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THE CRETACEOUS-TERTIARY BOUNDARY IN THE RATON BASIN, NEW MEXICO AND COLORADO

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Abstract—The Cretaceous-Tertiary (K-T) boundary is preserved in a sequence of coal-bearing, fluvial rocks in the lower part of the Raton Formation (late Cretaceous and Paleocene) at more than 20 sites in the southern and east-central parts of the Raton basin. The boundary occurs at the top of a kaolinitic claystone layer, commonly referred to as the “K-T boundary claystone,” in an interval of coal and carbonaceous shale. The claystone has also been found and correlated with remarkably similar claystone layers that occur at sites in the Powder River Basin in Wyoming, and north through Montana into Saskatchewan and the Red Deer Valley of Alberta, Canada—a distance of more than 1600 km. Throughout the region, the K-T boundary claystone displays a distinctive characteristic: it is always overlain in sharp contact by a 0.1- to 0.2-in.-thick laminated bed of claystone, termed the K-T boundary impact layer, that contains shocked quartz and high concentrations of iridium—both signatures of asteroid impact. In contrast, shocked quartz grains are extremely rare and Ir markedly less abundant in the underlying K-T boundary claystone.

Field relations suggest that both the boundary claystone and the impact layer resulted from an asteroid impact(s). The wide distribution of this thin couplet of beds suggests a fallout origin, and the ubiquitous, sharp, uncontaminated contact between the two units indicates a genetic relationship and nearly simultaneous deposition. However, a simple graded-bed fallout model is precluded by the presence of the coarser shocked grains at the top of the boundary claystone bed.

INTRODUCTION

The Cretaceous-Tertiary (K-T) boundary has been identified at more than 20 sites throughout an area of about 1000 mi² in the east-central and southern parts of the Raton basin, northern New Mexico and southern Colorado. Figure 1 shows the location and distribution of several of the sites. The boundary occurs in a sequence of fine-grained rocks in the lower part of the Raton Formation (Maastrichtian and Paleocene, Pillmore and Flores, this guidebook) and has been defined by R. H. Tschudy (Orth et al., 1981; Pillmore et al., 1984; Tschudy et al., 1984; Tschudy and Tschudy, 1986) on the basis of the abrupt disappearance of several taxa of fossil pollen. The boundary is also characterized by the presence of shock-metamorphosed mineral grains (Bohor et al., 1984; Izett and Pillmore, 1985a, b; Izett, 1987) and an anomalously high abundance of iridium (Orth et al., 1981, 1982). The following discussion is modified from Pillmore et al. (1984) and Pillmore and Flores (1987), with additional comments on palynology by R. F. Fleming.

Lee (1917) originally placed the K-T boundary below the unconformity at the base of the Raton Formation. Later, Brown (1962) identified Cretaceous plant fossils in the lower part of the Raton, at a site about 3.5 mi north of Trinidad, Colorado, and indicated that the boundary should be placed at least 50 ft above the base of the formation. The K-T boundary was later identified in a drill core by Tschudy (Tschudy, 1973; Orth et al., 1981) 262 ft above the base of the Raton Formation at York Canyon, New Mexico, on the basis of the abrupt disappearance of several taxa of fossil pollen. In the Raton basin, this extinction horizon is coincident with the top of a 0.5- to 1.0-in.-thick claystone bed termed the boundary claystone (Fig. 2). This horizon (the top of the claystone) also coincides with an anomalously high concentration of Ir (Orth et al., 1981; Pillmore et al., 1984), the abrupt appearance of shock-metamorphosed minerals (Izett and Pillmore, 1985a, b) and a sudden change in the relative proportion of fern spores to angiosperm pollen (Tschudy et al., 1984) (Fig. 3).

