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A Review of the Daimonelix Problem

C. Bertrand Schultz
Nebraska State Museum

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Note to Cataloger

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C. B. S.

A Review of the Daimonelix Problem*

THE first paleontological expedition of the University of Nebraska State Museum was organized in the summer of 1891 and was led by Erwin H. Barbour, now Director Emeritus of the Museum. The most important and interesting discoveries made during the season were some very peculiar spiral fossils called by the field party "Devil's Corkscrews," or Daimonelix,[1] which were found in the Miocene deposits near Harrison in Sioux County, Nebraska. During the fifty years that have intervened scientists have tried to determine the origin of these strange forms. Several controversies arose, and although various theories have been proposed, none as yet has been demonstrated to the complete satisfaction of all concerned. Most paleontologists now believe, however, that Daimonelices are the casts of rodent burrows. This theory, together with various others, will be reviewed in the present paper and it is hoped that the accompanying discussion will aid in the clarification of the subject.

The term Daimonelix was first used by Barbour in 1892[2] in describing the large, vertical, open spiral structures which he had located in Sioux County. That the discoverers were greatly impressed and somewhat puzzled by these unusual fossils is shown in the following passage from Barbour's type description:

These fossils seem altogether so remarkable and of such imposing size and peculiarity of forms, that I have felt great hesitancy in offering any suggestions as to what they are or in describing them at all; and what I now venture to publish is proposed tentatively, till I can return to this spot and complete the work cut short last season. Not less than two genera and three species of the family were noted, and, because of their similarity to immense corkscrews, we dubbed them "Devil's Corkscrews" and I offer for them the provisional name Daimonelix. At least two gigantic and one small species were observed. They are almost mathematically exact and regular in form, and suggest a great

* EDITOR'S NOTE: It is just half a century since the first study on the Daimonelix, "Notes on a New Order of Gigantic Fossil," by Erwin Hinckley Barbour, appeared in the University of Nebraska Studies, Vol. 1, No. 4, July, 1892. It is with great pleasure that we publish the present study in the same series of University of Nebraska Studies, setting another milestone in the Daimonelix Problem.

[1] See discussion of spelling Daimonelix on p. 28.

[2] Erwin H. Barbour, "Notice of new gigantic fossils," Science, N. S., 19:99–100, 3 figs.

three-inch vine coiled with strict uniformity of pitch about a four or five inch pole. . . . At the bottom of all is a transverse piece, indefinitely long, and about ten inches in diameter, rendering the appearance of the whole like that of the veritable corkscrew. Just what this great "rhizome" is, remains to be learned. . . . While reminding one forcibly of some monstrous fossil bryozoan, it seems improbable that it is such, nor is it a plant, or mollusk, as I believe. Possibly it is the case of some ancient worm.

Later in the same year Barbour [3] described five new "species" of Daimonelix and was inclined to believe that these strange "fossils" were fresh-water sponges. Barbour also reported in the same paper the discovery of a finely preserved rodent skeleton in the great stem of one specimen, and according to him [4] it is possible that the rodent, after being "submerged in Miocene waters, became a suitable anchorage for the living, growing Daimonelix, which eventually enveloped it." At that time Barbour definitely believed in a lacustrine or "lake-bed" theory of the origin of the continental Tertiary deposits, which apparently influenced his early studies in Daimonelices and resulted in his opposition to the rodent burrow hypothesis.[5] The "lake-bed" theory was abandoned, however, during the late 1890's and early 1900's, resulting in a changing of ideas concerning Daimonelix and a strengthening of the rodent burrow theory.

Daimonelices have been compared with various other geologic and paleontologic spiral forms. James F. Hall [6] likened them to *Taonurus* (=*Spirophyton*) and *Spiraxis* of the Paleozoic of New York and Pennsylvania, which were marine forms and were much smaller than the Nebraska Miocene types. Comparisons have also been made with examples of the following spiral structures: *Daemonhelix krameri* from the Oligocene fresh water Molasse of Peissenberg in Southern Bavaria;[7] "Steinspiralen" or "screw-stones" from the marine Miocene of Austria and Switzerland;[8]

[3] "Notes on a new order of gigantic fossils," Univ. Neb. Studies, 1 (4) :301–35, 18 figs., 6 pls., 1892.

[4] *Ibid.*, p. 313.

[5] "Additional notes on the new fossil Daimonelix, its mode of occurrence, its gross and minute structure," Univ. Neb. Studies, 2 (1) :1–16, 1 fig., 12 pls., 1894; "Is Daemonelix a burrow? A reply to Dr. Theodor Fuchs," Amer. Nat., 19 (342) :517–27, 5 figs., 1895.

[6] "Observations upon some spiral-growing fucoidal remains of the Paleozoic rocks of New York," N. Y. State Cabinet Nat. Hist., Ann. Rept. Regents Univ., 16:76–83, 4 figs., 1863.

[7] Ludwig von Ammon, "Ueber das Vorkommen von 'Steinschrauben' (Daemonhelix) in der oligocanen Molasse Oberbayerns," Geognostische Jahreshefte, 13. Jahrg. :55–69, 2 figs., 1 pl., 1900.

[8] Othenio Abel, "In den Prärien von Nebraska," Amerikafahrt (Jena: Gustav Fischer) :385, 1926.

Xenohelix marylandica from the marine Miocene of Maryland;[9] *Xenohelix? clarki* from the Miocene of California;[10] and *Xenohelix? mexicana* from the marine Cretaceous of Mexico.[11] Although these structures from various European and American deposits resemble Daimonelix in form, they seem to represent instances of parallel development rather than definite relationship.

Barbour continued his research on the Daimonelix problem in the 1890's and soon developed an elaborate phylogeny [12] which

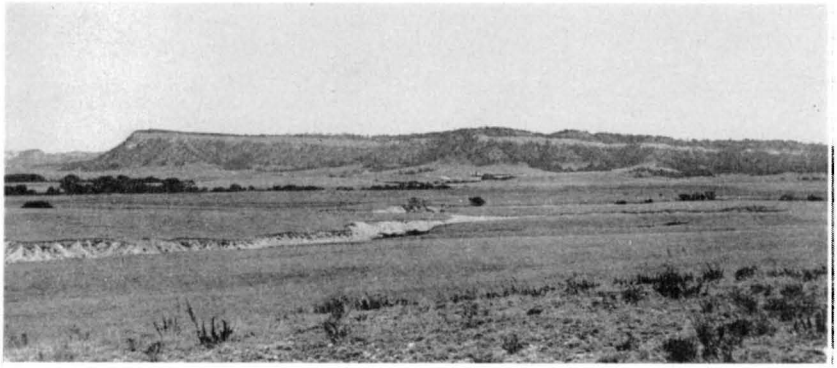

Fig. 1. Pine Ridge east of Five Points, Sioux County, Nebraska. Gering and lower Monroe Creek largely talus covered (many pines on slope); upper Monroe Creek = bare, perpendicular exposures; Harrison ("Daimonelix beds") = pine-covered top of ridge.

was never generally accepted. In the proposed phylogeny many new "Daimonelix forms" were called "fibers," "cakes," "balls," and "cigars," which described the shape of the specimens under consideration. Their origin was thought to be the mineralization of plant growths, which now appears to be at least partially true. The suggested phylogeny indicated that the spiral Daimonelix might have evolved in consecutive stages from 'fibers" through "cakes," "balls," and "cigars." The "cigars" or "fingers," as they were often called, would have given rise to the irregular spiral Daimonelix, and the larger well-formed spirals were the ultimate stage. The present writer believes, however, that these forms have little or no relation to the true or original spiral Daimonelix.

