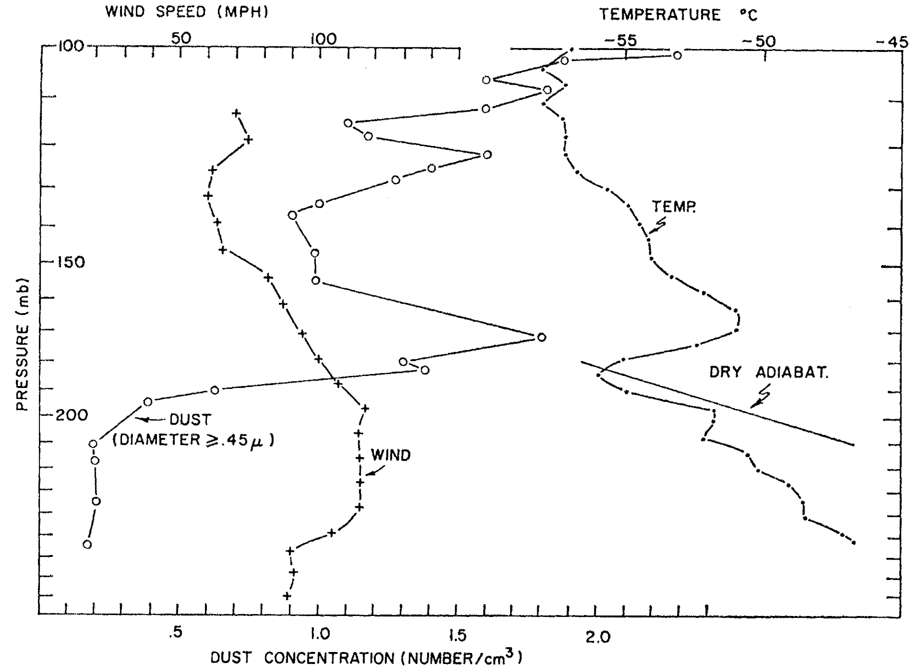

Fig. 3. Fine structure of the dust, wind, and air temperature obtained between 300 and 100 mb on flight 719, 18 August 1964.

earth's surface. The total aerosol area A in a 1-cm^2 column of stratosphere is given by:

$$A = N\,4\pi R^2 H$$

where N is the number density of aerosol particles at the base of the stratosphere, R is the mean particle radius, and H is the atmospheric scale height. If $N \simeq 3$ per cm^3, $R \simeq 0.5$ μ, and $H \simeq 7 \times 10^5$ cm, then $A \simeq 0.1$ cm^2.

Thus it seems not unreasonable to expect that the surface area of aerosols in the stratosphere may be as much as one-tenth of the earth's surface area. However, the diffusion of ozone to the aerosol particles does not impede the ozone decomposition process as it does at the earth's surface. Furthermore, the aerosol is strategically located in the stratosphere where the ozone concentration is five to ten times higher than the concentration near the earth's surface.

Thus, unless an activation energy or adsorption energy of ozone on the aerosol is important, it appears that the stratospheric aerosol may be an important sink for ozone. Decomposition must be catalytic, since the ozone concentration exceeds the aerosol concentration by a weight factor of ~ 100.

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9 December 1964

Entrainment of a Tidal Rhythm

Abstract. *The endogenous tidal rhythm of locomotor activity of the sandbeach isopod,* Excirolana chiltoni, *has been entrained in the laboratory by a device designed to simulate wave action on a beach. The essential component of the treatment appears to be mechanical stimulation by a water current.*

Endogenous tidal rhythms—behavioral and physiological oscillations which are synchronized with the tides under field conditions and which persist in the animals for several cycles in a constant laboratory environment—were first described more than 50 years ago (*1*). The occurrence of these rhythms, particularly in intertidal crustaceans of several orders, has been thoroughly documented in recent publications (*2, 3*). The nature of the environmental stimuli which synchronize tidal rhythms on the shore, however, has remained an open question (*4*); hypotheses have ranged from mechanical or chemical stimulation (*3*) to the actions of subtle geophysical influences linked directly with lunar gravitation (*5*).

