normal faults with a north-south orientation and offsets of tens of centimeters break the Prairie Bluff surface. They are buried by the overlying Danian Basal Clayton Sands. The faults and the surface markings indicate an instantaneous event for their origin. We interpret these features as having formed as a result of a tsunami wave and earthquakes created by a bolide impact at Chixulub Crater in Yucatan.

The overlying Clayton Basal Sands fill in the topographic lows on the Prairie Bluff Chalk and thin over the topographic highs. As a consequence, the basal Danian Zone P0 is found where the Clayton Basal Sands are thickest and is absent where the sands thin on topographic highs. Calcareous microfossil biostratigraphy shows that the Prairie Bluff Chalk lies within the uppermost Maestrichtian calcareous nannofossil *Micula prinsii* zone, which is equivalent to the upper part of the planktonic foraminiferal *Abathomphalus mayaroensis* zone. Paleomagnetic data show that the Prairie Bluff Chalk/Clayton Basal Sands (KT) boundary lies in the middle part of paleomagnetic chron 29R in the cores taken at Millers Ferry. The last occurrence (LO) within the Prairie Bluff Chalk of the planktonic foraminifer *Gansserina gansseri* is a datum from which to measure the degree of topographic irregularity on the top of the Prairie Bluff Chalk. This indicates about a meter or so of relief. The relief could be due entirely to the erosive effect of a tsunami wave or it could represent a modified original depositional surface. In either case, it is clear that the KT boundary at Millers Ferry is biostratigraphically continuous but it is not contained in one section.

We interpret that the abrupt change from the Prairie Bluff Chalk to the Clayton Basal Sands is due to the mass extinction of the Prairie Bluff Chalk biota, which includes planktonic foraminifera, calcareous nannoplankton, and the molluscan megafauna. Benthic foraminifera, which were little affected by the extinction event indicate that there was little, if any, change in sea level across the boundary. Minor changes in foraminiferal taxon abundances across the boundary are due to substrate change from chalk to sand.

At Brazos River, Texas, the "tsunami bed" has been placed in the Cretaceous [7,3] and in the Danian [8]. A Danian age would indicate a similar origin for this unit as the Clayton Basal Sands. A Cretaceous age does not necessarily exclude a bolide impact-generated tsunami wave origin. At Mimbral, Mexico, the sand unit at the boundary interpreted as a tsunami deposit, whereas an alternate hypothesis regards it as a possible incised valley deposit of Cretaceous age. These different interpretations are not necessarily incompatible since they center around the age of the sand unit and the interpretation of the origin of the spherules at the base of the unit. The use of different biostratigraphic criteria for placing the KT boundary may give a different age assignment to the sand unit [2]. It is difficult to ignore the fact that thin discontinuous sands occur in very close proximity to the KT boundary around the Gulf Coastal Plain for a distance of about 2000 km in different paleodepth settings (upper bathyal at Mimbral to shallow shelf at Millers Ferry). The origin of these sands could well be different and still be related to a KT terminal event, which dispersed enormous energy. Some of the sands could be tsunami deposits, whereas others must represent a brief period of increased clastic deposition that can be explained by a fireball-denuded, erosion-enhanced landscape. The scoured surface upon which these sands lie can also be regarded as evidence of the passage of a powerful tsunami wave.

At the Caribbean deep-sea drilling sites the apparent record [6] of hiatuses on either side of the KT boundary can be interpreted as evidence for signicant disturbance of the sea bottom. Enormous earthquakes generated by a bolide impact would cause displacement of sediments and would lead to the development of localized hiatuses. At greater distances away from the impact, such as El Kef in a deep margin setting, the KT boundary records the mass extinction event of calcareous marine plankton, the spherule layer, and the Ir anomaly in direct succession.

In our view KT boundary sections should be taken at face value because they each record various aspects of the KT event. In highly disturbed areas, such as the Gulf of Mexico and the Caribbean, the regional picture of the terminal event needs to be developed in order to appreciate the reality of the KT event.