[9] C. W. Mansfield, "Some peculiar fossil forms from Maryland," Proc. U. S. Nat. Mus., 71:1–9, 5 pls., 1927.

[10] Mansfield, "Some peculiar fossil forms from California and Mexico," Proc. U. S. Nat. Mus., 77:1–3, 2 pls., 1930.

[11] *Ibid.*, pp. 1–3.

[12] Barbour, "Progress made in the study of Daemonelix," Proc. Neb. Acad. Sci. Pub., (5):24–8, 18 figs., 1896; "History of the discovery and report of progress in the study of Daemonelix," Univ. Neb. Studies, 2 (2):81–124, 20 figs., 18 pls., 1897; "Nature, structure, and phylogeny of Daemonelix," Bul. Geol. Soc. Amer., 7:305–14, 9 pls., 1897 (abstracts in Jour. Geol., 5:223–4, and Science, N. S., 5:94–5).

Considering now the distribution of these various types, especially in the light of recent explorations of the Miocene of western Nebraska, it should be stated that Daimonelices of the spiral and irregular spiral types are limited to the Harrison formation, while the other structures have a much greater distribution. Daimonelices may be observed at various levels in the Harrison but as yet

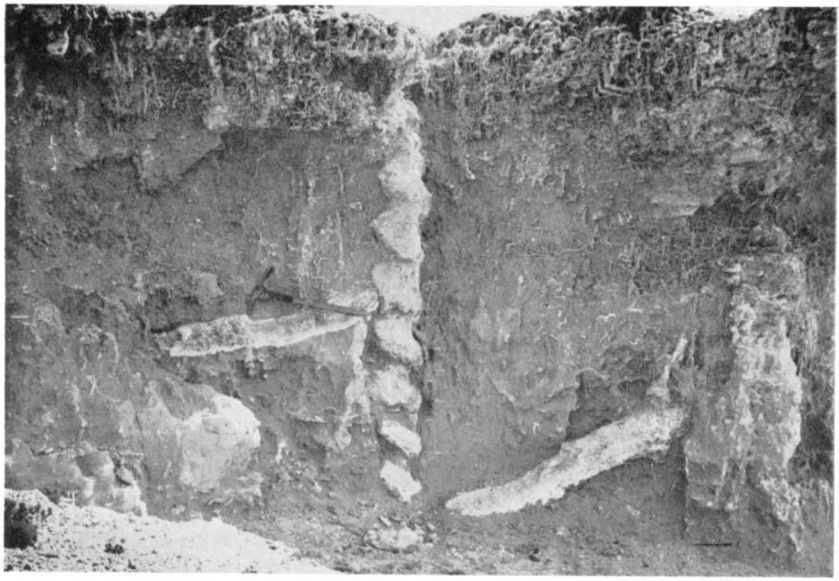

Fig. 2. Harrison exposure, showing Daimonelix with "rhizome" or "nest," 2 miles southeast of Andrews, near the head of White River, Sioux County, Nebraska. Note "rhizome" from a second specimen at left. Scale, prospecting pick with a 22-inch handle.

none have been found in the lowest portion. They are not uniformly distributed, either geographically or stratigraphically, and often occur more numerously at certain levels than at others, at least in some localities. The "fibers" are found throughout the upper Tertiary and are especially well-developed in the Harrison and Marsland. The "cakes" and "balls" occur in the Gering, Monroe Creek, and Harrison. In the latter formation they are found at all levels and are not restricted to the zone below the Daimonelix as Barbour's original phylogeny indicated.

Barbour reported that the range of "Daimonelix proper," referring to the spiral forms, was limited to ". . . beyond the highlands of central Sioux County as far west as Lusk, Wyoming, and

as far east as Eagle Nest Butte, South Dakota." [13] Explorations since 1903 have not extended this range of the Miocene Daimonelices but indicate instead that their occurrence is somewhat more limited. In Nebraska Daimonelices occur only in Sioux County, where examples may be found along the Niobrara and White rivers and along Pine Ridge. Although Pine Ridge passes

DIVISIONS OF THE MIOCENE OF NEBRASKA

MIOCENE	Hemingford group	Sheep Creek
		Marsland
	Arikaree group	Harrison ("Daimonelix beds")
		Monroe Creek
		Gering

through Dawes and Sheridan counties no Daimonelices have been observed in those regions. The Wyoming localities are near Lusk and Van Tassel in Niobrara County, and near Spoon Butte in Goshen County. Both counties adjoin Sioux County, Nebraska, and it is evident that the Wyoming Daimonelix beds are continuations of those in Nebraska. Erich M. Schlaikjer [14] has referred to a single locality at the east end of Bear Creek Mountain in the Goshen Hole region of Wyoming, where specimens of Daimonelix were observed. In South Dakota Daimonelices are rare and have been reported only by Barbour and O'Harra. During July of 1941 the present writer examined good examples of typical Daimonelices in the Martin Canyon region northwest of Sterling, Colorado, but the age of these new specimens was not determined.

[13] "Present knowledge of the distribution of Daimonelix," Science, N. S., 18 (459): 504–5, 1903.

[14] "Contributions to the stratigraphy and paleontology of the Goshen Hole area, Wyoming. Pt. 4, New vertebrates and the stratigraphy of the Oligocene and early Miocene." Bul. Harvard College Mus. Comp. Zool., 76 (4):113, 1935.

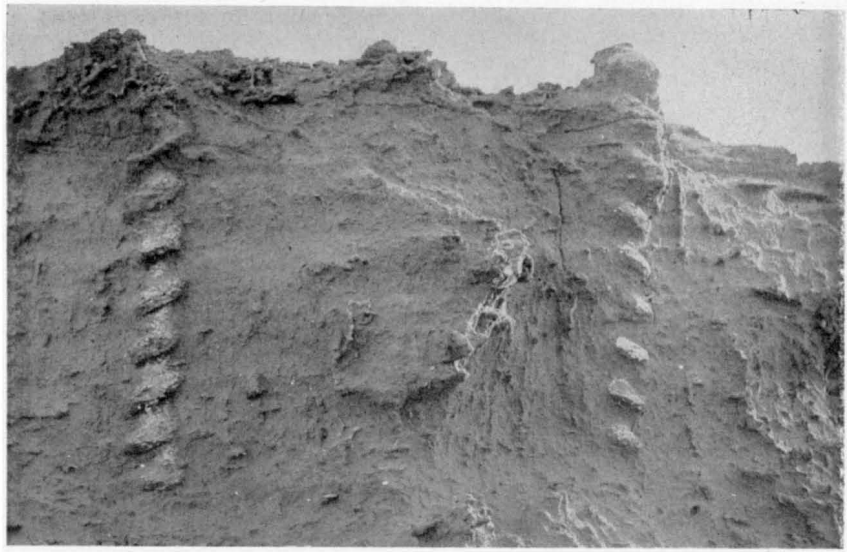

Fig. 3. Dextral and sinistral Daimonelix spirals in Harrison formation, Sioux County, Nebraska. Photograph by George Meyer.