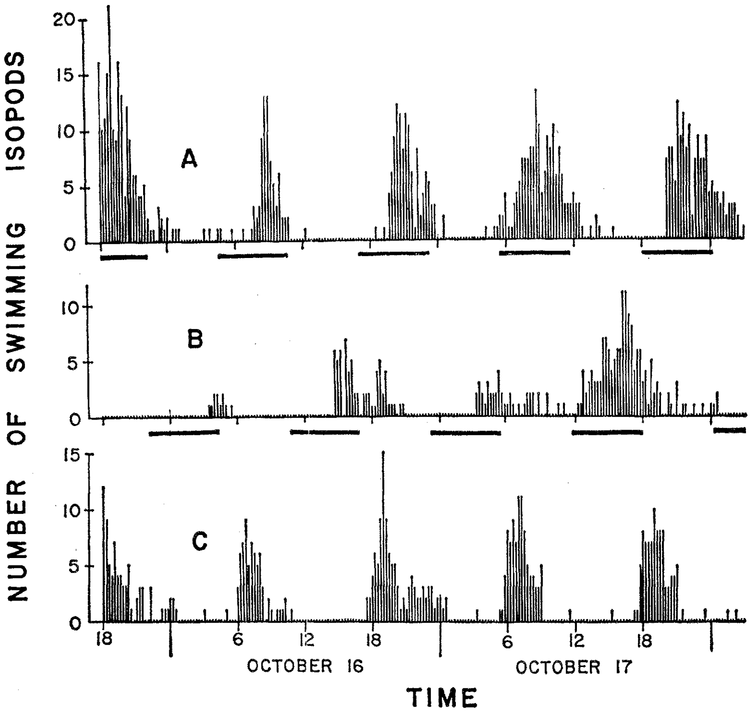
Experiments have now been conducted, in which synchronization of the activity rhythm of an intertidal isopod was achieved by means of water movements, which suggest that mechanical stimuli arising from wave action on a beach may be the normal synchronizing factor for the tidal rhythm of these crustaceans. This is apparently the first experimental demonstration that ecological factors other than cycles of light and temperature can act to synchronize an endogenous rhythm (*6, 7*).

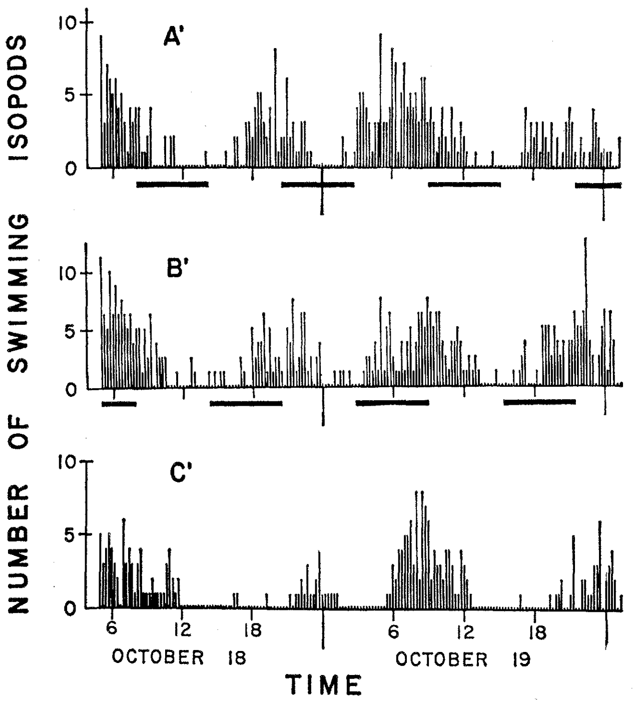
Cirolanid isopods, *Excirolana chiltoni* (Richardson, 1905), were collected on 5 October 1964 from the mid-intertidal zone of the sand beach which fronts the Scripps Institution of Oceanography, La Jolla, California. This species, when freshly collected and placed in seawater in a laboratory aquarium, shows an activity rhythm similar to that described for *Synchelidium* sp. (*3*): if sand is provided, the animals remain buried except during a 4- to 6-hour interval shortly after tide crest on the beach of collection; during this interval, a large percentage of the animals can be seen swimming in the water of the aquarium.