PALYNOLOGY

In the northern part of the Rocky Mountain region, the K-T boundary was placed at the base of the lowest persistent lignite above the highest dinosaur remains; the palynological K-T boundary was originally defined on the basis of the disappearance of fossil pollen of *Proteacidites* spp. and most species of *Aquilapollenites* (Tschudy and Tschudy, 1986). This horizon occurs within a few feet of the disappearance of dinosaur

fossils. In the Raton basin, the K-T boundary is defined solely on the basis of palynology due to the absence of dinosaur fossils. Because *Aquilapollenites* occurs only rarely in the southern part of the Rocky Mountain region, Tschudy used the extinction of “*Tilia*” *wodehouseii* Anderson, *Trisectoris* and *Trichopeltinites* sp. in addition to the extinction of *Proteacidites* spp. to locate the K-T boundary in the Raton basin (Tschudy, 1973; Orth et al., 1981; Tschudy and Tschudy, 1986). For discussions of the Raton basin these taxa are herein called the *Proteacidites* assemblage.

Tschudy et al. (1984) concluded that the K-T boundary event caused massive destruction of vegetation, disrupted the terrestrial ecosystem and resulted in the extinction of the *Proteacidites* assemblage. The plants that survived exhibit three basic patterns of survival. The first pattern is shown by pollen of *Kurtzipites* spp., which are common in the latest Cretaceous, survive the K-T boundary event and persist into the Paleocene until they become extinct about the middle Paleocene (Tschudy and Tschudy, 1986). *Psilastephanocolpites* sp. exemplifies the second pattern. This fossil pollen is rare in the Cretaceous but becomes more abundant in the Paleocene, perhaps because the plant that produced it was better adapted to the new ecological conditions that followed the boundary event. The last pattern is characterized by species little affected by the K-T boundary impact and includes such fossil pollen as *Ulmipollenites krempfi* and *Pandaniidites radicus*.

Detailed palynological sampling just above the K-T boundary has revealed the presence of an anomalously high abundance of fern spores which appears to be unique to the K-T boundary event. This high abundance of fern spores (sometimes called the “fern spike”) occurs in K-T boundary sections from the Raton basin to south-central Saskatchewan (Tschudy et al., 1984; Nichols et al., 1986; Tschudy and Tschudy, 1986). In Cretaceous and Paleocene assemblages of the Raton basin, fern spores usually constitute 15–30% of the palynomorph assemblages (Fig. 4). Just above the K-T boundary claystone, the fern-spore percentage increases dramatically to as much as 99% (Fig. 3). Within 4–6 in. above the boundary, the fern-spore percentage returns to the 15–30% level. Tschudy et al. (1984) pointed out the importance of this phenomenon with respect to the destruction of terrestrial vegetation. They attributed the “fern spike” to early colonization of the devastated landscape by ferns. The temporary dominance of ferns at the K-T boundary is due to the “early arrival of wind-dispersed spores, the removal of competitors, and the known tolerance of ferns to soils deficient in mineral nutrients” (Tschudy et al., 1984, p. 1031).

