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15. Experiments were performed with a modified version of the apparatus described in (*6*). A rectangular cuvette made of optically clean glass (inner cross section 0.7 mm × 0.7 mm; length 84 mm) was placed horizontally between two chambers filled with the reaction solution where the Pt plate electrodes were immersed. The entire apparatus was thermostated at 15° ± 0.2°C. We prepared the reaction mixture by mixing the proper amount of stock solutions from reagent-grade chemicals and distilled water, except for bromic acid, which was directly synthesized from $BaCl_2$, $NaBrO_3$, and H_2SO_4 (*6*). To prepare the agar gel system, we mixed the reaction solution with agar gel in the liquid state (final concentration 0.4%) and filled the cuvette with it. The concentrations after mixing were 0.201 M $HBrO_3$, 0.007 M KBr, 0.05 M malonic acid, and 4 mM ferroin. Propagating waves were investigated with a 2-D spectrophotometer. The intensity of the light beam (λ = 490 nm) passing through the cuvette was recorded with a Hamamatsu video camera and digitized by the analog-digital converter in a video frame buffer. A system of mirrors allowed the light beam to pass the cuvette either horizontally or vertically to estimate the one-dimensionality of the wave propagation. The maximal magnification corresponded to a space resolution of 18 mm per pixel. The waves traveling into the cuvette were produced spontaneously at the inlet holes where the cuvette is attached to the solution chambers.
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Coeval $^{40}Ar/^{39}Ar$ Ages of 65.0 Million Years Ago from Chicxulub Crater Melt Rock and Cretaceous-Tertiary Boundary Tektites

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$^{40}Ar/^{39}Ar$ dating of drill core samples of a glassy melt rock recovered from beneath a massive impact breccia contained within the 180-kilometer subsurface Chicxulub crater in Yucatán, Mexico, has yielded well-behaved incremental heating spectra with a mean plateau age of 64.98 ± 0.05 million years ago (Ma). The glassy melt rock of andesitic composition was obtained from core 9 (1390 to 1393 meters) in the Chicxulub 1 well. The age of the melt rock is virtually indistinguishable from $^{40}Ar/^{39}Ar$ ages obtained on tektite glass from Beloc, Haiti, and Arroyo el Mimbral, northeastern Mexico, of 65.01 ± 0.08 Ma (mean plateau age for Beloc) and 65.07 ± 0.10 Ma (mean total fusion age for both sites). The $^{40}Ar/^{39}Ar$ ages, in conjunction with geochemical and petrological similarities, strengthen the recent suggestion that the Chicxulub structure is the source for the Haitian and Mexican tektites and is a viable candidate for the Cretaceous-Tertiary boundary impact site.

The global search for an impact crater of sufficient size to account for the extinctions at the close of the Cretaceous period has focused recently on a subsurface circular structure, 180 km in diameter, centered at Chicxulub on the north coast of the Yucatán Peninsula (*1, 2*) (Fig. 1). If an impact origin is confirmed, the Chicxulub structure, whose outline is based on circular magnetic and gravity anomalies, will be the largest impact crater yet found on Earth. Its size and the proximity to abundant tektites and microtektites recovered in marine Cretaceous-Tertiary (K-T) deposits near Beloc, Haiti (*3–5*), and at Arroyo el Mimbral in northeast Mexico (*6*) and to proximal wave deposits of probable tsunami origin in the Gulf of Mexico (*6, 7*) make the Chicxulub structure an ideal candidate for the K-T impact site that triggered the mass extinctions at the close of the Cretaceous period.

The stratigraphy of the Chicxulub structure is known primarily from a transect of petroleum exploration wells drilled across the Yucatán Peninsula by Petróleos Mexicanos (PEMEX) (*8–10*) (Fig. 1). Three of these wells, Yucatán 6 (Y-6), Chicxulub 1 (C-1), and Sacapuc 1 (S-1), occur within the Chicxulub geophysical anomaly. These wells penetrated marl and limestone underlain by coarse breccia, polymict breccia, and glassy rocks of andesitic composition. The polymict breccia is composed of a mixture of microcrystalline crystals of alkali and plagioclase feldspar, pyroxene (augite), rounded and angular quartz, and minor amounts of euhedral zircon, barite, and Ti-Fe oxides. The angular quartz grains appear to be etched and show multiple sets of planar lamellae indicative of shock metamorphism. The underlying unit is composed of angular pyroxene (augite) crystals embedded in a glassy or microcrystalline groundmass of alkali and plagioclase feldspars. These andesitic glasses and microcrystalline rocks are interpreted as impact breccias and melt rocks of andesitic composition (*2*). Earlier workers (*8*) concluded that the breccia above the melt rocks is Upper Cretaceous in age, which would indicate that the impact age is older than the K-T boundary. However, other workers have estimated on the basis of poorly preserved foraminifera that the rocks are as young as early Paleocene (P3) (*11*). A plausible explanation for the occurrence of Cretaceous deposits above the melt rocks is that they represent fallback breccia of Cretaceous limestone infilling a crater of K-T age. The uncertainty in the age of the Chicxulub crater makes radioisotopic dating of the melt rock imperative.

