um anomaly has been found in 50 sections worldwide (Fig. 1). Most of these sections show clear relationships that are in accord with the impact theory. Officer and Drake have chosen to base their case on the few sites where stratigraphic complications make the interpretation ambiguous.

In summary, the portion of Officer and Drake's paper that evaluates T and δt contains numerous errors and misunderstandings. This is the most critical part of their argument, but it is simply wrong and cannot be taken as evidence against the impact hypothesis. We have space to comment on only a few of the other points made in their paper.

Officer and Drake make reference to the work of Rampino and Reynolds (*3*), who found that various K/T boundary clays are "neither mineralogically exotic nor distinct from clays above and below the boundary" (*4*, p. 1390). This conclusion is in disagreement with the findings of Kastner (*27*) and Bohor (*28*). It also disagrees with Rampino and Reynolds' own findings on the section at Nye Kløv, Denmark, where they report pure smectite in the boundary layer and different clay minerals above and below. They consider this smectite layer to be unimportant, because they interpret it as an altered volcanic ash. Both Kastner (*27*) and Bohor (*28*) have noted that the clay minerals of the K/T boundary layer could be produced by alteration of impact-melt glass, as well as by alteration of volcanic ash. Furthermore, by looking only at < 2 μm clays, Rampino and Reynolds discarded the boundary spherules (*29*), which are not only exotic but apparently unique to the K/T boundary.

Officer and Drake also cite Wezel *et al.* (*30*), who have reported iridium anomalies both above and below the K/T boundary in some Italian sections, notably in the 1-m black, cherty shale called the Bonarelli level, about 240 m below the K/T boundary. We have been concerned about this report, because Wezel's group have also published strange micropaleontological results (*31*) that later were shown to be due to contamination (*32*), and contamination is all too easy in chemical analytical work at the parts-per-billion level. To test the results of Wezel *et al.*, we have analyzed 12 independently collected samples that completely cover the Bonarelli level at the site where Wezel's group reported an iridium anomaly. The results are shown in Fig. 2, and we conclude that there is no evidence for an iridium anomaly at the Bonarelli level.

The last paragraph of Officer and Drake's article seems to be a plea for a return to the time before the iridium anomaly was discovered, when almost any speculation on the K/T extinction was acceptable. This idea is pleasantly nostalgic, but there is by now a large amount of detailed astronomical, geological, paleontological, chemical, and physical information which supports the impact theory. Much interesting work remains to be done in order to understand the evolutionary consequences of the impact on different biologic groups, but the time for unbridled speculation is past.

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Mass Spawning in Tropical Reef Corals

Abstract. *Synchronous multispecific spawning by a total of 32 coral species occurred a few nights after late spring full moons in 1981 and 1982 at three locations on the Great Barrier Reef, Australia. The data invalidate the generalization that most corals have internally fertilized, brooded planula larvae. In every species observed, gametes were released; external fertilization and development then followed. The developmental rates of externally fertilized eggs and longevities of planulae indicate that planulae may be dispersed between reefs.*

It has been widely accepted that most scleractinian corals are viviparous, often releasing larvae intermittently throughout the year (*1–3*). This view is supported by studies of a few species that release planula larvae in the laboratory (*1, 4–10*). Recent studies have shown that some corals are not viviparous, but spawn gametes during brief annual spawning periods (*11–18*). To determine the typical mode and timing of sexual reproduction in corals, we studied gametogenesis and spawning in a large number of hermatypic coral species from the central Great Barrier Reef Province.

Studies were undertaken on nearshore fringing reefs at Magnetic Island and Orpheus Island, and on a midshelf platform reef, Big Broadhurst Reef (Table 1). We observed gamete release in 23 species in situ and in the laboratory. In nine other species, spawning was inferred from the disappearance of mature gametes in sequential samples, or from the presence of gametes in aquaria or plankton mesh bags placed over corals in

situ (Table 1). No corals were observed to brood or release planulae. Before 1981, 46 coral species were known to brood planulae, whereas only 8 species were reported to spawn gametes. The results of this study, and other recent publications, show that more than 60 coral species spawn gametes. No further species have been reported to brood planulae. Hence, the majority of coral species for which data are available spawn gametes, rather than brood planulae.

Most of the corals studied were simultaneous hermaphrodites, with an annual gametogenic cycle (*19*). Microscopic examination of live, freshly broken coral pieces allowed rapid assessment of polyp reproductive status. Approximately 3 weeks before spawning, during rising sea temperatures in the spring, oocytes of many species began changing color from white to pinkish-red, green, or tan. This change could easily be seen in the field. In the week before spawning, sperm squashes showed condensation of spermatozoa heads and increased flagellar activity.

