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Part I.

THE UNIVERSITY OF KANSAS
SCIENCE BULLETIN

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Derivation of Certain Relations Involving Sums of Determinants

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IN THIS paper we prove certain theorems on sums of determinants by means of partial derivative operators and generalized Kronecker symbols. Other methods of approach have been, for the most part, rather long and difficult. Several known theorems have been generalized and a few new theorems discovered and proved.

In Part I we employ partial derivative operators in a manner as first suggested in a paper by Stouffer[1] in 1925.

In Part II we employ the generalized Kronecker symbol as introduced by Muraghan[2] in the same year.

I

The expansion of a determinant $A = |a_{rs}|$ of order n with respect to row r takes the form

$$A = a_{r1}\, A_{r1} + a_{r2}\, A_{r2} + \dots + a_{rn}\, A_{rn}$$

where A_{rs} is the cofactor of element a_{rs}. Unless otherwise specified it will be assumed that the n^2 elements constituting any determinant are mutually independent. It follows that

$$\frac{\partial}{\partial a_{rs}} A = A_{rs}, \text{ while } \sum_{s=1}^{n} a_{rs} \frac{\partial}{\partial a_{rs}} A = A.$$

Again it is evident that the operator $\sum_{s=1}^{n} b_{rs} \frac{\partial}{\partial a_{rs}}$ acting on A will replace the elements of row r by the elements $b_{r1}, b_{r2}, \dots, b_{rn}$; the operator $\left(1 - a_{rs} \frac{\partial}{\partial a_{rs}}\right)$ acting on A will replace the element a_{rs} by a zero element; and the operator $\left(1 - 2\, a_{rs} \frac{\partial}{\partial a_{rs}}\right)$ acting on A will change the sign of the element in row r and column s.

To avoid the printing of a subscript to an index character, and to condense the notation we shall indicate the element in row r_1 and column s_1 by $a_{rs(1)}$; the partial derivative $\partial/\partial a_{rs(1)}$ by $E_{rs(1)}$; and the repeated operator $(E_{rs(k)}) \quad . \quad . \quad . \quad (E_{rs(2)})(E_{rs(1)})$ by $\overset{k}{\underset{m=1}{R}} E_{rs(m)}$.

If M is the minor of order k of the determinant A, in which the rows $r_1, r_2, \ldots r_k$ and columns $s_1, s_2, \ldots s_k$ are represented, then the algebraic complement of M will be denoted by $A_{rs(1,\,2,\,\ldots,\,k)}$. If, however, the rows and columns are definitely prescribed, as for instance rows 2, 5, 6, 8, columns 1, 3, 4, 8, then we shall represent the corresponding algebraic complement by the usual notation $A_{2568,\,1348}$.

THEOREM I. Let $A = |a_{rs}|$ be a determinant of order n and D be a determinant of the same order formed from A by substituting zero elements for the k elements $a_{rs(1)}, \cdots, a_{rs(k)}$, no two of which are in the same row or column; then

$$D = A - \Sigma\, a_{rs(1)} A_{rs(1)} + \Sigma\, a_{rs(1)} a_{rs(2)} A_{rs(1,2)}$$
$$- \quad . \quad . \quad . \quad . \quad . \quad .$$
$$+ (-1)^k a_{rs(1)} \cdots a_{rs(k)} A_{rs(1,2,\cdots k)} \qquad (1)$$

where $\Sigma\, a_{rs(1)} a_{rs(2)} \cdots a_{rs(m)} A_{rs(1,2,\cdots,m)}$

represents the sum of $\binom{k}{m}$ terms, each of which is formed by taking the product of m of the k deleted elements into the algebraic complement of the minor in which the m rows and m columns containing these m elements are represented.

By hypothesis the k indices $r_1, \ldots r_k$ are all distinct, the indices $s_1, \ldots s_k$ are all distinct; and $k \leqq n$.

The operator $(1 - a_{rs(1)} E_{rs(1)})$ when applied to A replaces the element $a_{rs(1)}$ by zero, and the repeated operator

$\overset{k}{\underset{m=1}{R}} (1 - a_{rs(m)} E_{rs(m)})$ when applied to A replaces the elements $a_{rs(2)}, \cdots, a_{rs(k)}$ by zeros. Therefore

$$D = [\overset{k}{\underset{m=1}{R}} (1 - a_{rs(m)} E_{rs(m)})]A. \qquad (2)$$

Upon expanding the right-hand member of (2) the equality takes the form

$$D = [1 - \Sigma\, a_{rs(1)} E_{rs(1)} + \Sigma\, a_{rs(1)} a_{rs(2)} E_{rs(1)} E_{rs(2)}$$
$$- \quad . \quad . \quad . \quad . \quad . \quad .$$
$$+ (-1)^k a_{sr(1)} \cdots a_{rs(k)} E_{rs(1)} \cdots E_{rs(k)}]\, A \qquad (3)$$

which is equivalent to the equality (1) given in the theorem.

If the k elements are chosen as the first k elements of the main diagonal, this theorem becomes the following corollary proved by Stetson[(3)] in 1904.

COROLLARY I. If D is the determinant of order n formed by substituting zero elements for the first k elements of the main diagonal in A, then

$$D = A - \Sigma\, a_{11} A_{11} + \Sigma\, a_{11} a_{22} A_{12,12} - \cdots\cdots\cdots + (-1)^k a_{11} \cdots a_{kk} A_{1\cdots k,\,1\cdots k}. \qquad (4)$$

If in addition to the above conditions we assume $k = n$, a second form results which is identical with the original theorem on this type of expansion proved by Muir[(4)] in 1898.

COROLLARY II. If D is the invertebrate determinant of order n formed by substituting zero elements for the main diagonal elements in A, then

$$D = A - \Sigma\, a_{11} A_{11} + \Sigma\, a_{11} a_{22} A_{12,12} - \cdots + (-1)^k a_{11} a_{22} \cdots a_{nn}. \qquad (5)$$

THEOREM II. Let determinants A and D be as defined in Theorem I; then

$$D = A - a_{rs(1)} |A_{rs(1)}|_0 - a_{rs(2)} |A_{rs(2)}|_0 - \cdots - a_{rs(k)} |A_{rs(k)}|_0, \qquad (6)$$

where $|A_{rs(m)}|_0$ represents the determinant formed from $A_{rs(m)}$ by substituting zeros for the elements $a_{rs(m+1)}, \cdots, a_{rs(k)}$.

The right-hand member of equation (2) may be written as

$(1 - a_{rs(1)} E_{rs(1)}) [\underset{i=2}{\overset{k}{R}} (1 - a_{rs(i)} E_{rs(i)}) A]$, since the elements of A are mutually independent. If we now add

$a_{rs(1)} E_{rs(1)} [\underset{i=2}{\overset{k}{R}} (1 - a_{rs(i)} E_{rs(i)}) A]$ the result is

$[\underset{i=2}{\overset{k}{R}} (1 - a_{rs(i)} E_{rs(i)}) A]$. From $k - 1$ similar additions will result $(1 - a_{rs(k)} E_{rs(k)}) A$ which, if the term $a_{rs(k)} E_{rs(k)} A$ be added, will equal A. That is,

$$[\underset{i=1}{\overset{k}{R}} (1 - a_{rs(1)} E_{rs(1)})] A + \sum_{m=1}^{k-1} [a_{rs(m)} E_{rs(m)} \underset{i=m+1}{\overset{k}{R}} (1 - a_{rs(i)} E_{rs(i)})] A + a_{rs(k)} E_{rs(k)} A = A \qquad (7)$$

Upon substituting D for the first term of the equality and transposing the rest of the left-hand member we have

$$D = A - \sum_{m=1}^{k-1} [a_{rs(m)} E_{rs(m)} \overset{k}{\underset{i=m+1}{R}} (1 - a_{rs(i)} E_{rs(i)})] A$$
$$- a_{rs(k)} E_{rs(k)} A, \qquad (8)$$

which equation is equivalent to (6).

We can at once state two important corollaries of this theorem.

COROLLARY I. If D be the determinant of order n formed from A by substituting zero elements for the first k elements of the main diagonal, then

$$D = A - a_{11} | A_{11} |_0 - a_{22} | A_{22} |_0 - \cdot \cdot \cdot - a_{kk} A_{kk}. \qquad (9)$$

COROLLARY II. If D be the determinant of order n formed from A by substituting zero elements for the n elements of the main diagonal, then

$$D = A - a_{11} | A_{11} |_0 - a_{22} | A_{22} |_0 - \cdot \cdot \cdot - a_{nn} A_{nn}. \qquad (10)$$

This last corollary was stated as a theorem by Horta[5] in 1890.

THEOREM III. Let $A = | a_{rs} |$ be a determinant of order n and Δ be a determinant formed from A by deleting k elements $a_{rs(1)}, \cdot \cdot \cdot, a_{rs(k)}$, no two of which are in the same row or column, and substituting respectively the elements $b_{rs(1)}, \cdot \cdot \cdot, b_{rs(k)}$ where $b_{rs} = a_{rs} - x_{rs}$; then

$$A = \Delta + \Sigma x_{rs(1)} \Delta_{rs(1)} + \Sigma x_{rs(1)} x_{rs(2)} \Delta_{rs(1,2)} + \cdot \cdot \cdot$$
$$+ x_{rs(1)} \cdot \cdot \cdot x_{rs(k)} \Delta_{rs(1,2,\cdot \cdot \cdot,k)}. \qquad (11)$$

where $\Sigma x_{rs(1)} \cdot \cdot \cdot x_{rs(m)} \Delta_{rs(1,2 \cdot \cdot \cdot, k)}$ represents the sum of $\binom{k}{m}$ term each consisting of the product of m of the k elements $x_{rs(1)}, \cdot \cdot \cdot, x_{rs(k)}$, into the algebraic complement of the minor in which the rows $r_1, \cdot \cdot \cdot, r_m$ and columns $s_1, \cdot \cdot \cdot, s_m$ are represented. The elements x_{rs} are any k variables which are mutually independent of the elements a_{rs}.

The single operator $(1 + x_{rs(1)} E_{rs(1)})$ applied to Δ will substitute the element $a_{rs(1)}$ for $b_{rs(1)}$; and the repeated operator

$\overset{k}{\underset{m=1}{R}} (1 + x_{rs(m)} \Sigma_{rs(m)})$ applied to Δ will substitute "a" elements for the respective "b" elements hence:

$$A = [\overset{k}{\underset{m=1}{R}} (1 + x_{rs(m)} E_{rs(m)})] \Delta. \qquad (12)$$

Upon expanding, the right-hand member of (12) takes the form

$$[1 + \Sigma x_{rs(1)} E_{rs(1)} + \Sigma x_{rs(1)} x_{rs(2)} E_{rs(1)} E_{rs(2)} + \cdots + x_{rs(1)} \cdots x_{rs(k)} E_{rs(1)} \cdots E_{rs(k)}] \Delta \qquad (13)$$

which is identically the right-hand member of the equality (11).

THEOREM IV. If A and D are defined as in the preceding theorems, then

$$A = D + \Sigma a_{rs(1)} D_{rs(1)} + \Sigma a_{rs(1)} a_{rs(2)} D_{rs(1,2)} + \cdots + a_{rs(1)} \cdots a_{rs(k)} D_{rs(1,2,\cdots,k)} \qquad (14)$$

This theorem follows at once if we consider the limiting form of Theorem III when the variables $x_{rs(m)}$ approach as limits the respective elements $a_{rs(m)}$.

Stetson[3], in proving a generalization of Muir's Expansion Theorem (Th. 1., Cor. I.), obtained zero elements in his determinants by employing a compound element similar to b_{rs}.

COROLLARY I. If D be the determinant of order n formed from A by substituting zero elements for the first k elements of the main diagonal, then $A = D + \Sigma a_{11} D_{11} + \Sigma a_{11} a_{22} D_{12,12}$

$$+ \cdots + a_{11} \cdots a_{kk} A_{12\cdots k, 12\cdots k}. \qquad (15)$$

COROLLARY II. If D be the determinant of order n formed from A by substituting zero elements for the n elements of the main diagonal, then

$$A = D + \Sigma a_{11} D_{11} + \Sigma a_{11} a_{22} D_{12,12} + \cdots + a_{11} \cdots a_{nn}. \qquad (16)$$

Corollary II was first stated as a theorem by Cayley[6] in 1848 and is known as Cayley's Expansion Theorem. Corollary I, which is more general than Corollary II, was first stated as a theorem by Muir[7] in 1896.

THEOREM V. Let $A = |a_{rs}|$ be a determinant of order n and δ be a determinant of the same order formed from A by changing the signs of the k elements $a_{rs(1)}, a_{rs(2)}, \cdots, a_{rs(k)}$, no two of which are in the same row or column; then

$$\delta = A - 2\Sigma a_{rs(1)} A_{rs(1)} + 2^2\Sigma a_{rs(1)} a_{rs(2)} A_{rs(1,2)} - \cdots + (-2)^k a_{rs(1)} \cdots a_{rs(k)} A_{rs(1,2,\cdots,k)} \qquad (17)$$

where the terms in the expansion are as defined in the first theorem.

The single operator $(1 - 2\, a_{rs(1)}\, E_{rs(1)})$ when applied to A changes the sign of $a_{rs(1)}$; and the repeated operator $\underset{m=1}{\overset{k}{R}}(1 - 2\, a_{rs(m)}\, E_{rs(m)})$ when applied to A changes the signs of the k elements

$a_{rs(1)}, a_{rs(2)}, \cdots, a_{rs(k)}$.

Hence

$$\delta = [\underset{m=1}{\overset{k}{R}}(1 - 2\, a_{rs(m)}\, E_{rs(m)})]A. \tag{18}$$

Upon expanding the right-hand member of (18) the equality takes the form

$$\begin{aligned}\delta = [1 &- 2\, \Sigma\, a_{rs(1)}\, E_{rs(1)} + 2^2\, \Sigma\, a_{rs(1)}\, a_{rs(2)}\, E_{rs(1)}\, E_{rs(2)} \\ &- \cdots \\ &+ (-2)^k\, a_{rs(1)}\, a_{rs(2)} \cdots a_{rs(k)}\, E_{rs(1)}\, E_{rs(2)} \cdots E_{rs(k)}]\, A\end{aligned} \tag{19}$$

which is equivalent to the equality of (17).

II.

The ordinary Kronecker symbol is denoted by δ_r^s and has the value zero or unity according as r and s are different or identical. The two indices r and s assume independently any integral values within the range $1, 2, \cdots n$.

The general Kronecker symbol as introduced by Murnaghan[(2)] may be denoted by

$$\begin{bmatrix} s_1 s_2 \cdots s_m \\ r_1 r_2 \cdots r_m \end{bmatrix}$$

where the indices r_i, s_i assume independently any integral values within the range $1, 2, \cdots n$; and $m \leqq n$.

This generalized symbol is characterized by the following postulates or definitions:

(1) If the elements r_i are not all distinct, or if the elements s_i are not all distinct, the generalized symbol is taken to be zero.

(2) If, neglecting order, the set of elements r_i is in any way different from the set of elements s_i then the generalized symbol is again taken to be zero.

(3) If the elements r_i are all distinct, and if the set of elements s_i is identical with the set of elements r_i, then the symbol is taken to be plus one or minus according as the two sets become identical in order after an even or an odd number of inversións within either set.

We shall adopt the common convention that whenever a Greek letter index appears twice in a term that term is to be summed for all values of the index within the range 1, 2, $\cdots$ n.

The determinant A may now be defined in several equivalent forms:

$$A \equiv \begin{bmatrix} \sigma_1 \sigma_2 \cdots \sigma_n \\ r_1 r_2 \cdots r_n \end{bmatrix} a_{r\sigma(1)}\, a_{r\sigma(2)} \cdots a_{r\sigma(n)}$$

$$\equiv \begin{bmatrix} s_1 s_2 \cdots s_n \\ \rho_1 \rho_2 \cdots \rho_n \end{bmatrix} a_{\rho s(1)}\, a_{\rho s(2)} \cdots a_{\rho s(n)}$$

$$\equiv \frac{1}{n\,!} \begin{bmatrix} \sigma_1 \sigma_2 \cdots \sigma_n \\ \rho_1 \rho_2 \cdots \rho_n \end{bmatrix} a_{\rho\sigma(1)}\, a_{\rho\sigma(2)} \cdots a_{\rho\sigma(n)}.$$

The algebraic complement $A_{r\sigma(1,2,\cdots k)}$ is identically

$$\begin{bmatrix} \sigma_1 \sigma_2 \cdots \sigma_n \\ r_1 r_2 \cdots r_n \end{bmatrix} a_{r\sigma(k+1)} \cdots a_{r\sigma(n)}.$$

THEOREM VI. If A is a determinant of order n and $B, C, \cdots, L$ are p other determinants of the same order, the sum of the $(n)(n-1)\cdots(n-p+1)$ determinants composed of $n-p$ rows from A and one row from each of the p determinants $B, C, \cdots, L$ is equal to that of the same number of determinants composed of $n-p$ columns from A and one column from each of the p determinants $B, C, \cdots, L$. The columns and rows are to occupy the same places in the new determinants as in the originals, and $p \leqq n-1$.

First we recognize

$$\begin{bmatrix} \sigma_1 \sigma_2 \cdots \sigma_n \\ r_1 r_2 \cdots r_n \end{bmatrix} b_{r\sigma()1}\, c_{r\sigma(2)} \cdots l_{r\sigma(p)}\, a_{r\sigma(p+1)} \cdots a_{r\sigma(n)}$$

to be a determinant composed of $n-p$ rows from A and one row from each of the p determinants $B, C, \cdots, L$. Furthermore

$$\frac{1}{(n-p)\,!} \begin{bmatrix} \sigma_1 \sigma_2 \cdots \sigma_n \\ \rho_1 \rho_2 \cdots \rho_n \end{bmatrix} b_{\rho\sigma(1)}\, c_{\rho\sigma(2)} \cdots l_{\rho\sigma(p)}\, a_{\rho\sigma(p+1)} \cdots a_{\rho\sigma(n)} \tag{20}$$

represents the sum of the $n(n-1)\cdots(n-p+1)$ determinants composed of $n-p$ rows from A and one row from each of the p determinants $B, C, \cdots, L$.

Again we recognize

$$\begin{bmatrix} s_1 s_2 \cdots s_n \\ \rho_1 \rho_2 \cdots \rho_n \end{bmatrix} b_{\rho s(1)}\, c_{\rho s(2)} \cdots l_{\rho s(p)}\, a_{\rho s(p+1)} \cdots a_{\rho s(n)}$$

to be a determinant composed of $n-p$ columns from A and one column from each of the p determinants. Furthermore

$$\frac{1}{(n-p)!}\begin{bmatrix}\sigma_1\,\sigma_2 \cdots \sigma_n \\ \rho_1\,\rho_2 \cdots \rho_n\end{bmatrix} b_{\rho\sigma(1)}\, c_{\rho\sigma(2)} \cdots l_{\rho\sigma(p)}\, a_{\rho\sigma(p+1)} \cdots a_{\rho\sigma(n)} \tag{21}$$

represents the sum of the $n(n-1)\cdots(n-p+1)$ determinants composed of $n-p$ columns from A and one column from each of the p determinants. It is identical with (20).

An interesting example of the theorem occurs when $p+1=n$, in which case one row is taken from each of the n given determinants $A, B, C, \cdots, L$ for the construction of each new one.

Another example of interest is obtained if $p=1$, in which instance one row is taken from B and the remaining rows from A in the construction of each new determinant. This example was stated as a theorem by Muir[8] in 1888.

If $B=C=D=\cdots=L$ the theorem reduces at once to:

COROLLARY I. If A and B are two determinants of order n, the sum of the $\binom{n}{p}$ determinants of the same order composed of $n-p$ rows from A and of p rows from B is equal to that of the $\binom{n}{p}$ determinants composed of $n-p$ columns from A and of p columns from B.

This corollary was given as a lemma by J. Deruyts[9] in 1883.

A second corollary is obtained if certain groups of the determinants are identical. Suppose that k_1 determinants are identical with B, k_2 determinants are identical with C, and so on, where $\Sigma k_i \leqq n$.

COROLLARY II. If $A, B, C, \cdots, L$ are $p+1$ determinants of order n the sum of the $\dfrac{n(n-1)\cdots(n-p+1)}{(k_1!)(k_2!)\cdots(k_p!)}$ determinants each composed of k_1 rows from B, k_2 rows from $C, \cdots, k_p$ rows from L, and the remaining $n-\Sigma k_i$ rows from A, is equal to the sum of the same number of determinants each composed of k_1 columns from B, k_2 columns from $C, \cdots, k_p$ columns from L, and the remaining $n-\Sigma k_i$ columns from A. The columns and rows are to occupy the same places in the new determinants as in the originals and $\Sigma k_i \leqq n$.

THEOREM VII. If $\delta_{k_i} = |a_{rh}|$, $r=1, 2, \cdots n$, $h=k_i, k_i+1, \cdots, n, n+1, 1, 2, \cdots, k_i-2$, and if $k_1, k_2, \cdots, k_p$ are p distinct positive integers each different from unity and less than $n+1$; then the sum of the $p!\binom{n}{p}$ determinants of order n, composed of

$n - p$ rows from $A = |a_{rs}|$ and one row from each of the p determinants $\delta_{k_1}, \delta_{k_2}, \cdots, \delta_{k_p}$ is equal to $(-1)^{\Sigma k} p!\, \Delta_{n+p+1-\Sigma k}$ where Δ_r denotes the determinant obtained by deleting the r the column of the n by $n+1$ array $||a_{rs}||$ $r = 1, 2, \cdots n$, $s = 1, 2, \cdots n+1$. If the number $n + 1 + p - \Sigma k$ is not between 1 and $n + 1$, inclusive, then a convenient multiple of $n + 1$ is to be added to it.

By Theorem VI the above sum of $p!\binom{n}{p}$ determinants is equal to the sum of the same number of determinants composed of $n - p$ columns from A and one column from each of the p determinants δ_{k_i}. Most of these determinants are zero due to duplicate columns.

In the determinant δ_{k_i} the elements in column s_i have for second index $s_i + k_i - 1$. If $s_i + k_i - 1$ is not between 1 and $n + 1$, inclusive, then $n + 1$ is to be subtracted from it. Now $s_i + k_i - 1$ cannot equal s_i since by hypothesis $k_i \neq 1$. Hence to construct a nonvanishing determinant composed of $n - p$ columns from $A = |a_{rs}|$ and one column, with index s_i, from each of the p determinants δ_{k_i}, we must take $s_1 + k_1 - 1 = n + 1$. Note again that the elements in column s_1 have then the second index equal to $s_1 + k_1 - 1$. Having fixed s_1 we must next take
$s_2 + k_2 - 1 = s_1 = n + 2 - k_1$, $s_3 + k_3 - 1 = s_2 = n + 3 - k_1 - k_2$, etc.
For each arrangement of the p numbers k_i there is a corresponding set of indices s_i and one nonvanishing determinant. Since the p numbers k_i can be permuted in $p!$ ways there are just $p!$ nonvanishing determinants. All of these determinants are characterized by the absence of elements with the second index equal to

$$n + p + 1 - \Sigma k.$$

Hence each determinant is equal to $\Delta_{n+p+1-\Sigma k}$ except for the sign which is $(-1)^{\Sigma k}$.

If in the statement of the theorem we assume $k_1 = k_2 = \cdots = k_p$ a corollary follows at once.

COROLLARY I. The sum of the $\binom{n}{p}$ determinants of order n composed of $n - p$ from A and of p rows from δ_k is equal to $(-1)^{pk}$ $\Delta_{n+p+1-pk}$.

This theorem(9) and corollary(10) were theorems of Deruyts published in 1883 and 1881. Le Paige(11) proved the corollary for the special case $p = 1$, $k = 2$ in 1880.

THEOREM VIII. If $A = |a_{rs}|$ is a determinant of order n, and if from A a new determinant be formed by altering the order of the elements in the first row, a second determinant by making the same alteration in the elements of the second row, and so on, the sum of the n determinants thus derived is m times the original, where m is the number of elements of a row that after the change of order occupy the same positions as before.

To prove this theorem first construct a new determinant B from A by altering the order of the columns then apply Theorem VI. The sum of the n determinants each composed of one row from B and the remaining rows from A is equal to the sum of the n determinants each composed of one column from B and the remaining columns from A. But all the n determinants composed of one column from B and the remaining columns from A are zero due to duplicate columns except for those m determinants in which the column taken from B is identical with the one it replaces in A.

This theorem is equivalent to a theorem given by Deruyts[12] in 1885.

THEOREM IX. If $A = |a_{rs}|$ is a determinant of order n and

$$B = \begin{vmatrix} \lambda_1 a_{1n} & \lambda_2 a_{11} & \lambda_3 a_{12} & \cdots & \lambda_n a_{1\,n-1} \\ \lambda_1 a_{2n} & \lambda_2 a_{21} & \lambda_3 a_{22} & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \lambda_1 a_{nn} & \lambda_2 a_{n1} & \lambda_3 a_{n3} & \cdots & \lambda_n a_{n\,n-1} \end{vmatrix}$$

where $\lambda_1, \lambda_2, \cdots \lambda_n$ are n arbitrary multipliers different from zero, then the sum of the $\binom{n}{p}$ determinants, each composed of p rows from B and $n - p$ rows from A, is equal to zero. The rows are to occupy the same positions in the new determinants as in the originals, and $p < n$.

Applying the statement of Theorem VI, Corollary I, it is evident that the determinants obtained by inserting columns from B into A are all zero due to duplicate columns.

This theorem was stated as a theorem for the special case of $p = 1$, $n = 4$ by Hammond[13] in 1881.

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A Reduced System of Differential Equations for the Invariants of Ternary Forms

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1. INTRODUCTION. Let C_n represent a general ternary form of order n in the variables x_1, x_2, x_3, and let T denote the general linear transformation

$$T = \begin{cases} x_1 = a_{11}\xi_1 + a_{12}\xi_2 + a_{13}\xi_3, \\ x_2 = a_{21}\xi_1 + a_{22}\xi_2 + a_{23}\xi_3, \\ x_3 = a_{31}\xi_1 + a_{32}\xi_2 + a_{33}\xi_3, \end{cases} \qquad |a_{ik}| \neq 0.$$

It is well known that the necessary and sufficient condition that a homogeneous function F of the coefficients of C_n be invariant under T, is that F be a solution of a certain system of nine linear partial differential equations of the first order, each coefficient of T giving rise to an equation of the system.

By the use of the special transformation

$$\begin{aligned} x_1 &= \xi_1 + a_{12}\xi_2 + a_{13}\xi_3, \\ x_2 &= \xi_2 \,, \\ x_3 &= \xi_3, \end{aligned}$$

Junker* found solutions for two of the nine equations and by the introduction of these solutions as new variables reduced the number of equations in the complete system to seven.

It is the purpose of this work to reduce the number of equations in the system to six. We use the special transformation

$$(1) \quad T_1 = \begin{cases} x_1 = \xi_1 + a_{12}\xi_2 + a_{13}\xi_3, \\ x_2 = \xi_2 + a_{23}\xi_3, \\ x_3 = \xi_3, \end{cases}$$

and define a seminvariant of the ternary form as any homogeneous function of the coefficients which is invariant under T_1.

* Math. Annalen, vol. 64, pp. 328-343.

2. CALCULATION OF THE SEMINVARIANTS. The general ternary n-ic, C_n may be written as a determinant* with linear elements in the form

$$(2)\quad C_n = \begin{vmatrix} x_1 + a_{11}x_2 + b_{11}x_3 & a_{12}x_2 + b_{12}x_3 & \cdots \\ a_{21}x_2 + b_{21}x_3 & x_1 + a_{22}x_2 + b_{22}x_3 & \cdots \\ \cdots & \cdots & \cdots \\ a_{n1}x_2 + b_{n1}x_3 & & x_1 + a_{nn}x_2 + b_{nn}x_3 \end{vmatrix}.$$

When expanded C_n may be written

$$(3)\quad I^{n0}x_1^n + I^{n-1,0}x_1^{n-1}x_2 + I^{n-1,1}x_1^{n-1}x_3 + \cdots + I^{jk}x_1^i x_2^j x_3^k,$$

where $I^{n0} = 1$ and $I^{r0} (r < n)$ is the sum of all principal minors of order $n - r$ of the determinant

$$A = \begin{vmatrix} a_{11} & \cdots & \\ \cdots & \cdots & \\ & \cdots & a_{nn} \end{vmatrix},$$

and I^{rs} $(r + s \leqq n)$ is the sum of all possible determinants obtained by replacing s columns at a time in each of the principal minors of I^{r0} by the same columns from the corresponding minors of

$$B = \begin{vmatrix} b_{11} & \cdots & \\ \cdots & \cdots & \\ & \cdots & b_{nn} \end{vmatrix}.$$

For example $I^{00} = A$, and I^{01} is the sum of the n determinants of the form

$$\begin{vmatrix} b_{11} & a_{12} & a_{13} & \cdots & a_{1n} \\ b_{21} & a_{22} & \cdots & & \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ b_{n1} & a_{n2} & \cdots & & a_{nn} \end{vmatrix} + \begin{vmatrix} a_{11} & b_{12} & a_{13} & \cdots & a_{1n} \\ a_{21} & b_{22} & \cdots & & \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{n1} & b_{n2} & \cdots & & a_{nn} \end{vmatrix} + \cdots.$$

The coefficients I^{rs} may be obtained from $A = I^{00}$ by means of two differential operators†

$$D_a = \sum_{i=1}^{n} \frac{\partial}{\partial a_{ii}} \text{ and } D_{ab} = \sum_{i=1}^{n} \sum_{j=1}^{n} b_{ij} \frac{\partial}{\partial a_{ij}}.$$

* Dickson, Transactions of the American Math. Soc., vol. 22, pp. 167-179; Stouffer, *ibid.*, vol. 26, No. 3, pp. 356-368.

† cf., Stouffer, loc. cit., p. 363.

In general for the ternary form

$$D_a I^{rs} = (r+1)\, I^{r+1,\, s},$$

and

$$D_{ab} I^{rs} = (s+1)\, I^{r,\, s+1}.$$

If we represent the result of k successive applications of D_a upon I^{rs} by $D_a^k I^{rs}$ and of D_{ab} on I^{rs} by $D_{ab}^k I^{rs}$ we have

$$D_a^k I^{rs} = \frac{(r+k)!}{r!} I^{r+k,\, s},$$

and

$$D_{ab}^k I^{rs} = \frac{(s+k)!}{s!} I^{r,\, s+k}.$$

In terms of I^{rs} the differential equations* satisfied by the invariants of a ternary n-ic may be written in the following form. The summations extend over the coefficients of C_n.

$$E_1 = \Sigma\Sigma\, (i+1)\, I^{i+1,k} \frac{\partial f}{\partial I^{ik}} = 0,$$

$$E_2 = \Sigma\Sigma\, (i+1)\, I^{i+1,k-1} \frac{\partial f}{\partial I^{ik}} = 0,$$

$$E_3 = \Sigma\Sigma\, (n-i+1-k)\, I^{i-1,k} \frac{\partial f}{\partial I^{ik}} = 0,$$

$$E_4 = \Sigma\Sigma\, (k+1)\, I^{i-1,k+1} \frac{\partial f}{\partial I^{ik}} = 0,$$

(4) $$E_5 = \Sigma\Sigma\, (n-i-k+1)\, I^{i,k-1} \frac{\partial f}{\partial I^{ik}} = 0,$$

$$E_6 = \Sigma\Sigma\, (k+1)\, I^{i,k+1} \frac{\partial f}{\partial I^{ik}} = 0,$$

$$E_7 = \Sigma\Sigma\, (i-1)\, I^{ik} \frac{\partial f}{\partial I^{ik}} = 0,$$

$$E_8 = \Sigma\Sigma\, (n-1-2k)\, I^{ik} \frac{\partial f}{\partial I^{ik}} = 0,$$

$$E_9 = \Sigma\Sigma\, (n-2i-k)\, I^{ik} \frac{\partial f}{\partial I^{ik}} = 0.$$

* E. B. Elliott, Algebra of Quantics, p. 379.

After transformation (1) has been applied to C_n in form (2) the finite transformations of the elements a and b may be built, and from these their infinitesimal transformations calculated. The resulting infinitesimal transformations of a and b

$$\begin{aligned} \delta a_{ii} &= \Phi_{12}\,\delta t, \\ \delta a_{ij} &= 0 \quad (i \neq j), \\ \delta b_{ii} &= (\Phi_{13} + \Phi_{23} a_{ii})\ \delta t, \\ \delta b_{ij} &= (\Phi_{23} a_{ij})\ \delta t \quad (i \neq j), \end{aligned}$$

are found to have the same form as the infinitesimal transformations obtained by Stouffer* when working on an entirely different problem, that of seminvariants and invariants of a system of linear homogeneous differential equations.

The differential equations considered by Stouffer are of the form

$$y''_i + \sum_{k=1}^{n} (2p_{ik}\, y'_k + q_{ik}\, y_k) = 0 \qquad (i = 1, 2, \cdots, n),$$

where the primes indicate differentiation with respect to the independent variable x, and p_{ik} and q_{ik} are functions of x. A function of the coefficients and their derivatives which is unchanged by the general transformation of the dependent variables

$$(5)\quad y_k = \sum_{\lambda=1}^{n} a_{k\lambda}(x)\, \eta_\lambda \qquad (k = 1, 2, \cdots, n),$$

is defined as a seminvariant, and if this function is also invariant under the general transformation of the independent variable $\xi = \xi(x)$, it is called an invariant of the system. The seminvariants of the system or the invariants under the group formed by transformations (5), are solutions of the system of partial differential equations obtained by equating to zero the most general infinitesimal transformation of the group.

Determinants having the same form as our coefficients in (3) are shown to be seminvariants, the infinitesimal transformations of which are identical in form with the infinitesimal transformations of our coefficients I^{rs}. With certain minor changes in constants the seminvariants of our problem are the same functions of the coefficients I^{rs} as the invariants of Stouffer's problem are of his seminvariants. Consequently, by the use of Stouffer's results we know that the following functions are seminvariants of our ternary $n-ic$, facts which may also be verified directly by means of equations (4).

* Stouffer, Proceedings of the London Math. Soc., Sec. 2, vol. 15, Part 3, and Sec. 2, vol. 17, Part 5.

$$(6)\quad A_a = (I^{n-1,0})^a - a! \sum_{i=2}^{a-1} \frac{1}{(a-i)!\,i!} (I^{n-1,0})^{a-i} A_i$$

$$- \frac{a!\,n^{a-1}}{(n-1)(n-2)\ldots(n-a+1)} I^{n-a,0} (I^{n0})^{a-1} \quad (a = 2, 3, \ldots, n),$$

$$(7)\quad A_{a\beta} = 2A_2 D_{ab} A_{a,\beta-1} - a A_{a,\beta-1} D_{ab} A_2$$

$$(a = 3, 4, \cdots, n;\ \beta = 1, 2, \cdots, a),$$

$$(8)\quad B = 4A_2(I^{n-1,1})^2 - \frac{8n}{n-1} I^{n-2,2} I^{n0} A_2 - (D_{ab} A_2)^2.$$

The seminvariants A_a, $A_{a\beta}$, and B are independent, for if they are arranged in the order A_a, B, and $A_{a\beta}$, and according to ascending values of a, and β, each contains a coefficient I^{rs} not in those which precede.

3. THE DIFFERENTIAL EQUATIONS IN TERMS OF THE SEMINVARIANTS. The expressions A_a, $A_{a\beta}$, B, and I^{no}, $A_2 \neq 0$, may be introduced as new variables into the set of nine differential equations (4), and the new coefficients expressed in terms of these seminvariants. Equations E_1, E_2, and E_5 are satisfied identically by the new variables and thus the number of equations in the set will be reduced by three. In order to introduce* the new variables I^{no}, A_a, $A_{a\beta}$, and B, into any other of the partial differential equations $E_i = 0$, we operate with E_1 on A_a, $A_{a\beta}$, B, and I^{no}. Equation $E_i = 0$, in terms of the new variables, will read

$$\Sigma E_i (A_a) \frac{\partial f}{\partial A_a} + E_1 (A_{a\beta}) \frac{\partial f}{\partial A_{a\beta}} + E_i (B) \frac{\partial f}{\partial B}$$

$$+ E_i (I^{n0}) \frac{\partial f}{\partial I^{no}} = 0,$$

where by $E_i\ (F)$ we represent the results obtained by operating on F by E_i.

After having operated with E_i upon the seminvariants, we may as a matter of simplification set $I^{n-1,o} = I^{n-1,1} = I^{n-2,1} = 0$. This may be done without loss of generality since by choosing in transformation (1)

$$a_{12} = -\frac{I^{n-1,0}}{nI^{n0}},$$

$$a_{13} = \frac{2I^{n-1,1} I^{n-2,0} - I^{n-2,1} I^{n-1,0}}{(n-1) A_2},$$

$$a_{23} = \frac{nI^{n-2,1} I^{n0} - (n-1) I^{n-1,0} I^{n-1,1}}{(n-1) A_2};$$

* Horn, Einfuhrung in die Theorie der partiellen differential-gleichungen.

the three transformed coefficients $\overline{I^{n-1,0}}$, $\overline{I^{n-1,1}}$ and $\overline{I^{n-2,1}}$ of the resulting n-*ic*, will be reduced to zero without having changed the value of the seminvariants.

We shall consider in detail only

$$E_3 = \Sigma\,\Sigma\,(n - i + 1 - k)\,I^{i-1,k}\,\frac{\partial f}{\partial I^{ik}} = 0.$$

If we operate upon the seminvariants with E_3 and simplify, we have:

$$E_3\,(I^{n0}) = 0,$$

$$E_3\,(A_a) = \frac{a(n-1)}{n}\,A_2\,A_{a-1} + \frac{(n-a)}{n}\,A_{a+1}\,,$$

$$E_3\,(B) = \frac{(n-2)\,A_{32}}{6n\,A_2} + \frac{3(n-2)\,A_3\,B}{2n\,A_2}\,,$$

(9) $$E_3\,(A_{a\beta}) = \frac{(n-2)\,A_3\,A_{a\beta}}{n\,A_2} - \frac{a\,(n-2)\,A_{a,\beta-1}\,A_{31}}{3n\,A_2} + 2A_2\,E_3\,(D_{ab}\,A_{a,\beta-1}).$$

If $\beta = 1$ in (9) the last term may also be expressed directly in terms of the new variables and we have

$$E_3\,(A_{a1}) = \frac{(n-2)\,A_3\,A_{a1}}{n\,A_2} + \frac{a(n-1)\,A_2\,A_{a-1,1}}{n} + \frac{a(n-a)\,A_{a+1,1}}{n(a+1)} - \frac{a(n-2)\,A_a\,A_{31}}{3n\,A_2}.$$

If $\beta = 2$ we have

$$E_3\,(A_{a2}) = \frac{(2-2a)(n-2)\,A_{31}\,A_{a1}}{3n\,A_2} + \frac{2(n-2)\,A_3\,A_{a2}}{n\,A_2} + \frac{a(n-2)\,A_3\,A_a\,B}{2n\,A_2} + \frac{(a-1)(n-a)\,A_{a+1,2}}{n(a+1)} - \frac{(n-a)\,A_{a+1}\,B}{n} + \frac{a(n-1)\,A_{a-1,2}\,A_2}{n} - \frac{a(n-1)\,A_{a-1}\,A_2\,B}{n} - \frac{a(n-2)\,A_{32}\,A_a}{6n\,A_2}.$$

In the general case it is necessary to prove that $E_3\,(D_{ab}\,A_{a,\beta-1})$ may for any particular value of β be expressed in terms of the new variables. The proof of this fact may be given in three parts.

(I) We shall first show that $D_{ab}\,(A_{a\beta})$ may be expressed as a function of A_a, $D_{ab}\,A_a, \cdots D^q_{ab}\,A_a$. If we can find a value of γ

such that $A_{\alpha\gamma}$ is a function of (10) $A_a, D_{ab} A_a \cdots D^r_{ab} A_a, A_2,$ $D_{ab} A_2, D^2_{ab} A_2, (a>2)$ then from (7) it follows that $A_{a,\gamma+1}$ is a function of (10) and $D^{r+1}_{ab} A_a$. But we may write A_{a_2} in the form

$$A_{a_2} = 2A_2 D_{ab}(2A_2 D_{ab} A_a - aA_a D_{ab} A_2) - a(2A_2 D_{ab} A_a - aA_a D_{ab} A_2) D_{ab} A_2.$$

It now follows that $A_{a_3}, A_{a_4}, \cdots$ and finally $A_{a\beta}$ may be expressed as a function of (10). Thus (I) follows immediately.

(II) We shall next show that

$$E_3 [D^q_{ab}(A_a)] = \frac{(a+1-q)(n-a)}{n(a+1)} D^q_{ab} A_{a+1} - \frac{a(n-1)}{n} A_2 D^q_{ab} A_{a-1} \quad (q = 1, 2 \cdots a).$$

By direct operation with D_{ab} upon (6) we obtain

$$D_{ab}(A_a) = a(I^{n-1,0})^{a-1} I^{n-1,1} - a! \sum_{i=2}^{a-2} \frac{(a-i)}{(a-i)!\, i!} (I^{n-1,0})^{a-i-1} I^{n-1,1} A_i$$

$$- a! \sum_{i=2}^{a-2} \frac{(I^{n-1,0})^{a-i}}{(a-i)!\, i!} D_{ab}(A_i) - a I^{n-1,1} A_{a-1}$$

$$- a I^{n-1,0} D_{ab} A_{a-1} - \frac{a!\, n^{a-1} I^{n-a,1} (I^{n0})^{a-1}}{(n-1)(n-2)\ldots(n-a+1)}.$$

A second operation gives us $D^2_{ab}(A_a) = -2a I^{n-1,1} D_{ab} A_{a-1}$

$$- a I^{n-1,0} D^2_{ab} A_{a-1} - \frac{2a!\, n^{a-1} I^{n-a,2} (I^{n0})^{a-1}}{(n-1)(n-2)\ldots(n-a+1)}$$

$+ (\ldots$ a series of terms of second or higher degree in $I^{n-1,0}$ and $I^{n-1,1})$.

By induction we may show that $D^q_{ab}(A_a) = -qa I^{n-1,1} D^{q-1}_{ab} A_{a-1}$

$$- a I^{n-1,0} D^q_{ab} A_{a-1} - \frac{q!\, a!\, n^{a-1} I^{n-a,q} (I^{n0})^{a-1}}{(n-1)(n-2)\ldots(n-a+1)}$$

$+ (\ldots$ terms of second or higher degree in $I^{n-1,0}$ and $I^{n-1,1})$. If we operate on the above by E_3 and set $I^{n-1,0} = I^{n-1,1} = I^{n-2,1} = 0$, we have (II).

(III.) We shall show finally that $D^q_{ab}(A_a)$ $(q = 1, 2, \ldots a)$, may be expressed as a function of the seminvariants $A\alpha$, $A\alpha_\beta$, and B. If we apply the operator D_{ab} to $A\alpha$ and $A\alpha_\beta$ and set $I^{n-1,0} = I^{n-1,1} = I^{n-2,1} = 0$, we have

$$D_{ab}(A_2) = 0,$$

$$D^2_{ab}(A_2) = \frac{B}{2A_2},$$

$$D_{ab}(A_2) = 0,$$

$$D_{ab}(A\alpha) = \frac{A\alpha_1}{2A_2} \quad (\alpha = 3, \ldots, n),$$

(11) $$D^2_{ab}(A\alpha) = \frac{1}{4A_2^2}[A\alpha_2 + 2(\alpha-1)A\alpha_1 D_{ab} A_2 + \alpha(\alpha-2)A\alpha(D_{ab}A_2)^2 + 2\alpha A_2 A\alpha D^2_{ab} A_2].$$

$$D_{ab}(A\alpha_\beta) = \frac{A\alpha,_{\beta+1}}{2A_2} \quad [\beta = 1, \ldots, (\alpha-1)].$$

If we can find a value for r such that $D^r_{ab}(A\alpha)$ may be expressed as a function of

(12) A_2, A_α, $A_{\alpha 1}$, $A_{\alpha 2}$ ... $A_{\alpha r}$, $D_{ab}A_2$, $D^2_{ab}A_2$, then by means of the above results $D^{r+1}_{ab}(A_\alpha)$ $(r = 1, 2, \ldots, \alpha - 1)$, may in turn be expressed as a function of A_2, A_α, $A_{\alpha\beta}$, and B. In (11) we have $D^2_{ab}(A_\alpha)$ defined in terms of functions (12). Thus by induction (III) follows.

By (I), (II), and (III), it now follows that $E_3(D_{ab}A\alpha_{,\beta-1})$ may be expressed in terms of the seminvariants, thus completing the proof that $E_3(A\alpha_\beta)$ may be expressed in terms of the seminvariants as new variables.

The method of introduction of $A\alpha$, $A\alpha_\beta$, B, and I^{n0} into the remaining differential equations of set (4) parallels very closely that used for E_3.

As a result we have the following six partial differential equations which for $A_2 \neq 0$ must be satisfied by the invariants of a ternary n-ic. The summations extend over all subscripts α and β.

$$E_3 = \Sigma\left[\frac{\alpha(n-1)}{n}A_2 A\alpha_{-1} + \frac{n-\alpha}{n}A\alpha_{+1}\right]\frac{\partial f}{\partial A\alpha} + \left[\frac{(n-2)A_{32}}{6n A_2} + \frac{3(n-2)A_3 B}{A_2}\right]\frac{\partial f}{\partial B}$$

$$+ \Sigma \Sigma \left[\frac{(n-2)\, A_3\, A_{\alpha,\beta}}{n\, A_2} - \frac{\alpha(n-2)\, A_{\alpha\beta-1}\, A_{31}}{3n\, A_2} \right.$$

$$\left. + 2A_2\, E_3\, (D_{ab}\, A_{\alpha,\beta-1}) \right] \frac{\partial f}{\partial A_{\alpha\beta}} = 0,$$

$$E_4 + \Sigma \left[\frac{(n-\alpha)\, A_{\alpha+1,1}}{2n\,(\alpha+1)\, A_2} \right] \frac{\partial f}{\partial A_\alpha} + \left[\frac{(n-2)\, A_{33}}{12n\, A_2^2} \right.$$

$$\left. + \frac{3(n-2)\, A_{31}\, B}{4n\, A_2^2} \right] \frac{\partial f}{\partial B}$$

$$+ \Sigma \Sigma \left[\frac{(n-2)\, A_{31}\, A_{\alpha\beta}}{6n\, A_2^2} - \frac{\alpha(n-2)\, A_{32}\, A_{\alpha,\beta-1}}{12n\, A_2^2} \right.$$

$$\left. - \frac{\alpha(n-2)\, A_3\, B\, A_{\alpha,\beta-1}}{4n\, A_2^2} + 2A_2\, E_4\, (D_{ab}\, A_{\alpha,\beta-1}) \right] \frac{\partial f}{\partial A_{\alpha\beta}} = 0$$

$$E_6 = \Sigma \left(\frac{A_{\alpha 1}}{2A_2} \right) \frac{\partial f}{\partial A_\alpha} + \Sigma \Sigma\, D_{ab}\, (A_{\alpha\beta})\, \frac{\partial f}{\partial A_{\alpha\beta}} = 0.$$

$$E_7 = n\, I^{n0} \frac{\partial f}{\partial I^{n0}} + \Sigma\, \alpha(n-1)\, A_\alpha \frac{\partial f}{\partial A_\alpha} + (4n-6)\, B \frac{\partial f}{\partial B}$$

$$+ \Sigma \Sigma\, [2(n-1)\, A_{\alpha\beta} + 2A_2\, E_7\, (D_{ab}\, A_{\alpha,\beta-1})]\, \frac{\partial f}{\partial A_{\alpha\beta}} = 0.$$

$$E_8 = \Sigma \alpha\, A_\alpha \frac{\partial f}{\partial A_\alpha} + \Sigma \Sigma\, [2A_{\alpha\beta}$$

$$+ 2A_2\, E_8\, (D_{ab}\, A_{\alpha,\beta-1})] \frac{\partial f}{\partial A_{\alpha\beta}} = 0,$$

$$E_9 = \Sigma\, (2\alpha - \alpha n)\, A_2 \frac{\partial f}{\partial A_\alpha} - n\, I^{n0} \frac{\partial f}{\partial I^{n0}} + (6-4n)\, B \frac{\partial f}{\partial B}$$

$$+ \Sigma \Sigma\, [(4-2n)\, A_{\alpha\beta} + 2A_2\, E_9\, (D_{ab}\, A_{\alpha,\beta-1})]\, \frac{\partial f}{\partial A_{\alpha\beta}} = 0.$$

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On the Geometry Associated with Certain Determinants with Linear Elements

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1. INTRODUCTION. The types of forms expressible as determinants with linear elements have been determined by Dickson* whose results are given by the following theorem: "In the field of all complex numbers every binary form, every ternary form, every quaternary quadratic form and a sufficiently general quaternary cubic form can be expressed in determinantal form. No further general form has this property."

Similar results were obtained by Stouffer† by entirely different methods.

Let the determinantal form of the nth order in k variables

$$f = \begin{vmatrix} a_{11}x_1 + b_{11}x_2 + \cdots & \cdots & a_{1n}x_1 + b_{1n}x_2 + \cdots \\ \vdots & & \\ a_{n1}x_1 + b_{n1}x_2 + \cdots & \cdots & a_{nn}x_1 + b_{nn}x_2 + \cdots \end{vmatrix}$$

be changed by the transformation

$$\begin{aligned} x_1 &= \xi_{11}\,x'_1 + \xi_{12}\,x'_2 + \cdots \xi_{1k}\,x'_k \\ &\vdots \\ x_k &= \xi_{k1}\,x'_1 + \xi_{k2}\,x'_2 + \cdots \xi_{1k}\,x'_k \end{aligned} \qquad \Delta = \begin{vmatrix} \xi_{11} & \cdots & \xi_{1k} \\ \vdots & & \vdots \\ \xi_{k1} & \cdots & \xi_{kk} \end{vmatrix} \neq 0$$

into the determinantal form

$$F = \begin{vmatrix} A_{11}\,x'_1 + B_{11}\,x'_2 + \cdots & \cdots & A_{1n}\,x'_1 + B_{1n}\,x'_2 + \cdots \\ \vdots & & \\ A_{n1}\,x'_1 + B_{n1}\,x'_2 + \cdots & \cdots & A_{nn}\,x'_1 + B_{nn}\,x'_2 + \cdots \end{vmatrix}$$

in such a way that each element $a_{ii}\,x_1 + b_{ii}\,x_2 + \cdots$ is transformed into the element $A_{ii}\,x'_1 + B_{ii}\,x'_2 + \cdots$ Under the conditions of the transformation if any changes are made in the rows and columns of f

* Transactions of the American Mathematical Society, Vol. 22, (1921), pp. 167-179.
† *Ibid.*, Vol. 26, pp. 356-368.

similar changes must be made in the rows and columns of F. A function of the coefficients $a_{ij}, b_{ij}, c_{ij}, \ldots\ldots$ of f which is equal to the same function of the coefficients $A_{ij}, B_{ij}, C_{ij}, \ldots\ldots$ of F multiplied by a factor which is a power of the modulus λ shall in this paper be called an invariant of f. Similarly we shall define a covariant of f to be a function of the coefficients $a_{ij}, b_{ij}, \ldots\ldots$ and the variables $x_1, x_2, \ldots\ldots x_k$ of f which is equal to the same function of the coefficients $A_{ij}, B_{ij}, \ldots\ldots$ and variables $x'_1, x'_2, \ldots\ldots x'_k$ of F, except for a factor which is a power of the modulus λ.

If the elements of the determinantal form f be regarded as a set of n^2 simultaneous linear forms in k variables, the following theorems concerning the invariants and covariants of f may be stated at once since they are true of simultaneous linear forms:*

I. The resultant of any k elements of f is an invariant of f.

II. Every rational integral invariant of f is a homogeneous polynomial in the resultants of the n^2 linear elements taken k at a time.

III. Any element of f is a covariant of f.

IV. Every integral covariant of f is expressible in terms of the elements of f and the invariants of f.

There are an infinite number of different sets of linear elements for a given determinantal form. However, with a given set of linear elements there is only one determinant. It is the purpose of this paper to discuss the geometry of the lines obtained by equating to zero the linear elements of the determinantal forms of the second and third order in three variables. There is associated with the lines a plane curve, in the one case a conic, and in the other a cubic. We shall study the geometry of the lines by placing restrictions on the functions which we have called the invariants and covariants of f.

The covariants will be represented by

$$l_{ij} = a_{ij} x_1 + b_{ij} x_2 + c_{ij} x_3 \qquad (i, j = 1, 2, 3)$$

and the invariant

$$\begin{vmatrix} a_{pq} & a_{pq} & c_{pq} \\ a_{ij} & b_{ij} & c_{ij} \\ a_{rs} & b_{rs} & c_{rs} \end{vmatrix}$$

by $[pq, ij, rs]$. The point of intersection of two lines, for example, $l_{pq} = 0$ and $l_{ii} = 0$ will be indicated by the symbol (l_{pq}, l_{ii}).

2. SECOND ORDER FORMS. The equation

$$(1) \qquad \begin{vmatrix} l_{11} & l_{12} \\ l_{21} & l_{22} \end{vmatrix} = 0$$

* Clebsch, Crelle's Journal, Band 59, pp. 1-15.

represents a conic which is associated with the four lines of the determinantal form. The proofs of two well-known theorems follow immediately from this form of the equation of a conic.

Theorem I. Every conic may be generated by two projective pencils of lines.

In order to prove this let us note that equation (1) may be written in the form

$$(2) \qquad \begin{vmatrix} l_{11} + kl_{12} & l_{12} \\ l_{21} + kl_{22} & l_{22} \end{vmatrix} = 0$$

from which it is clear that every point which is a point of intersection of corresponding lines of the two pencils $l_{11} + kl_{12} = 0$ and $l_{21} + kl_{22} = 0$ satisfies the equation of the conic. Conversely, every point on the conic is the intersection of a corresponding pair of lines of the two pencils, a fact which is shown by the equations,

$$\frac{l_{11}}{l_{12}} = \frac{l_{21}}{l_{22}} = k.$$

Theorem II. Any point on the conic may be a vertex of one of the two pencils of lines generating the conic.

This theorem is readily proved by addition of the rows and columns of the determinantal form (1).

We shall consider only those restrictions on the invariants and covariants of the linear elements, which do not make the associated conic degenerate. The restrictions to be placed on the covariants may be divided into two main classes:

1. No covariant identically zero, and all covariants distinct.
2. No covariant identically zero, and two covariants, either l_{11} and l_{22}, or l_{12} and l_{21}, identical.

There are four invariants under the conditions of the first class. If any two of these invariants are zero, the lines pass through a point and the conic is degenerate. Hence we shall consider this class when, (*a*) no invariant is zero, and (*b*) only one invariant is zero.

In case (*a*), the four lines meet in six points, of which four, two on each line, lie on the associated conic.

In case (*b*), the four lines meet in four points, three of which are points on the associated conic. When $[22, 21, 12] = 0$, the line $l_{22} = 0$ is tangent to the conic at (l_{21}, l_{12}). To show this let us solve $l_{22} = 0$ for one variable, say x_1, and substitute into equation (1). Then (1) takes the form,

$$\begin{vmatrix} ax_2 + bx_3 & cx_2 + dx_3 \\ ex_2 + fx_3 & 0 \end{vmatrix} = 0.$$

The line $ex_2 + fx_3 = 0$ lies on the point (l_{12}, l_{21}) for it is the line of the pencil $l_{21} + kl_{22} = 0$ for which $k = -a_{21}/a_{22}$; also the line $cx_2 + dx_3 = 0$ must be on the point (l_{12}, l_{21}) for a similar reason. Since the lines $ex_2 + fx_3 = 0$ and $cx_2 + dx_3 = 0$ lie also on the point $(1, 0, 0)$, the equations differ at most by a numerical factor. Therefore $l_{22} = 0$ meets the conic in two coincident points at (l_{21}, l_{12}) and is a tangent to the conic.

In the second class, let $l_{12} \equiv l_{21}$. Then the line $l_{11} = 0$ is tangent to the associated conic at (l_{11}, l_{12}) and the line $l_{22} = 0$ is tangent at (l_{12}, l_{22}).

3. THIRD ORDER FORMS. In the study of the lines which result from equating to zero the linear elements of a third order determinant, we shall, as in the case of the second order consider only those arrangements of lines which do not make the associated cubic degenerate.

Every such determinantal form which has been equated to zero may by a combination of rows and columns be reduced to the form,

$$(3) \qquad \begin{vmatrix} l''_{11} & 0 & l''_{13} \\ l''_{21} & l''_{22} & 0 \\ 0 & l''_{32} & l''_{33} \end{vmatrix} = 0.$$

To prove this statement let A be a point on the cubic curve whose equation is

$$(4) \qquad \begin{vmatrix} l_{11} & l_{12} & l_{13} \\ l_{21} & l_{22} & l_{23} \\ l_{31} & l_{32} & l_{33} \end{vmatrix} = 0.$$

Evidently it is possible to determine numbers k_1, k_2, k_3, such that the lines $k_1 l_{21} + k_2 l_{22} + k_3 l_{23} = 0$ and $k_1 l_{11} + k_2 l_{12} + k_3 l_{13} = 0$ pass through A. The equation of the cubic can be written in the form

$$(5) \qquad \begin{vmatrix} l_{11} & l_{12} & k_1 l_{11} + k_2 l_{12} + k_3 l_{13} \\ l_{21} & l_{22} & k_1 l_{21} + k_2 l_{22} + k_3 l_{23} \\ l_{31} & l_{32} & k_1 l_{31} + k_2 l_{32} + k_3 l_{33} \end{vmatrix} = 0$$

from which we see that if A is chosen on the cubic in such a way that it is not on the conic

$$\begin{vmatrix} l_{11} & l_{12} \\ l_{21} & l_{22} \end{vmatrix} = 0$$

it lies on the line $k_1 l_{31} + k_2 l_{32} + k_3 l_{33} = 0$. Consequently there exist two numbers in h and r such that $h(k_1 l_{11} + k_2 l_{12} + k_3 l_{13}) + r(k_1 l_{31} + k_2 l_{32} + k_3 l_{33}) = k_1 l_{21} + k_2 l_{22} + k_3 l_{33}$. Then the determinantal form (4) may by a combination of rows and columns be reduced to the form

$$\begin{vmatrix} l'_{11} & l'_{12} & l'_{13} \\ l'_{21} & l'_{22} & 0 \\ l'_{31} & l'_{32} & l'_{33} \end{vmatrix} = 0$$

By a repetition of this process the determinantal form (4) can be reduced to the form (3).

Two well-known methods of generating a cubic curve result readily from a consideration of the determinantal form of the equation of a cubic curve.

Theorem III. A non-degenerate cubic curve is generated by three projective nets of lines.

By a method analogous to that used previously in showing that a conic is generated by two projective pencils of lines it may be shown that a cubic curve is generated by the three projective nets of lines

$$\begin{aligned} k_1 l_{11} + k_2 l_{12} + k_3 l_{13} &= 0 \\ k_1 l_{21} + k_2 l_{22} + k_3 l_{23} &= 0 \\ k_1 l_{31} + k_2 l_{32} + k_3 l_{33} &= 0 \end{aligned} \qquad (6)$$

or by the set obtained by adding the columns of the determinant.

This method of generating a cubic has been developed* by establishing a polarity in the plane such that to every point in the plane there correspond three polars, the intersections of which are points on the cubic curve. A similar development has been effected by employing skew reciprocity.†

Corollary. Every non-degenerate cubic curve is generated by three pencils of lines which are related in the following way:

$$\begin{aligned} k_1 l_{11} + k_3 l_{13} &= 0 \\ k_1 l_{21} + k_2 l_{22} &= 0 \\ k_2 l_{32} + k_3 l_{33} &= 0 \end{aligned} \qquad (7)$$

This corollary follows from the fact that if the cubic (4) is written in the form (3), equations (6) reduce to equations (7).

Theorem IV. Every non-degenerate cubic curve is generated by a pencil of lines and a projective pencil of conics.‡

In order to prove this we shall use the form of the equation of the

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* Schroeter, Ebenen Curven Dritter Ordnung, § 2, p. 4.

† White, Plane Cubic Curves, pp. 98-100.

‡ Chasles, Rapport Sur Les Progres de la Geometrie, p. 224.

cubic in which one element of the determinant is zero. This equation may be written in the form

$$\begin{vmatrix} l_{11} & l_{12} + kl_{13} & l_{13} \\ l_{21} & l_{22} + kl_{23} & l_{23} \\ 0 & l_{32} + kl_{33} & l_{33} \end{vmatrix} = 0$$

which may be expanded into

$$(8)\quad (l_{32} + l_{33}) \begin{vmatrix} l_{11} & l_{13} \\ l_{21} & l_{23} \end{vmatrix} - l_{33} \left\{ \begin{vmatrix} l_{11} & l_{12} \\ l_{21} & l_{22} \end{vmatrix} + k \begin{vmatrix} l_{11} & l_{13} \\ l_{21} & l_{23} \end{vmatrix} \right\} = 0.$$

It is clear from the form of equation (8) that every point of intersection of a line of the pencil of lines $l_{32} + kl_{33} = 0$ with the corresponding conic of the pencil of conics

$$\begin{vmatrix} l_{11} & l_{12} \\ l_{21} & l_{22} \end{vmatrix} + k \begin{vmatrix} l_{11} & l_{13} \\ l_{21} & l_{23} \end{vmatrix} = 0$$

is a point on the cubic curve. Conversely, every point on the cubic is a point of intersection of a line of this pencil with the corresponding line from the pencil of conics; for, from the equations of the two pencils, we have the equations

$$\frac{l_{32}}{l_{33}} = \frac{\begin{vmatrix} l_{11} & l_{12} \\ l_{21} & l_{22} \end{vmatrix}}{\begin{vmatrix} l_{11} & l_{13} \\ l_{21} & l_{23} \end{vmatrix}} = k$$

which makes it evident that every point on the cubic curve determines a value of k.

We shall study the geometry of the lines obtained by equating to zero the elements of the determinantal form (3) in which three covariants were identically zero. All covariants which are not subjected to restrictions are assumed to be distinct. The covariants which are said to be identical may differ by a numerical factor so that the equation of the cubic is changed although the lines remain the same. Consequently there is associated with any one arrangement of lines a system of cubic curves, *i. e.*, all the cubic curves through the nine points of intersection of the six lines. The restrictions which may be placed on the remaining covariants fall into the following five classes:*

I. The six covariants distinct.

II. Two covariants, not in the same row or column, identical.

* Salmon, Higher Plane Curves, 2d edition, pp. 127-130.

III. Three covariants, no two in the same row or column, identical.

IV. Two sets of two identical covariants, no identical covariants in the same row or column.

V. Two sets of identical covariants, one set containing two covariants, and the other three covariants, but no covariants in the same row or column identical.

In the determinantal form (3) there are twenty invariants which are not necessarily zero. They may be grouped in the following way: the one invariant $\alpha = [11, 22, 23]$, the one invariant $\beta = [12, 21, 23]$, the nine invariants $[ii, jj, mn]$, and the nine invariants $[mn, pq, ii]$. In the last two groups ii and jj mean any pair of subscripts of l_{11}, l_{22}, or l_{33} and mn and pq mean any pair of subscripts of l_{13}, l_{21}, or l_{32}. In what follows we shall have occasion to consider various sets of invariants. In a given set, a pair of letters which appears in the symbol for one invariant represents the same pair of subscripts in all other invariants. This statement has no meaning with respect to the invariants α and β.

If an invariant involving one set of subscripts from α (or β) and two from β (or α) is equated to zero, the line in whose equation appears the set from α (or β) is tangent to the associated cubic curve at the point in which the three lines meet, provided the three lines only meet in this point; *e. g.*, if $[ii, jj, mn] = 0$ then $l_{mn} = 0$ is tangent to the cubic curve at (l_{ii}, l_{jj}). This, and similar statements made in what follows, may be proved by the methods used in the second part of this paper.

If two lines in whose equations appear subscripts from α (or β) coincide, then all lines in whose equations appear subscripts from β (or α) are tangents to the cubic curve at their intersections with the coincident lines, provided the two lines only meet in this point. If a line in whose equation appear subscripts from α (or β) passes through the intersection of the three lines in whose equations appear subscripts from β (or α) then the line is a tangent to the associated cubic curve at a point of inflection. If three lines in whose equations appear subscripts from α (or β) coincide then all lines in whose equations appear subscripts from β (or α) are inflection tangents at their intersections with this line. If two lines in whose equations appear subscripts from α (or β) pass through the intersection of two, or three, lines (whether distinct or coincident) in whose equations appear subscripts from β (or α) the point of intersection is a double point.

In the accompanying table the information obtained concerning the different cases which arise under the five classes is listed as follows:

1. The invariants which are set equal to zero.
2. The number of distinct points of intersection of the line.
3. The number of intersections of the lines which are also points on the associated cubic curve.
4. The number of intersections of the lines which are also points of tangency on the associated cubic curve.
5. The number of intersections of the lines which are points of inflection on the cubic curve.
6. The equations of the tangents at the double points and the equation in k whose roots are the values of the parameter k which make the lines tangents. The double point will be a crunode, cusp, or acnode according as the roots of the equation in k are real and unequal, real and equal, or imaginary.

(References to articles discussing special cubic curves are given at the end of the table.)

CLASS I. $l_{12} = 0$, $l_{23} = 0$, $l_{31} = 0$.

1	2	3	4	5	6
(1) None	15	9			
α or β	13	9			
[ii, jj, pq] or [mn, pq, ii]	13	8	1		
α and β	11	9			
α and [mn, pq, ii] or β and [ii, jj, mn]	11	8	1		
[ii, jj, pq] and [tt, mn, rs]; or [ii, jj, pq] and any one of [ii, mn, rs], [jj, mn, rs], or [mn, pq, tt]; or [ii, jj, pq] and either [ii, tt, mn] or [jj, tt, mn]; or [mn, pq, ii] and either [pq, rs, jj] or [mn, rs, jj]	11	7	2		

α and [ii, jj, pq] or β and [mn, pq, ii]	10	7		1	
[ii, jj, pq] and [mn, ii, pq]	10	6			$l_{mn} + kl_{jj} = 0$; k^2 [jj, rs, pq] + k ([mn, rs, pq] + [jj, ii, tt]) + [mn, ii, tt] = 0
α, [mn, pq, ii] and [pq, rs, jj] or β, [ii, jj, pq] and [ii, tt, rs]	9	7		2	
[ii, jj, pq], [ii, mn, rs] and any one of [tt, mn, pq], [tt, pq, rs], [tt, jj, mn], or [tt, jj, rs]; or [ii, jj, pq], [jj, mn, rs], and any one of [tt, pq, mn]; [tt, pq, rs], [tt, ii, mn], or [tt, ii, rs]; or [ii, jj, mn], [ii, tt, pq], and [jj, tt, rs]; or [mn, pq, ii], [pq, rs, jj] and [mn, rs, tt]	9	6	3		
α, [mn, pq, ii] and [pq, rs, ii] or β, [ii, jj, pq] and [ii, tt, rs]	8	7		1	
[ii, jj, pq], [tt, mn, rs] and [tt, mn, pq]; or [ii, mn, pq], [jj, tt, rs] and [jj, tt, ii]	8	6	1	1	
[ii, jj, pq], [ii, jj, mn] and any one of [tt, rs, ii], [tt, rs, jj], [tt, rs, pq], [tt, rs, mn]	8	5	1		$l_{mn} + kl_{jj} = 0$; k^2 [jj, rs, pq] + k([mn, rs, pq] + [jj, ii, tt]) + [mn, ii, tt] = 0
α, [jj, ii, pq] and [ii, jj, mn] or β, [ii, pq, mn] and [jj, pq, mn]	6	4			$l_{pq} = 0$ and $l_{mn} = 0$. (For first set) $l_{ii} = 0$ and $l_{jj} = 0$. (For second set)
[pq, mn, rs] [ii, jj, pq] [jj, tt, mn] [tt, ii, rs]	7	6	3		
(2) [ii, jj, pq] [ii, tt, mn] [rs, mn, jj] [pq, rs, tt]	7	5	4		

CLASS II. $l_{12} \equiv 0$, $l_{23} \equiv 0$, $l_{31} \equiv 0$, and $l_{22} \equiv l_{33}$.

1	2	3	4	5	6
(3) None	10	6	3		
β	8	6	3		
[11, pq, rs]	8	5	4		
[11, 33, pq]	8	5	2	1	
[33, pq, mn]	8	5	1		$l_{mn} + kl_{33} = 0$; k^2 [rs, 33, pq] + k [rs, mn, pq] + [11, 33, mn] = 0
β and [11, 33, pq]	6	5	2	1	
[11, 33, pq] and [mn, rs, 11]	6	4	3	1	
[pq, mn, 33] and either [rs, pq, 11] or [rs, mn, 11]	6	4	2		$l_{mn} + kl_{33} = 0$; k^2 [rs, 33, pq] + k [rs, mn, pq] + [11, 33, mn] = 0
[33, mn, pq] and [11, 33, rs]	6	4		1	$l_{mn} + kl_{33} = 0$; k^2 [rs, 33, pq] + k [rs, mn, pq] + [11, 33, mn] = 0
β and [11, mn, pq]	5	4	3	1	
β and [33, mn, pq]	5	4			$l_{33} = 0$; [11, 33, mn] = 0 or $k = \infty$ in $l_{mn} + kl_{33} = 0$
[11, 33, pq] and [11, mn, pq]	5	3	1		$l_{pq} = 0$ and $l_{mn} = 0$.

CLASS III. $l_{12}\equiv 0$, $l_{23}\equiv 0$, $l_{31}\equiv 0$ and $l_{11}\equiv l_{22}\equiv l_{33}$.

1	2	3	4	5	6
(3) None	6	3		3	
β	4	3		3	
[11, mn, pq]	4	2		1	$l_{pq}=0$ and $l_{mn}=0$

CLASS IV. $l_{12}\equiv 0$, $l_{23}\equiv 0$, $l_{31}\equiv 0$ and $l_{11}\equiv l_{22}$ and $l_{13}\equiv l_{21}$.

1	2	3	4	5	6
(3) None	6	4	2		$l_{21}+kl_{22}=0$; k^2 [32, 21, 11] + [33, 21, 11] = 0
[11, 32, 33] or [21, 32, 33]	4	3	1	1	$l_{21}+kl_{22}=0$; k^2 [32, 21, 11] + [33, 21, 11] = 0
[11, 21, 33] or [11, 21, 32]	4	3	1		$l_{21}=0$.

CLASS V. $l_{12}\equiv 0$, $l_{23}\equiv 0$, $l_{31}\equiv 0$, $l_{11}\equiv l_{22}$ and $l_{11}\equiv l_{22}\equiv l_{33}$.

1	2	3	4	5	6
(4) None	3	2		1	$l_{21}=0$.

(1) Salmon, loc. cit.
(2) Wehr, Monatschefte für Mathematik und Physik, Band IV, (1893), p. 154.
(3) Salmon, loc. cit.
(4) Durege, Mathematische Annalen, Band 1, (1869), pp. 509-512.

4. FORMS OF HIGHER ORDER. Two of the theorems given in the second part of this paper may be extended at once to curves of order n.

Theorem V. Every plane curve of order n may be generated by a pencil of lines and a projective pencil of curves of order $n-1$.

