceous-Paleogene boundary" (5 March, p. 1214), P. Schulte *et al*. conclude that "the Chicxulub impact triggered the mass extinction." However, the Review does not give sufficient and accurate consideration to the volcanic hypothesis. The authors claim that for Chicxulub, "the extremely rapid injection rate of dust and climate-forcing gases would have magnified the environmental consequences compared with more-prolonged volcanic eruptions." As evidence, they cite our paper (*1*), saying, "the injection of ~100 to 500 Gt of sulfur into the atmosphere within minutes after the Chicxulub impact contrasts with volcanic injection rates of 0.05 to 0.5 Gt of sulfur per year during the ~1-million-year-long main phase of Deccan flood basalt volcanism." This contains a substantial error and a fundamental misrepresentation of our paper. Half a Gt per year of sulfur for 1 million years amounts to 500,000 Gt of sulfur, which in any

CREDIT: GSFC/NASA

CORRECTIONS AND CLARIFICATIONS

Reports: "Cryogenian glaciation and the onset of carbon-isotope decoupling" by N. L. Swanson-Hysell *et al*. (30 April, p. 608). A typographical error in the Fig. 2 caption was introduced to the print edition during page proofs. The correct final sentence of the Fig. 2 caption is, "An increase in k_w and in the relative burial of C as organic matter can result in a decrease in CO_2, as shown for the Mesoproterozoic ⊠Tonian ⊠ Cryogenian, without changes in volcanic CO_2 input." The caption is correct in the HTML version online.

Cover caption: (23 April, p. 397). The cover image showed children studying chemistry, not nuclear physics.

Reports: "Protein kinase C-θ mediates negative feedback on regulatory T cell function" by A. Zanin-Zhorov *et al*. (16 April, p. 372). In the first sentence of the second paragraph on p. 372, T_{eff} should have been defined as $CD4^+$ $CD25^-$.

Reports: "Arsenic trioxide controls the fate of the PML-RARα oncoprotein by directly binding PML" by X.-W. Zhang *et al*. (9 April, p. 240). In the legend for Fig. 3C, the local structure models were described incorrectly; Zn-PML-R is blue and As-PML-R is orange.

Policy Forum: "China's road to sustainability" by J. Liu (2 April, p. 50). In the first sentence, China refers to the People's Republic of China. The word "caused" was missing from the sentence "The 'Great Leap Forward' movement (1958–1961) caused the loss of at least 10% of China's forests to fuel backyard furnaces for steel production."

News Focus: "Immunology uncaged" by M. Leslie (26 March, p. 1573). The article incorrectly stated that the Center for Human Immunology, Autoimmunity, and Inflammation was part of the National Heart, Lung, and Blood Institute. It is a separate initiative sponsored by several NIH institutes. The article should also have emphasized that the center is conducting immunological research and is not a technical service facility.

News Focus: "Treatment as prevention" by J. Cohen (5 March, p. 1196). The title on the graphic mistakenly indicated that "incidence" dropped. The researchers did not measure "incidence" but did find a drop in the number of HIV infections detected.

Reports: "Acetylation of metabolic enzymes coordinates carbon source utilization and metabolic flux" by Q. Wang *et al*. (19 February, p. 1004). In Fig. 2B, the inhibitor used to mimic the *cobB* mutation was NAM (nicotinamide) not NAD^+ (nicotinamide adenine dinucleotide).