Lunar periodicity of spawning has been described in brooding corals (*4, 5, 7, 20*) and in gamete releasing species (*12, 14, 18*). Spawning was first observed in corals in aquaria at Magnetic Island in 1981, 5 to 8 nights after a full moon in mid-October (Table 1). One lunar month later, synchronous, epidemic spawning was observed in situ on the fifth night after the full moon in mid-November (Table 1). There was only one major spawning period at Magnetic Island in 1982, 4 and 5 nights after the full moon in early November (Table 1). Spawning at Orpheus Island and Big Broadhurst Reef occurred 4 and 5 nights after a full moon in early December 1982 (Table 1).

Spawning appears to be induced by specific dark periods, characteristic for each species. *Acropora tenuis* spawned on dusk at 1900, and *Galaxea* spp. from 1945, while most of acroporiid and faviid corals spawned between 2000 and 2330. Freshly collected corals maintained in the laboratory under natural light regimes spawned simultaneously with corals in situ; experimentally extended light periods delayed spawning. As in many temperate marine invertebrates (*21–23*), the reproductive cycles of these corals also appeared to be broadly influenced by temperature. Cooler water tempera-

Table 1. Coral spawning dates from three reefs during 1981 and 1982. The data were collected on the nights indicated (4, 5, 6, 7, and 8) after the full moon. Dates when spawning was not observed are not included in the table. Spaces indicate either that the species were not present at the site or were not observed spawning. Abbreviations: F, spawning observed in the field; (F), spawning inferred in the field from daily samples; (.F.), spawning inferred in the field from samples taken a few days apart; A, spawning observed in aquaria; and (A), spawning inferred from presence of gametes in aquaria.

Species	Magnetic Island (146°51′E; 19°09′S)									Orpheus Island (146°29′E; 18°36′S) 5 to 6 December 1982		Big Broadhurst (148°43′E; 18°57′S) 6 December 1982
	18 to 21 October 1981				16 November 1981	5 to 6 November 1982		5 to 6 December 1982				
	5	6	7	8	5	4	5	4	5	4	5	5
Acroporidae												
Acropora austera												(F)
A. clathrata												(F)
A. cerealis												(F)
A. cytherea						(F)						(F)
A. elseyi					(.F.)							
A. formosa	(A)		A	A	F	A (F)	F			A		
A. gemmifera												F
A. humilis		A			F	A (F)						F
A. hyacinthus					(.F.)	A (F)	F					(F)
A. intermedia					(.F.)							(F)
A. listeri										A		
A. longicyathus					(.F.)					A		
A. loripes												F
A. millepora					F	A (F)	F				A	(F)
A. microphthalma						A (F)						(F)
A. nasuta											A	F
A. pulchra						(F)	(.F.)					
A. tenuis					(.F.)		F					
A. valida		A				A (F)						(F)
*Montipora ramosa**					(.F.)							
Faviidae												
Favia pallida											F	
F. rotumana										A	A	
Favites chinensis											F	
Goniastrea aspera	(F) (A)	A				A				A	FA	
G. favulus	(F) A	A				A				FA	A	
G. retiformis											F	
Hydnophora exesa								(.F.)	(.F.)			
Platygyra sinensis							F			A	FA	
Oculinidae												
Galaxea astreata											A	
G. fascicularis							F					
Mussidae												
Lobophyllia sp.		A†										
Poritidae												
Goniopora sp.		A†										

*A. Heyward, James Cook University, personal communication. †P. Watson, Shark World, Nelly Bay, Magnetic Island, personal communication.

Table 2. Planulae development times, settlement dates, and longevity in the laboratory.

Species	Planula (days after spawning)				Age at settlement (days)	Maximum longevity of planulae (days)
	Motile ciliated	In mid-water	In mid-water and on bottom	Benthic searching		
Acropora hyacinthus	1.5	2.5	3–4	7	36	91
A. formosa	1.5	3	4–5	5	16–20	23
A. tenuis	1.5	6	7			7
A. millepora	1.5	2–3	3–4			5
Goniastrea aspera	1–2	2–4	5	6		60
G. favulus	1–2	2	5	6	14–22	

tures at Orpheus Island and offshore reefs in November 1982 probably account for slower gamete maturation and later spawning at these sites. Thus spawning can be predicted to occur at characteristic hours, 4 to 5 nights after one or two full moons in spring, from October to December. The local sea temperature pattern in winter and spring probably determines when, and how many, spawning periods occur at each site.

Of the corals studied, only four species of *Turbinaria* did not spawn in spring. Instead they spawned in autumn in 1981 and 1982 when sea temperatures were falling (*19*). *Turbinaria* species were also unusual in having colonies with separate sexes and a spawning season extending over 3 months.