Fig. 4. Part of type collection of Daimonelices from the Harrison formation, Sioux County, Nebraska. Display in the University of Nebraska State Museum.

Fig. 5. A typical Daimonelix, with a large "rhizome" or "nest," as exhibited in the University of Nebraska State Museum. The Daimonelix is not coiled about an axis as the picture would indicate but is only partially excavated. The axial structure is part of the original matrix in which the specimen was buried and was left by the preparators for support of the coils. The fine parallel marks or scratches on the surface of the Daimonelix were made with tools during preparation.

Several scientists [15] accepted in part Barbour's hypothesis concerning the plant origin of the Daimonelix. E. M. Kindle [16] believed, however, that some Daimonelix forms were concretionary. Horace Elmer Wood, 2nd, and Albert Elmer Wood [17] regarded this as a plausible explanation for at least the "cakes" and "balls." The plant theory for the origin of the Daimonelix was based primarily on the microscopic structure of the various forms, in which connection many photomicrographs and camera lucida sketches were made by Barbour [18] and by Otto E. Jennings.[19] Peterson [20] was inclined to believe that the microscopic studies of Jennings, who was at that time custodian of botany at the Carnegie Museum, demonstrated that the spiral Daimonelices were the casts of rodent burrows which were filled with fossilized remains of vegetable tissue. Enough plant structure remained to show that the tissues represented roots rather than stems, and nearly all of the roots identified were those of angiosperms. Jennings thought that the tissues preserved in Daimonelices were simply the remains of roots such as are sometimes found clogging a tile drain (Fig. 17). The arrangement of the tissues in a Daimonelix strongly suggests this phenomenon. The Jennings botanical report concerning Daimonelix has been reprinted here that the reader may have an opportunity to reread or acquaint himself with this work.

An examination of thirty-two microscopical sections obtained from various parts of the so-called devil's corkscrews (Daemonelix), in the collections of the Carnegie Museum, invariably revealed the fossilized remains of vegetable tissue. Although the sections had been cut from many different places in the Daemonelix specimens, the vegetable tissues were usually more abundant in those sections obtained near the surface of the specimens, and the tissues in these sections gave better results under the microscope. The sections best showing the cellular structure and the differentiation of tissues were longitudinal sections cut parallel to the surface and of the so-called corkscrews. A careful study of the slides involved the examination of a large number of tissue fragments, as in some of the slides, at least one fourth of the total area of the section was occupied by plant remains.

[15] Frederick C. Kenyon, "In the region of the new fossil, Daemonelix," Am. Nat., (19):213–27, 1 pl., 1895; Jacob L. Wortman, "On the so-called devil's corkscrews of Nebraska," Amer. Nat., (19):403, 1895; Abel, *op. cit.*, pp. 288, 354, 357–8, 382–94; "Das Daemonelix-Problem," Paleont. Zeit., 9:179–80, 1927.

[16] "Range and distribution of certain types of Canadian Pleistocene concretions," Bul. Geol. Soc. Amer., 34:611, 631, 1923.

[17] "Daemonhelix in the Pleistocene of Texas," Jour. Geol., 41 (8):830, 1933.

[18] "History of the discovery . . . ," *op. cit.*; "Nature, structure, and phylogeny . . . . ," *op. cit.*, pp. 312–4.

[19] O. A. Peterson, "Description of new rodents and discussion of the origin of Daemonelix" (with "Notes on the vegetable tissues in Daemonelix" by Otto Emery Jennings), Mem. Carn. Mus., 2 (4):190–1, 202, 1906.

[20] *Ibid.*, pp. 185–90.

Fig. 6. Weathered surface of Harrison deposits, 7 miles northwest of Harrison, Sioux County, Nebraska. Note large (at lower right) and small (at upper left) Daimonelices. Scale, prospecting pick with a 21-inch handle.

The vegetable tissues are apparently simply the remains of a mesh of roots such as is sometimes found clogging a tile drain or sewer. The tissues were most commonly found in the form of hollow tubes, such as would be obtained by sectioning rubber tubing at various angles. The central portion of the root has, in most cases, disappeared leaving only the outer tissues—the epidermis and the cortex. The root cap was searched for in vain, although root-hairs were rather common.

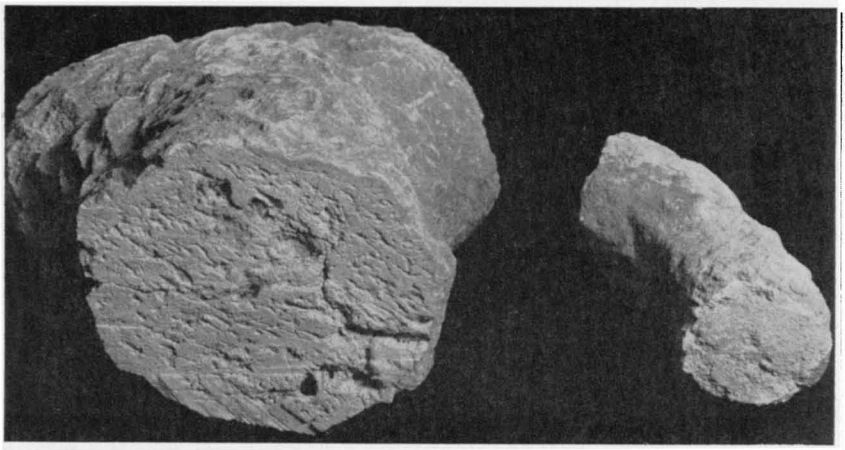

Fig. 7. Cross sections of a large and a small Daimonelix from Sioux County, Nebraska.

The reason, that the thin epidermal covering and the rather large thin-walled cells of the cortical tissue should be the best preserved, may be, that these parts of a living root soon become more or less impervious to water. That portion of a living root just back of the tip is the most absorptive. In the older portions farther back the epidermis may have become cutinized, or the cortex may have become suberized, or both; in either event the tissue thus becomes impervious to both water and gases. On the other hand, the tissues of the central portion of the roots, the stele, even though they may have become lignified or woody, are still permeable to these fluids, and thus can be readily entered by some of the bacteria of decomposition.