Dickson* has shown that every plane curve may be written in the form

$$(9)\qquad \begin{vmatrix} x_1+a_{11}x_2+b_{11}x_3 & b_{12}x_3 & \cdots & b_{1n}x_3 \\ x_3 & x_1+a_{22}x_2+b_{22}x_3 & \cdots & b_{2n}x_3 \\ 0 & x_3 & & b_{3n}x_3 \\ \vdots & \vdots & & \vdots \\ 0 & 0 & & x_1+a_{nn}x_2+b_{nn}x_3 \end{vmatrix} = 0.$$

If we multiply the nth column of equation (9) by k and add to the n–1st column, we obtain the equation

$$\begin{vmatrix} x_1+a_{11}x_2+b_{11}x_3 & b_{12}x_3 \cdots\cdots & b_{1,n-1}x_3+kb_{1n}x_3 & b_{1n}x_3 \\ x_3 & x_1+a_{11}x_2+b_{22}x_3 \cdots & b_{2,n-1}x_3+kb_{2n}x_3 & b_{2n}x_3 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & x_1+a_{n-1,n-1}x_2+b_{n-1,n-1}x_3+kb_{n-1,n}x_3 & b_{n-1,n}x_3 \\ 0 & 0 & x_3+k(x_1+a_{nn}x_2+b_{nn}x_3) & x_1+a_{nn}x_2+b_{nn}x_3 \end{vmatrix} = 0,$$

which may be expanded into

* Loc. cit.

$$(10)\qquad [x_3 + k\,(x_1 + a_{nn}\,x_2 + b_{nn}\,x_3)]\begin{vmatrix} l_{11} & \dots & b_{1,n-2}\,x_3 & b_{1n}\,x_3 \\ x_3 & \dots & b_{2,n-2}\,x_3 & b_{2n}\,x_3 \\ 0 & \dots & b_{3,n-2}\,x_3 & b_{3n}\,x_3 \\ \vdots & & \vdots & \vdots \\ 0 & \dots & x_3 & b_{n-1,n}\,x_3 \end{vmatrix} +$$

$$(x_1 + a_{nn}\,x_2 + b_{nn}\,x_3)\left\{\begin{vmatrix} l_{11} & \dots\dots\dots\dots & b_{1,n-1}\,x_3 \\ x_3 & \dots\dots\dots\dots & b_{2,n-1}\,x_3 \\ \vdots & & \vdots \\ 0 & \dots & x_1 + a_{n-1,n-1}\,x_2 + b_{n-1,n-1}\,x_3 \end{vmatrix} + k\begin{vmatrix} l_{11} & \dots & b_{1,n-2}\,x_3 & b_{1n}\,x_3 \\ x_3 & \dots & b_{2,n-1}\,x_3 & b_{2n}\,x_3 \\ \vdots & & & \vdots \\ 0 & \dots & x_3 & b_{n-1,n}\,x_3 \end{vmatrix}\right\} = 0$$

From the form of equation (10) it is clear that every point of intersection of the pencil of lines

$$x_3 + k\,(x_1 + a_{nn}\,x_2 + b_{nn}\,x_3) = 0$$

with the corresponding curve of order $n-1$ from the projective pencil of curves

$$\begin{vmatrix} l_{11} & \dots\dots\dots & b_{1,n-1}\,x_3 \\ x_3 & \dots\dots\dots & b_{2,n-1}\,x_3 \\ \vdots & & \vdots \\ 0 & \dots & x_1 + a_{n-1,n-1}\,x_2 + b_{n-1,n-1}\,x_3 \end{vmatrix} + k\begin{vmatrix} l_{11} & \dots\dots & b_{1,n-2}\,x_3 & b_{1n}\,x_3 \\ x_3 & \dots\dots & b_{2,n-2}\,x_3 & b_{2n}\,x_3 \\ \vdots & & \vdots & \vdots \\ 0 & \dots\dots & x_3 & b_{n-1,n}\,x_3 \end{vmatrix} = 0$$

is a point on the plane curve of order n. Conversely, for every point on the curve of order n, there is a value of k determined by the equations

$$\frac{x_3}{(x_1 + a_{nn} x_2 + b_{nn} x_3)} = \frac{\begin{vmatrix} l_{11} & \dots\dots\dots\dots\dots & b_{1,n-1} x_3 \\ x_3 & \dots\dots\dots\dots\dots & b_{2,n-1} x_3 \\ \vdots & & \vdots \\ 0 & \dots\dots x_1 + a_{n-1,n-1} x_2 & + b_{n-1,n-1} x_3 \end{vmatrix}}{\begin{vmatrix} l_{11} & \dots\dots & b_{1,n-2} x_3 & b_{1n} x_3 \\ x_3 & \dots\dots & b_{2,n-2} x_3 & b_{2n} x_3 \\ \vdots & & \vdots & \vdots \\ 0 & \dots\dots & x_3 & b_{n-1,n} x_3 \end{vmatrix}} = k.$$

Theorem VI. Every plane curve of order n may be generated by a pencil of conics and a projective pencil of curves of order n–2.

Equation (9) may be written in the form

$$\begin{vmatrix} x_1 + a_{11} x_1 + b_{11} x_2 & \dots & b_{1,n-2} x_3 + k l_{1n} & 0 & l_{1n} \\ x_3 & \dots & b_{2,n-2} x_3 + k l_{2n} & 0 & l_{2n} \\ 0 & \dots & b_{3,n-2} x_3 + k l_{3n} & 0 & l_{3n} \\ \vdots & & \vdots & \vdots & \vdots \\ 0 & \dots & x_3 + k b_{n-1,n} x_3 & x_1 + a_{n-1,n-1} x_2 + b_{n-1,n-1} x_3 & b_{n-1,n} x_3 \\ 0 & \dots & k(x_1 + a_{nn} x_2 + b_{nn} x_3) & x_3 & x_1 + a_{nn} x_2 + b_{nn} x_3 \end{vmatrix} = 0.$$

which may be expanded into

$$
\left\{\begin{vmatrix} l_{11} & \dots & b_{1,n-2}\,x_3 \\ x_3 & \dots & b_{2,n-2}\,x_3 \\ \vdots & & \vdots \\ 0 & \dots & b_{n-2,n-2}\,x_3 \end{vmatrix} + k \begin{vmatrix} l_{11} & \dots & b_{1,n-3}\,x_3 & l_{1n} \\ x_3 & \dots & b_{2,n-3}\,x_3 & l_{2n} \\ \vdots & & \vdots & \vdots \\ 0 & \dots & 0 & l_{n-2,n} \end{vmatrix}\right\} \begin{vmatrix} l_{n-1,n-1} & b_{n-1,n}\,x_3 \\ x_3 & l_{nn} \end{vmatrix} +
$$

(11)

$$
\begin{vmatrix} l_{11} & b_{1,n-3}\,x_3 & l_{1n} \\ x_3 & b_{2,n-3}\,x_3 & l_{2n} \\ 0 & x_3 & l_{n-2,n} \end{vmatrix} \left\{\begin{vmatrix} x_3 & l_{n-1,n-1} \\ 0 & x_3 \end{vmatrix} + k \begin{vmatrix} b_{n-1,n}\,x_3 & l_{n-1,n-1} \\ l_{nn} & x_3 \end{vmatrix}\right\} = 0.
$$

From the form of equation (11) we see that every point of intersection of a conic from the pencil of conics

$$
\begin{vmatrix} x_3 & l_{n-1,n-1} \\ 0 & x_3 \end{vmatrix} + k \begin{vmatrix} b_{n-1,n}\,x_3 & l_{n-1,n-1} \\ l_{nn} & x_3 \end{vmatrix} = 0
$$

with the corresponding curve of order $n-2$ from the pencil of curves

$$
\begin{vmatrix} l_{11} & \dots & b_{1,n-2}\,x_3 \\ x_3 & \dots & b_{2,n-2}\,x_3 \\ \vdots & & \vdots \\ 0 & \dots & b_{n-2,n-2}\,x_3 \end{vmatrix} + k \begin{vmatrix} l_{11} & \dots & b_{1,n-3}\,x_3 & l_{1n} \\ x_3 & \dots & b_{2,n-3}\,x_3 & l_{2n} \\ \vdots & & \vdots & \vdots \\ 0 & \dots & 0 & l_{n-2,n} \end{vmatrix} = 0
$$

is a point on the curve of order n. Conversely, every point on this curve determines a value of k, since

$$\frac{\begin{vmatrix} x_3 & l_{n-1,n-1} \\ 0 & x_3 \end{vmatrix}}{\begin{vmatrix} b_{n-1,n}\,x_3 & l_{n-1,n-1} \\ l_{nn} & x_3 \end{vmatrix}} = \frac{\begin{vmatrix} l_{11} & \ldots\ldots & b_{1,n-2}\,x_3 \\ x_3 & \ldots\ldots & b_{2,n-2}\,x_3 \\ & & \\ 0 & \ldots\ldots & b_{n-2,n-2}\,x_3 \end{vmatrix}}{\begin{vmatrix} l_{11} & \ldots\ldots & b_{1,n-3}\,x_3 & l_{1n} \\ x_3 & \ldots\ldots & b_{2,n-3}\,x_3 & l_{2n} \\ & & & \\ 0 & \ldots\ldots & 0 & l_{n-2,n} \end{vmatrix}} = k.$$

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An Irreversible Hydrocarbon Cell

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INTRODUCTION AND STATEMENT OF THE PROBLEM

SINCE the advent of Arrhenius' theory of electrolytic dissociation and the subsequent tendency to explain all possible phenomena as ionic, the whole subject of voltaic cells has become hopelessly involved with reactions among ions. Contemporary textbooks of electrochemistry contain, for example, such statements as these:

1. Allmand: Principles of Applied Electrochemistry, p. 87.
Edward Arnold, London, 1920.

"For a chemical reaction to be carried out electrochemically, it must be of an oxidation-reduction nature, the substances taking part must be capable of ionization, and must be spatially separated, but in electrical connection."

2. LeBlanc: A Textbook of Electrochemistry, p. 261.
Macmillan, New York, 1907.

"It has been seen that in all galvanic cells a reduction and oxidation take place; that is, at one electrode ions come into existence, and at the other ions disappear. (And in italics) . . . a chemical reaction between two substances can only be used as a source of electrical energy when electricity is produced or disappears during the reaction (*i. e.,* by changes in the charges of ions), and also when the two substances separated from each other are still capable of undergoing this reaction."

3. Creighton and Fink: Electrochemistry, Vol. I, p. 160.
Wiley and Sons, New York, 1924.

"If a voltaic cell is to produce a continuous current it is essential that positive ions enter solution, and simultaneously, an equivalent quantity of negative ions leave solution."

* From a thesis submitted by Selma Gottlieb to the Faculty of the Graduate School of the University of Kansas in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Our ordinary conception of reactions at the electrodes accords with these statements, and is that at the anode, for example, we may have: (1) discharge of an anion, (2) formation of a cation, (3) increase of positive charges on a cation, (4) decrease of negative charges on an anion, (5) or formation of a complex anion. We may, nevertheless, define voltaic cells as devices for the conversion of free chemical energy into electrical, made up of spontaneously and simultaneously occurring oxidation and reduction reactions which are capable of taking place at two different points and with a decrease in free energy. In the light of this definition it is apparent that the chemical phenomena capable of producing potential differences in a voltaic cell need not be limited to ionic reactions. A difference of potential is produced whenever an electrode takes up or gives off electrons, regardless of the cause. The transfer of electrons may be due to ionic reactions, but it may also be due to any other chemical reaction involving electron change, whether it concerns ions or not. We have, for instance, the entire field of organic chemistry with such reactions occurring among compounds which we certainly cannot consider as ionizing in the usual sense of the word. From theoretical considerations there is no reason why these organic oxidations and reductions cannot be made to fulfill the general conditions for a voltaic cell as stated above, since, after all, the essential feature of all oxidation-reduction reactions is electron change. In such a cell, oxidation and reduction at the electrodes would involve only electronic changes not directly concerned with the formation, discharge, or change of valence of an ion.

For such a purpose, easily oxidizable or easily reducible compounds would naturally be considered first. In this class come the unsaturated aliphatic hydrocarbons, which are particularly advantageous because of their active double and triple bonds and because of the gaseous nature of the lower members of both the acetylene and olefine series. In this work, therefore, acetylene and ethylene were used, in a cell constructed much like the usual hydrogen gas cell.

EXPERIMENTAL WORK

The ethylene used was the commercial gas obtained in metal cylinders, but the acetylene was prepared as needed by dropping lumps of commercial calcium carbide into water, thus reversing the usual process. This was accomplished by using a ten liter bottle which was closed at the top with a rubber stopper carrying a glass stopcock, and which had at the bottom another vent similarly closed.

The bottle was completely filled with water and tilted in a sink at an angle of about thirty degrees with the vertical. The stopper at the bottom was then carefully removed without allowing air to enter, lumps of calcium carbide about 1.5 cm. in diameter were dropped into the bottle at a convenient rate, and the displaced water was allowed to escape, also through the lower opening.

The electrolyte used was a molar solution of potassium chloride made by dissolved the carefully dried salt in freshly boiled and cooled distilled water. A normal calomel electrode was used rather than a saturated one in order to avoid errors due to liquid junction potentials.

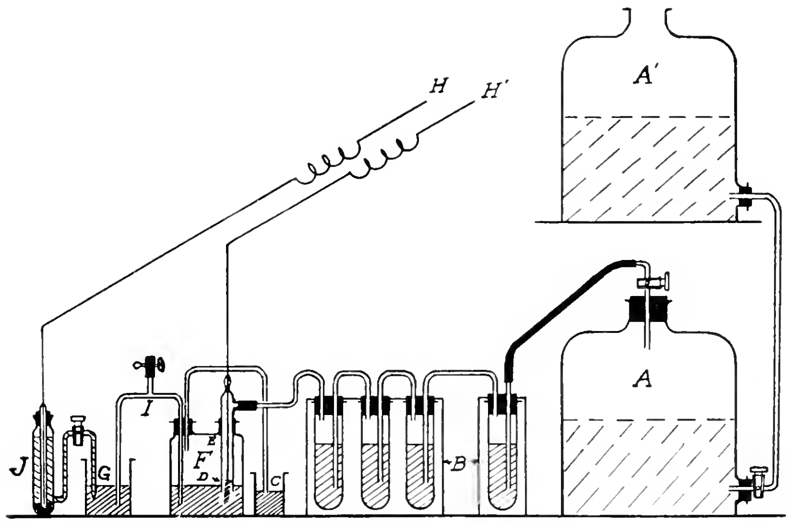

FIG. 1. Acetylene side of hydrocarbon cell.

Figure 1 shows the acetylene side of the cell; the ethylene side differed only in that the source of gas supply was a metal cylinder. The acetylene was stored in the tubulated bottle, *A*, and forced through the cell by displacing it with water flowing from a similar bottle, *A′*, placed on an elevated shelf. The first of the scrubbers, *B*, contained acid dichromate solution, the next two, 10% sodium hydroxide solution, and the last, distilled water. The electrode vessel, *E*, carrying the electrode, *D*, was supported in one neck of the Woulff bottle, *F*, from the other neck of which the salt bridge, *I*, passed to the small beaker, *G*. The calomel electrode vessel, *J*, and the salt bridge from the ethylene side of the cell also dipped into this same beaker. The beaker, *C*, served as a water trap. Connection with the electrical measuring part of the apparatus was made at *H* and *H′*.

In this cell, one Woulff bottle would have served to hold both electrodes, but it seemed desirable to avoid, in as far as possible, diffusion of gases from one electrode to the other. Because of this, each electrode had its own Woulff bottle, and the two electrodes were further separated by a small beaker of potassium chloride solution placed between the two Woulff bottles. Connection was made by salt bridges of the form shown in the figure; the electrolyte was drawn into them and held by pinchcocks on the rubber tubing. When a calomel half-cell was used, it was arranged to dip into the small beaker, *G*, and was thus presumably not contaminated by diffusion of gases from either electrode.

This apparatus was at best not air-tight although air could not pass into the electrode jacket. When the openings were sealed any differences in gas pressure between the two sides forced electrolyte from one Woulff bottle into the other, sometimes even separating one of the electrodes from contact with the electrolyte. The water traps were used to prevent diffusion of air through the gas escapement tubes.

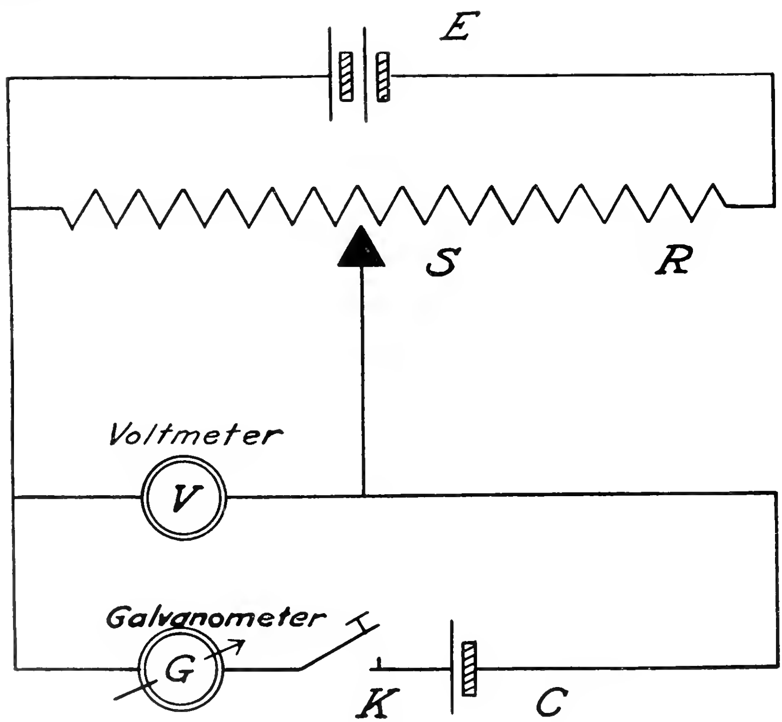

FIG. 2. Diagram of testing circuits.

Since the reproducibility of the measurements did not justify the use of a potentiometer, a simpler type of apparatus was subsituted. As shown in figure 2, the slide, S, on the resistance coil, *R*, was moved until the galvanometer, *G*, gave no deflection when the key, *K*, was depressed, showing that the electromotive force being produced in the arm containing the unknown cell, *C*, was just equal to that being shunted off the pair of dry cells, *E*, in the upper arm of the circuit. The voltage was then read directly on the voltmeter, *V*. While this is essential a potentiometric method, it does not, of course, possess the accuracy and refinement of the more delicate and more complicated apparatus.

MEASUREMENTS WITH NICKEL ELECTRODES

In the choice of electrodes, attention was naturally directed to those metals which have been found particularly useful in reactions among gases. The first work was therefore done with nickel electrodes, which always gave an electromotive force, though unfortunately not a reproducible one. It was later noted that the nickel was being slowly attacked by the potassium chloride used as electrolyte, so slowly that the effects were not visible during the time occupied by a single set of measurements, but when the electrodes were allowed to remain overnight in the electrolyte, a greenish gelatinous precipitate was present next morning. It seems rather unlikely, however, that this corrosion could have been responsible for all the difference of potential observed. A one to ten ratio of nickel ion concentrations on the two sides would account for a difference of potential of only 0.029 volt, and it seems almost inconceivable that the two gases could have been influenced the rates of attack by the potassium chloride solution to such an extent that the ratio of nickel ion concentrations on the two sides could have approached 1 to 1×10^{10}, as would be necessary to account for the difference of potential observed.

The nickel electrodes were made by wrapping nickel gauze around a wire of the same metal to make a roll about four cm. long and one cm. in diameter, and bending an end of the wire up to hold the gauze in place. The gauze rolls were corroded by dipping them into concentrated nitric acid for a moment; the green coating of nickel nitrate thus produced was converted into the oxide by heating to redness in a Bunsen flame. The oxide was then reduced by heating in a stream of hydrogen gas, and the reduced electrodes were cooled in a stream of natural gas to prevent, in as far as possible, the adsorption of hydrogen. Since this treatment was repeated for each determination, there was always present a coating of freshly reduced nickel with a fairly large surface. With these electrodes, the readings on fifteen determinations ranged between 0.07 and 0.24 volt, with six of the fifteen values lying between 0.22 and 0.24 volt. The acetylene electrode was in every case positive to the ethylene electrode.

MEASUREMENTS WITH MISCELLANEOUS ELECTRODES

Before proceeding to a discussion of the results with platinum electrodes, it may be well to mention the work done with a variety of other substances as electrodes.

Copper electrodes were prepared by heating to redness coils of copper gauze attached to a copper wire, plunging them immediately into alcohol, and washing them in water. When these were used in the ethylene-acetylene cell, the electromotive force produced was so small that the galvanometer gave no noticeable deflection until the cell was short-circuited through it. If the electromotive force produced with nickel electrodes is to be considered due to reactions between the gases and the metal, a difference of potential should certainly be expected in the case of the copper electrodes, due to the formation of small amounts of copper acetylide.

No electromotive force was produced when the electrodes were of gold foil with a surface freshly plated from a gold cyanide solution. This inertness of the gold electrodes is of interest in connection with the later work in which platinum black was deposited on a piece of platinum foil freshly coated electrolytically with a layer of gold.

Electrodes of tungsten, iron, tin, zinc, lead, cadmium, silver and carbon were inert or practically so in this cell. Aluminum electrodes gave potentials ranging from 0.13 to 0.20 volt, but the metal was apparently being attacked by the electrolyte.

Palladium was used both in the massive form and as palladium black plated electrolytically on the smooth surface. The massive form gave an electromotive force of 0.10 volt, with the acetylene positive, but the rise to this value was very slow. The palladium black gave values ranging from 0.15 to 0.30 volt, with the acetylene positive as before.

MEASUREMENTS WITH PLATINUM ELECTRODES

Platinum black electrodes were used in a large series of experiments whose results, although not satisfactorily reproducible, are more reliable than those made with nickel, in that the platinum may safely be considered as inert. These experiments may be divided into two groups: those made with the platinum black deposited directly on platinum foil electrodes in the usual manner, and those in which a layer of gold was interposed between the foil and the deposit. With the ordinary type of platinum black electrode, equilibrium is delayed by the fact that it must be established throughout the whole mass of platinum, including the supporting foil. With the interposition of the layer of gold, the attainment of equilibrium is hastened, since the gold serves only as an electrical conductor and does not otherwise enter into the reaction.

The gold deposit, when used, was plated from a solution containing one gram of $AuCl_3$ and two grams of KCN in 65 cc. of water. A good gold deposit was obtained only when the voltage and current density were very low; otherwise there appeared a coppery film which was not adherent.

In the first experiments, the piece of platinum foil, about 1 cm. square, was welded to a short platinum wire, which was then sealed into a piece of glass tubing. Electrical connection was made by means of a copper wire dipping into mercury in the tube. It was later considered advisable to remove any suspicion of mercury contamination of the electrodes by welding the platinum wire directly to the copper wire, thus making it possible to omit the mercury from the connection. The glass tube was of course retained for protection.

When the layer of gold was not used in preparing the platinum black electrodes, the potentials showed a marked tendency to drift, equilibrium was reached only very slowly, and attainment of the true maximum value was very uncertain. The potentials on six determinations varied from 0.19 to 0.285 volt, with the ethylene electrode positive. These values were reached in from 32 to 107 minutes.

Even when the layer of gold was interposed between the platinum foil and the coating of platinum black it was not possible to duplicate results satisfactorily, but the attainment of equilibrium was usually much more rapid. In a total of thirty-two determinations, the potentials varied from 0.20 volt with the acetylene positive to 0.52 volt with the acetylene negative. However, the ethylene was positive in twenty-four of the measurements, or 75%, and the other 25% included most of the occasions when difficulty was experienced in getting a satisfactory coating of platinum black on the electrodes.

Believing the fault to lie with the electrodes, they were introduced into the following cell,

(—)		(+)	
Pt black on Au	0.1 M-HCl H_2	M-KCl HgCl	Hg,

for which Lewis, Brighton and Sebastian* give a value of 0.3182 volt at 20° C. with a pressure of one atmosphere, using iridium electrodes instead of platinum. Since the iridium is here an inert electrode, the same value should be obtained with the inert platinum electrodes used in this work, if they were functioning properly. On eight trials, very good agreement was found with this value, using both platinum electrodes in each trial. When used in the ethylene-acetylene cell immediately after these satisfactory measurements, the electrodes gave no better results than on other occasions. Of course it is entirely conceivable that the electrodes, although in condition to catalyze the reaction, $H_2 - 2\ (-) = \text{or} \rightarrow 2H^+$, might still not be active for the reactions in which the ethylene and acetylene were involved.

In the ordinary type of voltaic cell, such as the Daniell cell, the products of the reactions are present at the start. In the case of the gas cell, the products were not known, and since they were being formed only in minute quantities during the brief time when the circuit was closed, it was impossible to determine what they were. Without any clues as to their nature, a few empirical attempts were made to find them by noting the results of adding various organic compounds to the potassium chloride electrolyte.

If we could assume that at the cathode, acetylene was being reduced to ethylene, and that at the anode, ethylene was being oxidized to acetylene, the process would be that of a concentration cell. With this thought in mind, in spite of the fact that the sign of the potential difference in 75% of the cases did not support this view, mixtures were made of one volume of ethylene to nine of acetylene and vice versa. Using these mixtures instead of the pure gases, the difference of potential was 0.05 volt, with the positive pole that concentrated with respect to the ethylene. This value, although by no means proof of the nature of the cell, is of the order of magnitude which a concentration cell would give with these concentration ratios.

An electrolyte was prepared which was molar with respect to both potassium chloride and ethyl alcohol. (It was necessary to introduce the test substance into both sides of the cell in order to avoid discrepancies on that score.) The cell in which this electrolyte was used gave an electromotive force of only 0.04 volt on one trial, but on a later attempt yielded 0.40 volt after the passage of five hours, with the acetylene positive. Still a third measurement gave only

* Jour. Amer. Chem. Soc., 39, 2245 (1917).

0.10 volt with the acetylene positive again. Results were no more satisfactory when the electrolyte was saturated with ether.

As routinely prepared, the electrodes were cleaned immediately before use by running them as cathodes in dilute sulfuric acid, and as a consequence were saturated with hydrogen. There was always then the possibility that one of the gases being passed over the platinum black displaced hydrogen from it to a greater extent than did the other, and that, as a result, the measurements actually represented a hydrogen gas concentration cell. In refutation of this, it can be stated that experiment showed the ethylene-acetylene cell to have so small a temperature coefficient that the potential was not appreciably changed even when the system was brought from room temperature to nearly 0° C. In an attempt to minimize the interference of adsorbed hydrogen, determinations were made with electrodes which had been prepared as usual but, before use, boiled in water at about 40° C. under reduced pressure to remove as much of the hydrogen as possible. Ethylene or acetylene was passed around the electrode during the process to saturate the platinum black with the gas with which it was to be used. When the electrodes were allowed to stand overnight after the dehydrogenation, the difference of potential resulting on two occasions was 0.075 and 0.115 volt with the ethylene positive. When used immediately after the dehydrogenation, the value was 0.11 volt with the ethylene negative.

Since oxygen is adsorbed by platinum black to a much less extent than is hydrogen, it seemed desirable to take advantage of the possible greater ease with which the oxygen could be removed from the electrodes, by running them as anodes instead of cathodes in the dilute sulfuric acid. When used immediately after degassing, the cell gave a reading of 0.28 volt after two hours, with the ethylene positive. A second determination gave the same value, but the time was three and one-half hours. When boiled under atmospheric pressure in degassing, the cell gave only 0.075 volt, with the ethylene positive; when previously saturated with hydrogen and boiled under atmospheric pressure, the reading was 0.09 volt. Later determinations were made with the potassium chloride solutions made up separately for the two sides of the cell, one from boiled distilled water saturated with ethylene while cooling, and the other solution from water similarly treated with acetylene. The electrodes were prepared by running them as anodes in dilute sulfuric acid and degassing as described; the readings were 0.20, 0.41, and 0.33 volt, with the ethylene positive. Of these, the second value, 0.41 volt, seems unreliable because in this case the electromotive force of the acetylene-calomel cell fell to zero and then gave a reading of 0.01 volt in the opposite direction from the previous ones.

Obviously a reversible cell should give far more definite and more reproducible values than these. The only conclusion possible from a study of these data is that we are here dealing with irreversible electrodes or with electrodes which are only partially reversible.

However, the fact that these rather considerable differences of potential were obtained indicates that reactions of some sort were taking place at the electrodes. What these reactions were cannot be stated from experimental observations, since the products were being formed only during the brief intervals when the circuit was closed by depressing the key, and then only in very minute quantities. The irreversibility of the electrodes indicates that one or more of the substances formed is a gas or a volatile liquid and is consequently lost to the cell, or that the situation is complicated by secondary reactions at the electrodes. It is entirely possible that both of these factors play a part in the phenomena within the cell.

CONCLUSIONS

1. A voltaic cell can be made with hydrocarbons as the active electrode agents.
2. The ethylene-acetylene cell is not of the concentration type.
3. The ethylene-acetylene cell is irreversible, or at best only partially reversible.

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A Revised Checklist of the Snakes of Kansas

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SINCE the publication of Branson's "Snakes of Kansas,"* the Biological Survey of the University of Kansas has collected a large number of snakes, among which are species not hitherto recorded from Kansas, and others that have been reported on doubtful authority. In order to bring our knowledge of the ophidian fauna up to date I am presenting here a list of the species known with certainty from the state, with notes on their distribution.[1] I also comment on the species excluded from the state list.

Due to recent research in the taxonomy of the snakes, and the revision of several genera, the nomenclature used in Branson's paper is so very much out of date that I am showing in a footnote the present equivalents for the names in his list.[2]

* Bull. Univ. Kansas, vol. IV (Science Bulletin, vol. II (1904), pp. 353-430, June.

1. In the following annotated list the county records are based on specimens in the Kansas University collections, except in one or two cases where the snakes have been recently reported from Riley by Burt (1927) and from Franklin by Gloyd (1928). Old and doubtful records are excluded.

2. NOTE:
Pityophis catenifer sayi Schlegel = *Pituophis sayi sayi* (Schlegel).
Eutænia proxima Say = *Thamnophis saurius proximus* (Say).
Eutænia radix Baird and Girard = *Thamnophis radix radix* (Baird and Girard).
Eutænia elegans vagrans Baird and Girard = *Thamnophis ordinoides vagrans* (Baird and Girard).
Eutænia sirtalis parietalis Say = *Thamnophis sirtalis parietalis* (Say).
Eutænia sirtalis sirtalis Linnaeus = *Thamnophis sirtalis sirtalis* (Linné).
Tropidoclonium lineatum Cope = *Tropidoclonion lineatum* (Hallowell).
Cyclophis æstivus Linnaeus = *Opheodrys æstivus* (Linné).
Heterodon platyrhinus Latreille = *Heterodon contortrix* (Linné).
Heterodon nasicus Baird and Girard = *Heterodon nasicus* Baird and Girard.
Natrix grahami Baird and Girard = *Natrix grahamii* (Baird and Girard).
Natrix rhombifera Hallowell = *Natrix rhombifera* (Hallowell).
Natrix fasciata sipedon Linnæus = *Natrix sipedon* (Linné).
Natrix fasciata erythrogaster Shaw = *Natrix erythrogaster transversa* Hallowell.
Coluber spiloides Duméril and Bibron = ? *Elaphe obsoleta obsoleta* (Say) Young.
Coluber obsoletus obsoletus Say = *Elaphe obsoleta obsoleta* (Say).
Coluber vulpinus Baird and Girard = *Elaphe vulpina* (Baird and Girard).
Coluber emoryi Baird and Girard = *Elaphe læta* (Baird and Girard).
Storeria occipitomaculata Baird and Girard = *Storeria occipto-maculata* (Storer).
Storeria dekayi Holbrook = *Storeria dekayi* (Holbrook).
Ophibolus calligaster Say = *Lampropeltis calligaster* (Harlan).
Ophibolus gentulus sayi Holbrook = *Lampropeltis getulus holbrooki* (Stejneger).
Ophibolus doliatus triangulus Cope = *Lampropeltis triangulum triangulum* (Lacépède).

1. *Carphophis amœna vermis* (Kennicott). Worm snake.

This species is found commonly under rocks on hillsides in the eastern part of the state. (Leavenworth, Jefferson, Douglas, Osage, Franklin, Anderson, Montgomery, Riley, Neosho, and Crawford counties.)

2. *Diadophis punctatus arnyi* (Kennicott). Ring-necked snake.

Probably more specimens of this species have been found by collectors than any other in Kansas. It is surprisingly common in habitats occupied by the worm snake during the latter part of March and April. It is highly probable that the species is confined to the eastern part of the state, although one specimen in the University collection purports to come from Gove county. I strongly suspect that this locality is erroneous. (Doniphan, Riley, Jefferson, Leavenworth, Wyandotte, Douglas, Osage, Franklin, Anderson, Neosho, Montgomery and Cowley counties).

3. *Heterodon contortrix* (Linné). Spreading adder.

Locality records show the presence of this species throughout the state. Nowhere does it appear to be common. (Wyandotte, Douglas, Riley, Franklin, Cowley, Ellsworth, Stafford, Sumner, Pratt, and Morton counties.)

4. *Heterodon nasicus* Baird and Girard. Hog-nosed snake.

All the specimens that I have examined have been obtained in the western half of the state. (Morton, Rawlins, Lane, Graham, Trego, Riley, Washington, Russell and Stafford counties.)

5. *Opheodrys æstivus* (Linné). Rough green snake.

Specimens of this species in the University collections have all been obtained in the southeastern part of the state. (Franklin, Miami, Anderson, Linn, Bourbon, Labette, Montgomery and Cowley counties.)

Ophibolus doliatus doliatus Linnæus = *Lampropeltis triangulum syspila* (Cope).
Ophibolus doliatus gentilis Baird and Girard = *Lampropeltis triangulum gentilis* (Baird and Girard).
Rhinochilus lecontei Baird and Girard = *Rhinocheilus lecontei* Baird and Girard.
Carphophis amœnus Say = *Carphophis amœna vermis* (Kennicott).
Diadaphis regalis Baird and Girard = *Diadophis* sp.?
Diadophis punctatus Linnaeus = *Diadophis punctatus arnyi* (Kennicott).
Liopeltis vernalis DeKay = *Liopeltis vernalis* (Harlan).
Zamenis flagellum flagellum Shaw = *Masticophis flagellum flavigularis* (Hallowell).
Zamenis constrictor Linnæus = *Coluber constrictor flaviventris* (Say).
Tantilla gracilis Baird and Girard = *Tantilla gracilis* Baird and Girard.
Tantilla negriceps Kennicott = *Tantilla nigriceps* Kennicott.
Chionactis episcopus isozonus Cope = *Sonora semiannulata* Baird and Girard.
Ancistrodon contortrix Linnæus = *Agkistrodon mokasen* Beauvois.
Ancistrodon piscivorous Lacepede = *Agkistrodon piscivorous* (Lacépède).
Sistrurus catenatus Garman = *Sistrurus catenatus catenatus* (Rafinesque).
Crotalus horridus Linnæus = *Crotalus horridus* Linné.
Crotalus confluentus Say = *Crotalus confluentus confluentus* Say.

6. *Liopeltis vernalis* (Harlan). Smooth green snake.

This snake appears to be rare in the state. H. K. Gloyd (1928) reports a specimen collected in Franklin county. The specimen is now in the collection of Ottawa University, Ottawa, Kan. The locality data are undoubtedly authentic. (Franklin county.)

7. *Coluber constrictor flaviventris* (Say). Blue racer.

The blue racer is one of the commonest snakes in Kansas and appears to be found with equal frequency in all parts of the state. (Bourbon, Cherokee, Labette, Anderson, Franklin, Douglas, Leavenworth, Jefferson, Wyandotte, Coffey, Woodson, Greenwood, Elk, Chautauqua, Marion, Stafford, Pratt, Barber, Clark, Meade, Lane, Gove, Trego, Graham, Rawlins, Wallace, Riley, Hamilton and Morton counties.)

8. *Masticophis flagellum flagellum* (Shaw). Coachwhip.

The species referred to this name in Branson's paper (*loc. cit.*) is now recognized under the subspecific name *flavigularis*, a form confined to the western half of the state. He mentions a specimen occurring in Douglas county in the eastern part of the state, but makes no mention of its differing from the western form. This specimen is no longer extant.

There are two specimens of this species now in the collections of the University of Kansas, one collected by Wayne B. Whitlow who obtained it at Wayside, Montgomery county, August, 1924. The second specimen was caught in July, 1926, by T. E. White at Sycamore, Montgomery county. Farmers in Montgomery and Cherokee counties state that the species is not rare. They distinguish this dark snake from the pilot black snake by its habit of moving rapidly when disturbed. (Montgomery county.)

9. *Masticophis flagellum flavigularis* (Hallowell). Western coachwhip.

This species is not uncommon throughout the western half of Kansas. It is usually found in open prairie country and along draws. (Morton, Barber, Pratt, Graham, Trego, Gove, Lane, Logan and Wallace counties.)

10. *Elaphe læta* (Baird and Girard). Rat snake.

This form so frequently confused with *Lampropeltis calligaster* is found only in the western third of the state. Most of the specimens collected by the Biological Survey have been taken under rocks along hillsides in early spring. It does not appear to be common. (Shawnee, Osage, Douglas, Riley, Franklin, Anderson, Woodson, Greenwood and Labette counties.)

11. *Elaphe obsoleta obsoleta* (Say). Pilot black snake.

Timbered areas along streams during the summer, and rocky hillsides in the early spring have yielded most of the specimens of the pilot black snake. Among Kansas snakes this species is exceeded in length by only the bull snake. It is confined to the eastern third of the state. (Doniphan, Leavenworth, Douglas, Franklin, Osage, Linn, Anderson, Woodson, Bourbon, Cherokee, Elk and Riley counties.)

12. *Arizona elegans elegans* (Kennicott). Faded snake.

Mr. C. D. Bunker, Curator of Birds and Mammals of the University museum collected the first specimen of this species taken in the state. It was captured in the daytime crawling across the road near Ashland, Clark county. The species is strictly nocturnal and the finding of the species in the daytime is very unusual. Henry Burt, a student in the University of Kansas, collected two specimens at night in Morton county while trapping small mammals. A fourth specimen was collected in the summer of 1927 in Stafford county by the Biological Survey party. (Morton, Stafford and Clark counties.)

13. *Pituophis sayi* (Schlegel). Bull snake.

The largest of our Kansas snakes has a state-wide distribution. Specimens appear to be more numerous in the open prairie country. (Douglas, Franklin, Anderson, Allen, Montgomery, Osage, Riley, Cloud, Republic, Pratt, Stafford, Clark, Trego, Gove, Lane, Washington, Rawlins and Morton counties.)

14. *Lampropeltis calligaster* (Harlan). King snake.

This common snake appears to be confined to the eastern third of the state. (Shawnee, Osage, Douglas, Franklin, Anderson, Woodson, Washington, Greenwood, Labette, Crawford and Riley counties.)

15. *Lampropeltis triangulum syspila* (Cope). Painted king snake.

This brightly colored snake due to its secretive habits is rare in the collections made in Kansas. It is somewhat difficult to certainly differentiate this form from the subspecies *L. triangulum gentilis*. (Doniphan, Douglas, Osage, Coffey, Franklin, Anderson, Linn, Labette and Riley counties. Specimens doubtfully referable to this form are known from Republic, Russell and Rice counties.)

16. *Lampropeltis triangulum gentilis* (Baird and Girard). Prairie painted king snake.

I have referred to this species specimens from the western part of the state. These are very much faded and the red is very indistinct in life. The specimens from Morton county were taken deeply buried under rocks. (Morton and Wallace counties.)

17. *Lampropeltis getulus holbrooki* (Stejneger). Salt-and-Pepper king snake.

This distinct black and yellow snake ranges over the eastern two-thirds of the state. (Leavenworth, Douglas, Osage, Coffey, Franklin, Anderson, Linn, Labette, Riley, Russel, Rice and Pratt counties.)

18. *Rhinocheilus lecontei* Baird and Girard. Leconte's snake.

The nocturnal habits of this species is probably responsible for its remaining rare in collections. So far as I am aware only four specimens have been collected in the state. During the summer of 1928 a specimen of this species was caught near Alva, Oklahoma, only some 14 miles from the Kansas state line by Alonzo Wilson. This is the only recent collection of the snake in or near Kansas. The brilliant black, red and gold coloration of the form is equalled by no other snake except that of the painted king snake. (Clark, Barber and Finney counties.)

19. *Sonora semiannulata* Baird and Girard. Banded ground snake.

Specimens of this diminutive species have been taken only in the southeastern corner of the state where they appear to be common. Three color phases are present, the red and black banded forms being rarest. (Montgomery and Cherokee counties.)

20. *Natrix grahamii* (Baird and Girard). Graham's water snake.

This species is plentiful along streams and ponds in the eastern part of the state. A single specimen was captured at Pratt, Kansas, in 1928. This is, I believe, the most western record for the state. (Douglas, Franklin, Miami, Anderson, Linn, Woodson, Pratt, Wilson, Riley and Montgomery counties.)

21. *Natrix sipedon* (Linné). Common water snake.

This is the commonest water snake in collections. It probably occurs throughout the state since the University collection contains a specimen from Colorado. However, no specimens are in the collections from the western fourth of the state. (Cherokee, Crawford, Linn, Anderson, Franklin, Douglas, Doniphan, Osage, Woodson, Riley, Chase, Greenwood, Elk, Cowley, Butler, Marion, Pratt, Stafford, Rooks and Trego counties.)

22. *Natrix erythrogaster transversa* (Hallowell). Yellow-bellied water snake.

The form is unquestionably specifically distinct from *Natrix sipedon*, and has practically the same range throughout the state. A few specimens appear to be uniformly colored on the ventral surface. (Linn, Bourbon, Cherokee, Doniphan, Douglas, Franklin, Anderson, Allen, Labette, Montgomery, Woodson, Osage, Greenwood, Stafford, Pratt and Clark counties.)

23. *Natrix rhombifera* (Hallowell). Diamond backed water snake.

This form reaches a greater size than any of the other water snakes in Kansas. The largest specimens are usually encountered about lakes and marshes. (Linn, Miami, Douglas, Franklin, Anderson, Cowley, Montgomery, Osage, Woodson and Coffey counties.)

24. *Storeria occipito-maculata* (Storer). Red-bellied Dekay snake.

Only a few specimens of this species have reached the University collections. It seems to be confined to the extreme eastern part of the state. Gloyd (1928) reports six specimens from Franklin county. (Douglas, Franklin, Anderson and Cherokee counties.)

25. *Storeria dekayi* (Holbrook). DeKay's snake.

This species is distinctly more common than the red-bellied species. It appears to frequent wet localities, where earthworms are plentiful. (Doniphan, Leavenworth, Douglas, Franklin, Anderson, Cherokee, Montgomery, Chautauqua and Riley counties.)

26. *Virginia valeriæ elegans* (Kennicott). Virginia brown snake.

The first specimen of this species to be taken in the state was collected by me in Anderson county, in August, 1910. H. K. Gloyd collected two specimens in Franklin county in 1926. Students in my class in herpetology obtained four specimens of this snake in Jefferson county in the spring of 1929. (Franklin, Anderson, Douglas and Jefferson counties.)

27. *Tropidoclonion lineatum* (Hallowell). Lined snake.

This shy, secretive form appears to be rather rare or at least difficult to find. It is confined to the eastern third of the state. (Jefferson, Leavenworth, Douglas, Osage, Franklin, Anderson, Cowley, Dickerson and Riley counties.)

28. *Thamnophis marcianus* (Baird and Girard). Marcy's snake.

This species was first reported from Kansas in 1878 by Miss Mozley with the following notation: "*E(utænia)*. Marcinana (*sic*) B. & G. Douglas county." This specimen is no longer present in the Kansas University collections or if present has received other designation. This record should be disregarded. It also appears in Cragin's (1879) list with the following notation: "*Eutænia marciana* B. & G.; Marcy's Garter Snake. Ft. Hays (Garman). Douglas Co., (Mozley)."

I collected two specimens of this species, August 19, 1926, at a small creek fed by springs, which empties into the Cimarron river in Morton county. Another specimen was obtained in Meade county in 1928 by Albert Lunceford, Jr. This form appears to maintain its identity and does not merge with *Thamnophis radix radix* which occurs in the same immediate locality. (Morton and Meade counties.)

29. *Thamnophis sauritus proximus* (Say). Western ribbon snake.

This species is rarely found away from the immediate vicinity of water. It prefers ponds and lakes to running streams. (Doniphan, Douglas, Osage, Franklin, Miami, Montgomery, Riley, Stafford, Pratt, Barber, Harper, Washington, Graham, Clark and Meade counties.)

30. *Thamnophis radix radix* (Baird and Girard). Plains garter snake.

This form, which is especially common in western Kansas, also occurs throughout the eastern part of the state. The specimens examined from the east differ in some respects as regards lateral and ventral markings, and do not appear to reach as large a size as the western examples do. (Douglas, Franklin, Coffey, Labette, Riley, Republic, Cloud, Osborne, Russell, Stafford, Rice, Harper, Rooks, Trego, Gove, Lane, Meade, Rawlins, Wallace and Morton counties.)

31. *Thamnophis sirtalis parietalis* (Say). Red-barred common garter snake.

This is the common garter snake of the eastern part of the state. (Atchison, Jefferson, Douglas, Osage, Franklin, Coffey, Anderson, Linn, Woodson, Montgomery, Riley, Cloud, Greenwood, Cowley, Sumner, Pratt, Comanchee, Meade and Hamilton counties.)

32. *Tantilla gracilis* Baird and Girard. Graceful tantilla.

This species is relatively common. Its small size and inconspicuous coloring, however, causes it to escape observation unless encountered under a rock. (Riley, Wabaunsee, Leavenworth, Jefferson, Douglas, Montgomery and Sumner counties.)

33. *Tantilla nigriceps* Kennicott. Black-headed tantilla.

The only specimens of this species that have undoubtedly authentic locality data, in the University collections, are from Morton county. It has been reported from a number of counties, even as far east as Geary and Riley counties by Branson. It may overlap the territory occupied by *Tantilla gracilis*. (Morton county.)

34. *Agkistrodon mokasen* Beauvois. Copperhead.

The copperhead is common in the eastern part of the state, but is either extremely rare or entirely wanting in the western third of the state. (Doniphan, Leavenworth, Jefferson, Douglas, Anderson, Franklin, Montgomery, Cherokee, Osage, Bourbon, Labette and Riley counties.)

35. *Sistrurus catenatus catenatus* (Rafinesque). Pigmy rattlesnake.

This species is rare in eastern Kansas but is relatively plentiful throughout the central part of the state. (Franklin, Osage, Coffey, Greenwood, Butler, Dickinson, Stafford and Pratt counties.)

36. *Crotalus confluentus confluentus* (Say). Prairie rattler.

This form has been reported as far east as Riley county. It is probably wanting in the eastern part of the state. (Republic, Ellsworth, Barber, Trego, Graham, Gove, Sherman, Wallace and Morton counties.)

37. *Crotalus horridus* (Linné). Timber rattlesnake.

This form is far from rare in certain localities in the eastern part of the state. Gloyd (1928) reports finding large numbers in Franklin county. There are many specimens in the University collections from Douglas county. (Doniphan, Leavenworth, Jefferson, Wyandotte, Franklin, Douglas, Anderson and Riley counties.)

SPECIES EXCLUDED FROM THE STATE LIST.

Several species reported in Branson's paper have either not been found or their place on the list is not above question. I believe it wiser to question some of these older records than to include incorrectly species that are not positively known from the state.

1. *Eutænia elegans vagrans* (Baird and Girard).

This species of Thamnophis is reported from the western part of the state. Branson says: "The snake is quite rare in the western part of Kansas. None have been reported in the eastern part." Cragin states: "*Eutænia vagrans* B. & G. Wandering garter snake. Ft. Riley (Nolan). In the Cambridge Museum of Comparative Zoölogy, from Kansas (Garman). I collected a specimen of *Thamnophis ordonoides elegans* (Baird and Girard) in southern Colorado in 1928 at a distance of about 100 miles from the Kansas line. It is not improbable that the species will be discovered or rediscovered within the limits of the state."

2. *Eutænia sirtalis sirtalis* (Linné).

Branson reports this species as common in all parts of the state but less numerous than *E. sirtalis parietalis*. He reports specimens from Douglas, Lyon, Mitchell, Wallace and Shawnee counties. One specimen identified as this species in the National Museum purports to come from Woodson county. None of Branson's specimens are in the collection at the present time.

3. *Coluber spiloides* Dumeril and Bibron.

It is probable that a young specimen of *Elaphe obsoleta obsoleta* was referred to this species.

4. *Coluber vulpinus* (Baird and Girard).

The fox snake is included on insufficient evidence, and must be regarded as of very doubtful occurrence in the state.

5. *Diadophis regalis* Baird and Girard.

Burt (1927) is of the opinion that this is a synonym of *Diadophis punctatus arnyi*, which does occur in Riley county. This is the locality from which Branson's specimens are reputed to come.

6. *Ophibolus doliatus triangulus* Cope.

Blanchard (1921) in his revision of the King snakes believes that *Lampropeltis triangulum triangulum* is limited in its western distribution by the Mississippi. Branson claims to have collected the species in Douglas county, and examined a specimen from Franklin county. A specimen, No. 12,524 U. S. National Museum, purports to come from Ft. Scott, Kan. Until future collections reveal the presence of this form in the state I believe it well to omit it from Kansas lists.

7. *Agkistrodon piscivorous* Lacepede.

Branson lists this form as probably occurring in Kansas. To this date no specimen of the poisonous water moccasin has been taken by any collector in the limits of the state.

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THE UNIVERSITY OF KANSAS
SCIENCE BULLETIN

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List of Reptiles and Batrachians of Morton County, Kansas, Reporting Species New to the State Fauna

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DURING the summers of 1926, 1927 and 1928, parties from the University of Kansas Biological Survey spent some time in Morton county for the purpose of making collections of birds, mammals and reptiles.

In 1926 the party consisted of Henry Burt, Theodore White, Wallace Lane and Edward Taylor. White and Taylor devoted most of their efforts to obtaining herpetological specimens, during the stay which lasted from August 16 to August 24.

In 1927 a party consisting of Henry Burt, Lawrence Compton, Wallace Lane and Harry Parker spent most of the month of June in the county. Special emphasis was placed on mammal and bird collecting, and only a meager collection of reptiles and batrachians was obtained.

In June, 1928, Edward Taylor and Albert Lunceford, Jr., visited the county and practically all the time of the seven days' stay was spent in searching for reptiles and batrachians. A few days were also spent there late in August.

Morton county lies in the extreme southwestern corner of the state of Kansas. It is crossed by the Cimarron river which here is a veritable river of sand; and much sand is to be found along its valley. To the north are low bluffs which show an outcropping of hard volcanic ash.

Camps were made at the Wood Walsh ranch. The collecting for the most part was done along the river, in the sand dunes to the south and along the low bluffs to the north where the blocks of weathered volcanic ash offer shelter to certain species of lizards, snakes and batrachians. This general locality is about 12 miles northeast of Elkhart.

The collecting parties are under greatest obligation to Mr. Wood Walsh and his family for innumerable courtesies and valued assistance.

The following species were taken:

TURTLES

1. *Chelydra serpentina* (Linné). One specimen taken (1926) in a small pool in the Cimarron river.

2. *Kinosternon flavescens* (Agassiz). Extremely common in occasional pools in the river bed, and in ponds and reservoirs. More than fifty specimens were collected.

3. *Terrapene ornata* (Agassiz). Specimens of this species were plentiful everywhere. A large series was taken.

LIZARDS

4. *Holbrookia maculata maculata* (Girard). Very common on both sides of the Cimarron river.

5. *Sceloporus undulatus thayerii* (Baird and Girard). Very common on both sides of the Cimarron river.

6. *Phrynosoma cornutum* (Harlan). More than 25 specimens were collected which represented all that were seen. This species is much less common than the two preceding species.

7. *Cnemidophorus sexlineatus sexlineatus* (Linné). Rare. No specimens were found in 1926 or 1927. A few specimens were taken in 1928 near the ranch house.

8. *Eumeces obsoletus* (Baird and Girard). Rare. Two specimens taken in 1926 and two in 1928 represent all the specimens found.

SNAKES

9. *Heterodon contortrix* (Linné). A single specimen taken in 1926.

10. *Heterodon nasicus* (Baird and Girard). A single dead specimen was found, but not preserved (1926).

11. *Coluber constrictor flaviventris* (Say). Several specimens taken each of the three years. Common.

12. *Masticophis flagellum flavigularis* (Hallowell). Several specimens taken each of the three years. Common.

13. *Pituophis sayi sayi* (Schlegel). Several specimens found each of the three years. Common.

14. *Lampropeltis triangulum gentilis* (Baird and Girard). Discovered by Albert Lunceford, Jr., in the bluffs to the north of the river. Four specimens taken in June, 1928.

15. *Arizona elegans elegans* (Kennicott). Two specimens of this rare night-roving snake were collected by Henry Burt in 1927. He found the specimens in the sand dunes south of the river at night while trapping small mammals. These represent the second and third specimens known from the state. The

first was collected by C. D. Bunker in Clark county. This is the first published record of its occurrence in Kansas.

16. *Thamnophis marcianus* (Baird and Girard). Taken at Spring creek, a small rivulet fed by springs, north of the river and near the western border of the county. Two specimens were obtained in 1926, and one in 1928. They seem to maintain their typical characters and do not appear to merge into *Thamnophis radix radix* (Baird and Girard), which occurs in the same locality. No specimens of this form have been taken in Kansas in recent years. The name appears in two early lists.*

17. *Thamnophis radix radix* (Baird and Girard). Common along small pools in the river, reservoirs and ponds, and along Spring creek.

18. *Tantilla nigriceps* (Kennicott). A few specimens were taken each year under rocks along the bluff north of the river.

19. *Crotalus confluentus confluentus* (Say). This form was reported as being common but only a single specimen was acquired on the three collecting trips.

AMPHIBIANS.

20. *Ambystoma tigrinum* (Green). Larvæ were extremely numerous in a reservoir on a farm six miles north of the river; more than two hundred were taken in a tank about 50 feet long by 25 feet wide. Adults were found about midnight coming to the surface of the ground out of prairie dog holes in a prairie dog town about three hundred yards north of the river and about 200 yards from a water reservoir. Only a single salamander was found in each hole. Dunn expresses the opinion (in letter) that the Kansas form is *A. mavortium*.

21. *Scaphiopus hammondi bombifrons* (Cope). Specimens were taken on August 18, 1926, and on June 8, 1928, after very heavy rainfalls. Large numbers congregated at breeding places. Three such groups were found in a radius of two miles and more than fifty specimens were taken on each of the two dates.

22. *Bufo debilis* (Girard). I found this small toad after a heavy hail and rainstorm on August 8, 1926. While collecting late at night the thin, feeble piping was heard more than half a mile away. After long search two specimens were found in icy water in a small temporary pool into which much hail had washed. Several dead specimens killed by hail were found at a large temporary lake six miles north of the river. In 1928, Albert Lunceford, Jr., discovered specimens under rocks in the bluffs north of the river. These records are the first authentic reports of occurrences of this species in the state.

23. *Bufo woodhousii* (Girard). Common. Very large adults were found in the prairie-dog villages at night. They hide in the holes during the day.

24. *Bufo cognatus* (Say). Three specimens were found dead after the hail and rainstorm August 18, 1926, six miles north of Walsh's ranch.

25. *Rana pipiens* (Schreber). This species was found to be very numerous along Spring creek about 6 miles west of Walsh's ranch. Specimens appear to approach the characters of the southern *Rana sphenocephala* (Cope).

* Mosley, Kansas Acad. Sci., vol. 6 (1877-'78), 34-35, lists "*E Marcinana* (sic) B. and G Douglas Co." which is either an error of identification or of locality. Since *Thamnophis radix radix* is not listed, I strongly suspect the specimen examined was of this species since it occurs in Douglas county.

Cragin, Kansas Acad. Sci., vol. 7 (1878-'80), 116, lists "*Eutænia marciana* B. and G. Marcy's garter snake. Ft. Hays (Garman), Douglas county (Mozley)."

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A Species of Lizard New to the Fauna of the United States: *Eumeces callicephalus* Bocourt

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WHILE collecting with Albert Lunceford, Jr., in the Huachuca mountains of southern Arizona between July 1 and July 10, 1928, I obtained four specimens of a small skink which differed from the species known from the United States. At first I concluded that it was a new species but later study has proved it identical with the Mexican form, *Eumeces callicephalus* Bocourt.*

The specimens were obtained in Ash canyon at an elevation of approximately 6,000 feet. Three were captured under small stones, and a fourth was discovered running about over the stones in the small stream that trickles in the bottom of the canyon. We found no other species of skinks in the Huachucas although *Eumeces obsoletus* (Baird and Girard) has been reported by other collectors from the immediate locality of Ash canyon.

Through the courtesy of Mr. Joseph Slevin, of the California Academy of Sciences, I was permitted to examine the skinks which he collected in the Huachuca mountains. I found in this material two specimens of this species. By permission of Mr. Slevin I am including data on these two specimens in this paper.

Since the type description of *Eumeces callicephalus* is not generally available† and no description appears in any American work on herpetology, I append a color description of the form, and a table showing variation in the principal characters.

The color of the back is brownish gray showing less brown posteriorly; anteriorly this color covers 6 scale rows and 8 posteriorly.

* I am under obligation to Dr. Alexander Ruthven of the University of Michigan for a confirmation of this identification.

† Bocourt, Mission Sci. Mexique; Rept., p. 431, pl. XXII, D, fig. 2, and pl. XXII, E, fig. 2.

On the side a broad blackish brown band begins back of the nostril, and extends along the sides of the body to the hind leg where it stops abruptly. Anteriorly the band covers three scale rows, but narrows to a single row posteriorly. A narrow greenish to bluish white line, beginning on the first superciliary and extending about two-thirds the distance from axilla to groin, borders the wide lateral band above. A second narrow line, greenish in color, beginning on the rostral and continuing on the labials through the ear to the hind limb, borders the lateral band below. The head is brown with two narrow whitish stripes which begin at the same point on the rostral scale then separate passing gack to the nuchal scales where they re-unite and continue back on the middorsal line some six or seven scale lengths as a narrow light line. The labials, chin, throat and the underside of the limbs are pure paper white. The belly is grayish to grayish blue or ultramarine. The tail is ultramarine, slightly less distinct on the underside.

The color pattern on the six specimens shows practically no variation and agrees with Bocourt's figure (*loc. cit.*) in detail. The youngest specimens (No. 6475) shows a slightly deeper shade of blue on the tail, and in the largest specimen (No. 6473) the blue on the tail has almost disappeared, and its color is similar to the color of the back; the lines on the head are scarcely discernible.

The following table shows the variations in measurement and scale characters:

TABLE OF MEASUREMENTS AND SCALE COUNTS OF *EUMECES CALLICEPHALUS* BOCOURT.

Number[1]	48096 C. A. S.	48095 C. A. S.	6473 K. U.	6474 K. U.	6476 K. U.	6475 K. U.
Snout to foreleg (mm)	18	17.8	22	20	17	14.5
Snout to anus (mm)	50	52.2	64.2	56.2	50	46.5
Tail	86	87	reg.	104	89	broken
Fore limb	12	11.2	15	13	12	9.4
Hind limb	16	16.8	21	17.5	15.8	15.1
Axilla to groin	26.7	27	36	32.8	27.5	23
Width of head (greatest)	7	7.1	9.2	8.5	7	6
Snout to end of parietal	8.1	8	10.2	10	8	8
Post anal width of tail	6	4.9	7	7.2	5.7	6
Scale rows on neck	29	29	28	28	28	27
Scale rows on body	28	28	28	28	27	26
Scales, occiput to above anus	58	56	59	58	58	58
Supraoculars	4	4	4	4	4	4
Superciliaries	6	7	7	7	6	7
Scales surrounding ear	17	16	17	16	16	15
Post nasals	0	0	0	0	1–0	1 1
Post mentals	2	2	2	2	2	2
Frenals	2	2	2	2	2	2
Upper labials	8	8	8	8	8	8
Lower labials	6	6	6	6	6	6
Plates on lower eyelid	5	1–5	1–5	5	4	4
Supraoculars touch frontal	3	3	3	3	3	3
Nuchals (pairs)	1	1	1	1 1/2	1	1 1/2
Ear lobules (enlarged)	2	2	2	2	2	1–2
Subcaudals enlarged	no	no	no	no	no	no
Preanals somewhat enlarged	yes	yes	yes	yes	yes	yes
Parietals enclose interparietal	yes[2]	yes	yes	yes	yes	yes
Scale rows parallel	yes	yes	yes	yes	yes	yes
Dorsal nuchal scale rows widened	yes	yes	yes	yes	yes	yes
3 pairs chinshields, median widest	yes	yes	yes	yes	yes	yes
Adpressed limbs touch	yes	yes	no	yes	no	yes
Nasal, divided	yes	yes	yes	yes	yes	yes
Frontonasal separated from frontal and rostral	yes	yes	yes	yes	yes	yes
Frontonasal touches frenal	yes / no	no	yes	no	yes / no	yes / no

1. Numbers marked C. A. S. are from the California Academy of Science. Those marked K. U. are in the Kansas University Museum of Birds and Mammals

2. The parietals are separated by a small intercalated scale posteriorly.

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PART II.

THE UNIVERSITY OF KANSAS
SCIENCE BULLETIN

VOL. XIX]　　　　JULY, 1930　　　　[No. 8

The Fauna of the Drum Limestone of Kansas and Western Missouri.*

ALBERT NELSON SAYRE,
Department of Geology, University of Kansas.

INTRODUCTION.

THE Drum limestone is of considerable interest paleontologically because of the sharp contrast which its dominantly molluscan fauna presents to the dominantly molluscoidean faunas of the preceding and succeeding limestones of the Pennsylvanian system of Kansas. In the northern area of its outcrop the upper one-half to two-thirds is oölitic and is like most of the oölitic limestone of North America in that it contains a dwarfed molluscan fauna; while in its southern outcrops, although the limestone is almost entirely oölitic, the fauna is quite robust. This shows that the conditions under which oölites are formed do not necessarily result in dwarfed faunas. Stratigraphically, the Drum is interesting because it is oölitic, at least in part, in most places, and this makes it easier to trace, but its very rapid changes in lithology and in thickness make it more difficult to trace.

In this paper the writer has described and figured the entire known fauna of the Drum and has endeavered to place the correlation of the Drum in its type locality with the Drum of the Kansas City area on a more secure basis stratigraphically and paleontologically; and to explain the conditions of sedimentation which gave rise to the oölitic portions of the Drum.

The collections made by the writer were obtained during 1923-1924 while a member of the faculty and a graduate student at the University of Kansas; and, under the auspices of the State

* Submitted in partial fulfillment of requirements for the degree Doctor of Philosophy, to the Ogden Graduate School of Science, University of Chicago, 1928.

Geological Survey of Kansas, during the summer of 1925. Determinations were made and descriptions written in Walker Museum, at the University of Chicago, during the calender years 1925-1926. Types are deposited in the Geological Museum at the University of Kansas. Paratypes and representative material are deposited in Walker Museum.

ACKNOWLEDGMENTS.

It is a pleasure to acknowledge my indebtedness to Richard Schweers for the loan of his collection of trilobites: to Dr. Carl O. Dunbar for his determination of specimens of fusulinids; to Dr. R. S. Bassler for the opportunity of studying the collections of Pennsylvanian fossils in the U. S. National Museum; and to Arthur W. Slocom for his assistance in the determination of species. My wife has rendered valuable assistance in the preparation of the manuscript. Especially am I under obligation to Dr. R. C. Moore, who lent the University of Kansas collections of Drum fossils from Kansas City and vicinity, and who arranged the means of transportation which has made this work possible. A debt of deepest gratitude is due to the late Dr. Stuart Weller for the kindly assistance he has so freely given at every stage of the work, in the identification of species, in the preparation of descriptions and illustrations, in the comparison with type and other specimens in the Walker Museum collections, and for access to his library and manuscript bibliographies.

STRATIGRAPHIC RELATIONS OF THE DRUM LIMESTONE

The most recent work on the stratigraphy of the Pennsylvanian series of Missouri is that of Hinds and Greene.[1] They define the Kansas City formation as the basal formation of the Missouri group. It is the equivalent of series II of the early Kansas survey,[2] which lies at the base of the Upper Coal Measures of Kansas. As defined, the Kansas City formation comprises nine members, named in order from the bottom as follows: Hertha limestone, equivalent to Haworth's Bethany Falls limestone; Ladore shale; Bethany Falls limestone, equivalent to the Mound Valley limestone of southeastern Kansas; Galesburg shale; Winterset limestone, equivalent to the Dennis limestone of southeastern Kansas; Cherryvale shale; Drum limestone; Chanute shale; Iola limestone.

1. Hinds, Henry, and Greene, F. C.: The Stratigraphy of the Pennsylvanian Series of Missouri. Mo. Bur. Geol. and Mines, vol. 13, 2d ser., p. 15 et seq.; 1915.

2. Haworth, Erasmus: The Stratigraphy of Kansas. Univ. Geol. Surv. Kansas, vol. 9, p. 69 et seq.; 1908.

RÉSUMÉ OF LITERATURE CONCERNING THE DRUM LIMESTONE

The first geological description of the Drum seems to be that of Haworth and Piatt.[3] In 1894 they described the Drum in its type locality, just east of Independence, Kansas, and named it the Independence limestone. They gave it formational rank, erroneously correlating it with the Oswego limestone.

Later (1898) Haworth[4] again described the limestone and again used the designation "Independence limestone."

In 1900 Beede[5] described and figured part (Foraminifera to Pelecypoda) of the more common invertebrate fossils of the Pennsylvanian rocks of Kansas. These forms were largely from the northeastern part of the state and included a number of species from the Drum of the Kansas City area.

Adams[6] proposed the name "Drum" for the limestone occurring so abundantly along Drum creek and in the vicinity of Independence. He pointed out the fact that the name "Independence" was preoccupied by the Independence shale[7] of Iowa. He also gives an incomplete faunal list of the Drum and correlates it with the Erie limestone.

In 1906 Schrader and Haworth[8] consider the Drum of southeastern Kansas as a separate formation and state that at Independence it is a single heavy limestone member, but that it divides toward the south into three members. Again in 1908 Schrader,[9] in the Independence folio, describes the Drum and enlarges somewhat on his previous statements.

In 1908 Siebenthal[10] states: "The Drum limestone outcrops with a thickness of 22 feet on the point of the ridge at the state line 3 miles southwest of Coffeyville, Kan., and extends westward adjacent to the state line for about 4 miles to a point where it thins out and disappears. It does not outcrop at a corresponding elevation on the south side of Opossum creek and was not identified elsewhere."

3. Haworth, Erasmus, and Piatt, W. H. H.: Kansas Univ. Quart., vol. 2, p. 115; 1894.

4. Haworth, Erasmus: Stratigraphy of the Kansas Coal Measures. Univ. Geol. Surv. Kansas, vol. 3, p. 48; 1898.

5. Beede, J. W.: Carboniferous Invertebrates. Univ. Geol. Surv. Kansas, vol. 6, pp. 1-178, pl. I-XXII; 1900.

6. Adams, G. I.: Stratigraphy and Paleontology of Upper Carboniferous Rocks of the Kansas Section. U. S. Geol. Surv., Bull. 211, p. 37; 1903.

7. Calvin, Samuel: Amer. Jour. Sci. (3), vol. 15, p. 460; 1878.

8. Schrader, F. C., and Haworth, Erasmus: Economic Geology of the Independence Quadrangle. U. S. Geol. Surv., Bull. 296, p. 14; 1906.

9. Schrader, F. C.: Geol. Atlas of the U. S., Independence, Kansas, Folio, No. 159, p. 2; 1908.

10. Siebenthal, C. E.: Mineral Resources of N. E. Oklahoma. U. S. Geol. Surv., Bull. 340, p. 195; 1908.

In the same year Haworth and Bennett[11] considered the Drum as a separate formation and stated that although it had not been traced in detail to Kansas City, there is little doubt but that it is the equivalent of one of the limestones in the bluffs around Kansas City, and, on the basis of faunal evidence supplied by Beede, it appeared to be the same as the "Kansas City oölite." In the same report Beede and Rogers[12] consider the Drum as a separate stage of their Series II, and remark that this is the most strongly marked stage in the Kansas Coal Measures, being characterized by the invasion of an oölitic fauna so different in its general make-up that it forms a distinct and important chapter in the Coal Measures history of the state. They note especially the presence of a molluscan fauna and the apparent incongruity of the genus *Pseudomonotis* with Pennsylvanian forms. A faunal list is given.

In 1915 Hinds and Greene[13] defined the Missouri group and the Kansas City formation, and gave a series of sections purporting to show that the Drum of the Kansas City area was traceable to the Missouri-Iowa boundary line. They also state that the Drum of northern Missouri may prove to be the same as the DeKalb of Iowa, as it agrees with that member lithologically and faunally.

In the same report Girty[14] makes a faunal study of the Pennsylvanian rocks of Missouri. This study includes a number of new species and a faunal list of the Drum based on one collection from Kansas City. He notes that the decidely molluscan fauna from the Drum in Kansas City is a dwarf fauna, while that from the Drum in its type locality is robust. Girty regards the Drum as merely a member of the Kansas City formation, and not as a separate formation.

McCourt,[15] in 1917, describes the Drum in some detail in Jackson county, Missouri, and gives a faunal list, prepared by Bennett, of over one hundred species.

In 1920 Tilton[16] takes exception to the use of the term "Drum" as applied by Hinds and Greene in the report cited above. He says that Bain[17] had used the term De Kalb in Iowa for a member which

11. Haworth, Erasmus, and Bennett, John: Univ. Geol. Surv. Kansas, vol. 9, p. 96.

12. Beede, J. W., and Rogers, A. F.: Coal Measures Faunal Studies. Univ. Geol. Surv. Kansas, vol. 9, p. 340; 1908.

13. Hinds, Henry, and Greene, F. C.; op. cit., pp. 107-164; 1915.

14. Girty, G. H.: idem., p. 278.

15. McCourt, W. E.: The Geology of Jackson County. Missouri Bur. Geol. and Mines, vol. 14, 2d ser., p. 52; 1917.

16. Tilton, J. L.: The Missouri Series in Southwestern Iowa. Iowa Geol. Surv., vol. 29, pp. 230-231; 1920.

17. Bain, H. F.: Geology of Decatur County. Iowa Geol. Surv., vol. 3, p. 278; 1897.

is the same as the Drum of northern Missouri six years before Adams named the Drum limestones in southeastern Kansas, and that the Drum limestone of northern Missouri should, therefore, be called the De Kalb limestone.

In a tentative correlation of the formations of Oklahoma, eastern Texas and southeastern Kansas, 1925, the U. S. Geological Survey[18] correlates the Drum of southeastern Kansas with the Dewey limestone, the Nellie Bly shale and the Hogshooter limestone of Oklahoma.

DETAILED DESCRIPTION OF THE DRUM LIMESTONE.

In its type locality, along Drum creek, just east of Independence, Kan., the Drum consists of a single member of rather pure oölitic limestone (90 to 95 per cent calcium carbonate), and is strongly cross-bedded and quite fossiliferous. It has a thickness of about 80 feet just east of the Atlas Portland cement quarry, where Rock creek enters the Verdigris river. The fresh surface of the limestone shows a dark buff color, while the weathered surface is nearly white. Toward the south the limestone thins rapidly and is found five miles southwest of Coffeyville, Kan., as a very thin limestone conglomerate, which becomes lost in the sandy formations above and below, a few miles south of the Oklahoma-Kansas line. Here the Drum lies well above the Hogshooter and the Nellie Bly. It may possibly be the equivalent of the Dewey limestone, but is certainly not the direct continuation of it, for the Dewey has none of the oölitic character of the Drum, nor does it contain a fauna at all similar to that of the Drum.

Northeast of Independence the Drum becomes thinner and increasingly arenaceous. It forms the resistant caps of the hills in the vicinity of Cherryvale and Morehead, where it is 5 to 12 feet thick, the thickness being reduced somewhat by erosion in places. East of Thayer its thickness is about 18 inches, and it is lost between the sandy layers of the Chanute and Cherryvale shales a little southeast of Chanute.

The writer endeavored to trace the Drum northward to Kansas City, but was unable to do so because of the poor exposures. The Drum is not, in most places, a resistant formation, and as it is overlain by the scarp-forming Iola limestone, the Drum occupies the gentle slopes or occurs in the valleys, and is, therefore, generally

18. U. S. Geol. Surv., Tentative Correlation of the Formations of Oklahoma, Eastern Texas and Southeastern Kansas.

covered by residual soil. However, outcrops of the Drum were found at several places between Chanute, Kan., and Kansas City, Mo. It occurs along Big creek, 4½ miles west-southwest of Elsmore, Kan., with a thickness of 8 feet, the top being covered. Again, 2 miles northeast of Elsmore, it occurs overlying 1 foot of hard, dense, massive, blue limestone, which is, in turn, underlain by a buff-colored limy shale 15 feet in thickness. Four miles northeast of Bronson, Kan., it outcrops in the bottom of a small creek, and is a white, porous, oölitic limestone.

On the Marais des Cygnes river, 5 miles south-southwest of Paola, Kan., a very strongly cross-bedded, oölitic limestone more than 15 feet in thickness is found. This may be the Drum, but its lack of fossils makes its identification doubtful.

From this point northward no trace of the Drum is found until the vicinity of Kansas City is reached. It is well exposed about 1 mile south of Turner, Kan., along the Union Pacific railroad tracks from Muncie to Kansas City, Kan., and again in the bluffs at Kansas City, Mo. Here it is overlain by the Chanute shale and underlain by the Cherryvale shale, and consists of three members: a lower, compact, resistant limestone, 3 to 5 feet thick, and known to the quarrymen as the bull-ledge; an upper, oölitic limestone member, quite fossiliferous, light gray in color, varying from 6 to 20 feet in thickness, and strongly cross-bedded; and an intervening shale, rarely more than a few inches thick.

Southward from Kansas City, Mo., the Drum becomes thinner and loses its oölitic character. Northward it becomes thinner and loses much of its oölitic character. There may be some question as to the continuation of the Drum from Kansas City to the Iowa boundary. Its rapid variation elsewhere suggests that it does not continue. The fauna of the De Kalb of Iowa and of the so-called Drum of northern Missouri are said to be similar, but the fauna of the De Kalb of Iowa is certainly quite distinct from that of the Drum of the Kansas City area, being composed principally of brachiopods, while even the commonest of the mollusks found in the Drum are not listed as occurring in the De Kalb. This seems to indicate that the De Kalb is not the equivalent of the Drum of the Kansas City area.

THE DRUM FAUNA.

The Drum fauna in the type locality is generally robust, while that of the Drum of the Kansas City area is essentially a dwarf fauna, although some forms attain large size. Otherwise the faunas of the two areas are similar, with the exception of the gastropod elements, which appear less abundant in the south. The collections from the Kansas City area are the more complete and represent more fully the life of the sea in which the Drum was laid down, because it has been a favorite collecting ground for many years of a number of collectors. These collections have been studied by the present writer along with collections made by him in the field.

In the identification of species it has been thought advisable to identify dwarf forms (especially the gastropods) with established normal-sized forms whenever possible, even though the small size with an equal or greater number of whorls would ordinarily constitute sufficient grounds for specific separation. The fauna consists of 70 genera and 131 species, of which 33 are described for the first time and 4 are referred to genera without specific identification because of their poor preservation.

The fauna is composed of the following forms: Protozoa, 1 genus and 1 species; corals, 2 genera and 2 species; vermes, 1 genus and 1 species; crinoids, 2 genera and 2 species; echinoids, 1 genus and 1 species; bryozoans, 7 genera and 9 species; brachiopods, 12 genera and 16 species; pelecypods, 23 genera and 40 species; gastropods, 22 genera and 47 species; cephalopods, 8 genera and 11 species; trilobites, 1 genus and 1 species: This shows a ratio of molluscs to molluscoids of more than three to one.