The possibility that the Chicxulub structure is the source for the Haitian and Mexican tektites has recently been strengthened by chemical analyses of the microcrystalline melt rocks recovered from Yucatán 6 (*2*) (Table 1). The composition of the andesitic melt rock is clearly within range of that observed for the Haitian and Mimbral tektites; and the limestones of the Yucatán Platform can explain the more Ca-rich tektites (*4, 6*). Detailed microprobe analyses of the glassy feldspathic groundmass from sample C-1 (Fig. 1 and Table 1) from the Chicxulub 1 well indicate that it is andesitic in composition and

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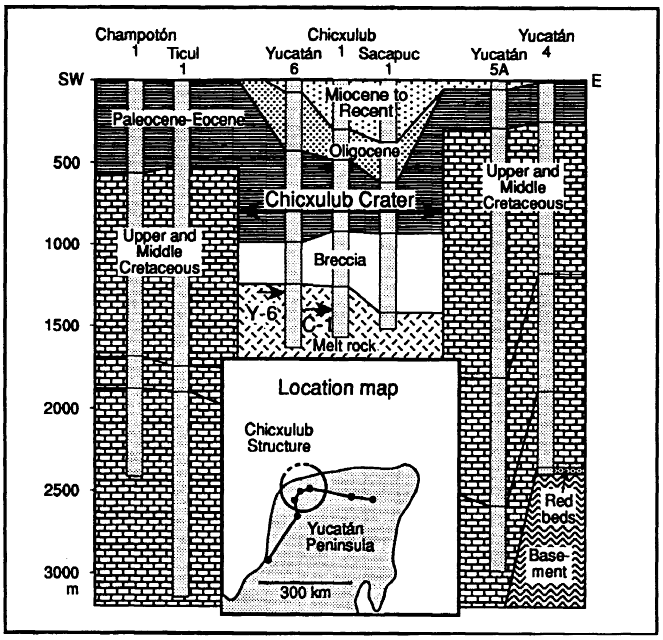

Fig. 1. Generalized stratigraphic cross section of PEMEX wells in the northwestern Yucatán Peninsula, Mexico. The unit marked "Breccia" has a complex internal stratigraphy. The sample of altered melt rock from the Chicxulub crater analyzed by Hildebrand *et al.* (*2*) is from the Yucatán 6 well, marked on the figure as Y-6. The andesitic glassy melt rock that we analyzed from the Chicxulub 1 well is marked C-1. [Figure based on data from López Ramos (*8*) and Hildebrand *et al.* (*2*)]

Table 1. Electron microprobe data. Chemical comparison of melt rock from the Chicxulub impact structure and K-T glasses from Mimbral, Mexico, and Beloc, Haiti. Numbers in parentheses give $\pm 1\sigma$ or 1 standard deviation. Data for Mimbral tektites are from (*6*) and for dark brown to black glasses only. Data for Beloc tektites are from (*4*) for dark brown to black glasses only. Data for Y-6 are altered melt rock and from (*2*). C-1 is andesitic glassy melt rock; from 100 electron microprobe spot transverses of polished section. Ranges (max-min) are indicated for Chicxulub melt rocks.