---

climate model would lead to a "snowball" Earth! In (*1*), we estimate the total amount of SO_2 released by the traps at about 10,000 Gt, less by a factor of 50 than that in Schulte *et al*.'s Review. The Deccan erupted in a small number of short, huge pulses, reducing actual injection duration to far less than 1 million years. We and others (*2*, *3*) have argued that two main phases likely lasted a few thousand to tens of thousands of years, during which individual flows would have reached volumes of 10,000 km^3 and released up to 100 Gt of sulfur in one or a few decades (based on analysis of paleomagnetic secular variation). Schulte *et al*. use our study to show that volcanism did not lead to the extinction, yet we showed that injection of SO_2 by a single volcanic pulse could have had a climatic impact similar to Chicxulub. We estimated (*1*) that the largest Deccan pulses emitted up to 100 Gt of sulfur at 0.5 Gt per year for a few decades to tens of decades, implying a radiative effect slightly lower but lasting substantially longer than in the impact case. Whereas impact was a single event, some 30 volcanic pulses emitted total amounts of SO_2 not very different from Chicxulub. Their sequence would have generated a runaway effect not allowed by a single impact or volcanic pulse. Evidence of an association between extinctions and continental flood basalts (CFBs) arising from eruption has been proposed since at least 1986 (*4*–*7*). Subsequent work has shown that all extinction or oceanic anoxia events in the past 300 million years are associated with a large accumulation of igneous material of the same age within uncertainties (*8*). No conclusive impact has been demonstrated at any mass extinction boundary other than the Cretaceous-Paleogene. The case of the largest CFB (Siberian traps) and mass extinction (Permo-Triassic ~250 million years ago) is now generally accepted. Without challenging the existence or age of the Chicxulub impact, we believe that it is increasingly arguable that it could not by itself have caused a mass extinction, but that because it took place demonstrably during Deccan eruptions (*9*, *10*), it contributed significantly to the mass extinction, as yet another giant lava flow could have, in an already very weakened environment.

VINCENT COURTILLOT* AND FRÉDÉRIC FLUTEAU

Institut de Physique du Globe, Paris, France.

*To whom correspondence should be addressed. E-mail: courtil@ipgp.fr

References

1. A.-L. Chenet *et al*., *J. Geophys. Res*. **114**, B06103, 10.1029/2008JB005644 (2009).
2. S. Self, T. Thordarson, M. Widdowson, A. Jay, *Earth Planet. Sci. Lett*. **248**, 518 (2006).
3. G. Keller, T. Adatte, S. Gardin, A. Bartolini, S. Bajpai, *Earth Planet. Sci. Lett*. **268**, 293 (2008).
4. V. Courtillot *et al*., *Earth Planet. Sci. Lett*. **80**, 361 (1986).
5. M. R. Rampino, R. B. Stothers, *Science* **241**, 663 (1988).
6. V. Courtillot, *Isr. J. Earth Sci*. **43**, 255 (1994).
7. V. Courtillot, *Evolutionary Catastrophes: The Science of Mass Extinctions* (Cambridge Univ. Press, Cambridge, 1999).
8. V. Courtillot, P. Renne, *C. R. Acad. Sci*. **335**, 113 (2003).
9. N. Bhandari, P. N. Shukla, Z. G. Ghevariya, S. M. Sundaram, *Geophys. Res. Lett*. **22**, 433 (1995).
10. V. Courtillot *et al*., *Earth Planet. Sci. Lett*. **182**, 137 (2000).

Cretaceous Extinctions: Evidence Overlooked

IN THEIR REVIEW "THE CHICXULUB ASTEROID impact and mass extinction at the Cretaceous-Paleogene boundary" (5 March, p. 1214), P. Schulte *et al*. analyzed the 30-year-old controversy over the cause of the end-Cretaceous mass extinction and concluded that the original theory of 1980 was right: A large asteroid impact on Yucatan was the sole cause for this catastrophe. To arrive at this conclusion, the authors used a selective review of data and interpretations by proponents of this viewpoint. They ignored the vast body of evidence inconsistent with their conclusion—evidence accumulated by scientists across disciplines (paleontology, stratigraphy, sedimentology, geochemistry, geophysics, and volcanology) that documents a complex long-term scenario involving a combination of impacts, volcanism, and climate change. Here, we point out some of the key evidence that Schulte *et al*. overlooked.

The underlying basis for Schulte *et al*.'s claim that the Chicxulub impact is the sole cause for the Cretaceous-Paleogene (K-Pg) mass extinction is the assumption that the iridium (Ir) anomaly at the K-Pg boundary and Chicxulub are the same age. There is no evidence to support this assertion. No Ir anomaly has ever been identified in association with undisputed Chicxulub impact ejecta (impact glass spherules), and no impact spherules have ever been identified in the Ir-enriched K-Pg boundary clay in Mexico or elsewhere (*1*, *2*). In rare deep-sea sites where the Ir anomaly is just above impact spherules, it is due to condensed sedimentation and/or nondeposition.