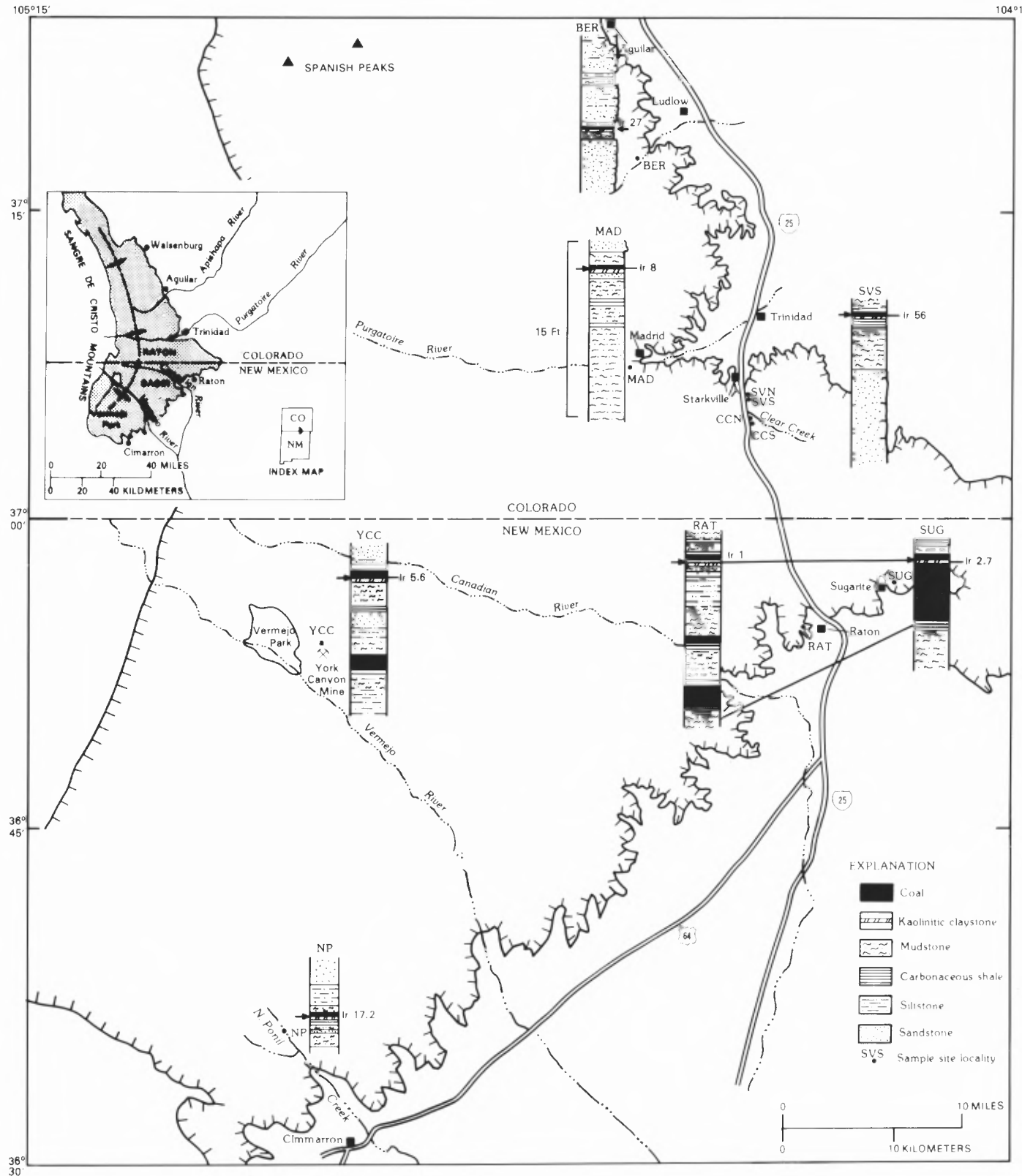


FIGURE 1. Index map showing location of Raton basin and representative Cretaceous-Tertiary boundary sites in New Mexico and Colorado. Columnar sections at or near top of lower zone of Raton Formation show lithology of the boundary interval at selected sites: YCC, York Canyon; RAT, Raton; SUG, Sugarite; SVS, Starkville South; BER, Berwind Canyon; NP, North Ponil; and MAD, Madrid. Arrows indicate the K-T boundary. Measured iridium concentrations shown in ng/g (10^{-9} g/g). Hachured line shows top of Trinidad Sandstone. Modified from Pillmore and Flores (1987).



FIGURE 2. Photograph of the Cretaceous-Tertiary boundary claystone at the Starkville North site (diagrammed in Fig. 3). The pencil points to the fossil-pollen-defined boundary at the top of a 2- to 2.5-cm (1 in.) thick bed of white-weathering, kaolinitic claystone. A thin flaky dark shale, and the iridium-rich K-T boundary impact bed (the dark band at the top of the claystone) that contain shocked quartz grains, overlie the kaolinitic claystone.

In general, palynological observations of patterns of extinction and survival suggest that the terrestrial ecosystem was stressed by a significant, though geologically brief, event (or events) which was responsible for the K-T boundary claystone (Tschudy et al., 1984; Tschudy and Tschudy, 1986).