			Chicxulub crater	
	Mimbral	Beloc	Y-6 altered melt rock	C-1 andesitic/ glassy melt rock
SiO_2	62.97 (1.55)	63.09 (2.13)	63.2–60.5	59.71–58.45
Al_2O_3	15.73 (0.63)	15.21 (0.31)	13.6–12.6	15.84–13.77
FeO	5.32 (1.48)	5.44 (0.38)	5.0–4.5	4.36–3.49
MgO	3.01 (0.58)	2.74 (0.30)	3.2–3.1	5.42–4.06
CaO	6.88 (1.87)	7.26 (1.72)	10.5–10.2	11.24–9.35
K_2O	1.50 (0.37)	1.59 (0.12)	1.9	2.42–2.07
Na_2O	3.34 (0.32)	3.63 (0.27)	4.7–4.0	4.60–4.01
TiO_2	0.70 (0.09)	0.67 (0.07)	0.4	0.13
MnO	0.13 (0.08)	0.14 (0.05)	0.1	0.14
CrO	0.05 (0.02)	0.03		
NiO	0.03	n.d.*		
CuO	0.04	n.d.		
Total	99.7	99.49	100	99.83

*n.d., Not determined.

is composed of a fine-grained mixture of unaltered plagioclase and K-rich feldspar (average composition Ab_{58}, Or_{32}, An_{10}). The wide range of feldspar compositions appears unlike that of any terrestrial volcanic andesite and probably reflects the composition of the target rocks. Sample Y-6 from the Yucatán 6 well (Fig. 1 and Table 1), although similar in composition to sample C-1, contains anhydrite replacing quartz, indicating some secondary alteration. Attempts to date sample Y-6 by laser $^{40}Ar/^{39}Ar$ incremental-heating techniques resulted in hump-shaped spectra that reached a maximum apparent age of about 58 Ma. From these spectra, we conclude that the Y-6 melt rock was too altered to yield reliable $^{40}Ar/^{39}Ar$ ages. On the other hand, the higher K_2O content of sample C-1, as well as the freshness of the unaltered glassy matrix, suggested that it might be a better candidate for $^{40}Ar/^{39}Ar$ dating.

The microphenocrysts of the C-1 sample were too small to allow separation of the feldspar from the K-rich glassy melt; therefore, part of the C-1 sample was crushed and sieved to yield small chips of the glassy melt rock 0.4 to 0.5 mm in diameter, weighing approximately 0.2 to 0.3 mg each. These chips were treated in an ultrasonic cleaner with dilute (~10%) hydrochloric and dilute (~0.7%) hydrofluoric acid for 3 min each to remove any altered glass and adhering clays, then rinsed for 5 min in distilled water.

The C-1 glassy melt rock chips were irradiated together with a centrally located monitor mineral (Fish Canyon Tuff sanidine, FC) for 14 hours in the hydraulic rabbit core of the Omega West research reactor at Los Alamos National Laboratory following procedures in (*12*). After irradiation, single crystals of the monitor mineral and single chips of the C-1 glassy melt rock were loaded into individual 2-mm-diameter wells of a copper sample disk, then placed within the sample chamber of the extraction system and baked out at 200°C for 8 hours. Incremental heating and total fusion

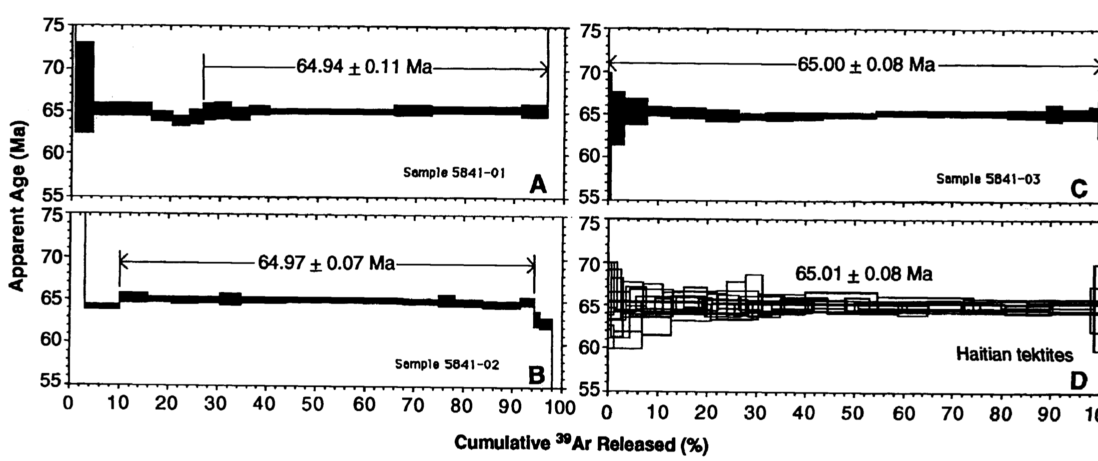

Fig. 2. $^{40}Ar/^{39}Ar$ laser incremental heating spectra for C-1 melt rock (**A** to **C**) and Haitian tektites (**D**).

of the samples and monitor mineral were accomplished with a 6-W Coherent Ar ion laser. The released gases were purified by two Zr-Fe-V getters operated at approximately 150°C, and condensable gases were collected on a cold-trap operated at −45°C. Argon was measured in an on-line Mass Analyzer Product 215 noble gas mass spectrometer operated in the static mode. Laser heating, gas purification, and mass spectrometry were completely automated. Uncertainty in the fluence-calibration parameter (J) for this irradiation was less than 0.1% (12).