A Chicxulub impact–generated tsunami is another basic assumption of Schulte *et al*. to account for the impact spherules in late Maastrichtian sediments (including a sandstone complex) in Mexico and Texas. Multiple lines of evidence contradict this assumption and demonstrate long-term deposition before the K-Pg, including burrowed horizons, multiple impact spherule layers separated by limestone, and spherule-rich clasts that indicate the original deposition predates the K-Pg and excludes tsunami deposition (*1*–*4*).

Evidence of the pre–K-Pg age of the Chicxulub impact can also be found in sediments above the sandstone complex in Texas and northeastern Mexico and above the impact breccia in the Chicxulub crater. Evidence shows that the K-Pg boundary is not linked to the sandstone complex and impact spherules (*1*, *2*, *4*–*7*).

Evidence that supports the pre–K-Pg age of the Chicxulub impact is also found in the

Published by AAAS

presence of a spherule layer in late Maastrichtian sediments below the sandstone complex in northeastern Mexico and Texas (*2*, *4*, *8*).

Deccan volcanism is dismissed by Schulte *et al*. as much older and of no consequence in the K-Pg mass extinction. Recent Deccan volcanism studies show the contrary (*9*–*11*). These studies link the mass extinction with the main phase of Deccan eruptions.

When this evidence is taken into account, it is clear that the massive Chicxulub and Deccan database indicates a long-term multicausal scenario and is inconsistent with the model proposed by Schulte *et al*.

GERTA KELLER,[1]* THIERRY ADATTE,[2]
ALFONSO PARDO,[3] SUNIL BAJPAI,[4]
ASHU KHOSLA,[5] BANDANA SAMANT[6]

[1]Department of Geosciences, Princeton University, Princeton, NJ 08544, USA. [2]Geological and Paleontological Institute, University of Lausanne, CH 1015 Lausanne, Switzerland. [3]Escuela Politécnica Superior de Huesca, Universidad de Zaragoza, Carretera Cuarte s/n 22071, Huesca, Spain. [4]Department of Earth Sciences, Indian Institute of Technology, Roorkee 247 667, Uttarakhand, India. [5]Center for Advanced Study in Geology, Panjab University, Chandigarh 160014, India. [6]Department of Geology, Nagpur University, Nagpur 440 001, Maharashtra, India.

*To whom correspondence should be addressed. E-mail: gkeller@princeton.edu

References

1. G. Keller, *Geol. Soc. Amer. Spec. Pap.* **437**, 147 (2008).
2. G. Keller, W. Stinnesbeck, T. Adatte, D. Stueben, *Earth Sci. Rev*. **62**, 327 (2003).
3. A. A. Ekdale, W. Stinnesbeck, *Palaios* **13**, 593 (1998).
4. G. Keller *et al*., *Earth Planet. Sci. Lett*. **255**, 339 (2007).
5. G. Keller *et al*., *Proc. Natl. Acad. Sci. U.S.A.* **101**, 3753 (2004).
6. W. C. Ward, G. Keller, W. Stinnesbeck, T. Adatte, *Geology* **23**, 873 (1995).
7. M. L. Prauss, *Paleogeogr. Paleoclimatol. Paleoecol*. **283**, 195 (2009).
8. G. Keller, T. Adatte, A. J. Pardo, J. G. Lopez-Oliva, *J. Geol. Soc. London* **166**, 393 (2009).
9. G. Keller, T. Adatte, S. Gardin, A. Bartolini, S. Bajpai, *Earth Planet. Sci. Lett*. **268**, 293 (2008).
10. A.-L. Chenet, X. Quidelleur, F. Fluteau, V. Courtillot, S. Bajpai, *Earth Planet. Sci. Lett*. **263**, 1 (2007).
11. A.-L. Chenet, F. Fluteau, V. Courtillot, M. Gerard, K. V. Subbarao, *J. Geophys. Res*. **113**, B04101 (2008).