For the first 7 days after collection, the animals were used in a number of preliminary experiments. On 13 October about 200 of the survivors were thoroughly mixed and then divided at random into three approximately equal groups. Those in groups A and B were subjected to intermittent swirling with water and sand, 15 seconds out of every minute, for a period of 6 hours, and were then left for 6 hours without movement. This 12-hour cycle of swirling water as opposed to quiet water, simulating the tidal pattern, was repeated for five cycles (2½ days). Groups A and B received entrainment regimes which differed by 6 hours in timing: group A was swirled from 4 to 10 p.m. and from 4 to 10 a.m.; group B was swirled from 10 p.m. to 4 a.m. and from 10 a.m. to 4 p.m. The third group, C, was not swirled, and thus served as a control group.

During treatment, the animals were placed in 2-liter glass jars, 12 cm in diameter, containing about 500 ml of seawater and a 5-mm layer of fine beach sand. On each of two swirling devices ("wave simulators"), a jar was firmly mounted on a platform with its center 12 cm from a vertical shaft. The shaft in the center of the platform was then rotated by a geared motor at 70 rev/min. Swirling of the water during rotation was sufficient to suspend sand and animals, much as does the passing of a wave on the beach; the animals then tended to swim against the water current. Both treated and control animals were exposed continuously to ambient light of about 50 lux.

After five full cycles of treatment, the three groups of animals were transferred with the least possible disturbance to separate chambers of lucite, 15 cm by 6 cm by 15 cm high, filled with seawater and containing a 5-mm layer of fine sand. Activity of the animals was then recorded by means of time-lapse photography, one exposure being made every 15 minutes with a 16-mm motion picture camera using a strobe flash for each picture. The chambers were exposed to continuous light of about 300 lux, and room temperature was regulated to 21°C. The film