The low blank $^{40}Ar/^{39}Ar$ laser system permitted the analysis of extremely small amounts of the glassy melt rock; each chip weighed 0.2 to 0.3 mg. The laser beam was defocused to heat evenly the 2-mm-diameter sample wells. Each of the contained C-1 samples was incrementally heated for 45 s by stepwise increases in the output from the Ar ion laser. The $^{40}Ar/^{39}Ar$ ages of the C-1 glassy melt rock were calculated with the use of a J value determined from the monitor FC sanidine.

Three $^{40}Ar/^{39}Ar$ incremental heating analyses of the C-1 glassy melt rock chips yielded three essentially flat spectra (Fig. 2). The plateau ages are calculated as the weighted (by inverse variances) mean of all increments defining the plateau and the uncertainties that accompany the plateau ages are standard errors (SE) (14). The plateaus consist of more than three contiguous increments that overlap the mean at the 2σ level and compose approximately 70% of the total ^{39}Ar released in the first spectrum and greater than 90% in the second and third (15). The first two spectra, 5841-01 and 5841-02, show a slight disturbance in the low-temperature and high-temperature increments, reflecting slight recoil or possible entrapment of excess argon. However, these increments accounted for less than 30% of the total ^{39}Ar released in the first spectrum and less than 10% in the second, and the third spectrum, 5841-03, shows no low-temperature disturbance. The plateau ages calculated for the three spectra are 64.94 ± 0.11 Ma, 64.97 ± 0.07 Ma, and 65.00 ± 0.08 Ma (Fig. 2 and Table 2). The weighted mean of the three plateau ages is 64.98 ± 0.05 Ma.

At first appearance, the calculated mean age for the C-1 glassy melt rock of 64.98 ± 0.05 Ma is approximately 1% older than recently published $^{40}Ar/^{39}Ar$ laser incremental heating and total fusion ages of 64.38 ± 0.18 Ma and 64.48 ± 0.08 Ma for the Beloc tektites (16, 17). In the most detailed study, Izett *et al.* (16) reported two different ages for the Haitian tektites that differed by as much as 2%, depending upon whether the analyses were made in the Menlo Park laboratory or in the Denver laboratory. About 1% of this age difference is largely due to the adopted age of the irradiation standards by the two laboratories. The 64.38 ± 0.18 Ma and 64.48 ± 0.22 Ma ages for the Beloc tektites were calculated using ages of 513.9 and 27.55 Ma for MMhb-I and FC sanidine, respectively. The Denver results were calculated using the value of MMhb-I of 520.4 Ma and an FC sanidine age of 27.8 Ma (13). Our age of 64.98 ± 0.06 Ma for the C-1 glassy melt rock was calculated for an age of FC sanidine of 27.84 Ma and MMhb-I of 520.4 Ma.

If we recalculate the Izett *et al.* incremental heating and total fusion ages of 64.38 ± 0.18 Ma and 64.48 ± 0.08 Ma using our age for FC sanidine, the age of the

Table 2. $^{40}Ar/^{39}Ar$ incremental laser heating analyses of andesitic impact melt (sample S) from the C-1 core of the Chicxulub impact structure. Step is the laser watt output. J = 0.0099585 ± 0.0000058; decay constants are as follows (also for Tables 3 and 4); $\lambda_\epsilon + \lambda_{\epsilon'} = 0.581 \times 10^{-10}\ yr^{-1}$; $\lambda_\beta = 4.962 \times 10^{-10}\ yr^{-1}$; $^{40}K/^{40}K_{total} = 1.167 \times 10^{-4}$.

