

Chicxulub impact: The origin of reservoir and seal facies in the southeastern Mexico oil fields

José M. Grajales-Nishimura
Esteban Cedillo-Pardo
Carmen Rosales-Domínguez } Subdirección de Exploración y Producción, Instituto Mexicano del Petróleo, 07730 México, D.F., México

Dante J. Morán-Zenteno } Departamento de Geoquímica, Instituto de Geología, Universidad Nacional Autónoma de México, 04510 México, D.F., México

Walter Alvarez } Department of Geology and Geophysics, University of California, Berkeley, California 94720-4767, USA

Philippe Claeys } Museum für Naturkunde, D-10099 Berlin, Germany

José Ruíz-Morales } Región Marina Noreste, PEMEX Exploración y Producción, Ciudad del Carmen, Campeche, México

Jesús García-Hernández } Subdirección de Exploración y Producción, Instituto Mexicano del Petróleo, 07730 México, D.F., México

Patricia Padilla-Avila } Subdirección de Exploración y Producción, Instituto Mexicano del Petróleo, 07730 México, D.F., México

Antonietta Sánchez-Ríos } Subdirección de Exploración y Producción, Instituto Mexicano del Petróleo, 07730 México, D.F., México

ABSTRACT

Stratigraphic and mineralogic studies of Cretaceous-Tertiary (K-T) boundary sections demonstrate that the offshore oil-producing breccias and seals from oil fields in the Campeche marine platform are of K-T boundary age and that their mode of formation is probably related to the K-T impact event at Chicxulub. The oil-producing carbonate breccia and the overlying dolomitized ejecta layer (seal) found in several wells on the Campeche marine platform contain typical Chicxulub impact products, such as shocked quartz and plagioclase, and altered glass. These offshore units are correlated with thick (~50–300 m) onshore breccia and impact ejecta layers found at the K-T boundary in the Guayal (Tabasco) and Bochil (Chiapas) sections. Regionally the characteristic sequence is composed of, from base to top, coarse-grained carbonate breccia covered by an ejecta bed and typical K-T boundary clay. The onshore and offshore breccia sequences are likely to have resulted from major slumping of the carbonate platform margin triggered by the Chicxulub impact. Successive arrival times in this area, ~350–600 km from the crater, of seismic shaking, ballistic ejecta, and tsunami waves fit the observed stratigraphic sequence. The K-T breccia reservoir and seal ejecta layer of the Cantarell oil field, with a current daily production of 1.3 million barrels of oil, are probably the most important known oil-producing units related to an impact event.

Keywords: K-T boundary, Chicxulub, carbonate breccia, oil reservoir, Mexico.

INTRODUCTION

In the Gulf of Mexico region, two types of high-energy sedimentary deposits have been described near or at the Cretaceous-Tertiary (K-T) boundary that are thought to be related to the Chicxulub impact event. In Texas, northeast Mexico, and Alabama, the K-T boundary consists of a high-energy coarse clastic unit as much as 4 m thick containing ejecta products at its base and a clay bed with the classic Ir anomaly at its top (Bourgeois et al., 1988; Smit et al., 1996). Farther south, in the Chiapas and Tabasco region, at closer proximity to the crater and near the western margin of the Campeche marine platform, a chaotic carbonate breccia more than several tens of meters thick is found directly below the K-T ejecta sequence (Limón-González et al., 1994; Montanari et al., 1994; Grajales et al., 1996).

Bralower et al. (1998) described evidence for platform margin collapse and debris-flow deposits at several Ocean Drilling Program sites proximal to the crater, triggered by the Chicxulub impact event. In Cuba, a similar uppermost Cretaceous breccia may reach a thickness of 450 m

(Pszczolkowski, 1986), or more than 300 m (Kiyokawa et al., 1999; Takayama et al., 1999).

The offshore zone in the western part of the Campeche marine platform (Fig. 1) is the most prolific oil-producing province in southeastern Mexico and includes the Cantarell oil field (Santiago-Acevedo, 1980). The Cantarell field has produced more than 6934 million barrels (m.b.) of oil and 2954 billion cubic feet ($8365 \times 10^7 \text{ m}^3$) of gas. It contains additional recoverable reserves of 10176 m.b. of oil and 5169 billion cubic feet ($1464 \times 10^8 \text{ m}^3$) of gas (PEMEX Exploración y Producción, 1999). It produces oil from three different stratigraphic levels and it is estimated that 70% of the total production comes from the K-T breccia. For comparison purposes, the most prolific oil field in the United States related to an impact event, the Red Wing Creek field, has a cumulative production of 12.7 m.b. of oil and additional recoverable reserves of 40–70 m.b. of oil (Donofrio, 1981; Grieve and Masaitis, 1994).