References: [1] Smit J. et al. (1992) *Geology, 20*, 99–103. [2] Olsson R. K. and Liu C. (1993) *Palaios, 8*, 127–139. [3] Keller G. (1989) *Paleocean., 4*, 287–332. [4] Stinnebeck W. et al. (1993) *Geology, 9*, 797–800. [5] Smit J. (1990) *Geol. Mijnbouw, 69*, 187–204. [6] Keller G. et al. (1993) *Geology, 9*, 776–780. [7] Jiang M. J. and Gartner S. (1986) *Micropaleon., 32*, 232–255. [8] Montgomery H. et al. (1992) *EPSL, 100*, 503–

AN EXTRATERRESTRIAL EVENT AT THE TERTIARY-QUATERNARY BOUNDARY. H. Peng, First Institute of Oceanography, State Oceanic Administration, Qingdao, 266003, P.R. China.

During the North Pacific Manganese Nodules Investigation in 1983, we collected a large-diameter core M14 (8°00.15'N, 176° 10.65'W; 3991-m depth of water). This gravity core is 420 cm long in total. It is composed of calcureous ooze at 0–320 cm and siliceous ooze at 320–420 cm of depth. A great number of microtektites were found at 270–300 cm (average content is 15 microtektites per 100-g sediment). Because abundant microtektites are restricted to a 30-cm-thick zone of deep-sea core, we called this zone the microtektite layer. The age of the sedimentary stratum containing microtektites is 2.14–2.30 m.y., corresponding to the Pliocene to Pleistocene Periods as indicated by paleomagnetic and paleontologic analysis[1].

Most microtektites appeared as light-yellowish-green, small, glassy spherules and their average size is 137 µm in diameter. The individual grain is dumbbell shaped and its size is 652 × 223 × 151 µm (Fig.1). The average refractive index of microtektites determined by the oil immersion method is 1.52.

The SiO_2 contents of five microtektites are 69.13–70.54%, Al_2O_3 is 15.89–18.95%, FeO is 3.45–4.96%, MgO is 2.33–3.62%, CaO is 1.93–2.60%, and K_2O is 1.24–2.78%. These oxide contents are similar to the North American microtektites. But core M14 microtektites have unique properties, i.e., their Na_2O contents are only 0.11–0.18%, which is lower than North American microtektites and other microtektites; their TiO_2 contents reached 1.08–1.34%, which is higher than North American microtektites and other microtektites.

Core M14 microtektites also have a high siderophile-element content. For example, Ni content reached 1380 ppm, Co reached 21.7 ppm, Os reached 22.5 ppm, and Ir reached 0.026 ppm. This high concentration of siderophile elements indicates that their parent materials come from outside the Earth. We also found that core M14 microtektite layer is apparently associated with the beginning of the Reunion geomagnetic event, and is probably associated with

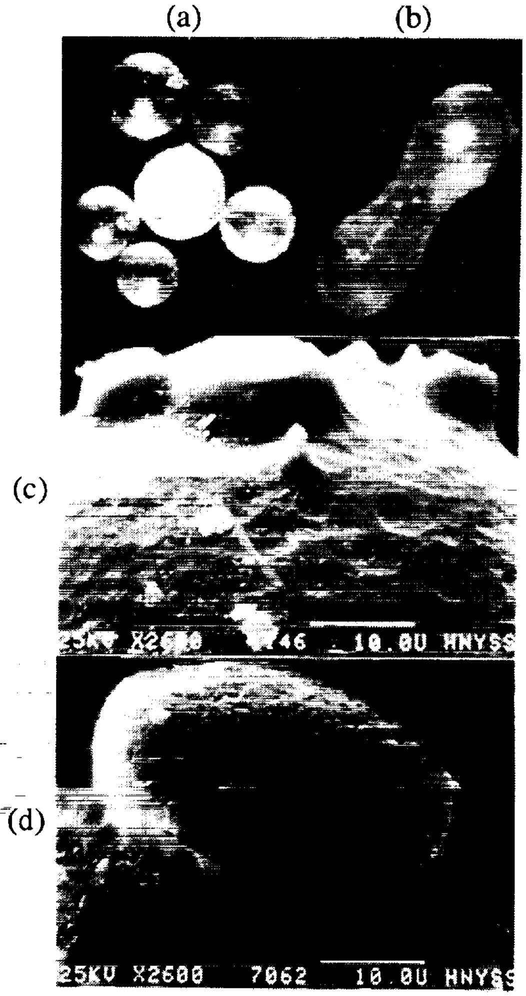

Fig. 1. Microscope and SEM photographs of Microtektites from core M14. **(a)** Microscope photograph of spherical microtektites; **(b)** a large dumbbell microtektite (652 × 223 × 151 μm in size); **(c)** and **(d)** SEM photographs of microtektites with circular, flat-topped, elevated area at top.