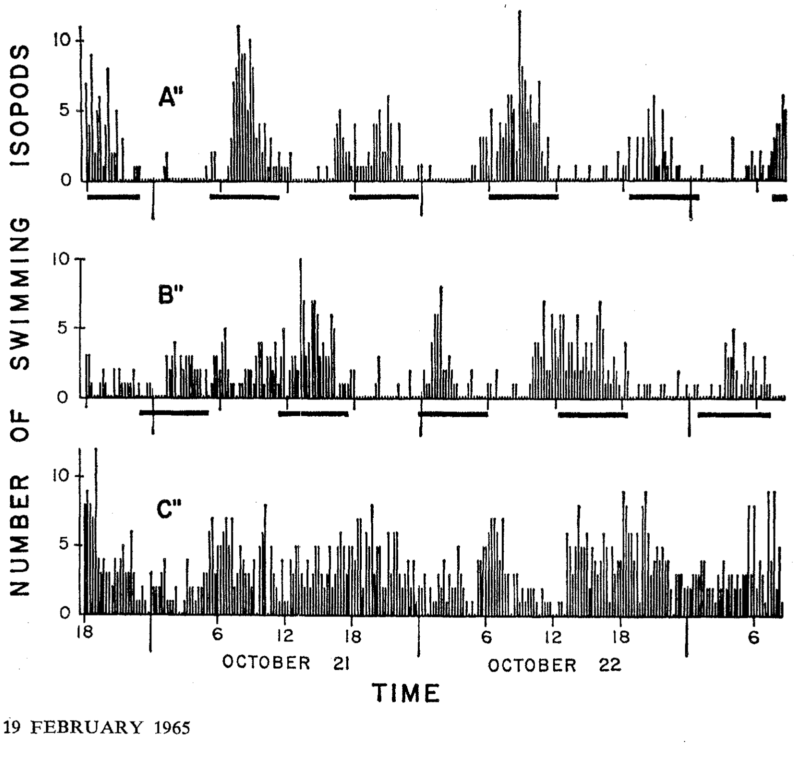


Fig. 1 (top left). Activity rhythms of isopods after treatment in "wave simulators" with 12-hour cycles of water circulation in the presence of sand (*A* and *B*) compared with the rhythm of an untreated control group (*C*). In this and in Figs. 2 and 3, the vertical bars represent counts of the numbers of swimming animals visible in photographs taken every 15 minutes. Total number of animals in group *A*, 81; group *B*, 64; group *C*, 66. Times of expected activity for groups *A* and *B* indicated by the heavy horizontal bars beneath the time axis. Fig. 2 (top right). Activity rhythms of isopods after subjection to 12-hour light-dark cycles (*A'* and *B'*) compared with the rhythm of a control group subjected to continuous light (*C'*). Total number of animals in group *A'*, 54; group *B'*, 53; group *C'*, 51. Expectations (horizontal bars) based on the hypothesis that light exposure caused synchronization shown in Fig. 1. Fig. 3 (left). Activity rhythm of isopods after treatment in "wave simulators" with 12-hour cycles of water circulation in the absence of sand (*A"* and *B"*) compared with that of an untreated control group (*C"*). Total animals in group *A"*, 52; group *B"*, 55; group *C"*, 65. Expected times of activity for groups *A"* and *B"* indicated by horizontal bars. See text for full description of treatment regimes.

was subsequently examined under a dissecting microscope, and the numbers of visible—and hence swimming—isopods were recorded.

The results are presented in Fig. 1. The control group C showed a clear rhythmicity, with times of greatest activity some 12 to 13 hours apart. It is uncertain to what extent the handlings during the preceding 10 days induced this rhythmicity or shifted in phase the field-induced rhythm. Since, however, the control and experimental animals were thoroughly mixed prior to the experiment, the observations for group C indicate the behavior to be expected as a result of conditions and treatments which were common to all control and experimental animals. The two experimental groups also showed periodicities in their swimming activity, but with differences in timing from the control animals. The peaks of activity of group A came some 2 to 3 hours after those of the control group; and the activity peaks of group B were advanced by 2 to 3 hours.

The times of expected activity are indicated in Fig. 1 by horizontal bars. These expectations were calculated on the basis of three assumptions: (i) complete resynchronization within the population by the swirling treatment; (ii) a "free-running" period of the rhythm of about 25 (or 12½) hours; and (iii) no phase lag or lead between the swirling cycle and the activity maxima. In both groups A and B, the intervals of intense activity occurred somewhat later than midterm of expectations, suggesting that assumption (iii) is not completely fulfilled. This departure was more extreme in group B than in group A, suggesting that phase shifting was less complete in group B. Nevertheless, the difference in timing between groups A and B—only slightly less than the 6-hour difference in the treatment schedule—makes it evident that the treatment regimes markedly shifted phases of the rhythms in the expected direction. Qualitatively similar results have been obtained in five other experiments of this type.

Swirling of the water is the most obvious component of the treatment in the "wave simulator," but it is conceivable that swirling with sand represents for the isopods an imposed light-dark cycle. The swirling disturbs the sand in which the animals are otherwise buried, exposing them cyclically to light, even though treatment is administered under constant ambient light. Therefore, experiments were conducted to determine whether entrainment of the rhythmicity by the light component of the treatment could be a plausible explanation of results like those shown in Fig. 1.

Three groups of animals were maintained for 60 hours in seawater without sand. Group A′ received a 12-hour light-dark cycle (6 hours of about 20 lux, 6 hours of darkness of less than 0.001 lux) with light from 7 p.m. to 1 a.m. and from 7 a.m. to 1 p.m.; group B′ received a similar light cycle shifted by 6 hours (that is, light from 1 to 7 a.m. and from 1 to 7 p.m.); group C′ was kept in continuous light of about 50 lux. The activity rhythms of these animals after five full cycles of treatment are summarized in Fig. 2.

Certain differences in behavior of the three groups are evident, but there is no clear correspondence between expectations (horizontal bars) based on the preceding light regimes and the timing of the activity of groups A′ and B′. The periods of greatest activity of group B′ occurred slightly later than those of group A′; and both groups A′ and B′ were active somewhat earlier than group C′. These differences are probably real results of the differences in treatment, but they definitely do not support the hypothesis that results such as those shown in Fig. 1 were due primarily to an effect of the light component of the treatment on the animals.