PALEOBOTANY

Wolfe and Upchurch (1986) analyzed fossil leaves and dispersed fragments of leaf cuticles from K-T boundary sequences in the Raton Formation. Their evidence supports a brief, low-temperature excursion (mean temperature near 0°C) that caused a mass-kill and ecological disruption of terrestrial vegetation at the K-T boundary. Leaf size and

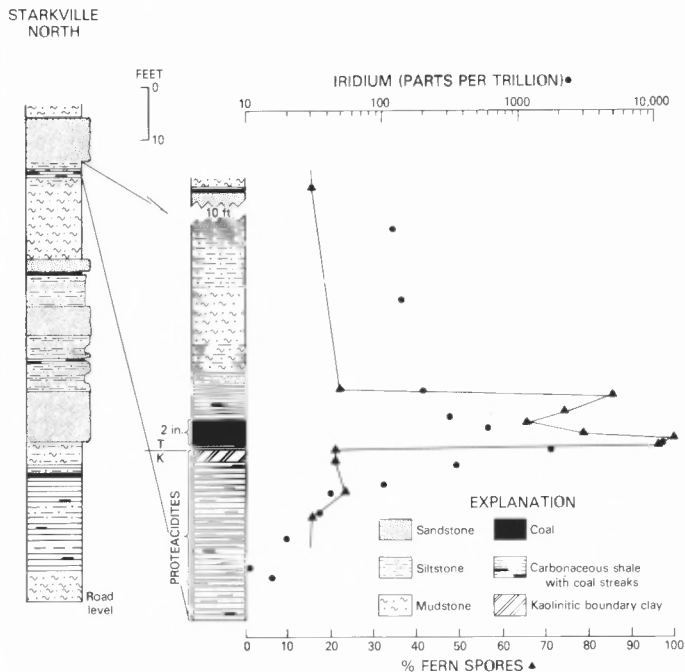


FIGURE 3. Diagram showing the lithology of the rock sequence containing the K-T boundary at the Starkville North site, 4.8 km (3 mi) south of Trinidad, Colorado. The large black dots show the variation in iridium concentration, the solid line and triangles show the fern-spore percentage, and the inset shows the detail of the K-T boundary interval. Modified from Tschudy et al. (1984).

shape indicate that a major increase in precipitation occurred across the boundary. Their data are consistent with the bolide impact hypothesis (Alvarez et al., 1980).

TONSTEINS

Tonsteins (kaolinitic claystone partings thought to result from alteration of volcanic ash beds in acidic coal swamps) occur in coal beds throughout the Western Interior, including the Raton basin, and in many other parts of the world (Williamson, 1970; Bohor and Pillmore, 1976; Bohor et al., 1978; Spears and Kanaris-Sotiriou, 1979). These kaolinite-rich beds commonly weather to a distinctive light-gray "bone" color and are characterized by generally sharp contacts and a blocky ledge-forming appearance in coal outcrops (Fig. 5). Most tonsteins in the Raton basin appear smooth and even-textured and contain little or no detectable grit (Bohor and Pillmore, 1976). Petrographic analyses show that they consist largely of coarsely crystalline authigenic vermicules of kaolinite in a fine-grained kaolinitic matrix with varying amounts of quartz and feldspar. In hand specimens, some of the coarser grained tonsteins resemble siltstones with resinous luster. Tonsteins, mostly less than 2 in. thick, occur in many Raton basin coal beds. Some probably represent major volcanic eruptions that blanketed the landscape with ash, but we have not observed a significant change in fern spore-angiosperm pollen ratios in any non-boundary tonstein-bearing coals that we have studied in the Raton basin. However, local concentrations of fern spores, due only to regional ecological conditions, would be expected, as shown in Figure 4.