The following species are described for the first time: Bryozoans, *Fenestella moorei*, *Rhabdomeson kansasense*; brachiopods, *Productus missouriensis*, *Dielasma ventricosa*; pelecypods, *Edmondia ? kansasensis*, *Nucula triangularia*, *Pteria welleri*, *Parallelodon kansasensis*, *Pseudomonotis spinosa*, *Myalina ? slocomi*, *Schizodus trigonalis*, *Lithophaga subelliptica*, *Pleurophorus turnerensis*, *P. attenuatus*; gastropods, *Pleurotomaria bilineata*, *P. fisheri*, *P. lineata*, *P. kansasensis*, *Ptychomphalus laudenslageri*, *Murchisonia matheri*, *Phanerotrema ornatum*, *Goniospira heliciformis*, *Microdoma ornatus*, *Naticopsis minuta*, *Hemizyga? cancellata*, *Orthonema liratum*, *Bulimorpha meeki*, *B. turnerensis*, *Trachydomia pustulosa*, *Aclisina breva*, *A. parallela*; cephalopods, *Orthoceras kansasense*, *Metacoceras cavatiforme* var. *angulatum*.

Besides these, twenty or more species have been found in no other Pennsylvanian limestone of Kansas except the Drum. They are: *Fenestella mimica ?*, *Leda bellistriata*, *Pseudomonotis robusta*, *Limatula fasciculata*, *Bucanopsis tenuilineata*, *B. textiliformis*, *Pleurotomaria granulostriata*, *P. beckwithana*, *P. subsinuata*, *P. subconstricta, Strophostylus peoriensis, Naticopsis pricii, N. scintilla, Zygopleura nana, Z. teres, Z. attenuata, Sphærodoma paludinæformis, Soleniscus typicus, Aclisina swalloviana, Orthoceras occidentale, Gonioloboceras parrishi, G. goniolobum,* and *Schistoceras missouriense.*

The species appearing here for the first time in the Pennsylvanian rocks of Kansas are: *Tabulipora heteropora, Edmondia nebrascensis, Yoldia glabra, Pseudomonotis hawni, P. equistriata, Monopteria marian, Aviculopectuen sculptilis, Streblopteria tenuilineata, Pleurophorus subcostatus, Cypricardinia carbonaria, Bellerophon stevensianus, Patellostium marcouianum, Orestes intertexta, Pleurotomaria subconstricta, Naticopsis monilifera, Sphærodoma primigenius, Ephippioceras divisum,* and *Metacoceras cavatiforme.*

Six species here make their last appearance so far as observed in the Pennsylvanian rocks of Kansas. They are *Worthenia speciosa, Zygopleura plicata, Z. multicostata, Bulimorpha chrysalis, Sphærodoma fusiformis,* and *Aclisina stevensiana.*

Lithophaga subelliptica, Pleurophorus attenuatus, and *Pteria welleri* recall some of the forms found in the oölitic limestones of the Chester series. The Pseudomonoti form a bond with the Permian, four of the species of that genus appearing in the Drum limestone.

It is readily seen that every important group of the invertebrates is represented in the Drum and, as pointed out above, the gastropods and the pelecypods are much more abundant here than in any of the other limestone members of the Pennsylvanian system of Kansas. This abundance of mollusks, however, is probably due to the conditions under which the limestone was formed rather than to a distinct invasion from some other region.

CONDITIONS OF DEPOSITION.

In order to understand the conditions under which oölitic limestones are formed, it is necessary to know the conditions under which present-day oölites are forming. Vaughan,[19] in studying the oölites of the Bahamas and Florida, states that in the shoal waters of this region denitrifying bacteria are causing the precipitation of great quantities of calcareous muds and oozes which are composed almost entirely of either calcite or aragonite; and that oölites are forming either as concentric rings about some foreign material, such as a grain of sand, or by accretion in the muds. The newly

19. Vaughan, T. W.: Preliminary Remarks of the Geology of the Bahamas. Carn. Inst. of Wash., No. 182, vol. 5, Pap. 3, pp. 49-54; 1914.

formed oölites are soft and easily crushed. He states, further, that all marine, originally calcareous oölites, whether recent or ancient, were formed in calcareous oozes or muds precipitated by chemical action in warm, shallow seas.

There can be no doubt that the Drum is marine and that it was originally calcareous, for its fauna is a marine fauna, and there is no sign of replacement of any other material, such as silica, by calcium carbonate. Obviously the mud bottoms would be ideal for the existence of a strongly molluscan fauna, but at the same time, in deeper, clearer waters, a dominantly molluscoidean fauna might exist. So that the presence of a strongly molluscan fauna does not, necessarily, indicate the invasion of an alien fauna, as was suggested by Beede.

In shallow waters the movements at the surface cause the motion to be transmitted downward, and movement takes place in the materials at the bottom. Thus we should expect the oölitic limestone to be more or less cross-bedded. In general, cross-bedding implies much wearing of the shells which may be in the rock, but in the oölite, the oölite grains are as soft or softer than the shells and, therefore, very little wearing is shown by the shells. Only the more fragile forms in the Drum are broken, and the ornamentation is very distinct in many cases, showing that little wearing has taken place.

The oölites are generally composed of concentric lamellæ of calcium carbonate formed around a grain of sand, but many of them are calcium carbonate throughout. Very often the slower moving or sessile forms of shells are coated with calcium carbonate on the outside, but not coated on the inside, indicating that the shell became coated during the life of the animal. This, also, would be expected to happen in the calcareous muds in which the oölites were forming.

Finally, if the place of deposition of the oölites is near a low-lying land mass, very little detritus will enter the sea and the resulting limestone will be nearly pure calcium carbonate. If, on the other hand, it is close to a high land mass or near the mouth of a river, considerable detritus will enter the sea and the resulting limestone will be impure. Obviously the impurity will increase as the proximity is greater to the source of land detritus, the detritus may entirely displace the calcareous muds, and the result will be the formation of a sandstone or shale. Thus, where the Drum is quite pure, it seems probable that adjacent land, if present, was low-lying during the time of its deposition; where it is impure, the adjacent land mass was high or there was a stream close by. It appears that during the deposition of the Drum the Kansas City area and the Drum Creek area were close to low-lying land masses, while the areas both north and south of these points were either close to higher lands or marked the entrance of streams into the sea.

From the foregoing statements, it is readily seen that the conditions in Kansas during the deposition of the Drum were somewhat similar to those in Florida at the present time. The climate was probably subtropical and, at least in places, the land was low-lying.

DESCRIPTION OF SPECIES.

PROTOZOA.

FAMILY FUSULINIDÆ.

GENUS TRITICITES Girty.

Triticites irregularis (Schellwien and Staff) Emend. Dunbar and Condra.

1912. *Fusilina centralis*, var. *irregularis*. Schellwien and Staff (in parts), Paleontographica, vol. 59, p. 178-179; p. 17, figs. 10, 11 (not p. 16, figs. 7 or 9 or pl. 17, figs. 5 or 7, or pl. 18, fig. 6).

1927. *Triticites irregularis*. Dunbar and Condra, Neb. Geol. Surv., Bull. 2, 2d ser., p. 108, pl. 8, figs. 7-10; pl. 9, figs. 1-3.

A number of fusulinids were found in the collections. All of them were more or less incrusted with calcium carbonate, which obscured the surface markings almost completely. These specimens and several poor sections were sent to Dr. Carl O. Dunbar, who has identified them. He states that the species is characterized, not only by its proportions, but also by a tendency toward irregular growth. Instead of tapering toward the poles it frequently undulates by radial expansion and contraction; while the antetheca and front line of growth is usually uneven.

"This species has a considerable range, appearing in the Wayland shale of central Texas, a zone equivalent to some part of the Kansas Marmaton group, and running up to the Deer Creek limestone in Kansas. However, it is never so abundant elsewhere in the Mid-continent field as in the Drum limestone and closely adjacent members of the Kansas City formation. It seems to be rare in the oölitic phase of the Drum, but is abundant in parts of the bed on Turkey creek, near Kansas City, Mo. Your specimens are, of course, more or less broken and encrusted so that they do not look very typical, but I have no doubt of their identity."[20]

Horizon and locality. Drum limestone, oölitic member, at Turner, Kan.

20. Dunbar, C. O.: In a letter written April 2, 1928.

CŒLENTERATA.

FAMILY ZAPHRENTIDÆ.

GENUS LOPHOPHYLLUM Milne-Edwards and Haime.

Lophophyllum profundum (Milne-Edwards and Haime).

(Pl. I, figs. 3-5.)

1916. *Lophophyllum profundum.* Mather, Bull. Sci. Lab. Denison University, vol. 18, p. 91, pl. 1, figs. 11-13.*

The fossils here under consideration show considerable variation. They have a conical shape and vary from gently curving to nearly straight; the long specimens expanding less abruptly than do the short ones. In the long specimens the maximum dimensions observed are 6 cm. long by 2 cm. in diameter, the most abrupt curvature occurring near the base. In the shorter forms the average is about 2.5 to 3 cm. long and 8 mm. wide. Epitheca thin, showing concentric striæ and growth lines, which vary in sharpness and regularity from specimen to specimen. These are crossed by strong, more or less rounded longitudinal ridges which are situated opposite the interseptal loculi and are separated by sharp depressions which are opposite the septa. Calice deep, circular, and provided with a columella which is compact, prominent and flattened with the general curve of the corallum. Sections show the columella to be connected at the bottom of the calice with one of the septa. Septa arranged in two alternating sets of about twenty-eight each. One set extending to, or nearly to, the columella, the other short and extending only a short distance beyond the epitheca; the longer septa being generally a little tortuous below the calice. Tabulæ fairly numerous, generally extending outward and downward from the columella, although in some instances they do not reach the columella, but coalesce with adjacent tabulæ.

Horizon and locality. Drum limestone, oölitic and shale members, at Kansas City, Mo.; Turner, Muncie, Independence (stations 12 and 23), Kan.

FAMILY FAVOSITIDÆ.

GENUS MICHELINIA De Koninck.

Michelinia eugeneæ White.

(Pl. I, figs. 1-2.)

1916. *Michelinia eugeneæ.* Mather, Bull. Sci. Lab. Dension University, vol. 18, p. 95, pl. 1, figs. 17, 17a; pl. 2, fig. 1.

Corallum globular, or irregularly ovoid, somewhat higher than wide; maximum dimensions: height, 5 cm.; width, 3.5 cm. Corallites diverging from the small base and increasing interstitially so as to open on all sides. Corallites polygonal, commonly hexagonal or pentagonal in section and varying in size with the stage of growth, the majority being between 2 mm. and 3 mm. in diameter. Walls thin, perforated at irregular intervals by minute pores, and striated longitudinally. Lines of growth numerous and gathered

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* In this paper long synonomy lists will not be given. The most recent published synonomy list of each species is given for reference.

at irregular intervals into low transverse ridges. Tabulæ numerous, very thin, and irregularly spaced; generally crossing the corallites from wall to wall, but in many cases arching from the central part of the tabula to the wall of the corallite. Base unknown.

Two specimens are referred with some question to *M. eugeneæ* White. They are larger than typical members of that species and the tabulæ are somewhat more numerous. The thickness of the tabulæ, as compared with that of the walls, however, is about the same as is the size and distribution of the mural pores, and the size and shape of the corallites are also quite similar. Consequently, it seems advisable, for the present at least, to consider them as members of this species.

Horizon and locality. Drum limestone, oölitic member, Independence (station 12), Kan.

CRINOIDEA.

FAMILY POTERIOCRINIDÆ.

GENUS HYDREIONOCRINUS De Koninck.

Hydreionocrinus sp.

A number of the spines which surround the summit of the ventral sac of the crinoids belonging to this genus are found among the collections. Nothing further is known about the other parts of these fossils, and specific identification cannot be made.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo., and Turner, Kan.

GENUS EUPACHYCRINUS Meek and Worthen.

Eupachycrinus sp.

A number of rather large plates, pentagonal or hexagonal in outline and somewhat curved, are found in collections. The outer convex side is ornamented with numerous rather large nodes. These plates are similar to the plates of the crinoids referred to *Eupachycrinus,* with which genus these plates are identified.

Horizon and locality. Drum limestone, oölitic member, Turner and Muncie, Kan., and Kansas City, Mo.

ECHINOIDEA.

FAMILY ARCHÆOCIDARIDÆ.

GENUS ARCHÆOCIDARIS McCoy.

Archæocidaris sp.

The echinoidea are represented in the Drum limestone by a large number of spines and small, hexagonal plates which are equipped with a ball-and-socket joint for the attachment of the spine. The spines are quite variable in size, but are broken off for the most part. The specific position of these forms is not clear, but they may be referred to the genus *Archæocidaris.*

Horizon and locality. Drum limestone, oölitic member, near Turner, Kan.

ANNELIDA—TUBICOLA.

GENUS SERPULOPSIS Girty.

Serpulopsis insita (White).

(Pl. XXI, fig. 1.)

1915. *Serpulopsis insita.* Girty, U. S. Geol. Surv., Bull. 544, p. 41, pl. 5, figs. 7, 8; pl. 6, fig. 13.

A few specimens of this species are found attached to other fossils, but they are by no means abundant in the Drum. They consist of small tubes which are somewhat smaller at their inception than distally, but for the most part retain about the same diameter elsewhere. Some of them are straight or only slightly curved, while others are very much contorted and so laced together that they cross one another. They appear to be partly imbedded in the shell substance of the fossil, to which they are attached, and should, therefore, be placed in Girty's genus *Serpulopsis.*

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.

BRYOZOA.

FAMILY FISTULIPORIDÆ.

GENUS FISTULIPORA McCoy.

Fistulipora nodulifera Meek.

(Pl. II, figs. 4-6.)

1903. *Fistulipora nodulifera.* Condra, Neb. Geol. Surv., vol. 2, pt. 1, p. 30, pl. 1, figs. 1-5.

Zoarium usually found incrusting other objects and assuming the form of the incrusted object. Zoarium varying from a few millimeters to about 2 cm. in width, with a maximum thickness of about 3 mm. Surface sometimes smooth, but generally with irregularly distributed nodes. Zoëcial apertures subcircular; 0.24 to 0.26 mm. in diameter, averaging over the surface a little less than their own diameter apart but more widely separated on the nodes. Peristome in unworn specimens a prominent lip extending about one-half way around the apertures. Zoëcia short, prostrate at first, then curving rather abruptly toward the surface, which they approach at nearly right angles. Zoëcial tubes circular in section, small at first, increasing gradually in size to the point of most pronounced curvature and extending from this point to the apertures with about the same diameter. Diaphragms wanting or only one present near the apertures. Interzoëcial spaces filled with small, thin-walled vesicles, wider than deep, irregularly arranged about the zoëcia in one to two series.

The walls of the zoëcia of many of the specimens found in the Drum limestone appear quite thick due to an incrustation of calcite. In some specimens calcite has so completely replaced the original structures that the walls of the interzoëcial vesicles cannot be distinguished from the material filling them.

This species may be distinguished from *F. carbonaria* Ulrich and *F. car-*

bonaria-nebrascensis Condra by its thin growth, its usual lack of diaphragms and by the smaller, more numerous and more irregular vesicles.

Horizon and locality. Rather uncommon in the oölitic member of the Drum limestone. Independence (stations 9, 12, 23), Turner and Muncie, Kan.

FAMILY BATOSTOMELLIDÆ.

GENUS TABULIPORA Young.

Tabulipora heteropora (Condra).

(Pl. II, figs. 2-3.)

1903. *Stenopora heteropora.* Condra, Neb. Geol. Surv., vol. 2, pt. 1, p. 43, pl. 4, figs. 7, 8.

Zoarium massive or incrusting; upper surface with clusters of apertures larger than the others about 5 mm. apart and generally elevated, but sometimes even with the general surface; lower surface concentrically wrinkled. Apertures polygonal to rectangular, 0.24 to 0.4 mm. in diameter (average 0.26 to 0.28 mm.), with about 15 in 5 mm. arranged more or less in concentric series about the monticules. Zoëcial tubes about 3 mm. long; prostrate at their inception, then curving quickly to the surface, which they approach at right angles; tubes polygonal in section; walls usually not more than 0.02 mm. in thickness, but increasing in thickness near the surface to about 0.05 mm. Interspaces 0.05 to 0.06 mm. wide. Diaphragms thin, sometimes perforated in the center, with usually five to eight in each tube, about 0.25 mm. apart in the straight portion of each tube. Acanthopores few, of medium size, located at the cell angles. Line of division between adjacent zoëcia quite distinct. Occasionally one layer of zoëcia is found located on top of another. The largest zoarium found is incomplete, but measures 5.5 cm. across and 6 mm. in thickness.

Horizon and locality. Drum limestone, oölitic member, Muncie, Turner, Independence (stations 9, 12 and 23), Kan.; Kansas City, Mo.

FAMILY FENESTELLIDÆ.

GENUS FENESTELLA Lonsdale.

Fenestella mimica var. *latirama* Sayre, n. var.

(Pl. II, figs. 1, 1a.)

Zoarium a delicate foliar expansion. Branches straight, with few bifurcations, slender, and uniformly about 0.28 mm. wide, with 13 to 14 in 5 mm. Dissepiments short, about half as wide as the branches, expanded terminally, much depressed on the obverse side, and but slightly depressed or nearly level on the reverse side. Fenestrules quite regular in size, rectangular on the reverse, sides slightly concave on the obverse face; about 0.16 mm. wide and 0.30 mm. long, with 13 in 5 mm. Carina faint, slightly elevated, with small nodes about 0.15 mm. apart. On well-preserved specimens the nodes are elongated into small spines. Zoëcia in two alternating ranges, so arranged that one aperture occurs at the end of each dissepiment with another at each side of the fenestrule. Apertures small, about 0.1 mm. in diameter and about 0.12 mm. apart; 25 to 27 in 5 mm. Peristome strongly raised. On the reverse face the branches and dissepiments are smooth or very slightly nodose and regularly rounded.

This variety differs from *F. mimica* Ulrich in its slightly wider branches, and shorter, narrower and more closely spaced fenestrules. The nodes on the keel of the obverse face are farther apart, and the number of zoëcia in a given distance is constantly greater.

Horizon and locality. Muncie, Turner and Independence (stations 12 and 23), Kan.

Fenestella moorei Sayre, n. sp.

(Pl. II, figs. 7-7a; Pl. 3, fig. 1.)

Zoarium a small, thin, delicate, foliar expansion. Branches slender, straight, with a nearly uniform width of about 0.16 mm. and 15 in 5 mm.; bifurcations few. Dissepiments rather long, about half as wide as the branches, expanded terminally to receive the zoëcia; depressed below the branches on the obverse face. Fenestrules variable, generally having an hour-glass shape; about 0.2 mm. wide, and 0.36 mm. long, with 12 in 5 mm. Carina very faint or lacking, its position marked by a row of very small nodes separated by about a distance equal to that between the zoecia. Zoëcia in two alternating ranges, so arranged that one lies at the end of each dissepiment and one midway between; apertures oval in outline, 0.06 to 0.08 across and about 0.16 mm. apart, with 24 in 5 mm., each one projecting decidedly beyond the margin of the branch and thus giving the branch a very irregular outline on the obverse face. On the reverse face the branches are strongly striated and regularly rounded. Dissepiments delicate, straight, striated also, and well depressed below the branches. Fenestrules subrectangular and only slightly indented at the sides.

This species may be readily distinguished from all other forms except, possibly, *F. perminuta* Ulrich by its extremely thin, delicate zoarium and its projecting apertures. It is apparently very closely related to *F. perminuta* Ulrich, but may be distinguished by its more regular growth, wider dissepiments, smaller fenestrules, and more numerous zoëcia.

Horizon and locality. Muncie, Turner and Independence (stations 9 and 12), Kan.

GENUS POLYPORA McCOY.

Polypora elliptica Rogers.

(Pl. III, figs. 2-4.)

1903. *Polypora elliptica.* Condra, Neb. Geol. Surv., vol. 2, pt. 1, p. 69, pl. 11, figs. 4-11; pl. 12, figs. 1-13; pl. 16, fig. 3.

Zoarium a large, undulating, foliar expansion. Branches straight or slightly flexuous, 0.4 to 0.5 mm. wide, 7 to 8 in 5 mm.; rounded and bearing numerous nodes on the obverse side; bifurcations few. Dissepiments short, about half as wide as the branches and depressed below them. Fenestrules elliptical; 0.25 mm. wide, 0.45 mm. to 0.5 mm. long with 4 to 5 in 5 mm. Zoëcia in 3 to 4 alternating rows; this number may be reduced to 2 just after bifurcation or increased to 5 just before bifurcation. Apertures large, separated by a little more than their own diameter; 17 in 5 mm., sometimes displaying a distinct peristome. Ranges separated by low undulating ridges and bearing distinct nodes which are about as numerous as the apertures. On the reverse face the branches are flat, almost angular at the edges; sometimes striated and sometimes bearing very numerous, irregularly arranged, small nodes; dissepiments almost as wide as the branches and nearly level with them; fenestrules elliptical to subcircular.

The specimens at hand show considerable variation from the original description of *P. elliptica* in the number of ranges of zoëcia and the size and shape of the fenestrules and branches. As Condra has shown the species to be quite variable, there can be little doubt that the specimens at hand belong to this species.

Horizon and locality. Drum limestone, oölitic member, at Turner, Muncie and Independence (stations 9, 12 and 23), Kan.; Kansas City, Mo.

Polypora submarginata var. *nodosa* Sayre, n. var.

(Pl. III, figs. 5-5a; Pl. IV, fig. 2.)

Zoarium a large, undulating, flabelliform expansion. Branches with numerous bifurcations near the base; 0.9 to 1.4 mm. wide, with 6 to 8 in 10 mm.; subpentagonal in outline, obverse face gently rounded to nearly flat, subangular at the margins, sides flattened, reverse narrowly rounded. Dissepiments short, similar to the branches in outline; 0.6 to 1.0 mm. in width; much expanded terminally; depressed on the obverse, but nearly level with the branches on the reverse. Fenestrules averaging 0.7 mm. wide and 1.8 mm. long, with 3 to 4 in 10 mm.; generally elongate oval in shape. Zoëcia arranged in vertical and curved diagonal rows; the latter crossing in the middle of the branch to form an irregular inverted V. Zoëcia in five ranges just after bifurcation and generally eight just before bifurcation. Apertures averaging 0.10 mm. in diameter, about 0.2 mm. apart, with 16 to 17 in 5 mm.; provided, in well-preserved specimens, with a strongly raised peristome which tends to be better developed in the outside ranges. The majority of the specimens show a row of low nodes alternating with the zoëcia of the central range. Some, however, bear, besides the central row, two other rows of very faint nodes alternating in position with the zoëcia of the ranges on either side of the central range. Reverse face often beautifully striated. One specimen shows a row of nodes down the middle of each branch, four to each fenestrule.

These specimens were at first referred to *P. submarginata* Meek. More careful consideration, however, leads the writer to believe that the differences observed between them and Meek's species are worthy of at least varietal and perhaps specific distinction. The principal differences are: the lack of the submarginate character of the branches; a little greater variation in size; the presence of two extra rows of nodes on the obverse face; and the presence of a row of nodes along the middle of the reverse face of the branches. This last character is not certainly constant, as not all specimens examined show it. The chalky character of most of the specimens would easily permit the wearing away of these nodes except under exceptional conditions. On the other hand, the nodes on the reverse face may be characteristic of certain parts of the zoarium and absent in other parts.

Horizon and locality. Muncie, Turner and Independence (stations 9, 12 and 23), Kan.

FAMILY ACANTHOCLADIIDÆ.

GENUS SEPTOPORA Prout.

Septopora biserialis (Swallow).

(Pl. IV, figs. 9-9a.)

1903. *Septopora biserialis.* Condra, Neb. Geol. Surv., vol. 2, pt. 1, p. 93, pl. 18, fig. 5.

Zoarium a large, irregular, strongly folded expansion. Branches nearly parallel except near the base of the zoarium; increasing in number by interpolation; averaging 0.5 mm. wide, but quite variable and with 10 to 12 in 10 mm.; carinate on the obverse face, regularly rounded on the reverse. Dissepiments about two-thirds as wide as the branches; slightly depressed below the branches; usually arched, and faintly carinate on the obverse face; regularly rounded on the reverse and depressed below the branches. Carina on both the branches, and the dissepiments bearing a row of nodes, which are long and prominent on some specimens and spaced 0.6 mm. apart. Fenestrules transversely oblong; quadrangular or often crescentic; generally wider than the branches; averaging 12 in 10 mm. Zoëcia in two ranges, separated by the median carina, on both the branches and the dissepiments. Apertures subcircular to ovate, about two-thirds their own diameter apart and with 24 to 27 in 5 mm. Dissepiments with 3 to 12 apertures. Accessory pores few in number, on the obverse face, scattered among the zoëcia; on the reverse generally located at the junction of the branches with the dissepiments and surrounded by a small rim. Reverse face generally striated.

This group of fossils differs from described *S. biserialis* in having a uniformly greater number of zoëcia. On this basis alone it might be considered as a new species or a new variety. In other respects, however, the form is so similar to *S. biserialis* that the writer believes it best for the present to consider it as identical with that species. It is closely related to *S. subquadrans*, but differs in its mode of growth, branches increasing by interpolation instead of bifurcation.

Horizon and locality. U. P. railroad west of Kansas City, Muncie, Turner and Independence (station 12), Kan.

FAMILY RHABDOMESONTIDÆ.

GENUS RHABDOMESON Young.

Rhabdomeson kansasense Sayre, n. sp.

(Pl. I, figs. 9-11.)

Zoarium slender, ramose, 0.5 to 1.5 mm. in diameter; branching nearly at right angles to the main stem at distant intervals. Zoëcia arranged in longitudinal and diagonal rows on the surface; originating at a central axial tube and passing direct to the surface at an angle of 30 to 40 degrees. Walls thin in the immature region, thickening in the mature region. Acanthopores large, few in number, projecting from the surface of the zoarium in well-preserved specimens, arranged longitudinally in line with the zoëcia, with generally two (sometimes only one) above each zoëcium and two below it. Zoëcial tubes rhombic in cross section in the immature region, circular to oval in the mature region. Tabulæ wanting. Superior and inferior hemisepta present, the latter being more strongly developed and nearer the aperture. Apertures rather large, suboval, opening into subhexagonal vestibules.

This species is closely related to *R. americanum* Rogers. It differs in being somewhat larger, the apertures are more closely spaced, and this species has well-developed hemisepta.

Horizon and locality. Found in the oölitic member of the Drum limestone at Turner, and Independence (stations 9, 12 and 23), Kan.

GENUS RHOMBOPORA Meek.

Rhombopora lepidodendroides Meek.

Pl. I. figs. 6-8.)

1903. *Rhombopora lepidodendroides.* Condra, Neb. Geol. Surv., vol. 2, pt. 1, p. 99, pl. 6, figs. 2-4; pl. 7, figs. 1-12.

Zoarium ramose, cylindrical or slightly compressed, straight or slightly irregular between bifurcations; surface bearing very small nodes; bifurcations at irregular intervals. Diameter of branches varying from 1 mm. to 3.5 mm. Zoëcia originating at the center and passing upward and outward gradually to the cortical portion of the zoarium. Zoëcial walls thin in the immature region, becoming thicker as the surface is approached. Acanthopores prominent, two sizes being generally present; a small size quite numerous and surrounding each zoëcium, and a larger size, generally situated at the cell angles, and in well-preserved specimens projecting above the surface of the zoarium as small nodes. Zoëcial tubes polygonal in section in the immature region, but circular in the mature region. Apertures subcircular, opening into rhombic vestibules, which are sometimes lost due to abrasion; arranged in vertical and diagonal intersecting series. Tabulæ wanting in most zoëcia, but sometimes found in old growths.

This widespread species, as noted by previous writers, shows considerable variation in character. While much of this variation is undoubtedly real, some of it may be only apparent and due to the confusion of this species with species of the genus *Rhabdomeson*, which is very similar in outward appearance and may only be distinguished by sections showing the central tube.

Horizon and locality. This species is very abundant in both the limestone and shale member of the Drum limestone. Kansas City, Mo.; Muncie, Turner and Independence (stations 9, 12 and 23), Kan.

BRACHIOPODA.

FAMILY DISCINIDÆ.

GENUS ORBICULOIDEA d'Orbigny.

Orbiculoidea convexa (Shumard).

(Pl. IV, figs. 1-1a.)

1906. *Orbiculoidea convexa.* Woodruff, Neb. Geol. Surv., vol. 2, pt. 2, p. 274, pl. 12, fig. 11.

Superior valve patelliform, nearly circular, convexity equal to a little less than half the diameter. Shell thin. The beak, situated about one-third of the diameter from the posterior side, is slightly incurved so as to cause a slight depression beneath it on the posterior side. Surface marked by fine concentric striæ. Dimensions: breadth, 30 mm.; height, 13 mm.

White describes what he supposes to be an inferior valve as being flat, marked like the superior valve and possessed of a foramen directly below the beak of the superior valve.

Horizon and locality. Two superior valves were found in the oölitic member of the Drum limestone at Kansas City, Mo.

FAMILY STROPHOMENIDÆ.

GENUS DERBYA Waagen.

Derbya crassa (Meek and Hayden).

(Pl. IV, figs. 3-5.)

1915. *Derbya crassa.* Girty, Bull. U. S. Geol. Surv., No. 544, p. 54, pl. 7, figs. 1-1c.

Shell semicircular, generally wider than long; hinge margin equal to or less than the greatest width of the shell. Anterior margin more or less regularly rounded. Dorsal valve only slightly convex, with greatest convexity near the middle or a little behind it. Beak indistinct and extending very little beyond the cardinal margin. Surface of the valve marked by numerous radiating striæ of unequal size which are crossed by fine concentric striæ. These latter give a finely crenate appearance to the radiating striæ. Ventral valve unknown.

Several dorsal valves of this species, all more or less imperfect, were found at Turner, Kan. No ventral valves were found.

Horizon and locality. From the oölitic member of the Drum limestone, Turner, Kan.

FAMILY PRODUCTIDÆ.

GENUS CHONETES Fischer de Waldheim.

Chonetes verneuilianus Norwood and Pratten.

(Pl. IV, figs. 6-8.)

1906. *Chonetes verneuilianus.* Woodruff, Neb. Geol. Surv., vol. 1, pt. 2, p. 276, pl. 11, fig. 8.

Shell rather small; transversely subsemicircular, the width being greater than the length; hinge line a little longer than the greatest width of the shell. Ventral valve convex, with the greatest convexity slightly anterior to the middle. Dorsal valve concave. A narrow, rounded mesial sinus extends from the beak, becoming broader and deeper as it approaches the anterior margin, causing a slight sulcus in the outline of the shell and dividing the gibbous portion of the valve into two distinct divergent rounded ridges, which are set off from the ears by a broad depression. Ears triangular and pointed at the junction of the lateral and cardinal margins. Beak incurved, scarcely projecting beyond the hinge line, which is provided with four to five spines with sometimes a rudimentary sixth spine near the beak. Cardinal area narrow, slightly larger on the ventral valve, and inclined to the plane of the shell. Pedicle opening large, subtriangular, partly closed above by an arching deltidium and nearly filled with the bilobate cardinal process of the other valve. Interior of the ventral valve marked by numerous small nodes which are opposite small pits in the dorsal valve. Dorsal valve concave, bearing a median fold which extends part way to the beak. Surface of each valve marked by 100 to 130 very small, bifurcating, rounded ribs radiating from the beak and, near the margin, a few lines of growth which sometimes give the radiating ribs a nodose appearance.

Dimensions: Length of a large specimen, 8 mm.; width 12.4 mm.; convexity, 4 mm.

Some of the specimens under consideration show less convexity than the typical *C. verneuilianus,* and also a larger number of radiating ribs. It may be that these should be considered as a distinct variety, but as their state of preservation does not permit accurate description it is considered best to identify them with this species.

Horizon and locality. Drum limestone, oölitic and shale members, at Turner, Kan.

GENUS PRODUCTUS Sowerby.

Productus insinuatus var. *missouriensis* Sayre, n. var.

(Pl. V, figs. 1-2b; Pl. VI, fig. 1.)

Shell very large, subovate, strongly arched toward the beak and much produced anteriorly; width greater than length; hinge line a little shorter than the greatest width: ventral valve very convex, strongly arched over the umbo to the beak. Two varieties can be distinguished: one wide, like typical *P. cora* in outline and with the umbo somewhat flattened; the other narrower, with the median portion elevated, almost subcarinate and with a corresponding shallow inflection in the anterior margin. Ears large, flattened and marked by strong rugæ which pass inward from the cardinal margin upon sides of the umbo, where they become obsolete. Beak small and strongly incurved over the cardinal margin. The whole surface is ornamented with small, even, rounded, crowded, radiating costæ, which increase by bifurcation, and fine, obscure, concentric growth lines. Spines are situated on the costæ at rather wide intervals and are so arranged as to form diagonal rows. The cardinal margin also bears a row of spines.

Dimensions of two shells: Width, 80 mm.; length, 76 mm.; convexity, 25 mm.; and width, 60 mm.; length, 58 mm.; convexity, 34 mm.

This variety differs from *P. insinuatus* Girty in its more numerous spines and in the regular arrangement of the spines in diagonal rows, while the sinus in the anterior margin is not nearly so deep as that indicated in the illustrations of that species. It is, perhaps, closely related to *P. americanus* Swallow, which is described, but not figured. Swallow's species is characterized by the regular arrangement of the spines in diagonal rows and is, apparently, quite similar to this variety; according to his description, however, it is longer than wide, while the present variety is regularly wider than long. Compared with *P. magnus*, this variety is considerably smaller, much more convex and is ornamented with many spines.

Horizon and locality. Drum limestone, oölitic member, Kansas City, Mo., and Elsmore (station 46), Kan.

Productus sp.

One fragment of a shell from the shale member of the Drum limestone at Muncie, Kan., shows the heavy costæ and the reticulation of the visceral portion characteristic of *P. semireticulatus* Martin, but the state of preservation is such that this identification cannot be certain. The fragment is 2¼ by 2 inches.

GENUS PUSTULA Thomas.

Pustula symmetrica (McChesney).

(Pl. VII, figs. 6-6b.)

1892. *Productus symmetricus.* Hall and Clarke, Pal. N. Y., vol. 8, pt. 1, pl. 17a, figs. 19, 20.

Shell large, slightly wider than long, gently rounded on the sides; hinge line a little shorter than the greatest width; cardinal extremities angular to subangular. The dimensions of a complete specimen a little below average size are: Length from hinge line to anterior margin, 24 mm.; length from umbonal region to front margin, 28 mm.; width, 33 mm.; length of hinge line, 28 mm.; convexity, 13 mm.

Ventral valve convex, gently rounded in the middle and curving quickly to the anterior margin in front and to the beak posteriorly; viewed from the front the shell curves regularly from one lateral margin to the other. Mesial sinus broad and shallow. Umbo extending well beyond the hinge line. Beak fairly large, rounded, and strongly incurved. Ears small, flattened, rounded to subangular. Surface of the valve marked by strong, closely set, concentric wrinkles of nearly uniform size which bear numerous closely spaced, prominent nodes which appear to be spine bases. Dorsal valve nearly flat, but slightly concave in the middle and in the two posterior lateral areas, so as to cause two broad, low ridges which originate at the middle of the cardinal margin and extend toward the anterior margin at an angle of about 100 degrees to each other. Surface covered with closely set concentric wrinkles on which there are rather widely spaced, small spines, and a few pits are noted in the intervening depressions.

This species is quite abundant in the oölitic member of the Drum limestone. It resembles *P. symmetrica* (McChesney) very closely, but it is smaller, more convex and has a small sinus in the ventral valve. This last, however, is not of great importance, for the writer has seen specimens of *P. symmetrica* which show the sinus or depression quite as well developed as in the specimens at hand. The convexity is not as great as in *P. nebrascensis* (Owen), while the wrinkles are much more closely set, the anterior margin is rounded regularly, and the brachial valve is nearly flat and not concave at the margins.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Muncie, Turner and Independence (station 12), Kan.

Pustula semipunctata (Shepard).

(Pl. VI, figs. 2-2b.)

1920. *Pustula punctata.* Mather, Bull. Sci. Lab. Den. Univ., vol. 18, p. 172, pl. 8, fig. 11.

Two specimens from the oölitic member of the Drum limestone at Kansas City, Mo., are complete and apparently adult forms. In every respect, save that of size, they agree with published descriptions of *P. punctata.* They bear well-marked concentric bands, ornamented with spines; hinge margin shorter than the greatest width of the valve; mesial sinus distinct and extending from the anterior margin nearly to the beak; beak strong and incurved a little beyond the cardinal margin. They are, however, much smaller than the typical members of the species. Length, 23 mm.; width, 25 mm.; convexity, 12 mm.

Horizon and locality. Drum limestone, oölitic member, Kansas City, Mo. Elsmore (station 46), Kan.

Pustula nebrascensis (Owen).

(Pl. VI, figs. 3-3b.)

1920. *Pustula nebrascensis.* Mather, Bull. Sci. Lab. Den. Univ., vol. 18, p. 169, pl. 5, figs. 6-7.

This species has been described so often that it is not necessary to repeat the description here. Several specimens were found in the oölitic member of the Drum limestone at Turner, Kan. These agree entirely with Meek's description, to which the reader is referred. Length of shell from the hinge line to the anterior margin, 20 mm.; length from the umbo to the anterior margin, 23 mm.; width, 28 mm.; convexity of the pedicle valve, 13 mm.

Horizon and locality. Drum limestone oölitic member, at Turner, Kan.

FAMILY RHYNCHONELLIDÆ.

GENUS PUGNAX Hall and Clarke.

Pugnax osagensis (Swallow).

Pl. VII, figs. 10-10c.)

1915. *Pugnax osagensis*. Girty, U. S. Geol. Surv. Bull., 544, p. 81, pl. 10, figs. 11-11c.

Meek's description: "Shell small, more or less variable in form, often subtrigonal, generally wider than long, more or less gibbous; front truncated, or sometimes sinuous in outline; anterior lateral margins rounded in outline; posterior lateral margins convex, or nearly straight and converging to the beaks at an angle of about 90 degrees to 120 degrees. Dorsal valve more convex than the other, greatest convexity near the middle or between it and the front, which has a broad rather deep, marginal sinus for the reception of a corresponding projection of the anterior portion of the other valve; mesial fold somewhat flattened, but slightly prominent, and rarely traceable back of the middle of the valve; generally composed of three, but sometimes of four—rarely more—plications; sides rounding down rapidly on each side of the mesial fold, and each occupied by about three or four simple plications; beak curving strongly beneath that of the other valve; interior with a faint linear mesial ridge, on each side of which is a raised curved line inclosing an ovate space, occupied by the adductor muscular impressions. Ventral valve distinctly less convex than the other, with a broad, shallow, short sinus occupied by about two or three short plications; anterior lateral margins on each side of the sinus, with from two to four simple plications; beak moderately prominent, and more or less arched, rather pointed; foramen small."

Length of a medium-sized specimen, 6.5 mm.; width, 7 mm.; convexity, 4 mm.

Seven specimens are identified as belonging to this species which, according to Girty, is distinct from *P. uta* Marcou. Marcou's species, according to A. L. Mathews, is a Mesozoic form.

Horizon and locality. Drum limestone, oölitic member, at Independence (stations 12 and 23), Kan.

FAMILY TEREBRATULIDÆ.

GENUS DIELASMA King.

Dielasma bovidens (Morton).

(Pl. VII, figs. 4-5b.)

1903. *Dielasma bovidens*. Girty, Prof. Paper, U. S. Geol. Surv., No. 16, p. 409, pl. 7, figs. 11-11a.

Meek's description: "Shell ovate, rounded, and rather compressed at the anterior and anterior-lateral margins, and most convex a little behind the middle; valves nearly equally convex; ventral valve strongly arcuate longitudinally, and presenting a regularly increasing curve, from the front to the beak, which is moderately prominent, and very strongly and closely curved over and upon that of the other valve; foramen a little oval, and not truncating the immediate apex of the beak, but situated directly outside of it; mesial sinus rather wide, and rounded at the front, but narrowing and becoming less deep farther back, until it dies out near the curve of the umbo, which is sometimes slightly flattened. Dorsal valve often nearly straight, or but slightly convex, along the middle, from the beak to the front, where its margin is usually somewhat raised for the reception of the slightly produced margin of the other valve at the termination of the sinus; sides sloping from the middle to the lateral margin along nearly the entire length of the valve; beak terminating directly under that of the other valve, without any distinct curvature. Surface nearly smooth, or only showing moderately distinct marks of growth; and, by the aid of the magnifier, exhibiting very distinctly the moderately large, regularly arranged punctures."

Length of a medium-sized specimen, 17 mm.; breadth of same, 13 mm.; convexity, 8 mm.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Muncie, Turner, Cherryvale (station 40), Urbana (station 43), and Independence (stations 9, 12 and 23), Kan.

Dielasma ventricosa Sayre, n. sp.

(Pl. VII, figs. 1-3c.)

Shell subovate, elongate and rather compressed laterally, quite convex, with the greatest convexity behind the middle. The dorsal valve is more convex than the ventral. The ventral valve is quite arcuate in the middle portion and is strongly and rather sharply bent downward at both ends, so that the beak, which is prominent and large, is closely bent down over and upon that of the dorsal valve. Foramen oval and not truncating the immediate apex of the back, but situated just outside it. Mesial sinus fairly wide and rather deep at the anterior margin, but becoming less pronounced toward the beak, it becomes obsolete at the umbo. Dorsal valve convex, and somewhat sinuous in outline when viewed from the side, due to the heavy growth lamellæ. When viewed anteriorly the valve is rather narrowly rounded in the middle and slopes directly to the lateral margins in all portions except those close to the beak. The beak terminates with slight curvature directly under that of the ventral valve. Anterior margin subtruncate, slightly sinuous in the middle, due to the deep sinus of the ventral valve. Surface marked by heavy concentric, imbricating growth lamellæ, and showing, under the lens, numerous closely spaced, fairly large and regularly arranged punctæ.

D. ventricosa is very much like *D. bovidens* internally. Two prominent dental lamellæ in the ventral valve extend from the beak to a point slightly beyond the hinge. From the beak to the hinge these lamellæ touch both the bottom and the top of the shell. Beyond the hinge the lamellæ are not connected with the inner surface of the ventral valve. A long, narrow, upcurved plate occupies the median portion of the dorsal valve and extends from the beak about half the length of the valve. Near the beak it is attached to the shell along the middle and is supported on each side by a small plate. Anteriorly the lateral plates disappear and the curved plate is attached only in the middle. Divergent crura are attached to the edges of the curved plate near the beak, and long cruralia, extending over half the length of the valve, are attached to the crura.

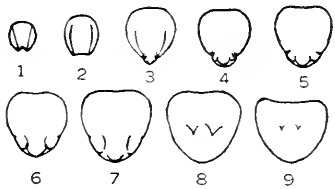

FIG. 1. A series of sections of *D. ventricosa*, showing the internal structure. × 2.5.
1, section of the beak of the ventral valve showing the dental lamellæ touching both the top and bottom of the valve; 2, section near the hinge; 3, section anterior to the hinge, with the dental lamellæ still persisting and showing the beginning of the development of the curved plate in the dorsal valve; 4, 5, the curved plate is raised above the floor of the dorsal valve and the edges are supported by vertical plates, small crura are developing on the edges; 6, 7, 8, 9, sections showing the development of the cruralia.

Length of a rather large specimen, 23 mm.; width, 16 mm.; convexity, 13 mm.

This species is found associated with and is nearly as abundant in the Drum limestone as *D. bovidens*. But the latter species is smooth and subspatulate in shape, while the former is much more convex, longer and narrower in proportion to its width, and the surface is covered with concentric growth lamellæ, which are not found on *D. bovidens*. The mesial sinus is deeper and sharper. The internal structure of these specimens places them definitely in the genus *Dielasma*. Although some of the immature specimens are more or less subspatulate like *D. bovidens*, the rather wide, subimbricating growth lamellæ serve to distinguish even the young specimens from that species.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Turner, Muncie and Independence (station 12), Kan.

FAMILY SPIRIFERIDÆ.

GENUS SPIRIFER Sowerby.

Spirifer triplicatus Hall.

(Pl. VII, figs. 8-9.)

1920. *Spirifer cameratus.* Girty, U. S. Geol. Surv., Bull. 544, p. 87, pl. 11, figs. 4, 4*b*.

The collections contain several shells of the Spirifer type which, from their fasciculated costæ, are believed to be *Spirifer triplicatus* Hall. These shells are poorly preserved and it is impossible to determine the character of the area or of the pedicle opening. The pedicle valve has a long hinge extended into pointed ears. The beak is fairly prominent and incurved. Mesial fold prominent, subangular, and becoming broader and deeper toward the anterior margin. Surface covered with radiating costæ, which are grouped or fasciculated. Marks of growth are fairly distinct.

Length of a large specimen, 41 mm.; breadth of same 55 mm.

Horizon and locality. Oölitic member of the Drum limestone, at Kansas City, Mo.; Turner, Urbana (station 43), Independence (stations 9, 12 and 23), Cherryvale (station 40), Kan., and shale member at Kansas City, Mo.

GENUS SQUAMULARIA Gemmellaro.

Squamularia perplexa (McChesney).

(Pl. VII, figs. 13-14a.)

1915. *Squamularia perplexa.* Girty, U. S. Geol. Surv. Bull. 544, p. 92, pl. 11, figs. 1-3a.

Seven specimens from the oölitic member of the Drum limestone at Independence (station 12), Kan., all more or less imperfect, are identified with this well-known species.

Dimensions: Length of dorsal valve, 12 mm.; width, 15 mm.; convexity of both valves, 8 mm.

FAMILY SUESSIDÆ.

GENUS SPIRIFERINA D'Orbigny.

Spiriferina kentuckiensis (Shumard).

(Pl. VII, figs. 7-7b.)

1920. *Spiriferina kentuckyensis.* Girty, U. S. Geol. Surv., Bull. 544, p. 85, pl. 11, figs. 8-8a.

Meek's description: "Shell rather small, varying from subglobose to semicircular, or even subfusiform, always wider than long; breadth sometimes twice or even three times the length; hinge line always equaling the greatest breadth of the valves, occasionally greatly extended, and terminating in slender mucronate ears; anterior and lateral margins generally forming a nearly semicircular curve.

"Ventral valve somewhat more convex than the other, the greatest convexity being between the beak and the middle; beak moderately prominent, and rather distinctly arched or incurved; area arched, usually of moderate height, well defined, and extending nearly or quite to the lateral extremities, highest in gibbous specimens, in which it is narrow near the extremities, while it increases rapidly in height with concave lateral margins toward the beak; foramen generally higher than wide, with a marginal furrow on each side, and, so far as known, not closed by a deltidium; mesial sinus narrow, rather deep, sometimes with a small obscure rib along its middle, but more frequently without it; plications on each side of the sinus about five to eight or nine, rather narrow, simple, prominent, and a little rounded; mesial septum of interior moderately prominent.

"Dorsal valve with greatest convexity near the middle; beak scarcely projecting beyond the hinge margin, more or less incurved; area very narrow, and incurved with the beak; mesial fold narrow, not very prominent, nor greatly larger than the first plication on each side, most generally rounded, but not infrequently with an obscure sulcus along the middle, near the front; lateral plications as in the other valve.

"Entire surface of both valves ornamented with numerous closely crowded, very regularly arranged, subimbricating lamellæ of growth, strongly arched in passing over the costæ; over the whole may also be seen, by the aid of a magnifier, numerous granules, apparently connected with the punctures passing through the shell, which are comparatively large and distant, though regularly arranged."

Length of a well-developed, fairly large specimen, 7.4 mm.; breadth of same, 11 mm.; convexity, 5.5 mm.

The specimens from the Drum limestone show many of the variations which Meek notes. Some are extremely long on the hinge line, some show the sulcus on the fold and some show the rib along the middle of the sinus. Others are quite normal and agree with the figured specimens of both Meek and Hall.

Horizon and locality. This species is found rather abundantly in the oölitic member of the Drum limestone at Kansas City, Mo.; Muncie, Turner, Independence (stations 9, 12, 23) and Urbana (station 43), Kan.

FAMILY RHYNCHOSPIRIDÆ.

GENUS HUSTEDIA Hall and Clarke.

Hustedia mormoni (Marcou).

(Pl. VII, figs. 11-12b.)

1915. *Hustedia mormoni.* Girty, Bull, U. S. Geol. Surv., No. 544, p. 103, pl. 12, figs. 5-6a.

Meek's description: "Shell small, ovate; in mature specimens gibbous; hinge line short, or scarcely extended enough to show distinctly the little ears at the extremities. Ventral valve more convex than the other, the greatest convexity being between the middle and the umbo, which is prominent, rounded, more or less strongly arched, and provided with a moderately large circular foramen; area well defined, triangular, and arching with the beak. Dorsal valve most convex near the middle; beak extending a little beyond the hinge margin, and distinctly incurved. Surface of each valve ornamented by fourteen or fifteen (very rarely sixteen to seventeen) simple, rather prominent, radiating costæ, one or two of which are sometimes slightly more depressed than the others near the front of the ventral valve, so as to cause some appearance of an obscure mesial sinus, but without producing any corresponding mesial elevation on the other valve, or visibly interrupting the general straightness of the uniting margin of the two valves; lines of growth obscure; punctures visible under a good lens, and very regularly disposed."

Length of well-developed specimen, 5 mm.; breadth of same, 4.8 mm.; convexity, 3 mm.

The specimens at hand show the mesial sinus to be well developed in most specimens, but in some it is entirely lacking. On well-preserved specimens the lines of growth may be plainly seen without the aid of a lens. There can be no doubt, however, that these specimens may be correctly referred to *H. mormoni,* as redescribed by Meek.

Horizon and locality. Drum limestone, oölitic member, at Turner, Muncie and Independence (stations 9, 12, 23), Kan.; Kansas City, Mo.

FAMILY ATHYRIDÆ.

GENUS COMPOSITA Brown.

Composita subtilita (Hall).

(Pl. VI, figs. 4-8c.)

1915. *Composita subtilita.* Girty, Bull. Geol. Surv., U. S., No. 544, p. 96, pl. 12, figs. 4-4c; pl. 5, fig. 7; pl. 6, fig. 13.

This well-known form is the most abundant species in the collection. It occurs at every locality from which collections have been made of the Drum fauna. Although the specimens show wide variation in form, it does not seem possible to split them up into separate species. For variations pass easily from long thin forms into short squat ones, and gradations are found between shells with a deep V-shaped sinus to those which are without a median sinus. In general, however, the younger specimens tend to show a nearly circular outline and a narrow shallow sinus, with almost no sulcus on the anterior margin. The older specimens are, as a rule, gibbous, much longer than wide, and show a broad, deep sinus with a pronounced sulcus on the anterior margin.

One specimen shows the interior of the hinge of the pedicle valve. This has a hinge plate with two dental lamellæ which extend upward to the shell above and form a rectangular cavity in the interior of the beak of the pedicle valve. Length of a medium-sized specimen, 15 mm.; width of same, 12 mm.; convexity, 9 mm.

Horizon and locality. Very abundant in the oölitic member of the Drum limestone at Turner, Muncie, Elsmore (station 46), Urbana (station 43), Cherryvale (station 40), Independence (stations 9, 12, 23), Kan.; and Kansas City, Mo. Also from the shale at these localities.

PELECYPODA.

FAMILY SOLENOMYACIDÆ.

GENUS SOLENOMYA Lamarck.

Solenomya sp.

(Pl. VIII, figs. 4-4a.)

One large cast appears to belong to this genus, but it is broken along the anterior margin and along the cardinal margin so that determination is very difficult. Shell elongate, subtrapezohedral in outline. Posterior extremity rather narrowly rounded, posterior margin sloping downward and forward from it with a slight appearance of truncation. Ventral margin gently curved to about one-fifth the length of the shell from the anterior extremity, where there is a broad, shallow sinus. Shell convex, the greatest convexity being about the middle. Beaks depressed, not extending beyond the hinge line. Surface crossed by strong concentric wrinkles which become increasingly strong near the margins, and numerous fine radiating striæ. Just below the beak there is a vertical, broad, shallow sulcus which gives rise to the sinus of the ventral margin. Anterior adductor scar rather strong, subelliptical in outline, situated about midway between the ventral and cardinal margins and just in front of the sulcus. Posterior adductor scar subcircular, situated near the middle of the shell and close to the cardinal margin.

Horizon and locality. Drum limestone, oölitic member, at Turner, Kan.

FAMILY GRAMMYSIIDÆ.

GENUS EDMONDIA De Koninck.

Edmondia nebrascensis (Geinitz).

(Pl. VIII, figs. 3-3a.)

1900. *Edmondia nebrascensis.* Beede, Univ. Geol. Surv. Kan., vol. 6, p. 166, pl. 20, fig. 5.
1911. *Edmondia nebrascensis.* Mark, Bull. Sci. Lab. Den. Univ., vol. 16, p. 310, pl. 9, fig. 4.

Shell of medium size, equivalve, inequilateral, subquadrate in outline. Dimensions of a typical specimen are: Length, 28 mm.; height, 24 mm.; length of hinge line, 20 mm.; convexity of right valve, 6.2 mm. Anterior, posterior and basal margins nearly straight or subtruncate, broadly rounded on the corners. Posterior side of the shell broader than the anterior so that the basal margin is not parallel to the hinge line. Hinge line nearly straight, becoming a little curved distally to the anterior and posterior margins. Umbones prominent, the greatest convexity being near the middle. Beaks situated about a third of the distance from the middle to the anterior extremity; prominent, extending well beyond the hinge line, directed forwarded and incurved. Surface ornamented by sharp concentric ridges which are separated by furrows three to four times as wide. In well-preserved specimens minute crenulations mark the crests of the ridges and the furrows; and some specimens also show fine concentric lines of growth.

Comparison of the specimens at hand with specimens from the type locality identified as *E. nebrascensis* Geinitz shows them to be identical in every respect.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Turner, Muncie and Independence (stations 12, 23), Kan.

Edmondia aspinwallensis Meek.

(Pl. VIII, figs. 1-1a.)

1900. *Edmondia aspinwallensis.* Beede, Univ. Geol. Surv. Kan., vol. 6, p. 166, pl. 22, figs. 3-3b.

Shell large, inequilateral, equivalve, subovate in outline. The dimensions of one specimen are: Length, 48 mm.; height, 35 mm.; convexity of left valve, 16 mm. Anterior margin subtruncate; basal margin broadly semielliptical; posterior margin rounded. Cardinal margin sloping from the beaks abruptly in front, less abruptly behind, and rounding distally into the posterior and anteror margins. Beaks somewhat prominent, situated in front of the middle of the shell and a little elevated above the hinge line. Umbonal region prominent, flattened, and with the sides rounded and sloping rather abruptly down to the margins of the shell. Surface marked by regular, concentric, sharply elevated ridges separated by furrows from three to five times their width, some of which show faint radiating crenulations or striæ. Surface of internal casts marked by heavy, regular concentric undulations. Hinge unknown.

A comparison of this specimen with the type of the species leaves no doubt as to the correctness of the identification.

Horizon and locality. Drum limestone, oölitic member, at Turner, Muncie, Elsmore (station 46) and Independence (station 23), Kan.

Edmondia ? kansasensis Sayre, n. sp.

(Pl. VIII, figs. 5-5a.)

Shell below medium size, subquadrate, equivalve, and inequilateral. Dimensions: Length, 21 mm.; height, 13 mm., convexity of the right valve, 6.5 mm. Anterior and basal margins nearly straight, at slightly more than 90 degrees to each other and with the basal-anterior margin rounded. Posterior margin broadly rounded. Cardinal margin sloping gently posteriorly and curving downward distally into the posterior margin; sloping abruptly downward anteriorly. Umbonal region raised, flattened, sloping gently to the margin posteriorly, more abruptly anteriorly. Beaks compressed, slightly elevated above the hinge, directed forward and situated about one-sixth the length of the shell back from the anterior margin. Surface marked with fine, low, subregular, concentric, rounded ribs.

Two specimens in the collections at hand belong to this species. The general shape, the absence of a lunule and escutcheon, and the fact that the valves are close all round would indicate that this species is a member of the genus *Edmondia*. Whether this conclusion will be supported by subsequent evidence is, of course, unknown. It resembles *E. bellula* Girty, but differs from that species in being much larger (about X3) and in having the beaks situated nearer to the anterior extremity. It also resembles *E. glabra* Meek, but the beaks are nearer the anterior margin, the basal margin is nearly straight and the posterior margin is not so narowly rounded.

Horizon and locality. Drum limestone, oölitic member, at Turner, Urbana (station 43) and Independence (stations 9, 12, 23), Kan.

FAMILY NUCULIDÆ.

GENUS NUCULA Lamarck.

Nucula anodontoides Meek.

(Pl. VIII, figs. 8-8a.)

1915. *Nucula anodontoides.* Girty, Bull. U. S. Geol. Surv., No. 544, p. 111, pl. 13, figs. 1-5.

Meek's description: "Shell ovate, ventricose, the greatest convexity being in the umbonal region; posterior side short, faintly subtruncate vertically at the immediate extremity; basal margin semielliptical in outline; cardinal margin nearly straight externally, equaling about half the length of the valves, carinate at the extremities; anterior side rather long, very narrowly rounded in the middle of the extremity, to which point the basal margin rounds up rather gradually, and the anterior dorsal edge slopes obliquely from the edge of the hinge; beaks moderately prominent, convex, incurved without very distinct obliquity and located about halfway between the middle and the posterior side; umbonal slopes, both before and behind, subangular, in consequence of the presence of a lunule and escutcheonlike impression, of which that on the anterior or longer side is the larger, being usually continued nearly or quite to the extremity of that side. Surface smooth, or only showing under a magnifier very obscure lines of growth.

"Length of the largest specimen, 0.57 inch; height, 0.40 inch; convexity, 0.30 inch. Some of the other specimens are proportionately more convex.

"I have described the shorter side as the posterior of this shell, which, of course, would probably be incorrect if it is not a true Nucula, although I only know from some of the imperfect specimens that it has a coarsely crenate hinge, there can be little doubt that it has an internal ligament, and this differs from Tellinomya and other Paleozoic types that have been separated under other names, since the dorsal margin of the valves can be seen to fit closely all the way along, so as to show no traces of an external ligament. It has not the physiognomy of the typical modern Nuculas, but looks externally like a miniature Anodon. It seems to be closely allied to *N. beyrichi* V. Schauer, from the Permian of Germany, but is larger, more robust, more nearly smooth, and differs in the lunulelike impressions before and behind the beaks.

"*Locality and position.* Just below the Mahoning sandstone, Monogalia county, West Virginia Coal Measures."

The shells under observation seem to fit this description very well, although there is no illustration of the type specimen with which to compare them. The lunule and escutcheon are not so pronounced as they apparently were on Meek's specimens. Dimensions of an average specimen: Length, 10 mm.; height, 7 mm.; convexity, 6 mm. The species is about twice the size of *N. beyrichi* as figured by Meek, its ventral margin has a slightly different curvature, and the beaks are slightly more prominent. It differs from *N. parva* McChesney in its less prominent beaks and in the fact that the basal margin is subparallel to the hinge line.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Turner and Muncie, Kan.

Nucula triangularis Sayre, n. sp.

(Pl. VIII, figs. 6-6c.)

Shell very small, inequilateral, equivalve, subtriangular in outline. The dimensions of a large specimen are: Length, 4 mm.; height, 3.6 mm.; convexity, 2.8 mm. Basal margin nearly straight in the middle and curving narrowly into the posterior and anterior margins; a little longer than the posterior margin, but shorter than the anterior margin. Anterior and posterior margins nearly straight and forming an angle of about 70 degrees, with the cardinal margin represented by a narrowly rounded point. Umbones prominent, flattened; surface of the shell dropping abruptly from the umbones to the margins of the shell. Beaks prominent, close together, extending well beyond the hinge line, directed backward and nearly terminal. Lunule and escutcheon poorly defined, the latter being the longer. Surface nearly smooth, but showing fine concentric lines under the lens; near the margin there are distinct lines of growth, which are especially prominent on some of the older, more gibbous shells.

The outline of this species is so different from any other in the collections that it cannot be confused. Not only is it much smaller than any other, but its triangular outline with nearly straight sides and base, and its highly convex valves serve to differentiate it. It differs from *N. wewokana* Girty in its comparatively greater height and straight base, and in the much poorer definition of its lunule and escutcheon. Its straight base and triangular shape serve to distinguish it from *N. beyrichi* V. Schauer.

Horizon and locality. Drum limestone, oölitic member, Muncie and Turner, Kan.

GENUS NUCULOPSIS Girty.

Nuculopsis ventricosa (Hall).

(Pl. VIII, figs. 2-2c.)

1915. *Nuculopsis ventricosa.* Girty, Bull. U. S. Geol. Surv., No. 544, p. 117, pl. 15, figs. 1-8.

Shell small, transversely elliptical, the valves strongly convex. The dimensions of a medium-sized individual are: Length, 9 mm.; height, 6 mm.; convexity of both valves, 5 mm. Basal margin curving regularly, except for a slight indentation just behind the anterior extremity, to the posterior extremity, which is somewhat narrowly rounded. Anterior margin narrowly rounded and shorter than the posterior margin. Cardinal margin with about the same degree of curvature as the basal; curving abruptly into the anterior, and gently into the posterior margin. Beaks broad, prominent, strongly incurved and directed toward the anterior end of the shell. Lunule poorly defined, forming a slight concavity just below the beaks. Escutcheon scarcely distinguishable. Ligamental grooves present, but only slightly defined. The surface of the shell is nearly smooth, but close examination reveals the presence of faint concentric lines, the larger shells showing pronounced lines of growth.

The examples of this shell under observation are somewhat smaller than most of the specimens previously described, and they differ from them in having the anterior extremity a little more broadly rounded, and extended farther, but careful comparison with specimens from other localities suggests that these differences are due to a difference in the stage of growth. These Kansas specimens also seem to be slightly dwarfed.

Horizon and locality. Drum limestone, oölitic member, Turner and Muncie, Kan.

FAMILY LEDIDÆ.

GENUS LEDA Schumacher.

Leda bellistriata Stevens.

(Pl. VIII, figs. 7-7c.)

1915. *Leda bellistriata.* Girty, Bull. U. S. Geol. Surv., No. 544, p. 122, pl. 14, figs. 1-9a.

Shell small, longer than high, fairly convex and quite attenuate. The dimensions of an average-sized specimen are: Length, 8 mm.; height, 4.5 mm.; convexity, 3.5 mm. Anterior margin regularly rounded and passing into the basal margin, which is semielliptical in outline near the front, but becomes straight or slightly concave near the posterior extremity. Posterior extremity subangular. Cardinal margin concave posteriorly, anteriorly convex and rounding into the anterior margin. Umbonal ridge well defined; umbones most prominent just below the beaks. Beaks prominent, close together, extending well beyond the hinge line, directed backward, and situated just in front of the middle of the shell. Escutcheon well defined, nearly flat or with a slight concavity between the umbonal ridge and the hinge, and extending to the posterior extremity. Lunule poorly defined. Posterior portion attenuated, extremity slightly gaping. Anterior extremity slightly gaping. Surface ornamented with fine, regular, concentric lines which become obsolete on the posterior umbonal ridges.

This little shell agrees very well with specimens previously described. The umbonal ridge seems to be a little more strongly downcurved, the cardinal margin is hardly visible from the side, and in some specimens the basal margin seems to be a little more strongly curved. It differs from *L. arata* Hall in the evenness and fineness of the surface ornamentation, in the curvature of both the umbonal ridge and the ventral margin, as well as in its small size. It is much less attenuate then *L. meekana* and the beaks are nearer to the middle.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Turner and Independence (station 23), Kan.

GENUS YOLDIA Moller.

Yoldia glabra Beede and Rogers.

(Pl. IX, figs. 1-3.)

1899. *Yoldia glabra.* Beede and Rogers, Kan. Univ. Quart., vol. 8, No. 3, p. 133, pl. 34, figs. 4a-4b.)

1900. *Yoldia glabra.* Beede, Kan. Univ. Geol. Surv., vol. 6, p. 153, pl. 21, figs. 4a-4b.

1915. *Yoldia glabra.* Girty, U. S. Geol. Surv. Bull. 544, p. 126, pl. 13, figs. 9-15.

Shell much compressed, very thin, transversely elongate and nearly twice as long as high; widest part of the shell a little in advance of the middle. Anterior extremity somewhat narrowly rounded; posterior extremity very narrowly rounded; ventral margin broadly semielliptical; cardinal margin convex in front of the beaks, concave behind them, but becoming nearly straight before the posterior extremity is reached. Hinge line nearly straight. Escutcheon narrow, lancelike, and poorly defined. Greatest convexity near the middle, from which the sides slope gently to the margins. Beaks situated slightly in front of the middle, depressed, incurved and directed backward. Surface ornamented by fine regular concentric lines, which become obsolete at the cardinal margins.

Most of the shells of this species are broken so that it is not possible to give dimensions of mature forms. A small, nearly complete shell gives the following dimensions: Length, 14 mm.; height, 7.5 mm.; convexity, 2 mm. (right valve).

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Turner and Cherryvale (station 40), Kan.

FAMILY PARALLELODONTIDÆ.

GENUS PARALLELODON Meek.

Parallelodon sangamonensis (Worthen).

(Pl. IX, figs. 17-17a.)

1916. *Parallelodon sangamonensis.* Mather, Bull, Sci. Lab. Den. Univ., vol. 18, p. 214.

Shell rather large, transversely elongate, equivalve, inequilateral. Dimensions of a large individual are: Length, 40 mm.; length of hinge line, 34 mm.; height, 18 mm.; convexity, 8 mm. The anterior margin meets the hinge at nearly right angles, extends downward and curves backward into the ventral margin which is somewhat sinuous near the middle. Posterior margin obliquely truncated so as to meet the hinge at an oblique angle; posterior extremity narrowly rounded. Hinge line straight, subparallel to the ventral margin but diverging from it slightly from front to back, and about seven-eighths as long as the entire shell. Beak depressed, incurved, directed forward, extending above the hinge line, and situated about one-fifth the length of the shell behind the anterior margin. Area above the umbonal ridge depressed, subalate. On the umbonal region, a broad shallow depression extends from near the beaks backward and downward to the margin of the shell, causing a slight sulcus in the outline, and some specimens show a second less oblique depression in front of this. Surface of the shell marked by radiating ribs, of which there are six or seven above the umbonal ridge, where they are broadest and strongest, and about twenty-nine on the remainder of the shell. On the umbones the radiating ribs are nearly obsolete, but near the margins they are strong except in the middle portion.

These specimens differ from *P. sangamonensis* Worthen in their smaller size, in the possession of two constrictions in many cases and in the lack of striations on the anterior portion of the shell, where rather strong ribs are observed instead. They differ from *P. striata* (Schloth) in the straighter ventral margin and in the obsolete area in the middle portion of the shell.

Horizon and locality. Drum limestone, oölitic member, at Turner, Cherryvale (station 40) and Independence (stations 12, 23), Kan.

Parallelodon kansasensis Sayre, n. sp.

(Pl. IX, figs. 4-7.)

Shell small, subquadrate, inequilateral, equivalve, and somewhat convex. Dimensions of a rather large specimen: Length, 23 mm.; height, 10 mm.; length of hinge line, 19 mm.; convexity of left valve, 4.5 mm. Hinge line straight, a little shorter than the greatest length of the valve, extending to the anterior extremity, from which the anterior margin extends downward and curves backward into the ventral margin, which is subparallel to the hinge line and is sometimes faintly sinuous near the middle. Posterior margin truncated obliquely so as to meet the hinge line at an oblique angle; posterior extremity narrowly rounded. Beaks placed about one-fourth of the length of the shell behind the anterior extremity, extending beyond the hinge line, flattened, incurved and directed obliquely forward. Umbonal region marked by a broad depression which extends obliquely backward from the beak and sometimes causes a faint sulcus in the ventral margin. Umbonal ridge rounded, directed obliquely backward from the beak to the posterior extremity. Above the unbonal ridge the shell is depressed to the hinge line. Surface marked with irregular, concentric lines of growth which are of variable strength and sometimes attain the prominence of low, rounded ridges. Portion above the umbonal ridge marked with radiating striæ, which are, in some cases, found also upon the umbonal ridge, but do not extend to the rest of the surface. Hinge narrow, bearing six teeth in front and ten behind; those nearest the center are perpendicular, while on each side they become successively more inclined until the outer teeth are subparallel to the hinge line.

This species is closely related to *P. tenuistriata* Meek, but differs from that species in the absence of radiating striæ on the anterior portion of the shell and in the less-pronounced sinus on the umbonal region.

Horizon and locality. Drum limestone, oölitic member, at Turner, Cherryvale (station 40) and Independence (stations 12, 23), Kan.; and Kansas City, Mo.

FAMILY CONOCARDIDÆ.

GENUS CONOCARDIUM Bronn.

Conocardium parrishi Worthen.

(Pl. IX, figs. 20-20c.)

1915. *Conocardium missouriensis.* Girty, Mo. Bureau Geol. and Mines, vol. 13, 2d ser., p. 353, pl. 28, figs. 3-3c.

Shell small, equivalve, inequilateral, length slightly greater than height. Posterior margin slightly sinuous and somewhat longer than the anterior; hinge line straight. Umbones prominent and sharp, with the sides sloping down to the margins rather more abruptly in front than behind. Beaks small, situated in front of the middle, extending beyond the cardinal margin and apparently anchylosed. Cardinal margin smooth except for fine concentric striæ and raised above the hinge line so as to form with it a V-shaped trough. Shell widely gaping behind and extended in front into a tubelike rostrum, which is slightly inclined upward from the end of the hinge. Anterior portion of the shell marked by eight strong, angular, radiating costæ, which increase by bifurcation so that only six of them reach the cardinal margin. Posterior portion marked by about thirteen radiating costæ, separated by angular furrows as on the anterior portion; but these are crossed by numerous liræ which give this portion of the shell a reticulated appearance. Dimensions: Height, 7 mm.; length, 11 mm.; convexity, 5.5 mm.; length of rostrum, 3 mm.

This group of fossils agrees with *C. parrishi* Worthen in every respect save the reticulation of the posterior portion of the shell, of which he makes no mention. In his figure, however, these are indicated. These fossils also agree with *C. missouriensis* Girty, some specimens showing the nodes which he mentions on the umbonal ridge, while others lack any indication of nodes. All three are from the same locality and the same horizon. Many of the fossils found in the oölitic member of the Drum limestone are coated with varying thicknesses of hard calcium carbonate, which may obscure the markings and make determination difficult. It seems probable therefore, that they are identical.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo., Independence (station 23), Kan.

FAMILY PTERIIDÆ.

GENUS PTERIA Scopoli.

Pteria longa (Geinitz).

(Pl. IX, figs. 13-14.)

1900. *Pteria longa.* Beede, Univ. Geol. Surv. Kan., vol. 6, p. 125, pl. 16, fig. 4.

Shell small, elongate, convex and obliquely alate. Shell elongate, more or less arcuate, the umbo curving from the beak obliquely backward and downward to the posterior extremity. Anterior extremity narrowly rounded. Ventral margin curving, with a pronounced sulcus about one-third the distance from the anterior extremity. Posterior extremity narrowly rounded. Cardinal margin slightly curved, parallel with the ventral margin, and separated from the ear by a deep sinus. Hinge line, equaling about two-thirds the length of the oblique body portion of the valve, provided with a marginal ridge which is much produced into a long, pointed ear posteriorly. Anterior ear much shorter and broader, somewhat pointed and only slightly convex. Beaks very convex, pointed, and extending beyond the hinge line, placed one-fourth to one-fifth the length of the hinge behind the anterior extremity. Umbo prominent, with the sides of the shell dropping abruptly to the cardinal margin and rounding downward to the ventral margin. Dimensions: Greatest length, 15 mm.; height, 7 mm.; length of hinge line, 12 mm.

Only one of the fossils in this group is of normal size. This is a cast of the left valve. There are, however, a number of smaller specimens which are proportionally longer and thinner, and lack the pronounced sinus of the larger shell. These are referred to the same species.

Horizon and locality. Drum limestone, Oölitic member, at Kansas City, Mo.; Turner and Independence (stations 12, 23), Kan.

Pteria welleri Sayre, n. sp.

(Pl. IX, figs. 15-16.)

Shell small, elongate, obliquely alate. Hinge line straight, equaling about half the length of the oblique body portion of the shell. Anterior margin truncate, meeting the hinge at an angle of nearly 90 degrees. Posterior margin narrowly rounded; cardinal margin straight; ventral margin gently convex and, except for a slight sinus about one-fourth the distance from the anterior margin, subparallel to the cardinal margin, and oblique to the hinge line. Ears small; posterior ear longer than the anterior, rounded distally, flattened and separated from the body by a shallow sinus; anterior ear small, flattened, triangular, depressed, and set off from the body by the abrupt rise of the umbo. Umbo strongly convex, the shell dropping abruptly from it to the cardinal margin and curving to the ventral margin. Umbo crossed by a broad, shallow sulcus extending from near the beak in a direction almost perpendicular to the hinge line, to the margin where it causes a slight sinus in the outline. Beak prominent, extending beyond the hinge line and directed forward. Surface marked by fine, irregular, concentric lines of growth. In the sulcus and parallel to it is a strong ridge which extends nearly to the hinge. Behind the lower half of this ridge and perpendicular to it, but never touching it, are six or seven, sometimes less, parallel ridges separated by furrows of about equal width, and which are equal in length to about one-tenth of the shell, while in front of it there are two to three ridges similar to those behind. On the posterior wing, convex lines of growth are rather pronounced, and are crossed by two or three radiating lines which extend backward from the beak, and give it a very pretty reticulated appearance. Dimensions: Height perpendicular to the hinge, 3.5 mm.; length, 8 mm.; length of hinge line, 5 mm.; convexity, 1.5 mm.