The platform is the submerged western part of the Yucatán platform and has been the site of carbonate and evaporite deposition since Early Cretaceous time. In this paper we describe the

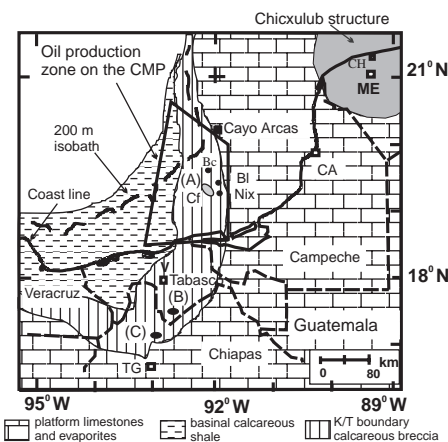


Figure 1. Schematic lithofacies-paleogeographic map for late Maastrichtian platform limestone and basinal calcareous shale in southeastern Mexico. Distribution of Cretaceous-Tertiary (K-T) boundary breccia on Campeche marine platform (CMP) is also shown (Meneses de Gyves, 1980; Santiago-Acevedo, 1980; Sohl et al., 1991). (A) Cantarell field (Cf) and wells Balam-101 (Bl), Bacab-1 (Bc), and Nix-1 (Nix); (B) Guayal, Tabasco; (C) Bochil, Chiapas; CH, Chicxulub; ME, Mérida, Yucatán; CA, Campeche, Campeche; V, Villahermosa, Tabasco; TG, Tuxtla Gutiérrez, Chiapas.

stratigraphy and petrology of seal and reservoir lithofacies from oil-producing wells (Bacab-1, Nix-1, and Balam-101) and suggest that their mode of formation is related to the nearby Chicxulub impact crater. Other aspects of the petroleum system (source rock, timing of oil generation, and migration) have been published elsewhere (González and Holguín, 1992; Guzmán-Vega and Mello, 1999) and are beyond the scope of this paper. The precise stratigraphic age of the Upper Cretaceous dolomitized carbonate breccia and the processes by which it was formed have remained unclear (Meneses de Gyves, 1980; Santiago-Acevedo et al., 1984). We present new results of Upper Cretaceous-lower Tertiary stratigraphic sections of the Campeche marine platform subsurface and compare them with selected

coeval onshore sequences to document their age, mode of formation, and relationship to the K-T boundary Chicxulub event.

K-T BOUNDARY IN THE TABASCO-CHIAPAS-CAMPECHE REGION

In the Chiapas, Tabasco, and Campeche regions of southern Mexico, ~350–600 km from the center of the Chicxulub crater, a chaotic carbonate breccia more than several tens of meters thick is directly below the K-T classic ejecta sequence. Several correlatable K-T stratigraphic sequences were studied: (1) the El Guayal section, located about 60 km southeast of Villahermosa, Tabasco, (2) the Bochil section, briefly described by Montanari et al. (1994), located at km 11.7 on the road leading to the PEMEX well Soyol6-1A about 40 km northeast of Tuxtla Gutiérrez, Chiapas; and (3) a composite section from three offshore wells in the Campeche marine platform (Fig. 2).

Guayal Section

The riverbanks near the town of El Guayal expose a stratigraphic section (17°32'6.15"N, 92°36'15.1"W) of about 100 m across the K-T boundary (Figs. 1B and 2B). This succession can be divided from base to top into the following four distinct units. Unit 1 is 14 m of 10–30-cm-thick hemipelagic limestone beds. The limestone is mainly a biomicrite with abundant planktonic foraminifera such as *Tritinella scotti*, *Racemiguembelina fructicosa*, and *Contusotruncana contusa*, suggesting a middle to late