THE K-T BOUNDARY CLAYSTONE

The boundary claystone bed resembles tonstein, but it usually weathers to a lighter color and exhibits a fine-grained to amorphous texture and a distinctive hackly to conchoidal fracture. The boundary claystone is mostly gray and grayish pink to grayish yellow and commonly con-

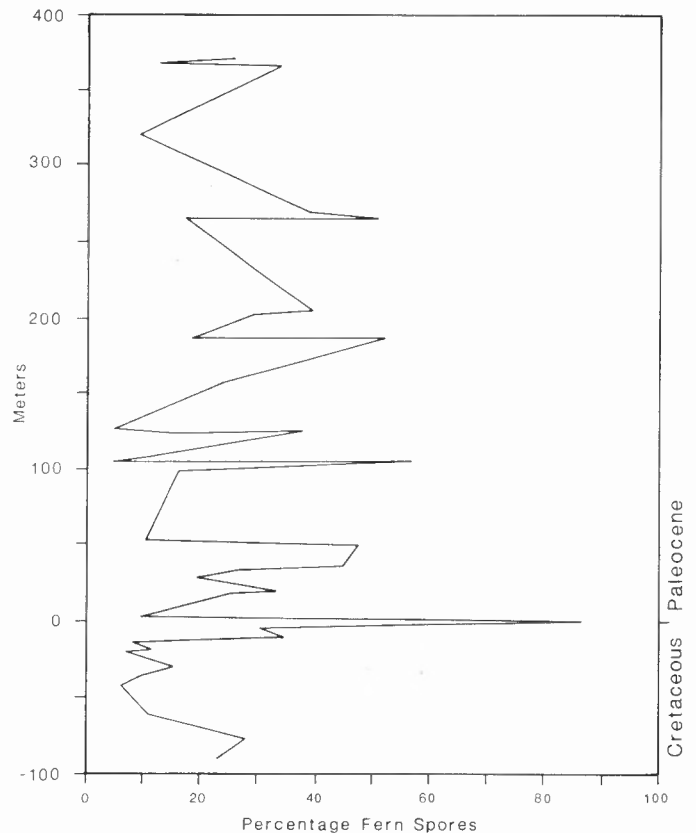


FIGURE 4. Fern-spore percentages for the Cretaceous and Paleocene Raton Formation. Stratigraphic position of samples shown in meters above and below K-T boundary. The highest percentage (90%) of fern spores occurs immediately above the K-T boundary.

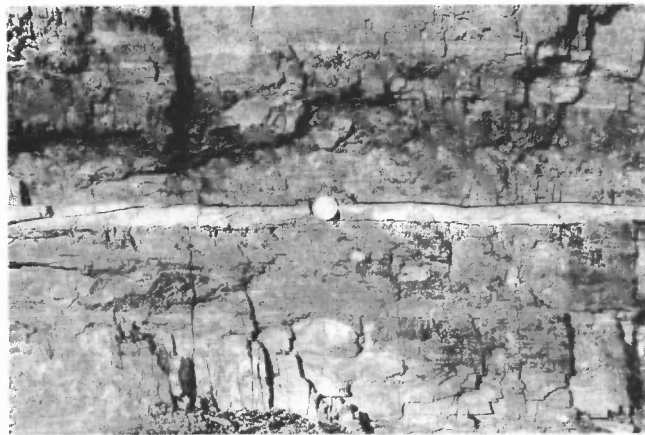


FIGURE 5. Photograph of a tonstein in a coal bed.

tains tiny specks and thin contorted lenses or layers of organic matter, especially near its margins. Small spheroidal structures can be seen on fracture surfaces of some specimens and in thin section. X-ray diffractograms show that, like many tonsteins, the boundary claystone is nearly pure, well-crystallized kaolinite with lesser amounts of randomly stratified illite-smectite clay and some quartz and feldspar (Pollastro et al., 1983; Pollastro and Pillmore, 1987). However, the boundary claystone is texturally and chemically different from typical Raton basin tonsteins. As seen in ultrathin section, it is fine-grained to amorphous but may exhibit an imbricate fabric and relics of small bubbles in a fine crystallite matrix of kaolinite. Microspherules (40–120 microns in diameter) consisting of calcium, aluminum, strontium, cerium, rare earth elements and phosphorous (a composition similar to goyazite, a hydrous strontium aluminophosphate; microprobe analysis by Ralph Christian) have been observed in the boundary claystone at some sites (Fig. 6). These phosphatic spherules have not been seen in other Raton basin tonsteins, but goyazite has been reported from other kaolinitic, altered tuff beds of Cretaceous age (Triplehorn and Bohor, 1983). Smit (1984) refers to similarly shaped grains he has observed in the boundary claystone from the Raton basin and other areas as microtektite-like structures, implying an impact origin. The goyazite-like grains from Raton basin sites are mostly spheroidal to subspheroidal and resemble tiny, dull to shiny resinous balls under the microscope. Some are hollow. Under the scanning electron microscope, they have an uneven surface texture and