This species is similar to *P. sulcata* Geinitz in some respects, but differs from it in being much smaller, more elongate, with a shorter posterior ear, and in having only one ridge or wrinkle across the umbo. Doctor Weller had in his collections from the Chester series several shells which were very similar in appearance and in size.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Turner and Independence (station 12), Kan.

GENUS MONOPTERIA Meek.

Monopteria marian White.

(Pl. IX, figs. 18-19a.

1900. *Limopteria marian.* Beede, Univ. Geol. Surv. Kan., vol. 6, p. 128, pl. 16, figs. 5-5c.

Shell convex, alate, obliquely elongated, and pointed on the posterior extremity. The dimensions of a rather small individual are: Height, 24 mm.; length, about 40 mm.; length of hinge, about 25 mm.; convexity, 10 mm. (the posterior end of the body and the wing are broken off slightly). Posterior ear depressed nearly flat, attenuate and separated from the shell by a deep, narrowly rounded U-shaped sinus. Cardinal margin straight, subparallel to the hinge line; posterior extremity narrowly rounded; ventral margin extending forward in a nearly straight line to about the middle of the shell, from which point it is regularly curved to the lunular area; anterior margin obliquely truncate. Umbonal ridge prominent, curved; the shell sloping abruptly from it on the posterior cardinal side, and on the anterior side, gently at first, but with increasing curve to the anterior and basal margins. Beak prominent but not extending appreciably beyond the hinge line. Hinge line straight. The surface is marked by concentric lines and occasional lamellæ of growth which are about parallel to the outline of the shell. The beak is slightly behind the anterior extremity of the shell. Lunule deep and sharply defined.

This shell varies in length and in the width of the body of the shell. It differs from *M. gibbosa* in having a longer spine, considerably less height, and less curvature to the anteroventral margin. The umbo is more angular than in *M. longispina,* and the form is more slender.

Horizon and locality. Drum limestone, oölitic member, at Turner, Kan., and Kansas City, Mo.

Monopteria longispina (Cox).

(Pl. IX, figs. 8-9.)

1900. *Limopteria longispina.* Beede, Univ. Geol. Surv. Kan., vol. 6, p. 127, pl. 16, fig. 6.

Shell large, oblique, slender, alate, and nearly equivalve. Dimensions of a rather small specimen: Length, 39 mm.; height, 28 mm.; length of hinge, 21 mm.; convexity of left valve, 9 mm. Shell wide anteriorly tapering to a rather narrowly rounded posterior extremity. Basal margin straight from the posterior extremity to a point directly below or slightly behind the beak; then curving upward to the anterior margin, which is nearly perpendicular to the hinge line. Anterior margin obliquely truncated above by the lunule, which is slightly concave in outline. Hinge line straight, equaling nearly three-fourths the total length of the shell. Posterior ear well developed, depressed, narrowly rounded posteriorly, and separated from the body of the shell by a deep U-shaped sinus. Umbo a strong, prominent, rounded, backward-curving ridge from which the sides of the shell drop abruptly to the margin above, while below they are slightly depressed, but extend nearly parallel to the plane of the shell and curve abruptly downward near the anterior and basal margins. Beak prominent, extending well beyond the hinge line, directed forward, incurved and situated about one-fourth the length of the shell behind the anterior extremity. Lunule subelliptical, deep, concave, and very pronounced. Surface marked by fine concentric lines of growth, which become rather coarse near the margins.

The extreme prominence of the beak is one of the outstanding characteristics of this species; this, with the relatively greater height, will serve to distinguish it from *M. marian.*

Horizon and locality. Drum limestone, oölitic member, at Turner and Elsmore (station 46), Kan.

GENUS PSEUDOMONOTIS Beyrich.

Pseudomonotis hawni (Meek and Hayden).

(Pl. X, figs. 1-2.)

1909. *Pseudomonotis hawni.* Girty, Bull. U. S. Geol. Surv., No. 369, p. 79, pl. 9, fig. 4.

Meek and Hayden's description: "Shell subcircular, or subovate; hinge straight, equaling about half the length of the valves; beaks subcentral, short, not oblique; ears nearly obsolete; base rounded; anteroventral and posteroventral margins rounded, the latter being somewhat more rounded than the other. Left valve convex; anterior margin sometimes slightly sinuous near the hinge above; posterior margin intersecting the hinge at an obtuse angle; beak convex, extending but little beyond the hinge line. Right valve nearly or quite flat; back flat, not projecting beyond the hinge line; byssal sinus narrow, deep and extending back parallel to the hinge to a point nearly under the beak. Surface of both valves, particularly the left one, ornamented by more or less distinct radiating costæ, which are usually separated by a space three or four times their own width, and armed with regularly disposed, vaulted, spinelike prominences, formed apparently from the projecting laminæ of growth. Between each two of the principal radiating costæ from one to three or four much smaller radiating ribs or lines are usually seen, crossed by obscure concentric markings. Hinge and muscular impressions unknown. Length, 1.47 inches; height, 1.42 inches; convexity, about 0.40 inch."

This form is distinguished from others by its subcircular outline and by the character of its radiating costæ separated by three to four or less radiating striæ.

Horizon and locality. Drum limestone, oölitic member, at Turner, Muncie, Urbana (station 43), Independence (stations 12, 23), Cherryvale (station 40), Kan., and Kansas City, Mo.

Pseudomonotis kansasensis Beede.

(Pl. X, fig. 6-7.)

1915. *Pseudomonotis kansasensis.* Girty, Bull. U. S. Geol. Surv., No. 544, p. 129, pl. 17, figs. 4-4a.

Beede's description: "Shell large, ovate in outline, rather compressed; beak moderately prominent, projecting beyond the hinge, which is nearly straight. Anterior ear small, rounded to meet the hinge, rather flat, the shell rising rather abruptly to the swell of the umbo. Anterior margin slightly sinuate; antero-ventral margin broadly rounded to the ventral portion of the shell, where it becomes nearly straight, then rounding more abruptly to the posterior ear, which is also rounded to the hinge. Greatest convexity a trifle below the beak, but it is very slight. The surface is marked by many fine, wavy, radiating striæ of uniform size, extending from the beak to the ventral margin; occasionally one striation will be a trifle larger than another on the central portion of the shell, but it soon loses itself, and on old individuals the striæ on the ventral border are all about equal. They increase by implantation and are rather sharply defined, separated by troughs from one to three times their own width, and are generally crossed by fine concentric lines or laminæ; right valve unknown. Height, 62 mm.; length, 69 mm.; length of hinge, 23 mm.; convexity, 10 mm.

"This species differs from *P. hawni* in always having small, regular striæ and shorter hinge in the large individuals, as well as being a larger species."

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Turner, Urbana (station 43) and Independence (station 12), Kan.

Pseudomonotis ? robusta Beede ?

(Pl. X, fig. 5.)

1899. *Pseudomonotis ? robusta.* Beede, Kan. Univ. Quart., vol. 8, p. 82, pl. 18, figs. 2-2c.

1900. *Pseudomonotis ? robusta.* Beede, Univ. Geol. Surv. Kan., vol. 6, p. 133, pl. 14, figs. 2-2c.

Beede's description: "This shell differs from the preceding* in being much more convex and arcuate, in having a longer hinge, higher umbo, beak very much more compressed and scarcely distinct from the umbo, not projecting very sensibly above the hinge. The striæ are more regular and much fainter, and either very indistinct or absent on at least the upper third of the shell. Both concentric wrinkles and lamellæ of growth are distinct. Length, 48 mm.; convexity, 18 mm.; height, 42 mm.; length of hinge, about 28 mm.

"This species differs from *P. hawni* in being very arcuate, having a plain umbo, and full anterior and posterior outlines, and fine, even striæ on the margins. It differs from *P. kansasensis* in its broad, smooth umbo and indistinct beak, long hinge and more circular outline."

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Turner and Independence (stations 12, 23), Kan.

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* *P. kansasensis.*

Pseudomonotis equistriata Beede.

(Pl. IX, figs. 10-12.)

1899. *Pseudomonotis hawni equistriata.* Beede, Kan. Univ. Quart., vol. 8, p. 82, pl. 18, figs. 3-3b.

1900. *Pseudomonotis hawni equistriata.* Beede, Univ. Geol. Surv. Kan., vol. 6, p. 134, pl. 14, fig. 3-3b.

1903. *Pseudomonotis equistriata.* Girty, Prof. Paper, U. S. Geol. Surv., No. 16, p. 428, pl. 8, fig. 5.

Beede's description: "Shell of medium size, ovate in outline, moderately to quite gibbous, a little oblique with respect to the hinge; beak moderately prominent, extending to or a little beyond the hinge, which is about half the length of the shell and somewhat arcuate. Umbo quite gibbous. Posterior ear very slighty developed, merging into and forming a slight sinus in the posterior margin; ventral, anteroventral and posteroventral margins regularly rounded; anterior margin sinuate in the upper portion on account of the anterior ear, which is small and round. The surface is marked by fine, somewhat regular, rather wavy striæ, which increase by intercalation, each fourth to tenth being usually a little larger than the remainder, though not very conspicuously so. Small lamellæ of growth sometimes distinguishable. Some of the striæ extend nearly to the beak. The right valve is flat or a little concave; otherwise unknown. Measurements of two specimens: Height, 31 mm., 34 mm.; length, 24 mm., 26 mm.; convexity, 7 mm., 13 mm.; length of hinge, 12 mm., 16 mm. These two specimens represent the extremes of convexity.

"This variety differs from *P. hawni* in being a shorter shell and a little more convex, having regular striæ, and in being a little smaller. *P.* cf *hawni,* in the article above referred to, should also be considered as a true member of the species. The species here separated are, I believe, distinct from *P. hawni;* and this variety is worth varietal distinction, as often shells of these kinds are found in localities where others are absent, and some method of distinguishing the two forms of the species is necessary."

The specimens at hand are somewhat more convex than those figured by Beede.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (stations 12, 23), Kan.

Pseudomonotis spinosa Sayre, n. sp.

(Pl. X, figs. 3-4a.)

Shell below medium size, subovate and rather convex. Dimensions of a fairly large specimen: Height, 24 mm.; length, 24 mm.; length of hinge about 7 mm.; convexity, 8.5 mm. Hinge short, straight, and slightly oblique, meeting the anterior margin at an angle slightly greater than 90 degrees. Anterior margin slightly sinuous in the middle and rounding into the basal margin. Basal margin regularly arched and rounding into the posterior margin, which is somewhat extended to the rear in a regular curve, but becomes straight just a little above the middle of the shell and slants in to the hinge, meeting it at any angle greater than 90 degrees. Ears slightly flattened and not marked off from the shell except by a slight sinuosity. Umbo prominent, rounded, and subcentral; sides sloping more abruptly to the anterior margin than to the posterior. Beak prominent, well demarked, sharp and extending past the hinge. Surface ornamented by three concentric bands: The first, from the beak for a distance of 8 mm., appearing smooth and only marked by very fine growth lines; below this for a distance of 12 mm. the surface is ornamented by regularly arranged, closely spaced, minute spines, and shows only traces of radiating and concentric lines; from this point to the border is a concentric ring on which the shell is folded into numerous short, broad ribs, separated by furrows of a little more than their width. This concentric band is also covered with regularly arranged spines. Right valve unknown.

The outline of this species is variable, as is the convexity; in some cases the ears appear to be better marked than in others, but the three concentric bands, the beak portion of the umbo smooth, the middle portion marked only by spines, and the marginal area marked by plications and spines, are characteristic of the species. In its general outline and in its variability of form this shell appears to be a Pseudomonotis, and it is referred to that genus temporarily. However, a knowledge of the right valve and the interior is necessary before it can be definitely placed.

Horizon and locality. Drum limestone, öolitic member, at Kansas City, Mo.; Turner and Independence (stations 12, 23), Kan.

FAMILY MYALINIDÆ.

GENUS MYALINA De Koninck.

Myalina kansasensis Shumard.

(Pl. X, figs. 9-10a.)

1900. *Myalina kansasensis.* Beede, Univ. Geol. Surv. Kan., vol. 6, p. 140, pl. 16, fig. 11.

Shell subrhomboidal, inequilateral, and somewhat gibbous. The dimensions of a fairly large specimen are: Height from beak to ventral margin, 59 mm.; width perpendicular to the elongation of the shell, 29 mm.; width of hinge line, 33 mm.; convexity, 11.5 mm. Left valve, the cardinal margin forms an angle of about 60 degrees to the anterior margin of the shell; it is straight and makes an angle of about 120 degrees with the posterior margin. Posterior margin straight near the hinge, but becoming more and more rounded until it curves into the rather narrowly rounded basal margin. Anterior margin sinuous, being rounded at the base and becoming concave a little more than half way up to the beak. Umbo prominent; sloping very abruptly to the anterior margin and more gently to the posterior. Beaks terminal, attenuated, extending obliquely forward and slightly twisted and incurved. Surface with strong nearly equidistant concentric, imbricating lamellæ, whose free edges are often irregularly crenate. The ligament face is broad, marked with a number of close-set, equidistant, parallel lines which are parallel to the cardinal margin. Right valve a little less convex than the left. Beak sharp, incurved, twisted, and terminal. Surface marked by strong, imbricating, concentric lamellæ which show slight traces of crenulations.

This species may be easily distinguished by its crenate lamellæ when these are preserved, and by the small angle of the hinge line with the anterior margin.

Horizon and locality. Drum limestone, oölitic member, at Turner, Muncie, Cherryvale (station 40) and Independence (stations 9, 12, 23), Kan.

Myalina (?) swallovi McChesney.

(Pl. X, figs. 8-8b.)

1900. *Myalina swallovi.* Beede, Univ. Geol. Surv. Kan., vol. 6, pl. 16, p. 137, fig. 7.

Shell of medium size, modioliform, and somewhat gibbous on the umbones. The dimensions of a rather large specimen are: Height perpendicular to the hinge, 24 mm.; length oblique to the hinge, 36 mm.; length of the hinge line, 21 mm.; convexity of right valve, 7 mm.; obliquity, about 40 degrees. Ventral margin somewhat sinuous, bulging below the beak, concave in the middle, and narrowly rounded into the posterior margin. Posterior margin gently and regularly rounded into the cardinal margin, which is slightly arched. Umbonal ridge prominent, nearly straight, but with a slight curvature near the beak; subparallel to the posterior margin, narrowly rounded, with sides of shell sloping gently to the posterior margin, but dropping abruptly to the ventral margin on the lower half of the shell; and in the upper half separated from the bulge by a narrow, shallow sulcus, which extends from the hinge just in front of the beak obliquely backward to the middle of the ventral margin. Beak small, not pronounced, extending but slightly beyond the hinge line, subterminal, slightly twisted and directed forward. Surface ornamented by numerous fine concentric lines which become stronger near the border of the shell. Hinge area marked by one or sometimes two impressed lines which are parallel to the margin. Shell thin.

This species is quite common in the oölitic member of the Drum limestone, and the numerous specimens show some variation in form. The umbonal ridge is more narrowly rounded in some cases than in others, and the sulcus in front of the umbonal ridge is variable in prominence, being hardly discernible in some specimens; while in some specimens the umbonal ridge is more oblique than in others. These variations, however, seem to be conditions of growth, and there can be little doubt as to the correctness of this identification.

Concerning this species Meek says in his Nebraska report: "The cardinal plate, as seen in authentic specimens from Illinois, is quite narrow, and shows only obscure traces of two cartilage furrows. As I have been unable to see any traces of prismatic structure in the shell, there may be some reason for doubting whether this is a true *Myalina*." According to De Koninck's description of the genus *Myalina*, it is thick-shelled, with terminal beaks and a broad cardinal plate bearing numerous parallel, impressed lines. The species under discussion is thin-shelled, with a narrow hinge plate bearing one or two impressed lines, and the beaks are not quite terminal. From this evidence *Myalina swallovi* is not a true member of the genus *Myalina*, but would appear to be more properly considered a member of the genus *Modiola*. Muscle scars and pallial lines are not discernible on any of the casts in the collections at hand.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Turner, Muncie, Cherryvale (station 46), Urbana (station 43) and Independence (stations 9, 12, 23), Kan.

Myalina (?) slocomi Sayre, n. sp.

(Pl. XI, figs. 1-1a.)

Left valve large, convex, oblique-subquadrate in outline, the dimensions of an apparently full-grown specimen being: Height from beak to basal extremity, 67 mm.; length, 33 mm.; length of hinge line, 42 mm.; convexity, 13 mm.; angle between the hinge and the anterior margin, 76 degrees. The outline of this shell in its anterior-basal-posterior outline is U-shaped, the basal margin being subsemicircular, and the anterior and posterior margins being nearly parallel, except for the upper portion of the anterior margin, which is slightly concave. The beak curving forward, subterminal, twisted, and extending slightly beyond the hinge line; hinge line slightly arched. Umbonal ridge rounded and sloping downward rather abruptly on the lower portion of the anterior side, but sloping gently on the posterior side. The reverse of this is true near the beaks due to the twisting of the beak and the bulging of the superior anterior margin. Umbo separated from the margin in the upper portion by a shallow sulcus extending from about the middle of the anterior side obliquely forward toward the hinge, but dying out before reaching it. Surface crossed by numerous fine concentric striæ and rather distant imbricating lamellæ. Hinge area narrow, with two subparallel grooves at the beak, of which the inner one extends into the valve and becomes obsolete, and the outer one extends for nearly the length of the hinge. Shell thin; interior unknown.

On the exterior, this shell has somewhat the appearance of *M. subquadrata*. It differs from that species in that the beak is not nearly so elongate anteriorly, in the straightness of the posterior margin, which shows no sign of sinousity, in the narrow hinge area, in being thin-shelled, as well as in its oblique cardinal margin. This shell shows the same general characteristis as *Myalina* (?) *swallovi*. It, too, is probably not a true *Myalina*, but must be placed in some other genus.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (stations 12, 23), Kan., and Kansas City, Mo.

FAMILY TRIGONIIDÆ.

GENUS SCHIZODUS King.

Schizodus harii Miller ?

(Pl. XI, figs. 4-4b.)

1892. *Schizodus harii.* Miller, 17th Rep. Geol. Surv. Ind., p. 701, pl. 20, figs 1-3.

Shell large, subovate, quite convex, equivalve, inequilateral. Anterior margin regularly rounded; ventral margin semielliptical; posterior extremity subangular; posterior margin obliquely truncate so as to meet the hinge line at an angle of about 135 degrees. Beaks prominent, extending beyond the hinge line about one-seventh of the total height of the shell; rounded, incurved, directed forward and located slightly in front of the middle of the shell. Greatest convexity near the middle. Posterior umbonal slope nearly perpendicular to the plane of the valves, and forming with the shell a subangular ridge which extends from the posterior extremity to the beak. Anterior umbonal slope more gentle, but rather abrupt. Surface marked by rather fine concentric lines widely spaced. Anterior and posterior adductor scars subovate, strong and deep; situated on the umbonal slopes, slightly below the hinge line, and rather near the beak. Dimensions of a right valve: Length, 45 mm.; height, 36.5 mm.; convexity, 15 mm.; length of hinge line, 25 mm.

It is with some doubt that this shell is referred to *S. Harii*. The posterior margin is more clearly truncated than in that species, and the beak appears to be more nearly central. The posterior extremity is more pointed. In this respect the shell resembles *S. wheeleri*, from which species it differs, however, in the more centrally located beak and less-produced posterior side.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo., and Turner, Kan.

Schizodus trigonalis Sayre, n. sp.

(Pl. XI, figs. 2-2a.)

Shell under medium size, subtriangular and somewhat compressed. Dimensions of a large specimen (left valve) are: Length, 13.8 mm.; height, 12 mm.; convexity, 3.8 mm. Anterior margin subtruncate, rounding into the ventral margin, which is gently arched and at about 90 degrees to the anterior margin. Posterior extremity angular; posterior margin obliquely truncated; hinge line short. Beak somewhat depressed, subcentral, incurved, pointed and extending only a short distance beyond the hinge line. Posterior umbonal ridge prominent and extending from the beak to the posterior extremity; anterior more gently rounded and not so pronounced. Posterior umbonal slope perpendicular to the plane of the shell near the beak, but becoming slanting as the posterior extremity is approached, so that the posterior margin projects beyond the umbonal ridge. Surface almost smooth, but showing, under the magnifier, very fine concentric striæ.

This species differs from *S. securus* Girty in its short hinge line. It resembles *S. depressus* Worthen from the St. Louis group, but is more convex; the posterior extremity is more sharply angular, and the anterior margin is not so regularly curved.

Horizon and locality. Drum limestone, oölitic member, Muncie, Kan.

FAMILY PECTINIDÆ.

GENUS AVICULOPECTEN McCOY.

Aviculopecten providencesis (Cox).

(Pl. XII, figs. 1-2.)

1900. *Aviculopecten providencesis.* Beede, Univ. Geol. Surv. Kan., vol. 6, p. 119, pl. 13, fig. 2.

Shell large, subcircular, with the height equal to the width, rather convex. Dimensions of a large specimen are: Height, 71 mm.; greatest length, 71 mm.; length of hinge line, 41 mm.; convexity, 15 mm.; angle between the sides of the umbo, 87 degrees. Left valve large and rather convex, the greatest convexity being near the beak. Ventral margin regularly rounded from below the anterior ear to the posterior extremity, from which point it is straight, except for the ears, to the beak. The umbo is pronounced, the beak extending very slightly beyond the hinge line. Ears are depressed and subequal, the posterior one being a little the larger, and both being defined from the shell by the abrupt swell of the umbo. The anterior ear is separated from the body of the shell by a sharp, deep sinus, and is rounded upward, passing into the hinge line at an angle of about 90 degrees. The posterior ear is separated from the shell by a rounded, shallow sinus and terminates in a point. Surface of the shell ornamented by a number of radiating costæ made up of from two to five or six striæ, so as to give a fasciculated appearance to the shell. The striæ are present on the anterior ear, but only one or two of them are seen on the posterior ear. Crossing the costæ are numerous rather fine concentric lamellæ, which are difficult to discern on the body of the shell, but show up rather strongly on the ears.

The right valve and the interior of the shell are not known.

This species is easily distinguished by its fasciculated appearance. It resembles *A. chesterensis* Worthen in its fasciculation, but is a larger shell, more convex, and has larger, less numerous fascicles, and a longer hinge line.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Muncie and Independence (station 9), Kan.

Aviculopecten sculptilis Miller.

(Pl. XI, figs. 9-10.)

1892. *Aviculopecten sculptilis.* Miller, 17th Rep. Goel. Surv. Ind., p. 702, pl. 20, fig. 5.
1900. *Aviculopecten sculptilis.* Beede, Univ. Geol. Surv. Kan., vol. 6, p. 122, pl. 13, figs. 3-3b.

Shell rather large, auriculate, subovate exclusive of the ears, inequivalve, height greater than length. Left valve moderately convex. Lateral and ventral margins regularly rounded and tapering to the beak at an angle of about 90 degrees. Beak small, depressed and scarcely extending beyond the hinge line, situated about two-thirds of the way back from the anterior end of the hinge. Ears small, depressed and sharply defined from the swell of the umbo; anterior ear about twice the size of the posterior, and each is separated from the shell by a more or less distinct sinus in the margin. Both ears are marked by well-defined concentric striæ, and the anterior ear shows faint traces of radiating lines. Surface of the shell marked by fine, regular, concentric lines crossed by equally prominent and closely set radiating lines, which give the shell a beautifully reticulate appearance. Near the borders the enlargement of these lines gives a very rough appearance to the shell. Dimensions: Length, 41 mm.; height, 49 mm.; length of hinge line, 17 mm.; convexity of left valve, 8 mm.

This shell differs from *A. hertzeri* in being more slender, with a more acute angle at the beak, and is a larger shell.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Turner and Independence (stations 9, 12, 23), Kan.

GENUS DELTOPECTEN Etheridge.

Deltopecten occidentalis (Shumard).

(Pl. XI, figs. 5-8.)

1916. *Deltopecten occidentalis.* Mather Bull. Sci. Lab. Den. Univ., vol. 18, p. 227.

Shell of medium size, pectenate, subovate, not oblique, inequivalve. Left valve moderately convex, with ears subequal; anterior ear rather sharply defined from the swell of the umbo by a broad groove, rounded at the tip and marked with distinct radiating costæ. Posterior ear pointed, flattened, and not so well defined from the umbo, sometimes without radiating costæ, but in other cases having them well developed. Both ears separated from the shell below by a rounded, broad sinus, which is deeper on the anterior side than on the posterior. Surface of the shell covered with radiating costæ generally of unequal width, of which only the largest extend to the beak, while the others die out at various distances from the beak. Crossing these are numerous fine concentric lines, some of which sometimes form vaulted scales on the costæ of the ears, particularly the anterior one, and generally these vaulted projections are well and strongly developed on the posterior costa of the body part of the shell.

Right valve much flatter than the left, but having the same general outline. Beak depressed and hardly distinct from the hinge line. Anterior ear defined from the body of the shell by a sharply angular sinus; posterior ear defined by a broad rounded sinus. Surface of the body of the valve marked by broad, low, radiating costæ separated by depressions of less than a quarter of their width and crossed by fine, indistinct concentric lines which extend to the ears, while the radiating costæ do not appear on the posterior ear, and only rarely on the anterior. Interior nearly smooth except for narrow, rather widely separated, radiating lines. The muscular area is very obscure on the posterior side of the body of the shell and about two-thirds of the distance from the margin to the beak. A more or less serrate ridge extends along the hinge line. A mature specimen measures: From beak to ventral margin, 28 mm.; length, 23 mm.; length of hinge line, 21 mm.; convexity, 5 mm.; angle of the umbo, 78 degrees.

This species is abundant in the Drum limestone, and in a large number of specimens shows minor variations. Occasionally a slightly oblique specimen is found, the obliquity never being more than 5 degrees. Small specimens appear narrower than more mature ones. The hinge line varies somewhat in length.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Muncie, Turner, Elsmore (station 46), Urbana (station 43), Cherryvale (station 40) and Independence (stations 12, 23), Kan.

GENUS ACANTHOPECTEN Girty.

Acanthopecten carboniferus (Stevens).

(Pl. XII, figs. 5-6.)

1915. *Acanthopecten carboniferus.* Girty, Bull, U. S. Geol. Surv., No. 544, p. 134, pl. 17, figs. 10-10a.

Shell a little under medium size, auriculate, inequivalve, and with regularly arranged spines. Left valve convex, subcircular in outline, and with a serrate edge. Posterior ear separated from the valve by a well-defined sinus, and from the swell of the umbo by a rather strong sulcus. The ear is extended and terminates in a point. Anterior ear shorter, more obtuse, and defined from the umbo by a deep angular sulcus. Both ears flattened. Surface of the valve ornamented by fifteen to seventeen distinct, regular, angular plications, separated by furrows of like size, which terminate on the ventral border in short, strong spines. Numerous fine concentric lines may be seen by the aid of a hand lens. At intervals which decrease as the beak is approached, are found laminæ of growth which follow the outline of the shell, and provide a series of bands of spines on the surface of the shell. Beak prominent, but scarcely extending beyond the hinge line. The right valve is similar in outline to the left, but is much less convex, and the beak is much less prominent. Dimensions: Length, 21 mm.; height, 18 mm.; length of hinge line, 15 mm.; convexity of left valve, 5 mm.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.; Turner, Muncie, Elsmore (station 16), Urbana (station 43), Cherryvale (station 40) and Independence (station 12), Kan.

FAMILY PECTINIDÆ.

GENUS STREBLOPTERIA McCoy.

Streblopteria tenuilineata (Meek and Worthen).

(Pl. XI, figs. 3-3a.)

1860. *Pecten tenuilineatus.* Meek and Worthen, Proc. Acad. Nat. Sci. Phil., p. 452.

1866. *Streblopteria ? tenuilineata.* Meek and Worthen, Geol. Surv. Ill., vol. 2, p. 334, pl. 26, figs. 9 a-b.

1903. *Streblopteria tenuilineatus.* Girty, Prof. Paper, U. S. Geol. Surv., No. 16, p. 419.

Shell small, compressed, thin, subcircular in outline except for the ears. Dimensions of one specimen are: Greatest anteroposterior diameter, 14 mm.; height, 14 mm.; length of hinge line, 7.4; angle between sides of umbo, about 100 degrees.

Right valve compresed, subcircular and thin-shelled, with the anterior side wider than the posterior. From just below the posterior ear the margin is a regular semicircular curve to just below the anterior ear, which is separated from it by a sharp angular sulcus passing obliquely backward to the hinge, which also separates the ear from the umbo. Anterior ear larger than the other, convex, but not equaling the prominence of the umbo, and rounded on its anterior margin. Posterior ear triangular, nearly obsolete, obliquely truncated and compressed, defined by a very slight marginal sinuousity, and not separated from the umbo by a pronounced sulcus. Beak small, pointed, and rather compressed, terminating a little behind the middle of the hinge line and projecting very slightly beyond it. Anterior umbonal slope oblique and more distinct from the ear than the posterior one. Surface appearing smooth to the unaided eye, but with the aid of a lens fine concentric lines of growth may be seen closely spaced over the surface, and occasionally crossed by radiating lines which are even fainter. Anterior ear marked by concentric wrinkles.

One specimen of this species, which is a right valve, is found in the collections.

Horizon and locality. Drum limestone, oölitic member, at Turner, Kan.

FAMILY LIMIDÆ.

GENUS LIMATULA Wood.

Limatula ? fasciculata Girty.

(Pl. XII, figs. 7-8a.)

1911. *Limatula ? fasciculata.* Girty, New York Acad. Sci. Annals, vol. 21, p. 134.
1916. *Limatula ? fasciculata.* Girty, U. S. Geol. Surv., Bull. 544, p. 138, pl. 17, figs. 6-7.

Shell small, oblique, depressed, equivalve. Left valve obliquely subovate. Hinge line short; anterior and posterior margins nearly straight; anterior extremity narrowly rounded; ventral margin gently rounded and curving into the posterior margin. Beak small, depressed and extending slightly beyond the hinge line. Ears small, sloping down from the umbo, not much depressed; anterior ear slightly larger and somewhat more depressed. Ears not separated from the margins of the shell, but sloping gradually into them. Umbo prominent, with sloping sides. Surface of the valve marked by about forty radiating lines which become obsolete on the anterior and posterior margins, and which are grouped into fascicles of three or more lines each, and the fascicles are separated by rounded furrows of about half their width. These are crossed by very fine concentric striæ and a few lamellæ of growth, which may also be seen upon the ears. Right valve of essentially the same size, outline, and convexity. Although the markings are somewhat obscure, close examination indicates that they are similar to those on the left valve.

Dimensions: Length, 5 mm.; height, 6 mm.; length of hinge line, 2 mm.; convexity, 1 mm.

This shell is much smaller than *L. fasciculatus*, but the markings and general shape appear to be identical.

Horizon and locality. Drum limestone, oölitic member, at Turner, Kan.

FAMILY MYTILIDÆ.

GENUS LITHOPHAGA Lamarck.

Lithophaga subelliptica Sayre, n. sp.

(Pl. XII, figs. 9-9a.)

Shell small, slender, subelliptical, equivalve, convex. The dimensions of a rather large individual are: Length, 11.5 mm.; height perpendicular to the hinge line, 4.5 mm.; convexity, 1.8 mm. Anterior and posterior margins narrowly rounded, the anterior somewhat more narrowly than the posterior; ventral margin nearly straight, arching upward rather slowly distally to the posterior and anterior extremities. Hinge line straight or only slightly arched, equaling about three-fourths the entire length of the shell. Posterodorsal margin sloping obliquely forward, and nearly straight from the posterior extremity to the hinge line, and meeting the latter at only a slight angle. Shell convex, the umbonal region being extended at a slight angle to the hinge line. Beaks compressed, not extending beyond the hinge line and very nearly terminal. Surface of the valve nearly smooth, but fine concentric striæ, rather irregular in size, may be noted under the lens. Interior and hinge unknown.

This species resembles *L. pertenuis* Meek and Worthen, from the Mississippian, in general outline but is a much smaller form, has less prominent beaks, and is more oblique.

Horizon and locality. Drum limestone, oölitic member, at Turner and Muncie, Kan.

FAMILY PHOLADELLIDÆ.

GENUS ALLERISMA King.

Allerisma costatum Meek and Worthen.

(Pl. XII, fig. 10.)

1900. *Allerisma costatum.* Beede, Univ. Geol. Surv. Kan., vol. 6, p. 170, pl. 20, fig. 12.

Shell transversely elongate, equivalve, inequilateral and somewhat under medium size for the genus. The dimensions of a fair-sized shell are: Length, about 40 mm.; height, 15.5 mm.; convexity of right valve, 6 mm. Anterior margin rather short and narrowly rounded; basal margin forming a broad, nearly semielliptical curve; posterior portion compressed and truncated vertically from the base to a little over halfway up, and thence obliquely forward and upward to the cardinal margin. Posterior dorsal region compressed above the umbonal ridge. Hinge line straight, and equaling about two-thirds the entire length of the shell. Beaks convex, directed forward, extending slightly beyond the hinge line, and placed well forward on the shell. Lunule narrow, elongate, and extending from the beak to the anterior margin. Surface ornamented by strongly raised, sharp, angular, concentric costæ, which are separated by furrows about three times their width. They extend backward from the lunule, parallel to the margins, to the well-defined umbonal ridge, which extends from the posterior extremity to the beaks. Above the umbonal ridge they become much smaller and their number doubles on the flattened posterior cardinal region. They are crossed by a second ridge, less strong than the first, which extends from the middle of the posterior margin to the beak.

This shell seems to agree closely with Meek's description except that it is a little larger, and not so convex. He makes no mention of the doubling of the number of the costæ above the umbonal ridge, nor does he figure it. It is true that here they are less pronounced than below the ridge, but are certainly stronger than mere lines of growth on the lower portion of the area above the umbonal ridge, although above this they become more and more indistinct. In a later paper Meek again describes *A. costata,* and his figure does not show the truncation of the posterior portion, but simply a rounding of it, and lacks, besides, the second ridge on the depressed superumbonal region. In this figure, however, he shows the costæ doubling in number.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (stations 12, 23), Kan.

FAMILY PLEUROPHORIDÆ.

GENUS PLEUROPHORUS King.

Pleurophorus subcostatus Meek and Worthen.

(Pl. XII, figs. 11-13a.)

1900. *Pleurophorus subcostatus.* Beede, Univ. Geol. Surv. Kan., vol. 6, p. 161, pl. 20, figs. 11-11b.

Shell of medium size, elongate, moderately convex and equivalve. The dimensions of a fairly large specimen are: Length, 27 mm.; height, 12 mm.; convexity of one valve, 4 mm. Cardinal margin nearly straight and subparallel to the ventral margin, which is sometimes faintly sinuous along the middle. Posterior and anterior extremities rather narrowly rounded, the former being a little wider than the latter, and sometimes faintly subtruncate. Most convex portion of the shell along the umbonal ridge, which extends obliquely backward from the beak to the posterobasal margin. Beaks small, somewhat compressed, and not extending beyond the cardinal margin, directed forward and situated about one-ninth the length of the shell back from the anterior margin. Surface marked by fine concentric lines of growth and crossed on the posterodorsal region by about three faint radiating costæ. On the cardinal margin there is a strong, angular ridge, which marks the outline of a long lancelike escutcheon. Scar of the anterior adductor, subtriangular, deep, pointed above, and strongly defined by a prominent, nearly vertical ridge behind it. A broad, shallow sulcus crosses the umbo obliquely and extends from the beak obliquely backward to about the middle of the ventral margin.

This shell seems to be a little larger than Meek's shell, and the ventral margin makes a little greater angle with the cardinal margin. It is, however, almost certainly the form identified by Girty as *P. subcostatus*, from the Yeso Formation.

Horizon and locality. Drum limestone, oölitic member, at Turner, Elsmore (station 46), Cherryvale (station 40) and Independence (stations 12, 23), Kan.

Pleurophorus tropidophorus Meek.

(Pl. XII, figs. 14-15.)

1916. *Pleurophorus tropidophorus.* Mather, Bull. Sci. Lab. Den. Univ., vol. 18, p. 230.

Shell transversely elongate, compressed; length about twice as great as the height. Cardinal margin nearly straight, equaling about two-thirds the length of the valves. Anterior margin sloping abruptly forward from the beaks, rounded below, with the anterior extremity subtruncate and nearly vertical. Ventral margin long, parallel to the cardinal margin, forming a well-defined angle with the posterior margin and rounding upward anteriorly. Posterior extremity truncated vertically; posterocardinal margin truncated oblique to the hinge. Umbo angular, extending obliquely backward from the beak to the posteroventral extremity, while a second carina passes down the middle of the space above the umbonal ridge of each valve. Beaks depressed to the cardinal margin and directed forward, placed about one-fifth the length of the valves behind the anterior margin. Surface marked by distinct, concentric lines of growth, rather irregular in size, which are very strong on the anteroventral portion of the valves, but are less distinct above and behind the umbonal ridge. Shell thin.

The most characteristic features of this species are the increased strength of the lines of growth on the anteroventral portion of the shell, the truncations of the posterior margin, and the strong angulation of the posterior umbonal slope.

Horizon and locality. Drum limestone, oölitic member, at Turner, Cherryvale (station 40) and Independence (stations 9, 12, 23), Kan.

Pleurophorus attenuatus Sayre, n. sp.

(Pl. XII, figs. 3-4a.)

Shell of medium size, elongated transversely, equivalve, inequilateral, and moderately convex. The dimensions of a fairly large individual are: Length, 33.5 mm.; height, 11.5 mm.; convexity, 5.5 mm.

Cardinal and ventral margins straight and subparallel, but converging slightly toward the posterior end of the shell. Anterior and posterior margins narrowly rounded; posterior end a little more narrowly rounded. Hinge line equaling about two-thirds the length of the shell, and meeting the narrowly rounded posterior margin with only a slight angle. Umbonal ridge the most convex part of the shell and extending from the beak to the posteroventral extremity as a gently rounded ridge. Posterocardinal region depressed. Beaks depressed to the cardinal line, and situated near the anterior extremity. A broad, shallow sulcus extends obliquely downward and backward from the beaks to a little in front of the middle of the ventral margin. Surface marked by fine, irregular, concentric lines of growth. On the depressed area above the posterior umbonal ridge may be seen three to four small, more or less pronounced, radiating ridges. Escutcheon well defined, elongate, lance-ovate in form, and extending from the beaks to the posterior extremity of the hinge line. Anterior adductor trigonal-ovate in form and pointed above, deeply impressed and demarked by a strong, nearly perpendicular ridge which lies behind it; situated in front of the beaks and somewhat below them. Posterior adductor scar ovate, somewhat larger than the anterior muscular scar, situated below the posterior end of the hinge. Hinge unknown.

This shell is apparently closely related to *P. mexicanus* Girty, and also to *P. subcostatus* Meek. It differs from the former in having the ventral margin straight instead of arched, in being less convex, in having the posterior margin more rounded than truncate, and in being proportionately longer and narrower. It differs from the latter in having a longer, straighter appearance, in lacking the ventral sinuosity, and in being broader on the anterior end instead of the posterior.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (stations 9, 12), Kan.

Pleurophorus turnerensis Sayre, n. sp.

(Pl. XII, figs. 16-17a.)

Shell of medium size, transversely elongate, inequilateral, equivalve. Length more than twice the greatest height. Hinge line slightly arched and equaling about two-thirds the greatest length of the shell. Anterocardinal margin set somewhat below the beaks, parallel to the hinge line, and extending beyond the beaks about one-fifth the entire length of the shell. Anterior extremity nearly vertical; anterior margin rounding rapidly into the basal margin, which is straight or slightly sinuous and diverges slightly from the parallel with the cardinal margin posteriorly. Posterior extremity narrowly rounded; posterior margin slightly arched and meeting the hinge line at an angle of about 60 degrees. Convexity moderate, greatest just behind the middle of the shell. Posterior umbonal slope with a distinct ridge which extends from the beaks obliquely backward to the posterior extremity. Beaks depressed on a line with the hinge, and directed forward. Surface marked by fine concentric lines of growth, of which every seventh or eight is stronger than average. Shell thin.

This species is closely related to *P. taffi* Girty. It is possible that the two will be found identical, although *P. turnerensis* is smaller, higher in relation to its length, the anterior portion of the shell more extended, and the posterior margin at a greater angle to the hinge line.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (stations 12, 23), Kan.

FAMILY ASTARTIDÆ.

GENUS CYPRICARDINIA Hall.

Cypricardinia carbonaria Meek.

(Pl. XIII, figs. 1-2a.)

1900. *Cypricardinia ? carbonaria.* Beede, Univ. Geol. Surv. Kan., vol. 6, p. 164, pl. 20, fig. 16.

Shell small, inequilateral, equivalve, and oblique. The dimensions of a fairly large specimen are: Length, 12 mm.; height from the base to hinge line, 7.5 mm.; convexity of left valve, 3 mm.; length of hinge line, 7 mm. Anterior extremity narrowly rounded. Posterior margin obliquely truncate, meeting the hinge at an obtuse angle. Posterior extremity not so narrowly rounded. Ventral margin nearly straight or only slightly concave near the middle, oblique to the hinge, and rounding up at the ends. Hinge line straight, forming an acute angle with the ventral margin. Posterior cardinal area compressed and flattened, giving it a subalate appearance. Umbones prominent, rounded and oblique. Beaks oblique, directed forward, incurved, and nearly terminal, broad, and extending beyond the hinge line. There is a slight, broad, shallow sulcus at about the middle of the umbonal region, extending obliquely backward and downward from the beaks, and becoming obsolete at the margin. The surface is ornamented by numerous regular, broad, subimbricating, flattened, concentric lamellæ, which become closer and finer near the beak. On some specimens there are about nine radiating striæ located on the posterior umbonal ridge, and in most cases only touching the outer edges of the lamellæ, clearly seen in some cases, but very obscure in others.

These shells are a little narrower at the anterior end than Meek's figures show; and also he makes no mention of the radiating striæ. Nevertheless, it appears to be the same species or very closely allied to it, as these characters vary from specimen to specimen.

Horizon and locality. Drum limestone, oölitic member, at Turner, Muncie and Independence (stations 9, 12, 23), Kan.; Kansas City, Mo.

GENUS ASTARTELLA Hall.

Astartella gurleyi White.

(Pl. XIII, figs. 3-3a.)

1880. *Astartella gurleyi.* White, Cont. to Inv. Pal., No. 8, p. 166, pl. 42, figs. 6 a-b.

White's description: "Shell small, not very gibbous, subtetrahedral in outline; anterior end truncated from the beaks obliquely downward and forward to about midheight of the shell, where the front is sharply rounded to the somewhat broadly rounded basal margin; posterior margin broadly convex or sometimes almost straight and perpendicular, and adjoining both the basal and dorsal margins by abrupt curves; dorsal margin comparatively short, nearly straight; beaks small; umbones not elevated nor very prominent. An indistinctly defined umbonal ridge extends from each of the umbones to the posterobasal margin, behind which ridge the shell is slightly compressed. Surface marked by concentric furrows, which are separated by sharp linear ridges. Length of an average-sized example, 7 mm.; height from base to beaks, 4.5 mm.

"This species differs from *A. vera* Hall, from the same formation, in its smaller size, in the slight prominence and want of elevation of the umbones, the greater proportional projection of the front beyond the beaks, and in being wider behind than in front, the reverse being the case with *A. vera.*"

It is with some hesitation that this shell is referred to the species *A. gurleyi.* It differs from that shell in being larger, and lacks the faint sinuosity behind the beak which that shell shows. Otherwise it is much the same. Dimensions of my shell are: Height, 8 mm.; length, 11 mm. It differs from *A. concentrica* in having the beaks placed further forward, and in having less coarse striæ. *A. vera* shows similar differences.

Horizon and locality. Drum limestone, oölitic member, Turner, Muncie, Elsmore (station 46) and Independence (stations 12, 23), Kan.

GASTROPODA.

Family BELLEROPHONTIDÆ.

Genus Bellerophon Montfort.

Bellerophon stevensianus McChesney.

(Pl. XIII, figs. 7-7a.)

1860. *Bellerophon stevensianus.* McChesney, Desc. New. Pal. Foss., p. 61.
1865. *Bellerophon stevensianus.* McChesney, Ill. New Spec. Foss., pl. 2, figs. 18 a-c.
1868. *Bellerophon stevensianus.* McChesney, Trans. Chicago Acad. Sci., vol. 1, p. 46, pl. 2, figs. 18 a-c.

Shell small, subglobose, convolute, with only the last whorl visible. Volutions sublunate in outline, deeply impressed on the inner side. Aperture not expanded, interrupted on the outer lip by a fairly deep V-shaped slit; inner lip reflected at the sides. Umbilicus entirely closed. Surface marked by lines of growth which are strengthened to heavy wrinkles near the slit band, but become fine lines on the sides of the volution; lines broadly arched forward on the sides, bending backward into the slit band on the periphery. Slit band narrow, peripheral, slightly raised and flattened on top, margined on each side by a sharp, shallow, depressed line. Dimensions of two specimens: Breadth, 5 mm., 18 mm.; diameter, 6 mm., 20 mm.

This species differs from *B. crassus* in its smaller size, closed umbilicus, and in the nature of the slit band.

Horizon and locality. Drum limestone, oölitic member, at Turner, Muncie and Cherryvale (station 40), Kan.

Genus Patellostium Waagen.

Patellostium marcouianum (Geinitz).

(Pl. XIII, figs. 9-9a.)

1866. *Bellerophon marcouianus.* Geinitz, Carb. und Dyas in Neb., p. 7, tab. 1, fig. 12
1872. *Bellerophon marcouianus.* Meek, U. S. Geol. Surv. Neb., p. 226, pl. 4, fig. 17; pl. 11, figs. 13a-b.

Shell of medium size, convolute, volutions increasing rapidly in size, lip greatly expanded. Aperture subcircular, the lip flaring out in front and reflected in the rear so as to extend well beyond the apex of the shell; slit, as indicated by lines of growth, narrow, shallow, and V-shaped. Umbilicus deep and rather wide. Slit band a strong, raised median ridge margined on each side by a deep angular sulcus. Surface marked with fine, numerous, closely spaced longitudinal lines; crossed by obscure lines of growth which are arched forward from the umbilicus to a point near the slit band, where they are curved gently backward. On the flare, two weak concentric wrinkles are observed. Dimensions: Lip, 40 to 43 mm. in diameter; height of shell, 18 mm.

This shell differs from the shell figured by Geinitz in that the slit band is not so abruptly raised nor so roughened by growth lines. Meek states, however, that the shell figured by Geinitz shows these characters to an unusually marked degree, the majority of the representives of the species being less strongly marked. It is probably the same species or a very closely related form. It is distinguished from other species of the genus by its surface ornamentation and by the strong median ridge, which is also marked by fine longitudinal striæ.

Horizon and locality. Drum limestone, oölitic member, at Muncie and Independence (station 23), Kan.; and Kansas City, Mo.

GENUS BUCANOPSIS Ulrich.

Bucanopsis tenuilineata (Gurley).

(Pl. XIII, figs. 6-6a.)

1884. *Bellerophon tenuilineatus.* Gurley, New Carb. Foss., Bull. No. 2, p. 10.
1899. *Bucanopsis tenuilineata.* Girty, 19th Ann. Rep. U. S. Geol. Surv., pt. 3, p. 591.

Shell under medium size, subglobose, convolute, the body whorl moderately expanding. Aperture with a broad notch, marking the postition of the slit, sublunate in outline; inner lip reflected and forming a thick, smooth callus over the preceding volution; sides reflected and thickened, forming a nearly horizontal plate which is slightly curved with the curve of the shell. Umbilicus broad and deep. Slit band broad, not raised above the general surface of the shell, and margined on each side by a strong, heavy, longitudinal line. Entire surface ornamented with numerous fine, closely set longitudinal lines, separated by furrows of equal width, and increasing by implantation, those on the slit band being a little stronger than the rest. These are crossed by regularly arranged, rather faint lines of growth, which pass forward from the umbilical region and thence curve gently backward when near the slit band. Dimensions: Transverse diameter, 17 mm.; longitudinal diameter, about 17 mm.

This species is distinguished by its flat slit band and the regular longitudinal striæ, which are much stronger than the transverse striæ.

Horizon and locality. Drum limestone, shale member at Turner, Cherryvale (station 40) and Independence (stations 9, 23), Kan.

Bucanopsis textiliformis (Gurley).

(Pl. XIII, figs. 4-5.)

1883. *Bellerophon textiliformis.* Gurley, New Carb. Foss., Bull. No. 1, p. 6.

Shell rather small, subglobose, convolute; volutions expanding rather rapidly. Aperture sublunate; outer lip cut medially by a narrow, deep slit extending about 3.5 mm.; lip extending forward in the curve of the shell, but not flaring; sides reflected and thickened; inner lip reflected and forming a thick, smooth deposit over the preceding volution. Umbilicus narrow and deep. Surface marked medially by a slightly raised slit band which is margined on each side by a narrow angular sulcus; lines of growth of varying strength, but generally pronounced, with every third or fourth one stronger than the others, and generally less prominent on the slit band than on the shell. Crossing these, and separated by about three times their width, are strong, longitudinal lines which give the shell a beautiful cancellated appearance. Dimensions: Width, 17.5 mm.; diameter, 17.8 mm.

These specimens compare favorably with Gurley's type and come from the same locality and horizon. It seems probable that *B. bellus* Keyes should be referred to this species. It comes from the same locality. No differences of specific value are observed in his figure, and he cites none in his description.

Horizon and locality. Drum limestone, oölitic member, at Turner and Muncie, Kan., and Kansas City, Mo.

FAMILY PLEUROTOMARIDÆ.

GENUS PLEUROTOMARIA Sowerby.

Pleurotomaria granulostriata Meek & Worthen ?

(Pl XIV, figs. 2-2a.)

1860. *Pleurotomaria granulostriata.* Meek and Worthen, Proc. Acad. Nat. Sci. Phil., p. 459.

1866. *Pleurotomaria granulostriata.* Meek and Worthen, Geol. Surv., Ill., vol. 2, p. 356, pl. 28, figs. 2 a-d.

Shell very small, conical subovate; spire moderately elevated. Volutions five or six, flattened or slightly convex, and subparallel to the slope of the spire on the upper side of the volution, narrowly rounded or subangular at about the middle, and somewhat convex on the lower side. Suture well defined. Aperture subcircular, flattened on the top, and oblique; inner lip not reflected; outer lip rather deeply slit at about the middle. Slit band situated on the subangular carina near the middle of the volution on the last whorl, and passing around just above the suture on the others; narrow, and defined by small ridges on each side. Axis imperforate. Surface ornamented by about twelve spiral lines, of which there are four on the upper surface; crossed by numerous transverse lines, which, in crossing the spiral lines, particularly on the upper surface, give them the appearance of rows of small nodes. Length, 7 mm.; breadth, 4.5 mm.; apical angle about 53 degrees.

This shell is somewhat larger than *P. granulostriata* Meek and Worthen; the apical angle is smaller by seven degrees; and the shape of the volutions is different, being distinctly subangular about the middle. No trace of a revolving line is found on the midde of the slit band, as his description would indicate. On the other hand, since the surface ornamentation is identical, with these exceptions, and the one specimen in the collections is more or less coated with calcium carbonate, which somewhat obscures the surface, the material at hand is considered insufficient to permit differentiation.

Horizon and locality. Drum limestone, oölitic member, Turner, Kan.

Pleurotomaria beckwithana McChesney.

(Pl. XV, figs. 1-1b.)

1860. *Pleurotomaria beckwithana.* McChesney, Desc. New. Pal. Foss., p. 61.

1865. *Pleurotomaria beckwithana.* McChesney, Ill. New Spec. Foss., pl. 2, figs. 17 a-b.

1868. *Pleurotomaria beckwithana.* McChesney, Trans. Chic. Acad. Sci., vol. 1, p. 47, pl. 2, figs. 17 a-c.

Shell small, low-spired, subglobose, composed of about four volutions, of which the last equals about two-thirds the entire height of the shell. Volutions subovate in outline and increasing rapidly in size. Suture linear, and deep. the upper portion of the lower volution rising somewhat above the suture line. Aperture subcircular; outer lip thin, with a rather deep slit in the middle; lower lip slightly deflected on the inner side; inner lip reflected so as to partially close the broad, deep umbilicus. Surface with nine low, broad, revolving lines separated by narrow striæ above the slit band, which is slightly depressed, and eighteen below it. This number seems to remain constant with growth while the separating striæ become successively broader. Crossing these are numerous fine lines of growth which curve backward from the suture to the slit band, and then forward again, and curve gently into the umbilicus. On the later portions of the shell these lines of growth are sometimes gathered into wrinkles near the suture. Slit band situated at about the middle of the volution, and plainly visible on the last whorl, but partially hidden in the earlier volutions due to the depth of the suture. Dimensions: Height, 4 mm.; diameter, 5 mm.

Typical specimens of *P. beckwithana* are much larger than the present forms, and the spiral lines are larger and better marked. In general form and outline, and in the number of liræ on the volutions, they are the same. It may be worthy of note that McChesney's figures show the transverse wrinkles near the suture larger and more prominent than those observed in this collection.

Horizon and locality. Drum limestone, oölitic member, at Muncie and Independence (station 23), Kan.

Pleurotomaria subconstricta Meek and Worthen.

(Pl. XIV, figs. 4-4a.)

1860. *Pleurotomaria subconstricta.* Meek and Worthen, Proc. Acad. Nat. Sci. Phil., p. 458.

1866. *Pleurotomaria subconstricta.* Meek and Worthen, Geol. Surv. Ill., vol. 2, p. 351, pl. 28, figs. 6-6a.

Shell small, conical, somewhat turreted, the last whorl equaling about half the height of the shell. Volutions five to six, thickened near the suture into a subangular prominence which is occupied by a series of small nodes; shell obliquely flattened or slightly concave below this. Most prominent part of the volution about the middle, which bears two carinæ separated by a vertical, flattened, or concave portion of the shell, with the upper carina more pronounced. Base slightly convex. Whorls so aligned that only the upper carina shows at about the middle of the upper volutions. Suture linear. Aperture broad, subovate to subcircular, inner lip thickened but not reflected. Shell imperforate. Slit band narrow, flat, and situated just above the middle angle, bounded on each side by a fine spiral line. Surface of the shell ornamented by about fifteen or more spiral liræ, of which there are twelve on the lower side, where they are larger than above; crossing all these lines are fine, closely arranged lines of growth. Length, 11 mm.; diameter, 7.5 mm.; apical angle 65 degrees.

This shell is a little larger than specimens observed from the type locality of the species. It lacks the row of small nodes on the second angle of the body whorl as shown in Meek and Worthen's figures, but not mentioned in their description. Otherwise it is identical.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (sation 12), Kan.

Pleurotomaria subsinuata Meek and Worthen.

(Pl. XIV, figs. 3-3b.)

1860. *Pleurotomaria subsinuata.* Meek and Worthen, Proc. Acad. Nat. Sci. Phil., p. 460.
1866. *Pleurotomaria subsinuata.* Meek and Worthen, Geol. Surv. Ill., vol. 2, p. 358, pl. 28, figs. 4 a-d.

Meek and Worthen's description: "Shell under medium size, conical-ovate; spire rather elevated; volutions six, convex, last one in mature shells sometimes obliquely flattened a little above, just below the suture, thence rounded below. Suture well defined; spiral band narrow, prominent angular, located above the middle of the body whorl, at the lower edge of the slight flattening of its upper side, and passing around the middle of the upper turns; sinus of the lip shallow, judging from the slight curve of the lines of growth; aperture nearly circular; columella not distinctly perforated. Surface ornamented by about fifteen distinct revolving lines, some three or four of which on the middle are larger than those above, while those below gradually diminish in size towards the small umbilical impression; only two or three of the smaller lines usually occupy the slightly depressed portion of the whorls above the spiral band, where they are crossed obliquely by a series of regularly arranged wrinkles; lines of growth extremely fine and very obscure. Length of the largest specimen, 0.40 inch; breadth, 0.31 inch; apical angle convex, divergence, 55 degrees.

"The spiral band of this species is so little apparent that we were at first in doubt as to whether it really belongs to the genus *Pleurotomaria*. On examining carefully, however, by the aid of a lens, the obscure lines of growth, we observe that they make a small but distinct backward curve in crossing the upper of the three or four larger revolving lines passing around the middle of the body whorl, so as to indicate the presence of a shallow sinus in the lip at the tremination of this revolving line. The band of the sinus being angular or carinated, and scarcely larger than the other revolving lines, would not be distinguished from them where the surface has been a little weathered so as to obliterate the obscure striæ of growth. The surface markings will at once distinguish this shell from any of its associates, and we know of no foreign forms with which it is likely to be confounded."

Two specimens of this species were found at Kansas City, Mo. They are a little smaller than Meek and Worthen's shell (height, 7 mm.; diameter, 5 mm.; divergence, 58 degrees); they have only five volutions, and the lines of growth form small nodes on the spiral lines above, but are otherwise identical with shells from the type locality.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.

Pleurotomaria bilineata Sayre, n. sp.

(Pl. XIII, fig. 13.)

Shell rather small, high-spired and turreted. The dimensions of one individual which has only a portion of the apex broken off are: Height, about 17 mm.; diameter, 12 mm.; apical angle, about 45 to 50 degrees. Volutions four, with at least the first two, and possibly three, broken off; quadrangular, subovate or angular in outline on the outer side, and rounded on the inner, the last volution equaling about half the height of the spire. The volution bears three angles, one next to the suture, a second very prominent peripheral angle or carina about one-third of the way down, and a third angle about two-thirds of the way down, which is not so prominent and less angular than the second. Between the first and second angles the surface is obliquely flattened or concave; between the second and third the surface is concave and slopes slightly inward toward the bottom. Base quite convex; axis imperforate. Aperture subcircular, with the inner lip slightly reflected. Surface smooth except for the lines of growth which pass obliquely backward from the suture, and are rather narrowly recurved above the carina, and thence pass forward across the carina and pass almost radially to the center, becoming more pronounced on the lower surface. Below the third angle there are two broad, obscure spiral ridges. The shell is so aligned that the third carina is almost hidden on the upper volutions.

This shell differs from both *P. inornata* and *P. perhumerosa* in having the third angle, and a more or less constricted spiral band about the shell, between the second and third angles. The slit band is broad and poorly defined. Its apical angle is smaller than that of *P. perhumerosa* and larger than in *P. inornata*. In the position of the slit band and its constricted spiral band, this species resembles *P. subconstricta*, but is almost entirely lacking in ornamentation, and is a larger shell.

Horizon and locality. Drum limestone, two specimens from the oölitic member at Kansas City, Mo.

Pleurotomaria fisheri Sayre, n. sp.

(Pl. XIII, figs 10-10b.)

Shell small, spirally coiled, somewhat turreted. The dimensions of a rather large individual are: Height, 4.5 mm.; diameter, 4.5 mm.; apical angle, about 83 degrees. Volutions four to five, angular, enlarging rather rapidly, the last one equaling nearly half the entire height. Shell angular near the suture, upper surface of the volutions obliquely flattened or slightly concave; carina sharp, angular, and about one-fourth of the distance down; below this the surface is vertical, slightly concave or rather depressed, and nearly flat to about one-fourth the distance from the bottom, where it is abruptly rounded, almost angularly into the base, which is convex, and rounds into a rather large and deep umbilicus. Volutions subquadrate, rounded on the inner side. Aperture subquadrate in section. Slit apparently not deep and situated just above the carina which forms the lower boundary. Slit band prominent, situated above the carina; bounded on the lower side by the ridge of the carina, and on the upper by a sharp linear ridge. Suture linear and well marked. Volutions aligned so that the top of the succeeding volution falls on the lower edge of the perpendicular peripheral surface of the preceding one. Surface marked by about twelve spiral lines, of which four are on the upper surface and the remainder on the lower surface, the nearly perpendicular peripheral surface being smooth except for one spiral line near the lower edge.

P. gurleyi is the only species in the Pennsylvanian which resembles this form. It differs from that species in the height of the spire, and in having the peripheral surface narrower and marked by one spiral line, in its more convex base, larger umbilicus, and in the ornamentation of the upper surface of the volution, which, in this species, is marked by four strong spiral lines.

Horizon and locality. Drum limestone, oölitic member, at Turner, Cherryvale (station 40) and Independence (station 23), Kan.

Pleurotomaria kansasensis Sayre, n. sp.

(Pl. XIV, figs. 1-1a.)

Shell small, low-spired, width greater than height. Volutions about five, elongate oval in outline, increasing rapidly in size, the last one equaling about two-thirds the height of the shell. Shell thickened and strongly subangular below the suture, and bearing a row of nodes; flat or slightly concave below this, and thence rounding rapidly into the sides, which are nearly flat and vertical; base flattened. Aperture oblique, sublunate in outline; inner lip apparently not reflected. Umbilicus, if present, closed by a thick callus. Slit band narrow and poorly demarked, its presence being indicated only by the strongly bent lines of growth. Suture narrow and deep. Surface smooth except for the row of nodes below the suture, and numerous very fine lines of growth which extend obliquely backward from the suture to the slit band, where they are strongly recurved, indicating that the slit was fairly deep, arched forward on the sides and bending backward again to cross the base. Dimensions: Height, 7 mm.; diameter, 8.5 mm.; apical angle variable, generally about 115 degrees.

This shell is characterized by its low spire, the row of nodes below the suture, the vertical sides, smooth surface, and the large callus on the base. So far as the writer is aware, there is no species with which it can be confused.

Horizon and locality. Drum limestone, oölitic member, at Muncie, Kan.

GENUS PTYCHOMPHALUS Agassiz.

Ptychomphalus laudenslageri Sayre, n. sp.

(Pl. XV, figs. 4-4a.)

Shell small, conical, height greater than width; composed of seven or eight volutions, expanding rather gradually, the last one equaling about one-third the height of the shell. Volutions flattened on the upper surface and nearly parallel to the slope of the spire, but with the lower margin of the preceding volutions projecting slightly beyond the upper margin of the next. Peripheral portion strongly subangular; base flattened. Aperture oblique, quadrangular, with nearly equal width and breadth, broken by a deep slit, which extends about one-third the circumference of the shell, and is situated about its width above the angular periphery. Slit band narrow, concave and bounded on each side by a narrow spiral line, which is the only spiral ornamentation of the shell. Umbilicus closed. Suture well marked. Lines of growth regular, fine, rather crowded, and gathered into small transverse wrinkles on the upper portion of the volution. Dimensions: Height, 6.5 mm.; diameter, 4 mm.; apical angle, about 37 degrees.

This species differs from *P. coniformis* Meek and Worthen in its greater height, smaller apical angle, and in lacking the spiral lines on the bottom of the shell.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (stations 12, 23), Kan.

Ptychomphalus lineata Sayre, n. sp.

(Pl. XIV, figs. 5-5b.)

Shell small, conical, spire depressed. Volutions about four, increasing slowly in size, the last one equaling about half the height of the entire shell; triangular in outline, upper surface obliquely flattened parallel to the slope of the spire, periphery angular with about three-fourths of the volution above it; base slightly convex. Aperture oblique, triangular in outline; inner lip not reflected, slit deep and extending about one-fourth the circumference of the shell. Umbilicus absent. Slit band concave, narrow, situated about its own width above the peripheral angle, and bounded on each side by a pronounced ridge. Surface marked by numerous spiral lines, of which there are seven on the upper surface and a larger number on the lower surface. Peripheral angle marked by a strong, heavy ridge. All these are crossed by numerous lines of growth which extend backward from the suture to the slit band, where they are strongly recurved, and thence extend forward over the periphery and with slight sinuosity across the base. On the upper surface, particularly, they give the spiral lines the appearance of bearing many small nodes, and lend a finely crenate outline to the peripheral ridge. Dimensions: Height, 5.2 mm.; diameter, 6.5 mm.; apical angle, about 85 degrees.

This species resembles *P. scitula* more closely than any other Pennsylvanian species, but differs from it in its less prominent markings and lower spire. It has a much lower spire and stronger spiral markings than does *P. subdecussata* Geinitz.

Horizon and locality. Drum limestone, oölitic member, at Turner, Kan.

GENUS MURCHISONIA D'Archiac and De Verneuil.

Murchisonia matheri Sayre, n. sp.

(Pl. XVI, figs. 1-2.)

Shell small, high-spired, closely coiled, and obscurely turreted. The dimensions of a fair-sized individual are: Height, 13.5 mm.; breadth, 5.2 mm.; apical angle (variable) about 18 degrees. Volutions eight or nine, increasing very gradually in size, subcircular in the smaller portion, but becoming subangular in the larger portion, the sides being beveled so that they are nearly perpendicular. Suture well marked, linear. Aperture subovate and slightly extended below, inner lip slightly thickened, outer lip apparently cut by a pronounced slit, as indicated by the growth lines, which curve backward from the suture to about one-fourth of the height of the volution, where there is an obscure slit band equaling about one-fourth the height, and marked only by the lines of growth, which are strongly bent here, and thence pass slightly forward to the middle of the base. Surface smooth in appearance, but the lens reveals, besides the lines of growth, a number of fine, rather closely set, spiral liræ below the slit band.

This species is characterized, by its high spire, nearly smooth surface, and the minute spiral liræ on the lower portion of the shell.

Horizon and locality. Drum limestone, oölitic member, at Turner and Muncie, Kan.

GENUS GONIOSPIRA Girty.

Goniospira helicaformis Sayre, n. sp.

(Pl. XV, fig. 2.)

Shell elongate, helicaform, high-spired. Composed of a large number of very gradually enlarging volutions, each of which is subquadrate in section, being angular at the suture, flattened or concave below it to a prominent angular carina, which passes around the periphery of the shell just below the middle, while at the base there is another carina, from which point the shell slopes inward to the middle with very slight convexity. On the second carina there are two heavy parallel ridges set close together, and the shell is so aligned that the succeeding volution falls on the upper of these two ridges, so that the structure is only seen on the last. The slit is apparently deep, narrow, with parallel edges, and situated on the periphery, its borders being marked by very inconspicuous spiral lines. Shell imperforate. Aperture subquadrate; inner lip thickened, and slightly twisted. The only marks on the surface are those already mentioned and the lines of growth, which slope slightly obliquely backward from the suture to the carina, on which they are strongly recurved, and thence curve forward with about the same curvature as on the upper slope. No complete specimens were found.

This species differs from *Goniospira lasallensis* Worthen in that the slit band is on the carina, and it lacks the prominent ridges on the periphery.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (station 23), Kan.

GENUS PHANEROTREMA Fisher.

Planerotrema ornatum Sayre, n. sp.

(Pl. XV, figs. 3-3b.)

Shell small, low-spired, almost discoidal. The dimensions of a relatively large specimen are: Height, 7 mm.; breadth, 10 mm.; apical angle, about 120 degrees. Volutions three to four, quadrangular or sublunate to elliptical in outline, the last one equaling about three-fourths the height of the entire shell. Upper portion of the volutions thickened so as to form an angular prominence next to the suture, below which the shell is concave outward to the angle, which is not quite peripheral, and bears a pair of close-set, sharp ridges. Below this the shell rounds rather abruptly to the base, which is gently convex. Inner lip reflected so as to leave a callused ring around the broad, shallow sulcus which it partially closes. Slit band situated on the upper side of the volution between the two ridges on the angle, and the volutions are so aligned that the shell below these two ridges is not seen on the lower volutions. Surface of the shell marked by a row of strong nodes just below the suture, and numerous spiral lines, which are rather obscure on the upper surface but become much stronger on the lower surface. Fine lines of growth cross the spiral lines in such a way that the whole surface of the shell has a nodose appearance

This species is a lower spired form than *P. grayvillense* Norwood and Pratten, and the slit band is not peripheral.

Horizon and locality. Drum limestone, oölitic member, Turner, Cherryvale (station 40) and Independence (station 23), Kan.

GENUS EUCONOSPIRA Longstaff.

Euconospira turbiniformis (Meek and Worthen).

(Pl. XV, fig. 5.)

1884. *Pleurotomaria turbiniformis.* White, 13th Rep. Geol. Surv. Ind., p. 160, pl. 32, figs. 7-8.

Meek and Worthen's description: "Shell rather large, trochiform; height and breadth nearly equal; spire conical, moderately depressed; volutions about five and a half, flat, last one distinctly angular around the periphery, and flattened or slightly convex below; umbilical region a little concave; umbilicus very small, and bound by a small, obscure, revolving ridge; spiral band extremely narrow, grooved, occupying the angle around the periphery of the body whorl, and passing around scarcely above the suture on the other volutions, margined above and below by a sharply elevated line; suture linear, having a somewhat banded appearance in consequence of the development of a rather distinct revolving line at the upper margin of each whorl; aperture apparently rhombic-subquadrate in form. Surface ornamented by about twenty obscure, closely arranged revolving striæ, crossed by stronger, very regular transverse lines, which are most distinct on the upper part of the whorls, and pass with a gentle curve backward and outward to the spiral band. Below the angle the under side of the body whorl is nearly smooth, or only marked by very obscure lines of growth, and faint traces of revolving striæ. Length, about 0.93 inch; breadth, nearly 0.97 inch; apical angle regular, divergence 64 degrees.

"This shell seems to be very closely allied to *P. Riddelii*, of Shumard, and a more careful comparison with his description leads us to suspect that it may possibly prove identical. Yet, as Dr. S. describes his species as having only twelve or thirteen revolving lines on each whorl, while our shells show uniformly nearly double this number, we are in doubt whether they should be considered identical or not. It is also related to *Pleurotomaria missouriensis*—(*Trochus missouriensis*, Swallow), but never attains so large a size as that noble species, from which it also differs in having a much stronger transverse striæ; while Prof. Swallow's species has not the prominent linear ridge just above and below the spiral band, seen in our shell."

The writer is in some doubt as to whether the shells referred to this species are not the young forms of *E. missouriensis.* The principal differences shown are the concave slit band, and the smaller angle, while the revolving lines of this form are not so strong as those seen in *E. missouriensis.* There is evidence to show that the angle of neither form is constant, but increases with the number of whorls developed. The number of volutions on the specimens at hand are seven, which is greater than the number given by Meek and Worthen.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (station 23), Kan., and Kansas City, Mo.

Euconospira missouriensis (Swallow).

(Pl. XIII, fig. 12.)

1860. *Trochus missouriensis.* Swallow, Trans. St. Louis Acad. Sci., vol. 1, p. 657.
1894. *Pleurotomaria missouriensis.* Keyes, Mo. Geol. Surv., vol. 5, p. 136, pl. 48, figs. 3 a-b.
1897. *Euconospira missouriensis.* Ulrich, Geol. Minn., vol. 3, pt. 2, p. 956.

Shell large, conical, trochiform, with about eight or nine volutions, the breadth being a little greater than the height. Base flat or slightly convex, angular on the periphery, and flattened or only slightly convex on the sides, which are nearly parallel to the slope of the spire. The preceding volution overlaps the succeeding one slightly, so as to leave a strong linear suture on the lower portion of the shell, while the first two or three volutions are distinctly rounded, have a much wider suture, and a smaller spiral angle. Umbilicus small and passing all the way to the apex. Slit band convex, on the periphery, and marked on each side by a sharp spiral ridge. Lines of growth strongly bent. Surface ornamented by about forty spiral lines on the face of the largest volution, but with a much smaller number on the smaller portion of the shell. The base bears numerous very fine, regular, revolving lines. These increase by addition on the side next to the slit, and by occasional bifurcation. Crossing the spiral lines there are numerous very fine regular lines of growth which curve strongly and obliquely backward to the slit, which is deep and rather narrow, with parallel sides. Here they are strongly bent, and emerging on the base follow a gentle sigmoidal curve to the umbilicus. Every fourth or fifth line is stronger than the others.

Width of a specimen on which the spire is broken, 62 mm.; height, probably about 65 mm.; apical angle, 55 to 70 degrees.

This species differs from *E. planibasalis* in the less regular ornamentation of the base. The sculpture of the slit band and on the sides of the shell is identical with that figured by Ulrich. It differs from *E. turbiniformis* in its larger size and convex slit band.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (station 23), Kan., and Kansas City, Mo.

GENUS ORESTES Girty.

Orestes intertexta (Meek and Worthen).

(Pl. XIII, figs. 8-8a.)

1866. *Pleurotomaria intertexta.* Meek and Worthen, Geol. Surv. Ill., vol. 2, p. 356.

Shell small, trochiform, height about equal to the diameter, and composed of about five to six volutions, the last of which is equal to a little less than half the height of the entire shell. Volutions obliquely flattened or slightly concave above and subparallel to the slope of the spire; most prominent part a little below the middle and consisting of two equally prominent carinæ with the slit band placed between them; base flattened or slightly convex. On the upper volutions, only the upper one of the carinæ is seen, the other being hidden by the succeeding volution of the shell. Just beneath the well-defined suture the volution is thickened and angular, and is ornamented with a row of nodes. Aperture subrhombic, inner lip thickened. Umbilicus small and deep. Surface ornamented with numerous closely set, small, spiral liræ, of which there are from one to three on the slit band. These are crossed by equally fine lines of growth which give the surface a beautifully cancellated appearance. The lines of growth curve obliquely backward from the suture to the slit band, where they are strongly reëntrant, and thence pass forward at first, and then backward with a gentle curve, and into the umbilicus. Dimensions: Height, 7.2 mm.; diameter, 7 mm.; apical angle, 67 degrees.

This species seems to show some considerable variation of form. Of several hundred specimens which appear to belong in the same group the apical angle varies from 60 to 70 degrees; and the alignment and contour of the volutions show similar variations, which appear to depend to some extent on the stage of development of the individual. The larger fossils under discussion agree very well with specimens of *O. intertexta* from the type locality of that species.

Horizon and locality. Drum limestone, oölitic member, at Turner, Muncie and Independence (stations 9, 12, 23), Kan.

