The Nemaha ridge remained an island in the Paleozoic sea, or perhaps it was a chain of islands, while sediments were piling up around and against it. The succeedingly younger systems of rock rest unconformably against the Sioux quartzite and granite by overlap. However, as indicated above, this simple relationship has been complicated by several stages of pronounced faulting, in every case apparently along the same rift or fault zone, which first seems to have come into existence late in the pre-Cambrian.

There is no known evidence indicating that any important displacements have taken place along the Nemaha structure during the Mesozoic and Cenozoic eras. Several mild earthquakes have been experienced during the last hundred years in eastern Nebraska, all or most of them apparently related to this ancient Nemaha structure. It is interesting and significant that this very ancient topographic and structural feature has to a large degree dominated the structural and depositional history of eastern Nebraska and Kansas, and adjacent areas since pre-Cambrian time, and that it apparently is not yet entirely static.

It is evident, in view of the facts stated above, that the region affected by the recent tremors in all probability will experience mild disturbances from time to time. It is also possible but not very probable that it may sometime experience an earthquake of destructive intensity.

The late John R. Freeman[2] regarded the Great Plains, an area of some 600,000 square miles, as the safest from earthquake danger in the United States. However, he thought it probable that this whole great region might experience one earthquake of destructive intensity in a century. Such a "destructive" earthquake would pretty completely wreck things within an area of about 2,500 square miles, according to Freeman. Thus, according to this probability, such centers as Kansas City, St. Joseph, Omaha or Lincoln, or any other single area of 2,500 square miles in the entire Great Plains region, as defined by Freeman, might expect one "destructive" earthquake in 24,000 years.

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## SYNCHRONOUS FLASHING OF FIREFLIES EXPERIMENTALLY INDUCED

Eighteen previous notes in Science concerning synchronous flashing of fireflies attest the wide interest accorded this remarkable phenomenon. It has been observed in the Philippines by Purssell[1] and F. Morse[2]; in Siam by Reinking[3] and Morrison[4]; and in this country by E. S. Morse,[5] Allard,[6] Hudson[7] and the Snyders.[8] In addition to these first-hand accounts there have appeared a considerable number of vicarious reports, such as those cited in the reviews of E. S. Morse[9] and Gudger,[10] and in the papers of Blair,[11] E. S. Morse,[12] Van Vleck,[13] Howard[14] and Merril.[15] In view of this large and varied mass of evidence from independent sources it seems to be well established that synchronous flashing of fireflies really occurs.

Several suggestions to explain the phenomenon have been advanced. McDermott,[16] Craig[17] and Gates[18] maintain that it is accidental. However, the chances are enormously against this, for according to all accounts the synchronism involves large numbers of individuals. Many formerly held that puffs of wind influence the insects alternately to expose and conceal their lights, but Allard, Morrison and the Snyders observed flashing in unison during "profound calm." Laurent[19] considers the phenomenon to be due to twitching eyelids of the observer (!), and Craig attributes it to illusion. Wheeler[20] lays the maintenance of the rhythm to an "Einfühlung" or "sympathy" in the insects. The Snyders found that the flashing interval is inversely correlated with temperature, and maintain that synchronism is due to uniformity in temperature, moisture, light and air currents, but they suggest no mechanism whatsoever for getting different individuals into synchronism with each other, asserting that this is purely accidental. Blair and Richmond[21] consider the rhythm to be due to alternate discharge and recovery of a battery-like mechanism, and these observers, together with Newman[22] and Hudson, believe that the flash of a leader sets off the flashes of the rest which build up a synchronism. This contention, and that of Wheeler, are opposed by Morrison, who points out that a "leader" could not be visible to all members of a large swarm, and that the synchronism, once initiated, does not proceed

2 John R. Freeman, "Earthquake Damage and Earthquake Insurance," McGraw-Hill Book Company, Inc., New York and London, 1932.

1 John V. Purssell, *Scientific American*, 118: 71, 1918.
2 F. Morse, Science, 48: 418, 1918.
3 Otto A. Reinking, Science, 53: 485, 1921.
4 T. F. Morrison, Science, 69: 400–401, 1929.
5 Edward S. Morse, Science, 43: 169, 1916.
6 H. A. Allard, Science, 44: 710, 1916.
7 George H. Hudson, Science, 48: 573–574, 1918.
8 Chas. D. and Aleida V'tH. Snyder, *Am. Jour. Physiol.*, 51: 536–542, 1920.
9 E. S. Morse, Science, 48: 92–93, 1918.
10 E. W. Gudger, Science, 50: 188–190, 1919.
11 K. G. Blair, *Nature*, 96: 411–415, 1915.
12 E. S. Morse, Science, 44: 387–388, 1916; 49: 163–164, 1924.
13 Hester L. Van Vleck, Science, 59: 379, 1924.
14 S. Francis Howard, Science, 70: 556, 1929.
15 R. H. Merril, Science, 71: 132, 1930.
16 F. Alex. McDermott, Science, 44: 610, 1916.
17 Wallace Craig, Science, 44: 784–786, 1916.
18 Frank C. Gates, Science, 46: 314, 1917.
19 Philip Laurent, Science, 45: 44, 1917.
20 W. M. Wheeler, Science, 45: 189–190, 1917.
21 C. A. Richmond, Science, 71: 537–538, 1930.
22 H. H. Newman, Science, 45: 44, 1917.

in waves from one or more sources, as maintained by both Allard and Hudson.

