found in fine intensely bioturbated silty chalk about 6–10 cm below an irregular 10 ± 5-cm-thick micritic limestone layer. The upper tail of the Ir peak extends into the micritic limestone (Fig. 1). There are other considerably smaller Ir peaks extending as high as 7 m and possibly 8 m above the main peak and 0.2 m and possibly 0.9 m below. Generally, the more distant the subsidiary peaks are from the main peak, the smaller are their abundances. The Ir abundance in a thin sandstone layer below the main peak, however, was found to be lower than those in underlying and overlying silt layers. If ratios are taken of Ir abundances to those of Fe or Cs, anomalously high ratios are found where the Ir abundance is anomalously high.

The element abundance patterns, which are similar to those found in other marine KT sections in Haiti, Mexico, and Texas, are consistent with a fining-up debris deposited from a tsunami triggered by a bolide impact on the Yucatan Peninsula. Our preliminary study of the Bochil section indicates the Ir began depositing (or redepositing) immediately before the first appearance of the lowermost Tertiary microfossils. The 38-m breccia unit may have resulted from breakage of reefal sediments triggered by the Chicxulub impact, but other explanations are possible.

Mechanism of Extraterrestrial Accretion: As the orbit of the Earth changes, it passes through different parts of the Sun's zodiacal ring, and should encounter different meteor streams. Changes in meteor flux can affect the density of dust and aerosols in the upper atmosphere. The fact that high-altitude dust can affect global climate is generally accepted. The eruption of Krakatoa has been estimated to cause global cooling >1°C, and climate changes have been attributed to El Chichon and other eruptions that injected megatons of material into the stratosphere. Measurements of Ir in oceanic sediments [6] show that long-term global average flux from extraterrestrial materials is 60–120 kt/yr [6], comparable over 10,000 yr to that from a large volcanic eruption. The meteorites may not come in at a steady rate but in bursts as we cross the meteor streams (with peaks much higher than the 60–120 kt/yr average) and in cycles as the Earth's orbit oscillates. The shortest variation detectable (the Nyquist period) in the best sediment records [6] = 600 k.y., so a 100-k.y. oscillation would have been missed. Clube [7] analyzed the possibility of large unobserved meteor streams and argued that the zodiacal ring of the Sun is largely meteoroid in composition rather than dust. He concluded that large unobserved streams exist, and suggested that encounters with them could cause climate excursions and extinction events; however, he did not propose a relationship with the known climate cycles.

A single meteor stream can contain the mass of one comet 10^5 Mt. The Earth can capture about 10^-4 of the stream with each passage = 10 M^t= 1 large volcano equivalent/yr, as long as the orbits intersect. The cumulative effect would be very much larger than Krakatoa.

We do not propose that the climate effects are due to a single meteor stream, rather that the solar ring has many, in nearly circular orbits with semimajor axis ≈ 1 AU, so that their own orbital perturbation frequencies (but not necessarily their phases) closely match those of the Earth. We do not explain how such rings were formed, but for our model to work, they must have been present for the last million years.

Another orbital parameter expected to have little effect on climate, because of its negligible effect on insolation, has been the inclination of the Earth's orbital plane. Changes in inclination also cause the Earth to probe different regions of interplanetary debris, so we predict correlations between inclination and climate. The long-term variation of the inclination was calculated by Berger [8], who showed that the behavior is quasi-periodic with a period of 70 k.y., and a fundamental frequency of 0.0144/k.y. Note that this frequency is, within errors, equal to the one unexplained peak in the δ18O data [3]; thus we explain the one "anomalous" frequency.

We can gain more insight into this effect, and possibly understand the relative intensities of the spectral lines, if we chose coordinates based on the invariant plane of the solar system, perpendicular to the total angular momentum vector of the planets, approximately the plane of Jupiter's orbit. In these coordinates the oscillations of inclination are nearly sinusoidal with peak-to-peak amplitude reduced by two, and period changed to 100 k.y. rather than 70 k.y. (The change simplifies the behavior because the primary perturber, Jupiter, has a nearly stationary orbit in this system.) In this frame the precession of the inclination vector, \(\Omega\), now shows a virtually steady advance of one cycle every 70 k.y. In the invariant frame, the inclination i oscillates with a 100 k.y. period, nearly identical to that of the eccentricity e. Changes in i and e both cause the Earth to sweep out new material with a frequency 0.01/k.y., identical to that of the strongest line seen in the climate data. The "anomalous" line [3] at 70 k.y. period is, \(\Omega\), the frequency of precession of the inclination vector (the advance of the line of nodes) measured in the invariant plane.

Accretion Measurements: Our proposed mechanism predicts a substantial reduction in the flux of meteoritic material in the present era compared to the long term average. In fact, just such a reduction is known. In a recent review, Rochia et al. [9] found six of seven published determinations of recent influx measured <10 kt/yr, yet the long-term flux [6] was 60–120 kt/yr. They speculate that the recent low flux is a fluctuation, due to few large meteoroid impacts recently. Yet the most straightforward measurement, that of Ir in Antarctic snow, gave 10 kt/yr despite the presence of the Tunguska event of 1908 = 0.1–1 Mt.

We offer a different interpretation, that the discrepancy is not from the absence of large impacts, but is due to the fact that interglacials (including the present one) are periods of low extraterrestrial meteoroid flux.


A KT Boundary Section from Northern Belize. A. C. Ocampo1 and K. O. Pope1, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA, 2Geo Eco Arc Research, 2222 Foothill Boulevard, La Canada CA 91011, USA, 3Institute of Geophysics, Mexico City, Mexico

A KT boundary section recently discovered in northern Belize provides new insights into cratering processes near the rim of the Chicxulub KT crater in northwestern Yucatan. The section is located in a quarry on Albion Island near the Mexican border, which is only 2–3 crater radii (~350 km) from the center of Chicxulub. This is the most proximal exposed KT section yet studied from the Chicxulub Crater, excluding material from deep drilling within the crater and on the rim. The Albion Island section provides an example of deposits intermediate between the crater rim and more distal, possible impact-tsunami deposits in the region [1–3].

Quarrying activity on Albion Island has exposed a 45-m-thick section in a region where deep weathering and dense vegetation has obscured most bedrock exposures. The regional stratigraphy has been established in two exploratory wells drilled at near by Orange Walk and San Pablo [4]. The Orange Walk 1 well records place the KT boundary between dolomites of the Sand Hill Formation and undifferentiated Tertiary limestones at a depth of ~1500 m. The KT boundary rises to a depth of ~150 m in the San Pablo 1 well located 11 km north of Orange Walk 1. The Albion Island quarry is located 15 km northwest of Orange Walk, near the crest of an anticlinal fold and possible uplifted fault block that has further elevated the KT boundary. A major erosional unconformity separates the hard crystalline Cretaceous dolomites and a chaotic, poorly sorted breccia at a depth of ~15 m in the quarry. We propose that this unconformity marks the KT boundary.