A range of spawning strategies was observed in the study corals, and these could influence both the degree of cross-fertilization within a population and the dispersal of gametes and embryos. In the acroporiid (Fig. 1a) and some faviid species (*Goniastrea retiformis* and *Platygyra sinensis*), the eggs and testes were compressed and slowly extruded as a positively buoyant egg-sperm bundle that rose to the surface and broke apart. In contrast, other faviid species actively expelled streams of buoyant egg-sperm bundles (*Goniastrea aspera*, Fig. 1b), or sperm followed by sticky, sinking eggs (*G. favulus*) through rapid polyp contractions.

The majority of gametes in each colony were shed on only one night, and entire populations spawned over one or two nights annually (*24*). Synchronous spawning within a population is advantageous for corals with external development as it maximizes fertilization and allows for genetic exchange through cross-fertilization. However, this does not explain why many species from different families spawn synchronously, or why spawning occurs predominantly 4 to 5 nights after the full moon. Epidemic spawning may increase the survival chances of planktonic larvae by satiating active predators and filter feeders during the spawning period. The risks of single epidemic spawning to corals with buoyant propagules were clearly demonstrated at Magnetic Island in November 1981 when a heavy rain squall coincided with spawning. Propagules on the surface were destroyed, probably by reduced salinity, thereby negating the entire reproductive effort of those corals for the year. Synchronous spawning of congeneric corals may also pose problems for the recognition of conspecific gametes. Sperm chemotaxis has been documented in many species of hydromedusae that exhibit simultaneous spawning, possibly to compensate for the multispecific spawning and high dilution of gametes (*25*). If coral eggs do not release sperm attractants, fertilization must rely upon chance encounters of conspecific gametes.

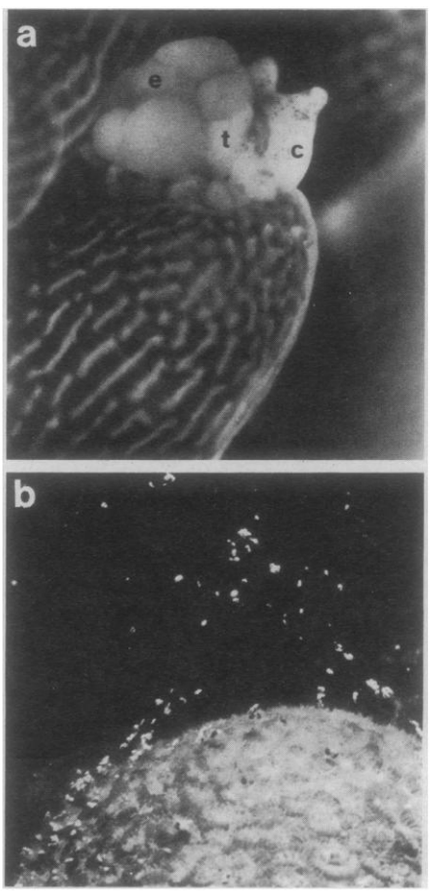

Fig. 1. Gamete release in corals. (a) *Acropora formosa* polyp slowly pushing an egg-sperm bundle through the mouth; *e*, egg mass; *t*, testis; *c*, contracted tentacles. The egg-sperm bundle is approximately 1.5 mm wide (×20). (b) *Goniastrea aspera* colony rapidly ejecting buoyant egg-sperm bundles, synchronously, over small portions of the colony (×0.8).

In the laboratory, motile planulae from four acroporiid and two faviid species developed within 2 to 3 days after spawning, and active benthic searching behavior began after 5 to 7 days (Table 2). Planulae settled between 14 and 36 days after spawning, and one *Acropora hyacinthus* planula survived for 91 days (Table 2). In plankton tows near Magnetic Island during the spawning periods in 1981, planulae were found up to 2.5 km from the nearest reef. Recent speculation that reefs are primarily self-seeded (*26*) was based on the rapid settlement times of a few hours to 2 days recorded for brooded planulae, which are well developed when released. However, the longer period required for development of externally fertilized eggs into planulae, and the observed dispersal of larvae, indicate that most of the planulae might be dispersed away from the parent reef. This suggests that reefs in the Great Barrier Reef Province are interdependent. Indeed, a survival period of 91 days shows that at least one species of *Acropora* is capable of surviving long enough to support the hypothesis that recruitment of *Acropora* to the Hawaiian Islands may occur by larval dispersal from Johnston atoll 720 km away (*27*).