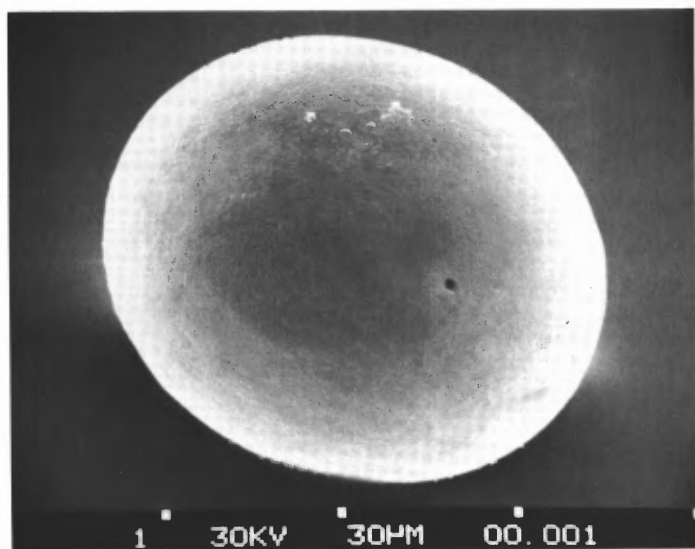


FIGURE 6. SEM photograph of a goyazite sphere from the boundary claystone at the Raton site 1 km (0.6 mi) west of Raton, New Mexico.

commonly are pitted by irregularly shaped cavities. The spherules may result from the alteration of material blown out during the K-T boundary event, but more likely represent authigenesis of some phosphatic constituent in the K-T boundary claystone layer.

The shock-metamorphosed mineral grains are compelling evidence of impact origin (Bohor et al., 1984; Izett, 1987). They occur at the top of the boundary claystone in a layer termed the K-T boundary impact bed (Izett and Bohor, 1986) that is always in direct contact with the claystone. The shocked grains consist mainly of quartz, with rare microcline and plagioclase. The shock-metamorphosed quartz grains contain as many as nine intersecting sets of closely spaced planar features per grain (Izett, 1987). Figure 7 is a photograph by Izett of one of the shocked grains of quartz from the Starkville South site, showing two sets of planar lamellae.

GEOCHEMISTRY

The boundary claystone and the tonsteins are high-alumina clays that characteristically contain about 32% Al_2O_3 (Gilmore et al., 1984). Iridium abundances as high as 56 ng/g (56×10^{-9} g/g, about 8000 \times background at the Starkville South site) have been measured in samples from the top of the boundary claystone collected from the study area (Pillmore et al., 1984). In comparison, background Ir concentrations of 0.004–0.040 ng/g are observed in tonsteins and other beds of coal and shale not associated with the boundary (Gilmore et al., 1984). In addition, titanium, scandium, vanadium, chromium and antimony in the boundary claystone are enhanced by factors of about four or more over their concentrations in all other Raton basin tonsteins that were analyzed by Gilmore et al. (1984). Table 1 shows a comparison of these and other elements in the boundary claystone with those of tonstein beds in the Raton basin (Gilmore et al., 1984).

SUMMARY

The boundary claystone has been found at scattered localities from Cimarron, New Mexico, to Red Deer Valley, Alberta. It is remarkably consistent in chemical composition, thickness and character. It is always in direct contact and forms a couplet with the high-Ir, shocked-quartz bearing K-T boundary impact layer (Izett, 1987). The wide geographic extent of the K-T boundary claystone, and its unusual textural and chemical character, suggest that it was derived from a different source than were the tonstein beds; however, its relation to the impact event is problematical because of its position directly beneath the K-T boundary impact layer.