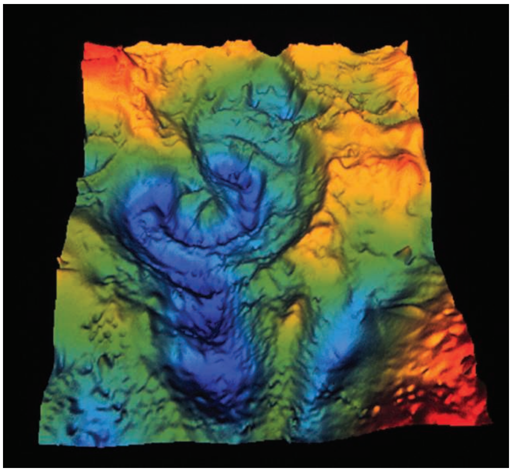
Response

THE LETTERS BY ARCHIBALD *ET AL.*, KELLER *ET al*., and Courtillot and Fluteau question our conclusion that the Cretaceous-Paleogene mass extinction was caused by the asteroid impact at Chicxulub. All three Letters stress that Deccan flood basalt volcanism played a major role in the extinction. Keller *et al*. and Archibald *et al*. also mention that climate change was a factor, and Archibald *et al*. point to marine regression as well.

We disagree with the hypothesis that volcanic activity can explain the extinction. First, geographically extensive biotic records of marine microfossils and terrestrial pollen and spores that reveal the nature of the Cretaceous-Paleogene (K-Pg) mass extinction with the greatest fidelity do not contain evidence of accelerated extinction rates during the last 400 thousand years of the Cretaceous [our Review and (*1*, *2*)] and therefore do not support the idea that the biosphere was somehow destabilized by Deccan volcanism. In fact, plant macrofossils record a diversification during this time (*2*). Studies of the last 1.5 million years of the Cretaceous from North America, Europe, and Asia [e.g., (*3*, *4*)] are compatible with a sudden extinction scenario for nonavian dinosaurs. Moreover, the constancy of late Maastrichtian open ocean sedimentation (as indicated by climate cycles driven by regular oscillations in Earth's orbit) does not provide evidence for overall declining productivity or instability in marine ecosystems preceding the boundary [e.g., (*5*)].

Second, recent studies suggest that the emplacement of the Deccan flood basalts took place during multiple (~30) large eruptive pulses, most of which predate the K-Pg boundary by several hundred thousand years (*6*). In contrast, others have argued that "activity in the continental flood basalt province as a whole is likely to have been quasi-continuous" (*7*). Nevertheless, it is extremely difficult to reconcile the protracted Deccan flood basalt eruption history with a single abrupt mass extinction horizon exactly at the K-Pg boundary. Although it is well documented that the Chicxulub impact event coincided precisely with sudden paleontological and paleoenvironmental changes and the K-Pg mass extinction [our Review and (*8*, *9*)], there are no comparable data demonstrating that a major pulse of Deccan volcanism coincided with the mass extinction. Moreover, it remains to be explained why one eruptive event would have resulted in mass extinction, whereas multiple earlier eruptive events of comparable magnitude and duration occurring up to 500 thousand years before the K-Pg boundary (*6*) left few global environmental traces [e.g., (*1*, *2*)].

Third, rates of sulfur injections are critically important to discriminating between environmental consequences of impact versus those of volcanism because the residence time of sulfur in the atmosphere is short (*10*). Courtillot and Fluteau claim that we misrepresent their 2009 paper (*6*). However, the paper includes exactly the numbers (reported as "0.1 to 1 Gt/a sulfur dioxide") we stated. We did not note their finding that the sulfur was released "over durations possibly as short as 100 years for each single eruptive event" (*6*) because this does not affect our conclusions. Maintaining such a sulfur release for 100 years would indeed result in a total sulfur release of 50 Gt, which is in the order of the lowest estimate for Chicxulub impact (see our Review). However, sulfur is removed from the atmosphere continuously (*10*) and therefore any accumulation in the atmosphere is unsupported, contrary to the claim made by Courtillot and Fluteau. We also emphasize that the instantaneous release of 100 to 500 Gt sulfur is only one consequence of the Chicxulub impact, and the K-Pg boundary mass extinction is likely the result of a combination of several impact-induced environmental effects (including the release of sulfur, soot, dust, and other effects, as noted in our Review), whereas the Deccan flood basalt hypothesis relies exclusively on the injection of sulfur dioxide (*6*).