As a result of this study, more coral species are now known to spawn gametes than to brood planulae, suggesting that viviparity may be the exception rather than the rule in coral reproduction. In addition, these corals do not breed continuously throughout the year, but spawn seasonally, most of them during a single brief annual period. The extremely short spawning period contradicts widespread assumptions about the lack of seasonality among tropical organisms. These observations are the first to show that synchronous multispecific spawning occurs in many corals and that the time of mass spawning is predictable.

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Phenylalanine Transfer RNA: Molecular Dynamics Simulation

Abstract. *Yeast phenylalanine transfer RNA was subjected to a 12-picosecond molecular dynamics simulation. The principal features of the x-ray crystallographic analysis are reproduced, and the amplitudes of atomic displacements appear to be determined by the degree of exposure of the atoms. An analysis of the hydrogen bonds shows a correlation between the average length of a bond and the fluctuation in that length and reveals a rocking motion of bases in Watson-Crick guanine · cytosine base pairs. The in-plane motions of the bases are generally of larger amplitude than the out-of-plane motions, and there are correlations in the motions of adjacent bases.*

Computer simulations with the molecular dynamics algorithm have been used to investigate intramolecular motions in proteins on the picosecond time scale (*1, 2*), and Levitt has recently reported the first simulation for DNA (*3*). He found that, when he included the partial atomic charges, the double helix unwound; to preserve the tertiary structure he had to set all of the partial charges to zero. We describe the first successful molecular dynamics simulation for a transfer RNA (tRNA). By careful equilibration of the structure, we have been able to include full electrostatic effects (*4*); a similar result for a DNA simulation has just been reported (*5*).

As in our previous conformational energy study (*6*) on large-scale bending in phenylalanine transfer RNA ($tRNA^{Phe}$), we began with the 2.5-Å crystal structure (*7*) and used standard parameters (*8–10*) for the potential energy functions. Partial atomic charges (*11*) have been included, and a distance-dependent dielectric constant was used to mimic solvent dielectric effects (*12*). No counterions were included, but their effect was approximated by scaling charges on atoms in phosphate groups to give a net charge of 0.2 electron per nucleotide. Explicit hydrogen atoms are not included, and extended atoms represent each heavy atom and the hydrogens covalently bound to it (*12*); hydrogen bond lengths thus refer to the distance between the heavy atoms of the donor and acceptor groups. A normal van der Waals potential function (*4*) was used in this simulation.

The structure was subjected to 100 cycles of steepest descent energy minimization, after which atomic velocities were assigned with a Maxwellian distribution corresponding to a temperature of 50 K, and the molecule was warmed by velocity reassignments at 1-picosecond intervals with temperatures rising to 300 K at 11 psec. This temperature was reassigned at 0.2-psec intervals over a period of 5 psec, and equilibration was completed by a 4 psec free run. Data analysis covered the interval from 20 to 32 psec, during which time the average temperature of the molecule was 303.7 K.

The integrity of protein structures during molecular dynamics experiments may be partly due to their compact and globular shapes and to the fact that the simulations are generally done near the isoelectric point. In view of the extended structure and net charge of $tRNA^{Phe}$, and because of the difficulties (described above) that Levitt encountered with structural degradation in his DNA simulation (*3*), we have examined several structural parameters to verify that our model of $tRNA^{Phe}$ does remain intact. To begin with, a visual inspection of computer graphics pictures of representative structures from the trajectory showed that the overall structure is preserved. The radius of gyration is 23.4 Å in the crystal structure (*7*), while it varies about a mean value of 22.7 Å with an amplitude of 0.5 Å and an apparent period of about 10 psec in the simulation (*4*). Since there is no solvent in the stimulation, so that there are no attractive forces between atoms on the surface of the molecule and the solvent, the 3 percent shrinkage of the model with respect to the crystal is not surprising. The oscillation in the radius of gyration reflects a concerted bending motion, a collective motion of small amplitude but extending over the entire molecule: the angle between the two arms oscillates with an amplitude of about 1°, and the distance between the anticodon and the acceptor terminus oscillates with an amplitude of about 1 Å. This motion is reminiscent of the hinge-bending mode proposed by others (*13, 14*) and examined in our earlier study (*6*).

More critical measures of the preservation of the structure are provided by an examination of the ribose puckers and of some of the parameters of the helix. We have calculated the puckering angle (*15*) for all 76 sugar moieties over the course of the trajectory, and we find that 65 of them are in the conformational energy valley near the C3′-*endo* configuration, and 11 are C2′-*endo*, exactly as in the crystal. Although the puckering angles oscillate about these two local minima, none of the sugars changes from C3′-*endo* to C2′-*endo* or vice versa. Helix integrity is demonstrated by the interphosphate distances, the twist angles of successive base pairs, and the orientation of base plane normal vectors, all of which also have average values near those of the crystal structure.

The root-mean-square deviations of