Sample step	^{39}Ar (%)	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{40}Ar^*/^{39}Ar$	$^{40}Ar^*$ (%)	Age (Ma ± 1σ)
			5841-01			
0.2	0.5	0.505	1.5359	39.698	8.0	601.00 ± 55.02
0.4	3.8	0.295	0.0670	3.841	16.3	67.72 ± 2.61
0.6	5.8	0.288	0.0064	3.695	66.2	65.20 ± 0.36
0.8	6.0	0.370	0.0041	3.697	75.6	65.23 ± 0.39
1.0	4.3	0.468	0.0029	3.655	81.4	64.49 ± 0.27
1.1	3.3	0.514	0.0016	3.620	89.5	63.90 ± 0.33
1.2	2.8	0.557	0.0017	3.650	88.8	64.42 ± 0.43
1.4	2.6	0.598	0.0015	3.683	90.5	64.98 ± 0.49
1.6	3.1	0.472	0.0015	3.689	89.9	65.08 ± 0.49
1.8	3.9	0.394	0.0018	3.671	88.2	64.78 ± 0.38
2.0	4.0	0.374	0.0019	3.693	87.6	65.16 ± 0.29
3.0	25.4	1.292	0.0033	3.690	80.9	65.10 ± 0.16
4.0	7.6	1.567	0.0057	3.696	70.4	65.20 ± 0.32
5.0	18.3	0.798	0.0032	3.702	80.5	65.32 ± 0.22
6.0	5.2	0.436	0.0035	3.699	78.7	65.26 ± 0.35
8.0	3.4	0.545	0.3941	13.703	10.5	230.78 ± 8.01
			5841-02			
0.2	0.1	0.853	2.1217	50.149	7.4	730.78 ± 61.15
0.4	3.1	0.309	0.1407	6.206	13.0	108.19 ± 4.23
0.6	6.9	0.292	0.0073	3.633	63.0	64.12 ± 0.17
0.8	5.6	0.426	0.0028	3.695	82.2	65.20 ± 0.28
1.0	5.1	0.542	0.0030	3.687	81.6	65.05 ± 0.17
1.3	5.1	0.600	0.0021	3.683	86.6	64.98 ± 0.22
1.6	4.7	0.629	0.0015	3.683	90.0	64.98 ± 0.21
2.0	4.3	0.549	0.0019	3.688	87.5	65.08 ± 0.32
2.5	9.1	0.453	0.0020	3.686	86.6	65.03 ± 0.18
3.0	23.9	0.695	0.0023	3.688	85.5	65.07 ± 0.17
3.5	7.2	0.801	0.0030	3.682	81.8	64.97 ± 0.17
4.0	3.2	0.699	0.0036	3.689	78.4	65.08 ± 0.35
4.5	5.7	0.784	0.0031	3.672	81.0	64.80 ± 0.21
5.0	7.6	0.562	0.0037	3.664	77.9	64.65 ± 0.17
5.5	2.8	0.472	0.0039	3.682	76.6	64.97 ± 0.24
6.0	1.3	0.918	0.0052	3.571	70.8	63.04 ± 0.46
8.0	2.3	0.862	0.0089	3.536	57.9	62.44 ± 0.29
8.0†	0.9	0.225	0.0167	2.824	36.4	50.03 ± 0.50
8.0†	1.2	0.689	0.0237	2.622	27.3	46.49 ± 0.78
			5841-03			
0.4	0.6	0.332	0.0977	3.464	10.7	61.18 ± 4.34
0.6	2.6	0.321	0.0477	3.654	20.6	64.48 ± 1.53
0.8	4.6	0.293	0.0101	3.702	55.5	65.31 ± 0.73
1.0	4.8	0.375	0.0043	3.702	74.8	65.32 ± 0.27
1.3	7.2	0.469	0.0042	3.690	75.5	65.11 ± 0.30
1.6	6.6	0.567	0.0023	3.673	85.4	64.81 ± 0.32
2.0	5.7	0.591	0.0018	3.671	88.5	64.78 ± 0.20
2.3	5.4	0.510	0.0013	3.669	91.4	64.74 ± 0.23
2.6	6.1	0.435	0.0016	3.674	89.3	64.83 ± 0.20
2.9	10.9	0.478	0.0018	3.681	87.9	64.95 ± 0.15
3.3	26.7	1.991	0.0028	3.693	84.5	65.15 ± 0.16
3.6	8.0	0.761	0.0030	3.689	81.8	65.09 ± 0.23
4.5	3.0	0.657	0.0035	3.698	78.8	65.25 ± 0.48
5.0	5.6	0.562	0.0028	3.692	82.5	65.14 ± 0.31
5.5	1.8	0.615	0.0028	3.698	82.4	65.24 ± 0.38
6.0	0.30	0.585	0.0029	3.741	82.0	66.00 ± 1.78
8.0	0.1	1.538	0.0060	3.997	70.7	70.42 ± 6.41

*Radiogenic. †Beam was refocused to assure sample fusion.