In another type of experiment, animals were swirled in seawater without sand—hence, in truly continuous light. Three separate experiments of this type were conducted; in all of them, the treatment resulted in approximate resynchronization of the animals in a manner similar to that shown in Fig. 1. One of these experiments was performed with the same animals as were used for the experiment of Fig. 1. Following those observations, the animals were thoroughly mixed and again divided into three groups, two of which were swirled without sand, again with a 6-hour difference between groups in timing of the treatments: group A″ was swirled from 4:30 to 10:30 a.m. and from 4:30 to 10:30 p.m.; group B″ from 10:30 a.m. to 4:30 p.m. and from 10:30 p.m. to 4:30 a.m. The control group was kept nearby in continuous light without sand and without swirling. After five cycles, the three groups of animals were returned to the observation chambers with sand; the results are presented in Fig. 3. The control group, C″, showed broadly distributed swimming activity, such as might be expected from a mixture of animals with the different phases of rhythmicity indicated in Fig. 1. Periodicity was more clearly defined in groups A″ and B″; the times of greatest activity correspond approximately to the times of expectation derived as for Fig. 1. Except for the first 6 to 12 hours of observation, an approximate 6-hour phase difference between times of greatest activity of groups A″ and B″ is unmistakable. Thus, neither the presence of sand during treatment nor an incidentally imposed light-dark cycle is necessary for the resynchronization of the activity rhythm by cyclically imposed water movement.

Nevertheless, the treatment seems to be more effective if sand is included during swirling. When sand was omitted, records of the subsequent behavior usually revealed greater activity scattered between the peaks—a more diffuse rhythmicity than seen in either freshly collected animals or in those swirled in the presence of sand (compare Figs. 1 and 3). Sand is, of course, a normal component of the habitat of these isopods; and a treatment regime in which sand is included more nearly resembles the natural stimulus situation accompanying a tidal cycle on the shore. Possibly the presence of sand in the water during swirling intensifies the mechanical stimulation by the moving water; or perhaps sand in which the animals can bury during inactivity furthers entrainment.

Attempts have also been made to rephase the activity rhythm of *E. chiltoni* by means of other sorts of environmental cycles, including chemical stimuli and feeding regimes; cycles of submergence and exposure; cycles of oxygen tension; and various light-dark cycles, in addition to those which preceded the observations of Fig. 2. No effects on the animals' rhythmicity have been observed comparable with those shown in Figs. 1 and 3. The evidence available thus suggests that mechanical stimulation by wave agitation is probably the dominant component of a natural tidal cycle for the entrainment of the endogenous activity rhythm of *E. chiltoni.*

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14 December 1964

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Alaskan Earthquake, 27 March 1964: Vertical Extent of Faulting and Elastic Strain Energy Release

Abstract. *The residual displacement field indicates that the primary fault responsible for the great Alaskan earthquake extended to depths of 100 to 200 kilometers and came to within 15 kilometers of the surface. The vertical extent is an order of magnitude greater than reported for all other earthquakes. Approximately 10^{25} ergs of elastic strain energy was released. About 12,000 aftershocks ($M_L \geqq 3.5$) probably occurred in a 69-day period after the main shock. One-half the strain rebound occurred the first day with the main shock contributing one-fourth of the total.*

It has become possible to determine several important properties of faults associated with major earthquakes, such as initial slip direction, orientation and horizontal extent of the fault plane, and rupture velocity. The vertical extent of faulting and the elastic strain energy release are parameters which have been estimated, but dilemmas arise in connection with the results. The vertical extent can be deduced from the rate of decrease of the residual displacement or the seismic energy with distance. When the data from the San Francisco earthquake (1906) were applied to the San Andreas fault, fault depths of 2 to 10 km were obtained (*1, 2*). It is difficult to reconcile these small values with the 436-km length of the fault break. Estimates of strain energy release depend on the extent of faulting, and they also are in doubt.