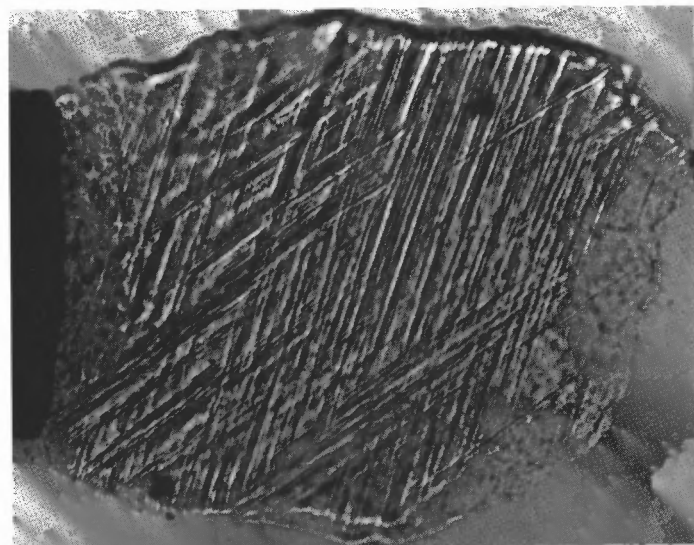


FIGURE 7. Photomicrograph by G. A. Izett of a 0.21-mm diameter shock-metamorphosed quartz grain from the Starkville South site. The grain is mounted in index oil on the needle (dark part of photograph) of a spindle stage. The two sets of planar lamellae that are prominent in the photograph are strong evidence of impact origin (Izett, 1987).

TABLE 1. Elemental abundances in thin kaolinitic claystone beds in the Raton basin.*

Element	K-T boundary bed		Beds above/below K-T boundary	
	Range	Average	Range	Average
Al ₂ O ₃ (%)	24-36	32.9	23-36	31.7
K (%)	0.2-1.1	0.52	0.2-2.5	0.81
Sc	21-26	23.3	3-12	6.0
TiO ₂ (%)	1.38-2.67	2.0	0.40-0.95	0.757
V	110-187	137	10-67	27
Cr	46-102	67.3	0.9-5.0	3.3
Co	1.2-5.3	9.8	0.7-4	2.7
As	1-95	36	0.2-46	4.1
Se	2-19	8	<0.1-6	4.8
Sb	0.3-11.5	6.3	0.1-0.8	0.38
La	16-80	43	9-88	28
Yb	0.7-2.2	1.5	0.8-4.1	2.1
Hf	3.3-6.4	4.5	3.2-10.6	7.6
Ir (ng per g)	0.90-2.7	1.7	0.005-0.020	0.010
Th	5-21	7.8	5-34	9.2
La/Yb	15-57	28.7	5-67	13.3
TiO ₂ /Al ₂ O ₃	0.056-0.074	0.060	0.016-0.027	0.024
Cr/Al ₂ O ₃	1.64-2.83	2.04	0.036-0.147	0.103

* Boundary data from six sampling sites, non-boundary data from 21 sites
 _ Concentrations in nanog per g unless noted otherwise
 - Cr/Al₂O₃ relative (p.p.m./%)

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The old Red River Road. This remarkably engineered road was built by the U.S. Forest Service in 1916 to open up the Red River valley to automobile traffic. Prior to 1916, wagons attempting to reach Red River from the east would tie a tree trunk to the back of the wagon before daring a descent down from Red River Pass. The unpaved, single-lane road has a maximum grade of 7.5%, total southern exposure to minimize snow accumulation, makes six switchback turns and climbs 1000 ft. Although this breath-taking road is still accessible, four-wheel-drive vehicles are now required. The new paved road, completed in 1966, follows the canyon of Bobcat Creek to Bobcat Pass, located out of sight to the left. In contrast to the old road, this highway has multiple lanes, steeper grades, fewer magnificent views and is prone to greater snow accumulation. Tall Pines Resort, home of Winifred Hamilton, sits at base of road. The photographer, Harold D. Walter of Santa Fe, was the first person to recognize that Wheeler Peak was the highest spot in the state. Courtesy of Mrs. Winifred Hamilton.