Maastrichtian age. The uppermost Maastrichtian marker *Abathomphalus mayaroensis* was not found in the thin sections studied. Intercalations of 20–30-cm-thick talus breccia beds are common in this unit. Unit 2 is a 40-m-thick chaotic clastic deposit composed of coarse calcareous breccia (34 m), grading to a finer microbreccia at the top (6 m). Large limestone blocks to 2 m in diameter form the base of unit 2. The breccia is essentially clast supported and matrix is rare. Toward the top of unit 2, blocks decrease in size to <1 m and the percentage of matrix increases significantly. The breccia fragments are made up of platform and hemipelagic limestone facies. Blocks with well-preserved rudist and platform coral fragments are common. The breccia matrix is composed of a cohesive mixture of centimeter to submillimeter-size angular dark gray to white limestone fragments. An assemblage of *Contusotruncana contusa* and *Racemiguembelina fructicosa* was found in the breccia matrix, suggesting a middle to late Maastrichtian age. Unit 3 is an 11-m-thick fining-upward unit that has at its base a 5-m-thick microbreccia composed of limestone fragments only a few centimeters in diameter that contain *Chubbina jamaicensis* of Maastrichtian age. The finer fraction contains submillimeter-sized shocked quartz and altered dark basement clasts of probable granitic or gneissic composition. This microbreccia is overlain by a 6-m-thick succession of medium- to fine-grained loose calcareous sandstone and siltstone beds. Above the siltstone beds is a 1–2-cm-thick brown

to yellowish layer of fine clay. Unit 4, the upper unit, consists of calcareous shales with laminated micritic limestone beds at the base, containing abundant tests of *Globigerina* sp. and *Parvularugoglobigerina eugubina* of earliest Paleocene age. The succession and age of the lithologic units closely resemble and are correlative with those units in the composite section from the Campeche marine platform offshore wells that is described in the following (Figs. 1A and 2A).

Bochil Section

The Bochil section (Chiapas, 17°00.32'N, 92°55.38'W) can be subdivided into three units (Figs. 1C and 2C) similar to those described in El Guayal (Fig. 2B). Although the actual contact between units 1 and 2 could not be observed, unit 2 appears to overlie Upper Cretaceous gray pelagic and hemipelagic marls and limestones. The breccia (unit 2) is composed of a very coarse grained breccia facies (>60 m thick) with blocks ranging in size from 1 to >5 m, followed by a finer grained breccia only a few meters thick composed of smaller fragments. The breccia texture greatly resembles that described in the Guayal section and is essentially clast supported. The matrix of the breccia consists of much finer carbonate clasts, usually less than a few centimeters in size. Tests of *Gansserina gansseri*, *Globotruncana mariei*, *Chubbina jamaicensis*, and *Orbitoides media* of Maastrichtian age are the youngest microfossils found in the breccia matrix. The blocks are composed of shallow-water limestone