The Chicxulub Crater. A computer-generated gravity map image shows the Chicxulub Crater on Mexico's Yucatan Peninsula.

CREDIT: NASA

With regard to Archibald *et al*.'s and Courtillot and Fluteau's comments about other Phanerozoic mass extinction events that co-occurred with the emplacement of flood basalt provinces, we note that these extinction events are commonly associated with oceanic anoxia, calcification crises, and strong global warming—none of which is observed at the K-Pg boundary (*2*, *10*–*13*). Furthermore, there is an absence of mass extinctions during several large flood basalt eruptions (*10*, *14*). Each mass extinction event should be considered relative to the record for that event [e.g., (*12*)], and we stress the unique aspects of the K-Pg boundary record. Chicxulub is by far the largest known impact event in the Phanerozoic, and the projectile hit an extraordinarily thick sulfur-rich sedimentary sequence (see our Review). The absence of evidence for impact phenomena at other mass extinctions, discussed by Archibald *et al*., is irrelevant for our synthesis of the stratigraphy and biotic response to the specific Chicxulub impact event.

Our work in no way diminishes the importance of gaining a better understanding of the environmental consequences of massive volcanism. We do not doubt that such volcanism can significantly perturb the global environment. However, a robust correlation between mass extinction and flood basalt volcanism as suggested by Courtillot and Fluteau is unlikely [see reviews of (*10*, *14*)].

Keller *et al*. and Archibald *et al*. mention that climate change contributed to the extinction. As outlined in our Review and in (*1*, *2*), climate fluctuations during the latest Maastrichtian (minor warming and subsequent cooling) and the associated faunal and floral consequences are clearly separated from the abrupt mass extinction event at the K-Pg boundary.

In response to Archibald *et al*.'s point about marine regressions, we note that marine mass extinctions may have coincided with global sea-level changes [e.g., (*15*)]. However, because sea-level changes are numerous (*15*), this association seems coincidental rather than causal (*16*). Sea-level change also fails to explain the disruption of vegetation and the faunal change observed in terrestrial environments at the K-Pg boundary (*1*).

We disagree with the comments of Keller *et al.* regarding the association between Chicxulub impact ejecta and the K-Pg boundary, and we point out that our Review addressed all of the issues to which they refer. Our Review integrated new data with previous work in the peer-reviewed literature to provide substantial corroborating evidence for a global correlation of the Chicxulub impact with the K-Pg boundary.

PETER SCHULTE,[1]* LAIA ALEGRET,[2] IGNACIO ARENILLAS,[2] JOSÉ A. ARZ,[2] PENNY J. BARTON,[3] PAUL R. BOWN,[4] TIMOTHY J. BRALOWER,[5] GAIL L. CHRISTESON,[6] PHILIPPE CLAEYS,[7] CHARLES S. COCKELL,[8] GARETH S. COLLINS,[9] ALEXANDER DEUTSCH,[10] TAMARA J. GOLDIN,[11] KAZUHISA GOTO,[12] JOSÉ M. GRAJALES-NISHIMURA,[13] RICHARD A. F. GRIEVE,[14] SEAN P. S. GULICK,[6] KIRK R. JOHNSON,[15] WOLFGANG KIESSLING,[16] CHRISTIAN KOEBERL,[11] DAVID A. KRING,[17] KENNETH G. MACLEOD,[18] TAKAFUMI MATSUI,[12] JAY MELOSH,[19] ALESSANDRO MONTANARI,[20] JOANNA V. MORGAN,[9] CLIVE R. NEAL,[21] RICHARD D. NORRIS,[22] ELISABETTA PIERAZZO,[23] GREG RAVIZZA,[24] MARIO REBOLLEDO-VIEYRA,[25] WOLF UWE REIMOLD,[16] ERIC ROBIN,[26] TOBIAS SALGE,[27] ROBERT P. SPEIJER,[28] ARTHUR R. SWEET,[29] JAIME URRUTIA-FUCUGAUCHI,[30] VIVI VAJDA,[31] MICHAEL T. WHALEN,[32] PI S. WILLUMSEN[31]