GENUS WORTHENIA De Koninck.

Worthenia speciosa (Meek and Worthen)?

(Pl. XIII, figs. 11-11b.)

1860. *Pleurotomaria speciosa.* Meek and Worthen, Proc. Acad. Nat. Sci. Phil., p. 461.

1866. *Pleurotomaria speciosa.* Meek and Worthen, Geol. Surv. Ill., vol. 2, p. 352, pl. 28, figs. 5 a-c.

Shell about medium size, length slightly greater than the breadth, volutions six or seven, the last one forming about half the entire length. The volutions angular or carinate below the suture, and thence flat or concave to the carina, which is peripheral, and above the middle of the volution; below this the shell is again concave vertically, so as to produce a third angulation below the middle of the volution; the base of the volution is gently convex. Suture well defined. Slit band narrow, prominent, occupying the middle carina, and crenulated on the edges. Aperture subquatrate to subcircular. Umbilicus small, nearly closed. Surface ornamented by a varying number of spiral lines, generally about seven on the upper slope, about five or six on the outer slope, and still more on the base. Crossing these are numerous very fine and regular transverse lines of growth, some of which are considerably larger near the suture than the others, and form a row of nodes on the angulation just below the suture. Length, about 21 mm.; breadth, about 20 mm.; apical angle, about 82 to 90 degrees.

There are only two specimens of this species in the collections. They differ slightly from *W. speciosa* in not having such strong wrinkles at the superior angle of the whorl, and in being somewhat larger than that species. In other respects, however, it is very similar to the shell described by Meek and Worthen. It is quite different from *W. subscalaris* in being smaller, less acute, and in having the milled edge on the middle carina. It is not nearly so turbinate as *W. tabulata,* and lacks the strong nodes on the middle carina.

Horizon and locality. Drum limestone, oölitic and shale members, at Turner, Muncie and Independence (stations 12, 23), Kan.

FAMILY TROCHONEMATIDÆ.

GENUS STROPHOSTYLUS Hall.

Strophostylus peoriensis (McChesney).

(Pl. XVIII, figs. 2-2b.)

1860. *Platyostoma peoriensis.* McChesney, Desc. New. Pal. Foss., p. 62.
1865. *Platyostoma peroriensis.* McChesney, Ill. New Spec. Foss., pl. 2, figs. 11 a-b.
1868. *Platyostoma peoriense.* McChesney, Trans. Chicago Acad. Sci., vol. 1, p. 49, pl. 2, figs. 11 a-b.

Shell of medium size, subovate to subglobose, composed of about one to one and a half volutions, close, coiled, and expanding rapidly, becoming much inflated near the aperture, which is oblique, subquadrate or subrectangular with the corners rounded. Spire depressed. Suture well marked. Surface marked only by lines of growth, which are not prominent. Umbilicus closed. Dimensions: Height, 31 mm.; greatest breadth, 35 mm.

There is only one specimen of this species, from which most of the shell is broken off, leaving an internal cast.

Horizon and locality. Drum limestone, oölitic member, Kansas City, Mo.

FAMILY TROCHIDÆ.

GENUS MICRODOMA Meek and Worthen.

Microdoma ornatus Sayre, n. sp.

(Pl. XVI, fig. 4.)

Shell small, high-spired, subtrochiform. Volutions six to seven, increasing rather gradually in size, the last one equaling about one-third of the entire height of the shell; flattened on a line with the slope of the spire and angular both above and below; base convex. Axis solid. Suture well marked. Aperture oblique, the inner lip being slightly reflected. Surface ornamented by two rows of small, closely set nodes, one just below the suture, the other on the peripheral angle, which lies slightly below the middle of the colution on the last, and just above the suture on the higher volutions. Lines of growth very fine, extending obliquely backward from the suture to the peripheral row of nodes and thence sigmoidally across the base to the depressed center. Dimensions: Height, 6.5 mm.; diameter, 4 mm.; apical angle, 48 degrees.

This species resembles *M. conicus* Meek and Worthen in shape, but has only two rows of nodes and a greater apical angle.

Horizon and locality. Drum limestone, oölitic member, Turner and Muncie, Kan.

FAMILY NERITOPSIDÆ.

GENUS NATICOPSIS McCOY.

Naticopsis ? monilifera White.

(Pl. XVIII, figs. 6-6a.)

1880. *Naticopsis monilifera.* White, Cont. to Inv. Pal., No. 8, p. 168, pl. 42, figs. 3 a-c.

White's description: "Shell small subglobose; spire short, obtuse, and its immediate apex flattened; volutions about six, but the apical ones are very small, the last one constituting the greater part of the shell, broadest upon its basal or proximal portion, the proximal side of which is somewhat abruptly rounded inward to the aperture; the small volutions of the apex are plain, but upon the distal border of the two last ones, adjacent to the suture, there is a conspicuous row of small nodes, constituting a pretty ornamentation of the shell; the remainder of the surface has a polished aspect, upon which a good lens reveals fine striæ of growth; aperture suboval in outline, inner lip having a distinct callus, especially in front; outer lip thin, its border sinuate, having an almost distinct notch just in front of the row of nodes.

Extreme length, 10 mm., extreme diameter of the last volution nearly the same."

The one specimen of this species in the collections at hand is only partially preserved, but the extreme diameter shows a width of 17.5 mm.; and a height, 16 mm.

Horizon and locality. Drum limestone, oölitic member, at Turner, Kan.

Naticopsis pricei Shumard.

(Pl. XVIII, figs. 1-1b.)

1858. *Naticopsis (Nerita) pricei.* Shumard, Trans. St. Louis Acad. Sci., vol. 1, p. 202.

Shumard's description: "Shell ovate, oblique, longer than wide; spire very much depressed, obtusely rounded at the apex; volutions two and a half or three, convex, the last one very large, regularly and rather strongly ventricose in young specimens, but as the shell advances in age its upper portion becomes gradually flattened and sometimes strongly channeled toward the aperture, and at the same time it becomes more or less shouldered just beneath the suture; below the flattened portion it is still evenly rounded to the base; suture indistinct at the apex, but gradually becoming more deeply impressed as it approaches the aperture; aperture large, rotundo-quadrate, its height usually a little greater than the width; very oblique to the axis of the shell, contracted below near the columbella: lip sharp, strengthened above at its juncture with the columella by the callosity of the latter; columellar lip thick, concave, callous, smooth; surface marked with very fine lines of growth, and on the upper part of the volutions with rather strong plicastriæ, which curve obliquely forward to the sutures. In some specimens the original coloring matter is still preserved, and the fossil presents a delicate vermilion hue.

"Dimensions: Spiral angle from 120 to 130 degrees; length from apex to base of an average specimen, .85; greatest width, .82; height of aperture, .50; width of same 45 degrees."

A number of the smaller specimens (height 10.5 mm.; width, 11 mm.; height of aperture, 9 mm.) agree quite well with *N. nana* Meek and Worthen. They differ, however, in being larger and in having the upper portion of the volution flattened. The larger specimens show about the same dimensions as

N. pricei Shumard (breadth, 19.5 mm.; height 21 mm.) and appear to answer the description of that species very well.

Horizon and locality. Drum limestone, oölitic member, Turner, Muncie and Independence (station 9), Kan., and Kansas City, Mo.

Naticopsis scintilla Girty.

(Pl. XVIII, fig. 7.)

1915. *Naticopsis scintilla.* Girty, Mo. Bur. Geol. and Mines, vol. 13, 2d ser. p. 538, pl. 29, figs. 3-3c.

Shell very small, consisting of two or three rapidly expanding volutions, the height being somewhat greater than the width. The spire rises but very little above the last volution, which is greatly elongated below and somewhat depressed on the upper side just below the suture. The surface is marked by very fine lines of growth and, at regular intervals, by somewhat stronger lines. The umbilicus is closed and a distinct callosity is present.

This species is characterized by its very small size, and by the shape of its volutions, which are very much elongated and have a broad sulcus just below the suture on the upper side.

Horizon and locality. Drum limestone, oölitic member, Kansas City, Mo.

Naticopsis ? minuta Sayre, n. sp.

(Pl. XVIII, figs. 5-5a.)

Shell small, subdiscoidal, with depressed spire. Volutions about three, very rapidly enlarging, so that the last one equals three-fourths the entire height of the shell; subovate in section, and more or less compressed from top to bottom. Suture deep, well marked, but narrow. Aperture, oblique, subovate, flattened both above and below; outer lip rounded and thin; inner lip slightly reflexed and apparently forming a slight callus. Axis apparently solid. Surface smooth and unornamented except for the last volution, on which there is a row of small nodes just below the suture. Height of a large specimen, 4 mm.; breadth of same, 5.5 mm.; height of aperture, about 3 mm.; width of same, 3.4 mm.

This species is distinguished by its low spire and discoidal shape, as well as by the lack of ornamentation of the volutions, except for the spiral row of nodes on the last volution. It is referred with some hesitation to the genus *Naticopsis,* which has only one species (*N. monilifera* White) which is similar to this. Certainly typical *Naticopsis* forms are destitute of a row of nodes and in this respect it is more like a *Pleurotomaria,* but, although some very well preserved specimens have been studied, no trace of lines of growth, or any sign of a slit band has been found.

Horizon and locality. Drum limestone, oölitic member, at Muncie, Kan.

FAMILY PYRAMIDELLIDÆ.

GENUS ZYGOPLEURA Koken.

Zygopleura rugosa (Meek and Worthen) ?

(Pl. XVII, fig. 9.)

1860. *Loxonema rugosa*. Meek and Worthen, Proc. Acad. Nat. Sci. Phil., p. 465.
1866. *Loxonema rugosa*. Meek and Worthen. Geol. Surv. Ill., vol. 2, p. 378, pl. 31, figs. 11 a-c.

Shell rather small, conical, spire elevated and having a divergence of about 24 degrees. Length of a nearly complete individual, 13 mm.; breadth of same, 4.4 mm. It consists of at least seven or eight volutions, and probably more, each of which is gently convex and bears about fourteen or fifteen sharp sub-vertical plications, which slope slightly forward from the suture and are arranged in line on the various volutions, so as to give a spiral appearance to the whole. Aperture ovate, acutely angular above, and slightly pointed below. Axis solid. Suture fairly deep and well marked. Plications becoming obsolete at the basal angle.

Some of these specimens seem to be considerably larger than the form described by Meek and Worthen. It is possible that they represent a new species, but with the poor material at hand it seems advisable to refer them to Meek and Worthen's species for the present.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (station 12), Kan.

Zygopleura teres Girty.

(Pl. XVII, fig. 13.)

1915. *Zygopleura teres*. Girty, Mo. Bur. of Geol. and Mines, vol. 13, 2d ser. p. 360, pl. 32, figs. 4-4a.

Inasmuch as all of the specimens of this species in these collections are more or less encrusted, Girty's description is given:

"Shell small, tapering, composed of seven or eight volutions. Length, 3½ mm., diameter, 1½ mm. The volutions are short with rather flat sides, strongly rounded below. They embrace so far as to leave a distinct though not deep suture, and the outline is therefore nearly smooth. The immature volutions increase in size more rapidly than the mature ones, so that the apical portion tends to be conical and the lower portion cylindrical, and a somewhat fusiform shape is produced. The aperture is small, oval. The axis is solid.

"The surface is marked by fine incremental lines parallel to the axis, which are gathered at regular intervals into fascicles or obscure plications.

"*Z. teres* is distinguished by its minute size, its fusiform shape, its slightly indented sutures and its obscure corrugations. In one or all of these particulars it differs from other American species, so that more detailed comparisons are not necessary. Indeed, the species is somewhat doubtfully referred to *Zygopleura* at all, and would perhaps better be placed under Pseudomelania. It resembles *Z. nana*, but is less distinctly corrugated."

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.

Zygopleura attenuata (Stevens) ?

(Pl. XVII, fig. 12.)

1858. *Chemitzia attenuata.* Stevens, Amer. Jour. Sci., (2) vol. 25, p. 259.
1915. *Zygopleura attenuata.* Girty, Bull. U. S. Geol. Surv., No. 544, p. 182.

Shell small, turreted, slender, consisting of somewhat more than six volutions, each of which is somewhat shouldered and bears a row of nodes just beneath the suture, each of which is extended below and gradually dies out as the bottom of the voluntion is reached, so that the lower portion is nearly smooth. Sides flattened, suture well marked by reason of the shoulder. Axis solid. Aperture subcircular. Volutions increasing more rapidly in size near the apex, so that the apical angle in different parts of the spire is not uniform.

It is with some doubt that this shell is referred to *Z. attenuata,* as that description is not complete and the shell described is apparently somewhat smaller. The largest of the specimens at hand are not complete, but are at least as large as the shell described by Stevens.

Horizon and lacality. Drum limestone, oölitic member, at Muncie, Kan.

Zygopleura multicostata (Meek and Worthen).

(Pl. XVII, fig. 7.)

1915. *Zygopleura multicostata.* Girty, Bull. U. S. Geol. Surv., No. 544, p. 184, pl. 25, fig. 2.

Meek and Worthen's description: "Shell small, conical, spire moderately elevated; volutions about seven and a half, somewhat convex, increasing gradually in size, last one forming about one-third the entire length, rounded but not much produced below; suture well defined; aperture oval subrhombic, slightly effuse on the inner side below; outer lip thin and nearly straight; inner lip a little reflexed. Surface ornamented by small, regular, straight, vertical folds or costæ, about equaling the spaces between and numbering near thirty on the body whorl. Costæ obsolete on the under side of the last turn; no lines of growth visible under a lens. Length, 0.36 inch; breadth, 0.15 inch; apical angle nearly regular, divergence about 28 degrees.

"This species resembles the last two in its general appearance, but differs in having more numerous, smaller, and more closely arranged costæ. Its whorls are also more convex, and its suture deeper. It is more nearly allied to *L. scalaroidea* (sp.) of Phillips, but differs from de Koninck's figures of that species in having perfectly straight, instead of flexuous, costæ. The number of its costæ is also less than in *L. Scalaroides,* and its spiral angle is greater than given by de Koninck in his description (22 degrees), though less than represented in his figures (about 32 degrees)."

No complete specimens of this species were found.

Horizon and locality. Drum limestone, oölitic member, at Turner and Muncie, Kan.

Zygopleura plicata (Whitfield) ?

(Pl. XVII, fig. 8.)

1915. *Zygopleura plicata.* Girty, Bull. U. S. Geol. Surv., No. 544, p. 183.

Shell very small, elongate, conical. Spire elevated and regularly tapering. Volutions about eleven, flattened in the direction of slope of the spire on the outer side. Suture distinct but not deep. Aperture elongate oval, slightly pointed below, and angular above. Axis solid. Surface ornamented on the last volution with about fourteen or fifteen plications and by nearly as many of the upper volutions, which are set at a slight angle to the axis of the spire, so that the upper end is slightly behind the lower, and the plication on the next volution above is set in line with the first, so as to give the whole a somewhat spiral arrangement on the shell. Crossing these are very fine spiral striæ, which give them a slightly crenate appearance. No complete specimens of this shell are found in the collections, but the largest is 12.5 mm. long, and 4 mm. wide, with an apical angle of 18 degrees.

Among the specimens referred to this species, there is a variation of three or four degrees in the apical angle; the suture is variable, although the shape of the volutions is fairly constant, and the number of plications remains, within rather narrow limits, about the same, although in some cases they are not so well marked as in others.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (station 12), Kan.

Zygopleura nana Girty

(Pl. XVII, fig. 10.)

Zygopleura nana. Girty, Mo., Bur. Geol. and Mines, vol. 13, 2d Ser., p. 360, pl. 32, figs. 5-5a.

Girty's description: "Shell small, conical, 1 mm. in diameter, rather less than 3 mm. long, composed of six or seven volutions. Volutions rather high, flattened at the sides and abruptly rounding below, embracing so far as to leave but a shallow suture and give the shell as a whole a smooth conical shape. The rate of increase in the size of the whorls is greater, however, in the younger than in the older stages, which renders the shape somewhat fusiform. The aperture is small, oval. The axis is solid. The sides are marked by rather large, rather strong, longitudinal plications about fourteen to a volution.

"This species is most closely allied to *Z. rugosa* and perhaps it might be considered only a dwarfed variety of it, especially as most of the associated species are small. Aside, however, from being only one-third as large, though composed of the same number of volutions, the volutions are comparatively higher, with flatter sides and shallower sutures, and the plications are less numerous."

Horizon and locality. Drum limestone, oölitic member, at Turner and Muncie, Kan., and Kansas City, Mo.

GENUS HEMIZYGA Girty.

Hemizyga? cancellata Sayre, n. sp.

(Pl. XVII, fig. 11.)

Shell small, subconical, rather low-spired, the apical angle being 50 degrees. Volutions few in number, very convex and subcircular in outline, increasing rather rapidly in size, so that an almost shouldered appearance is given to the shell. Suture deep and very well marked. Aperture subovate, pointed above and slightly extended below; outer lip regularly rounded; inner lip nearly straight, oblique to the axis of the shell, and very slightly reflected. Axis solid. Surface marked on the upper volutions by about thirteen heavy longitudinal costæ, which become obsolete, or nearly so, on the last volution;

crossed by rather fine, closely set spiral liræ, which, together with the nearly obsolete longitudinal costæ, form a more or less latticed pattern on the last volution, and serve to crenulate the costæ on the upper volutions.

This species is distinguished by its comparatively large apical angle and its surface ornamentation, as well as by the rapid increase in the size of its volutions. There is some doubt as to whether this shell belongs with Girty's genus *Hemizyga* as it shows spiral liræ on all parts of the volution, while in his typical species these are developed only on the lower portion. The apical angle is much larger and the spire more depressed than on any of his species. It bears some resemblance in form to *Sphaerodoma gracilis* Cox, but differs in possessing spiral liræ and in its larger apical angle.

Horizon and locality. Drum limestone, oölitic member, Turner, Kan.

GENUS BULIMORPHA Whitfield.

Bulimorpha chrysallis (Meek and Worthen).

(Pl. XVI, fig. 9.)

1903. *Bulimorpha chrysallis.* Girty, Prof. Paper, U. S. Geol. Surv., No. 16, p. 466, pl. 10, figs. 6-6a, 7-7a.

Shell small, spire conical, moderately elevated and pointed at the apex. Dimensions of a large individual are: Height, 8 mm.; breadth, 4.4 mm.; apical angle, about 45 degrees (not regular). Volutions about six or seven, slightly convex, the last one forming about two-thirds the entire length. Suture distinct. Aperture narrow, elongate, angular above, rounded and produced below, but somewhat ventricose in the middle. Inner lip wanting; columella arched and twisted. Surface smooth except for obscure lines of growth.

The shell is somewhat smaller than that figured and described by Meek and Worthen as *B. chrysallis,* and the volutions are a little more convex in the upper portion. In other respects it agrees very well, however.

Horizon and locality. Drum limestone, oölitic member, at Turner, Kan.

Bulimorpha meeki Sayre, nom. nov.

(Pl. XVI, fig. 6.)

1873. *Actæonina minuta.* Meek and Worthen, Geol. Surv. Ill., vol. 6, p. 594, pl. 29, fig. 2.

Shell very small, elongate, subterete. Volutions about five, slightly flattened on the sides, and very convex above, so as to give each a more or less shouldered appearance, last one equaling a little more than half the entire height of the shell. Suture well marked by reason of the convexity of the shell. Aperture elongate-ovate, acutely angular above, and apparently rounded below, so that the aperture equals about two-fifths of the entire height of the shell. Columella slightly arched, smooth, inner lip apparently lacking. Surface smooth except for very fine growth lines. Apical angle, 40 degrees; length, about 5 mm.; breadth, 2 mm.

This shell is readily distinguished from all other Pennsylvanian forms by reason of its small size, aperture rounded below, and the shouldered appearance of the volutions.

Girty has pointed out the inconsistency which exists between the form figured by Meek and Worthen as *B. minuta* Stevens, and that described by Stevens.[21] The specimens here described agree with the figures of Meek and Worthen, which undoubtedly represent a new species.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (station 23), Kan.

Bulimorpha turnerensis Sayre, n. sp.

(Pl. XVI, fig. 7.)

Shell very small, elongate, fusiform, the dimensions of a large individual being: Length, 6.5 mm.; breadth, 2 mm.; apical angle, about 15 degrees. Volutions about five, the last one equaling fully three-fourths the length of the shell; not very convex; elongate-ovate in section and slightly flattened on the sides. Suture poorly defined. Aperture lance-ovate, very acutely angular at the top, and somewhat rounded at the bottom; outer lip straight, and thin; inner lip apparently not reflected. Columella slightly bent. Surface smooth and lines of growth invisible even under the magnifier.

This shell is so elongated that it does not resemble any other Pennsylvanian species. It is distinguished, also, by the lack of convexity of the volutions, and the great length of the body whorl in comparison to the rest of the shell.

Horizon ad locality. Drum limestone, oölitic member, at Turner, Kan.

GENUS SPHÆRODOMA Keyes.

Sphærodoma fusiformis (Hall) ?

(Pl. XVI, fig. 10.)

1910. *Soleniscus fusiformis.* Raymond, Ann. Carnegie Mus., vol. 7, p. 156, pl. 24, fig. 7.

Hall's description: "Shell elongate, subfusiform. Spire gradually tapering from the last volution, which is more ventricose, consisting of seven or more volutions, which are very moderately convex except the last. Suture line faint in the shell, deeply canaliculate in the cast; aperture not fully known, nearly equaling half the length of the shell.

"This shell corresponds in general form and characteristics with *M. missouriensis* of Swallow, but the angular character of the volutions in the cast is not observed."

The specimens in the collections representing this group are rather poorly preserved, being either broken or covered with a coating of lime carbonate. In general appearance they seem similar to Hall's specimens, but no thickening of the inner lip is observed. The fold is sharp, and situated just below the middle of the volution.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (station 23), Kan.

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21. Girty, G. H.: Invertebrate Paleontology of the Pennsylvanian Series in Missouri. Mo. Bur. Geol. and Mines, vol. 13, 2d ser., p. 363; 1915.

Sphærodoma paludinæformis (Hall).

(Pl. XVI, fig. 5.)

1915. *Sphærodoma paludinæformis.* Girty, Bull. U. S. Geol. Surv., No. 544, p. 200, p. 207, pl. 24, figs. 5-6a.

Shell small, acute ovoid; the last volution ventricose, rapidly tapering, and about equal to the spire in height. Volutions five or six, the upper ones moderately convex. Suture line well marked on the last three or four volutions, but obscure on the upper ones. Aperture subovate, rather narrow and pointed above, but not much extended below, not quite half as high as the entire shell. Fold on the columella sharp, and situated a little below the middle of the aperture. Surface marked only by very fine lines of growth. Dimensions of a large individual are: Height, 7 mm.; breadth, 4 mm.; apical angle, about 52 degrees.

This shell is somewhat smaller than the one figured by Hall in his Iowa report, but shows the same general outline, and since many of the species in this horizon are somewhat dwarfed, it is probably identical. These specimens are certainly identical with the one figured by Marks in a report of the Ohio Geological Survey; and if Marks is correct in referring her specimens to this species, the specimens at hand may also be so referred.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (station 23), Kan.

Sphærodoma primigenius (Conrad).

(Pl. XVI, figs. 3-3a.)

1915. *Sphærodoma primogenia.* Girty, Bull. U. S. Geol. Surv., No. 544, p. 208, pl. 24, figs. 13-17a.

This species is represented by one cast. It is large, subglobose, consisting of three and a half whorls. Volutions rapidly expanding, subovate in outline, sides convex, rapidly expanding, the last one equaling half the height of the shell. Suture deep, linear. Dimensions: Height, 38 mm.; diameter, 29 mm.; apical angle, 93 degrees.

Horizon and locality. Drum limestone, oölitic member, Independence (station 12 ?), Kan.

GENUS SOLENISCUS Meek and Worthen.

Soleniscus typicus Meek and Worthen.

(Pl. XVI, fig. 8.)

1913. *Soleniscus typicus.* Mark, Geol. Surv. Ohio, 4th ser. Bull., No. 17, p. 317, pl. 16, fig. 16.

Shell small, high-spired, fusiform, conical. Whorls, about six, increasing rather rapidly in size, the last one forming about three-fourths the entire height of the shell. Volutions narrowly rounded above, expanding in the middle, and contracting rather gradually into the somewhat extended canal below. Aperture narrow, lancelike; outer lip thin; fold on the columella a little below the middle of the aperture. Suture shallow. Surface marked by very obscure lines of growth. Dimensions: Height, 8.4 mm.; breadth, 4.6.; apical angle, about 42 degrees.

This shell is somewhat smaller than the form figured and described by Meek and Worthen; otherwise the description applies to it very well.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (station 23), Kan.

FAMILY EPITONIIDÆ.

GENUS ACLISINA De Koninck.

Aclisina stevensana (Meek and Worthen).

(Pl. 17, XVII, fig. 5.)

1913. *Aclisina stevensana.* Mark, Geol. Surv. Ohio, 4th Ser. Bull. No. 17, p. 313, pl. 16, fig. 5.

Shell small, subterete. Volutions about ten or twelve, increasing very gradually in size, convex, all showing a narrow, obliquely flattened space just below the suture; sides slightly flattened, base convex. Suture well marked, as a result of the convexity of the volutions; surface ornamented below the obliquely flattened space at the top of the volutions by small, prominent revolving costæ, of which about four show on each of the upper, and about six or seven on the last volutions. Crossing all these may be seen numerous very fine lines of growth which bend distinctly backward from the suture, and then curve forward over the lower edge of the volution. Aperture subcircular and sinuate on the outer margin; lower portion slightly extended; inner lip apparently not callused; axis solid.

Dimensions of large individual: Height, 8 mm. (top of spire broken away); breadth, 3 mm.; apical angle, regular 20 degrees.

This shell differs from *A. swalloviana* Geinitz in its size, number of volutions, more revolving costæ, and in the sides of the volutions being somewhat flattened, while the suture is not so deep as in that species, the upper, smooth, flattened portion being narrower.

Horizon and locality. Drum limestone, oölitic member, at Turner and Independence (station 23), Kan.

Aclisina swalloviana (Geinitz).

(Pl. XVII, fig. 6.)

1866. *Turbonilla swalloviana.* Geinitz Carb. und Dyas in Neb., p. 5, Tab. 1, fig. 19.
1872. *Aclis swalloviana.* Meek, U. S. Geol. Neb., p. 229, pl. 11, figs. 7 a-b.

Shell very small, turreted, and quite elongate. Dimensions of a medium-sized individual: Height, 3.5 mm.; breadth, 1.2 mm.; apical angle of 17 degrees, quite regular. Volutions about eight, convex, increasing gradually in size; upper surface next to the suture smooth, flattened, and sloping outward; sides slightly flattened vertically, and bearing on the upper volutions four spiral lines, while on the body whorl there are five. Aperture subovate, a little pointed above, sinuous and thin on the outer side; a little extended below, and apparently not reflected on the inner side. Axis apparently quite solid.

This shell is similar in most respects to *A. swalloviana* Geinitz, but differs from it in being a more slender shell, the apical angle being constantly three degrees smaller than that given for that species. It differs from *A. breva* in having more spiral lines, and in being more slender.

Horizon and locality. Drum limestone, oölitic member, at Turner, Kan.

Aclisina breva Sayre, n. sp.

(Pl. XVII, fig. 4.)

Shell very small, turreted, and rather robust, The dimensions of a fairly large specimen are: Height, 5.5 mm., breath, 2.8 mm.; apical angle very nearly constant, 28 degrees. Volutions about seven, convex, increasing rather rapidly in size, the last one equaling about one-fourth the entire height; all distinctly flattened just below the suture; the flattened space sometimes marked by a very faint line near the middle; sloping outward and separated from the suture by a very narrow area, and distinct angle. Surface below the flattened area marked with revolving lines, of which two are generally seen on the upper volutions, and six on the last. Aperture subovate, pointed above, slightly extended below; outer lip thin; inner lip slightly thickened, and a very little reflected. Axis solid. Fine lines of growth may be seen extending obliquely backward from the suture, and thence curving forward over the lower edge of the volution, so as to give a rather sigmoidal outline.

This species differs from *A. minuta* Stevens in having a much smaller number of revolving lines, and a little larger apical angle. He makes no mention of the shape of the volutions or of the flattened area on the upper side. It differs from *A. conditi* Mark in having a smaller number of lines on the upper volutions, in being a little larger, and in not having the flattened area next to the suture. *A. swalloviana* (Geinitz) has a much smaller apical angle.

Horizon and locality. Drum limestone, oölitic member, at Turner and Muncie, Kan.

Aclisina parallela Sayre, n. sp.

(Pl. XVII, fig. 1.)

Shell very small and slender. Dimensions of a broken shell of apparently medium size are: Height, 5.5 mm.; diameter at top, 1 mm.; diameter at bottom, 1.6 mm. Volutions five, convex, increasing very graudally in size. Aperture subovate, with outer lip sinuous; lower lip somewhat extended; inner lip apparently neither reflected nor thickened. Axis imperforate. Suture well marked. Surface with seven spiral lines, of which five appear on the upper volutions. Lines of growth unknown.

This species resembles none of the speices previously described. It is much longer, more attenuated and has a larger number of spiral lines. It lacks the smooth, obliquely flattened space on the upper part of the volution next to the suture, and has a more elongate-ovate section of the volution.

Horizon and locality. Drum limestone, oölitic member, at Turner, Kan.

GENUS ORTHONEMA Meek and Worthen.

Orthonema liratum Sayre, n. sp.

(Pl. XVII, figs. 2-3.)

Shell small, elongate conical, acutely pointed at the apex. The dimensions of a specimen slightly under medium size are: Height, about 11 mm.; breadth, 3.2 mm.; apical angle, about 13 degrees (larger near the apex). Volutions eleven or twelve, vertically flattened around the middle and a little convex, but not much extended below. Suture linear, rather well defined. Aperture ovate, angular above, and rounded or slightly effuse on the inner side below; outer lip thin, and nearly straight; inner lip rounded; columella arcuate. Surface ornamented by four spiral lines, only three of which are seen on the upper volutions of the shell; two on the upper part of the whorl just behind the suture, and a third on the lower part of the whorl, just above the suture; the fourth is so situated that, as a rule, the succeeding volutions fall on it and it appears only on the last volution. It is paired with the lowest of the other three volutions. Lines of growth small and nearly straight until they reach the under side of the volution, where they arch a little forward, and then curve backward to the base of the columella.

This shell differs from *O. salteri* Meek and Worthen, which it most closely resembles, in having an apical angle of at least 10 degrees less, in being somewhat turreted, in having always the additional line on the base of the last volution, which sometimes shows on the higher volutions, and in being a slightly smaller species.

Horizon and locality. Drum limestone, oölitic member, at Turner and Muncie, Kan.

FAMILY PURPURINIDÆ.

GENUS TRACHYDOMIA Meek and Worthen.

Trachydomia wheeleri (Swallow) ?

(Pl. XVIII, figs. 4-4a.)

1910. *Trachydomia wheeleri*. Raymond, Ann. Carnegie Museum, vol. 7, p. 156, pl. 24, fig. 6.

Shell of medium size, subglobose. The dimensions of a fairly large individual are: Height, 15 mm.; breadth, 13 mm. Volutions three, the last one equaling about three-fourths the entire height of the shell, subovate to subcircular. Aperture subovate, with the upper extremity angular. Suture linear, well marked, and bounded on the lower side by a narrow concave area marked only by growth lines, below which the shell is convex and nodose. The nodes are arranged in rows parallel to the growth lines; most prominent near the suture, and becoming smaller near the base. Surface wrinkled near the aperture.

This shell differs from *T. wheeleri* in the wrinkling of the shell close to the aperture; the nodes are more closely situated and do not have a small depression on each of them. However, specimens of *T. wheeleri* in the various collections show considerable variation in these respects. It differs from *T. nodulosa* in lacking the notch at the lower extremity of the aperture and from

T. nodosum Meek and Worthen in having the nodes regularly arranged and more closely spaced, and in being a much smaller shell.

Horizon and locality. Drum limestone, oölitic member, at Turner and Muncie, Kan., and Kansas City, Mo.

Trachydomia pustulosa Sayre, n. sp.

(Pl. XVIII, figs. 3-3a.)

Shell small, subglobose, higher than wide. Dimensions of fairly large specimen: Height, 12 mm.; greatest breadth, 11 mm. Volutions three, rapidly enlarging, the last one equalling about three-fourths the entire height of the shell; a slight constriction passes around the shell a little above the middle of the volutions, and is most pronounced on the last. Aperture subovate with an acute angle above; lower lip slightly extended; inner lip very little callused. Surface covered with small indistinct nodes which are irregularly arranged, and serve to give a rough appearance to the surface. Suture indistinct even on the lower part of the shell, and very obscure on the upper.

The specimens of this group are of varying sizes, and it is distinguishable, even in the younger shells, from other species. It is characterized by the obscure suture, the rough irregular surface, and the depressed upper volutions.

Horizon and locality. Drum limestone, oölitic member, at Muncie and Turner, Kan., and Kansas City, Mo.

CEPHALOPODA.

FAMILY ORTHOCERATIDÆ.

GENUS ORTHOCERAS Breynius.

Orthoceras occidentale Swallow ?

(Pl. XIX, figs. 1-2a.)

1858. *Orthoceras occidentale*, Swallow, Trans. St. Louis Acad. Sci., vol. 1, p. 201.
1894. *Orthoceras occidentale*, Keyes, Mo. Geol. Surv., vol. 5, p. 226.

Shell elongate conical, flattened slightly on the side next the siphuncle. Tapering rather suddenly. Septa very concave and separated by about one-sixth the diameter of the shell, not noticeably sinuous in contact with the periphery. Siphuncle round, and situated about one-third of the diameter of the fossil from the flattened side. Surface smooth, revealing no markings even with the aid of a hand lens.

Diameter of the largest fragment, 16.5 mm.; and the convexity of the septa is more than equal to the distance separating them.

The species under consideration is referred to *O. occidentale* with some hesitation, as Swallow's description is not very complete. It is distinguished by the location of the siphuncle, and the convexity of the septa. It tapers more rapidly than does *O. kansasense*, and is not so flattened, the side away from the siphuncle being regularly rounded. The smooth surface distinguishes it from *O. moniliforme* Swallow.

Horizon and locality. Drum limestone, oölitic member, at Turner, Kan.

Orthoceras kansasense Sayre, n. sp.

(Pl. XIX, figs. 9-12.)

Shell large, elongate, ellipto-conical, tapering gradually and flattened on the sides, so as to give an elliptical cross section. Septa arched toward the apex on the flattened sides and convex; distant about one-eighth of their shorter diameter. Siphuncle small, situated slightly less than one-fourth the diameter from the flattened side. Surface markings not seen. As the apex is approached, the flattening of the sides of the shell becomes less pronounced until, at a diameter of 15 mm. the flattening is scarcely perceptible.

The smaller fragments of this shell bear a strong resemblence to *O. aculeatum* Swallow, but since he gave no figures of his species and the description is incomplete, a comparison is difficult to make. The older fragments resemble *O. illinoisense* from the Chester series, but differ from it in having a smaller siphuncle, although the other proportions are nearly the same.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo., and Turner, Kan.

GENUS PSEUDORTHOCERAS Girty.

Pseudorthoceras knoxense (McChesney).

(Pl. XIX, figs. 3-5.)

1915. *Pseudorthoceras knoxense.* Girty, U. S. Geol. Surv., Bull. 544, p. 227, pl. 27, figs. 1-6.

Shell rather small, tapering gradually, round, composed of many chambers which are about one-third the diameter of the shell in height, septa only moderately convex. Siphuncle, small, central. Outline of the septa on the shell slightly sinuous. Shell thin, surface marked by numerous small pits, which are without regular order. Other surface markings unknown.

In a distance of 20 mm., the shell tapers from 6.4 mm. to 3.6 mm. Body chamber and aperture unknown.

Horizon and locality. Drum limestone, oölitic member, at Turner, Kan.

FAMILY TRIGONOCERATIDÆ.

GENUS EPHIPPIOCERAS Hyatt.

Ephippioceras divisum (White and St. John) ?

(Pl. XX, figs. 1-2a.)

1868. *Nautilis divisus.* White and St. John, Trans. Chicago, Acad. Sci., vol. p. 124, fig. 9.

1891. *Ephippioceras divisum.* Hyatt, 2d Ann. Rep. Geol. Surv. Tex., p. 350, figs. 52-54.

Shell large, closely coiled, and measuring in its greatest diameter 65 mm.; greatest breadth, 67 mm.; length of the body chamber, 62 mm.; breadth of body chamber at rear end, 47 mm.; diameter of umbilicus, about 9 mm. Volutions increasing rapidly in size, about three in number; the first one being circular and the others developing rapidly into a subovate or kidney-shaped form. Early volutions entirely hidden by the last, which increases more rapidly in size than do the early ones, and is somewhat less deeply impressed. Chambers rather thin and narrow, septa passing radially from the umbilicus to the middle of the keel, where they are abruptly bent forward, forming a narrow, angular, ventral saddle and being divided internally by a dorsoventral median saddle. Siphuncle small, situated in about the middle of the median saddle in the later septa, but slightly nearer to the dorsal side as the apex is approached. Surface marked by rather fine lines of growth, with regularly spaced, deeper striæ about every fifth or sixth one, curving radially outward from the umbilicus and then broadly curving across the venter.

This specimen is much smaller than that figured as the type of the species, and does not increase quite as rapidly in size laterally as does the type, nor does it show a broad, shallow, longitudinal sulcus. It may represent the young of the species. It differs from *E. ferratum* Cox in having the volutions much wider than high, while the diameter is much less in comparison to the greatest width.

Horizon and locality. Drum limestone, oölitic member, at Turner, Kan. and Kansas City, Mo.

FAMILY RHINECERATIDÆ.

GENUS DISCITES McCOY.

Discites toddanus Gurley.

(Pl. XX, figs. 3-5.)

1883. *Discites toddanus.* Gurley, New Carb. Fossils, Bull. No., p. 7.
1890. *Discites toddanus.* Anon., The Naturalist (Kansas City), vol. 4, No. 10.

Shell of medium size closely coiled in a plane. Whorls increasing gradually in size, the last one being subquadrangular in outline; the dorsolateral margins angularly rounded; the sides compressed, nearly flat; venter depressed, flattened, and bounded by a sharp angle on each side. Greatest width at the dorsolateral margin, where the width is about equal to the height of the volution, and from which the sides converge toward the keel. Umbilicus small, the volutions being rather deeply impressed, most of the earlier volutions being hidden by the succeeding ones. The first two volutions are nearly circular, the change in shape being introduced rather suddenly and remaining constant through the rest of the shell. Septa rather closely arranged, strongly arched toward the apex on the sides to the ventrolateral margins, and thence passing nearly straight across the keel. Siphuncle of medium size, and situated about one-fifth the height of the volution from the ventral margin. Surface marked by fine lines of growth, closely spaced and regularly set, curving radially from the umbilicus and with a very strong backward curve on the keel. The angle of the keel not showing so strongly on the shell as on the cast, and showing a pair of very small parallel ridges which divide it into thirds.

Diameter, 33 mm.; convexity, 15.5 mm.; height of volutions, 17.5 mm.; diameter of umbilicus 6.5 mm.

This shell is exactly similar to Gurley's type and comes from the same horizon.

Horizon and locality. Drum limestone, oölitic member, at Turner, Kan.

FAMILY TAINOCERATIDÆ.

GENUS METACOCERAS Hyatt.

Metacoceras cavatiforme Hyatt.

(Pl. XXI, figs. 2-2a.)

1891. *Metacoceras cavatiformis.* Hyatt, 2d Ann. Rep. Geol. Surv. Tex., p. 334, figs. 30-33.

Shell attaining a rather large size, closely coiled. Whorl section rather irregularly hexagonal, consisting of a rather narrow ventral surface, two broad lateral surfaces, two umbilical zones, and an impressed zone, all narrow. The ventral surface is marked by a broad, rather shallow depression, flanked by two low subangular ridges, beyond which the shell is again depressed to the ventral shoulders. Sides nearly flat and sloping distinctly outward from above to the umbilical shoulders. Impressed zone rather shallow. Umbilical faces slightly convex. Ventrolateral shoulders sharply angular, distinct, and marked with a row of nodes, one node on each chamber; umbilical shoulders not so sharp, more rounded. Transverse diameter slightly greater, and increasing more rapidly than dorsoventral diameter. The volutions assume an angular form at about one-half a volution and at about the same time become marked with transverse costæ, which become obsolete at about one and one-half volutions. Surface of the shell unknown. Septa showing broad, shallow lobes on the ventral and lateral surfaces with rather sharp angular saddles at the ventrolateral shoulders.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo., and Turner, Kan.

Metacoceras cavatiforme var. *angulatum* Sayre, n. var.

(Pl. XX, figs. 6-6a.)

Shell of medium size, closely coiled. Whorl section irregularly hexagonal, consisting of a rather narrow, flattened ventral surface, two broad lateral surfaces, two narrow umbilical zones and a narrow impressed zone. The ventrolateral and umbilical angles are distinct, angular, or a little rounded. The ventral surface is marked by a broad, rather shallow depression flanked on both sides by low ridges, beyond which the shell is again depressed to the ventrolateral angles. Sides flattened and sloping distinctly outward from above to the umbilical shoulder. Umbilical shoulders abruptly angular, with nearly a 90-degree angle. Umbilical surfaces flat. Dorsoventral diameter increasing more rapidly than the transverse. Both the umbilical and the ventrolateral shoulders on the shell are marked with rows of nodes which are scarcely distinguishable on the ventrolateral shoulders of the cast, and cannot be seen on the umbilical shoulders. These occur on each chamber. The shell is marked from one-half a volution to a little over one-half a volution with transverse pilæ or costæ, the only other markings being faint lines of growth. The shell assumes an angular form at about one-half a volution. Septa with a broad, shallow lobe on the lateral sides, and a less deep lobe on the ventral side. Siphuncle small, a little ventral of the center.

Dimensions: Breadth of volutions across ventral surface, 18.4 mm.; across umbilical shoulders, 23 mm.; height of volution, 22 mm.; diameter of entire shell, 55 mm.; diameter of umbilicus, 20 mm.

This variety is similar to *M. cavatiforme*, but differs from it in increasing more rapidly in size dorsoventrally than laterally, in showing a somewhat stronger curvature on the lateral lobes, and in having less strong nodes.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.

GENUS TAINOCERAS Hyatt.

Tainoceras occidentale (Swallow).

(Pl. XXI, figs. 3-3a.)

1911. *Tainoceras occidentalis.* Raymond, Penn. Topog. and Geol. Surv. Comm. Rept. for 1908-10, pl. 6, fig. 7.

Shell of medium size, coiled in a plane; volutions a little wider transversely than dorsoventrally, and increasing rather gradually in size. In cross section the volution is heptagonal. Abdomen with two rows of nodes alternating in position and separated by a rather narrow, deep, longitudinal furrow. The abdominal shoulders bear a row of much stronger nodes, generally so placed that each alternate chamber has a pair of them, one on each shoulder. Each of the umbilical shoulders has a row of somewhat smaller nodes. Umbilicus wide and shallow, with nearly all of the preceding volutions visible. Septa very concave on the sides and silghtly less concave on the abdomen, with a pronounced saddle on each of the ventral shoulders. Siphuncle large, subcentral. Aperture and body chamber unknown.

Although there are only two fragments of this species at hand, these agree so well with the original description that there can be little doubt as to the correctness of the identification.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo.

FAMILY AGANIDIDÆ.

GENUS GONIOLOBOCERAS Hyatt.

Gonioloboceras parrishi (Miller and Gurley) ?

(Pl. XVIII, figs. 8-8b.)

1896. *Goniatites parrishi.* Miller and Gurley, Bull. Ill. State Mus. Nat. Hist., No. 11, p. 36, pl. 4, figs. 6-8.

1903. *Milleroceras parrishi.* Smith, Monog. U. S. Geol. Surv., vol. 42, p. 127, pl. 16, figs. 6-8.

1915. *Gonioloboceras parrishi?* Girty, Mo. Bureau Geol. and Mines, vol. 13, 2d ser., p. 364.

One shell in the collections appears to be a small individual of this species in a state of excellent preservation.

Shell very small, discoidal, volutions flattened laterally and inclined slightly toward the ventral margin; abdomen abruptly and narrowly rounded. Volutions increasing more rapidly in the dorsoventral diameter than in the transverse diameter, the outer ones embracing the inner completely and leaving a small, deep umbilicus. Septa curving gently forward on the side of the volution to about the middle, where there is small subangular lobe, while apparently a second deeper and sharper lobe occupies the venter. Surface marked by fine lines which curve sigmoidally backward from the umbilicus, and thence forward on the shoulders and backward again on the ventral surface.

Diameter, 7 mm.; convexity, 3.8 mm.; dorsoventral diameter of last volution, 4 mm.

As will be noted, this shell does not show the ventral saddle which *G. parrishi* shows, but it is much smaller and may be the young of this species.

Horizon and locality. Drum limestone, oölitic member, Turner, Kan.

Gonioloboceras goniolobum (Meek).

(Pl. XXI, fig. 5.)

1877. *Goniatites goniolobus.* Meek, U. S. Geol. Expl. 40th Par., vol. 4, p. 98, p. 9, figs. 5-5b.

1900. *Goniatites goniolobus.* Knight, Wyo. Univ. Exp. Sta. Bull., No. 45, p. 129, pl. 3, fig. 8.

1903. *Gonioloboceras goniolobum.* Smith, Monog. U. S. Geol. Surv., vol. 42, p. 123, pl. 4, figs. 1-3.

The specimen at hand is somewhat broken, therefore Meek's description is given:

"Shell distinctly discoid, with (in internal casts) a narrowly rounded periphery; volutions compressed laterally, with slightly convex sides, the greatest convexity being a little within the middle; about twice as wide in the dorsoventral diameter as at right angles to the same; each turn embracing all the others, so as to leave only a very small umbilicus, showing none of the inner volutions. Septa closely and very regularly arranged, but nowhere in contact or lapping upon each other; siphonal lobe (generally called the dorsal lobe) very large, and profoundly divided into two large, elongate, acutely pointed terminal branches, which lap so far over each side of the volutions as to appear each like a large lateral lobe, while between these there is a third minute central projection; first lateral sinus very deep, elongate-conical, very acutely angular at the extremity, and arched or obliquely curved toward the umbilical side; second lateral lobe of much the same form as the divisions of the siphonal lobe, but a little shorter; second lateral sinus wider than the lateral lobe, but more shallow, and merely forming a broad, forward arch to the umbilicus. Surface of the internal cast without nodes, costæ, or angles.

"Greatest diameter of a specimen with the body chamber broken away, 3.07 inches; convexity, 0.87 inch; breadth of outer volution, measuring in the direction of the plane of the shell, 1.72 inches.

"Excepting in being more compressed, with a narrowly rounded periphery, this species has much the general appearance externally of *G. rotatorius* de Koninck. Its septa are more closely approximated, however, and differ remarkably in having the siphonal lobe so enormously developed, and so wide and deeply divided as to lap over on the sides far enough to cause its large, acutely pointed terminal branch, on each side, to appear in a side view like the first lateral lobe, while the first lateral lobe is thus, as it were, crowded much farther inward, and appears like a second lateral lobe. From this structure the fossil looks very much as if there were two large, sharply angular lateral lobes where there is really only one."

The specimen in hand appears to fit this description exactly. The diameter of the outer volution is (measured radially) 39 mm.; the convexity at this point is 22 mm. The surface of the shell is smooth or nearly so.

Horizon and locality. Drum limestone, oölitic member, at Kansas City, Mo., and Cherryvale (station 40), Kan.

FAMILY GLYPHIOCERATIDÆ.

GENUS SCHISTOCERAS Hyatt.

Schistoceras missouriense (Miller and Faber).

(Pl. XXI, figs. 4-4a.)

1892. *Goniatites missouriensis.* Miller and Faber, Jour. Cinn. Soc. Nat. Hist., vol. 14, p. 164, pl. 6, fig. 1.

1903. *Schistoceras missouriense.* Smith, Monog. U. S. Geol. Surv., vol. 42, p. 111, pl. 8, fig. 1.

Smith's description: "Shell subglobose, involute, whorls highly arched, helmet shaped, sides somewhat flattened, about twice as high as broad, deeply embracing, showing but little of the inner whorls, and deeply indented by them. Umbilical shoulders abrupt and umbilicus is deep and rather narrow, being hardly one-fourth the total diameter. Surface apparently smooth, no constrictions being visible. The preservation of the cast does not permit the determination of the presence or absence of umbilical ribs.

"Septa consisting of four lateral lanceolate lobes on each side, and probably a fifth on the umbilical border. The saddles are also like the lobe, but more constricted and club-shaped. The form and septa are unmistakably those of *Schistoceras*, and the species may very likely be identical with either *S. hyatti* or *S. hildrethi*, but the figures and description of *S. missouriense* do not permit this determination. It seems to be more compressed and to have a narrower umbilicus than either of the other species."

The umbilicus on this shell is quite wide, being a little more than one-fourth the total diameter of the shell. There is a small ventral ridge around the periphery. The ventral lobe is long, fairly broad, and divided by a siphonal saddle of nearly equal breadth. There are at least two more lobes on the umbilical border. The type specimen of *S. missouriense* is cut through the middle in the plane of the shell, and so these latter characteristics are not observed. It is also somewhat larger than the specimen at hand and seems to be somewhat more compressed near the aperture. It is worthy of note, however, that this character is one developed rather later in the life of the animal, and that this may really be of no specific importance, as the shell at hand shows a tendency to develop the same character. Surface marked with numerous fine revolving lines, rather closely set and rather strong. Crossing these, and much finer, is another set of growth lines which, together with the others, serve to give a more or less concellated appearance to the shell. It is very similar to *S. hyatti*, and probably a close comparison of a large number of specimens will prove the two identical.

Horizon and locality. Drum limestone, oölitic member, Kansas City, Mo., and Cherryvale (station 40 ?), Kan.

TRILOBITA.

FAMILY PRŒTIDÆ.

GENUS PHILLIPSIA Portlock.

Phillipsia major Shumard.

(Pl. XIX, figs. 6-8.)

1858. *Phillipsia major.* Shumard, Trans. St. Louis Acad. Sci., vol. 1, p. 226.

The specimens studied include several pygidia, varying in size, associated with more or less complete cranidia and one pygidium with the thorax (somewhat broken) and cranidium attached, and three free cheeks. From these specimens the following description is given:

General outline elliptical, cephalon (without genal spines) about two-thirds as long as the pygidium and considerably wider.

The length of the cephalon is about equal to the width of the cranidium, which equals a little more than half the entire width of the cephalon; with the genal spines, the length of the cephalon is about equal to its width. The cranidium is slightly longer than wide, and the width in front is equal to the width at the eyes. The glabella is subrectangular in outline, with the sides converging slightly toward the front, anterior margin rounded; moderately convex, the greatest convexity being slightly behind the middle. It is sharply defined, being margined by a small but distinct groove on each side and another one in front, which separates it from the flattened anterior border. Glabellar furrows in three rather obscure pairs, the posterior pair being strongest and passing obliquely backward across the lateral angles of the glabella so as to divide it at the neck ring into three nearly equal parts. Two fainter pairs of furrows extend obliquely backward on the glabella. Neck ring prominent, narrow, extending laterally a short distance due to the rapid divergence of the facial suture. Neck furrow deep and narrow. Palpebral lobes moderately large and sharply defined. In the furrows which define the sides of the glabella, situated about one-third the length from the front, is a sharp, deep pit on each side of the glabella. The free cheeks are subtriangular in shape, produced at the genal angles into long spines; outer border flattened and defined from the interior by a shallow groove which is parallel to the margin, while another groove parallel to the posterior margin extends inward to connect with the neck furrow. Between these two grooves the cheek is somewhat raised and convex to the margin of the eye, which rises abruptly from it. Eyes large, lunate.

Pygidium subtriangular in outline, the width being a very little greater than the length, tapering rapidly from the anterior side of the abruptly rounded posterior extremity; side nearly straight. Border smooth, flat or concave at the posterior end and becoming narrower and somewhat sloping anteriorly. Axial lobe about two-thirds as wide as the pleural lobes on the anterior end, but all three narrow down to blunt points toward the posterior extremity. The axis is defined by a very deep, narrow groove on each side, and is composed of twenty-two segments while each of the pleural lobes has twelve.

The surface is smooth in appearance, but when examined with a lens is seen to be very finely pitted.

This species agrees so well with Shumard's description that there can be little doubt that the identification is correct. He gave as the dimensions of the pygidium: "Length, 1.1 inch; breadth, 1.2 inch." On the largest of the pygidia at hand the dimensions are: Length, .99 inch; breadth, 1.02 inch. Whether it is identical with Meek's specimen is somewhat doubtful, for comparing the length and breadth of about twenty pygidia in these collections reveals the fact that all of them are wider than long.

This is the species described by Hall as *Proetus longicaudus* and originally believed to be from the Devonian, but subsequently referred by him to the Carboniferous. A cast of the type is identical with the present fossils, even to the small pit on each side of the glabella, which for some reason he did not describe.

This species differs from *P. sangamonensis*, as described by Girty, from the Wewoka formation, in the pit on each side of the glabella, in the straight instead of sinuous sides of the glabella, and in the fact that the width of the anterior part of the cranidium is equal to the width at the eyes.

Horizon and locality. Drum limestone, oölitic member, at Turner, Elsmore (station 46), Cherryvale (station 40) and Independence (stations 12, 23), Kan., and Kansas City, Mo.

REGISTER OF LOCALITIES.

Kansas City, Mo.: West bluff and Sixth street; quarry at First and Michigan streets; north bluff and Garfield street.

Muncie, Kan.: In the Union Pacific railroad cut, Wyandotte county.

Turner, Kan.: In the abandoned quarry where the stream crosses the east-west road one mile south of Turner, Johnson county, Kan.; Kansas City quadrangle.

9. Independence, Kan., quadrangle: Drum limestone; two and a half miles east of Independence, Kan.; outcrop near road, SE¼, sec. 28, T. 32, S., R. 16 E.

12. Independence quadrangle: Drum limestone; one and a half miles southeast of Independence, Kan.; Atlas Portland cement quarry, NW¼, sec. 8, T. 33 S., R. 16 E.

23. Independence quadrangle: Drum limestone; three and a half miles southeast of Independence, Kan.; outcrop along the Verdigris river, SW¼, sec. 10, T. 33 S., R. 16 E.

25. Independence quadrangle: Drum limestone; five miles southwest of Coffeyville, Kan.; outcrop along the road, NE¼, sec. 19, T. 35 S., R. 16 E.

40. Independence quadrangle: Drum limestone; two and a half miles west of Cherryvale, Kan.; outcrop along the road, SW¼, sec. 7, T. 32 S., R. 17 E.

43. Iola quadrangle: Drum limestone; three miles south of Urbana, Kan.; outcrop along the east-west road, N½, sec. 23, T. 29 S., R. 18 E.

46. Iola quadrangle: Drum limestone; four and a half miles west-southwest of Elsmore, Kan.; outcrop along the road, SW¼, sec. 16, T. 26 S., R. 20 E.

48. Iola quadrangle: Drum limestone; four miles north-northeast of Bronson, Kan.; outcrop in the small creek, S½, sec. 13, T. 24 S., R. 21 E.

PLATE I.

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FIGS. 1-2.—*Michelinia eugeneæ* White.................................... 85

1. Portion of a large corallum, broken so as to show the tabulæ. Independence (station 12), Kan.

1*a*. Transverse section of a portion of the above.

2. Oblique section of another specimen from the same locality.

FIGS. 3-5.—*Lophophyllum profundum* Milne-Edwards and Haime......... 85

3. A nearly straight specimen. Turner, Kan.

4, 5. Vertical and transverse sections of a typical specimen.

FIGS. 6-8.—*Rhombopora lepidodendroides* Meek.......................... 92

6, 7, 8. Vertical, tangential and transverse sections of mature specimens. ×25. Turner, Kan.

FIGS. 9-11.—*Rhabdomeson kansasense* Sayre, n. sp....................... 91

9, 10, 11. Tangential, vertical, and transverse sections of typical specimens. ×25. Independence (station 12), Kan.

PLATE I.

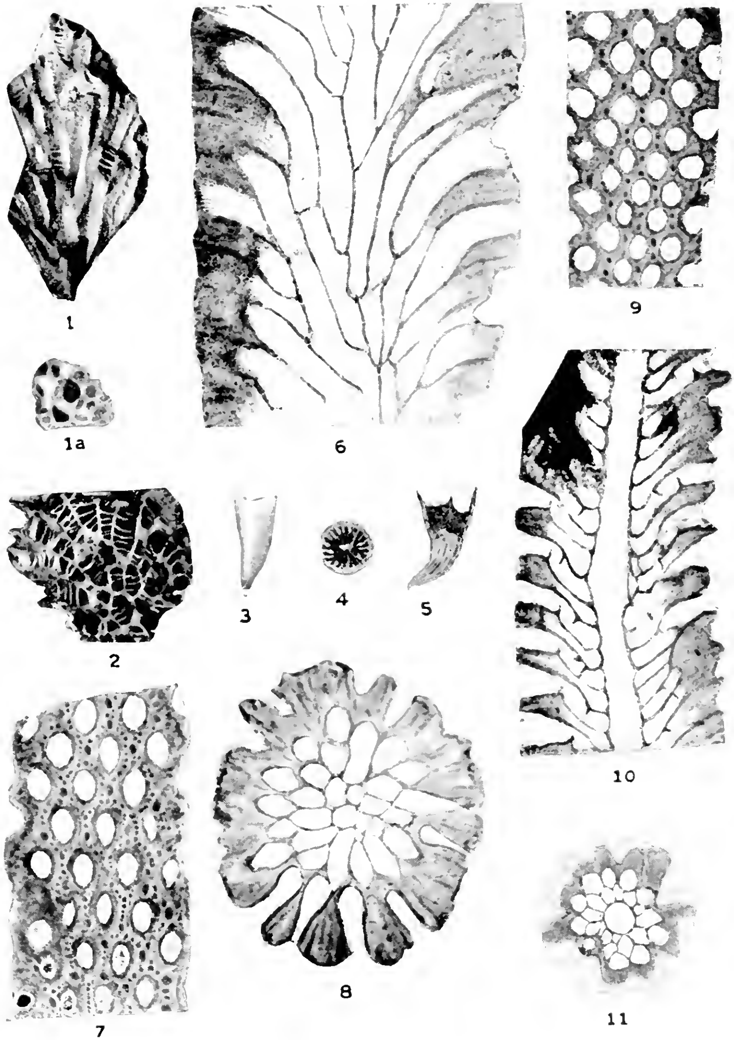


PLATE II.

PAGE

FIGS. 1-1*a*.—*Fenestella mimica* var. *latirama* Sayre, n. var. 88

1, 1*a*. Obverse and reverse views, ×25. The spines of the keel on the obverse face are only partially preserved. Independence (station 12), Kan.

FIGS. 2-3.—*Tabulipora heteropora* (Condra) 88

2. Transverse section, ×25.

3. Vertical section of a specimen which shows fewer tabulæ than typical members of the species, ×25. Turner, Kan.

FIGS. 4-6.—*Fistulipora nodulifera* Meek 87

4, 5. Transverse and vertical sections, ×25. Note the deposit of calcite within the zoœcial tubes and in the interzoœcial pores, giving them the appearance of being thick-walled. Turner, Kan.

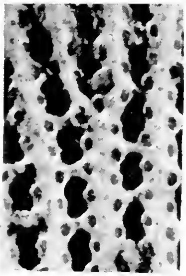
6. A portion of the surface of the zoarium, showing the raised lip of the aperture, ×12.5. Turner, Kan.

FIGS. 7-7*a*.—*Fenestella moorei* Sayre, n. sp. 89

7. Obverse face, ×25.

7*a*. Reverse face showing the striations, ×25. Independence (station 12), Kan.

PLATE II.



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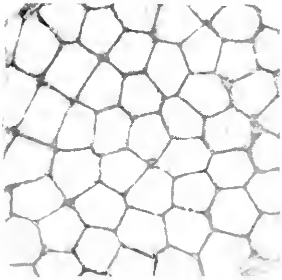

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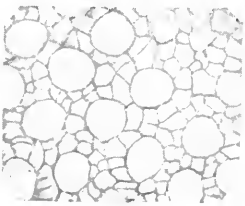

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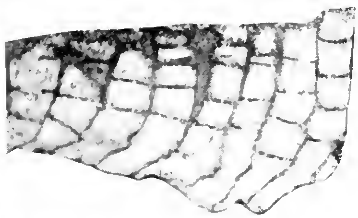

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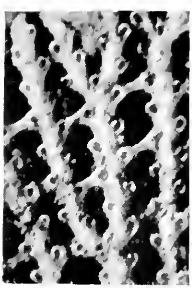

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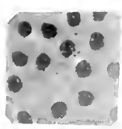


6

7a

PLATE III.

PAGE

FIG. 1.—*Fenestella moorei* Sayre, n. sp. 89

1. Obverse face. ×12.5. Independence (station 12), Kan.

FIGS. 2-4.—*Polypora elliptica* Rogers 89

2. Obverse view, showing the manner of growth, straight branches with few bifurcations.

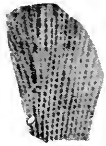
3, 4. Obverse and reverse views, ×25. Independence (station 12), Kan.

FIGS. 5-5*a*.—*Polypora submarginata* var. *nodosa* Sayre, n. var. 90

5, 5*a*. Reverse and obverse views. ×25. Independence (station 12), Kan.

PLATE III.

3



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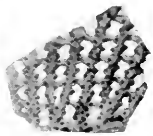

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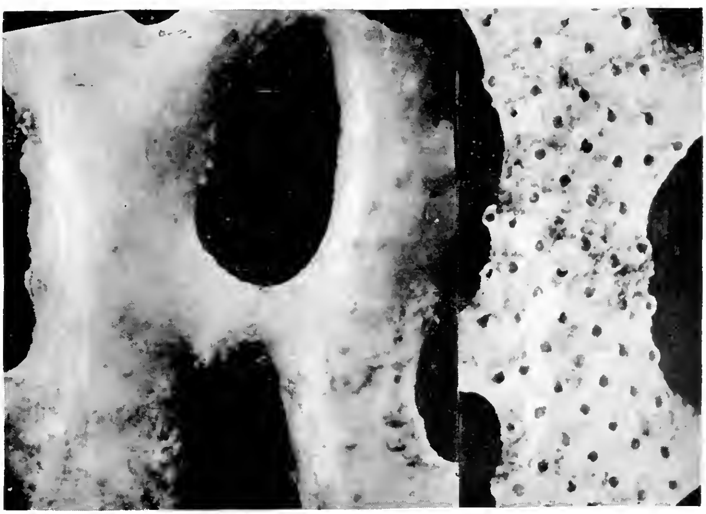


PLATE IV.

PAGE

FIGS. 1-1*a*.—*Orbiculoidea convexa* (Shumard) 93

1. Dorsal view of the superior valve.

1*a*. Side view of the same, Kansas City, Mo.

FIG. 2.—*Polypora submarginata* var. *nodosa* Sayre, n. var 90

2. View of a large zoarium. Independence (station 12), Kan.

FIGS. 3-5.—*Derbya crassa* (Meek and Hayden) 93

3, 4. Dorsal views of two large specimens.

5. Ventral view of a small specimen. Turner, Kan.

FIGS. 6-8.—*Chonetes verneuilianus* Norwood and Pratten 94

6, 6*a*. Ventral view of a small specimen, and the same, ×3.

6*b*. Posterior view of the same.

7, 7*a*, 7*b*. Ventral, dorsal, and posterior views of a larger specimen.

8. Posterior view of another specimen referred to this species with some hesitation. All from Turner, Kan.

FIGS. 9-9*a*.—*Septopora biserialis* (Swallow) 91

9, 9*a*. Reverse and obverse views, ×12. Independence (station 12), Kan.

PLATE IV.

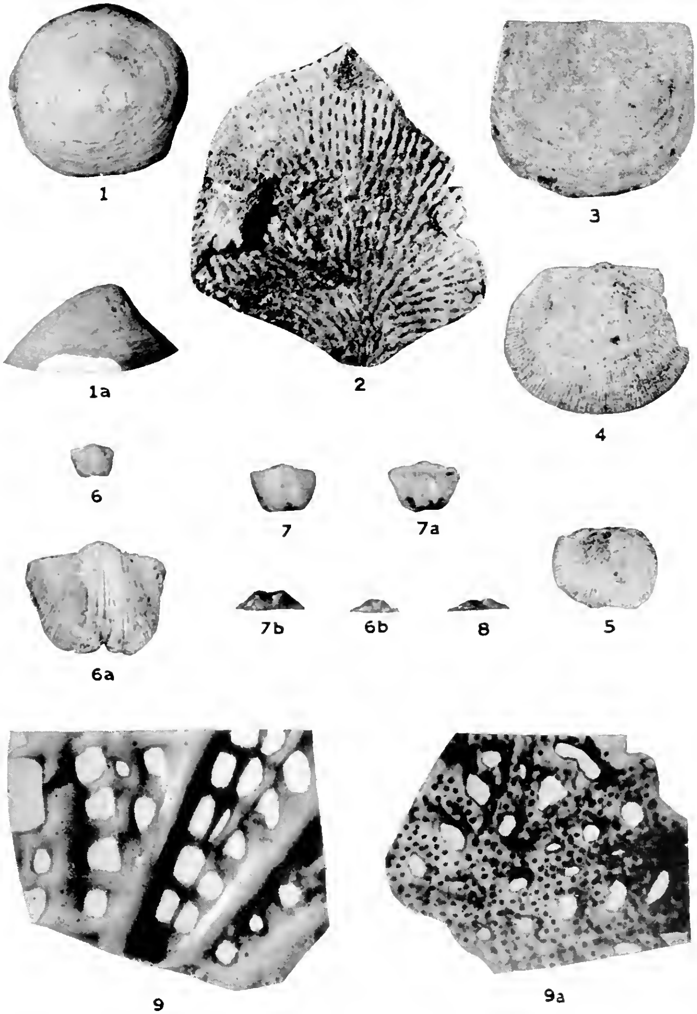


PLATE V.

PAGE

FIGS. 1-2*b*.—*Productus insinuatus* var. *missouriensis* Sayre, n. var.......... 94

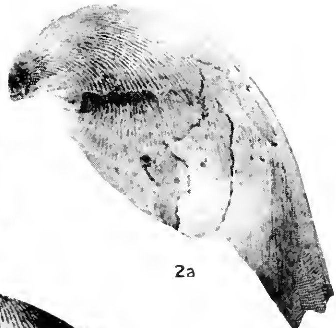
1, 1*a*. Anterior and side views of a narrow specimen.

2, 2*a*, 2*b*. Ventral, side and anterior views of a large, broad specimen.

Kansas City, Mo.

PLATE V.

1



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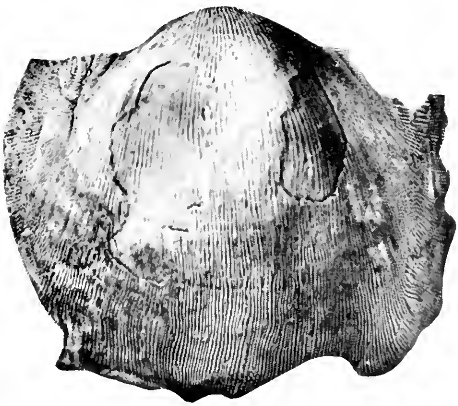

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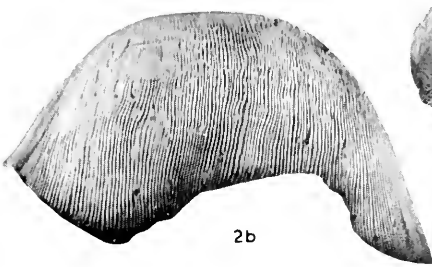

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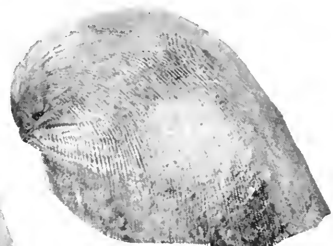

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PLATE VI.

PAGE

FIG. 1.—*Productus insinuatus* var. *missouriensis* Sayre, n. var. 94

1. Ventral view of a narrow specimen. Kansas City, Mo.

FIGS. 2-2*b*.—*Pustula semipunctata* (Martin) 96

2, 2*a*, 2*b*. Side, anterior and ventral views. Kansas City, Mo.

FIGS. 3-3*b*.—*Pustula nebrascensis* (Owen) 96

3, 3*a*, 3*b*. Anterior, side, and dorsal views of a characteristic specimen. Turner, Kan.

FIGS. 4-8*c*.—*Composita subtilita* (Hall) 102

4, 4*a*, 4*b*, 4*c*, 5, 5*a*, 5*b*, 5*c*, 6, 6*a*, 6*b*, 6*c*, 7, 7*a*, 7*b*, 7*c*, 8, 8*a*, 8*b*, 8*c*. Ventral dorsal side and anterior views of five specimens illustrating the youthful stages of development. Kansas City Mo.

PLATE VI.

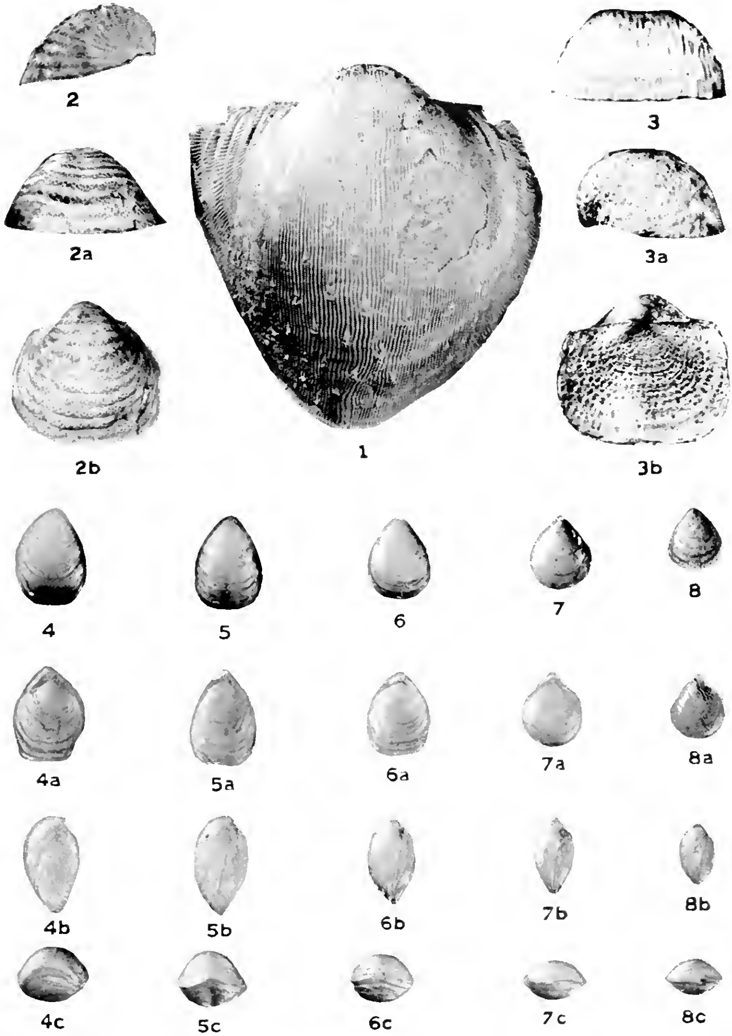

PLATE VII.

PLATE VII.

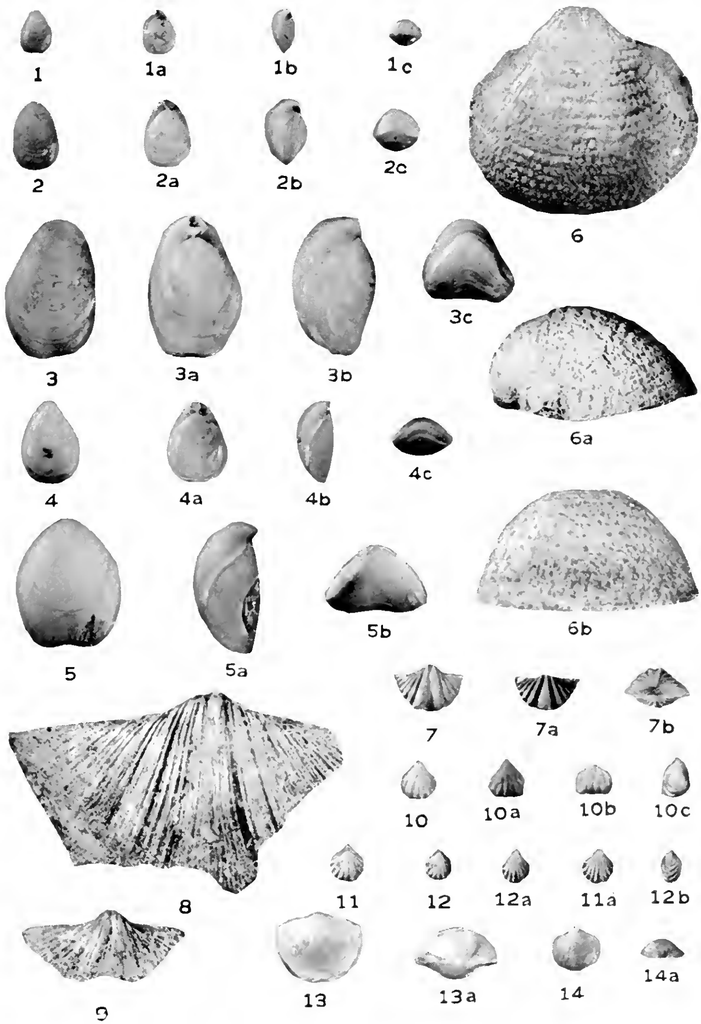
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PLATE VIII.