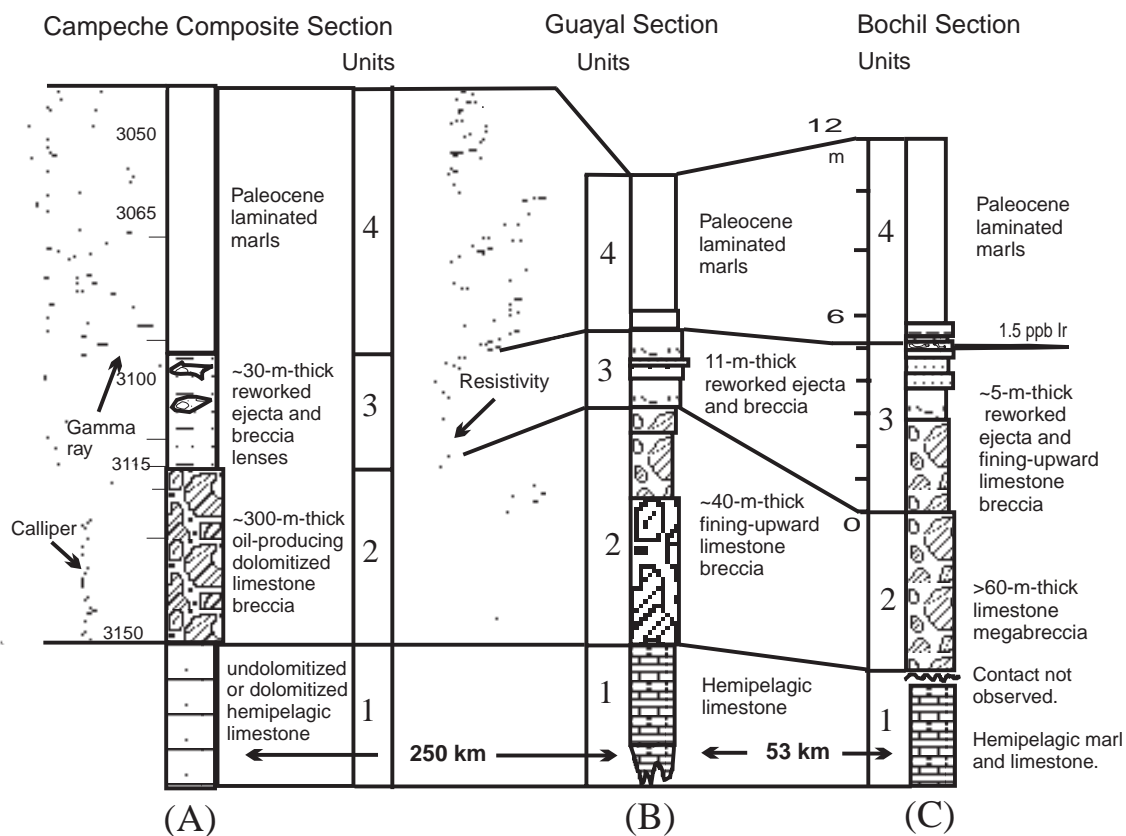


Figure 2. Composite offshore and measured outcrop sections showing stratigraphic positions of Cretaceous-Tertiary units in southern Mexico. (A) Composite section from oil-production zone of Campeche marine platform based on data from Balam-101, Bacab-1, and Nix-1 wells and information given in Meneses de Gyves (1980); Santiago-Acevedo (1980); and Santiago-Acevedo et al. (1984). Unit 2 corresponds to oil-producing dolomitized lower breccia and unit 3 is dolomitized ejecta layer that corresponds to upper seal of oil reservoirs (B) and (C). Measured sections are from Guayal, Tabasco, and Bochil, Chiapas, respectively.

facies, and rudist and coral fragments are also common. The breccia is overlain by a 1.5-m-thick fining- and thinning-upward sequence of ocher-colored, coarse- to fine-grained sandstone and siltstone and is topped by red and green clay laminae about 1 cm thick. This succession resembles unit 3 of the Guayal section and also contains shocked material (Vega et al., 1993; this work). A 1.5 ppb Ir anomaly was detected in the clay laminae that marks the top of this unit (Montanari et al., 1994) (Fig. 2). Above the Ir anomaly there is a 10-cm-thick succession of micritic limestone, clay, and chalk with abundant *Parvularugoglobigerina eugubina* tests indicative of the lowermost Paleocene (Danian). The overlying succession is formed of Paleocene homogeneous gray marls (unit 4) with common ~0.8–5-m-thick intercalations of talus breccia beds (Quezada-Muñetón, 1990; Pécheux and Michaud, 1997).

Composite Section from the Campeche Marine Platform

Stratigraphic data from wells drilled offshore on the Campeche marine platform indicate that calcareous breccia and ejecta deposits form a widely distributed reservoir and seal unit (Fig. 1) (Santiago-Acevedo, 1980; Meneses de Gyves, 1980; Santiago-Acevedo et al., 1984). Because no well shows a complete cored section across the oil-producing dolomitized breccia and basal Paleocene shale, a composite section was constructed with well logs and core samples from the Bacab-1, Nix-1, and Balam-101 wells (Fig. 2A).

Breccias. A lower and an upper breccia or conglomerate are recognized in the wells (Fig. 2A, units 2 and 3). The lower breccia is the oil-producing unit (unit 2). It is strongly dolomitized, and exhibits secondary vuggy porosity due to dissolution. Its average porosity varies from 8% to 12% and its permeability is 3000–5000 mD (PEMEX Exploración y Producción, 1999). It is estimated that 60% of the total current daily production of 1.3 m.b. of oil of the Cantarell field comes from the K-T breccia. The dolomite is coarse grained, and replaces limestone fragments or is present as cement partially filling the vuggy porosity. The upper breccia (unit 3), sampled in the Bacab-1 (core-1) and Balam-101 (core-1) wells, is a clast- or matrix-supported breccia or conglomerate composed mainly of shallow-water limestone or dolomite fragments. Shocked quartz and plagioclase were found in the upper breccia at the Bacab-1 well (Fig. 3B) (Limón-González et al., 1994; this work). The upper breccia is partially dolomitized, and only isolated euhedral crystals of dolomite are present. From well logs of the Bacab-1 and core samples from Balam-101, it appears that the upper breccia or conglomerate overlies or is intercalated with the seal ejecta layer (Figs. 2A and 4A).