[1]GeoZentrum Nordbayern, Universität Erlangen-Nürnberg, Schlossgarten 5, D-91054 Erlangen, Germany. [2]Departamento de Ciencias de la Tierra e Instituto Universitario de Investigación de Ciencias Ambientales de Aragón, Universidad de Zaragoza, Pedro Cerbuna 12, E-50009 Zaragoza, Spain. [3]Department of Earth Sciences, University of Cambridge, Cambridge CB2 3EQ, UK. [4]Department of Earth Sciences, University College London, Gower Street, London WC1E 6BT, UK. [5]Department of Geosciences, Pennsylvania State University, University Park, PA 16802, USA. [6]Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, Austin, TX 78759, USA. [7]Earth System Science, Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussels, Belgium. [8]Centre for Earth, Planetary, Space, and Astronomical Research, Open University, Milton Keynes, MK7 6AA, UK. [9]Earth Science and Engineering, Imperial College London, London SW7 2BP, UK. [10]Institut fur Planetologie, Universität Münster, D-48149 Münster, Germany. [11]Department of Lithospheric Research, University of Vienna, Althanstrasse 14, A-1090 Vienna, Austria. [12]Planetary Exploration Research Center, Chiba Institute of Technology 2-17-1 Tsudanuma, Narashino, 275-0016 Chiba, Japan. [13]Programa de Geología de Exploracíon y Explotacíon, Dirección de Investigación y Posgrado, Instituto Mexicano del Petróleo, Eje Lázaro Cárdenas No. 152, C.P. 07730, México City, México. [14]Earth Sciences Sector, Natural Resources Canada, Ottawa, ON K1A 0E4, Canada. [15]Research and Collections Division, Denver Museum of Nature and Science, 2001 Colorado Boulevard, Denver, CO 80205, USA. [16]Museum für Naturkunde, Leibniz Institute at the Humboldt University Berlin, Invalidenstrasse 43, D-10115 Berlin, Germany. [17]Center for Lunar Science and Exploration, Universities Space Research Association–Lunar and Planetary Institute, Houston, TX 77058–1113, USA. [18]Department of Geological Sciences, University of Missouri, Columbia, MO 65211, USA. [19]Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907–2051, USA. [20]Osservatorio Geologico di Coldigioco, 62021 Apiro (MC), Italy. [21]Department of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, IN 46556, USA. [22]SIO Geological Collections, Scripps Institution of Oceanography, La Jolla, CA 92093–0244, USA. [23]Planetary Science Institute, Tucson, AZ 85719, USA. [24]Department of Geology and Geophysics, School of Ocean and Earth Science and Technology, University of Hawaii, Manoa, Honolulu, HI 96822, USA. [25]Unidad de Ciencias del Agua, Centro de Investigación Científica de Yucatán, Cancún, Quintana Roo, 77500, México. [26]Laboratoire des Sciences du Climat et de l'Environnement, Institut Pierre et Simon Laplace, Commission à l'Énergie Atomique/CNRS/Université de Versailles Saint Quentin en Yveunes-UMR 1572, Avenue de la Terrasse, F-91198 Gif-sur-Yvette Cedex, France. [27]Bruker Nano GmbH, Schwarzschildstraße 12, D-12489 Berlin, Germany. [28]Department of Earth and Environmental Sciences, K.U.Leuven, Box 2408, Celestijnenlaan 200E, 3001 Leuven, Belgium. [29]Natural Resources Canada, Geological Survey of Canada Calgary, 3303 33rd Street NW, Calgary, AB T2L 2A7, Canada. [30]Laboratorio de Paleomagnetismo y Paleoambientes, Programa Universitario de Perforaciones en Oceanos y Continentes, Instituto de Geofísica, Universidad Nacional Autónoma de México (UNAM), DF 04510 México, México. [31]Department of Earth and Ecosystem Sciences, Lund University, Sölvegatan 12, 223 62 Lund, Sweden. [32]Department of Geology and Geophysics, University of Alaska, Fairbanks, AK 99775, USA.