The Alaskan earthquake (27 March 1964) produced residual vertical displacements which could be measured to distances of 200 km on the basis of tide gauge records and shoreline changes (*3*). These data are unmatched in extent and precision and offer an excellent opportunity for estimating the vertical extent of faulting and the elastic strain energy release.

The length of the primary fault is approximately 800 km as estimated from the extent of the belt of aftershocks. The distribution of polarity of first motion is consistent with a nearly vertical fault plane (*4*). Fault length determined from the spectra of surface waves is about 650 km, and a near-vertical fault plane is uniquely indicated (*5*). The residual vertical changes projected on a section normal to the strike of the fault are shown in Fig. 1. Locally on Montague Island, uplift exceeded 10 m. These points are not plotted since they are apparently secondary features, subsidiary to the regional uplift and associated with the zone of maximum flexure. Striking features of the residual displacement profile are (i) the occurrence of a zone of zero elevation change rather than a scarp separating the region of uplift and subsidence; (ii) zones of maximum elevation change and greatest flexure which roughly define the width of the belt of epicenters; (iii) gradual decrease in residual displacement to distances of 150 to 250 km; and (iv) asymmetry in the curves of uplift and subsidence.

The last feature may be due to slight dip in the fault plane. An approximate interpretation of the first three features can be made representing the fault as a vertical, rectangular dislocation sheet in a half-space. The displacement fields for such a source can readily be computed (*2, 6*) and fitted to the observed displacements with the vertical extent of faulting as an adjustment parameter. Two types of theoretical curves are drawn through the data in Fig. 1. The curves with $d = 0$ correspond to a fault reaching the surface and show the expected scarp. The curves with $d = .04\,L \sim 16$ km (L being the fault half-length) show zero displacement above the fault and a zone of flexure separating the uplifted and down-dropped blocks. The two curves are indistinguishable at distances greater than 30 km in the direction normal to the fault. At these larger distances the curves are sensitive

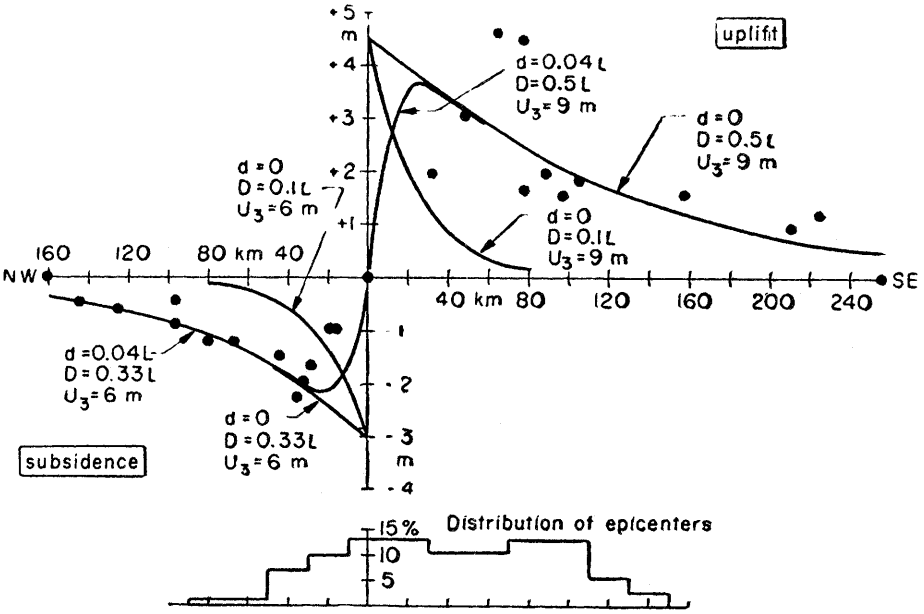

Fig. 1. Residual vertical displacements projected on a section normal to and bisecting the fault. Parameters for theoretical curves are d, depth to top of fault; D, depth to bottom of fault; L, half-length of fault (400 km); U_3 vertical slip; index of seismicity, shown at bottom, is percentage of aftershocks in zone 20 km wide in the 3 days after main shock.