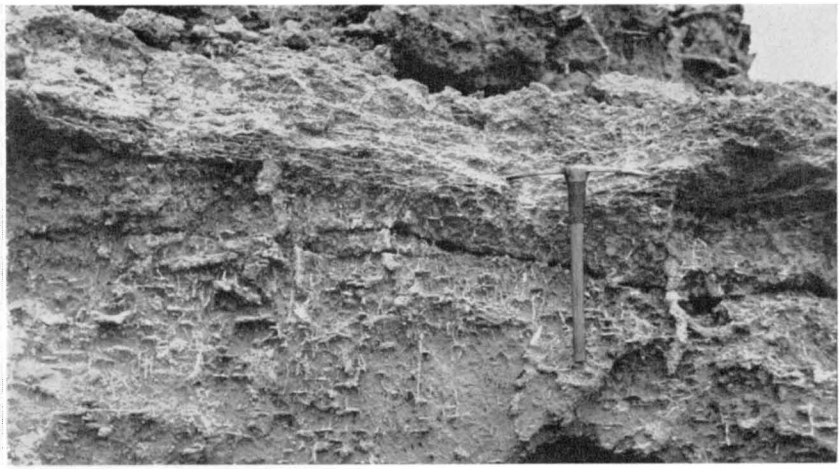

Fig. 8. Harrison exposure, showing fossil vegetation fibers and labyrinthine system of calcareous veins at top, 9 miles west of Harrison, Sioux County, Nebraska. Scale, prospecting pick with a 21-inch handle.

A few sections were found showing more or less completely the entire structure of the root, but the detail of the vascular bundle could be made out only with considerable difficulty, as the cells were usually very dark and the structure mostly obliterated. Enough was evident, however, to plainly indicate that nearly all of the roots were those of angiosperms, the cells discerned being quite typical. Rather large tracheae, with the customary rings and reticulations, together with longer cells of a smaller diameter, some of the latter also showing reticulations, were quite plainly to be seen in the stele. No pith cells were evident but the woody elements were enclosed by a well developed bundle sheath. Fragments of older roots with a strongly developed cortical region were found; in some of these the rectangular cortical cells were built up with all the regularity of brickwork, each successive layer being regularly and perpendicularly superimposed.

One of the main structural differences between stems and roots lies in the manner in which branches originate. In stems the branches originate near the surface but in roots the branches originate on the vascular cylinder and burrow upward through the cortex thus disturbing the arrangement of the cortical cells. An example of this was found in one of the sections, as may be seen by consulting the figure.

As for the "balls," "cakes," and "fibers," Peterson agreed with Barbour that they were indeed fossil plant tissue.

In connection with a possible plant origin of Daimonelix, Elmer S. Riggs [21] called attention to the resemblance of Daimonelices to the spirally coiled lianas common in tropical forests. He suggested that these plants, if buried in sand, might decay and leave open holes which could later be occupied by animals. The suggestion of Riggs received little support except from Abel [22] and A. L. Lugn.[23] Those supporting this theory did not take into account several important factors, first, that Peterson [24] had already demonstrated that the plant tissue found in Daimonelix was not that of woody stems such as is found in lianas but that of roots (Fig. 17) and second, that Daimonelix spirals are always erect or perpendicular with a rather uniform height of from six to eight feet. Rapid deposition would have been necessary in order to envelope the lianas before they deteriorated. If the rodents availed themselves of buried lianas, why did they not also use other vines of varying shapes? Lianas could have differed greatly in size, since a large amount of variation is found today in the size and form of tropical lianas. A. R. Wallace,[25] in describing the behavior of these modern plants wrote as follows:

Next to the trees themselves the most conspicuous and remarkable feature of the tropical forests is the profusion of woody creepers and climbers that everywhere meet the eye. They twist around slender stems, they droop down pendant from the branches, they stretch tightly from tree to tree, they hang looped in large festoons from bough to bough, they twist in great serpentine coils or lie entangled in masses on the ground. Some are slender, smooth, and root-like; others are rugged or knotted; often they twine in veritable cables; some are flat like ribbons, others are curiously waved and indented. . . .

[21] "Loup Fork beds of eastern Wyoming" (abstract), Science, N. S., 29 (735) :196, 1909.
[22] "In den Prärien . . . .," *op. cit.*, p. 288; "Das Daemonelix-Problem," *op. cit.*, pp. 179–80.
[23] "The origin of Daemonelix," Jour. Geol., 49 (7) :673–96, 6 figs., 1941.
[24] *Op. cit.*, pp. 190–1, 202.
[25] "The climbing plants of the equatorial forests," *Natural Selection and Tropical Nature* (London: Macmillan Co.) :246, 1895.

V. H. Blackman [26] considered Wallace's description well written and added that lianas reached their extreme development in rain forests of the tropics and that an estimated 2000 or more different forms of these climbing plants are known.

There appears to be no direct evidence that Nebraska was a tropical country during lower Miocene times. The Harrison sediments are of the typical aeolian types such as are deposited in the

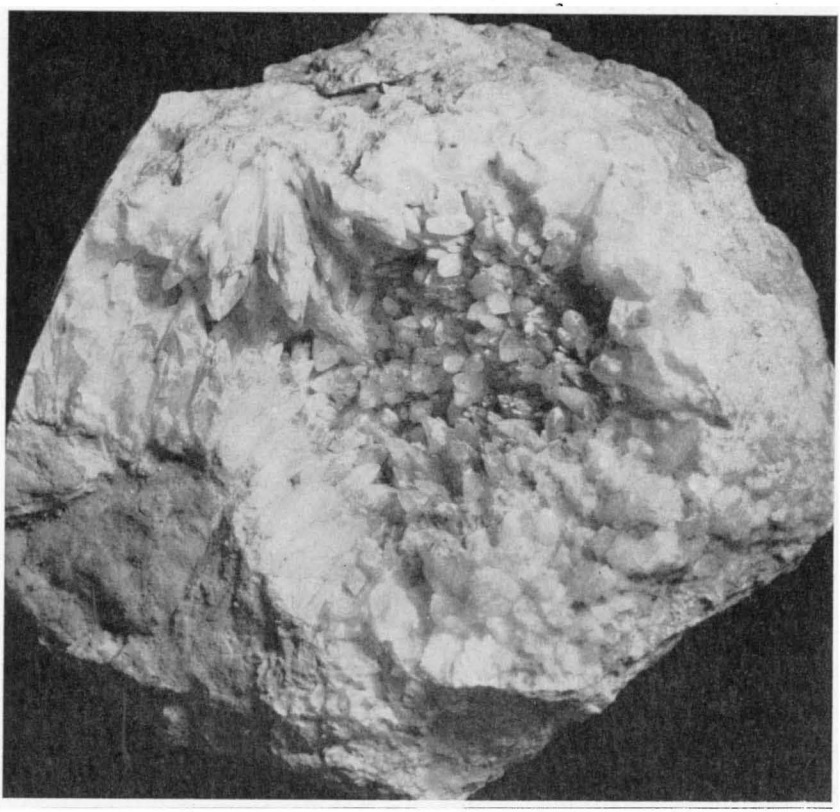

Fig. 9. Calcite crystals (Dog-tooth Spar or scalenohedral crystals, occasionally combined with a rhombohedral form) in the enlarged end of a Daimonelix "rhizome" or "nest," collected from the Harrison deposits southwest of Andrews, Sioux County, Nebraska. Crystals of this type are often found in geodes and commonly form in cavities or fissures.

temperate plains regions today, and certainly the large mammals are plains forms, chiefly ungulates, as for example horses, chalacotheres, rhinoceroses, camels, deer, antilocaprids, entelodonts, and oreodonts. The presence of none of these forms would in-

[26] "Lianes or lianas . . . .," *Encyclopaedia Britannica* (14th ed.) 13:993–4. 1938.

dicate that either tropical or swampy conditions prevailed. If these conditions did exist few fossils would be preserved because the rate of decay would have been rapid. The Harrison deposits instead have yielded an abundant vertebrate fauna.