*To whom correspondence should be addressed. E-mail: schulte@geol.uni-erlangen.de

References

1. D. J. Nichols, K. R. Johnson, *Plants and the K-T Boundary* (Cambridge Univ. Press, 2008).
2. P. Wilf, K. R. Johnson, B. T. Huber, *Proc. Natl. Acad. Sci. U.S.A.* **100**, 599 (2003).
3. D. E. Fastovsky, P. M. Sheehan, *GSA Today* **15**, 4 (2005).
4. V. Riera, O. Oms, R. Gaete, A. Galobart, *Palaeogeogr. Palaeoclimatol. Palaeoecol*. **283**, 160 (2009).
5. T. D. Herbert, I. Premoli-Silva, E. Erba, A. G. Fischer, *Soc. Econ. Paleont. Mineral. Spec. Publ*. **54**, 81 (1995).
6. A.-L. Chenet *et al.*, *J. Geophys. Res*. **114**, B06103 (2009).
7. A. E. Jay *et al.*, *J. Geol. Soc*. **166**, 13 (2009).
8. T. J. Bralower *et al.*, *Geology* **38**, 199 (2010).
9. S. Jiang *et al.*, *Nat. Geosci*. **3**, 280 (2010).
10. P. B. Wignall, *Earth Sci. Rev*. **53**, 1 (2001).
11. R. V. White, A. D. Saunders, *Lithos* **79**, 299 (2005).
12. V. Vajda, S. McLoughlin, *Rev. Palaeobot. Palynol*. **144**, 99 (2007).
13. W. Kiessling, C. Simpson, *Global Change Biol.*, published online 24 February 2010; 10.1111/j.1365-2486.2010.02204.x, in press.
14. S. Kelley, *J. Geol. Soc. London* **164**, 923 (2007).
15. K. G. Miller *et al.*, *Science* **310**, 1293 (2005).
16. A. B. Smith, A. S. Gale, N. E. A. Monks, *Paleobiology* **27**, 241 (2001).

Honing the Test-and-Treat HIV Strategy

IN HIS NEWS FOCUS STORY ("TREATMENT AS prevention," 5 March, p. 1196), J. Cohen reviews ideas presented at the 17th Conference on Retroviruses and Opportunistic Infections about the use of HIV treatment as prevention. Enthusiasm for the treatment-as-prevention approach has grown in recent years as (i) the drugs have become safer, better tolerated, and more widely available; (ii) widespread testing has become cheaper and more efficient; (iii) earlier therapy has become desirable; and (iv) mathematical modeling by some (*1*) (but by no means all) has suggested that a test-and-treat strategy could control the spread of HIV.

Cohen cites an observational analysis, by Donnell *et al.*, that reported considerable reduction of HIV transmission in HIV discordant couples when ART was provided to the HIV-infected index partner (*2*). This finding—similar to work from Sullivan *et al.* presented at Conference on Retroviruses and Opportunistic Infections in 2009 (*3*)—helps to support the key assumption that ART reduces infectiousness. However, these studies report only short-term observations; they do not address the durability of this effect or the risk of transmitted drug-resistant HIV strains, two critical considerations for the test-and-treat strategy.

TIMOTHY D. MASTRO[1]* AND MYRON S. COHEN[2]

[1]Family Health International, Research Triangle Park, NC 27709, USA. [2]Division of Infectious Diseases, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA.

*To whom correspondence should be addressed. E-mail: tmastro@fhi.org

References

1. R. M. Granich, C. F. Gilks, C. Dye, K. M. De Cock, B. G. Williams, *Lancet* **373**, 48 (2009).
2. D. Donnell *et al.*, abstract 136, presented at the 17th Conference on Retroviruses and Opportunistic Infections, San Francisco, CA, 16 to 19 February 2010.
3. P. Sullivan *et al.*, abstract 52bLB, presented at the 16th Conference on Retroviruses and Opportunistic Infections, Montreal, Canada, 8 to 11 February 2009.

Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 3 months or issues of general interest. They can be submitted through the Web (www.submit2science.org) or by regular mail (1200 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space.