at Stevns Klint is of extraterrestrial origin if the projectile was a C-1 chondrite component (*12*). With this constraint the dilution of the projectile osmium with crustal osmium would not change the $^{187}Os/^{186}Os$ more than 1 percent. This is not enough to raise the $^{187}Os/^{186}Os$ ratio to the value observed at Stevns Klint. An upper limit of possible contamination of a chondritic projectile osmium with crustal osmium can be set from the calculations of O'Keefe and Ahrens (*15*). They determined that a 10-km-diameter body would yield a mass of rock or water ejected at the time of collision equal to 10 to 100 times the mass of the projectile. A 100-to-1 dilution of crust to chondritic projectile would increase the $^{187}Os/^{186}Os$ ratio by 10 percent over the value in the chondritic projectile. The value of 1.65 is outside this limit. Therefore, we believe that the high ratio cannot be explained by simple dilution of projectile material with target material.

There are reliable data on the Re/Os ratio of meteorites which can be referred to a present-day $^{187}Os/^{186}Os$ ratio on the assumption of a common initial $^{187}Os/^{186}Os$ value and age for all the meteorites. Under these assumptions an $^{187}Os/^{186}Os$ ratio of 1.65 would require an Re/Os element ratio of about 0.30. Table 2, constructed from high-quality data, shows the range of values observed in a number of meteoritic classes. None of the chondritic classes, including carbonaceous chondrites, has an Re/Os ratio that comes close to that required for the alleged cosmic projectile. Iron meteorites and pallasites are higher than the chondrites in their Re/Os ratios, and a few even have sufficiently high values to suggest that the alleged cosmic projectile responsible for the imprint at Stevns Klint ought to belong to this class of objects. Perhaps fortuitously, the reported Re/Os ratios of the boundary clay bracket the value required to yield the observed $^{187}Os/^{186}Os$ ratio (Table 2).

Raton Basin. We also measured the $^{187}Os/^{186}Os$ ratio in an Ir-enriched layer from a nonmarine section in the Raton Basin (Colorado). The high-Ir layer is found at the base of a coal seam which, on the basis of pollen stratigraphy, has been inferred to be at the Cretaceous-Tertiary boundary (*16*). We received a sample of the material with the highest Ir concentration found at the Starkville South locality, south of Trinidad, Colorado, from C. J. Orth and analyzed it with the ion probe at Paris. The $^{187}Os/^{186}Os$ ratio is 1.29 ± 0.04.

This value is significantly lower than the Stevns Klint ratio. If we argue that crust-derived osmium is not a major contaminant at either of these sites, then clearly they represent projectiles or events of different composition. The $^{187}Os/^{186}Os$ ratios 1.29 and 1.65 are incompatible with chondrites and imply an iron meteorite projectile if we accept the impact hypothesis as the most probably one.

Conclusions. We conclude that the simplest interpretation of the Stevns Klint and Raton Basin evidence is that the layers high in Ir (and Os) are of meteoritic origin. Contamination with continental crust–derived osmium is small, if only simple mixing of our estimated crustal $^{187}Os/^{186}Os$ value is used. If no contamination by a crustal ^{187}Os-enriched source has occurred, then the projectiles cannot be any of the contemporary chondritic classes but may be of iron meteorite affinity. The difference in $^{187}Os/^{186}Os$ between the marine Stevns Klint and nonmarine Raton Basin samples is significant and implies that either different meteorites were involved, or that there have been different amounts of crustal osmium contamination, by unspecified processes, of the meteoritic projectile material at the two sites.

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19. We wish to thank S. R. Hart and N. Shimizu for permission to use the MIT-Harvard-Brown Consortium Cameca ion microprobe at MIT and C. J. Allegre for the one in Paris, S. Gartner and F. T. Kyte for generously providing the Stevns Klint samples, and C. J. Orth for the Raton Basin sample. C. Officer read the original version of the manuscript and alerted us to the possibility of a volcanic concentration of Os. Even though we have bet on a meteoritic origin, his arguments are forceful. E. Anders brought some additional meteoritic data to our attention and expressed concern that crustal contamination may not be ruled out because of our present level of knowledge. This research was supported by NSF grant OCE-8212733.

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Computer Simulations of the Belousov-Zhabotinsky Reaction

Abstract. *Morphological features of the two-dimensional Belousov-Zhabotinsky reaction were modeled with an algorithm involving only two simple parameters, one describing the productivity of the reaction on a local scale length and the other characterizing the delay or quiescent time after the localized reaction. Self-organizing wavelike structures, including single- and multiarmed spirals, were most easily generated.*

While investigating the range of spatial structures produced by varying the parameters of a self-propagating star formation algorithm (*1*), we found that some of the resulting patterns resemble those found in autocatalytic chemical reactions described in 1958 by Belousov and in 1964 by Zhabotinsky (*2*) and more recently by Winfree (*3*) and others (*4, 5*). The most striking feature of the chemical reaction is the spontaneous appearance of globally coherent structures developing from so-called local oscillators. Although these patterns have been ascribed to symmetry-breaking instabilities caused by diffusion in systems involving more than two variables (*6*), little more than asymptotic analysis of the rate equations has been performed (*7*), and the role of the putative local oscillator or echo waves (*8*) is in dispute. An introduction to the general analytic theory of such autocatalytic reactions can be found in Cohen *et al.* (*9*), Tyson (*8*), and Nicolis and Prigogine (*4*), while a more popular discussion of the spiral-producing reactions is given by Winfree (*10*). The simplicity of our simulations suggests that, while the underlying physics may be very complex, the macroscopic manifestations are easy to understand and model.