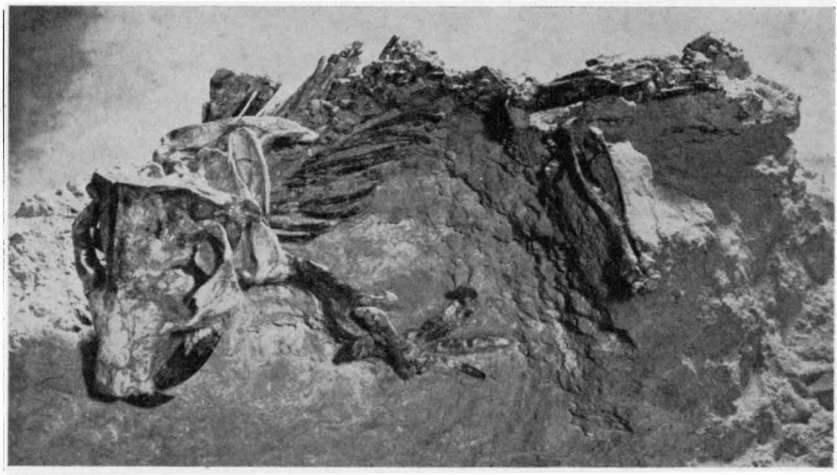

Fig. 10. A skeleton of a fossil beaver, *Palaeocastor fossor magnus* (Romer and McCormack), exposed in the original matrix of a Daimonelix "rhizome" or "nest," from the Harrison deposits near Andrews, Sioux County, Nebraska. Specimen No. 20-25-7-36 S.P., the University of Nebraska State Museum.

M. K. Elias, paleobotanist with the Nebraska State Geological Survey, has given the writer the following authorized statement concerning the climate and plant life of the Miocene of the Great Plains:

As far as Paleobotany is concerned Daimonelix never attained even the dignity of being placed among the so-called *incertae sedis* groups, and always was and still is in the group of problematic fossils.

If Daimonelix were a tropical liana, to which it has some resemblance, it could be considered an evidence of tropical lowland conditions in Nebraska in early Miocene time. However, there exists a definite, reliable evidence for judgment of climatic conditions, and this is the identifiable plant that remains in the same upper part of Harrison formation where Daimonelix belongs. These are the abundant seeds of hackberry found together with Daimonelix, and comparable in all respects to the seeds of *Celtis orientalis* now widely distributed in Nebraska and adjacent states, and fairly common seeds of fossil prairie grass *Stipidium,* with tuberculate hull, comparable to that now possessed by *Stipa comata,* the dominant grass of *mixed prairie* of western Nebraska.

On the ground of these identifiable plant remains I concluded and reported to the Geological Society of America in 1939 (Bul.

Geol. Soc. Amer., vol. 50, pp. 1907–1908, Abstract) that the annual rainfall in early Miocene time in Nebraska was probably from 14 to 24 inches. The same diagram of climatic cycles of the late Tertiary time in Nebraska on which this conclusion is shown, was demonstrated again as an illustration to my paper at the meeting of the Geological Society of America in 1940 (Bul. Geol. Soc. Amer., vol. 51, p. 1925). Early Miocene time of Nebraska is shown there as an extreme dry phase of the local climatic cycle, which was succeeded in Medial Miocene time by more mesic conditions, comparable to those of the present *true prairie* of Eastern Nebraska.

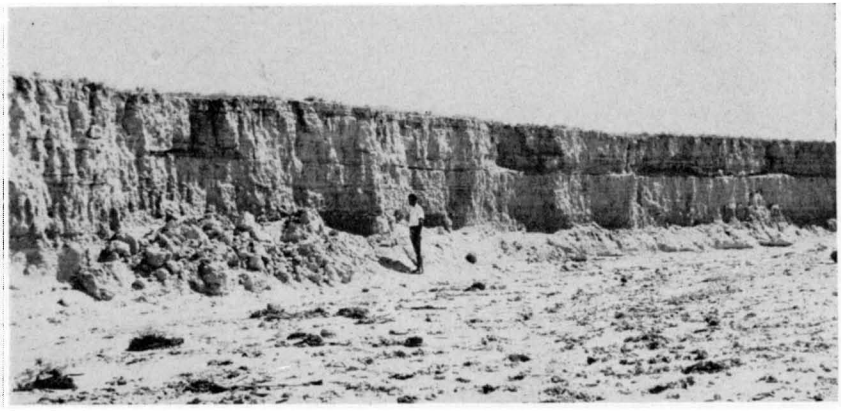

Fig. 11. Recent terrace containing many rodent burrows, some of which are spiral in form, located on Sand Creek, 10 miles north and west of Crawford, Dawes County, Nebraska. (See Figs. 12 and 15.)

E. D. Cope [27] was the first to propose the theory that the Daimonelix structures of the Miocene of Nebraska were the casts of rodent burrows. This hypothesis was also championed by Theodor Fuchs [28] and later by Peterson,[29] W. D. Matthew,[30] A. E. Ortman,[31] Abel,[32] A. W. Grabau,[33] Karl A. von Zittel,[34] Wood and Wood,[35]

[27] "A supposed new order of gigantic fossil from Nebraska," Amer. Nat., 27:559–60, 1893.
[28] "Ueber die Natur von Daimonelix Barbour," Annalen des K. K. Naturhistorischen Hofmuseums, Wien, 7:91–4, 1893.
[29] "Recent observations upon Daemonelix," Science, N. S., 20 (506):344–5, 1904; "Suggestions regarding the probable origin of Daemonelix" (abstract), Science, N. S., 21 (530) :296, 1905; "Description of new rodents . . .," *op. cit.*, pp. 185–91.
[30] "Zoology," Science History of the Universe (New York: Current Literature Publishing Co.), 6:160, 1909; "Symposium on ten years' progress in vertebrate paleontology," Bul. Geol. Soc. Amer., 23:186, 1912.
[31] "Teufels-Korkzieher," Aus der Natur., Leipzig, Jahrg. 5, H. 6:177–80, 3 figs., 1909.
[32] "Grundzüge der Palaeobiologie der Wirbeltiere," Schweizbart, Stuttgart :84–6, 1 fig., 1912.
[33] *A Textbook of Geology*, Pt. 2, Historical Geology (Boston: D. C. Heath and Co.) :43–4, 1921.
[34] "Mammalia," *Textbook of Paleontology*, ed. A. S. Woodward (London: Macmillan Co.) 3:106, 1925.
[35] *Loc. cit.*

and William Berryman Scott.[36] Abel, however, although at first strongly inclined to support the rodent burrow theory, later[37] joined the supporters of the plant hypothesis.