Beloc tektites would be 65.06 ± 0.18 Ma and 65.16 ± 0.08 Ma (*18*). These ages are indistinguishable at the 2σ level from our age of 64.98 ± 0.06 Ma for the C-1 microcrystalline melt.

To further address possible interlaboratory biases in our comparisons of the $^{40}Ar/^{39}Ar$ ages for the C-1 glassy melt rock and the Beloc tektites, we redated the Beloc tektites and also determined the age of microtektites from the Arroyo el Mimbral section in Mexico (*6*). The tektites were prepared using methods described above for the glassy melt rock, except that single tektites were first hand picked under a binocular microscope and treated only in hydrofluoric acid for 3 min and then rinsed for 5 min in distilled water. The tektites were then irradiated along with the FC sanidine monitor mineral for 21 hours in the hydraulic rabbit core of the Omega West research reactor at Los Alamos National Laboratory (*12*). Three tektites from Beloc and two from Mimbral yielded identical total fusion ages with an overall weighted mean age of 65.07 ± 0.10 Ma (Table 3). The age of the Mimbral microtektites was the same as the age of the Beloc tektites within uncertainties. A second group of tektites, collected from between levels *f* and *g* of the Beloc section (*5*), were much larger in size than the first suite of samples; thus detailed $^{40}Ar/^{39}Ar$ incremental heating analyses were possible. These tektites were irradiated for 7 hours as described above (*12*). Nine incremental heating analyses of the Beloc glass yielded five well-defined spectra with a weighted mean plateau age of 65.01 ± 0.08 Ma (Fig. 2 and Table 4). These weighted mean ages for the Haitian tektites of 65.07 ± 0.10 Ma and 65.01 ± 0.08 Ma are nearly identical with the recalculated mean plateau age from (*16*) of 65.06 ± 0.18 Ma and only slightly younger than their mean total fusion age of 65.16 ± 0.08 Ma. These results indicate that there is no interlaboratory bias for the ages of the K-T tektites and further confirm that there is no observable difference from the age of the Chicxulub glassy melt rock.

However, precise statements regarding the comparison of the ages of Chicxulub glassy melt rock and Haitian and Mimbral K-T tektites on the one hand, with ages obtained on sanidines separated from bentonites overlying the nonmarine K-T boundary, northern Western Interior of North America on the other, appear premature. Attempts to date these sanidines have yielded variable ages that range from 63.5 to 66.4 Ma (*16, 19*). It is uncertain, at this time, if the variable sanidine ages are a consequence of analytical or geological differences.

Since 1978 evidence has gradually accumulated in support of the hypothesis that a large-body impact or several impacts caused the K-T mass extinction, but the failure to locate a crater of sufficient size has been a problem (*20*). One proposed candidate, the 35-km subsurface Manson impact structure in Iowa, has been considered to be K-T age (*21*); however, it does not appear to be of sufficient size to trigger the mass extinctions at the close of the Cretaceous period. The Chicxulub structure was proposed as early as 1981 to be an impact crater (*1*), but only in 1991 was it suggested as a candidate crater for the K-T impact (*2*). The breccias from the Chicxulub crater are almost surely of impact origin, as indicated by the presence of shocked quartz (*2*); but the report of Upper Cretaceous sediments above the melt rock (*8*) seemed to indicate that this feature was too old to be the K-T crater (*22*). However, discovery of thick ejecta deposits at the biostratigraphic K-T boundary in the nearby sites of Beloc in Haiti (*3–5*), Arroyo el Mimbral in northeastern Mexico (*6*), and Deep-Sea Drilling Program holes 536 and 540 in the southeast Gulf of Mexico (*7*), containing ejecta of proximal character (*23*), implied that a K-T impact crater was nearby. Chemical similarities between the Chicxulub melt rock and glass from these four nearby sites further argued that Chicxulub was the K-T impact site (*2*).

Our $^{40}Ar/^{39}Ar$ ages for the Chicxulub melt rock and tektite glass from nearby marine K-T boundary sites indicates that the sediment of reported Upper Cretaceous age overlying the andesitic melt rocks is either misdated or is a crater-filling breccia derived from preexisting rocks. The $^{40}Ar/^{39}Ar$ ages reported here further add to the growing body of stratigraphic, sedimentologic, petrographic, geochemical, and geophysical data that indicate that the Chicxulub structure is indeed an impact crater of K-T age.