Seal. Well logs and cores from the Bacab-1 and Balam-101 show a very impermeable dolomitized bentonitic bed about 30 m thick (Figs. 2A and 4B)

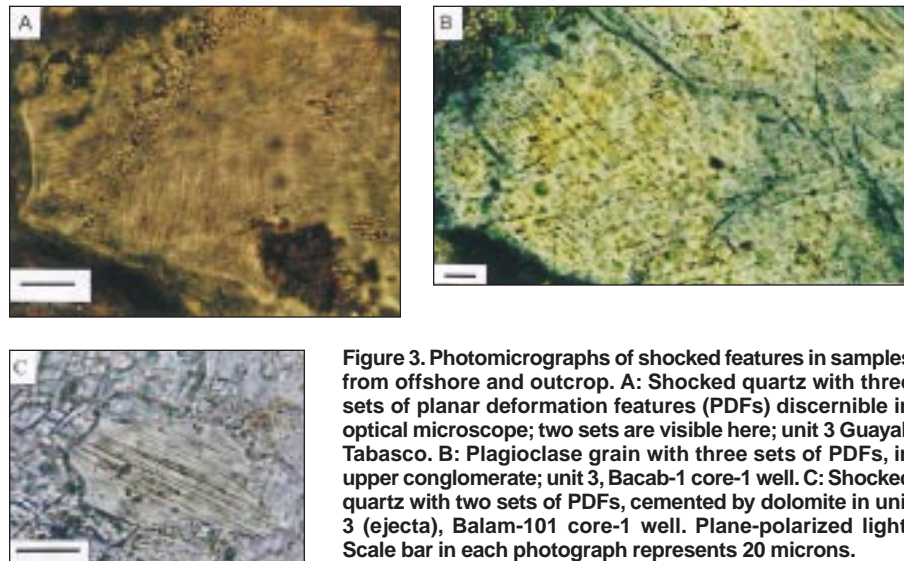


Figure 3. Photomicrographs of shocked features in samples from offshore and outcrop. **A:** Shocked quartz with three sets of planar deformation features (PDFs) discernible in optical microscope; two sets are visible here; unit 3 Guayal, Tabasco. **B:** Plagioclase grain with three sets of PDFs, in upper conglomerate; unit 3, Bacab-1 core-1 well. **C:** Shocked quartz with two sets of PDFs, cemented by dolomite in unit 3 (ejecta), Balam-101 core-1 well. Plane-polarized light. Scale bar in each photograph represents 20 microns.

that overlies the oil-producing breccia. This bed is composed of clay minerals and dolomite with thin layers of silt-sized fragments of feldspar and quartz. Pristine glass fragments are visible in thin sections from the Balam-101 well. Elongate and rounded fragments of greenish clay minerals were observed in the dolomitized bentonitic bed (ejecta layer) of the Balam-101 well. The close association of this greenish clay (smectite) with shocked minerals, its occurrence at a level equivalent to the Balam-101 impact glass, and its resemblance to the clay replacing impact glass in the Mimbral ejecta bed (Smit et al., 1996) suggest that it is the alteration product of impact glass. Shocked quartz (Fig. 3C), feldspar grains, and phosphatic grains representing fish fossil debris are common. In the wells Balam-101, core 1, and Nix-1, core 2, intercalations of thin lenses of conglomeratic material with current bedding are present toward the top of the bentonitic bed. Similar current bedding was documented in the nearby Deep Sea Drilling Project (DSDP) Sites 536 and 540 in the Leg 77 area by Alvarez et al. (1992).