Fig. 12. Plaster of Paris cast of a modern rodent burrow from a recent terrace exposed along Sand Creek 10 miles north and west of Crawford, Dawes County, Nebraska. (See Figs. 11 and 15.)

Fig. 13. Daimonelix (reversed) from the Harrison formation, on display in the University of Nebraska State Museum. The fine parallel marks and scratches were made with tools during preparation.

In 1904, a Carnegie Museum field party under the direction of O. A. Peterson became further interested in the Daimonelix problem. Peterson[38] examined many Daimonelices in the Harri-

[36] *A History of Land Mammals in the Western Hemisphere* (New York: Macmillan Co.) :201, 1 fig., 1937.
[37] "In den Prärien . . . .," *op. cit.*, p. 288; "Das Daemonelix-Problem," *op. cit.*, pp. 179–80.
[38] "Description of new rodents . . . .," *op. cit.*, pp. 185–91.

son deposits of Sioux County, Nebraska, and noticed that the remains of *Palaeocastor* (=*Stenofiber*) occurred frequently inside Daimonelices in various localities. It was assumed, therefore, that Daimonelices were casts of the habitations of this genus of small terrestrial and fossorial beavers. Peterson stressed the fact that the rodents found in the spirals and "rhizomes" were of the proper size to live in holes the diameter of the casts. He found no very small specimens of Daimonelix having the regularity of form exhibited by the larger ones, and believed that the small, irregular forms, such as "cakes," "balls," and "cigars," should not be considered as Daimonelices, preferring instead to apply the term only to the large coiled forms. The present writer agrees with Peterson in this belief and it is here suggested that the term Daimonelix henceforth be used only for the large spiral forms (regular and irregular) which Barbour [39] originally named and described. Peterson [40] also made a study of certain recent burrows of fossorial rodents, including those of several small colonies of prairie dogs (*Cynomys ludovicianus*) in Sioux County, Nebraska, not far from the Carnegie Museum fossil collecting locality. Casts were made of some of the burrows by filling them with a mixture of plaster of Paris and sand. No symmetrical spiral holes were found but irregular casts were obtained whose forms approached those of some of the large irregular Daimonelices of Barbour.[41] In the casts of the burrows were found fine rootlets and an abundance of dry grass (in the nest), together with the remains of beetles, worms, and grasshoppers. One important observation made by Peterson which was not emphasized as much as it might have been was that the walls of the tunnels of the recent prairie dogs were very firm, while the sand around the holes was loose and rather incoherent. The sediments in which the modern burrows were found are redeposited Miocene sands, indicating that the fossil beavers and the recent prairie dogs had to dig their burrows in almost the same type of matrix. The walls apparently were tamped and therefore remained harder than the surrounding earth. The cementing effect of the secretions of the rodents may also have been a contributing factor in the hardening of the walls of the burrows. Peterson thought it reasonable that during Miocene times roots and rootlets followed the line of contact be-

[39] "Notice of new . . . .," *op. cit.*, p. 89.
[40] "Description of new rodents . . . .," *op. cit.*, pp. 188–9.
[41] "Nature, structure, and phylogeny . . . .," *op. cit.*, pp. 305–14, figs. 17–9.

tween these hardened walls and the inside filling of the vacated beaver holes. The unconsolidated filling was also penetrated to some extent by roots, but the concentration of plant fiber was chiefly next to the hardened walls of the burrow. This type of growth would account for the cylinder of tangled roots which appears in the portion of the Daimonelix nearest the outside, for in all instances the center of the burrow contains a far less amount of root structure. The studies made by Peterson apparently influenced Barbour,[42] who later wrote, concerning Daimonelix, "These represent a plant growth which seems to have followed the course of burrows."

During the past nine years field parties (Morrill Paleontological Expeditions) from the University of Nebraska State Museum have explored extensively in the Harrison deposits of Sioux County, Nebraska, and in adjacent areas where Daimonelices occur. Many hundreds of fine examples of these spiral phenomena have been examined by the writer in the field, and numerous remains of *Palaeocastor* have been found inside the Daimonelices by members of the field parties. During one season (1936) five articulated skeletons and miscellaneous unassociated bones were collected. The remains were for the most part found in the "rhizomes," which apparently were the "nests" of the rodents, as Peterson[43] suggested. The "rhizomes" are on the average considerably larger in diameter than the spiral section of the Daimonelix (Fig. 2), with the largest section near the outer end. The upward slope of the "rhizomes" from the bottom of the spiral is noticeable in most specimens. This arrangement might have been made to effect proper drainage of the rodent "nest," for if the "rhizome" sloped downward or even extended horizontally from the lower end of the spiral the "nests" would have been flooded during heavy rains.

Another observation made in the field is the fact that Daimonelices vary greatly in size, the smallest measuring only about two and one-half inches in diameter and the largest approximately eight inches. The different sized forms were not restricted to any certain horizons in the "Daimonelix beds" of the Harrison, since both large and small examples are often found closely associated in the same exposure at the identical geologic level (Figs. 6–7).

[42] "A preliminary report on the Nebraska State Museum," Bul. Neb. State Mus., 1 (1):14, 1924.
[43] "Description of new rodents . . . ," *op. cit.*, pp. 185–90, figs. 5, 7, 9.

Several closely related varieties of beaver, differing in size and living at the same time, may each have had the tendency to dig spiral holes. Remains of *Palaeocastor fossor* Peterson, *P. fossor barbouri* (Peterson), and *P. fossor magnus* (Romer and McCormack) have actually been found within Daimonelices. *P. fossor milleri* (Olson) has also been described from the Harrison,[44] but it is not certain that remains of this form have been found directly associated with a Daimonelix. There is a considerable difference in size between the smallest (*P. fossor barbouri*) and the largest variety (*P. fossor magnus*) of beavers from the Harrison. The variations in size of the beavers have been found to correspond very well to the difference in the diameters of the Harrison Daimonelices.

Although the fossilized remains of many other genera and species of rodents have been found in the Harrison deposits only *Palaeocastor* has actually been found in the Daimonelices. If the holes were formed by the decaying of plants, as has been suggested by Riggs [45] and Lugn,[46] these cavities would also have been available and convenient for the other contemporaneous rodents and small mammals. When it is remembered that numerous small modern mammals, including several kinds of rodents, today use holes left by decayed roots, the presence of only *Palaeocastor* in Daimonelices seems significant. The very fact that fossil beavers are found within the Daimonelices demonstrates that the fossil vegetation in the spiral and "rhizomes" is of secondary origin in relation to the spiral itself since the beavers must have descended into the burrows before the sand and roots filled the cavities.