Note added in proof: C-1 melt rock chips were also dated at Stanford University (by M.O.M; data available upon request) following methods similar to those described in Izett *et al.* (*3*). Incremental heating of these chips was accomplished using a continuous argon-ion laser (five analyses) and a resistance-furnace analysis of a 12.6-mg bulk separate and yielded spectra with plateaus meeting formal criteria (*15*). The plateau ages of these six spectra range from 62.1 ± 0.3 Ma to 64.6 ± 0.4 Ma when referenced to the FC sanidine monitor mineral with an age of 27.84 Ma. Close inspection of the spectra proved that the release patterns are not flat; two of the spectra gradually rise in age with increasing temperature and four spectra show a U-shaped release pattern. The two rising release pat-

Table 3. $^{40}Ar/^{39}Ar$ laser total fusion analyses (±1 SD) of tektite glass from Arroyo el Mimbral, Mexico, and Beloc, Haiti. $J = 0.017015 \pm 0.000016$.

Sample	Ca/K	$^{36}Ar/^{39}Ar$	$^{40}Ar^*/^{39}Ar$	$^{40}Ar^*$ (%)	Age (Ma)
		Beloc			
5404-01	3.9908	0.000697	2.158377	97.5	65.07 ± 0.17
5404-02	5.6346	0.000964	2.159428	96.9	65.10 ± 0.19
5404-03	4.1912	0.000995	2.157073	94.1	65.03 ± 0.21
		Arroyo el Mimbral			
5405-01	3.6141	0.000905	2.157709	94.3	65.05 ± 0.30
5405-02	6.3868	0.002755	2.159127	79.1	65.09 ± 0.45
				Weighted mean age =	65.07 ± 0.10†
				Mean age =	65.07 ± 0.03

*Radiogenic. †Standard error.

Table 4. $^{40}Ar/^{39}Ar$ plateau data (±1 SD) for tektite glass from Beloc, Haiti. J for 5682 = 0.0059649 ± 0.0000096; J for 5690 = 0.0059058 ± 0.0000053.

Sample	Steps*	^{39}Ar (%)	Ca/K	Weighted age (Ma)
5682-01	6/10	79.3	9.78	64.97 ± 0.26
5682-02	10/10	100.0	4.10	64.97 ± 0.27
5682-03	10/10	100.0	3.37	64.97 ± 0.22
5690-02	12/12	100.0	2.74	65.16 ± 0.36
5690-03	8 /8	100.0	4.06	65.31 ± 0.39
5690-04	15/15	100.0	2.74	64.88 ± 0.16
5690-05	12/12	100.0	2.96	65.09 ± 0.18
5690-06	11/12	94.2	4.08	64.94 ± 0.31
5690-07	11/11	100.0	4.33	65.15 ± 0.23
			Weighted mean age =	65.01 ± 0.08†
			Mean age =	65.05 ± 0.14

* Number of plateau-defining steps divided by total steps analyzed. †Standard error.

terns are suggestive of low-temperature alteration; their higher temperature steps, representing 42 and 20% of the total ^{39}Ar released, would indicate minimal crystallization ages of 64.6 ± 0.4 Ma and 65.2 ± 1.2 Ma. In an addi-tional experiment, four increments in the middle of a rising release spectrum for a 1.0-mg bulk plagioclase analysis, between 800° and 1050°C, representing approximately 25 to 30% of the total ^{39}Ar released, yielded a weighted mean age of the C-1 melt rock, give a weighted mean age of 64.7 ± 0.4 Ma, consistent with the previously discussed results. The variability in release patterns noted here are most likely a result of differential alteration and small-scale inhomogeneity of the sample.