DISCUSSION AND CONCLUSIONS

There are lithological, biostratigraphic, and mineralogical similarities that support correlation among thick carbonate breccia successions identified in offshore wells on the Campeche marine platform and outcrops at Guayal and Bochil sections. On the basis of the unique stratigraphy and distribution of impact material within the calcareous breccia, the following sequence of events and products can be visualized as having taken place within few minutes or hours after the time of the impact: (1) carbonate platform collapse due to shaking, resulting in deposition of the lower breccia; (2) arrival of ballistic impact ejecta (ejecta layers with impact minerals); and (3) reworking and mixing of the ejecta layer with coarser material by one or more passages of the

impact-generated tsunamis that were reflected back and forth across the Gulf of Mexico paleogeography. By comparison with P-wave velocities in limestones and evaporites reported by Sheriff and Geldart (1995), we estimated that seismic waves generated by the impact may have been propagated at velocities of ~5–6 km/s in the carbonate-evaporite rock sequence. This explains why the coarser collapsed calcareous breccia underlies the ejecta layer in localities situated 350–600 km away from the center of the Chicxulub crater (Fig. 1). Ejecta material, such as shocked

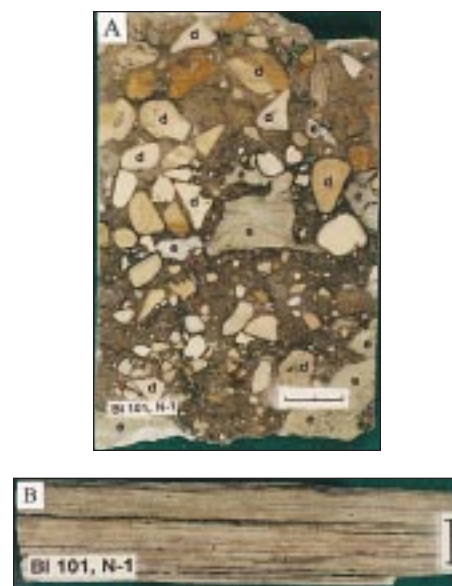


Figure 4. **A:** Core sample of redeposited dolomitized ejecta (e) mixed with dolomite fragments (d). Note rip-up-like clast in center of photo. **B:** Dolomitized ejecta material showing smectite laminations in unit 3. Shocked quartz and plagioclase were found in this sample. Sample in B is 1 m below A. Balam-101 core-1 well. Scale bar represents 2 cm in A and 1 cm in B.

grains and impact glass, reached Bochil, Guayal, and the actual oil-production zone later owing to the lower velocities of the ejecta (~3 km/s) (Alvarez et al., 1995). The upper part of the ejecta was later reworked by tsunami waves. This mechanism led to the deposition of lenses of breccia-conglomerate intercalated and sometimes mixed with ejecta material (Fig. 4A). The fragments in this fine-grained upper breccia or conglomerate came from two possible sources: eroded material from the shallow-water platform or ballistically emplaced material deposited around the crater. Some of this material was transported to deeper waters by the backwash of the tsunami. Similar deposits with pebbly mudstone and current-bedded sand from DSDP Leg 77 Sites 536 and 540 located 400–500 km from the rim of the Chicxulub crater were reported by Alvarez et al. (1992) and confirmed by Bralower et al. (1998).

The ejecta layer represented by the dolomitized bentonitic bed (unit 3) at the top of the lower breccia (unit 2) constitutes the seal for the offshore oil fields (Fig. 4B). This bed apparently inhibited the dolomitization of the upper units, acting as a seal for the diagenetic fluids as well as for the hydrocarbons. In summary, the carbonate breccia unit exposed at El Guayal and Bochil was generated by the K-T impact at Chicxulub, based on the presence of impact ejecta at El Guayal and an Ir anomaly at Bochil, as well as microfossil assemblages, that place the breccia at or extremely close to the K-T boundary. The oil-producing carbonate breccia unit on the Campeche marine platform is of the same age and origin as the Guayal and Bochil breccias, on the basis of the presence of shocked quartz and altered glass of probable impact origin in the Bacab-1 and Balam-101 wells and biostratigraphic age constraints. It has previously been recognized that some oil fields are located within impact structures and produce oil from impact breccias (Donofrio, 1981; Grieve and Masaitis, 1994). This study supports the idea that extraterrestrial impacts on Earth have generated structures, seals, and reservoir facies that are good targets for oil exploration. From the daily Mexican oil production (~2 m.b.), about 1.3 m.b. comes from the Cantarell oil field, which produces mainly from the dolomitized K-T breccia and has the ejecta layer as the upper seal. We conclude that the K-T breccia of the Campeche marine platform is probably the most important known oil-reservoir rock related to an impact event.

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