The forelimbs of the Harrison beavers (*Palaeocastor*) were specialized. The scapula, humerus, radius, and ulna are all proportionally massive, and with the exception of the scapula are very short. The manus is unusually large. Animal ecologists today consider these modifications as fossorial or burrowing characteristics. Within the genus *Palaeocastor* specialization of the forelimbs took place rather late in Arikaree times, since the Gering beavers referred to this same genus do not show these distinctive features.

Remains of larger fossil mammals have also been found in Miocene Daimonelices. Riggs [47] reported that associated with Dai-

[44] Everett Claire Olson, "Cranial foramina of North American beavers," Jour. Paleo., 14 (5):495–501, 1940.
[45] *Loc. cit.*
[46] *Loc. cit.*
[47] *Loc. cit.*

monelix spirals he had discovered the bones of five different genera of animals, namely, *Palaeocastor* (=*Stenofiber*), *Merychyus*, *Oxydactylus*, and two genera of carnivores. *Palaeocastor* and the two genera of carnivores were small forms and the skeletons lay completely within the Daimonelix. The carnivores may have entered the burrows to prey upon the beavers. *Merychyus*, which was represented only by a single jaw, was a small genus of

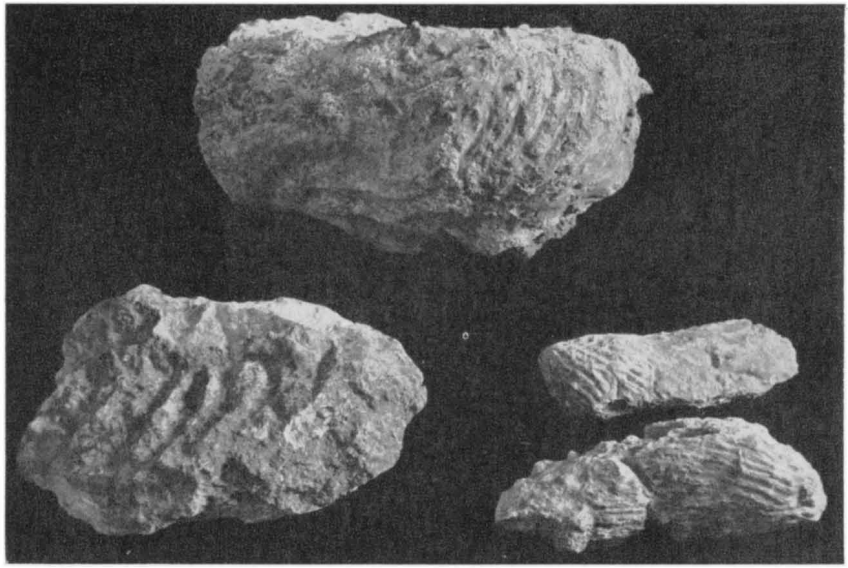

Fig. 14. Sections of Daimonelices from the Harrison formation of Sioux County, Nebraska, showing grooves suggestive of claw marks. (See recent claw marks, Fig. 15.)

oreodont, and it is altogether possible that this jaw fell into or was carried down one of the beaver burrows. But the presence of a partial skeleton of the camel, *Oxydactylus*, must be accounted for in a different way. It is probable that in this instance part of the skeleton was buried in the windblown sand, and at a later time the rodent, burrowing downwards, simply dug his way through the bones to complete his underground home.

Barbour [48] also reported finding the bones of a rather large artiodactyl encased in a "corkscrew" from Sioux County. This occurrence might be given the same explanation as that mentioned above, for examination of the specimen, which is now on display in the University of Nebraska State Museum, shows that the skeletal parts are also partly outside of a Daimonelix.

[48] "Additional notes . . . ," *op. cit.*, p. 12, pl. 4.

The abundance and distribution of Daimonelices in some localities in Sioux County, Nebraska, indicate that the beavers lived in colonies which were probably similar to the modern prairie dog "towns" of today. Frequently the tops of the spirals in one horizon at a given locality are roughly level, which suggests that the surface of the ground was at this particular level when the burrows were made. Approximately two miles southwest of the village of Andrews, in Sioux County, Daimonelices are exposed in an area of several acres where the average distance between spirals is not more than four or five feet.

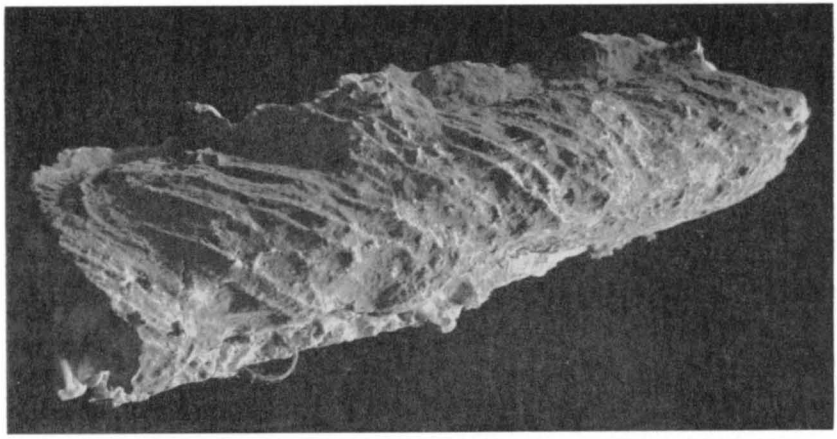

Fig. 15. Plaster of Paris cast of a section of recent rodent burrow which was associated with spiral burrow shown in Fig. 12. Note casts of claw marks.

Daimonelix spirals may be either dextral or sinistral (Figs. 3, 4, 6) and a census of the type collection in the University of Nebraska State Museum shows ten dextral and nine sinistral specimens. A field count also shows that the ratio in this respect is nearly fifty to fifty. Daimonelices are of a rather uniform height, between six and eight feet, and are rarely taller. The record example in the type collection measures slightly more than eight feet (specimen at extreme left in Fig. 4). The "rhizomes" vary in length but the average would be about four or five feet. The diameters of the whorls of a Daimonelix and the vertical distances between whorls usually become slightly and progressively greater from bottom to top in the spirals. This same tendency has also been observed in the spiral burrow of a modern rodent described below.

Axial supports have been reported[49] for Daimonelices but a careful examination of a large number of specimens in the field as well as in the type collection shows that the inner curves of the whorls are so abrupt and overlapping that there is never any longitudinal space in the center which could have been occupied by even the slenderest of supporting shafts (Fig. 16). Figure 5 shows a Daimonelix which appears to be "coiled" about an axis but this inner perpendicular structure is original sandy matrix which was left by the preparators for support of the spiral portion of the specimen. This evidence also tends to disprove the liana theory for the origin of Daimonelices because most spiral lianas require a central supporting shaft.