It is evident that none of these various notions provides a satisfactory explanation of synchronous flashing. It is the purpose of this paper to present experimental evidence that has a direct bearing on this problem.

Osten-Sacken,[23] McDermott[24] and Mast[25] have studied the mating habits of a number of native species of firefly. In *Photinus pyralis* the male flies about emitting a single short flash about every 5.7 seconds. The female remains in the grass and responds to some nearby male by flashing shortly after each of his flashes. This exchange of signals continues until the male reaches the female and copulates with her. The above investigators did not ascertain how the male distinguishes between the flash of the female and that of another male, but the writer demonstrated conclusively (forthcoming publication) that no possible difference in the light of the two sexes is operative in this discrimination, and that the essential factor involved is the fact that the female (who flashes only in response to the flash of the male) invariably maintains the period of about 2.1 seconds at which she replies to each flash of the male. A striking feature of this "attraction," observed many times by the writer, is that whereas the exchange of signals is initiated by a single pair of insects, other males within range of the female (10 feet) often join in also, so that at times as many as 5 males may fly simultaneously toward the same female, and that under these conditions all these males flash in unison.

Here, obviously, there is some mechanism other than chance which induces males originally out of phase with each other and flashing with different periodicities to break their ordinary rhythms and readjust them to that of the particular male which first responds to the female. The writer has often observed this readjustment of flashing in the field, but the factors involved therein still remain, in spite of considerable investigation, obscure. At any rate the process results in several males responding simultaneously to the same female, whereupon (since their flashing periods are nearly equal) they necessarily flash in unison. Thus it appears that synchronous flashing on a small scale occurs regularly in nature as a normal preliminary to mating.

Precisely the same response on a larger scale can readily be induced by selecting a male, and in proper imitation of the female, flashing a flashlight 2.1 seconds after each of his flashes. In a well-populated region the writer, in this way, has many times attracted from 15 to 20 males simultaneously to the flashlight. It is indeed an impressive sight to see such a group converging through the air toward one point, each member poising, flashing and surging forward in short advances, all in the most perfect synchronism. This extension of the normal phenomenon to a larger number of males is clearly due to the greater intensity of the light produced by the flashlight as compared with that produced by the female.

The facts presented indicate that the observed flashing in unison of large numbers of specimens distributed over a large area is probably produced as follows: A little group of synchronously responding males built up around one female, as described above, acts as a unit in stimulating another female a considerable distance away because the combined intensity of the several simultaneous flashes is greater than that of a single flash; the second female, then, in responding to the first group of males, gathers in to herself a coterie of males which flash in unison and are, of course, synchronized with the original group; they in turn stimulate a third female which "attracts" a third cluster of males, also synchronized with the original, and so on, until a large number of fireflies scattered over an extensive area are flashing in unison. The whole process thus depends on the fact that all the females reply to each of the flashes of the male at the same definite interval.

Several reports (Allard, Hudson, the Snyders, etc.) indicate that the apparent rarity of the phenomenon in large numbers of fireflies is due to the fact that it only occurs under special environmental conditions, such as calm, unusual humidity and darkness, and a large open space crowded with the insects. This fact supports the interpretation presented above, as such conditions would be favorable to the spread of synchronism from group to group, in the manner suggested. The flashing in unison, once established, would probably continue, owing to the normal rhythmic flashing period of the male, until terminated either by some environmental disturbance, such as a breeze (which does actually interfere with the regularity of flashing of the male), or, since luminosity ceases with copulation, by exhaustion of the evening's supply of responding unfertilized females.

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[23] Baron Osten-Sacken, *Stettiner Ent. Zeitung*, 22: 54, 1861.

[24] F. Alex. McDermott, *Canadian Entomologist*, 42: 357–363, 1910; 43: 399–406, 1911; 44: 73, 309–311, 1912; 49: 53–61, 1917.

[25] S. O. Mast, *Jour. Animal Behavior*, 2: 256–272, 1912.

## TREE RINGS IN NEW ENGLAND

IN the course of an attempt to determine how well the annual rings of wood in a tree reflect climatic influences in New England, some hemlock tree stumps