PAGE

FIGS. 1-1*a*.—*Edmondia aspinwallensis* Meek 103

1, 1*a*. A left valve, with most of the shell broken away and the cardinal view of the same. Turner, Kansas.

FIGS. 2-2*c*.—*Nuculopsis ventricosa* Hall 106

2, 2*a*. Right valve and cardinal view, natural size.

2*b*, 2*c*. Right valve and cardinal view, ×3. Kansas City, Mo.

FIGS. 3-3*a*.—*Edmondia nebrascensis* (Geinitz) 103

3, 3*a*. A slightly worn right valve and the cardinal view of the same. Turner, Kan.

FIGS. 4-4*a*.—*Solenomya* sp. *undet* 102

4, 4*a*. Internal cast of a right valve and cardinal view of the same. Turner, Kan.

FIGS. 5-5*a*.—*Edmondia ? kansasensis* Sayre, n. sp. 104

5, 5*a*. Right valve and cardinal view of the same. Turner, Kan.

FIGS. 6-6*c*.—*Nucula triangularis* Sayre, n. sp. 105

6. Left valve, natural size.

6*a*, 6*b*, 6*c*. Left valve, posterior and cardinal views, ×3. Muncie, Kan.

FIGS. 7-7*c*.—*Leda bellistriata* Stevens 106

7, 7*a*. Right valve and cardinal view natural size.

7*b*, 7*c*. Left valve and anterior view showing the slight gaping of the shell, ×3. Kansas City, Mo.

FIGS. 8-8*a*.—*Nucula anadontoides* Meek 104

8. An average size specimen, left valve.

8*a*. The same, ×3. Kansas City, Mo.

PLATE VIII.

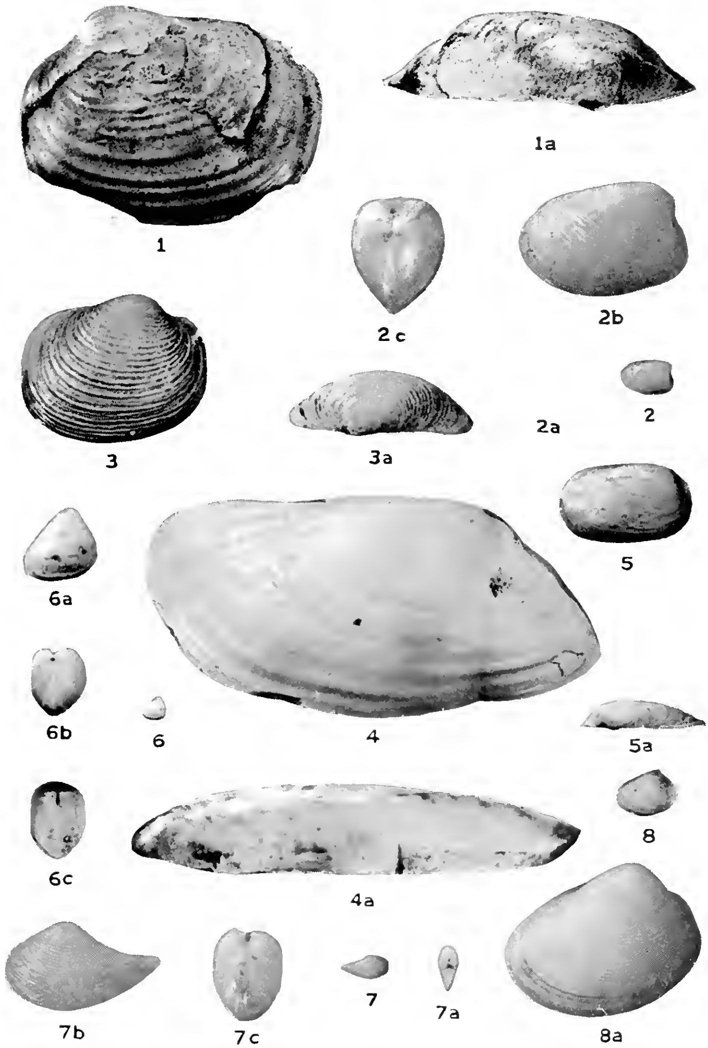


PLATE IX.

PAGE

FIGS. 1-3.—*Yoldia glabra* Beede and Rogers 107

1. Internal cast of a left valve.

2. A left valve with the posterior end broken off.

3. Cardinal view. Turner, Kan.

FIGS. 4-7.—*Parallelodon kansasensis* Sayre, n. sp. 108

4, 4*a*, 5, 5*a*. Side and cardinal views of a right and a left valve.

6-7. Two young individuals, right valves. Turner, Kan.

FIGS. 8-9.—*Monopteria longispina* (Cox) 112

8, 9. A nearly complete, immature right valve, and an adult right valve with the wing broken. Turner, Kan.

FIGS. 10-12.—*Pseudomonotis equistriata* Beede 114

10, 10*a*. Left valve and ventral view.

11, 12. Two smaller left valves. Turner, Kan.

FIGS. 13-14.—*Pteria longa* (Geinitz) 110

13, 13*a*. A small left valve, and the same, ×3. Referred to this species with some hesitation.

14. An internal cast of a left valve. Turner, Kan.

FIGS. 15-16.—*Pteria welleri* Sayre, n. sp. 110

15. Left valve, natural size.

15*a*, 16. No. 15, ×3, and another left valve showing slightly different ornamentation, ×3. Kansas City, Mo.

FIGS. 17-17*a*.—*Parallelodon sangamonensis* (Worthen)? 108

17, 17*a*. A large right valve and the cardinal view of the same. Turner, Kan.

FIGS. 18-19*a*.—*Monopteria marian* White 111

18. A specimen with the wing broken off.

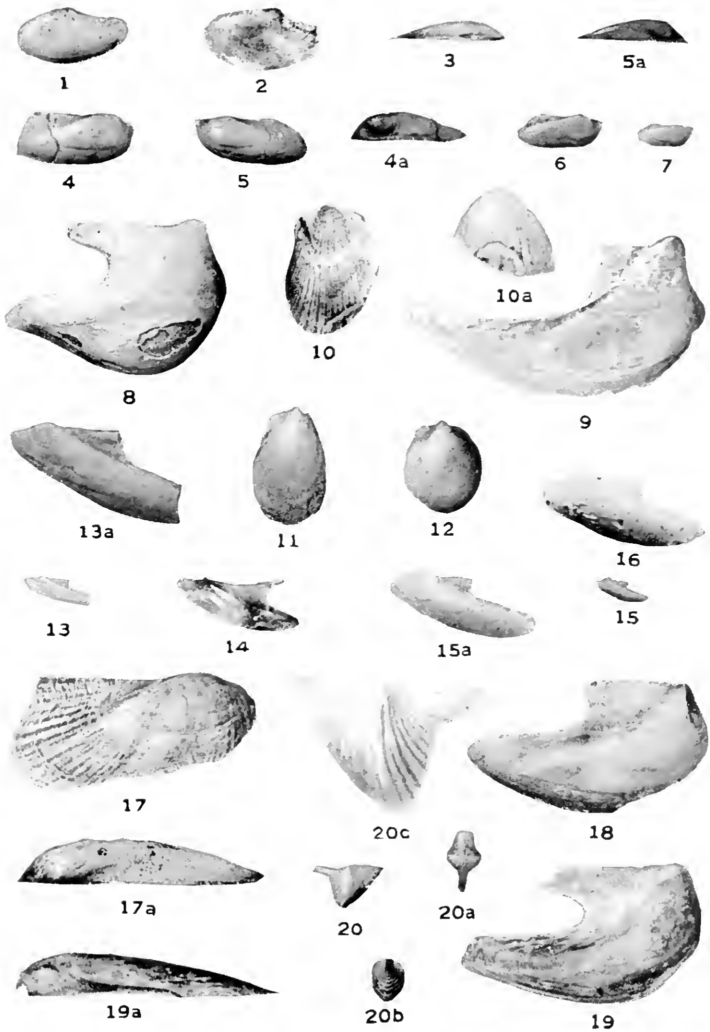
19, 19*a*. Another specimen with the tip of the wing broken, and a cardinal view of the same. Kansas City, Mo.

FIGS. 20-20*c*.—*Conocardium parrishi* Worthen 109

20, 20*a*, 20*b*. Side cardinal and anterior views.

20*c*. Right valve, ×3. Kansas City, Mo.

PLATE IX.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19a
20b
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PLATE X.

PAGE

FIGS. 3-4*a*.—*Pseudomonotis spinosa* Sayre, n. sp. 112

1, 2. A left valve and the interior of a right valve. Turner, Kan.

FIG. 5.—*Pseudomonotis ? robusta* Beede ? 114

3, 3*a*, 4 4*a*. Two left valves with their cardinal views showing the extremes of variation in shape. Kansas City, Mo.

FIGS. 1-2.—*Pseudomonotis hawni* (Meek and Hayden) 113

5. A left valve considerably smaller than the type, Kansas City, Mo.

FIGS. 6-7.—*Pseudomonotis kansasensis* Beede 113

6. A left valve of a small specimen.

7. Interior view of a slightly broken right valve. Turner, Kan.

FIGS. 8-8*b*.—*Myalina ? swallovi* McChesney 116

8. A right valve, nearly complete.

8*a*. Anterior view of the same.

8*b*. View of the same showing the edentulous hinge marked by two obscure ligament furrows. Kansas City, Mo.

FIGS. 9-10*a*.—*Myalina kansasensis* Shumard 115

9, 9*a*. Left valve and anterior view of the same.

10, 10*a*. Right valve of a smaller individual and the hinge area of the same. Turner, Kan.

PLATE X.

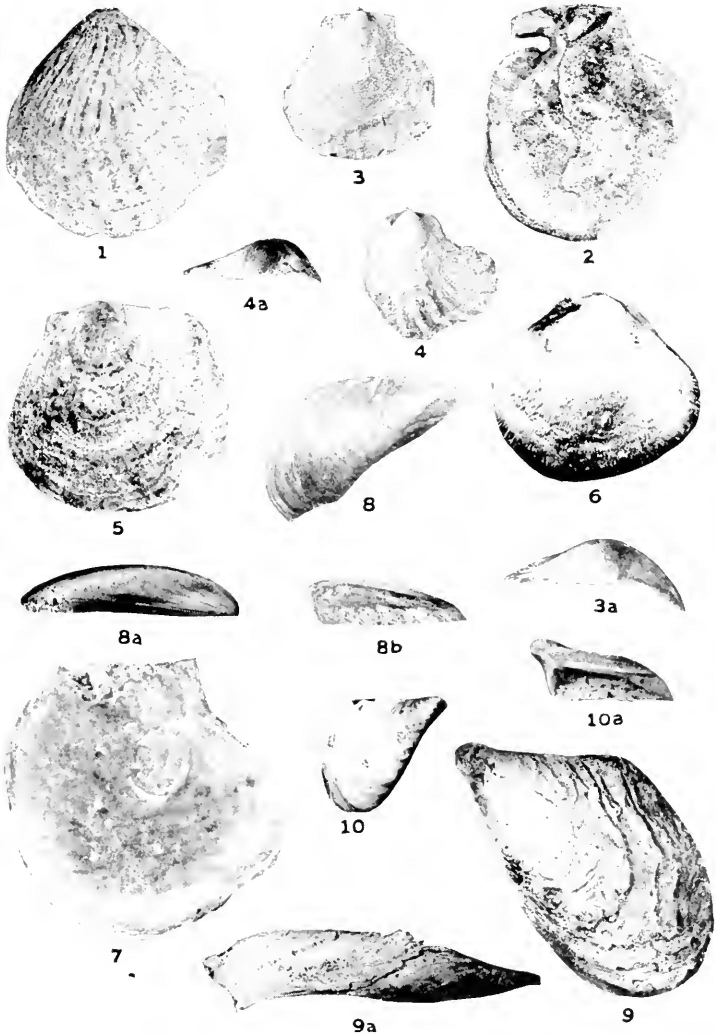

PLATE XI.

PAGE

FIGS. 1-1*a*.—*Myalina ? slocomi* Sayre, n. sp. 117

1. A left valve with part of the shell broken away.

1*a*. View showing the hinge area. Turner, Kan.

FIGS. 2-2*a*.—*Schizodus trigonalis* Sayre, n. sp. 118

2-2*a*. Left valve and cardinal view. Muncie, Kan.

FIGS. 3-3*a*.—*Streblopteria tenuilineata* (Meek and Worthen) 121

3, 3*a*. Right valve, and the same, ×3. Turner, Kan.

FIGS. 4-4*b*.—*Schizodus harii* Miller ? 117

4, 4*a*, 4*b*. Cast of a right valve with cardinal and anterior views. Kansas City, Mo.

FIGS. 5-8.—*Deltopecten occidentalis* (Shumard) 120

5, 6. Two left valves.

7. Interior of a small right valve.

8. A large right valve. Turner, Kan.

FIGS. 9-10.—*Aviculopecten sculptilis* Miller 119

9. A young individual, left valve. Turner, Kan.

10. An adult specimen, left valve. Kansas City, Mo.

PLATE XI.

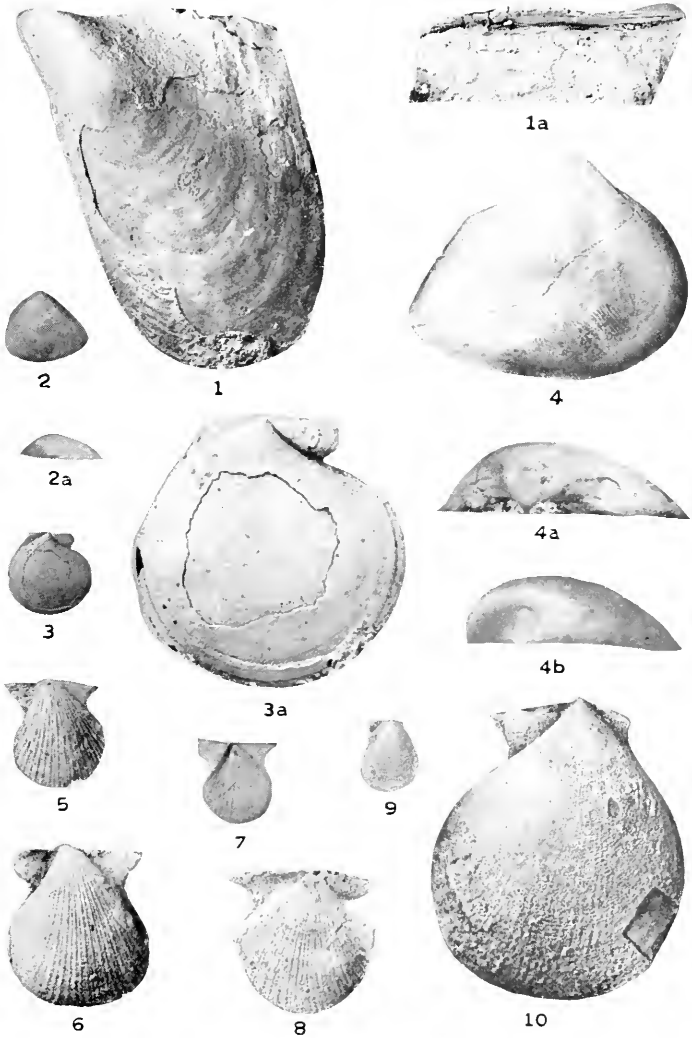

PLATE XII.

PAGE

FIGS. 1-2.—*Aviculopecten providencesis* (Cox) 118

1. A small left valve.

2. A large left valve. Kansas City, Mo.

FIGS. 3-4*a*.—*Pleurophorus attenuatus* Sayre, n. sp. 125

3, 3*a*. A left valve with the cardinal view.

4, 4*a*. A smaller right valve with the cardinal view. Kansas City, Mo.

FIGS. 5-6.—*Acanthopecten carboniferus* (Stevens) 121

5, 6. Two left valves. Kansas City, Mo.

FIGS. 7-8*a*.—*Limatula ? fasciculata* Girty 122

7, 8*a*. A right valve somewhat worn and a left valve nearly perfect, ×3.

8. The same as 8*a*, natural size. Turner, Kan.

FIGS. 9-9*a*.—*Lithophaga subelliptica* Sayre, n. sp. 123

9, 9*a*. A left valve and the same, ×3. Kansas City, Mo.

FIG. 10.—*Allerisma costatum* Meek and Worthen 123

10. A slightly broken right valve. Turner, Kan.

FIGS. 11-13*a*.—*Pleurophorus subcostatus* Meek and Worthen 124

11. A small, complete right valve.

12, 12*a*. A large, nearly complete right valve with the cardinal view.

13, 13*a*. A smaller nearly complete left valve with the cardinal view. Turner, Kan.

FIGS. 14-15.—*Pleurophorus tropidophorus* Meek 125

14, 15. Two incomplete right valves. Turner, Kan.

FIGS. 16-17*a*.—*Pleurophorus turnerensis* Sayre, n. sp. 125

16, 17. Two broken right valves.

17*a*. Cardinal view of No. 17. Turner, Kan.

PLATE XII.

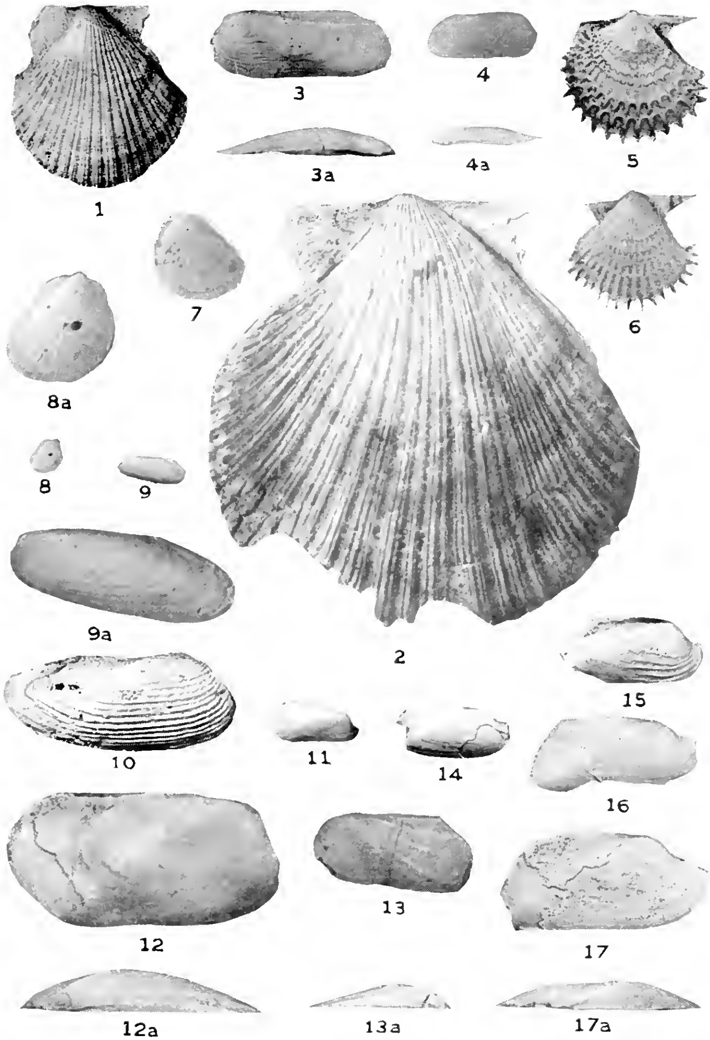

PLATE XIII.

PAGE

FIGS. 1-2*a*.—*Cypricardinia carbonaria* Meek 126

1, 1*a*. A right valve, and the same enlarged, ×3.

1*b*. Cardinal view of the same.

2, 2*a*. Left valve and cardinal view of the same. Kansas City, Mo.

FIGS. 3-3*a*.—*Astartella gurleyi* White 127

3, 3*a*. Right valve with cardinal view. Turner, Kan.

FIGS. 4-5.—*Bucanopsis textiliformis* (Gurley) 129

4, 4*a*. Top and side views of a small specimen.

5. Top view of a larger, incrusted specimen. Turner, Kan.

FIGS. 6-6*a*.—*Bucanopsis tenuilineata* (Gurley) 129

6, 6*a*. Side and anterior views. Turner, Kan.

FIGS. 7-7*a*.—*Bellerophon stevensianus* McChesney 128

7, 7*a*. Side and anterior views. Turner, Kan.

FIGS. 8-8*a*.—*Orestes intertexta* (Meek and Worthen) 138

8, 8*a*. Basal and apertural views, ×5. Turner, Kan.

FIGS. 9-9*a*.—*Patellostium marcouianum* (Geinitz) 128

9, 9*a*. "Dorsal" and side views of a specimen on which the broken, flared lip has been restored by a plaster of paris cast. Kansas City, Mo.

FIGS. 10-10*b*.—*Pleurotomaria fisheri* Sayre, n. sp. 133

10, 10*a*, 10*b*. Apertural, basal, and top views, ×5. Turner, Kan.

FIGS. 11-11*b*.—*Worthenia speciosa* (Meek and Worthen) 139

11, 11*a*, 11*b*. Side views and top view. Turner, Kan.

FIG. 12.—*Euconospira missouriensis* (Swallow) 138

12. Side view, natural size. Kansas City, Mo.

FIG. 13.—*Pleurotomaria bilineata* Sayre, n. sp. 132

13. Apertural view, ×2.5. Kansas City, Mo.

PLATE XIII.

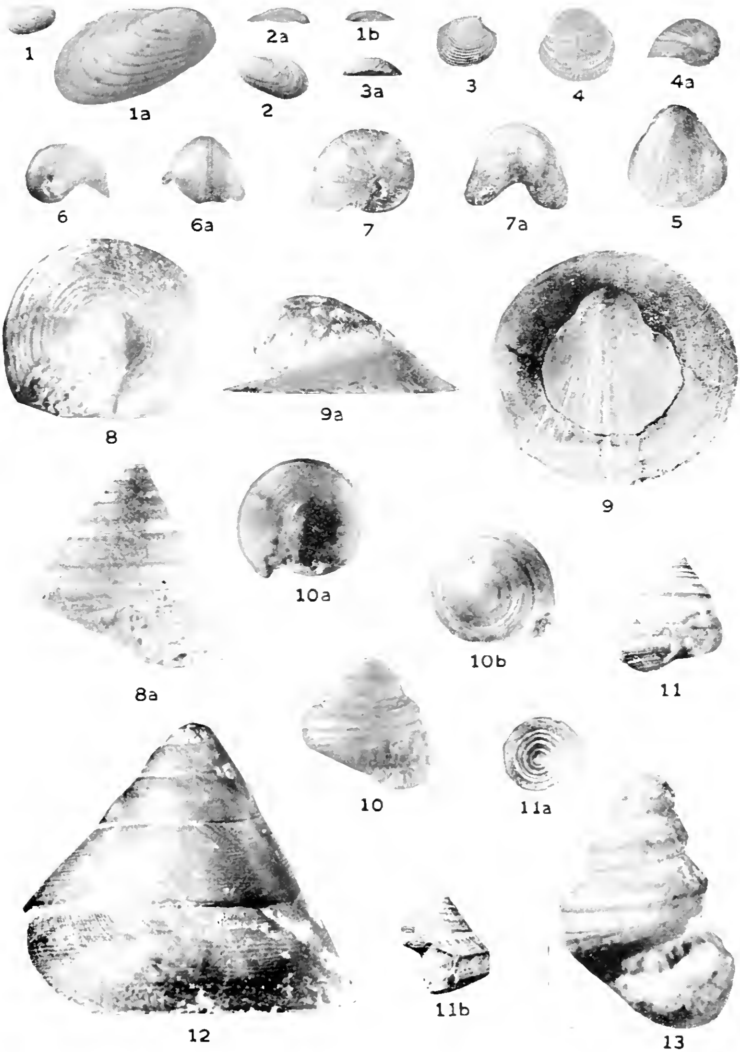

PLATE XIV.

PAGE

FIGS. 1-1a.—*Pleurotomaria kansasensis* Sayre, n. sp. 134
1, 1*a*. Side and top views, ×5. Muncie, Kan.

FIGS. 2-2*a*.—*Pleurotomaria granulostriata* (Meek and Worthen)? 130
2, 2*a*. Side and apertural views, ×7.5. Turner, Kan.

FIGS. 3-3*b*.—*Pleurotomaria subsinuata* Meek and Worthen 132
3, 3*a*, 3*b*. Apertural, basal and top views, ×7.5. Turner, Kan.

FIGS. 4-4*a*.—*Pleurotomaria subconstricta* Meek and Worthen 131
4, 4*a*. Apertural and basal views, ×5. Turner, Kan.

FIGS. 5-5*b*.—*Ptychomphalus lineata* Sayre, n. sp. 135
5, 5*a*, 5*b*. Apertural, basal and top views, ×5. Turner, Kan.

PLATE XIV.

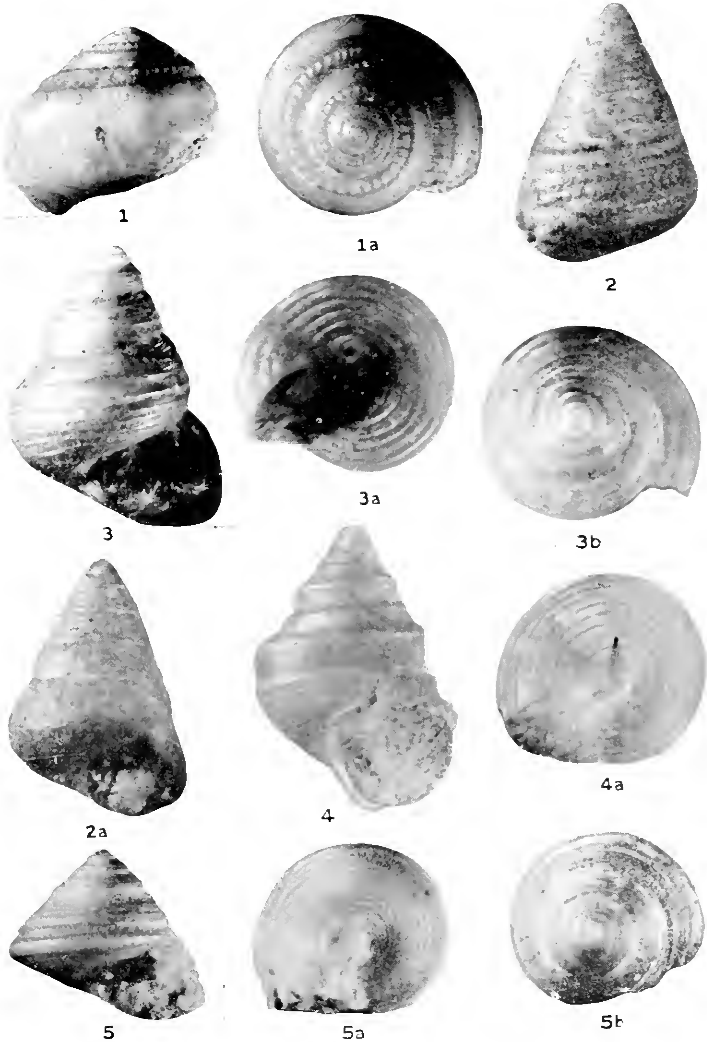

PLATE XV.

PLATE XV.

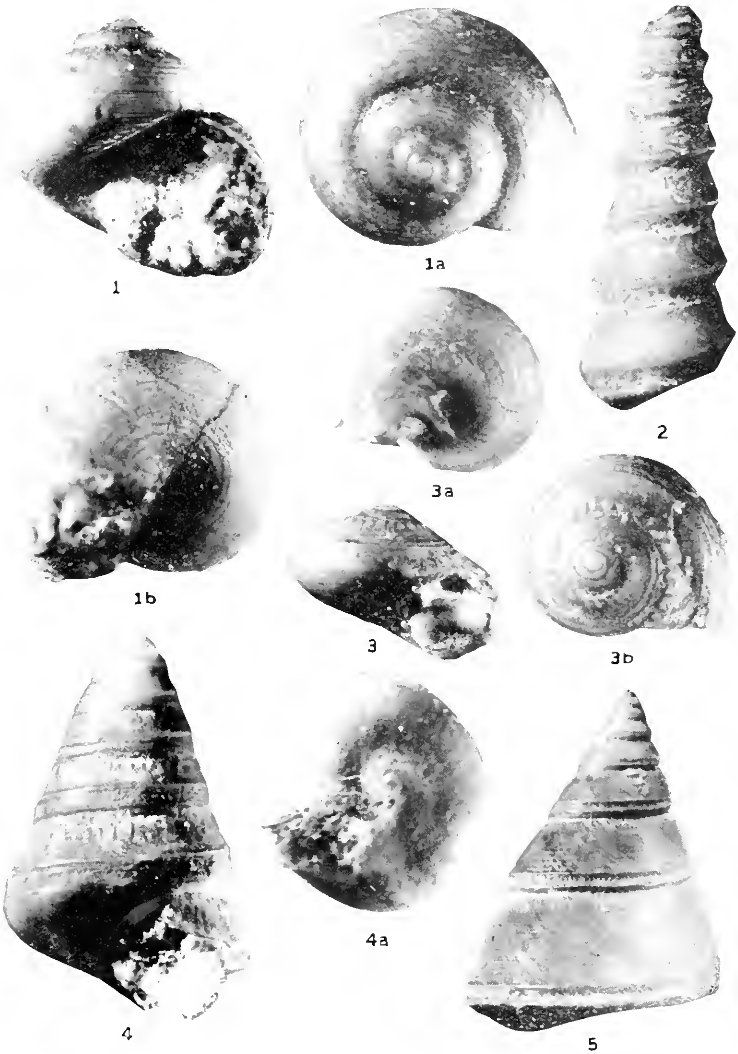

PLATE XVI.

PAGE

FIGS. 1-2.—*Murchisonia mattheri* Sayre, n. sp. 135

1. Side view of a broken specimen showing the surface markings, ×5.
2. Apertural view of a complete specimen, ×4.2. Turner, Kan.

FIGS. 3-3*a*.—*Sphærodoma primigenius* (Conrad) 148

3, 3*a*. Apertural and side views of a large internal cast. Independence (station 12), Kan.

FIG. 4.—*Microdoma ornatus* Sayre, n. sp. 140

4. Apertural view, ×7.5. Turner, Kan.

FIG. 5.—*Sphærodoma paludinæformis* (Hall) 148

5. Apertural view, ×5. Turner, Kan.

FIG. 6.—*Bulimorpha meeki* Sayre, nom. nov. 146

6. Apertural view, ×10. Turner, Kan.

FIG. 7.—*Bulimorpha turnerensis* Sayre, n. sp. 147

7. Apertural view, ×10. Turner, Kan.

FIG. 8.—*Soleniscus typicus* Meek and Worthen 148

8. Apertural view of a specimen with the lip broken, ×7.5. Turner, Kan.

FIG. 9.—*Bulimorpha chrysallis* (Meek and Worthen) 146

9. Apertural view, ×7.5. Turner, Kan.

FIG. 10.—*Sphærodoma fusiformis* (Hall) ? 147

10. Apertural view of a broken incrusted specimen, ×4. Turner, Kan.

PLATE XVI.

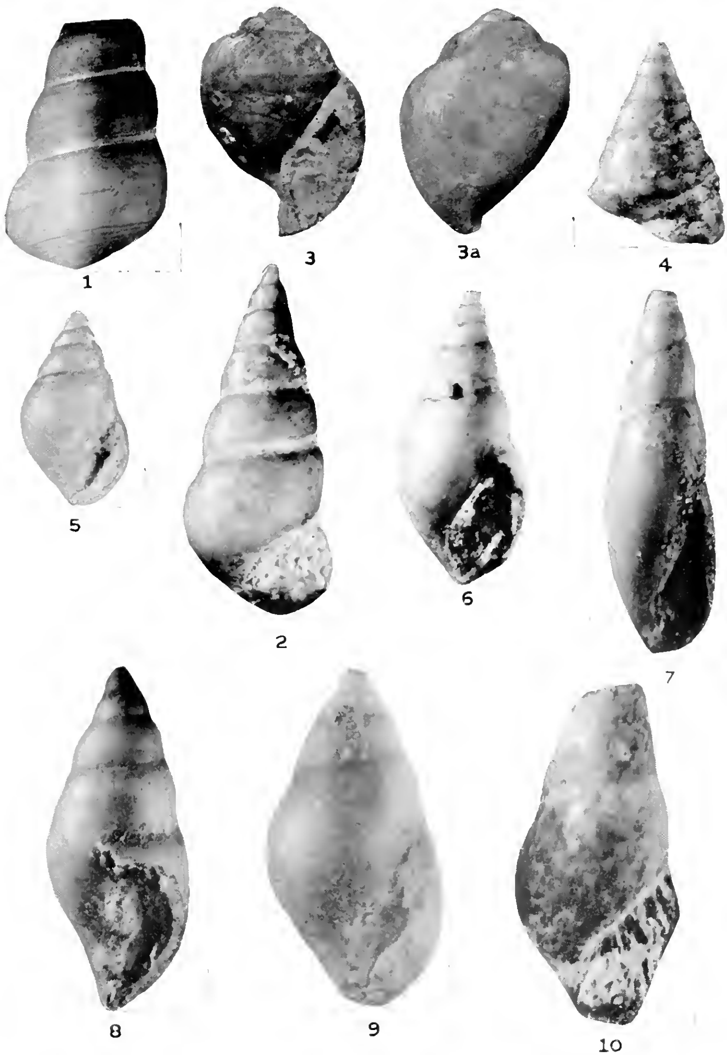

PLATE XVII.

PAGE

FIG. 1.—*Aclisina parallela* Sayre, n. sp. 170

1. Apertural view of a broken specimen, ×10. Turner, Kan.

FIGS. 2-3.—*Orthonema liratum* Sayre, n. sp. 151

2. Apertural view of a small complete shell, which is somewhat incrusted, ×10.

3. Side view of a broken specimen showing the surface markings, ×10. Turner, Kan.

FIG. 4.—*Aclisina breva* Sayre, n. sp. 150

4. Apertural view, ×10. Turner, Kan.

FIG. 5.—*Aclisina stevensana* (Meek and Worthen) 149

5. Apertural view, ×7.5. Turner, Kan.

FIG. 6.—*Aclisina swalloviana* (Geinitz) 149

6. Apertural view, ×10. Turner, Kan.

FIG. 7.—*Zygopleura multicostata* (Meek and Worthen) 144

7. A broken specimen, ×10. Muncie, Kan.

FIG. 8.—*Zygopleura plicata* (Whitfield)? 144

8. Apertural view, ×10. Kansas City, Mo.

FIG. 9.—*Zygopleura rugosa* (Meek and Worthen)? 143

9. Apertural view, ×5. Turner, Kan.

FIG. 10.—*Zygopleura nana* Girty 145

10. Apertural view, ×10. Kansas City, Mo.

FIG. 11.—*Hemizyga ? cancellata* Sayre, n. sp. 145

11. Side view, ×7.5. Turner, Kan.

FIG. 12.—*Zygopleura attenuata* (Stevens)? 144

12. Side view, ×7.5. Muncie, Kan.

FIG. 13.—*Zygopleura teres* Girty 143

13. Apertural view, ×10. Kansas City, Mo.

PLATE XVII.

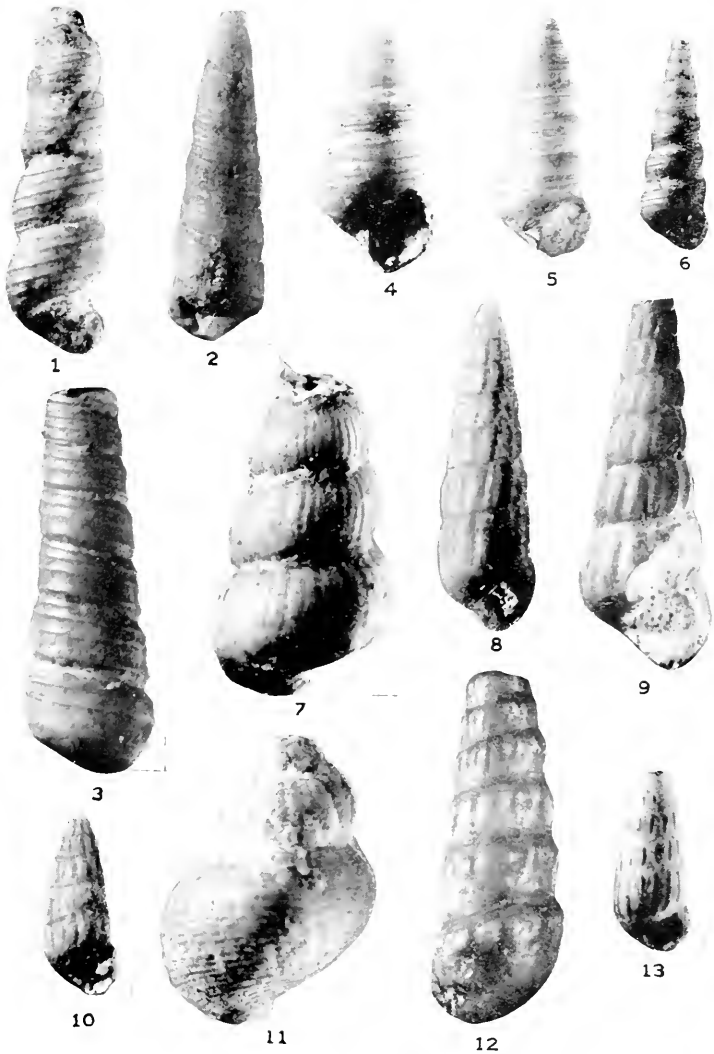

PLATE XVIII.

PAGE

FIGS. 1-1*b*.—*Naticopsis pricei* Shumard 141
1. Apertural view, ×2.5.
1*a*, 1*b*. Top and side views of the same specimen. Kansas City, Mo.

FIGS. 2-2*b*.—*Strophostylus peoriensis* (McChesney) 140
2, 2*a*, 2*b*. Top, side, and oblique views of a specimen with the shell partly broken away. Turner, Kan.

FIGS. 3-3*a*.—*Trachydomia pustulosa* Sayre, n. sp. 152
3, 3*a*. Apertural and side views, ×2.5. Muncie, Kan.

FIGS. 4-4*a*.—*Trachydomia wheeleri* (Swallow) ? 151
4, 4*a*. Apertural and side views, ×2.5. Kansas City, Mo.

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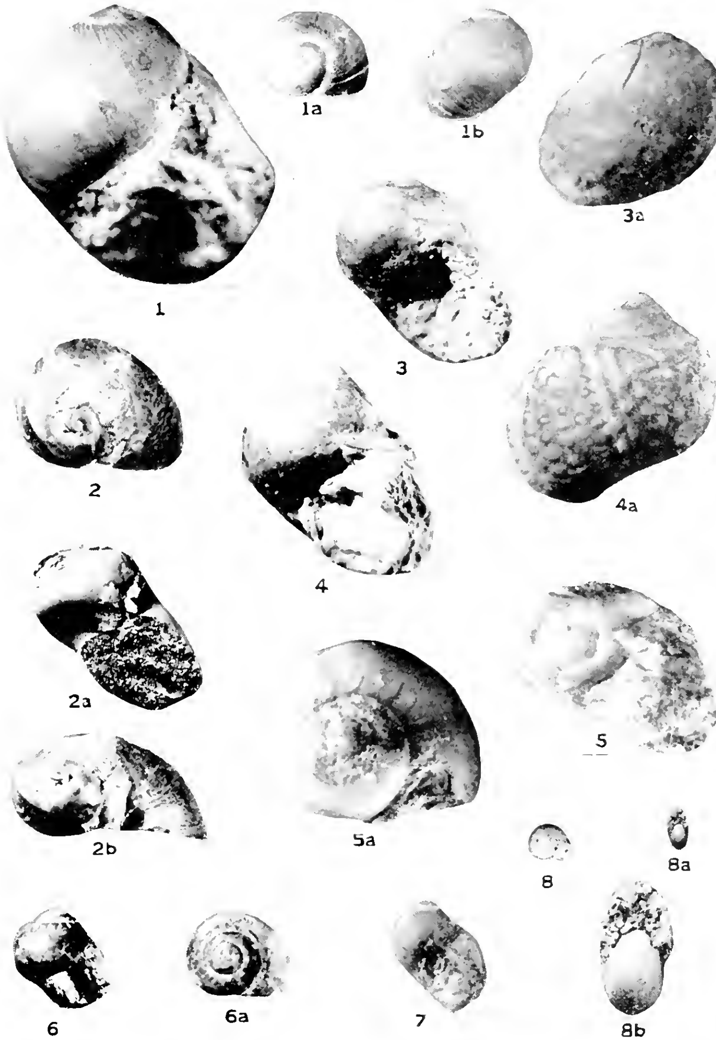
8, 8*a*. Side and apertural views.
8*b*. Apertural view, ×3. Kansas City, Mo.

PLATE XVIII.



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FIGS. 1-2*a*.—*Orthoceras occidentale* Swallow? 152

2, 2*a*. Another specimen showing the position of the siphuncle. Turner, Kan.

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6. An inrolled specimen consisting of the cranidium, and pygidium with the axial lobe of the thorax. Side view.

6*a*. The upper side of the same.

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8. A large pygidium. Kansas City, Mo.

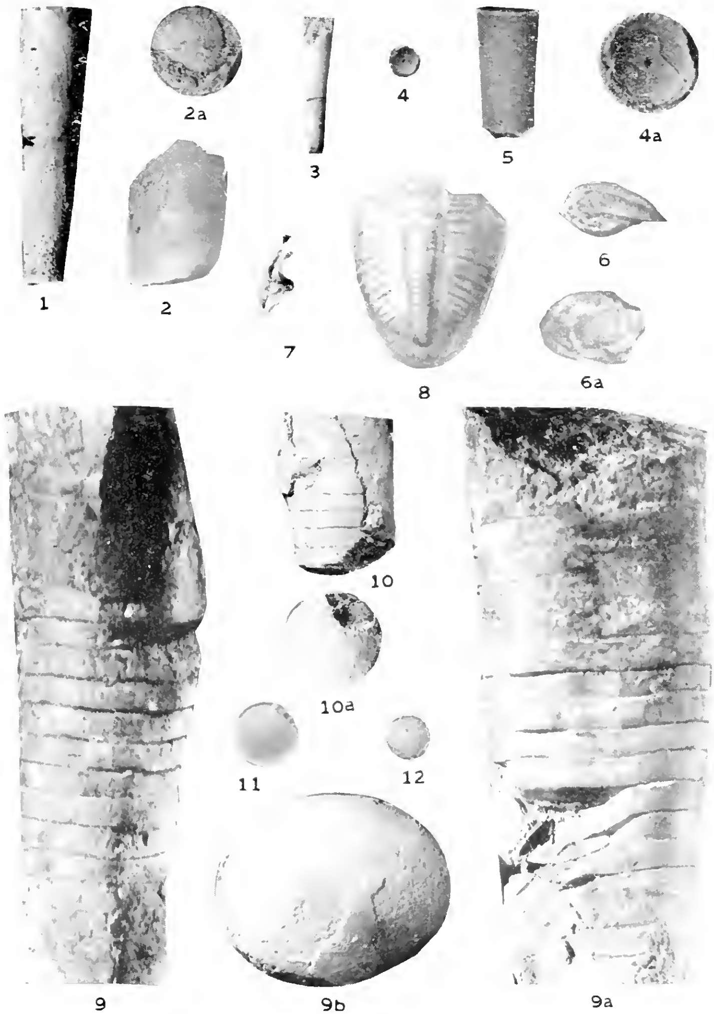
FIGS. 9-12.—*Orthoceras kansasense* Sayre, n. sp. 153

9, 9*a*, 9*b*. A large specimen, showing the rounded and flattened sides and the position of the siphuncle.

10, 10*a*. Another specimen, side view and a view showing the siphuncle.

11, 12. Two other specimens showing the position of the siphuncle in the younger forms. Kansas City, Mo.

PLATE XIX.



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FIGS. 1-2*a*.—*Ephippioceras divisum* (White and St. John)? 153

1, 1*a*. Side and ventral views of the largest specimen found. Kansas City, Mo.

2, 2*a*. A fragment of a small individual including the living chamber, and showing the shape of the septum and the position of the siphuncle. Turner, Kan.

FIGS. 3-5.—*Discites toddanus* Gurley 154

3. A fragment showing the living chamber and the shape of the septa.

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6. Side view of a nearly complete individual.

6*a*. Apertural view of the same. Kansas City, Mo.

PLATE XX.

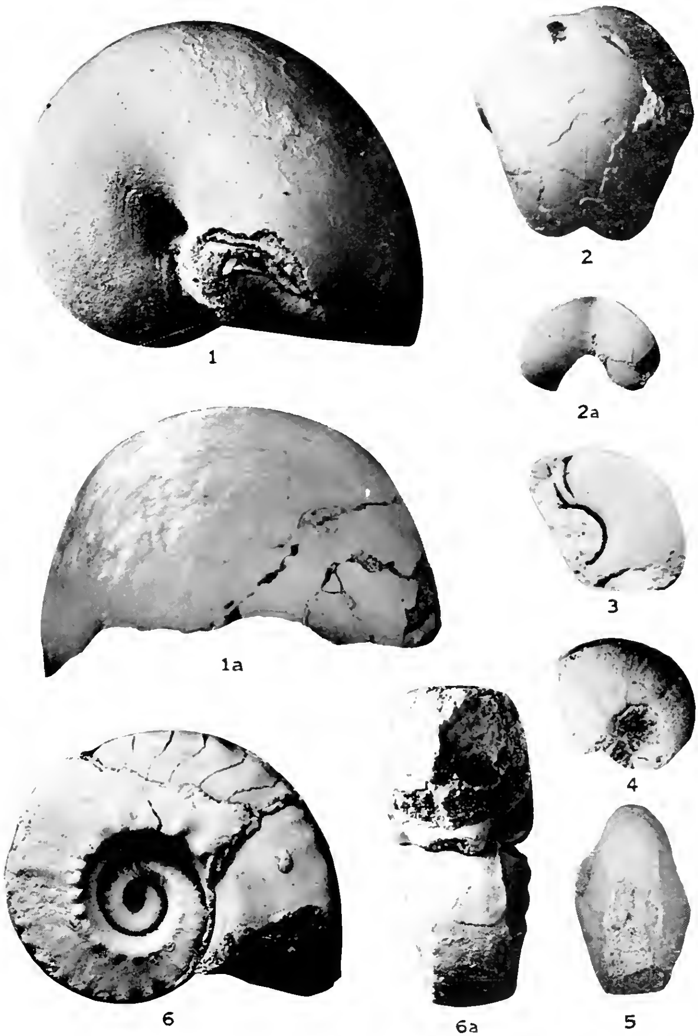

PLATE XXI.

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FIG. 1.—*Serpulopsis insita* (White) 87

1. A specimen of *Nucula anodontoides* covered with *Serpulopsis insita*. Kansas City, Mo.

FIGS. 2-2*a*.—*Metacoceras cavatiforme* Hyatt 155

2, 2*a*. Side and apertural views of a large, nearly complete specimen. Kansas City, Mo.

FIGS. 3-3*a*.—*Tainoceras occidentale* (Swallow) 156

3, 3*a*. Side and ventral views of an incomplete specimen. Kansas City, Mo.

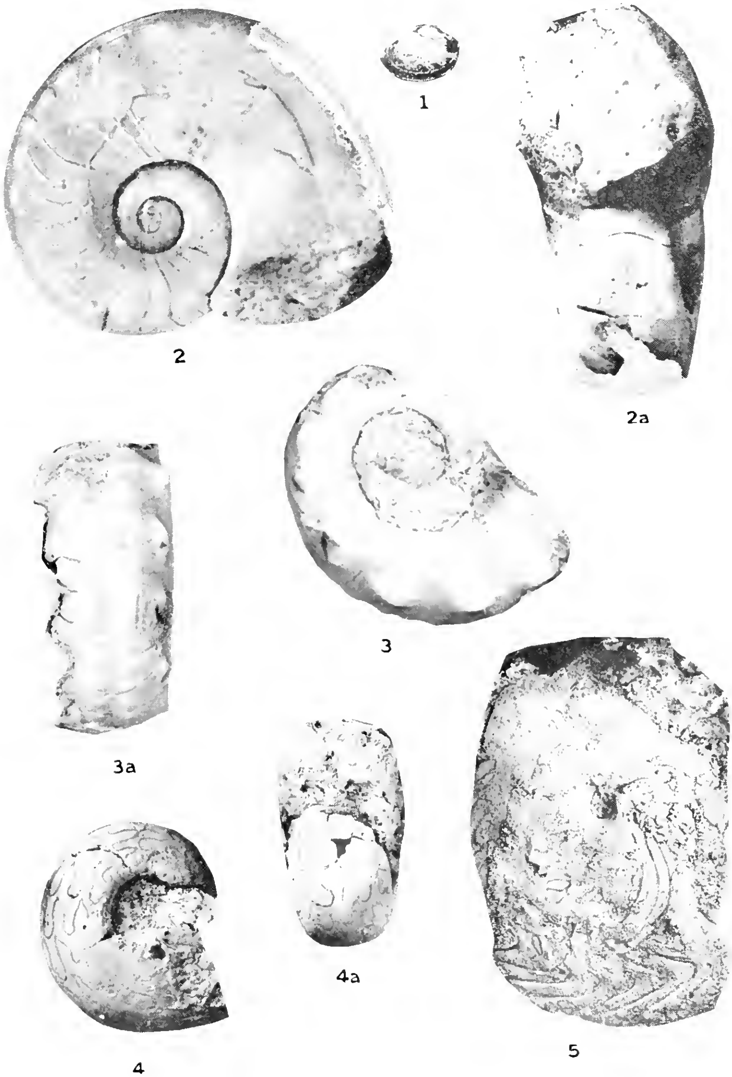
FIGS. 4-4*a*.—*Schistoceras missouriense* (Miller and Faber)................ 158

4, 4*a*. Side and apertural views. Westport, Mo.

FIG. 5.—*Gonioloboceras goniolobum* (Meek) 157

5. Side view of an incomplete specimen. Kansas City, Mo.

PLATE XXI.



THE UNIVERSITY OF KANSAS
SCIENCE BULLETIN

VOL. XIX] JULY, 1930 [No. 9

The Synthesis and Properties of the Possible Isomeric Mono-Chloro-mono-Iodo-Toluenes.

HENRY J. LONG[1] and F. B. DAINS,
Department of Chemistry, University of Kansas.

THE introduction of iodine, using nitric acid as an oxidizing agent, was first recorded by Dyer and Mixter (*2*), who dissolved oxanilide in acetic acid and then added iodine and nitric acid. La Datta and Chatterjee (*3*), extended this method to the aromatic hydrocarbons, describing the synthesis of a number of iodo derivatives of benzene, toluene, cymene, etc.

The authors have investigated the direct iodination of the three chlorotoluenes in order to determine the proper conditions for such iodination and also to ascertain the orienting and other effects of the methyl and chlorine groups. For the sake of identification and comparison it was found necessary also to prepare nine of the ten possible isomeric chloro-iodo-toluenes, and the following paper contains a description of their synthesis and in tabular form their physical constants. While five isomers had been previously listed in the literature, four of these were again synthesized, using frequently different methods, in order to obtain additional needed data.

1. Constructed from a thesis submitted in partial fulfillment for the requirements of the degree of doctor of philosophy at the University of Kansas.

2. Dyer and Mixter: Am. Chem. J., 8, 352 (1886).

3. Basik La Datta and Nihar Rangan Chatterjee: J. Am. Chem. Soc., 39, 435 (1917)

EXPERIMENTAL.

DERIVATION OF O-CHLOROTOLUENE.

I.—1-METHYL-2-CHLORO-3-IODOTOLUENE, $CH_3C_6H_3Cl\ I$.

This has been obtained in an interesting way by heating toluene m-iodo-dichloride, $CH_3C_6H_4ICl_2$ *(4)*, though Wynn and Greeves (5) first prepared it by the method used below.

PREPARTION OF 3-NITRO-O-TOLUIDINE $CH_3C_6H_3NO_2NH_2$ *(6)*.

The best yield (29 per cent) resulted when o-acet-toluide (60 gms.) was added to a mixture of fuming nitric acid (255 cc.) and glacial acetic acid (115 cc.) at 0°. After standing for three hours, the mixture was poured on ice, filtered, washed and dried. It was then saponified with sodium hydroxide (20 gms.) in alcoholic solution. After distilling off the alcohol, the residue was distilled with steam from acid solution. The slightly basic 3-nitro compound is slowly volatile with steam, while the 5-nitrotoluidine remains in the acid solution.

The amino group at position 2 was now replaced with chlorine (Sandmeyer) and the resulting 2-chloro-3-nitrotoluene reduced with tin and hydrochloric acid to the amine (yield 82 per cent), which was then diazotized in potassium iodide solution (yield 82 per cent).

The 2-chloro-3-iodotoluene thus obtained is a light yellow oil volatile with steam. When treated with fuming nitric acid it gave a nitro compound which melted at 118°.

II.—1-METHYL-2-CHLORO-4-IODOBENZENE.

The steps in the synthesis involved the nitration of p-toluidine, yielding the 2-nitro-p-toluidine (7), from which was obtained in good yield the 2-nitro-4-iodotoluene. (8.)

While the nitro group can be reduced with tin and hydrochloric acid, ferrous sulphate and ammonia gave more satisfactory results (72 per cent yield of the amine). The 1-methyl-2-amino-4-iodobenzene is volatile with steam and melts at 50° *(9)*.

The hydrogen chloride salt decomposed at 240-5°.

Analyses: Calcd. for $C_7H_8IN.HCl$: HCl, 13.54. Found: 13.74.

4. Caldwell and Werner; J. Chem. Soc., 91, 249 (1907).
5. C. B.: 1895 (2), 529.
6. Reverdin and Crepieux: Ber., 33, 2498 (1900).
7. Nolting and Collin: Ber., 17, 263 (1884).
8. Heynemann: Ann., 158, 337 (1871). Reverdin: Ber., 30, 3001 (1897).
9. Heynemann: Ann., 158, 338 (1871).

The acetyl derivative had a melting point of 183°, the benzoyl of 173°, and the picrate of 121°. The base combines with phenyl mustard oil, forming the corresponding thiourea (m.p. 152-3°). The thiourea from o-tolyl isothiocyanate melted at 162°.

The amine when diazotised with cuprous chloride gave the 2-chloro-4-iodotoluene, a light yellow oil volatile with steam. Its nitro derivative melted at 90°.

III.—1-METHYL-2-CHLORO-5-IODOBENZENE.

Wroblewski first prepared this compound from 5-amino-2-chlorotoluene (*10*), which was formed by the reduction of the nitro compound obtained by the direct nitration of o-chlorotoluene. It was synthesized here using three methods, each different from the above, and the identity of the products was proven by the fact that each with fuming nitric acid gave the same nitro derivative, melting at 84°.

Analyses: Calcd. for $C_7H_5ClINO_2$: N, 4.60. Found: 4.64, 4.51.

PREPARATION OF THE CHLOROTOLUIDINE.

METHOD A. m-Acettoluide was chlorinated with sodium chlorate and hydrochloric acid (*11*) in glacial acetic-acid solution and the resulting product hydrolyzed with boiling hydrochloric acid. The free 5-amino-2-chlorotoluene is volatile with steam and melts at 83°. The amino group was then replaced with iodine (Sandmeyer), yielding the halogen compound.

METHOD B. 2-Amino-5-iodotoluene was prepared in good yield by the direct iodination of o-toluidine in the presence of calcium or magnesium carbonate (*12*). This was then diazotised in the usual manner, replacing the amino group by chlorine.

METHOD C. The direct iodination of o-chlorotoluene. o-Chlorotoluene (45 gms.), iodine (45 gms.) and pyridine (5 cc.) were mixed and heated in a flask with ground-in condenser in a metal bath at 190-200°. In the course of an hour concentrated nitric acid (45 cc.) was added in small portions. The heating was continued for six hours until most of the iodine had disappeared, a little nitric acid being added from time to time. On cooling, the acid mixture was separated as completely as possible, the residue in the flask made alkaline and distilled with steam. The oil was purified by vacuum dis-

10. Wroblewski: Ann., 168, 211 (1873). Goldschmidt and Honig: Ber., 19, 2443 (1886); 20, 2000 (1887).

11. Reverdin and Crepieux: Ber., 33, 2503 (1900).

12. Wheeler and Liddle: Am. Chem. J., 42, 501 (1909). Artmann: Monats, 26, 1097 (1905).

tillation and the product then melted at 20°. This proved to be identical with the 5-iodo-2-chlorotoluene previously synthesized, and showed that most of the iodine had entered the ring in the position para to the chlorine. The best yield was 59 per cent. A small amount of an oily chloro-iodotoluene is also produced, which would seem to be the 3-iodo derivative.

FORMATION OF HALOGEN SUBSTITUTED BENZOIC ACIDS.

At the temperatures involved, the nitric acid oxidizes a portion of the substituted toluene to the corresponding benzoic acid. This is shown by some work of Donald M. Hetler in this laboratory, who iodinated the o-chlorotoluene at 205° and whose general results are in agreement with those of Mr. Long, so far as the chloro-iodotoluene is concerned. However, from the alkali-soluble residue in the flask was isolated o-chlorobenzoic acid (also found by Long) and two iodine-containing acids. One obtained in very small amount melted at about 195° and would seem to be impure 2-chloro-3-iodobenzoic acid (m.p. 210°). The other, which had a melting point of 145°, was proven to be 2-chloro-5-iodobenzoic acid, as follows: When 2-chlorobenzoic acid *(13)* was treated with iodine and nitric acid at 250°, an acid was obtained melting at 147°, after crystallization from boiling water.

Analyses: Calcd. for $C_7H_4ClIO_2$: Cl, 12.56; I, 44.92. Found: Cl, 12.50; I, 44.99.

The position of the iodine atom at 5 was shown by its identity with the acid formed from 5-nitro-2-chlorobenzoic acid, by reduction of the nitro to the amino group and replacement of that by iodine.

IV.—1-METHYL-2-CHLORO-6-IODOBENZENE.

Cohen and Miller *(14)* describe this as a colorless oil, prepared from 2-chloro-6-aminotoluene. It is the only isomer not synthesized in this investigation.

V.—1-METHYL-2-IODO-3-CHLOROBENZENE.

Following the method of Wheeler and Liddle *(15)*, 2-amino-3-nitrotoluene was converted into 2-iodo-3-nitrotoluene, the best yield of which was 86 per cent (compare isomer I). This was reduced with ferrous sulfate and ammonia in alcoholic solution to the 3-

13. Ullmann: Am. Chem. J., 16, 533 (1894).
14. Cohn and Miller: J. Chem. Soc., 85, 1627 (1909).
15. Wheeler and Liddle: Am. Chem. J., 42, 451 (1909).

amino-2-iodo compound. The amine (40 gms.) was dissolved in hydrochloric acid (100 cc.) diluted with water and diazotized with sodium nitrite (20 gms.) and cuprous chloride (30 gms.) at 0°. After standing for several hours the solution was distilled with steam and the chloro-iodotoluene purified by vacuum distillation. The yield was only 35 per cent. The yellow oil darkened on standing, and on treatment with fuming nitric acid gave a yellow nitro derivative, which, when crystallized from gasoline, melted at 84°.

VI.—1-METHYL-3-CHLORO-4-IODOBENZENE.

Preparation.

METHOD I: CHLORINATION OF p-ACETTOLUIDE.

The acettoluide (90 gms.) was dissolved in a mixture of glacial acetic acid (300 cc.) and pure hydrochloric acid (140 cc.) and cooled in an ice bath. Forty grams of sodium chlorate in concentrated solution were added slowly during a period of three hours with constant stirring. After standing in an ice box for twenty hours the mixture was poured into water. The yield of 3-chloro-p-acettoluide was 65 per cent (*16*). The acetyl group is best removed by hydrolysis in acid solution. For this purpose it was heated with four times its weight of 35 per cent hydrochloric acid, or, better, with 20 per cent by volume of sulphuric acid. Low yields of the amine were found in some cases to be due to the splitting off of the amino group, which appeared as ammonia when the reaction mixture was made alkaline.

The amine gave in 76 per cent yield on diazotizing with potassium iodide the 3-chloro-4-iodotoluene.

METHOD 2.

It has been found that when the acetyl derivative of p-toluidine is nitrated, the nitro group enters the 3 position (*17*), forming the 3-nitro-p-acettoluide, which is easily hydrolyzed with alcoholic sodium hydroxide. The amino group was replaced with iodine in the usual manner (*18*). The 4-iodo-3-nitrotoluene is volatile with steam and melts at 54-6°. Reduction of the nitro group to the 4-iodo-3-aminotoluene is best carried out by means of ferrous sulphate and ammonia (*19*), and on replacement of the amino group

16. Reverdin and Crepieux: Ber. 33, 2500 (1900).
17. Cossack: Ber. 13, 1088 (1880).
18. Wheeler: Am. Chem. J, 44, 139 (1910). Willgerodt and Simonis: Ber. 39, 269 (1906).
19. Wheeler and Liddle: Am. Chem. J, 42, 445 (1910).

with chlorine (48 per cent yield) the same chloro-iodotoluene was obtained. It is a light yellow oil which on treatment with fuming nitric acid gave a nitro compound melting at 83-5°.

VII.—1-METHYL-3-CHLORO-5-IODOBENZENE.

Since the groups in the substituted benzene are in the symmetrical (1.3.5) positions, all meta to each other, it could not be formed by direct substitution. Hence the following procedure was adopted:

The starting point was para-toluidine, which was converted into 3-chloro-4-aminotoluene as described under isomer VI.

1-METHYL-4-AMINO-3-CHLORO-5-IODOBENZENE FROM THE IODINATION OF 3-CHLORO-p-TOLUIDINE.

A mixture of the amine (44 gms.), calcium carbonate (33 gms.), iodine (75 gms.), ether (80 cc.) and water (80 cc.) was heated under a reflux until the iodine vapor had practically disappeared. The reaction mixture was then treated with a little sodium thiosulphate and steam distilled. A light-colored oil, which solidified in the received, came over very slowly (18 hours distillation) in 72 per cent yield. After crystallization from dilute alcohol or acetone, in which it is very soluble, it melted at 87°.

Analyses: Calcd. for C_7H_7ClNI: N, 5.52. Found: 5.42.

The position of the entering iodine atom is indicated by the fact the chloro-iodotoluene obtained from it differs from the other nine isomers and also by analogy from the work of Wheeler and Liddle with p-toluidine (*20*). They found that when this amine was treated with two mols of iodine the 3-5-di-iodo-p-toluidine resulted.

BENZOYL DERIVATIVE OF 3-CHLORO-5-IODO-p-TOLUIDINE.

This, made by the Schotten-Baumann reaction, melted at 167° after crystallization from alcohol.

Analyses: Calcd. for $C_{14}H_{11}ClINO$: N, 3.77. Found: 3.83, 3.78.

The amine is too weak a base to form a salt when dry hydrogen chloride is passed into its benzene solution.

ELIMINATION OF THE AMINO GROUP.

The base was diazotized with solid sodium nitrite, using concentrated sulphuric acid and absolute alcohol (*20*). A 70 per cent yield of the 3-chloro-5-iodotoluene was obtained after distillation with steam. It is a light yellow oil which gave on treatment with fuming nitric acid a nitro compound melting at 101°.

20. Wheeler: Am. Chem. J, 44, 144 (1910).

VIII.—1-METHYL-3-CHLORO-6-IODOBENZENE. (*21*)

(1-Methyl-2-Iodo-5-Chlorobenzene.)

Preparation.

METHOD 1: FROM O-ACETTOLUIDE.

This was chlorinated in acetic acid solution with sodium chlorate and hydrochloric acid and the acetyl derivative hydrolyzed with concentrated hydrochloric acid (40 gms. substance to 300 cc. acid). The free base, 2-amino-5-chlorotoluene, was then diazotized in the presence of potassium iodide. The chloro-iodotoluene is a stable oil (60 per cent yield) volatile with steam. It gives a nitro derivative melting at 88°.

METHOD 2: ACTION OF IODINE-MONO-CHLORIDE ON META-ACETTOLUIDE.

Wheeler (*22*) has shown that the 3-amino-6-iodotoluene can be easily made by the action of iodine chloride on m-acettoluide and hydrolysis of this product with excess of sodium hydroxide. If hydrochloric acid is used in the hydrolysis iodine is liberated and no pure product can be obtained. The replacement of the amino group by chlorine (Sandmeyer) was not satisfactory, the yield being only 25 per cent.

IX.—1-METHYL-2-IODO-4-CHLOROBENZENE. (*23.*)

This compound had been previously described by Wroblewski. His general method was followed though the intermediates were isolated in a more pure state. The reduction of 2-nitro-4-chlorotoluene from p-chlorotoluene gave the 2-amino-4-chlorotoluene, melting at 21-2° (*24*). This when diazotized gave in 78 per cent yield the desired chloro-iodotoluene. This is a light orange-yellow oil volatile with steam. With fuming nitric acid a nitro product melting at 166° was obtained.

X.—1-METHYL-3-IODO-4-CHLOROBENZENE.

This was synthesized by two methods—substitution of the amino group by chlorine in 3-iodo-p-toluidine, and by the direct iodination of p-chlorotoluene.

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21. Beilstein Kuhlberg: Ann. 156, 82 (1870).
22. Wheeler: Am. Chem. J. 44, 130 (1910).
23. Wroblewski: Am. 168, 210 (1875).
24. Goldschmidt and Honig: Ber. 19, 243, 842 (1886).

METHOD 1.

Para-toluidine was treated with iodine and calcium carbonate according to the method of Wheeler and Liddle (*25*), giving the 3-iodo-4-aminotoluene. The mono-iodotolyl urea, $CH_3C_6H_3INHCONH_2$, melts at 192° (Wheeler, 187°). On replacing the amino group with chlorine, an oil volatile with steam was obtained which proved to be the desired chloro-iodotoluene. This reacted with fuming nitric acid at 0°, giving a nitro compound that melted at 162°.

METHOD 2: DIRECT IODINATION OF P-CHLOROTOLUENE.

Para-chlortoluene (60 gms.), iodine (60 gms.) and pyridine (5 cc.) were heated in a metal bath at 195°. To this was added in the course of an hour a mixture of concentrated nitric acid containing 25 per cent of fuming acid. The heating was continued for a number of hours, adding a little nitric acid from time to time. When the iodine has disappeared the residue in the flask was steam distilled. The oil that came over proved to be the 3-iodo-4-chlorotoluene (42 per cent yield). The last of the distillate, ten grams in all, was a solid melting at 85°, and was found by analysis to be a di-iodo compound, $C_7H_5ClI_2$.

Analyses: Calcd. for $C_7H_5ClI_2$: Cl., 9.38; I, 67.11. Found: Cl., 9.36; I, 66.98.

It has doubtless the following structure, viz.: 1-methyl-4-chloro-3-5-di-iodobenzene, since it results from the further iodination of the 4-chloro-3-iodotoluene, and experiment has shown that a second iodine enters the 5-position of 4-amino-3-iodotoluene. Further light on the reaction was obtained by Mr. Hetler, who carried out the iodination at a higher temperature, 220-25°, which increased very definitely the oxidizing action of the nitric acid.

HALOGEN ACIDS FROM THE IODINATION OF p-CHLOROTOLUENE.

From the alkali soluble portion of the residue was isolated p-chlorobenzoic acid (m. p. 235°) and a small amount of an impure acid containing both chlorine and iodine formed by the oxidation of the 4-chloro-3-iodotoluene.

4-CHLORO-3-IODOBENZOIC ACID.

This acid was obtained in a pure state by the oxidation of 4-chloro-3-iodotoluene, using the method of Ullmann (*26*). It melted at 208° after crystallization from dilute alcohol.

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25. Wheeler and Liddle, Am. Chem. J., 42, 445 (1909).
26. Uullmann, Am. Chem. J., 16, 553 (1894).

TABLE OF CONSTANTS.

	Melting point	Boiling point.	Index ref. at 23.	SP. G. at 15.	Anal. calc. Cl and I. 61.35.	M. P. nitro deriv.
I 1-Methyl-2-Chloro-3-Iodobenzene.	—12°	110–125° at 11.1 mm.	1.608	1.657	64.50	118°
II. 1-Methyl-2-Chloro-4-Iodobenzene.	8°	136.5–147.6° at 16 mm.	1.624		64.19 63.76	90°
III 1-Methyl-2-Chloro-5-Iodobenzene.	25°	108–123° at 9.5 mm.	1.618	1.7857	64.38 63.72	84°
IV. 1-Methyl-2-Chloro-6-Iodobenzene	oil.	132–133° at 25 mm.		1.844 at 20		
V 1-Methyl-2-Iodo-3-Chlorobenzene.	−26°	139–145° at 25.5 mm.	1.608		63.78	84°
VI 1-Methyl-3-Chloro-4-Iodobenzene.	−12°	120–125° at 10 mm	1.618	1.8361	64.71 64.88	83–85°
VII 1-Methyl-3-Chloro-5-Iodobenzene.	12°	120–142° at 22 mm.	1.609	1.7682	64.75 64.76	101°
VIII. 1-Methyl-2-Iodo-5-Chlorobenzene.	24°	110–127° at 5.5 mm	1.616		64.52 64.62	88°
IX 1-Methyl-2-Iodo-4-Chlorobenzene.	27°	133.5–137.5° at 7.2 mm.	1.620	1.8358	64.50	166°
X 1-Methyl-3-Iodo-4-Cholobenzene.	16°	120–125° at 14.5 mm	1.614	1.7940	64.20 64.57	162°

Analyses: Calcd. for $C_7H_4ClIO_2$: Cl, 12.56; I, 44.95. Found. Cl, 12.57; I, 44.90.

The same acid as shown by its analysis and mixed melting point was produced by heating p-chlorobenzoic acid, iodine and nitric acid at 290°. Its constitution, and as a result that of the original chloro-iodobenzene, was proven by an independent method. Nitration of the p-chlorobenzoic acid gave the 3-nitro-4-chlorobenzoic acid which was then reduced to the 3-amino-4-chlorobenzoic acid (27). The acid formed by replacing the amino group by iodine melted at 208-9° and proved to be identical with the acids synthesized by the two other methods.

SUMMARY.

The table gives a résumé of the properties of the ten possible chloro-iodotoluenes. Numbers I, III, IV, VIII and IX have been previously noted in the literature. With the exception of IV, their preparation has been repeated by the same or usually different methods and additional data regarding them obtained. Numbers II, V, VI, VII and X have been synthesized by methods which proved their constitution, thus completing the list of the possible isomers. Two isomers have been obtained by direct iodination: No. III, 2-chloro-5-iodotoluene, from 2-chlorotoluene; and No. X, 3-iodo-4-chlorotoluene from p-chlorotoluene. The entering iodine atom occupies the position that would be expected, though the directing influence would seem to be mainly that of the chlorine atom. Any other possible isomers must be formed, if at all, in much smaller quantity.

The nitro derivatives were prepared simply as an aid in identification and differentiation. The question of the position of the nitro group must be left for later investigation.

The formation of m-iodobenzoic acid in this laboratory and of the two chloroiodobenzoic acids shows the possibility of iodinating benzoic and chlorobenzoic acids if sufficiently high temperatures are used.

27. Hunn, J. Am. Chem. Soc., 45, 1057 (1923).

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VOL. XIX] JULY, 1930 [No. 10

The Preparation of the Di-Substituted Formamidines and the Reactions of Di-p-Xylyl-Formamidine.

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DIPHENYL formamidine, $C_6H_5N:CHNHC_6H_5$, has been prepared by various methods, one of the simplest of which was suggested by Weith (*1*) and studied more in detail many years later by Shoesmith and Haldane (*2*). Their description is as follows: "Forty grams (1 mole) of 80 per cent formic acid were mixed with 160 grams (2.4 moles) of aniline. The water which was present in the original acid, together with that produced in the reaction, was distilled away through a fractionating column. The head of the column was fitted with a device for trapping the water as soon as it reached the top. After four hours gentle boil the temperature was raised until 60 cc. of aniline had distilled over. The residual diphenyl formamidine solidified on cooling, and after recrystallization from alcohol melted at 137 degrees (yield 63 grams)."

In our own experiments the pyrex flask was fitted with a 20-inch glass tube (3/8 in. diam.) the upper end of which bent so as to connect with an ordinary water condenser. When the contents of the flask were boiled gently water vapor was given off and condensed, carrying only a few drops of aniline with it. It was usually found necessary to continue the heating for from 8 to 12 hours before the reaction mixture solidified. This product was then transferred to a distilling flask and 60 to 70 cc. of aniline distilled over. The residue was purified by treatment with gasoline or absolute alcohol. The dipthenyl formamidine obtained was somewhat colored, but of good quality. However, the yields were not very satisfactory, ranging in nine trials from 33 to 50 grams, with an average of 37 grams.

1. Ber. 9, 454 (1876).
2. J. Chem. Soc. 123, 3705 (1923).

DI-p-TOLYL-FORMAMIDINE, $C_7H_7NCHNHC_7H_7$.

A mixture of formic acid (46 gms.) and p-toluidine (179 gms.) was heated under like conditions for 12 hours and then p-toluidine (60 cc.) was distilled from the reaction mixture. On working up the residual product a yield of from 33 to 40 grams of the pure formamidine was obtained.

DI-o-TOLYL-FORMAMIDINE, $C_7H_7NCHNHC_7H_7$.

The same proportions and procedure were used as with p-toluidine, but the yield is still more unsatisfactory, since only 23 grams of pure di-o-tolyl formamidine were obtained from 179 grams of o-toluidine.

The foregoing results show that the phenyl o- and p-tolyl formamidines can be synthesized by this method, but it is not practical except with the cheaper and more available aromatic amines.