The chemical experiments (*3*) show that the following structures can arise. If externally activated (by, say, a hot probe), a single point in the otherwise homogeneous chemical mixture gives rise to an expanding ring of activity. If internally activated (as by a contaminant), the point gives rise to periodic structures of concentric, wavelike rings. However, when a single shell is sheared across its diameter, the end points produce oppositely winding one-armed spirals. Two-, three-, and four-armed spirals can also be produced, depending on the initial conditions (*11*). All these structures are remarkably stable, except for colliding wave fronts of independent origin, which neither penetrate through nor reflect off each other but rather result in mutual annihilation on contact. Our computer model easily generates all these features.

Our algorithm operates on an initially homogeneous hexagonal grid. Initial conditions are set up such that one or more cells are "activated" while others are either "quiescent" or "receptive." In the next time step the activated cells may then stimulate (catalyze) the immediately adjacent cells into activity. The probability that this reaction is completed in one time step is governed by the first parameter, designated productivity. Propagation of activity is restricted by the second parameter, which specifies a period during which a cell must remain quiescent after stimulation. Cells cannot be propagated into during this quiescent phase, nor while they themselves are active. The active phase lasts one time step.

With the probability of propagation set to unity and the quiescent time set to two time steps, the following initial conditions give rise to the structures shown in Fig. 1.

1) An isolated active cell produces a single, circularly symmetric, expanding wavelike front of activity.

2) A single active cell buffered by an adjacent quiescent cell gives rise to a recurring series of concentric wavelike rings.

3) The end points of a line of activated cells buffered on one side by a line of quiescent cells give rise to growing one-armed spiral patterns.

4) The contact point between two lines of activated cells placed end to end but buffered on opposite sides by quiescent cells produces two-armed spiral patterns.

5) Multiarmed spirals (three or more arms) are generated by lines of buffered activators meeting at a common central cell.

These basic structures are extremely stable. When wave fronts from various centers meet, the fronts do indeed annihilate each other, but the structures internal to these surfaces of contact persist throughout the simulation. The only notable variation is illustrated by the time sequence, which shows that the spirals are intermittently connected and disconnected in the core region, as is also observed in active, excitable chemical media (*11*).

Given that the reaction is likely to occur, there is in fact only one free parameter in our model, the quiescent time. It should be emphasized that this parameter does not in any way affect the variety of forms that result but controls only the scaling of the features, such as the interarm separation in fully matured spiral patterns. Thus, the periodicity in these wavelike structures is intrinsic to the diffusion-reaction time scale of the chemical system. Specifically, it is not dependent on the properties of an unspecified local oscillator, nor are the patterns dependent on boundary conditions, of which there are none in this particular simulation. However, any inert boundary in this simulation, as in the chemical reactions, limits only the extent of the propagation.

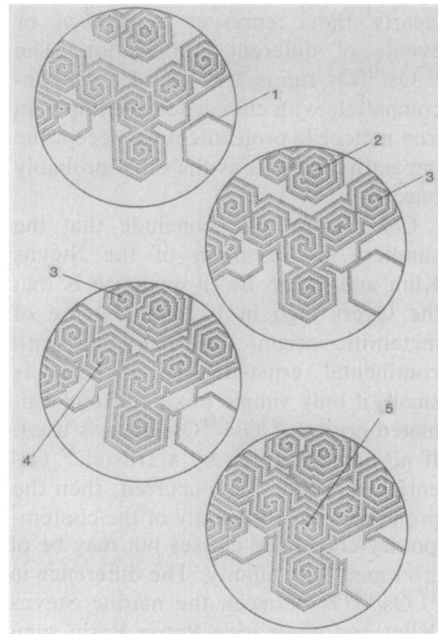

Fig. 1. Sequential time steps in the computer modeling of the Belousov-Zhabotinsky reaction. The structures numbered 1 to 5 result from the initial conditions described in the text.

We hope that these simulations will lead researchers to regard such self-organizing structures as the expected consequences of a wide class of propagating and autocatalytic reactions that can be easily modeled. This broad class, we believe, includes not only the chemical reactions described above but also morphologically equivalent growth patterns in slime molds, certain stages of embryonic development, and the shock-driven models of spiral arm development in galactic systems.

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Phaeodarian Skeletons: Their Role in Silica Transport to the Deep Sea

Abstract. *The skeletons of phaeodarian Radiolaria transport and redistribute silica to the tropical deep oceans by dissolving in the water column and on the sea floor. The skeletons are initially solid but within a few days to months become progressively more porous while settling through the water column. Phaeodarian Radiolaria are rarely preserved in the bottom sediments; in contrast, polycystine Radiolaria are the dominant Radiolaria preserved in the fossil record. This preservational difference may be due to differences in skeletal constituents.*

Phaeodarian Radiolaria are marine protozoans that are ubiquitous throughout the water column in the pelagic environment (*1, 2*), but their skeletons are commonly absent in marine sediments (*3*) and are much less well preserved than those of polycystine Radiolaria (*4, 5*). The skeletons of Phaeodaria are reported to be composed of an admixture of silica and organic matter (*2*); the organic content and the construction of silica into hollow bars (*3*) or porous skeletons (*2, 6*) are supposedly responsible for the poor preservation. We present new findings about the vertical mass flux of Phaeodaria together with observations