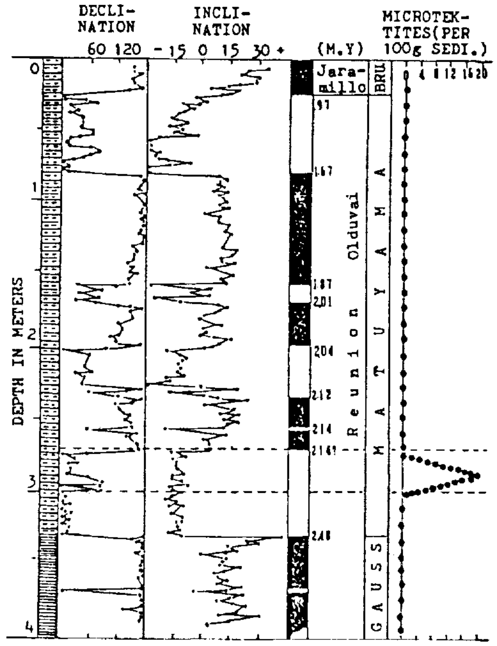

Fig. 2. Correlation between the microtektite layer and paleomagnetic stratigraphy in the core M14 collected from the North Pacific. Note the declination and inclination at the 270–320-cm depth (corresponding age of 2.14–2.48 m.y.) showing extreme variation.

the Matuyama/Gauss geomagnetic reversal boundary in core M14 (Fig.2). As you can see, the declination is ~170 decreasing sharply to 0 and the inclination is ~7 decreasing sharply to −15 at the 270-cm depth (corresponding age is 2.14 m.y.). In addition, three specific radiolarians that belong to the Tertiary are extinguished near the microtektite layer. They are *Pterocanium prismatium, Ommatartus antepenultimus, and Lamprocyrtis heteroporos* [1].

Based on the above data, we can give the following two primary conclusions: (1) The core M14 microtektites are products of a major meteorite or asteroid impact 2.14–2.30 m.y. ago. (2) The age of 2.14–2.30 m.y. is an important geological age; perhaps it is just a correct age for dividing the Tertiary/Quaternary boundary. This result is quite close to previous data. For example, Kyte et al. [2] found that high noble metals and meteoritic particle concentrations occur in upper Pliocene sediments (2.3 Ma B.P.) from the Antarctic Ocean; Yuan et al. [3] found the microtektite layer in clay between the Wuchen loess and Paleosol (2.4 Ma B.P.) from Luochuan county in Shanxi province in China; and Wu et al. [4] found the microspherule layer in the Paleosol, which is associated with the Matuyama/Gauss geomagnetic reversal [4].

References: [1] Wang Y. et al. (1986) in *Comprehensive Investigation Report on Manganese Nodules in the Northern Central Pacific,* 64–69. [2] Kyte F. T. et al. (1981) *Nature, 292,* 417–420. [3] Yuan B. et al. (1989) *Kexue Tongbao, 22,* 1725–1728 (in Chinese). [4] Wu X. et al. (1991) *Kexue Tongbao, 23,* 1799–1802 (in Chinese).

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FOOTPRINTS IN THE ROCKS—NEW EVIDENCE FROM THE RATON BASIN THAT DINOSAURS FLOURISHED ON LAND UNTIL THE TERMINAL CRETACEOUS IMPACT EVENT. C. L. Pillmore[1], M. G. Lockley[2], R. F. Fleming[1], and K. r. Johnson[3]; [1]U.S. Geological Survey, Denver CO 80225, USA, [2]University of Colorado, Denver CO 80217, USA, [3]Denver Museum of Natural History, Denver CO 80205, USA.

In recent months, we have found convincing evidence that dinosaurs were present and probably flourished in the Raton Basin, southern Colorado and northern New Mexico, possibly until, or only a very short time before, the asteroid impact at the end of the Cretaceous Period. This evidence is in the form of impressions and natural casts of dinosaur footprints that occur in the lower part of the continental Raton Formation of Late Cretaceous and Paleocene age within 1 m below the KT boundary claystone layer. Tracks are also present at several other horizons farther below the boundary. Curiously, Raton Basin rocks have never produced dinosaur skeletons.