The most satisfactory reagent for the preparation of these di-substituted formamidines is orthoformic ester. This gives clean products and almost quantitative yields, and has been used in this laboratory with a wide variety of aromatic amines. The procedure is simple, since it consists in heating the ester (1 mole) and the amine (2 moles) at 100 or 120 degrees for one to two hours and purifying the product from gasoline or gasoline and penzene. $HC(OC_2H_5)_3 + 2RNH_2 = RNCHNHR + 3C_2H_5OH$.

DI-p-XYLYL-FORMAMIDINE, $(CH_3)_2C_6H_3NH\text{-}CH{:}NC_6H_3(CH_3)_2$.

This was readily prepared in good yield by heating orthoformic ester (1 mole) and p-xylidine (1-amino-2-5-dimethyl-benzene) (2 moles) for two hours at 20 degrees in an oil bath. The solid product was washed on the filter with a little gasoline and purified by crystallization from benzene. It then melted at 155 degrees.

Analyses: Calcd. for $C_{17}H_{20}N_2$: N, 11.11. Found: 10.71.

REACTIONS OF THIS FORMAMIDINE.

In a previous series of papers it has been shown that the methylene hydrogen, both in open chain compounds such as aceto acetic ester and in heterocyclic rings such as the isoxazolones, could be readily replaced by the complex >CHNHR, thus giving a carbon—carbon synthesis, as follows:

$$X_2CH_2 + RN{:}CHNHR = X_2C{:}CHNHR.$$

Various syntheses were carried out using the xylyl formamidine in order to ascertain whether the presence of methyl groups at positions 2 and 5 in the amine would affect the general course of the reaction. The following results indicate that the syntheses proceeded normally:

3-METHYL-4-p-XYLYL-AMINO-METHYLENE-5-ISOXAZOLONE,

$$\begin{array}{l} CH_3C\text{——}C{:}CHNHC_8H_9. \\ \;\;\| \qquad\quad | \\ \;\;N\text{-}O\text{-}CO \end{array}$$

A molar mixture of di-p-xylyl formamidine and 3-methyl-4-benzal-isoxazolone in a little xylene was heated in an oil bath for a few minutes at 150 degrees and then the temperature was lowered to 115-120 degrees and kept there for two hours. After evaporating the xylene from the mixture, the reaction product was dissolved in hot alcohol, from which the above compound crystalizes in dark yellow needles, melting at 193 degrees, while the benzal-p-xylidine remains in solution.

Analyses: Calcd. for $C_{13}H_{14}O_2N_2$: N, 12.17. Found: 12.18.

It will be noticed that in this case an unusual type of reaction occurs, viz., the replacement of a doubly bound benzal grouping by the xylyl amino methylene complex:

$$\begin{array}{l} CH_3C\text{——}C{:}CHC_6H_5 + C_8H_9NCHNHC_8H_9 = C_6H_5CH{:}NC_8H_9 + \\ \;\;\| \qquad\quad | \\ \;\;N\text{-}O\text{-}CO \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad C_{13}H_{14}O_2N_2. \end{array}$$

In the case of the benzal compound such replacement takes place easily and smoothly which in the unsubstituted isoxazolones the yield is mainly tar.

1-p-TOLYL-3-METHYL-4-p-XYLYL-AMINO-METHYLENE-PYRAZOLONE.

$$\begin{array}{l} CH_3C\text{————}C{:}CHNHC_8H_9. \\ \;\;\| \qquad\qquad\quad | \\ \;\;N\text{-}N(C_7H_7)CO \end{array}$$

The formamidine and p-tolyl-methyl pyrazolone were heated at 120-130 degrees for two hours, with the formation of two products: (*a*) an orange red difficultly soluble compound melting at 249 degrees which proved to be the methenyl-bis-methyl tolyl pyrazolone; and (*b*) the yellow methylene derivative, which is much more readily soluble in alcohol.

Analyses: Calcd. for $C_{20}H_{21}ON_3$: N, 13.16. Found: 12.94.

The presence of the bis-pyrazolone is due to the action of a second mole of the pyrazolone upon the amino methylene compound as follows:

$$\begin{array}{l} CH_3C\text{————}C{:}CHNHC_8H_9 + H_2C\text{————}CH_3 = \\ \;\;\| \qquad\qquad\quad | \qquad\qquad\qquad\quad | \qquad\qquad\quad \| \\ \;\;N\text{-}N(C_7H_7)CO \qquad\qquad\qquad CON(C_7H_7)N \\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad HC \begin{smallmatrix} =Py \\ -Py \end{smallmatrix} + C_8H_9NH_2. \end{array}$$

p-XYLYL-AMINO-METHYLENE-CYANACETIC ETHYL ESTER,

$$\begin{array}{l}CN\text{-}C{:}CHNHC_8H_9.\\ \quad | \\ \quad COOC_2H_5\end{array}$$

This was synthesized when a mixture of ethyl cyanacetate and the formamidine was heated at 120 degrees for three hours. It crystallized from alcohol in colorless needles, which melt at 153 degrees.

Analyses: Calcd. for $C_{14}H_{16}O_2N_2$: N, 11.47. Found: 11.39.

p-XYLYL-AMINO-METHYLENE-ACETYL-ACETONE,

$$(CH_3CO)_2C{:}CHNHC_8H_9.$$

The methylene hydrogen in the acetyl-acetone was readily replaced on heating with the formamidine at 130 degrees for three hours.

$$(CH_3CO)_2CH_2 + C_8H_9NCHNHC_8H_9 = C_8H_9NH_2 + C_{14}H_{17}O_2N$$

It is easily soluble in alcohol, from which it separated in colorless needles melting at 125 degrees.

Analyses: Calcd. for $C_{14}H_{17}O_2N$. N, 6.06. Found: 5.77.

p-XYLYL-AMINO-METHYLENE-ACETO ACET-p-XYLIDIDE,

$$\begin{array}{l}CH_3COC{:}CHNHC_8H_9\\ \qquad | \\ \qquad CONHC_8H_9\end{array}$$

When the di-xylyl formamidine and ethyl acetoacetate are allowed to react at 110-120 degrees for two hours, not only is the methylene hydrogen replaced, but the xylidine set free combines with the carbethoxy group, yielding alcohol and the acid amide derivative. This illustrates the greater reactivity of the $COOC_2H_5$ grouping in acetoacetic ester as compared with the preceeding ethyl cyanacetate where no such replacement occurred. The new compound melted at 140 degrees when crystallized from alcohol.

Analyses: Calcd. for $C_{21}H_{24}O_2N_2$: N, 8.33. Found: 7.99.

p-XYLYL-AMINO-METHYLENE-BENZOYL-ACETO-p-XYLIDIDE,

$$\begin{array}{l}C_6H_5COC{:}CHNHC_8H_9.\\ \qquad | \\ \qquad CONHC_8H_9\end{array}$$

This was the main product when the amidine was heated with ethyl benzoylacetate for two hours at 110 degrees. It was difficultly soluble in alcohol and when crystallized from glacial acetic acid melted at 182 degrees.

Analyses: Calcd. for $C_{26}H_{26}O_2N_2$: N, 7.03. Found: 6.71.

A small amount of a compound melting at 130 degrees was isolated, but not enough for analysis. This was doubtless the ethyl ester of the amino-methylene derivative.

The p-Xylidides of benzoylacetic ester and acetoacetic ester were formed in good yields when the esters were heated with p-xylidine for three hours at 115-130 degrees. They were purified by crystallizing from alcohol.

BENZOYL-ACETO-p-XYLIDIDE. $C_6H_5COCH_2CONHC_8H_9$.
M. P. 142 DEGREES.

Analyses: Calcd. for $C_{17}H_{17}O_2N$: N, 5.24. Found: 5.30.

ACETYL-ACETO-p-XYLIDIDE, $CH_3CONHCONHC_8H_9$.
M. P. 98 DEGREES.

Analyses: Calcd. for $C_{12}H_{15}O_2N$: N, 6.82. Found: 6.83.

ACTION OF BROMINE UPON DI-p-XYLYL FORMAMIDINE.

Bromine (1 mole) acted upon the formamidine in chloroform solution, giving a yellow solid, melting at 162 degrees, which was evidently the HBr salt of a monobromo di-p-xylyl formamidine, $C_8H_9NCHC_8H_8Br.HBr$.

Analyses: Calcd. for $C_{17}H_{18}N_2Br_2$: N, 6.83. Found: 6.56.

SUMMARY.

(*a*) A study has been made of the preparation of di-phenyl, di-o-tolyl and di-p-tolyl formamidine from the amine and formic acid. The method, while feasible, gives unsatisfactory yields.

(*b*) Di-p-xylyl formamidine has been synthesized, as well as its condensation products, with a number of compounds containing methylene hydrogen.

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Comparative Anatomy Within the Genus *Euonymus*.

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THE family of Celastraceæ (Lindl.) contains about 38 genera, with 375 species of trees and shrubs, many of whoch are climbing. It is distributed throughout both hemispheres excepting in the Arctic zones.

Just where and when the family originated is very uncertain according to the available papers on this subject, but it is thought probable that it had its origin in Europe and was distributed in Europe and North America during the Cretaceous periods. During the Tertiary times the family, and especially the genera *Euonymus* and *Celastrus*, is thought to have been distributed not only in Europe and North America but as far as Greenland, Spitzbergen, Alaska, Australia and Java. The paleontological findings have been mostly leaves. The present-day distribution of the Celastraceæ, and in particular of *Euonymus* and *Celastrus*, lends support to the belief that the Celastraceæ were to be found in both Europe and North America during Tertiary times. Of the species of *Euonymus* living to-day, *E. europæus* and *E. latifolius* are known in the Quaternary strata from Europe.

Rehder lists only five out of the thirty-eight genera of the Celastraceæ as occurring in North America. The following notes concerning these five genera are taken from his "Manual of Cultivated Trees and Shrubs":

"*Euonymus:* About 120 species, in North and Central America, Europe, Asia and Australia.

"*Celastrus:* More than thirty species in eastern and southern Asia, Australia and America.

"*Pachistima:* Two species in North America.

"*Glossopetalon:* Three or four species in North America.

"*Tripterygium:* Three species in eastern Asia."

Because of their great ornamental value, these trees and shrubs have been under cultivation for a long time, a fact which makes it difficult to trace their distribution, or even, in fact, to know their native habitat in many instances.

Concerning the general distribution of *Euonymus*, the following is quoted from Sargent: "The Sylvia of North America," Volume 2:

"The genus *Euonymus* is widely distributed through the Northern Hemisphere, extending south of the equator to the islands of the Indian archipelago and to Australia. Botanists now distinguish about forty species, the largest number occurring in the tropical regions of southern Asia, in China and in Japan Several species are found as far south as the mountains of Ceylon. One of the Indian species occurs also in Sumatra and in Java, and one species has been detected in northern Australia.

"The genus is represented in central Asia and is widely scattered with a number of species through the Orient and through temperate and southern Europe. In North America two species occur in the Atlantic and one in the Pacific regions and three or four little-known species inhabit southern Mexico."

This paper will deal with nine species of *Euonymus*. This genus contains about 120 species, according to Rehder. He describes twenty-three species and a number of varieties as occurring in North America. In "Standardized Plant Names" only fourteen species and three varieties are listed for North America.

With the exception of *E. radicans*, all of the species studied are shrubs or small trees. They are easily recognized by the fruit. The next most marked field character is the four ridges in the bark, which is characteristic of most species. The stems are usually green, due to the persisting assimilatory tissue.

The following is a list of the species which are to be discussed in this paper. They represent, as far as is known to the writer, all of the available species to be found growing in this immediate locality. Rehder's "Manual of Cultivated Trees and Shrubs" has been used quite freely in writing the following brief descriptions. The dates of introduction are those given in the manual. Concerning these dates the following general explanation is quoted from Rehder's introduction:

"Most of the foreign trees and shrubs and even some native ones have reached our gardens by the way of Europe, and it is only within the last fifty years that, chiefly through the agency of the Arnold Arboretum, many plants have been introduced from their native country, mostly from eastern Asia, directly to American gardens. Lack of space forbids to give in this book details regarding the introduction, and only the year, if known, is given; when this could not be ascertained, the first record of the plant as being in cultivation is given, based either on the mention in horticultural literature or on dated herbarium specimens. As the most complete and reliable records regarding the introduction of plants into cultivation are found in English horticultural literature, most dates, particularly those of older introductions, refer to England, though in many cases the plants may have been in cultivation earlier on the continent of Europe or in this country."

Euonymus alatus Reg.

Winged Shrub.

Introduced 1860. Its native habitat is given as Japan, Korea, Manchuria and China.

This is one of the most easily recognized of all shrubs because of its unique cork wings, which grow out wedge-shaped along four sides of the stem. It is a more or less spreading shrub, growing to a height of eight feet. The branches are stiff with two to four (usually four) broad, corky wings. The leaves are short-stalked, elliptic or obovate, acute at both ends, finely and sharply serrate, one to two inches long.

E. americanus L.

Strawberry Bush; Brook *Euonymus*.

Introduced 1683. Habitat from New York south to Florida and west to Texas.

It is an upright shrub, six to eight feet high, easily recognizable in the late summer by its very numerous small clusters of fruit, which remind one of strawberries. The leaves are lance-ovate to lanceolate, one to three inches long, acuminate, cuneate, crenate-serrate, dark green in color.

E. atropurpureus Jacq.

Wahoo; Burning Bush.

Introduced 1756. Native from New York to Florida, west to Minnesota, Nebraska, Oklahoma and Texas.

A treelike shrub growing from six to as much as fifteen or eighteen feet high. It has a more or less fluted ash-gray bark on the older stems; the twigs vary from green to plum color. The leaves are elliptic or ovate-elliptic, acuminate, serrulate, pubescent beneath, one and one-half to five inches long. The petioles are one-third to two-thirds of an inch in length. The fruit is about a half inch across and matures in October. "The purple husk parts and reveals the seed, enveloped in a scarlet outer coat that fits it loosely. The delicate pale lining of the purple envelope makes harmony between the two stronger colors, and the plum-colored twigs and yellow leaves contribute to make this indeed a burning bush, that glows brighter as the advancing winter opens all the husks and displays the scarlet seeds. No brighter dash of color can be added to gardens or shrubbery borders than this tree, which shows its beauty chiefly in the dead of winter."

E. bungeanus Maxim.

Winterberry.

Introduced 1883. Native of China and Manchuria.

A shrub or small tree to fifteen feet high with slender branches. The leaves are elliptic-ovate to elliptic-lanceolate, two to four inches long, long-acuminated, broad cuneated at the base, finely serrate with petioles up to almost an inch in length.

E. europaeus Linn.

Spindle Tree; European Burning Bush.

In cultivation for a long time. A native of Europe to western Asia.

An erect shrub or sometimes a small tree to twenty feet high. The leaves are elliptic-ovate to lance-oblong, from one and a half to two and a half inches long, acuminate, cuneate, crenate-serrate, petiole up to half an inch in length.

E. europaeus nanus Lodd.

Dwarf Burning Bush.

Origin and introduction unknown.

This is a dwarf, dense and strictly upright form with elliptic to elliptic-lanceolate leaves from one to one and a half inches long or on vigorous shoots to two and a half inches long. No fruit has ever been produced by the plants which were studied for this paper.

E. maackii Rupr.

Cultivated since 1880. Native of north China, Manchuria and Korea.

Large shrub or small tree; leaves are glabrous, elliptic-oblong to lance-oblong, acuminate, gradually narrowed toward the base, serrulate, two to three inches long and three-fourths to one and one-fourth inches broad. The petioles are one-sixth to one-fifth as long as the leaves.

E. patens Rehd.

The Spreading *Euonymus*.

Introduced about 1860. Native of eastern and central China.

A half evergreen or nearly evergreen spreading shrub to ten feet. The lower branches procumbent and sometimes rooting, the branchlets obscurely four-angled, minutely warty. The leaves are elliptic to elliptic-oblong, rarely obovate-oblong, acute, cuneate at the base, crenately serrulate, bright green above.

E. radicans Sieb.

Winter Creeper.

Introduced 1865. Native of north and central Japan and Korea.

A low procumbent shrub, with often trailing and rooting or climbing branches, climbing sometimes to twenty feet. Branches are terete, densely and minutely warty. The leaves are roundish to elliptic-oval, rounded or narrowed at the base, crenately serrate, usually dull green above with whitish veins; one-half to two inches long. According to Schenck: "In Japan it climbs as an evergreen shrub in light places, especially on evergreen trees, and in the Japanese woods it takes the place of the less abundant ivy to a certain extent."

Of the above group, *E. atropurpureus* is the only species growing wild in this vicinity. Specimens of this species were collected from four different sources: From the timber on Botany Bluff, two or three miles east and north of Lawrence. From Gage Park at Topeka; some of the plants there had been obtained from the government, others were growing wild. From the timber near Mr. Bunker's cabin, seven miles south and west of Lawrence. A lawn in Lawrence; this plant had been brought in from the timber and replanted.

E. alatus and E. bungeanus specimens were obtained at the Mt. Hope Nurseries near Lawrence. There were about twenty-five individuals of *bungeanus* and between fifty and a hundred of *alatus*.

E. americanus, patens, radicans, europaeus nanus, and *maackii* were all collected from Gage Park. Most all of these had been obtained originally from the government, but it was impossible to get exact information concerning them. Definite information concerning the immediate genetic relationship of individuals would have been very helpful in attempting to explain several peculiarities which have appeared during the course of this study.

E. europaeus is growing on the University campus.

The most inclusive work that has been done on the genus *Euonymus* is that of Stenzel (*18*). He studied the leaf and stem of some seventeen species and made a key for the species studied. The key was based on the histological structures of the leaf and petiole. His material was chiefly herbarium specimens. The species he studied were *E. pauciflora, nanus, velutinus, atropupureus, alatus, occidentalis, angustifolius, japonicus, fimbriatus, pendulus, verrucosus, garcinoides, latifolius, europaeus, scandens, tarmentosus* and *japanicus*.

Metz (*8*) has fully described the leaf of *E. alatus, americanus* and *europaeus*.

Petit (*11*), discussing the occurrence of fat bodies in the assimilatory tissue, says that no great degree of systematic value can be attributed to their occurrence. With the fat bodies Petit also classes the small caoutchouc bodies which are to be found in some species. These caoutchouc bodies have been made the subject of two papers. Col (*2*) described their occurrence in a number of species, *E. japonicus, fimbriatus, radicans, nanus, europaeus, latifolius, americanus,* *verrucosus*, *alatus*, and in the root of *atropurpureus*. He concluded that they are generally present in the cortex, in the phloëm region of the stem and also of the root, although the cells secreting them do not appear in all species at the same age. In most species they do not occur until the stem is at least two years old, and in *E. alatus* they do not occur excepting in very old branches. He considered the secretions to be lactiferous, having some properties characteristic of caoutchouc. He did not find these secretions in the leaf blade, petiole, pith or cortical parenchyma. Metz (*8*), on the other hand, found what is probably this caoutchouc in the epidermal cells around the stomata, in the palisade cells and in special containing cells in the leaf of *E. alatus*, but not in *E. americanus* or *europaeus*.

Möeller (*9*), in an examination of the cortical region of *E. obovatus* (*E. americanus*), *latifolius*, and *verrucosus*, found in *obovatus* "compact worm-formed fibers" which it is presumed are the cells secreting the caoutchouclike substance. He considered them to have arisen by a "mucilaginous or pectin metamorphosis of certain bast fibers." Col (*2*), on the other hand, says that "he is completely mistaken in their nature inasmuch as he considers them as fibers in the process of pectic transformation."

The cells described by Möeller were present in the specimen of *americanus* studied for this paper. Their walls were slightly thicker than most of the parenchyma cells of the cortex, and in shape they are blunt-ended tubes. It seems more likely that they are simply modified parenchyma cells. The caoutchouclike substance was quite abundant in a four-year-old stem, occurring not only in these particular cells but also in other short parenchyma cells of the phloëm, and also in the thin-walled parenchyma cells inside of the assimilatory tissue. The same substance was found in the same regions in *E. radicans* and also in the cells of the outer cylinder of the collenchyma and occasionally in a medullary ray cell and in pith cells which were near the outer margin. In *E. patens* some of the parenchyma cells just outside of the phloëm contained caoutchouc. In the other species studied there was no indication of it.

Concerning the origin of the bark there are differences of opinion. Möeller (*10*) states that the epidermis forms the phellogen in the species which he studied. Solereder (*16*), quoting Stenzel (*18*), says the cork arises in the epidermis throughout *Euonymus*. Weiss (*19*) briefly states his findings in connection with cork formation in *E. alatus*, *latifolius* and *europaeus* as follows:

"Cork formation begins in the epidermis, where the outer walls are very much thickened. At first a phelloderm cell is cut off, then a cork cell toward the outside, which cell in *europaeus* and *alatus* constitute the complete cork layers in the two-year-old stem. The wings in *alatus* are cork formation composed of cells strongly stretched radially."

Gregory (*4*), in her study of *E. alatus*, *europaeus*, and three varieties of *europaeus*—*variegatus*, *ovatus* and *purpureus*, found in *E. europaeus purpureus* cork originating from the collenchyma cells immediately below the bundles of bast fibers at the corners of the stem. In *alatus* she says:

"The first indication of it externally is a little line of brown flecks at equal distances from the ridges at the corners. They may easily be mistaken for lenticels, but on examination they are found to be the first stages of the wing, which originates directly from the stomata. . . . It is well known that *E. verrucosus* has warty projections of cork which are said to arise from lenticels, though at the time of their origin there is no appearance of periderm, unless the outer cylinder, which we have described as collenchymatic cells, be considered periderm."

Concerning the little brown flecks of bark, etc., Stahl (*17*) says that these are not lenticels and that their origin is in no way connected with the stomata, but that they are rather corky outgrowths of the cortical parenchyma which elevates the epidermis.

Quoting from Stenzel (*18*):

"Von Höhnel describes the phellem of *E. europeus* very precisely. He describes four cork wings and cork masses lying between. The latter are very irregularly developed, in some places strongly, in others little or none at all. They consist of alternate layers of phelloid of varying thickness and true cork. The four cork wings are strong and consist for the most part of phelloid layers, which are the first thing formed each year, and consist of hard, brown-walled, radially elongated cells containing one or more red-brown clumps which are lacking in the cork cells. The three to four layers of cork cells which regularly alternate with the phelloid are quite small."

From the present studies it would seem that the origin of the cork is variable in the different species. In *E. europaeus nanus* it arises form the epidermis (pl. XXIV, Fig. 2). An epidermal cell divides first radially and then in the direction of the circumference. The inner cells then divide in the direction of the circumference of the stem and produce cork cells on the outside, and by the further production of these cork cells the epidermal layer is shoved out until it splits, resulting in a "little brown fleck" of bark which resembles a lenticel in appearance. These brown flecks increase in number, grow in size and unite with each other until eventually the stem is covered with a thin, rough bark.

The origin of the wings in *alatus* was found also to be epidermal (Pl. XXIV, Fig. 4). A cell is cut off from the epidermal cell, this cell then divides, producing a cork celi on the outside and itself becoming a phellogen cell.

In *E. americanus* the first indication of cork is at the four corners of the stem during the first season's growth. Here it is formed by the cells of the collenchyma cylinder inside of the epidermis (Pl. XXIV, Fig. 1, c-c).

It is also derived from the collenchyma in *E. atropurpureus* and *europaeus*. In *atropurpureus* bundles of bast fibers are always present at the corners of the stem, but within the collenchyma layers (as described later). The collenchyma cells around this bundle produce a ring of corklike cells completely surrounding these fibers, but more abundant toward the inner side. By their continued production the epidermis is broken and a weakly developed and temporary (as compared with *alatus*) cork wing arises (Pl. XXIII, Figs. 10, 11, 12, 13).

Gris (*5*), according to Stenzel, was the first to investigate the availability for taxonomy of the anatomical condition of the pith. On the basis of his results he established three types:

1. Homogeneous pith, consisting of living cells (thick-walled and starch-bearing) with or without crystal sacs.

2. Heterogeneous pith, consisting of living and of empty cells, the latter usually thin walled.

3. Empty pith, consisting of empty cells only.

Kasner (*6*) studied the large peculiar cavities in the pith and decided they were simply the results of tearing of the thin walls during growth by the large cluster crystals of calcium oxalate.

The purpose or purposes of this study have been to determine if the species characters are as clearly marked throughout all or any of the internal tissues as they are in the external structures, so that keys could be made for species identification based on the variations found in the tissues; to ascertain if some tissues are more variable than others, and if so to account for the differences; and to find out whether or not species which have been developed in geographically isolated regions differ from each other more than those which have been developed in the same general regions.

Cross and longitudinal sections as well as mascerations of the stem were studied from both fresh and preserved material. These studies were chiefly made from the fifth and sixth nodes from the last terminal bud scars of the two-year stems, although the fourth or fifth node of the one-year stem was also examined. The sections were cleared and detailed drawings were made at uniform magnifications. The leaves were studied from the surfaces and from sectioned material. The petioles were sectioned.

Where measurements are given they are the result of an average of at least ten cells and usually from two to three different pieces of material.

In the species studied it was impossible to definitely recognize an endodermis. Therefore, as is customary, all tissues from the epidermis to the phloëm will be called primary cortex. The secondary cortex will be considered as all tissues produced by the cambium toward the outside and all tissues of the periderm.

THE STEM.

E. atropurpureus Jacq.

The cells of the epidermis as seen in cross section are strongly arched, almost pointed on the outer side, and flat on the inner side, giving them a somewhat triangular shape (Plate XXII, Fig. 1). The radial diameter of the cell is 19.9 microns and the diameter at the base is 12.9 microns. The outer wall of the epidermis is usually comparatively thin, 7 microns, and is never equal to one-half of the radial diameter of the cell in thickness. Stomata are fairly numerous, they are sunken and have air spaces below.

Beneath the epidermis is a layer of clear collenchymalike cells. These cells have their long axes in the direction of the circumference of the stem. They are about twice as long as wide, being about as long as the epidermal cell is wide. This layer varies from two cells to three, four or even five cells in thickness at short intervals, resulting in a wavy or wrinkled appearance of the epidermis. At four nearly equidistant points these cells cut through the layer next beneath them and connect with another collenchymalike layer. Thus there are two cylinders of collenchymalike tissue connected with each other at four points, which will be termed the corners of the stem (Pl. XXIII, Fig. 1).

Between the two cylinders of collenchyma tissue there is a layer four or five cells thick of nearly isodiametric thin-walled cells which contain chloroplasts. These assimilatory cells in *atropurpureus* contain fewer chloroplasts than any other species studied, possibly due to the purplish pigment in the epidermis.

Toward the end of the first year, or during the early part of the second year of growth, cords of bast fibers are found at the corners of the stem in the collenchyma which connects the two collenchyma cylinders. These cords develop by differentiation and a thickening of the walls of the collenchyma cells in a region of tissue connecting the two cylinders just beneath the line of the outer cylinder (Pl. XXIII, Fig. 10). Differentiation continues until at times as many as seventy-five or eighty bast fibers are formed. Collenchyma cells completely surround this bundle of fibers. As growth continues the bundles are shoved outward, resulting in ridges on the stem. These ridges connect the outer angles of the leaf scars as shown in plate XXIII, figure 13. Toward the end of the second year the ring of collenchyma cells around the bast fibers produce corklike cells toward the inside, *i. e.*, immediately around the bast fibers (Pl. XXIII, Fig. 11). This proliferation is much greater on the inner side than on the outer (Pl. XXIII, Fig. 12). The epidermis is broken and sloughed off and the bast bundle is shoved to the outside, where it is gradually sloughed off along with the cork cells as new cork is formed. These cork lines are unquestionably derived from the collenchyma cells. The portions of the epidermis between the ridges remain intact into the third and fourth years except for thin, long patches which gradually grow larger and become more numerous until the entire stem is covered by a thin cork. By this time all indications of the original ridges of cork have disappeared.

Next inside of the inner collenchyma cylinder thin-walled parenchyma cells extend in to the phloëm region. These cells are all larger than the collenchyma cells, those nearer the phloëm being the largest. These large cells form a more or less continuous ring. They measure as much as 62 microns by 31 microns in cross diameter. Between these and the phloëm there is an irregular layer of much smaller parenchyma cells. Their walls are somewhat thicker than those of the other parenchyma cells. They are always so wrinkled that it is impossible to get accurate measurements of their size. Roughly, they are $\frac{1}{6}$ to $\frac{1}{8}$ the size of the larger cells just mentioned and from four to six times the size of the phloëm cells. In longitudinal sections they are seen to be short, blunt-ended tubes. Between the phloëm and the parenchyma are occasional solitary thick-walled bast fibers.

Cluster crystals of calcium oxalate are fairly numerous in the parenchyma, but they are also found in the other tissues of the cortex. Since their occurrence is variable and seemingly dependent on habitat, and possibly seasonal conditions of the plant, it is not considered that they have much systematic significance.

The cells of the phloëm in cross section are small and thin-walled, rectangular in shape and regular in size. They appear to be more or less marked off in squares by the medullary ray cells in the radial direction and by small parenchyma cells in the tangential direction. These cells are about four times as long as wide when seen in longitudinal sections.

The xylem consists chiefly of tracheal tubes, tracheids and wood fibers. The wood fibers frequently more or less encircle the larger tubes and are by far the most abundant elements of the xylem.

The medullary rays are one cell in thickness. The cells are flattened as seen in cross sections, while in longitudinal radial sections they vary. Some are square, some have their long axis in the radial direction and others have their long axis in the vertical direction (Pl. XXIV, Fig. 6). There are from four to six rays in an arc of 175 microns at the circumference of the xylem.

The pith cavity is roughly almost square in the two-year-old stem, although it is more rounded in the one-year-old stem, the four corners being at points alternate with the corners of the stem. The pith cells are empty, with the exception that some contain large clustered crystals of calcium oxalate, and are very thin-walled. They are usually torn out in sectioning. Starch is not stored in the pith.

E. europaeus Linn.

The epidermal cells are arched on their outer surface, but are more flattened than in *atropurpureus*, measuring 12.6 microns in their radial diameter and 23.1 microns in their tangential diameter. The outer wall of the epidermis is slightly thicker than in *atropurpureus*, 8.75 microns, and its surface conforms to the upper margin of the cavity (Pl. XXII, Fig. 2).

The collenchymatic tissue, as in *atropurpureus*, consists of two cylinders connected at the four corners and separated, excepting at the corners, by assimilatory tissue. The cells of this assimilatory tissue are small and rounded, their long axis in the direction of the circumference. Chloroplasts are very abundant, giving the stem a bright green color excepting at the four corners, where the absence of chlorophyll results in a whitish line. For the most part the stem is predominantly green for at least three years, frequently longer. The outer cylinder of collenchyma is quite uniformly two cells thick, consequently the epidermis has a smoother contour in contrast with the wavy or wrinkled condition in *atropurpureus*. The development of the walls of the collenchyma cells is much weaker than in *atropurpureus*. This is especially true of the inner cylinder, where frequently these cells merge into the thin-walled parenchyma layer beneath so gradually that it is difficult to distinguish the dividing line.

On stems of rapid growth bundles of bast fibers followed by lines of cork formation at the corners may or may not develop. In slow-growing stems they do not occur. The bundles of bast fibers, if present, never exceed twenty to twenty-five cells in number, usually fewer. The cork forms a considerable ridge at times, but generally it is sloughed off almost as rapidly as it is formed.

The parenchyma tissue in the cortex of *europaeus* is quite similar to that of *atropurpureus*, as are also the phloëm and xylem tissues. Occasional solitary bast fibers occur between the parenchyma and the phloëm.

The medullary rays are one cell thick. There are four to five of them in an arc of 175 microns at the outer edge of the xylem in the two-year stem (Pl. XXIV, Fig. 7).

The pith cells are empty excepting for clustered crystals. They are very thin-walled and are easily torn out, as in *atropurpureus*. The pith cavity in the one-year-old stem of *europaeus* is diamond-shaped, less than twice as long as broad in cross section, the ends of the diamond being rounded and protruding (Pl. XXIII, Fig. 2).

E. bungeanus Maxim.

The most noteworthy difference between *bungeanus* and *atropurpureus* is in the size of the cells. The corresponding tissues bear the same relationships to each other.

The epidermal cells have their long diameter in the direction of the circumference. They measure 30.8 microns by 19.9 microns. The outer wall of the epidermis measurers 10.5 microns in thickness. The epidermal cells are only slightly arched on their outer sides (Pl. XXII, Fig. 3.

The outer cylinder of collenchymatic tissue is composed of cells which are larger and more irregular in size and shape than in *atropurpureus*. The walls of the cells at the four corners are more thickened than elsewhere. No bundles of bast fibers develop at the corners but, usually not before the third year, cork ridges are formed which are similar in every way to those already described for *atropurpureus* and *europaeus*. The cells beneath these ridges become greatly stretched, seeming to indicate that growth was taking place more rapidly in all other parts of the cortex.

The assimilatory tissue is composed of rather uniformly large cells which are very abundantly supplied with chloroplasts.

The thin-walled parenchyma inside of the inner collenchyma cylinder is similar to that of the other species, excepting for the size of the cells. These measure as much as 28 by 56 microns. Bast fibers are found, solitary or in groups of two or three, in the layer of small parenchyma cells next inside of these large ones. In the great majority of stems these bast fibers are very scarce, but occasionally a stem is found in which they are quite abundant.

The medullary rays are a single cell in width (Pl. XXIV, Fig. 8). They average five in 175 microns at the outer margin of the xylem.

The pith is heterogeneous. Most of the cells have comparatively thin walls, but thicker than in *europaeus*. The cells are not uniform in size and do not contain stored starch or calcium oxalate crystals. The pith cavity in the one-year-old stem is diamond-shaped, but is much smaller in proportion to the size of the stem than in any other species studied excepting *alatus* (Pl. XXIII, Fig. 3).

E. maackii Rupr.

The epidermal cells are almost triangular in shape. Their average size is 21.4 microns in both the radial and the tangential diameters. The thin outer wall, 7 microns in thickness, is strongly arched. The epidermis remains intact as long as five or six years.

The collenchyma cylinders have their cell walls strongly thickened, especially so at the corners of the stem where the two cylinders are connected. The cells are quite regular in size and shape and give the cortex a very compact appearance (Pl. XXII, Fig. 4).

No bast fibers develop at the corners, nor is there any indication of cork-wing formation.

The cells of the assimilatory tissue are regular in size and shape, with a tendency to be longer than wide, as seen in cross section, the long axis being in the direction of the circumference.

The thin-walled parenchyma is not so abundant as in the forms previously described. The cells vary greatly in size. Those which make up the ring of large cells may be as much as 45.5 by 70 microns. No bast fibers are to be found between the phloëm and the parenchyma.

The medullary rays are one cell thick, averaging 3 to 4 in 175 microns at the circumference of the xylem. The cells of the rays are longer in their radial diameter. (Pl. XXIV, Fig. 9).

The xylem is not so compact as in other forms, owing to the greater abundance of tracheal tubes and fewer wood fibers. This condition may be due entirely to habitat conditions, however, altho it is marked in all stems studied.

The pith cavity in the one-year stem is diamond-shaped, the corners less rounded than in *europaeus*. The points alternate with the corners of the stem. The stem itself is flattened on two sides and rounded on the other two (Pl

XXIII, Fig. 4), a condition different from all other species studied. In the two-year stem the pith cavity is almost square. The pith cells are variable in size, with larger cavities and thicker walls toward the inside. Most of them have comparatively thick walls and are filled with starch grains. The cells containing clustered crystals have thin walls.

E. patens Rehd.

The epidermal cells are flattened, measuring 14.3 microns in their radial diameter by 26.2 microns in their tangential diameter. The outer wall, which averages 10.5 microns in thickness, is not so prominently arched as in other species. Stomata are very numerous (Pl. XXII, Fig. 5).

The outer collenchyma cylinder is strongly developed. At short intervals in the inner margin of this cylinder are large round thick-walled cells like the collenchyma cells which extend into the cylinder of the assimilatory tissue. The cells of the assimilatory tissue radiate more or less around these cells where they are present (Pl. XIII, Fig. 14).

The cells of the assimilatory tissue differ from all previously described in that their long axis as seen in cross section is in the direction of the radius.

There is no connection of collenchyma cells between the outer and inner cylinders. The inner cylinder of collenchyma cells is quite prominent, extending entirely to the phloëm in many places. In other regions thin-walled parenchyma lies between this and the phloëm. The thin-walled parenchyma cells vary in size from 24 by 52 microns to 45 by 70 microns, although the great majority are small. There is not a continuous ring of large cells.

The medullary rays are seven in 175 microns. The cells in some places are quite noticeable because of their large size, some of them being as wide in their transverse diameter as the medium-sized tracheal tubes. Their long axis is in the vertical direction (Pl. XXIV, Fig. 10). Many of them measure as much as five times as long as wide. They are seldom pitted on their horizontal walls. The rays are for the most part one cell thick, but some are two and three cells in thickness.

The pith cells are of moderate but fairly uniform size. Their walls are thick and not easily torn. In the two-year-old stem the cells are living and contain starch. Numerous large cluster crystals are present. The pith cavity is much larger than in any other species studied and is almost circular in cross section in both one- and two-year-old stems, contrasting with the diamond-shaped cavity of most species (Pl. XXIII, Fig. 5).

E. americanus L.

The cells of the epidermis are flattened, irregular in shape and size and are more or less crushed. They average 16.1 microns in the radial diameter by 22.7 in the tangential diameter. The outer wall of the epidermis is thick, measuring 17.5 microns.

The collenchyma cylinder immediately beneath the epidermis is usually only one cell layer in thickness, although it is two cells thick in places. The cells are rather irregular in size and shape.

The inner cylinder, if present, cannot be distinguished from the parenchyma cells beneath it. The walls of all of these cells are much thicker than the assimilatory tissue cells. There are no collenchymatic connections with the outer collenchyma cylinder.

Cords of bast fibers at the corners of the stem are always present (Pl. XXII, Fig. 6), but these differ from all other species in that they are inside of the cylinder of assimilatory tissue and remain in the cortex, *i. e.,* they are not cut out by cork-forming cells as in other species. The first cork formed is along the four corners and may appear there as early as the fifth or sixth node of the one-year-old stem (Pl. XXIII, Fig. 6). The cork is derived from the cells of the outer cylinder of collenchyma (Pl. XXIV, Fig. 1).

The cells of the assimilatory tissue are thin-walled and have their long axis in the radial diameter. They are much longer than wide in cross section, and as a result this tissue has all the appearance of the palisade tissue of a leaf.

The parenchyma tissue next inside of the assimilatory tissue, as already mentioned, cannot be divided into collenchyma and thin-walled parenchyma cells. All of the cell walls are considerably thicker than those of the assimilatory tissue. The long axes of the cells are in the direction of the circumference. The ring of large cells near the inner margin of this layer is very prominent. These cells measure as much as 52.5 microns in tangential diameter by 35 microns in their radial diameter, while in longitudinal sections some were found measuring 46.5 microns long. Since these cells show no contents, it is presumed their function is that of water storage.

The smaller parenchymalike cells between these large cells and the phloëm, already referred to in other species, are quite prominent in *americanus.* They are short, bluntended tubes measuring about 10.5 microns in their radial and tangential diameters by 63 to 70 microns long.

Most of the phloëm cells look very much alike in cross section, being rectangular in shape. Occasional rows of thinner-walled parenchyma cells at right angles to the medullary rays mark off more or less square areas of the rectangular cells. In longitudinal sections the cells are found to be sieve tubes and tube-like parenchyma cells many of them measuring ½ to 1 mm. in length, and contain simple pits in their walls. Many of these contain the brown secretion which is presumed to be the caoutchouc discussed by Möeller (loc. cit.).

The medullary rays are a single cell in thickness, five or six in 175 microns at the outer margin of the xylem. The long axis of the cells is in the vertical direction. They measure two to three times as long as wide (Pl. XXIV, Fig. 11).

The pith is heterogeneous, being composed of both living and dead cells, the latter having thin walls. There is great variability in the size of the cells. Cluster crystals are numerous; also cells containing caoutchouc are not infrequent. In the one-year stem the pith cavity is diamond-shaped, the corners alternating with the corners of the stem. The region of the vascular bundle is narrow as compared with the cortex or with the pith region. The one-year stem of *americanus* differs from all others studied in that its shape is nearly square in cross section (Pl. XXIII, Fig. 6).

E. europaeus nanus Lodd.

The outer wall of the epidermis in *europaeus nanus* is thick, 12 to 14 microns, and resembles that of *americanus* when seen in cross section. The epidermal cells are somewhat irregular, but are mostly rectangular in shape, measuring 22.75 microns in their tangential diameter by 18.2 microns in their radial diameter. Cells are frequently found which have recently divided. Sometimes this division is in the radial diameter, sometimes in the tangential. The walls of the cells cut off by the tangential division thicken and the cells become collenchymatic. When cork is produced it is in the form of longitudinal flecks scattered promiscuously over the stem. It is epidermal in origin (Pl. XXIV, Fig. 2).

The outer cylinder of collenchyma is one cell thick excepting where it has been added to by the epidermis.

The assimilatory tissue is three to four cells thick and is not cut through by collenchyma cells. The cells are more or less rounded (Pl. XXII, Fig. 7).

The walls of the collenchyma cells of the inner cylinder are not thickened in the angles between cells, but the walls are quite thick. They have simple pits. The cylinder is not of uniform thickness, being much thicker at the angles of the stem; in fact, it seems to be the inceased number of these cells that produces the angles. It is of interest here to note that the stem of *europaeus nanus* has six angles instead of four as in other species (Pl. XXIII, Fig. 7). The first cork forms in flecks between the angles.

Inside of the inner collenchyma layer is a cylinder, for the most part only one cell thick, of thin-walled parenchyma cells. These cells are of about the same size as the inner collenchyma cells. Interspersed with these thin-walled parenchyma cells, or more correctly, just inside of the single-cell layer but interrupted by other large thin-walled cells are patches of cells, as seen in cross section, which have their walls considerably thickened and pitted (Pl. XXIV, Fig. 3). In longitudinal sections these are short tubelike cells. Their walls are not lignified and yet they do not give the same color reactions for cellulose as the phloem and other prenchyma cells. Similar cells have been discribed for other species; in *europaeus nanus*, however, they are much more strongly developed. No bast fibers are to be found in the cortex of the two-year-old stem of the *europaeus nanus*.

The medullary rays average nine in the arc of 175 microns at the edge of the xylem. They are a single cell in thickness (Pl. XXIV, Fig. 13). The cells have their long axes in a vertical direction but are seldom more than twice as long as wide. The walls are exceptionally thin and sparsely pitted (Pl. XXIV, Fig. 12).

The pith cavity is irregularly circular in outline. The pith cells, which are rather loosely arranged, have fairly thick walls and many of them contain starch. Clustered crystals of calcium oxalate are very frequently found.

E. radicans Sieb.

The outer wall of the epidermis is thin, measuring between 6 and 7 microns. The epidermal cells are of two types. The majority are flattened rectangular cells measuring 10.5 microns in their radial diameter by 21.8 microns in their tangential diameter. Interrupting these at short intervals are larger cells, 24 microns in radial diameter by 21 microns in the tangential diameter. This gives a series of peaks to the outline of the epidermis as seen in cross section (Pl. XXIII, Fig. 8).

The outer collenchyma cylinder likewise consists of larger and smaller cells with pits communicating between them. This layer is typically one cell thick.

The assimilatory tissue is three to five cells in thickness. On one side of the stem the cells of the outer layer of this tissue are elongated in their radial diameter, while the cells of the other layers are round (Pl. XXII, Fig. 8).

On the opposite side of the stem there is a lesser development of this tissue, and all of the cells are round. This is probably due to the fact that the vines from which the specimens were taken were flat on the ground. On the under side of the stem most of the cells are of more or less irregular size and shape.

The inner collenchyma cylinder is well developed but only two to four cells in thickness. The cells are pitted.

The thin-walled parenchyma layer next inside of this inner collenchyma cylinder consists of cells having exceptionally thin walls. They are irregular in size and shape, and it is very seldom that a section is cut without tearing and crushing this layer. There is a considerable development of the thicker-walled, pitted, tubelike cells in patches just outside of the phloëm, especially on the upper side of the stem.

The medullary ray cells are exceptionally large as compared with the other species studied, some of them measuring as much as 14 microns in transverse diameter and occasionally as much as 28 microns in radial diameter. Most of them, however, are roughly almost square as seen in cross section of the stem. In longitudinal sections some are square. The great majority, however, are from 70 to 80 microns in length (Pl. XXIV, Fig 14). They are finely pitted on all surfaces. The rays are one cell in thickness for the most part although occasional rays two cells thick are found.

The pith is homogeneous. The cells are of fairly uniform size and have moderately thick walls. They contain stored starch and a few compound crysta's are present.

E. alatus Reg.

The outer wall of the epidermis in a section of the two-year stem measures 19.75 microns in thickness. The epidermal cells are sharply pointed outward, but from the margin of the outer wall the sides are perpendicular to the base. The epidermis is one to two cells thick. The cells measure 18.5 microns in the radial diameter by 12.25 microns in the tangential diameter (Pl. XXII, Fig. 9).

The outer collenchyma cylinder is strongly developed, being three to four cell layers in thickness. Beneath the cork wings these cells are stretched so much that it is impossible to distinguish them from other types of cells. The cork wing takes its origin from the epidermal cells (Pl. XXIV, Fig. 4). The shrubs from which specimens for these studies were taken were growing slowly, which may account for the precocious development of the wing somewhat at variance with descriptions of other writers. Plate XXIII, figure 9, is from a section cut two millimeters from the base of the terminal bud. The wings were well developed on three sides and just starting on the fourth; but two millimeters further back this wing was as large as the other three. The other tissues of the stem were equally well developed in this section.

The cork cells of the cork wings are quite large, thin-walled and elongated radially (Pl. XXIV, Fig. 5). Plate XXIV, figure 4, shows only a few of the cork cells at the corner of the wing, where they are very small.

The chlorophyll-containing layer is two to three cells in thickness and is not cut through by the collenchyma tissue, although beneath the wings these cells, along with all others, become so stretched that they cannot be distinguished from the collenchyma cells. The cells of the assimilatory tissue are small, roughly rectangular in shape, with their long axes in the radial diameter.

The inner collenchyma cylinder is well developed. The cells vary greatly in size, from 5 microns to 63 microns in the tangential diameter, which is the long axis of the cell. The larger cells are at the inner circumference of the cylinder and only rarely is one found which is as large as the measurement given. Great numbers of large clustered crystals are stored in the cells of this cylinder.

The parenchyma cells inside of the inner cylinder of collenchyma is composed for the most part of large cells. The cell walls are exceedingly thin and easily torn.

The medullary rays are one cell in thickness and average four to the arc of 175 microns at the edge of the xylem (Pl. XXIV, Fig. 15).

The pith is heterogeneous. The cells have thick walls, but vary greatly in size. They are empty excepting for an occasional compound crystal. The pith cavity is diamond-shaped and is smaller than in the other species studied. The points of the diamond are opposite the four wings. Using the position of the pith cavity as found in the other species as a criterion, it would seem that in *alatus* the wings form between the lines which produce the angles on the other species of the genus.

SUMMARY OF THE ANATOMY OF THE TWO-YEAR-OLD STEM.

The stems of the shrubs and vines of the genus *Euonymus* are often said to be characteristically four-angled. This statement is true in a general way, the angles being produced by the excessive development of collenchyma tissue under the epidermis. In some species this condition is so weakly developed that it is almost impossible to locate the angles. The condition has its typical development in *E. europaeus*, *atropurpureus*, *bungeanus* and *maackii*. An extreme condition is found in *americanus*, where the young stems are almost square. In *europaeus nanus* the young stems are distinctly six-sided. In *alatus* the angled characteristic of the others do not appear, but large cork wings are present between the lines where the angles are formed on the other species. In *patens* and *radicans* the angles are not apparent.

The outer epidermal wall throughout the species investigated is relatively thick. In *europaeus*, *bungeanus*, *patens*, *europaeus nanus* and *radicans* it is as thick or thicker than half the radial diameter of the epidermal cells, and in *americanus* and *alatus* it is thicker than the cavities in their radial diameter. In only two species studied, *atropurpureus* and *maackii*, it is less than half of the radial diameter of the cavities of the epidermal cells.

In *atropurpureus* and *alatus* the epidermal cells are pointed on the outer side and are longer in the radial than in the tangential diameter. In *alatus* the epidermis is variable, from one to two cells thick. In *maackii* the two diameters are of about equal length and the cells are somewhat pointed. In the remaining species the tangential diameter is the longest, *europaeus* and *patens* varying from one to two cells in thickness. The outer cell surface is rounded in *europeaus*, *bungeanus* and *patens*, but almost flat in *americanus*, *radicans* and *europaeus nanus*. In *radicans* single cells much larger than the others occur at short intervals, producing small peaks over the epidermis.

Cork is relatively slow in forming in most species. The cork wings of *alatus* are very precocious in their development. In *atropurpureus*, *europaeus*, *bungeanus* and *americanus* lines of cork appear along the angles of the stem usually by the early part of the second year of growth. In the two first-named species these lines take the form of rather temporary, weakly developed wings. In *bungeanus* these winglike growths appear occasionally, very weakly developed. The spaces between these lines remain more or less green from two to five years. In all species examined the cork, excepting in the wings of *alatus* and in that formed at the angles of the stem in the above-mentioned species, arises as little brown longitudinal flecks which resemble lenticels in appearance. These multiply in number and size until the stem is covered.

From my own findings and the work of other investigators it may be said that the cork usually is of epidermal origin. At the angles of the stem in *atropurpureus* and *americanus* however, it is derived from the collenchyma tissue beneath the epidermis.

Next beneath the epidermis is a layer of colorless collenchyma cells. This layer is only one cell thick in *patens*, *americanus*, *europaeus nanus* and *radicans*, but more than one cell thick in *atropurpureus*, *europaeus*, *bungeanus*, *maackii* and *alatus*. In *patens* and *radicans* large, round, thick-walled colorless cells occur in (*radicans*) or just beneath (*patens*) this layer of tissue.

A second layer of collenchyma tissue inside of a layer of chlorophyll-containing cells is characteristic of the genus, altho this is variable in the degree of its development. In some cases it grades off into an inner layer of thin-walled parenchyma cells so gradually that it is difficult to asertain the dividing line.

The two cylinders of collenchyma tissue are connected with each other by collenchyma cells at the four corners of the stem in *atropurpureus*, *europaeus*, *bungeanus* and *maackii*, but not in the other species. These collenchyma cells cut through the layer of chlorophyll-containing cells and thus produce the white lines which show through the epidermis in young stems.

The chlorophyll-containing layer is usually from three to five cells in thickness. In *atropurpureus* and *europaeus nanus* the cells are almost isodiametric in shape; in *europaeus*, *bungeanus* and *maackii* they have their long axes in a tangential direction, while in *patens*, *americanus*, *radicans* and *alatus* the long axis is in the radial diameter. In these last-named species this layer frequently looks very much like the palisade layer of leaves. The degree of development in this direction seems to be in response to the sunlight, since in *radicans* these assimilatory cells on the side of the stem which lies on the ground are irregular to isodiameteric in shape.

Inside of the inner collenchyma cylinder is a layer of parenchyma tissue of varying thickness. The cell walls of this tissue are characteristically thin, but in some of the species they are rather thick. In those forms in which the walls are thickened they are rather conspicuously pitted. The cells of this layer always have their long axis in the tangential direction. They vary in size, being smaller in the outer circumference and gradually becoming larger towards the inner circumference. These large cells at the inner circumference reach their greater development in *americanus*.

Between this layer and the phloëm are irregular patches of smaller blunt-ended tubelike cells. In most species the walls of the cells are only slightly thicker than those of the surrounding parenchyma cells, but in others, especially *europaeus nanus*, the walls become greatly thickened.

Bast fibers are not formed in the cortex of *maackii*, *patens*, *europaeus nanus*, *radicans* or *alatus*. In *atropurpureus* rather large bundles of fibers are found at the corners of the stem in the tissue just beneath the outer collenchyma cylinder. Also scattered fibers, single or in groups of two or three, are found just outside of the phloëm. In *europaeus* scattered fibers are found outside of the phloëm and small bundles may or may not develop at the corners of the stem. In *americanus* bundles of fibers develop at the corners of the stem, but in this species they are inside instead of outside of the assimilatory tissue.

The vascular bundles of the stem were quite similar in all species studied. The cells of the phloëm region are all thin-walled and more or less rectangular in shape, so that it is impossible to distinguish the sieve tubes and companion cells in cross sections. In the xylem wood parenchyma is scarce and tracheids with bordered pits are only infrequently found. The tracheal tubes are broadly pitted and have spiral or concentric thickenings of the walls. The wood fibers are mostly pitted and assist in the transportation of water.

The medullary rays in all species are normally one cell wide, although rarely here and there a ray of two cells in thickness was observed. In *maackii, patens, americanus, europaeus nanus* and *radicans* the cells of the medullary rays vary from square to long, the long axis being in the vertical direction. In *radicans* some of these cells are extremely long. They are very thin-walled and finely pitted. In *europaeus nanus* the cells are small, thin-walled and finely pitted. The rays in this species are seldom more than three to four cells high and never more than one cell wide. In *atropurpureus* the rays are prominent. The cells vary from square to long, but some of the long cells have their long axes in the vertical direction while others have it in the radial direction. In *europaeus, bungeanus* and *alatus* most of the cells are oblong and all have their long axes in the radial direction. Starch is stored in the medullary rays of all species investigated.

The pith throughout the group is alike in that the cells are longer in their vertical diameter, and compound crystals of calcium oxalate are found in all species. Starch is not stored in the pith of *atropurpureus, europaeus* and *alatus*, but is found in varying quantities in the other species. The cells are of different sizes in *atropurpureus, europaeus, bungeanus, maackii, americanus* and *alatus*, but more or less uniform in size in *patens, europaeus nanus* and *radicans*. According to the types of pith as described by Gris (5), the species studied are grouped as follows:

Homogeneous—*patens, europaeus nanus* and *radicans*.

Heterogeneous—*bungeanus, americanus* and *maackii*.

Empty—*atropurpureus, europaeus* and *alatus*.

THE PETIOLE.

E. atropurpureus Jacq.

(Pl. XXVII, Fig. 1.)

The petiole is strongly arched out on the upper surface between prominently projecting margins.

Two types of vascular bundles are present: The large central bundle is very curved with the ends bent sharply in. Opposite each upper outer angle where the ends bend in on each side is a small closed vascular bundle with the phloëm completely surrounding the xylem.

Outside of the vascular bundles the walls of all the cells are a little thickened and are finely pitted. Finely pitted collenchyma tissue occupies a layer five cells thick around the outside margin, immediately around the phloëm and inside of the xylem. One or two small vascular bundles occur at the bases of the projecting margins.

Compound crystals are abundant in the phloëm and are scattered in the outer parenchyma and collenchyma.

E. europaeus Linn.

(Pl. XXVII, Fig. 2.)

The petiole is somewhat arched outward on the upper surface between slightly projecting margins.

The vascular bundle it strongly curved with the ends curved in. Opposite each of the upper outside angles of this central bundle is a small open bundle.

Just beneath the epidermis is a layer five to six cells thick of strongly developed, unpitted collenchyma cells. Another layer of smaller collenchyma cells is just outside of the phloëm, but not inside of the xylem. Comparatively large, more or less rounded, thin-walled parenchyma cells extend between these two layers on the under and lateral sides and between the xylem and outer collenchyma on the upper side.

Compound crystals are abundant in the phloëm and thin-walled parenchyma and are found here and there in the collenchyma.

E. bungeanus Maxim.

(Pl. XXVII, Fig. 3.)

The upper surface is strongly arched inward from slightly projecting margins. The large vascular bundle is a wide, open arc, not bent in at the ends. A small open bundle is opposite each end of the arc.

Just beneath the epidermis is a layer four to five cells thick of greatly thickened collenchyma cells. Their cavities are angular and each cell connects with neighboring cells by a single pit to each cell. There is no collenchyma layer immediately outside of the phloëm.

The parenchyma tissue is composed of fairly thick-walled, finely pitted cells on the outer margin, small thin-walled cells just outside of the phloëm and inside of the xylem and large thin-walled cells between these two layers.

Compound crystals are scattered in the phloëm and parenchyma.

E. maackii Rupr.

(Pl. XXVII, Fig. 4.)

In cross section the petiole of *maackii* is longer than wide. The upper surface is slightly curved outward between projecting margins.

The vascular bundle is curved and slightly bent in at the ends. No small bundles are present at the angles of the one large bundle.

The collenchyma layer beneath the epidermis is strongly developed and is three to four cells in thickness. The cells are finely pitted. The tissue immediately outside of the phloëm is variable. Small patches of the cells have their walls so thickened as to almost obliterate the cavity of the cells. Others are hardly thickened enough to be called collenchyma.

The parenchyma cells have only slightly thickened, unpitted walls excepting those below the phloëm, which are quite large and thin-walled. Crystals are in the phloëm and parenchyma, but not abundant.

E. patens Rehd.

(Pl. XXVII, Fig. 5.)

The petiole is wider than long in cross section. There are no projecting margins. The upper surface is not smooth, due to small, protruding irregularities on the surface. In general outline it is curved inward for about the middle third; the outer third on each side curves outward.

The vascular bundle is flattened, curved at the ends, but not bent in.

The collenchyma layer beneath the epidermis is prominently pitted and is three to four cells thick. The cells have very thick walls and are considerably smaller on the upper than on the lower side of the petiole. That outside of the phloëm is irregularly developed and is not in a continuous layer. It is composed of small cells.

The parenchyma cells between the collenchyma layers have thick walls, are very noticeably pitted and have abundant large intercellular spaces between them.

Compound crystals are found in the phloëm and some in the collenchyma, but are most abundant in the outer region of the parenchyma.

E. americanus L.

(Pl. XXVII, Fig. 6.)

The upper surface curves inward. Small, blunt, single-cell trichomes are present on all sides of the petiole.

The vascular bundle is an open arc not curved in at the ends.

The collenchyma layer on the upper side and around the corners of the petiole is very strongly developed and is pitted. It merges into a thick-walled parenchyma layer which extends to the level of the tips of the vascular bundle. Beneath this and inside of the arc of the xylem the parenchyma cells are rounded and thinner-walled. Around the remainder of the circumference of the petiole the collenchyma is difficult to distinguish from the parenchyma, in so far as thickness of cell walls is concerned. The cells have their long axes in the direction of the circumference and any intercellular spaces are inconspicuous. The collenchyma layer outside the phloëm is poorly developed. There are scattered groups of small collenchyma cells. The parenchyma cells have very thick walls, very conspicuously pitted and large, prominent intercellular spaces. There are very few crystals.

E. europaeus nanus Lodd.

(Pl. XXVII, Figs. 7 and 8.)

This petiole is very small. Figure 7 is photographed at the same magnification as the others on the plate. The upper surface is flat.

The vascular bundle is in the form of a thick arc, almost fan-shaped.

The collenchyma tissue is not strongly developed. Around the margin of the petiole it is one to two cells in thickness. The cells are more or less rectangular in shape. On the upper surface the lateral cell walls are not thickened. This causes a layered appearance in this region. The cells are pitted.

Immediately outside of the phloëm and inside of the xylem the cells are small and have only slightly thicker walls than the thin-walled parenchyma which surrounds them. The walls of the parenchyma cells gradually get thicker toward the outer margin of the petiole until they merge into the collenchyma layer. Crystals are very few.

E. radicans Sieb.

(Pl. XXVII, Fig. 9.)

The outline of the cross section of the petiole of *radicans* is irregular, due to projections produced by occasional extremely large epidermal cells, or at times also to an enlarged collenchyma cell which shoves the epidermal cells out. As noted in the description of the stem of this species, the epidermal cells and the collenchyma cells are each quite uniform in size and shape excepting at short intervals, where much larger cells occur.

The upper surface of the petiole curves inward from rounded corners.

The vascular bundle is a broadly opened arc.

Groups of very small cells are immediately outside of the phloëm, but in this species they are not collenchymatous.

The collenchyma beneath the epidermis is one to two cells thick. The cell walls are pitted. The cavities of these cells are more or less rounded The parenchyma cells are rounded, have heavy, inconspicuously pitted walls and prominent intercellular spaces.

Crystals are few and scattered, with none in the phloëm.

E. alatus Reg.

(Pl. XXVII, Fig. 10.)

Occasional short single-cell trichomes are present. The upper surface is arched out in a peak almost to the level of the tips of the projecting margins. The vascular bundle is fan-shaped and not concave inside of the xylem.

There is no parenchyma layer, the entire region from phloëm to epidermis being a highly developed collenchyma. Even the phloëm parenchyma cells have their walls greatly thickened. At the corners inside of the marginal projections the cells are rather loosely arranged with large intercellular spaces. Crystals are numerous.

SUMMARY OF THE ANATOMY OF THE PETIOLE.

There are some very noticeable differences in the general outline of the cross section of the petioles among the species studied.

Scattered trichomes were found on the upper surface in *alatus* and on all surfaces in *americanus*. In *patens* the upper surface has many small irregularities in its contour. In *radicans* smaller irregularities occur more or less at intervals all around the petiole. In this case, as was described in the stem for this species, the epidermis has much larger cells at intervals, which produce small, peaked elevations.

The margins project up above the top in *atropurpureus, europaeus, bungeanus, maackii*, and *alatus*, but not in *patens, americanus, radicans*, and *europaeus nanus*.

The upper surface is flat in *europaeus nanus*. It is convex in *atropurpureus, europaeus, maackii* and *alatus*, and concave in *bungeanus, patens, americanus* and *radicans*. In *patens* the corners round in so gradually that only the middle third is concave.

The vascular bundle is more or less in the form of an arc in all species excepting *alatus*, where it is fan-shaped. In *patens* the arc is greatly flattened with only the ends cuurved. In *atropurpureus, europaeus* and *maackii* the ends of the arc are bent in sharply. Small bundles are present just above and outside the ends of the arc in *atropurpureus, europaeus* and *bungeanus*. In *atropurpureus* these small bundles are completely surrounded by phloëm, and there are also other small bundles at the bases of the marginal projections.

Bast fibers were not found in the petioles of any of the species studied.

The distribution of collenchyma tissue is somewhat variable in the nine species. In *alatus* all cells outside of the vascular bundle are strongly collenchymatous, while in *radicans* the only collenchyma tissue is a layer one to two cells thick around the outer margin, and even this is not strongly developed collenchyma. In *alatus* these cells are not pitted, but in *radicans* they are. In the other species, *atropurpureus, europaeus, bungeanus, maackii, patens, americanus* and *europaeus nanus*, there is a definite layer of collenchyma cells around the outer margin next beneath the epidermis. In *americanus* this layer is only two or three cells thick around the lower side, but is four to five rows thick across the upper surface. In *europaeus nanus* it is only one cell thick around the lower side, and these cells do not have greatly thickened walls. On the upper surface it is four to five rows thick, but here the side walls are not thickened, while the upper and lower walls are thick. These collenchymatic cells were not pitted in *europaeus* and *alatus*. In *atropurpureus* and *maackii*, the pits were very fine, while in *bungeanus*, *patens*, *americanus*, *radicans* and *europaeus nanus* the pits were quite prominent.

Just outside of the phloëm there was a layer of small collenchyma cells in *atropurpureus*, *maackii*, *patens* and *americanus* and, of course, *alatus*. In *europaeus*, *bungeanus*, *radicans* and *europaeus nanus* very small thin-walled parenchyma cells occupied this region.

Similar small collenchyma cells were found just above the xylem in *atropurpureus* and *bungeanus* but in all other species these cells were very small, thin-walled parenchyma.

The region between the vascular bundle and the outer collenchyma is occupied by rounded parenchyma cells. These parenchyma cells are thin-walled and without pits in *europaeus*, *maackii* and *europaeus nanus;* thin-walled with very fine pits in *atropurpureus* and *bungaeus;* while they have rather thick pitted walls in *patens*, *americanus* and *radicans*.

THE LEAF BLADE.

E. atropurpureus Jacq.

In surface view the epidermal cells of the upper surface of the leaf are irregular but have almost straight boundaries. The palisade cells are rather loosely arranged so that small intercellular spaces often reach the epidermis (Pl. XXV, Fig. 1). The cells of the lower epidermis are somewhat sinuous and are smaller (Pl. XXV, Fig. 2). The side walls of some of the cells of the upper epidermis are finely pitted, those of the lower epidermis are not pitted.

In cross section the cells of the upper epidermis are taller than those of the lower, in both they are more or less rounded and in both the cells are slightly broader than high. The outer walls on both surfaces curve outward; those of the upper epidermis are slightly thicker than those of the lower. The side walls are thinner than the outer walls and the inner walls are still thinner than these (Pl. XXVI, Fig. 1).

Stomata are present on the lower surface only. They are broadly elliptical in outline and are almost level with the surface. Short, blunt, single-cell trichomes are present on the lower surface of the leaf.

The palisade layer is two-rowed. The cells of the upper row are from three to four times as high as wide; those of the lower row are somewhat shorter.

The spongy mesophyll is from four to five cells thick, the cells are rounded or slightly elongated parallel to the surface. The walls of all mesophyll cells are very thin.

The vascular bundle of the midrib is only slightly curved. The bundle is surrounded by thin-walled parenchyma (Pl. XXIV, Fig. 16). A layer one to two cells thick above the xylem contains chloroplasts and is continuous with the palisade of the leaf. Collenchyma cells fill the region from the parenchyma to the epidermis on both the upper and the lower surfaces. The larger veins connect with both upper and lower surfaces of the leaf by rather large collenchyma cells. The smaller veins are completely immersed.

Compound crystals are found in the cells of all tissues of the leaf, but not abundantly in any. They are more numerous in the phloëm of the midrib and in the parenchyma sheath of the smaller veins.

E. europaeus Linn.

The cells of the upper epidermis are irregular in size and shape, but for the most part have almost straight walls (Pl. XXV, Fig. 3). The cells of the lower epidermis are quite variable in size, but most of them are much smaller than those of the upper epidermis. They are slightly sinuous (Pl. XXV, Fig. 4). The side walls of the upper epidermis are finely pitted; those of the lower are not. The palisade cells are quite compactly arranged. Stomata are found only on the lower surface. They are broadly elliptical and protrude but slightly below the level of the epidermal cells. No trichomes are present.

In cross section the cells of the upper and lower epidermis are about the same height. The outer walls of both are arched out slightly; those of the upper epidermis are much thicker than those of the lower. The side walls of both of the upper and the lower epidermis are quite sinuous and are only a little thicker than the curved inner wall.

The palisade layer is two rowed. The cells of the upper row are about four times as tall as broad. Those of the lower row are very irregular in shape and size and are not more than one and a half to two times as tall as broad. Most of them are broader than those of the upper layer.

The spongy mesophyll is three to four cells thick. The cells are rounded or irregular in shape and more or less compact (Pl. XXVI, Fig. 2).

The midrib protrudes on both sides (Pl. XXIV, Fig. 17). It, as well as the larger veins, are connected with both surfaces of the leaf by collenchyma tissue. The vascular bundle is a broadly open arc not bent in at the ends. Above, collenchyma tissue forms the ridge which protrudes on the upper surface of the leaf. Rounded cells containing chloroplasts extend in at least a third of the width of the rib on each side just beneath the collenchyma tissue. Between these cells and the xylem are comparatively large thin-walled parenchyma cells. Beneath the bundle outside of the phloëm, first small then larger thick-walled somewhat collenchymatous cells make up the portion of the rib which protrudes beneath the leaf. A layer four to six cells wide of collenchyma is around the margin. No other sclerenchyma cells are present. The larger veins extend through, both above and below, by strongly developed collenchyma cells. The smaller veins are completely immersed and surrounded by a parenchyma sheath.

Occasional compound crystals are found in the upper epidermis as well as in the upper palisade and the spongy mesophyll, but they are by far more numerous in the lower row of the palisade layer of the leaf.

E. bungeanus Maxim.

In surface view the cells of the upper epidermis are fairly regular is size with straight sides. The palisade cells are compactly arranged (Pl. XXV, Fig. 5). On the lower epidermis the cells are only slightly smaller than those of the upper and are not so regular in size or shape; the sides are frequently more or less curved, but are not sinuous (Pl. XXV, Fig. 6). The side walls of both the upper and the lower epidermis are finely pitted. Stomata are present on the lower surface only. They are rather broadly elliptical in shape.

In cross section the side walls of both the upper and the lower epidermises are not straight; some are curved, some are quite sinuous, some slant one direction and some the other. The outer cell walls curve outward slightly and are only a little thicker than the side walls. The cells on both surfaces are broader than tall (Pl. XXVI, Fig. 3).

The palisade tissue is two-rowed. The cells of the upper row are more than three times as tall as broad, those of the lower row are broader and are less than three times as tall as broad.

The spongy mesophyll is for the most part rather compact. It is composed of rounded, somewhat flattened cells. All of the mesophyll cells have very thin walls.

The midrib protrudes both above and below the leaf (Pl. XXIV, Fig. 18). The vascular bundle of the midrib is a very greatly flattened arc. It is surrounded by parenchyma cells which extend out to a collenchyma layer three to five cells thick on both the upper and lower surfaces. No sclerenchyma fibers are present in the midrib. Chlorophyll-containing tissue does not extend entirely across the upper surface of the vein. The lateral veins are immersed above, but extend through on the under side by slightly thickened parenchymalike cells.

A few compound crystals are scattered here and there in the tissues of the leaf and are not more abundant in one tissue than another.

E. maackii Rupr.

In surface view the cells of both epidermises are elongated, mostly twice as long as broad, with slightly curved edges. The elongation does not seem to bear any relationship to the long axis of the leaf (Pl. XXV, Figs. 7 and 8). The side walls of the cells of the upper epidermis are finely pitted; those of the lower are not. The palisade cells are rather loosely arranged. The cells of the lower epidermis are smaller than those of the upper, and are somewhat sinuous in outline. The cells of the spongy mesophyll, as seen through the epidermal cells, are smaller than the cells of the epidermis and are mostly rounded or elongated. The stomata are rather elongate-elliptical in shape and are found only on the lower surface.

In cross section (Pl. XXVI, Fig. 4) the cells of both epidermises are broader than tall. The outer walls curve outward. The outer walls of the upper epidermis are thicker than those of the lower and both are thicker than the side or inner walls. The side walls of the cells of both the upper and lower epidermises vary from straight to sinuous.

The palisade tissue is two rows high. The cells of the upper row are usually more than three times as high as wide. The cells of the second row are more than twice as high as broad. About two-thirds of the thickness of the leaf is occupied by palisade tissue. The spongy mesophyll is composed of loosely arranged, rounded cells, three to four cell layers thick.

The midrib protrudes on both upper and lower surfaces (Pl. XXIV, Fig. 19). The vascular bundle is a broad arc and is surrounded by a broad region of thin-walled parenchyma tissue. No sclerenchyma fibers accompany the bundle. Rounded chlorophyll-containing cells extend entirely across the upper surface of the rib. Above, outside of the assimilatory tissue, collenchyma tissue extends to the epidermis. On the lower side a layer of collenchyma tissue, five to six cells thick, is beneath the epidermis. The lateral veins extend through to both surfaces by rather large collenchymatous cells.

Compound crystals are scattered in all tissues, but are most numerous in the lower palisade layer, where they are contained in large rounded cells.

E. patens Rehd.

In surface view the cells of both surfaces are about the same size (Pl. XXV, Figs. 9 and 10). The cells of the upper epidermis are less than half as large as the corresponding cells of *maackii*. Their margins are slightly rounded and their side walls are pitted. The palisade tissue is fairly compact. The margins of the cells of the lower epidermis are irregular, usually curved but not sinuous. The side walls are pitted. The cells of the spongy mesophyll are rounded and irregular in shape with protruding processes. They are larger than the cells of the lower epidermis.

Stomata are present on the lower surface only. They are rather elongate elliptical in shape and protrude only silghtly below the surface (Pl. XXV, Fig. 11).

In cross section the cells of both surfaces are broader than tall. In the upper epidermis the outer cell walls are almost flat and are thicker than the outer walls; the inner wall is thicker than the side walls. The side walls are straight for the most part, although many are quite sinuous. In the lower epidermis the outer wall is thicker than the other walls, but is not so thick as the outer wall of the upper epidermal cells. The side walls are quite sinuous.

The palisade layer is mostly three rows in height and occupies about half the thickness of the leaf. The cells of the top row and the second row are about the same size, being a little more than twice as high as wide. Those of the third row are only slightly elongated in the vertical direction (Pl. XXVI, Fig. 5).

The midrib protrudes on both surfaces only slightly (Pl. XXIV, Fig. 20). The vascular bundle is a greatly flattened arc and is surrounded by thin-walled parenchyma. A bundle of bast fibers is just outside of each end of the phloëm Assimilatory tissue extends entirely across the upper surface. Outside of the assimilatory tissue to the epidermis is collenchyma. On the lower surface collenchyma is confined to a very narrow layer beneath the epidermis. Bast fibers accompany many of the smaller veins on their under side. These smaller veins have a prominent parenchyma sheath. They do not extend through to the surface of the leaf.

Compound crystals are fairly numerous and cannot be said to be more abundant in one tissue than another.

E. americanus L.

In surface view the cells of the upper epidermis are rounded or quite sinuous in outline. At the points where the cells join there is usually a very definite triangle produced by pectic modification of the side walls where three cells join (Pl. XXV, Fig. 12). The side walls are pitted. The palisade cells are quite compact. Short, blunt, single-cell trichomes (Pl. XV, Fig. 14) are found along all the larger veins on the upper surface and rarely on the epidermis other than above the veins.

The cells of the lower epidermis are quite sinuous but join together completely (Pl. XXV, Fig. 13). The side walls are finely pitted. No trichomes are present on the lower surface. The stomata, which are found only on the lower surface, are almost circular in surface view.