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12. Analytical procedures follow A. Deino and R. Potts [*J. Geophys. Res.* **95**, 8453 (1990)], A Deino, L. Tauxe, M. Monaghan, and R. Drake [*J. Geol.* **98**, 567 (1990)], C. C. Swisher III and D. R. Prothero [*Science* **249**, 760 (1990)], and P. R. Renne and A. R. Basu [*ibid.* **253**, 176 (1991)]. The maximum output of the laser during this study was approximately 8 W. Ca and K corrections were determined from laboratory salts: $(^{36}Ar/^{37}Ar)_{Ca} = 2.557 \times 10^{-4} \pm 4.6 \times 10^{-6}$, $(^{39}Ar/^{37}Ar)_{Ca} = 6.608 \times 10^{-4} \pm 2.53 \times 10^{-5}$, and $(^{40}Ar/^{39}Ar)_K = 2.4 \times 10^{-3} \pm 7.0 \times 10^{-4}$. *J* [0.0099585 ± 0.0000058 (± 0.06%)] was based on 20 replicate single crystal analyses of the monitor mineral Fish Canyon (FC) sanidine with an age of 27.84 Ma. Mass discrimination during this study, as determined by replicate air aliquots delivered from an on-line pipette system, was 1.006 ± 0.00015. The Haitian tektites were similarly irradiated for 21 hours (*J* = 0.017015 ± 0.000016) and for 7 hours (two levels; *J* = 0.0059649 ± 0.0000096 and 0.0059058 ± 0.00000534) according with procedures and calibrations outlined above and in text. Decay constants are those reccommended by R. H. Steiger and E. Jager [*Earth Planet. Sci. Lett.* **36**, 359 (1977)] and G. B. Dalrymple [*Geology* **7**, 558 (1979)].
13. The age of the FC sanidine adopted in this study (27.84 Ma) is similar to that recommended by G. T. Cebula *et al.* [*Terra Cognita* **6**, 139 (1986)] but slightly modified as a result of in-house intercalibration with MMhb-I with an age of 520.4 ± 1.7 Ma [S. D. Samson and E. C. Alexander, *Chem. Geol. Isot. Geosci. Sect.* **66**, 27 (1987)].
14. The uncertainties associated with the individual incremental apparent ages are 2σ errors, whereas those that accompany the calculated weighted mean ages of the plateau increments and weighted means of the replicate analyses are standard errors (SE) following J. R. Taylor [*An Introduction to Error Analysis* (Oxford Univ. Press, New York, 1982)].
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18. FC sanidine was used as a monitor over MMhb-I, primarily, because of its far superior grain to grain and irradiation to irradiation reproducibility. Izett *et al.* (*16*) indicated that FC sanidine was also used as one of their monitor minerals in the calibration of their age for the Haitian tektites. Using their reported age for FC of 27.55 Ma and our age for FC sanidine of 27.84 Ma, we recalculate the Menlo Park ages for the Haitian tektites as follows: plateau age = 64.38 × (27.84/27.55) = 65.06 Ma and total fusion age = 64.48 × (27.84/27.55) = 65.16 Ma.
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Pseudo–Half-Knot Formation with RNA

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A pseudo–half-knot can be formed by binding an oligonucleotide asymmetrically to an RNA hairpin loop. This binding motif was used to target the human immunodeficiency virus TAR element, an important viral RNA structure that is the receptor for Tat, the major viral transactivator protein. Oligonucleotides complementary to different halves of the TAR structure bound with greater affinity than molecules designed to bind symmetrically around the hairpin. The pseudo–half-knot–forming oligonucleotides altered the TAR structure so that specific recognition and binding of a Tat-derived peptide was disrupted. This general binding motif may be used to disrupt the structure of regulatory RNA hairpins.

The RNA duplex structure is not favorable for antisense or ribozyme binding. Folded RNA, however, has short single-stranded segments that may be used to initiate antisense hybridization, followed by propagation of the heteroduplex into structured regions (*1*). Structured RNA regions often are recognized by regulatory proteins (*2–5*), and targeting these structures with an antisense oligonucleotide may block binding of a regulatory protein.

The simplest example of RNA secondary structure is a hairpin consisting of a double-stranded stem region and a single-stranded loop. Hybridization to all of the unpaired bases in the loop without disrupting base pairing in the stem would seem an attractive strategy but is sterically impossible. Pseudoknots are naturally occurring RNA structures where hairpin loops are base paired in stable and sterically possible conformations. Single-stranded bases of an RNA hairpin loop create a pseudoknot by pairing with bases adjacent to the hairpin, forming a second stem and loop (Fig. 1) (*6–9*). An RNA pseudoknot contains two coaxially stacked stems and two topologically distinct loops, L1 and L2. L1 crosses the major groove and L2 crosses the minor groove.

When an antisense oligoribonucleotide is hybridized asymmetrically to the loop of a hairpin, the topology of the resulting complex resembles half a pseudoknot. If hybridized to the 3′ side of the loop (Fig. 1A, top path), a structure equivalent to S2 is formed and the looped-out RNA is equivalent to L1. If hybridized to the 5′ side of the

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