In 1936, the writer and associates, while exploring and mapping Quaternary terrace deposits ten miles north of Crawford, Dawes County, Nebraska, noticed in the walls of a recent ten-foot terrace (Fig. 11) exposures of numerous rodent burrows, some of which seemed to have a strong tendency to be spiral in form. A plaster of Paris cast was made of one of the holes, and when the cast was removed from the ground it was found to be in the shape of a perfect spiral (Fig. 12) and was almost an exact duplicate of the Miocene "devil's corkscrews," even to the markings on the outside (Figs. 12 and 13 for comparisons of the cast of a modern rodent burrow and a Miocene Daimonelix). This cast had the same type of cross section as is found in examples of the Miocene Daimonelix, even to the noticeable flattening of the bottom side of the spirals. This flattening is characteristic of most recent rodent burrows. Claw marks were observed in many of the modern holes and casts showed that they had the same appearance as the ridges on the Miocene examples (Figs. 14–15). Lateral burrows resembling the "rhizomes" of Daimonelices were also observed in the side of the terrace walls. These holes were filled with grass and other vegetation and seemed to be nests not unlike those which Peterson found associated with the prairie dog holes. A cast was made of one of these modern "rhizomes."

Not all of the modern burrows in the locality north of Crawford were of the spiral type, but many of them had this form or were irregularly spiral. To date the rodents which made these unusual burrows have not been discovered. A systematic trapping program has been planned for the locality and it is hoped that the

[49] Barbour, "Notes on a new . . .," *op. cit.*, figs. 6–7, 10–14; Lugn, *op. cit.*, fig. 4.

identity of the rodent in question will soon be known. Perhaps a skeleton will be found in one of the holes, thus disclosing the secret.

J. LeRoy Kay, Curator of Vertebrate Paleontology at the Carnegie Museum, has recently reported to the writer the presence of numerous recent spiral burrows in a locality in Juab County, Utah. It is thought that the little gray ground squirrel, *Citellus mollis mollis,* made the burrows and it is Kay's intention to investigate the Utah site further during 1942.

Fig. 16. View from above of a section of a typical Daimonelix showing the tightly spiralled coil and the lack of a central core or support.

The modern rodents which now make spiral burrows are not, of course, descendants or even close relatives of the beavers which lived during lower Miocene times. The tendency to dig spiral holes has developed quite independently and is an instance of parallel development.

Horace Elmer Wood, 2nd, and Albert Elmer Wood [50] have reported Daimonelix-like structures from the Pleistocene deposits of Rock Creek, Briscoe County, Texas. These examples, although not typical spirals, appear to be casts of rodent (*Cynomys leu-*

[50] *Loc. cit.*

curus) burrows, and therefore should be considered in the same class with irregular spiral Daimonelices. In their report Wood and Wood summarized the entire Daimonelix problem in a creditable manner.

The present writer has observed many rodent burrows in the late Pleistocene loess deposits of southwestern Nebraska. These

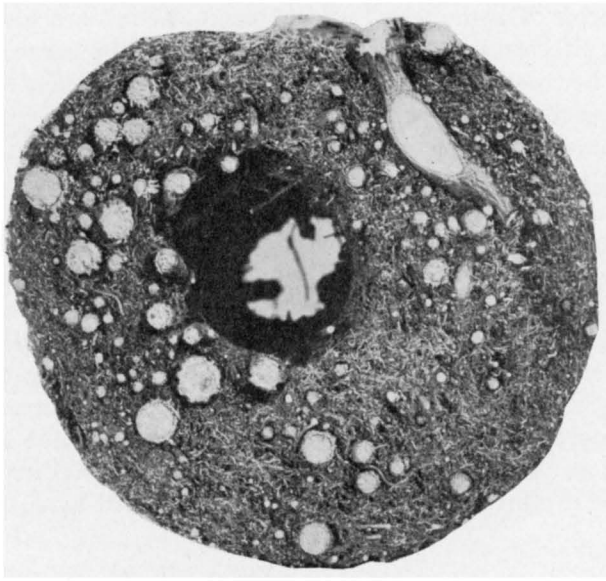

Fig. 17. Cross section of modern cottonwood roots from a 6-inch well casing, showing meshing of roots similar to that found in Daimonelices. Specimen collected near Bridgeport, Morrill County, Nebraska, by A. C. G. Kaemphfer and donated to the University of Nebraska State Museum.

burrows appear to be more like the Rock County, Texas, forms than the regular spiral types. Examples may be seen in Lincoln County south of Maxwell, Brady, and Gothenburg, at the top of the Loveland loess in the *Citellus* zone, and also in Harlan County, west of Orleans, in the vicinity of the old volcanic ash mines. Irregular types have also been examined in many other localities in the Pleistocene and Tertiary of Nebraska. Future explorations will no doubt extend the geographic distribution of Daimonelices and also yield additional facts concerning the origin of these interesting spiral structures.

SPELLING OF DAIMONELIX

Daimonelix has been spelled with an "ai" instead of an "ae" throughout the present paper because it is the original spelling of Barbour [51] as well as the most recent.[52] This may not be the preferred form but it is certainly acceptable. The term is made up of the two Greek words, *daimon,* a demon or evil spirit, plus *elix,* anything twisted or spiral.

The terms "Daemonelix" and "Daemonhelix" are also used in scientific literature. The latter appears to be the correct spelling if it is to be treated taxonomically (International Rules of Zoological Nomenclature, Appendix F, Transliteration of Greek Words, and Summaries of Opinions Rendered, 36). But since Daimonelices do not appear to be the actual remains of animals (or plants) the International Rules of Zoological (or Botanical) Nomenclature need not necessarily apply to the spelling of the term. Even if the rules were applied, the original spelling would be retained because there are no rules for subsequent corrections of improperly formed names of genera and species. Article 19 of the Rules (Zoological) provides that "The original orthography of a name is to be preserved unless an error of transcription, a *lapsus calami,* or a typographical error is evident." Therefore, since Barbour [53] intended to write the name as he did, the original orthography should be retained and this is also recommended by A. L. Lugn.[54]

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[51] "Notice of new . . . .," *op. cit.;* "Notes on a new . . . .," *op. cit.;* "Additional notes . . . .," *op cit.*

[52] "Present knowledge . . . .," *op. cit.;* "Report of . . . .," *op. cit.;* "The Boyd County mastodon, *Tetrabelodon osborni,*" Neb. Geol. Surv., 4:504; "A preliminary report . . . .," *op. cit.*

[53] "Notice of new . . . .," *op. cit.*

[54] Note by A. L. Lugn: "It appears from the above explanation by the author of this paper that the original spelling, Daimonelix, is the more correct form as between Daimonelix and Daemonelix, and the change by Barbour (1897) to the Latinized Daemonelix and my recent (1941) perpetuation of this 1897 spelling may have been ill-advised."

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