In cross section the cells of the epidermises are broader than tall. The outer wall of cells of the upper epidermis protrudes slightly and is somewhat thickened. The side walls are bent or sinuous. The cells of the lower epidermis are not so tall as those of the upper. The outer walls are thin.

The palisade layer is mostly one cell thick. The cells are broad, about twice as tall as wide. The spongy mesophyll occupies about two-thirds of the thickness of the leaf. The cells are short and stretched, with large intercellular spaces (Pl. XXVI, Fig. 6).

The midrib protrudes slightly on both surfaces (Pl. XXIV, Fig. 21). The vascular bundle is almost fan-shaped. Small bundles of bast fibers are scattered in the parenchyma just outside of the phloem. In some leaves small bundles of very thick-walled sclerenchyma cells were found just above the xylem; in others they were not present. Assimilatory tissue extends entirely across the vein. Collenchyma cells above this tissue produce the elevation on the upper side of the leaf. Below the bundle a layer of greatly thickened collenchyma cells occupy most of the space between the vein and the epidermis.

The smaller veins are immersed on the upper side, but connect with the epidermis by collenchyma cells on the lower. Bast fibers frequently accompany these smaller veins.

Compound crystals are chiefly found in the spongy mesophyll, but are not absent from the other tissues.

E. europaeus nanus Lodd.

In surface view the cells of the upper epidermis are mostly elongate, five- or six-sided polygons with straight sides. There is no correlation between the long axis of the leaf and the long axis of these cells. The side walls are prominently pitted with long oval pits. The palisade cells are quite compact (Pl. XXV, Fig. 15). On the lower epidermis the cells are only slightly smaller than those of the upper. They are not so regular in shape and in outline the walls are not straight but deeply curved, almost sinuous (Pl. XXV, Fig. 16). The pits in the side walls are like those of the upper epidermis but are finer. Stomata are present on the lower side of the leaf only.. They are elongate-elliptical in shape and have their long axes parallel with the midrib. The spongy mesophyll cells are rather small and rounded with small air spaces between.

In cross section the cells of the upper epidermis are much broader than tall. The outer wall protrudes usually to rather a broad peak, and is quite thick as compared with the previous species described. The side walls are straight and of about the same thickness as the inner wall. The lower epidermal cells are almost square or rectangular in shape. The outer wall is only slightly thicker than the others.

The palisade tissue is mostly three-rowed and occupies a little less than half of the thickness of the leaf. The cells of the upper layer are about twice as tall as broad. Those of the two lower rows are variable in form and are very loosely arranged. The spongy mesophyll in cross section shows up as rather compact, squarish cells (Pl. XXVI, Fig. 7).

The midrib protrudes only very slightly on the upper surface and but little on the lower (Pl. XXIV, Fig. 22). The vascular bundle is a greatly flattened arc. There is no collenchyma tissue in the midrib. Above the vascular bundle an outer row of palisade and below this one to two rows of rounded cells containing chlorophyll reach to the epidermis. Below the bundle almost round, thin-walled parenchyma cells fill all of the space to the epidermis. There are no bast fibers. The lateral veins are all completely immersed.

Compound crystals are found mostly in the spongy mesophyll.

E. radicans Sieb.

In surface view the cells of the upper epidermis are irregular polygons with mostly straight sides (Pl. XXV, Fig. 17). The side walls have prominent round pits. The palisade cells are compactly arranged. The cells of the lower epidermis are smaller and have slightly curved boundaries (Pl. XXV, Fig. 18). The side walls, also, have prominent round pits. Stomata occur on the under surface only and are broadly elliptical in shape.

In cross section the cells of the upper epidermis are broader than tall. The outer walls bulge outward and are only a little thicker than the other walls, all being relatively thick. The side walls are straight and the inner walls are convex, producing an almost oval cavity. The cells of the lower epidermis are smaller, but in general shape they resemble the upper epidermal cells. The outer wall is thicker than the side walls or the inner wall (Pl. XXVI, Fig. 8).

The palisade layer is made up of two rows of cells of about the same size and shape. They are broad and less than twice as tall as broad for the most part; frequently they are almost oval. The layer occupies one-third or less of the thickness of the leaf. The cells of the spongy mesophyll are much larger, irregular in shape and loosely arranged with large air spaces.

The midrib protrudes a little on the upper surface and not at all prominently on the lower (Pl. XXIV, Fig. 23). The vascular bundle here is an open arc and is accompanied outside of the phloëm by bundles of bast fibers.

Assimilatory tissue extends entirely across the upper surface of the vein. Above this are a few collenchyma cells. The lower portion of the vein is composed chiefly of thin-walled parenchyma cells, excepting for a very narrow layer of collenchyma just beneath the epidermis. The larger veins are immersed, but are surrounded by thick-walled cells which extend out to within one or two cells of the epidermis on both surfaces. Bast fibers are not present. Crystals are not abundant, but are scattered through all of the tissues.

E. alatus Reg.

In surface view the cells of the upper epidermis are irregular polygons with rounded borders (Pl. XXV, Fig. 19). The side walls are finely pitted. Scattered trichomes are present on the epidermis above the veins. The palisade cells are compactly arranged. The cells of the lower epidermis are quite sinuous in shape (Pl. XXV, Fig. 20). In some of the cells small pits are present in the side walls, but in the majority they are not present. Stomata occur only on the under surface and are rather elongate-elliptical in shape.

A striking feature found in leaves cleared in chloral hydrate is the lower layer of the spongy mesophyll (Pl. XXV, Fig. 21). This layer contains a substance that becomes somewhat of a salmon color and is almost opaque in this reagent only. The cells are extremely large as compared with all other cells of the leaf and in shape resemble giant flattened amebas, joined together by blunt pseudopods, leaving large air spaces between. The other mesophyll cells can be seen where they project over the air spaces and are of the same shape, but are colorless. This is in great contrast with the description of the spongy mesophyll as given by Metz (8), who says that they are "small oval cells." It is probable that he made this statement after observing the cells in cross section only. (See Pl. XXVI, Fig. 9.)

In cross section the cells of the upper epidermis are much broader than tall. The outer walls curve outward and are only slightly thicker than the other walls. The side walls are mostly almost straight; the inner walls curve inward somewhat. The cells of the lower epidermis are irregular in size and shape, as would be expected because of their sinuousness. The outer wall is slightly thicker than the others and is flat in some cells, bulged out in others. The side walls are straight in some cells, bent in others.

The palisade layer is very irregular—one, two or even three cells thick. The two- to three-rowed condition predominates. This layer occupies about half of the thickness of the leaf, and in places single long slender cells reach the entire distance across. Where two or three rows are found the inner rows are irregular in size, shape and position. The walls of almost all of the palisade cells are curved or bent. The cells of the spongy mesophyll appear rounded and fairly small when seen in cross section.

The midrib protrudes sharply on both surfaces (Pl. XXIV, Fig. 24). The vascular bundle is a thick open arc accompanied on the lower side by several bundles of bast fibers, on the upper side by bundles of very thick-walled sclerenchyma cells. The assimilatory tissue extends across the upper surface of the vein, but extends up into the elevated region. Collenchyma cells extend out to the epidermis. Between the assimilatory tissue and the xylem is parenchyma tissue. Below the bundle the entire vein is composed of thick-walled collenchyma tissue. The lateral veins are connected to both surfaces by large collenchyma cells. Below the vascular bundle of these veins large bundles of bast fibers are present.

Large compound crystals were found in all of the types of cells in the cross section of the leaf. They were most numerous around the veins, where there were often six or seven large crystals. Only occasionally were crystals found in either the upper or lower epidermis, more frequently in the lower, a few in the palisade, and fairly numerous in the spongy mesophyll.

SUMMARY OF THE ANATOMY OF THE LEAF BLADE.

The cells of the upper epidermis in all of the nine species studied were broader than tall. In surface view all are polygonal in shape, the sides of the polygon being more or less straight in *atropurpureus*, *europaeus*, *bungeanus*, *europaeus nanus* and *radicans*, curved in *maackii*, *patens* and *alatus*, but quite sinuous in *americanus*. In size the cells of *maackii*, *americanus* and *europaeus nanus* are quite large, those of *atropurpureus*, *europaeus*, *radicans*, and *patens* are intermediate, while those of *bungeanus* and *alatus* are small.

The cells of the lower epidermis are of about the same size as those of the upper in *bungeanus*, *patens* and *alatus*, but are smaller than the upper in all other species. They are also polygonal, but the sides of the polygon are more or less curved in all the species, even quite sinuous in *alatus* and *americanus*.

The side walls of the cells of the upper epidermis were pitted in all the species studied, and those of the lower epidermis in *bungeanus*, *patens*, *americanus*, *europaeus nanus*, *radicans* and *alatus*. The pits were very fine in *europaeus*, *atropurpureus*, *bungeanus*, *maakii* and *alatus*, but were quite prominent in the others. In *europaeus nanus* the pits are very long ovals in shape.

Stomata are found on the lower surface only, they protrude below the lower epidermis very slightly (Pl. XXV, Fig. 11, is typical) and have no distinctive characters excepting in *europaeus nanus*, where all have their long axes more or less parallel with the midrib.

Trichomes are present in only three species; *alatus* has very few on the upper surface above the midrib, *americanus* has them on the upper epidermis above all the larger veins, and *atropurpureus* has them on the lower epidermis excepting along the veins.

The palisade layer is mostly two rows of cells high, although in *americanus* there is only one row, and in *patens* and *europaeus nanus* there are three rows, while in *alatus* it ranges between one, two and three cells in height. The palisade tissue makes up about a third of the thickness of the leaf in *americanus* and *radicans*, about half in *atropurpureus, europaeus, bungeanus, patens, europaeus nanus* and *alatus*, and about two-thirds in *maakii*.

The spongy mesophyll is not distinctive excepting in *alatus*, where the lower layer is composed of very large, flattened, ameba-shaped cells which contain a substance that becomes somewhat salmon-colored when the leaves are cleared in chloral hydrate.

The midrib protrudes both above and below the leaf in all species excepting in *europaeus nanus*, and in *radicans* only a little. In all, the vascular bundle is in the form of an arc, varying only in the extent that the arc is flattened. Bast fibers accompany the vascular bundle in *patens, americanus, radicans* and *alatus*, but are not present in the others. Parenchyma tissue surrounds the vascular bundles in all species excepting *alatus*, where all of the cells are more or less collenchyma. Assimilatory tissue, continuous with the palisade layer of the leaf blade, extends across the midrib in all species excepting *europaeus* and *bungeanus*. The cells of this tissue are rounded instead of elongate in all excepting *europaeus nanus*, where they are very similar to the palisade cells of the mesophyll. A layer of collenchyma tissue is just beneath the epidermis on both the upper and lower surface of the midrib in all species excepting *europaeus nanus*. In *patens* and *radicans* this layer is very thin.

The lateral veins are connected with both upper and lower surfaces by more or less collenchymatous cells in *atropurpureus, europaeus, maackii* and *alatus*, connected to the lower surface by collenchyma but immersed above in *bungeanus* and *americanus*, and completely immersed in *patens, europaeus nanus* and *radicans*, although in *radicans* the sheath around the bundle extends to within about one cell layer of the epidermis. Bast fibers accompany the lateral veins in *patens, europaeus nanus* and *alatus*, but not in the others.

GENERAL SUMMARY.

The descriptions of the stem are based on studies of the fifth or sixth internode from the terminal bud-scale scars of the second year of growth, with supplementary studies of the fourth or fifth internode of the present year's growth.

The outer wall of the epidermis of the stem is rather thick; in only two species, *atropurpureus* and *maackii*, is it less than half of the thickness of the radial diameter of the epidermal cells. The epidermis is quite persistent, being still present in places on stems three to six or seven, or even more, years of age. It is usually but one cell in thickness.

Cork begins its formation in all species in either the first or second year, either as lines or wings at or between the corners of the stem or as small flecks which resemble lenticels scattered promiscuously over the stem. The so-called wings of *atropurpureus*, *europaeus*, and *bungeanus* are not *homologous* with the wings of *alatus*, either in the method of their origin, the general appearance of their cells, or their location on the stem. The cork is formed both from cells cut off from the epidermal cells and from the collenchyma cells beneath the epidermis.

Two cylinders of collenchyma tissue in the outer cortex, separated from each other by a layer of assimilatory tissue, is characteristic of the genus. The outer cylinder is just beneath the epidermis and is composed of colorless cells. The inner may or may not contain some chloroplasts. In some species the two cylinders are connected by collenchyma cells cutting through the assimilatory tissue at the corners of the stem. The inner layer of collenchyma is more variable than the outer in its prominence, the thickness of the cell walls, etc.

The assimilatory tissue present in the cortex of all species is from three to six cells in thickness. The cells in some species are palisade-like in arrangement, in others the long axis of the cells is in the direction of the circumference of the stem.

Between the inner layer of collenchyma and the phloëm is a layer of thin-walled parenchyma cells.

Bundles of bast fibers are found just outside of the assimilatory tissues at the corners of the stem in *atropurpureus* and *europaeus*, and just inside of the assimilatory tissue in *americanus*. Scattered fibers, singly or in groups of two or three, are present just outside of the phloëm in *atropurpureus*, *europaeus*, *bungeanus* and *americanus*.

Tracheal tubes, tracheids, wood fibers and wood parenchyma are all found in the xylem throughout the genus. The wood parenchyma is scarce, the cells are rather short and blunt and thin-walled as compared with the other elements. The borders of the pits of the tracheids are very narrow, making them very difficult to recognize. The cells are about the size and shape of the wood fibers. Solereder states that the tracheids are more abundant than the wood fibers. My observations have led me to believe that just the reverse is true.

The medullary rays may be considered as one cell thick throughout the genus. In some species the long axis of these cells is in the radial direction, in some it is in the vertical direction, and in still others long axes are found in both directions.

The cells of the pith are somewhat elongated vertically and are rounded in cross section. The pith varies with the species. In some it is empty, in others homogeneous and filled with starch, while in others it is heterogeneous, consisting of both living and dead cells.

In the petiole the vascular bundle in all species is an arc, although in *alatus* the xylem is more extended, making the bundle more fan-shaped. The ends of the arc in a few species bend sharply inward. In some species small cylinderical bundles occur just outside of the main bundle. In *atropurpureus* these small bundles have phloëm completely surrounding the xylem, but in the others this is not the case.

Bast fibers were not found in the petioles of any of the species studied. Stenzel reports bast fibers in the petiole of *europaeus*, but after repeated search I failed to find any in the materials used for this study.

Outside of the vascular bundle, the remainder of the petiole is composed of parenchyma and collenchyma cells, the collenchyma being constant for all species in the region just beneath the epidermis. The collenchyma and also the parenchyma cells are pitted in some species.

The upper surface of the petiole varies among the different species, and although the variations are probably dependent on the variations in the length of the petiole itself, they nevertheless seem constant enough in the species to be of systematic value. The margins project above the upper surface in some species, notably so in *atropurpureus*, in others the margins are completely rounded. The upper surface is concave in some species, flat in *europaeus nanus*, and convex in other species. Trichomes are present in *alatus* and *americanus*, although quite rarely in the former.

The epidermal cells of the leaf are always broader than tall. The outer walls are not greatly thickened, and for the most part vary from flat to slightly bulged outward, a variation which, like the variations from straight to curved or sinuous of the side walls, could be dependent on the amount of turgidity of the cells. Only in *europaeus nanus* was the bulging a noticeable natural character of the cells. The side walls of the cells of the upper epidermis in all species studied were pitted, although in some the pits were very fine. Those of the lower epidermis varied in this regard. In some they were pitted, while in others they were not.

Stomata were found on the under side of the leaves only.

Trichomes are present on the under surface of the leaf in *atropurpureus*, and along the veins on the upper surface in *alatus* and *americanus*.

The palisade layer is mostly two-rowed, although in one species it is only one row high and in others it is three rows. For the most part this layer makes up about one-half of the thickness of the leaf, but in *maackii* it occupies two-thirds of the thickness, while in *americanus* and *radicans* it occupies only one-third.

Collenchyma tissue is quite prominent in the midrib of most of the species studied. Bast fibers accompany the midrib and lateral veins in some species, but not in others. The lateral veins connect with both surfaces of the leaf by collenchyma cells in some species; with only one surface, the vein being immersed on the other side, in other species, while in still others it is completely immersed.

Concerning the effects of geographical isolation, it does not seem possible to attribute the variations found between the species studied to this cause, nor do those species found in comparative proximity seem to show greater likenesses to each other than to other species widely separated from them. *Patens* is a native of China and *radicans* a native of Japan and Korea. The former is a recumbent shrub while the latter is a trailing or climbing vine. These two species have a number of systematically important characters in which they do agree. *Alatus*, a native of Japan, Korea, China and Manchuria, stands out distinctly different from all other species. Further, *europaeus*, native of Europe, *atropurpureus* of North America and *maackii* of Korea, Manchuria and China, are much alike in many characters. *Bungeanus*, a native of China and Manchuria, strongly resembles *americanus* in some characters and *europaeus* in others.

KEY TO SPECIES BASED ON THE CHARACTERS OF THE STEM.

I. Collenchymatic cylinders connected at the corners of the stem.
  1. Outer collenchymatic cylinder more than one cell thick.
    A. Bast fibers in the cortex, at the corners very weakly developed cork wings which are soon sloughed off.
      a. Bundles of fibers at the corners just beneath the outer collenchymatic cylinder. Empty pith.
        (1) Assimilatory tissue cells with long axis in tangential direction, medullary-ray cells with long axes in their radial diameter. Outer wall more than half as thick as radial diameter of epidermal cells................*E. europaeus.*

(2) Assimilatory tissue cells with long axis not in tangential direction, medullary ray cells—some with long axis in vertical and others in radial diameter. Outer walls less than half as thick as the radial diameter of the epidermal cells. *E. atropurpureus.*

b. No bundles of bast fibers present. Pith is heterogeneous.

(1) Assimilatory tissue with the long axis of the cells in tangential direction. Medullary-ray cells with long axes in radial direction. Outer wall more than half as thick as radial diameter of epidermal cells.................*E. bungeanus.*

B. No bast fibers in the cortex. No corkwings.

a. Heterogeneous pith.

(1) Assimilatory tissue with long axes of cells in tangential direction. Medullary-ray cells with long axes in vertical direction. Outer wall more than half as thick as the radial diameter of the epidermal cells..............*E. maackii.*

II. Collenchyma cylinders not connected at the corners.

1. Outer collenchyma cylinder more than one cell thick.

A. No bast fibers in the cortex. Well-developed cork wings between the corners of the stem.

a. Empty pith.

(1) Assimilatory tissue cells with long axis in radial diameter. Medullary-ray cells with long axes in their radial direction. Outer wall thicker than the radial diameter of the epidermal cells ....*E. alatus.*

2. Outer collenchyma cylinder one cell thick.

A. Bast fibers in the cortex. Corkwings not present at the corners of stem.

a. Bundles of fibers at the corners of the stem inside of the assimilatory tissue. Heterogeneous pith.

(1) Assimilatory tissue with long axes of the cells in radial diameter. Medullary-ray cells with long axes in vertical direction. Outer wall thicker than radial diameter of the epidermal cells...........................*E. americanus.*

B. No bast fibers in the cortex. Cork wings not present at the corners of the stem.

a. Pith homogeneous. Medullary-ray cells with long axis in vertical direction.

(1) Assimilatory tissue cells with long axis in radial diameter. Outer wall more than half the radial diameter of the epidermal cells.

*. Assimilatory tissue palisadelike entirely around the stem. Epidermis one to two cells thick, cells of fairly uniform shape and size...........................*E. patens.*

†. Assimilatory tissue palisadelike on one side of the stem, irregular on the other. Epidermis one cell thick; large cells occur at short intervals, throwing the epidermis into small peaks............................*E. radicans.*

(2) Assimilatory tissue cells with long axes not in radial diameter. Outer wall more than half the radial diameter of the epidermal cells. Epidermis one cell thick. *E. europaeus nanus.*

KEY TO SPECIES BASED ON THE CHARACTERS OF THE PETIOLE.

I. Margins project above upper level of petiole.
  1. Upper surface of petiole convex.
    A. Collenchyma around outer margin pitted.
      a. Fine pits.
        (1) Vascular bundle an arc, ends bend sharply in.
          *. Accessory vascular bundles (closed bundles) near ends of the arc. Parenchyma outside of the vascular bundle thin-walled with fine pits........... *E. atropurpureus.*
          †. No accessory vascular bundles. Parenchyma outside of the vascular bundle thin-walled with no pits. *E. maackii.*
    B. Collenchyma around outer margin not pitted.
        (1) Vascular bundle an arc, ends bent sharply in.
          *. Accessory vascular bundle (open bundles) near ends of the arc. Parenchyma outside of vascular bundle thin-walled; no pits......................... *E. europaeus.*
        (2) Vascular bundle fan shaped.
          *. No accessory vascular bundles. Very thick-walled collenchyma instead of parenchyma outside of vascular bundle; no pits. Scattered trichomes on upper surface. *E. alatus.*
  2. Upper surface of petiole concave.
    A. Collenchyma around outer margin pitted.
      a. Prominent pits.
        (1) Vascular bundle an arc, ends not bent in.
          *. No accessory bundles. Parenchyma outside of vascular bundle thin-walled, fine pits........... *E. bungeanus.*

II Without margins projecting above upper level of petiole.
  1. Upper surface of petiole convex.
  2. Upper surface of petiole concave.
    A. Collenchyma around outer margin pitted.
      a. Prominent pits.
        (1) Vascular bundle an arc; ends not bent in.
          *. No accessory vascular bundles; parenchyma outside of vascular bundle thick-walled with prominent pits.
            o. Irregularities in epidermis but no trichomes.
              ‡. Arc of the vascular bundle greatly flattened; only the ends are curved. Middle third of the upper surface concave, outer thirds strongly convex. *E. patens.*
              §. Collenchyma layers around outer margin only one to two cells thick.................. *E. radicans.*
            oo. Trichomes present................. *E. americanus.*
  3. Upper surface of petiole flat.
    A. Collenchyma around outer margin pitted.
      a. Prominent pits. (Only the outer and inner walls of these collenchyma cells are thickened.)
        (1) Vascular bundle an arc; ends not bent in.
          *. No accessory bundles. Parenchyma outside of the vascular bundle thin-walled with no pits. *E. europaeus nanus.*

KEY TO SPECIES BASED ON THE CHARACTERS OF THE LEAF BLADE.

I. Bast fibers in the midrib.
  1. Bast fibers in lateral veins.
    A. Lateral veins immersed. Three rows of palisade cells. Side walls of both upper and lower epidermis pitted. No trichomes. *E. patens.*
    B. Lateral veins immersed on upper side; on under side extending through by collenchyma tissue. One row of palisade cells. Side walls of both upper and lower epidermis pitted. Trichomes on upper epidermis above all larger veins...... *E. americanus.*
    C. Lateral veins extending from surface to surface by means of collenchyma tissue. One-two-three rows of irregular palisade cells. Side walls of upper epidermis finely pitted, of lower may or may not be pitted. Scattered trichomes above midrib......*E. alatus.*
  2. No bast fibers in lateral veins.
    A. Lateral veins immersed (collenchyma cells around these veins almost through the leaf above and below.) Two rows of palisade cells. Side walls of both upper and lower epidermis prominently pitted. No trichomes............................*E. radicans.*

II. No bast fibers in midrib or lateral veins.
    A. Lateral veins immersed. Three rows of palisade cells. Side walls of both upper and lower epidermis pitted (long oval pits). No trichomes. No collenchyma in the midrib...*E. europaeus nanus.*
    B. Lateral veins immersed on upper side; on under side extending through by collenchyma tissue. Two rows of palisade cells. Side walls of both upper and lower epidermis finely pitted. No trichomes ....*E. bungeanus.*
    C. Lateral veins extending from surface to surface by means of collenchyma tissue. Two rows of palisade cells. Side walls of upper epidermis pitted, of lower not pitted.
      a. Trichomes on lower surface of the leaf....*E. atropurpureus.*
      b. No trichomes.
        (1) Cells of the upper epidermis very large, of the lower epidermis rather sinuous. Palisade cells very loosely arranged; occupy two-thirds of thickness of leaf. *E. maackii.*
        (2) Cells of upper epidermis moderate in size, of lower epidermis sides rounded but not sinuous. Palisade cells compactly arranged; occupy one-half of thickness of leaf. *E. europaeus.*

ACKNOWLEDGMENT.

This work was done in the botany laboratories of the University of Kansas under the direction of Prof. W. C. Stevens. It is with a deep sense of obligation that I wish to express my sincere appreciation to Professor Stevens for many helpful suggestions and for his continuous interest throughout the time that the work was in progress.

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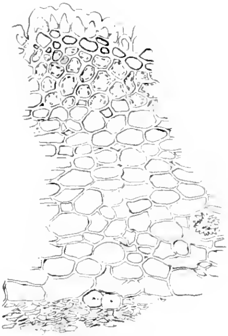
PLATE XXII.

FIGS. 1 TO 9.—Cross sections through the cortex of two-year-old stems.
1, *E. atropurpureus*; 2, *europaeus*; 3, *E. bungeanus*; 4, *E. maackii*; 5, *E. patens*; 6, *E. americanus*; 7, *E. europaeus nanus*; 8, *E. radicans*; 9, *alatus*.

PLATE XXII.



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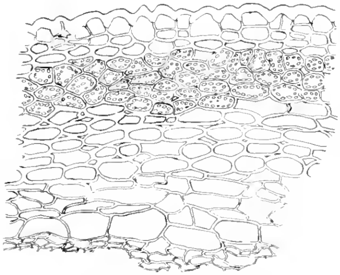

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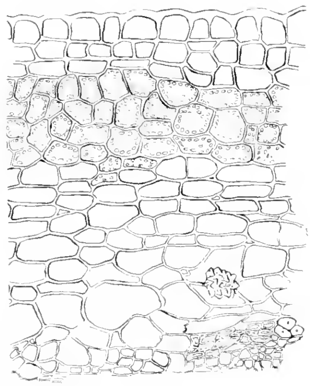

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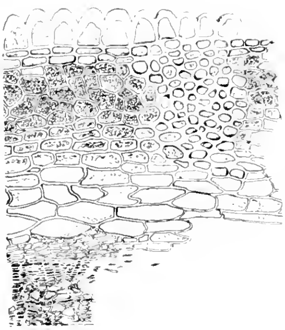

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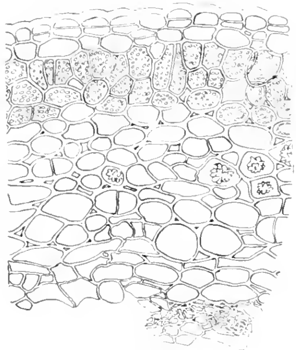

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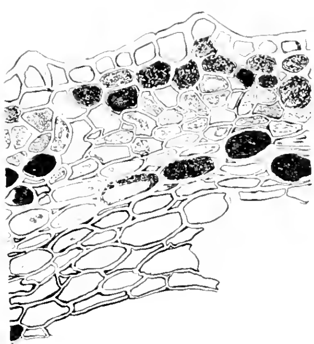

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PLATE XXIII.

FIGS. 1 TO 9.—Semidiagrammatic cross sections through one-year-old stem: 1, *E. atropurpureus*; 2, *E. europæus*; 3, *E. bungeanus*; 4, *E. maackii*; 5, *E patens*; 6, *E. americanus*; 7, *E. europæus nanus*; 8, *E. radicans*; 9, *E. alatus*.

FIG. 10.—*E. atropurpureus*. Origin of bast fibers in cortex of two-year-old stem.

FIG. 11.—*E. atropurpureus*. Collenchymatic origin of cork.

FIG. 12.—*E. atropurpureus*. Cork formation cutting out bundle of bast fibers at corner of stem.

FIG. 13.—E. *atropurpureus*. Drawing of the stem to show the location of the first cork lines.

FIG. 14.—*E. patens*. To show enlarged collenchymatic cell at A.

ABBREVIATIONS ON PLATE.

B, cork; *C*, collenchyma; *X*, assimilatory tissue; *P*, parenchyma (thin-walled).

PLATE XXIII.

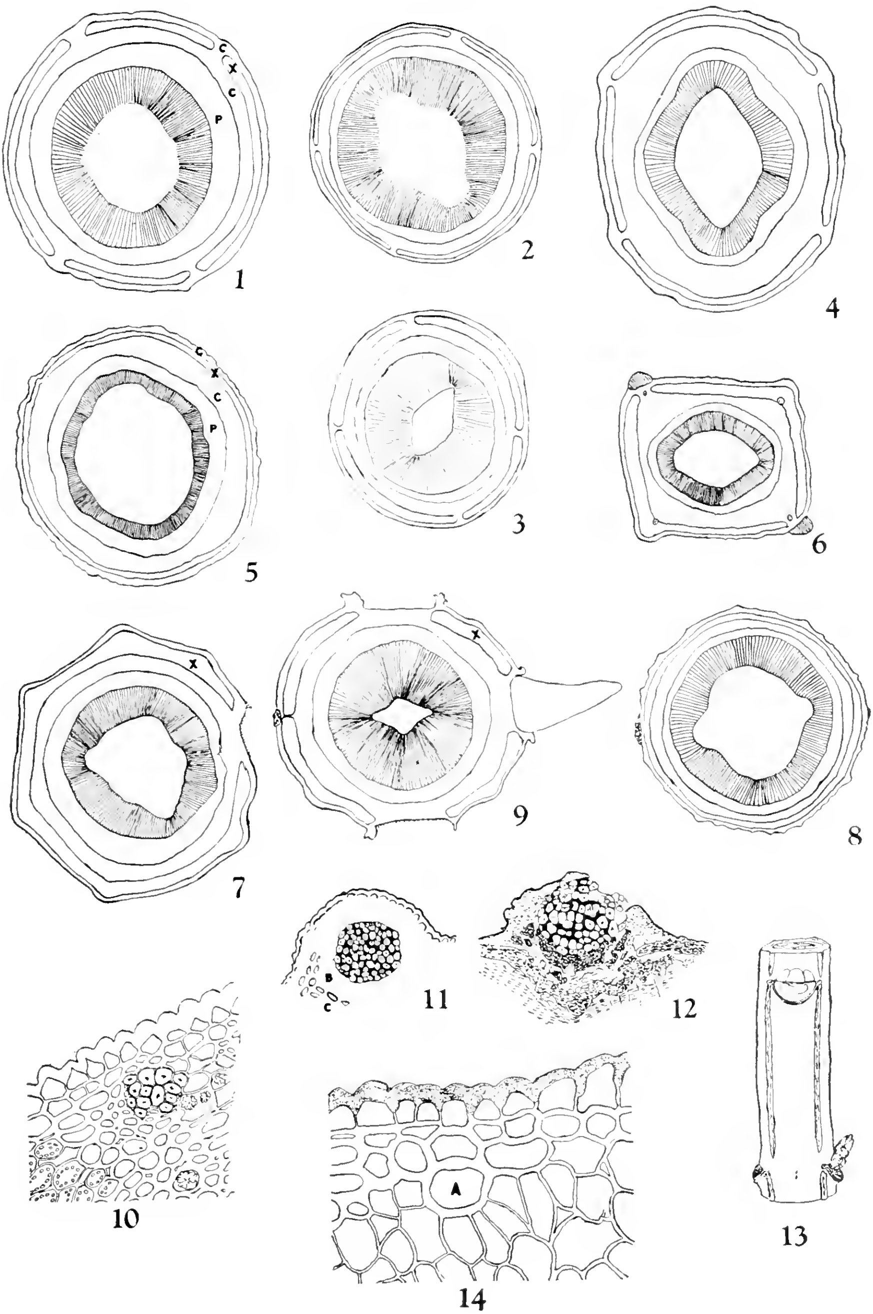


PLATE XXIV.

FIG. 1.—*E. americanus.* Collenchymatic origin of cork.

FIG. 2.—*E. europæus nanus.* Epidermal origin of cork in one of the lenticel-like cork warts.

FIG. 3.—*E. europæus nanus.* Cross section of thick-walled parenchyma tubes just outside of the phloëm.

FIG. 4.—*E. alatus.* Epidermal origin of cork wing.

FIG. 5.—*E. alatus.* Cork cells from the wing.

FIGS. 6 TO 15.—Portions of medullary rays drawn from radial sections:

6, *E. atropurpureus;* 7, *E. europæus;* 8, *E. bungeanus;* 9, *E. maackii;* 10, *E. patens;* 11, *E. americanus;* 12, *E. europæus nanus;* 13, *E. europæus nanus*, tangential section; 14, *E. radicans;* 15, *E. alatus.*

FIGS. 16 TO 24.—Semidiagrammatic cross sections through the midrib of the leaves.

16, *E. atropurpureus;* 17, *E. europæus;* 18, *E. bungeanus;* 19, *E. maackii,* 20, *E. patens;* 21, *E. americanus;* 22, *E. europæus nanus;* 23, *E. radicans;* 24, *E. alatus.*

ABBREVIATIONS ON PLATE.

C, collenchyma; *B,* bast fibers; *X,* assimilatory tissue; *S,* sclerenchyma cells; *P.* thin-walled parenchyma.

PLATE XXIV.

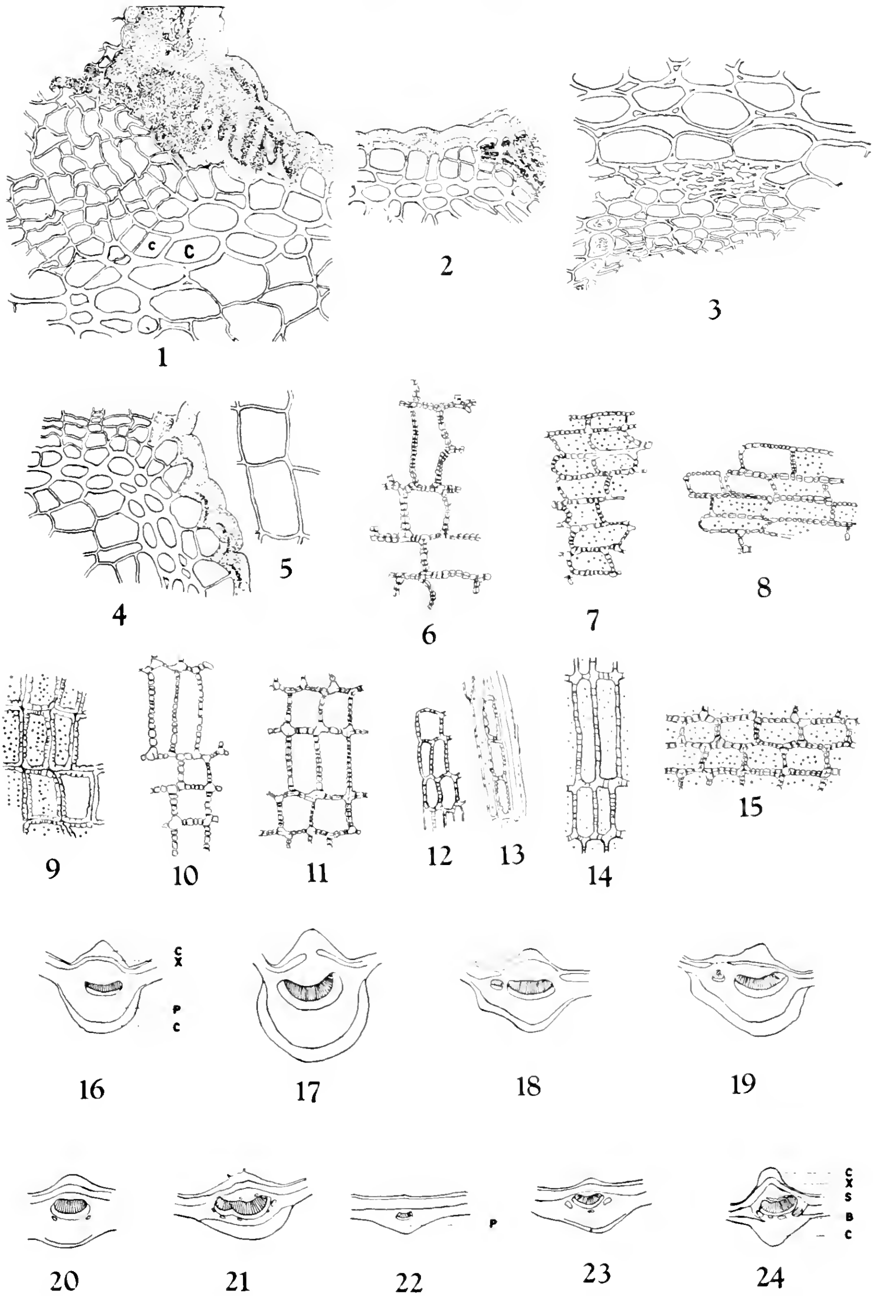


PLATE XXV.

Surface views of the upper and the lower epidermis of the leaves. The palisade cells are shown beneath the upper epidermis.

FIGS. 1 AND 2.—*E. atropurpureus.*

FIGS. 3 AND 4.—*E. europæus.*

FIGS. 5 AND 6.—*E. bungeanus.*

FIGS. 7 AND 8.—*E. maackii.*

FIGS. 9 AND 10.—*E. patens.*

FIG. 11.—Stoma from *E. patens.*

FIGS. 12 AND 13.—*E. americanus.*

FIG. 14.—Trichome from the epidermis of *E. americanus.*

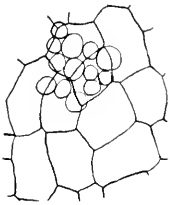
FIGS. 15 AND 16.—*E. europæus nanus.*

FIGS 17 AND 18.—*E. radicans.*

FIGS. 19 AND 20.—*E. alatus.*

FIG. 21.—*E. alatus.* Lower layer of spongy mesophyll as seen through the epidermis.

PLATE XXV.



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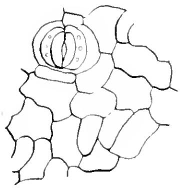

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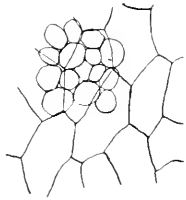

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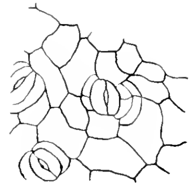

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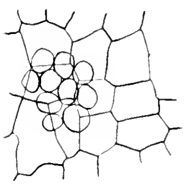

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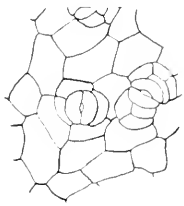

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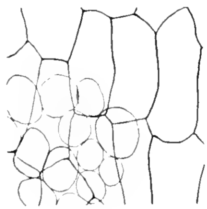

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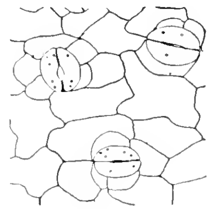

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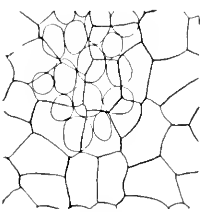

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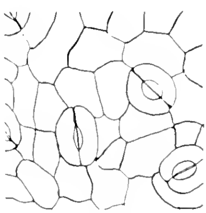

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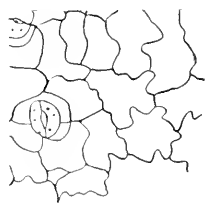

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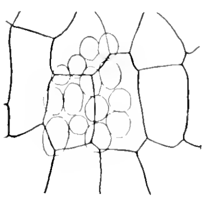

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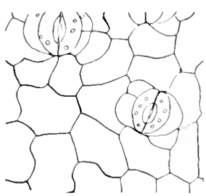

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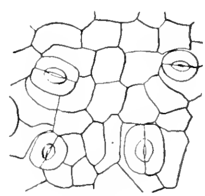

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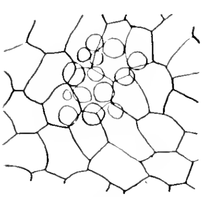

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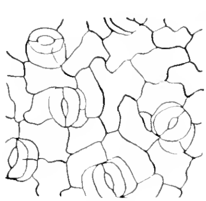

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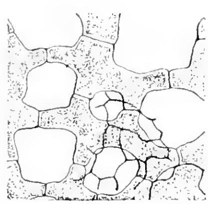

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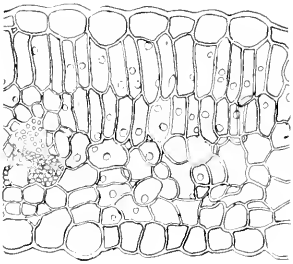
PLATE XXVI.

Cross sections through the leaves

FIG. 1.—E. *atropurpureus.*
FIG. 2.—*E. europæus.*
FIG. 3.—*E. bungeanus.*
FIG. 4.—*E. maackii.*
FIG. 5.—*E. patens.*
FIG. 6.—*E. americanus*
FIG. 7.—*E. europæus nanus*
FIG. 8.—*E. radicans.*
FIG. 9.—*E. alatus.*

PLATE XXVI.



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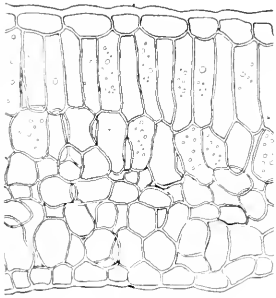

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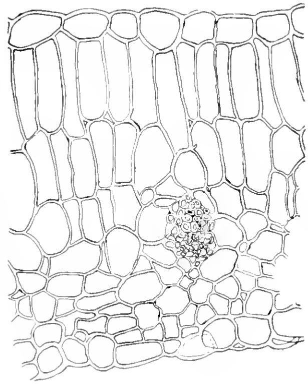

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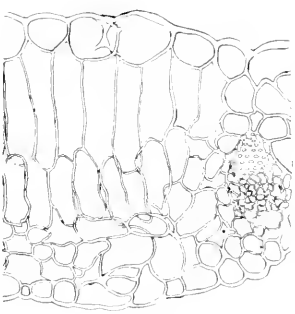

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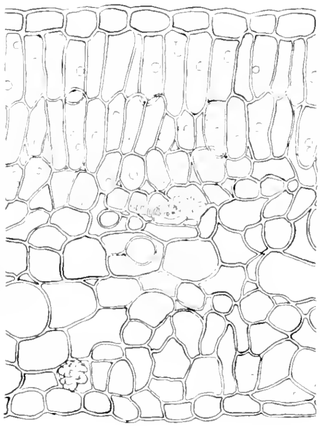

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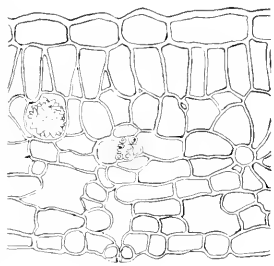

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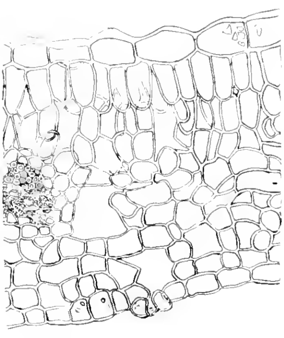

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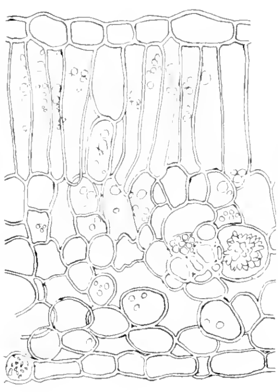

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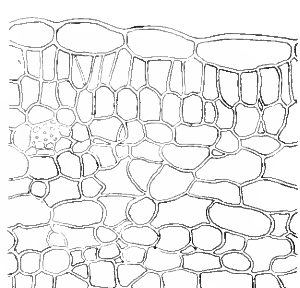

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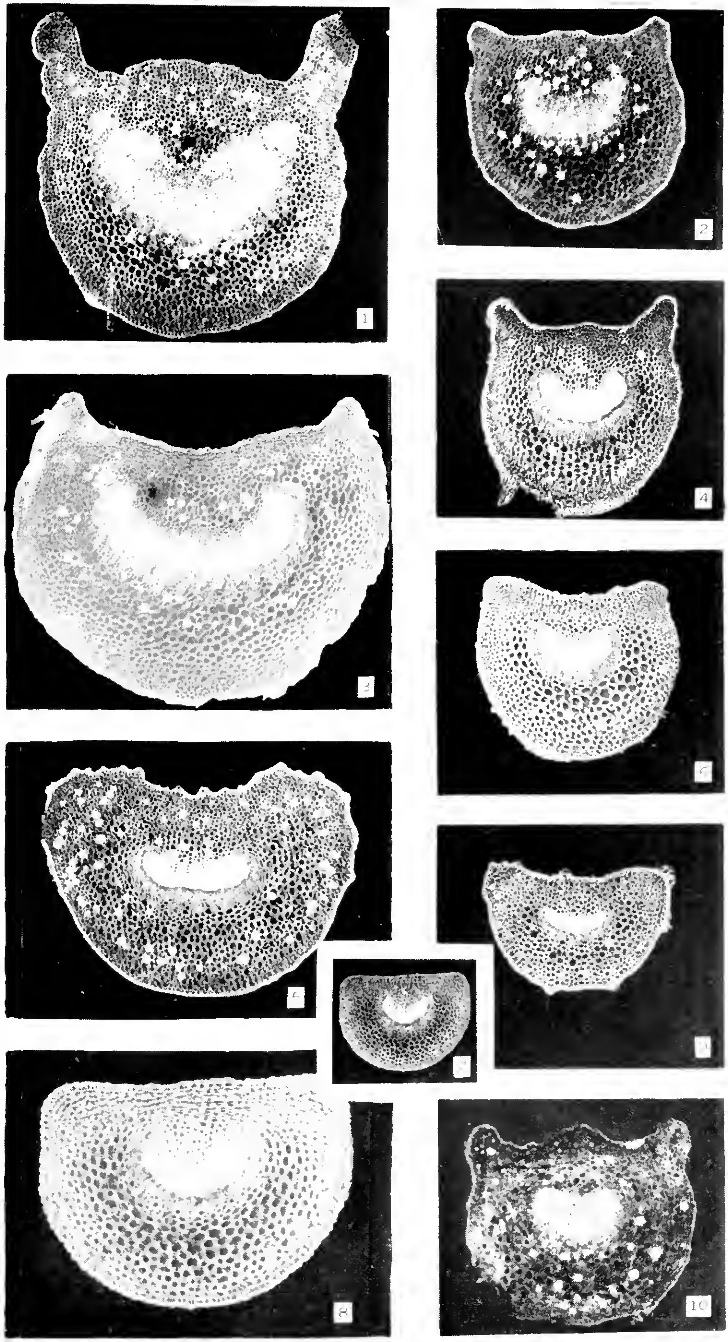
PLATE XXVII.

Microphotographs of petioles.

FIG. 1.—*E. atropurpureus.*
FIG. 2.—*E. europæus.*
FIG. 3.—*E. bungeanus.*
FIG. 4.—*E. maackii.*
FIG. 5.—*E. patens.*
FIG. 6.—*E. americanus.*
FIG. 7.—*E. europæus nans.*
FIG. 8.—*E. europæus nanus,* enlarged.
FIG. 9.—*E. radicans*
FIG. 10.—*E. alatus.*

PLATE XXVII.



THE UNIVERSITY OF KANSAS
SCIENCE BULLETIN

Vol. XIX] July, 1930 [No. 12

Metachaos granulosa in Kansas; Third Recorded Appearance of Gruber's Rare Ameba.

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Department of Zoölogy, University of Kansas.

I.

THIS ameba, whose first appearance was recorded in Germany by Gruber in "Studien über Amöben," 1885, was again observed and described in France by Penard, 1902. It has been found for the third time, in Kansas, in fresh laboratory cultures which were set up at the State University in the early part of June.

1. Gruber (*2*) described many species of amebas. He treated, in great detail, "*Amœba proteus*" (*Polychaos dubia?*) and several other species which he called "prima," "secunda" "tertia," etc. Then he mentioned a collection of smaller amebas with which he did not greatly concern himself, but which were of interest. In this collection there were two kinds of amebas which he watched as long as he could keep them alive, and then he recorded the fact that they were very different types. One he called (*Amœba*) *spumosa;* the other (*Amœba*) *granulosa.*

He writes that *granulosa* is about 0.03 mm. in thickness. The body is filled with a great number of clear refractive elliptic granules through which a vesicular nucleus may be seen. There is a single contractile vacuole and some food bodies.

In 1885 Gruber complained because too many species of amebas had been inadequately described. He said that it was hard to classify amebas because no secure basis for classification had been arranged. Nevertheless, he recognized that there were different kinds of amebas, and perhaps he realized that these maintained their individuality of structure, for he speaks of "Körper Merkmale" and of characteristic granules. At any rate, he did not hesitate to name a *number* of *new species*, among them (*A.*) *granulosa*, when markedly different organisms appeared in his cultures. Plate XXVIII, figure 1, is a reproduction of his drawing of *granulosa*.

2. Seventeen years later, Penard described (*A.*) *granulosa* Gruber in much greater detail. His scientific observations and illustrations (Pl. XXVIII, figs. 2-4) are a great addition to the meager remarks of Gruber. Penard, following the lead of Gruber, characterizes the species by means of the nucleus and the immense number of small crystals which fill the body—"d'une quantite immense de petits grains reguliers elliptiques, qui remplissent le corps presque completement et paraissent de nature siliceuse" (Pl. XXVIII, fig. 2). He says that the crystals are always regular and pointed at both ends. At first they seem to be simple ellipses, but on close examination it is evident that they are bicuspid and that the edges are rounded off. He notes the high refractive index, as well as the color: "They are a brilliant yellow, but give the body of the ameba a cast of dark violet when they are examined under high power.

Some time later Penard found more amebas in a culture which he obtained from a marsh mear Gaillard. These measured from 300 µ to 500 µ and were at first grouped with "*A. proteus*" (*P. dubia*). Later he decided that they approached nearer to (*A.*) *granulosa*, because they were filled with "de petits grains bicuspides."

Mention is made of a contractile vacuole which is always seen at the posterior end of the organism. The vesicular spherical nucleus is generally about 50 µ (Pl. XXVIII, fig. 14). It has a clear and strong membrane and the chromatin material, consisting of small grains, is arranged in a layer immediately under the membrane. The illustration of the nucleus (Pl. XXVIII, fig. 4) is doubtlessly a polar view, not an optical section.

The movement, generally very rapid, is compared to that of "*A. proteus*." Large pseudopods are produced on various parts of the body, and the endoplasm, with its inclusions, quickly penetrates these. The length of the organism, when still, is 300 µ. When flowing it may measure 500 µ. Extremely fine, dustlike granules are mentioned among the inclusions of the protoplasm; also brilliant bodies, yellow or greenish, globular in form or variable. Penard says that these may play the part of spore bodies.

3. Cash (*1*) cites a *granulosa* as a variety of "*A. proteus*," but it is evident from his figures that he is confusing *Chaos diffluens* with (*A.*) *granulosa* Gruber. The shape of the nucleus as well as the pronounced mulberry-shaped caudal extremity, as Cash has them,

are not characteristic of *granulosa*. Cash refers to Leidy's figure (*3*) in confirmation of his assertion, but from Schaeffer's ('20) research and differentiation (*5*) it is evident that both Cash and Leidy were dealing with *Chaos diffluens*, and probably also with *Metachaos discoides*.

II.

1. There is some question as regards the exact source of the local culture in which *granulosa* appeared at the University of Kansas. They were first observed in two watch glasses of green scum which came from the entomology greenhouse. Here a slow stream of water flows through a series of cement water basins in which blue-green algæ are growing. Scum and debris were collected and brought to the laboratory and distributed in culture dishes and watch glasses, which were half filled with hydrant water. In about three weeks there was a score of unfamiliar amebas in two of the watch glasses. After they were studied for some time it was concluded that they were the species which Penard called (*A.*) *granulosa* Gruber.

2. (*a*) This *Metachaos granulosa* most closely resembles *M. discoides*. It is from 200 μ to 250 μ in length and is densely filled with refractive granules, which often give the body a pronounced cerulean tint. It is fast-moving, a rate of 250 μ per minute having often been observed. (Pl. XXVIII, figs. 7, 8.) Very few lateral pseudopods are formed during locomotion. Wave after wave of clear hyaline ectoplasm is thrown out at the anterior end. The granular endoplasm follows. The manner of streaming is similar to that observed in the large amebas, *Chaos diffluens* and *Metachaos discoides*, especially the latter. The hyaline margin of ectoplasm is wider at the anterior end than that observed in closely related species. The hyaline margin or band becomes narrower toward the posterior end of the amebas, where it is hardly perceptible. The ectoplasmic surface is smooth, as in *discoides*. The large, well-defined contractile vacuole, pulsating about every 3.5 minutes (temp. 26° C.) is always at the extreme posterior part of the cell. A uroid is not present and the ameba never carries debris. A very common body form is limned by means of a posterior and lateral pseudopod which is retained for long periods (Pl. XXVIII, figs. 5, 6).

(*b*) The crystals, mentioned by Gruber and described by Penard, are a *nominal* outstanding characteristic. As mentioned before, they are so closely packed that when the light is diminished and the amebas are observed under low power the crystals cause the amebas to appear of a cerulean tint. The shape of most of the crystals is similar to those found in *discoides*. A polar view shows plainly the square base of its pyramidal form, while a side view shows the bipyramidal form. Together with these are found the bipyramidal crystals "pointed on both ends" (Pl. XXVIII, figs. 9, 10). An estimate of the percentage of each was not obtained, but there seemed to be more of the truncated variety.

Intermingled with the crystals are numerous—perhaps 200—so-called excretion spheres. Many are over 1 μ in diameter. Large food vacuoles are not present. No definitely recognized food masses were seen in any of the specimens.

(*c*) In the last analysis, it is the nucleus which most sharply separates *granulosa* from *discoides* and other species. To quote Schaeffer ('20), "No two species are alike in any respect whatsoever" (*5*). It does not require the expert's trained eye to see the difference in the nuclei of *discoides* and *granulosa* (see Pl. XXVIII, figs. 12, 14). *Metachaos granulosa* has a spherical nucleus; it is never a biconcave disc. The diameter of the nucleus is about 25 μ. A clear membrane surrounds the chromatin material, which appears as a single layer of small spheres at a uniform depth. A polar view of the nucleus and an optical section are shown in (Pl. XVIII, fig. 14.)

III.

These descriptions are based on somewhat meager data, for the culture was not successfully established; hence the records cannot be enlarged upon or accurately checked. Extensive research has been made on cultures similar to the ones first prepared, but *granulosa* amebas were not again discovered. It is just barely possible that the amebas were introduced from other local cultures, for the glassware was not sterilized. It has, nevertheless, been thought worth while to record the appearance of this interesting ameba, for when once it is seen and examined the distinctive characteristics are such that it is recognized as *granulosa*. It is probable, too, that there are more of these amebas in the Kansas distribution and these data may call attention to them.

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EXPLANATION OF PLATE XXVIII.

FIG. 1.—Gruber's *Amœba granulosa.*

FIGS. 2 TO 4.—Penard's illustrations, "*Amœba granulosa.*"

2. Animal in motion.
3. Details of the protoplasm.
4. Nucleus.

FIGS. 5 TO 8.—Laboratory specimens.

5. An odd specimen, the anterior half filled with excretion spheres. the posterior part crowded with crystals.
6. Normal specimen.
7, 8. Paths of locomotion.

FIGS. 9 AND 10. Crystals contained in the cytoplasm.

9. Truncated bipyramidal crystals, showing polar views and side views.
10. Bipyramidal crystals.

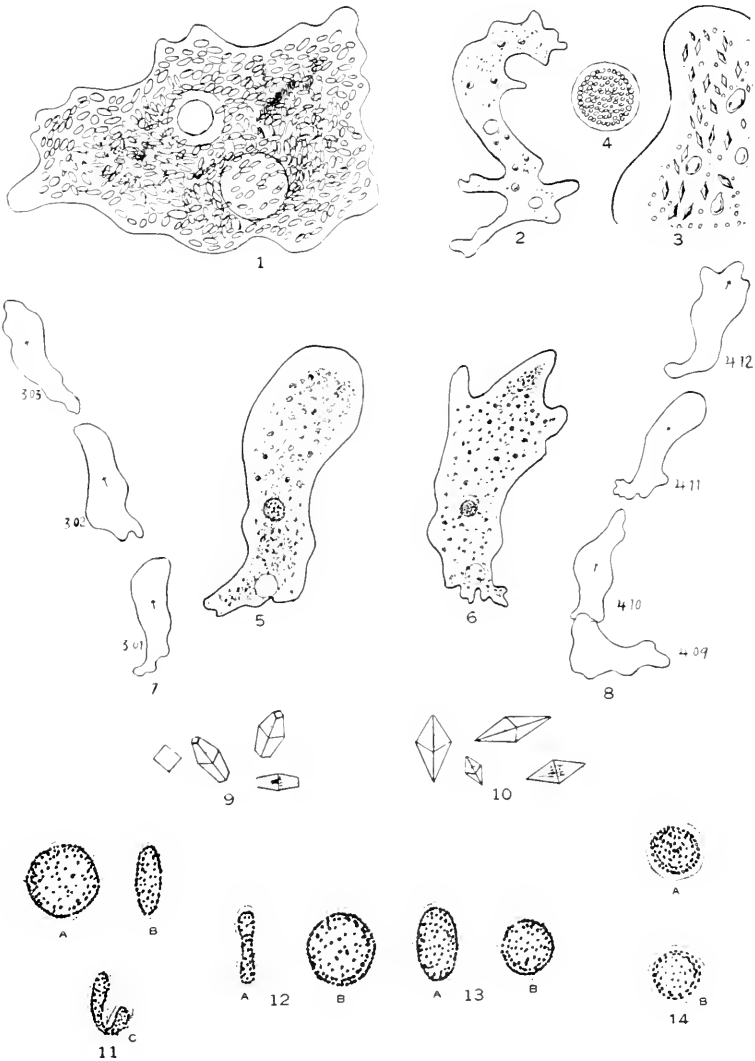
FIGS. 11 TO 14. Comparative table of nuclei.

11. *Chaos diffluens:* A, Polar view of the nucleus. B, Equatorial view of the discoid nucleus. C, Equatorial view of a folded or crushed nucleus.
12. *Metachaos discoides:* A, Equatorial view of nucleus. B, Polar view.
13. *Polychaos dubia:* A, Equatorial view of ovoid nucleus. B, Polar vief of same.
14. *Metachaos granulosa:* A, Polar view. B, Optical section.

Dimensions in microns: 11-B, 46 x 12; 12-A, 40 x 18; 13-A, 40 x 32; 14-A, 25 x 25.

(Figures 11 to 13 after Schaeffer.)

PLATE XXVIII.



THE UNIVERSITY OF KANSAS
SCIENCE BULLETIN

VOL. XIX] JULY, 1930 [NO. 13

A Skull of *Nothocyon* from the John Day Oligocene.

E. RAYMOND HALL and HANDEL T. MARTIN, Museum of Vertebrate Paleontology, University of Kansas.

AMONG verterbrate materials collected in the John Day beds of Oregon by a party from the University of Kansas in the summer of 1905 is a skull of one of the smaller species of *Nothocyon* which provides the upper and lower teeth associated. Inasmuch as this specimen seems to correct a misconception of long standing regarding the nature of the lower teeth of *Nothocyon lemur* (Cope), and because there is no immediate prospect of the collection as a whole being reported on, although it represents a fauna which just now claims the active attention of several paleontologists, we deem it proper to place this specimen on record and call attention to certain of its structural features.

The specimen (No. 600, Univ. Kan. Mus. Vert. Paleo.) is from John Day beds, Oligocene, Haystack Valley, below Turtle Cove, Oregon. Collected in summer of 1905 by Handel T. Martin, original field No. 113. The nature of the specimen is shown on Plate XXIX.

Without presuming to advance, at this time, any fixed ideas about the proper constitution of the genus *Nothocyon*, it is our opinion that several American species commonly referred to the Old World genus *Cynodictis* might better be placed in *Nothocyon*, and that assuredly there is confusion about the differential characters of certain species of the genus *Nothocyon* as they are at present recognized in the literature. Some of this confusion has clearly resulted from the lack of associated upper and lower teeth. *Nothocyon oregonensis* (Merriam, Univ. Calif. Publ. Dept. Geol. Sci., vol. 5, p. 11) although resembling *Nothocyon lemur* and *Nothocyon latidens* in several respects, is said to lack the posteroexternal tubercle at the base of the protoconid of M_1. Cope, as pointed out by Merriam (*loc. cit.*, p. 12), has referred disassociated lower jaws bearing teeth of this nature to *Galecynus lemur* and has regarded the postero-external cusp at the base of the protoconid of M_1 as distinguishing *Galecynus latidens* from *G. lemur*. The associated upper and lower teeth here described do not bear out this supposed distinction and seem to verify Merriam's (*loc. cit.*, pp. 11-16) suspicion, which is, essentially, that *Nothocyon lemur*, as well as *N. latidens*, possesses a posteroexternal tubercle at the base of the protoconid and that the lower jaws referred by Cope to *Galecynus lemur* really belong to Merriam's (*loc. cit.*, p. 11) later-described *Cynodictis oregonensis*. In any event, the cranium (No. 600, U. K. M. V. P.), seems to answer best in size and proportions (see measurements below) to the description of *Nothocyon lemur* (Cope) and at the same time definitely shows the posteroexternal tubercle at the base of the protoconid of M_1 to be present.

This immediately raises a question as to the validity of the species *N. latidens*. In the absence of the necessary material we do not attempt to settle this point, but would suggest that several other of the differential characters ascribed by Cope to *N. latidens* and *N. lemur*, if constant, are sufficient to distinguish the two species, one from the other. Also, it occurs to us that the great variation in size of individuals of *Nothocyon* may have a corollary in the structurally similar, recent genus *Vulpes*. Of this genus two species (one of the *velox* or kit-fox group and one of the *fulvus* or red-fox group) occur together at certain localities. The variation in size between skulls of the two sexes, of at least some races of the red fox, is, as regards actual mass, constantly greater than that between skulls of the same sex of two distinct species of the genus *Vulpes*. Indeed, the skull of the female is scarcely one-half as large as that of the male in some races of the red fox. It is, to say the least, possible that a similar state of affairs existed in the genus *Nothocyon* of the John Day region in Oligocene time, and this possibility, we suggest, should be carefully investigated by anyone undertaking a critical, systematic analysis of the group. In this connection we might point out, also, that constant, striking differences in proportions of the skull, in addition to differences in actual size, exist between skulls of the two sexes of certain species of *Fissipedia*. *Mustela noveboracensis* of the eastern United States furnishes a case in point.

The specimen here described has a relatively short rostrum, well-developed postorbital processes, and in general size only slightly exceeds No. 10208, U. C. C. V. P., which Merriam (*loc. cit.*, p. 14, pl. 2) has referred to *Nothocyon lemur*. Although the brain case is crushed, the temporal ridges appear to have been curved about as in No. 10208. P^3 has a well-developed posterior accessory cusp. P_3 and P_4 each, likewise, has a posterior, accessory cusp and in addition well-developed anterior and posterior basal tubercles. P_2 is not preserved. M_1 has a well-developed cingulum extending along the entire lateral base of the tooth, except for a short space at the base of the protoconid. The hypoconid is developed as an antero-posterior ridge. The entoconid is longer than wide, but has a tendency to be conical. Immediately anterior to the entoconid and just posterior to the metaconid there is a well-developed conical cusp on M_1. Although the talonid of this same tooth may be spoken of as basined, the posterior margin, between the entoconid and hypoconid, is lowest and gives it a troughlike, rather than a strictly basin-like, structure.

MEASUREMENTS OF *Nothocyon lemur* (COPE).

(No. 600, Univ. Kan. Mus. Vert. Paleo.)

Condylobasal length	73±
Width across palate at P^4	24±
Length of upper tooth row, C^1—M^2	32
P^2, length x breadth	3.9 x 1.6
P^3, length x breadth	5.2 x 2.5
P^4, length x breadth	6.7 x 4.7
M^1, length x breadth	5.3 x 6.3
M^2, length x breadth	3.1 x 4.5
M_2, length x breadth	4.3 x 3.0
M_1, length x breadth	6.9 x 3.4
P_4, length x breadth	5.4 x 2.6
P_3, length x breadth	4.5 x 2.0

PLATE XXIX.

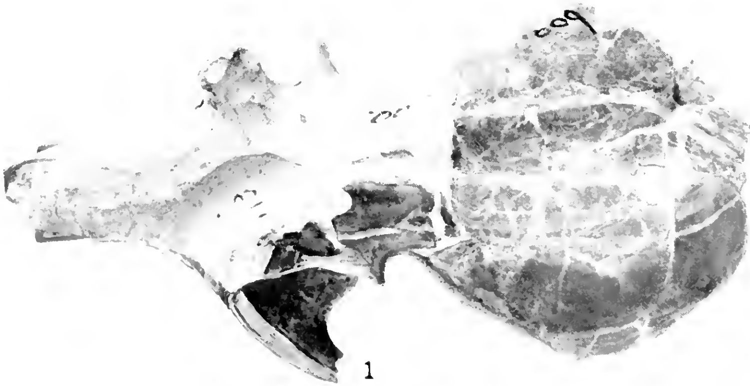
FIGS. 1 to 3.—Photographs, retouched, of the skull of *Nothocyon lemur* (Cope), No. 600, Univ. Kan. Mus. Vert. Paleo.; John Day beds, Oligocene, Haystack Valley, below Turtle Cove, Oregon. Collected in summer of 1905 by Handel T. Martin, original field No. 113. All figures 1.5 x natural size.

Figs. 1.—Dorsal view of skull.

2.—Lateral view of right lower jaw.

3.—Ventral view of skull.

PLATE XXIX.



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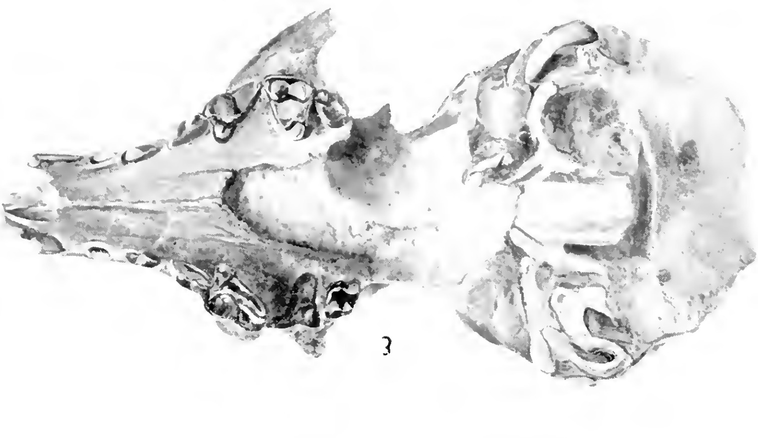

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THE UNIVERSITY OF KANSAS
SCIENCE BULLETIN

VOL. XIX] JULY, 1930 [NO. 14

An Addition to the Urodele Fauna of Kansas from the Lower Pliocene.

L. A. ADAMS and H. T. MARTIN, Museum of Vertebrate Paleontology, University of Kansas.

FOR several years expeditions from the Museum of Vertebrate Paleontology have collected in a rich field opened in a sand quarry in Sherman county, Kansas, where a large number of rare specimens was obtained. This fine, silty sand layer of Pliocene age consists of a stratum about twenty feet below the surface of the surrounding prairie. It is rich in animals of the period, and to date, after three years of research, has yielded the following vertebrates:

PERISSODACTYLA: *Aphelops, Parahippus, Merychippus, Pliohippus.*
ARTIODACTYLA: *Prosthenops (serus?), Procamelus, Pliauchenia; Prosthenops crassigenis, Dromomeryx. Blastomeryx.*
RODENTIA: *Mylogaulus* sp., *Sciurus* sp.
CARNIVORA:
Canidæ: *Ælurodon, Borophagus cyonoides.*
Mustelidæ: *Brachypsalis marshalli.*
Felidæ: *Pseudalurus, Machærodus.*
CHELONIA: Species not determined.
AVES: Fragments not determined.
REPTILIA: Fragments not determined.
AMPHIBIA: Anura not determined; Urodeles: *Plioambystoma kansense*, new genus, new species.

This material consists of disarticulated skeletons that have been deposited in the Pliocene sands and then covered, to remain until discovered by the three summer expeditions. Along with the larger material, smaller bones were discovered, and to secure these fine-meshed sieves were used, by means of which a mass of material, representing more than a hundred skeletons of the urodele amphibian, was secured, consisting entirely of the one species of urodele, with some fragments of another amphibian, an anuran, which has not been described because of the scantiness of the material of this particular form. It is to be hoped that other expeditions will uncover more of this fauna and that the entire amphibian population can be determined for this early period of the Pliocene.

From the conditions under which they were found it seems probable that these adult amphibia were deposited in an eddy of an early Pliocene river, covered with silt and sand, and then to have remained undisturbed for some thirty million years, until their recovery a few years ago.

Plioambystoma kansense is quite similar to the modern form, *Ambystoma tigrinum* in size and probably resembled it in color, since all of the Ambystomidæ have a somewhat similar type of coloration. In life it was about eight inches long, and probably lived much as do the Ambystomidæ of the present day.

The problems presented by this material are numerous: (1) To what group does it belong? The skeletal parts are clearly those of an amphibian with biconcave vertebræ and a skull typical of the urodeles. (2) Does the material represent one or more genera or species? Since there is ample material, comparison can be made of a series of 100 or more elements, and it is shown that the animals were all of the same type, with identical proportions, shape and bone markings. (3) To what particular group does it belong? This is a question of comparison with known modern forms, until a decision can be made. It was found that it could be included in the family Ambystomidæ and was close to the genus *Ambystoma*. The family, in so far as it is known at present, is an American product, with one representative, strangely enough, found in Siam. The total number of species known at present is about twelve.

While close to the genus *Ambystoma* in relationship, the new genus is much older and much more primitive in its palatal region, and for this reason a new genus was created, *Plioambystoma*.

The roof of the mouth in the Ambystomidæ is very typical, with the vomers and palatines united to form a vomero-palatine, while the pterygoid is retracted and not in contact with these anterior skull elements at all. However, in the axolotl stage the palate is different, as the pterygoids then extend anteriorly and are in contact with the palatines, and perform the function of bracing the quadrate by connecting it with the anterior region of the palate through the connection with the palatines. This ancestral condition is retained in *Plioambystoma*, as it shows the palatines attached to the pterygoid and extending forward to connect with the vomers, thus forming a brace. This stabilizes the weak connection of the quadrate, which is supported only by the thin squamosal and needs the additional attachments to make it solid for the articulation of the mandibles. No vomers were found in the material, so their condition is unknown, but it is suggested that their condition was somewhat as in the axolotl. In a series of fifty-one pterygoids studied but three were unbroken and joined to the palatine, thirty-one showed clearly where the palatine had broken off, while the rest were so broken as to offer no evidence either way. While there is variability in the pterygoid, the form is fairly definite and shows a number of differences separating it from *Ambystoma*. In perfect specimens teeth were found in position on the palatines, and from their remaining bases the number could be determined as being 6 to 8.

The other elements of the skull were compared and a number of significant differences were found separating the new genus from *Ambystoma*. The maxillæ are decidedly different in proportion and in the number of teeth. Premaxillæ, maxillæ, palatines and dentaries were found with a few teeth still in place. These teeth are different in the average number on the elements, and also different in shape, those of *Ambystoma* being cone-shaped while those of *Plioambystoma* are knobbed at the end and generally have a small cleft at the tip.

Among the interesting discoveries in the material were a number of stapes imbedded in the sand-filled otic capsule, loose in the sand, and anchylosed to the lip of the foramen vestibuli. In all, eight stapes were recovered. A few skeletal parts were found with natural articulations, among them a quadrate with a pterygoid attached, a few otic capsules with the parietals anchylosed in position and a few cases of attached otic capsules. In one specimen three vertebræ were found anchylosed together. These had evidently been crushed and repaired, possibly showing the results of the bite of some preying animal.

The relation of this early Pliocene form to the modern *Ambystoma* can only be conjectured, but it is highly probable that the former is an ancestral group in which the palatal relations were still retained in a simple condition.

All of the skeletal elements of the skull were found with the exception of the nasals and vomers. In the axial skeleton nothing was missing but the carpal and tarsal bones of the wrist and ankle. A complete description of the genus and species appeared in the *American Journal of Science*, vol. XVII, No. 102, pp. 504-520, June, 1929.

PLATE XXX.

UPPER.

Quarry in Sherman county, Kansas, where the urodele material was obtained. X marks the location of the deposit.

LOWER.

View showing the process of sifting the sands for the small urodele material. Mr. Martin and assistants.

PLATE XXX.

PLATE XXXI.

All of the skeletal elements of *Plioambystoma kansasense*, natural size

1. Premaxilla, right, dorsal.
2. Parietal, right, dorsal.
3. Frontal, right, dorsal.
4. Squamosal, right, ventral.
5. Pterygoid, left, dorsal.
6. Maxilla, right, inner face.
7. Orbitosphenoid, right, lateral face.
8. Quadrate, right, inner face.
9. Prefrontal, right, ventral face.
10. Parasphenoid, dorsal face.
11. Axis, anterior face.
12. Body vertebra, ventral.
13. Sacral vertebra, dorsal.
14. Otic capsule, left, ventral.
15. Caudal, lateral.
16. Second basibranchial, dorsal.
17. Ilium, dorsal.
18. Ischium, right, lateral.
19. Scapulo-coracoid, left, lateral.
20. Humerus, left.
21. Ulna, left, dorsal.
22. Radius, left.
23. Femur, right, mesial.
24. Tibia, right, dorsal.
25. Fibula, left, ventral
26. Dentary.
27. Rib, left.
28. Rib, left.
29. Rib, left.
30. Rib, right.
31. Rib, right.
32. Rib, right sacral.

PLATE XXXI.

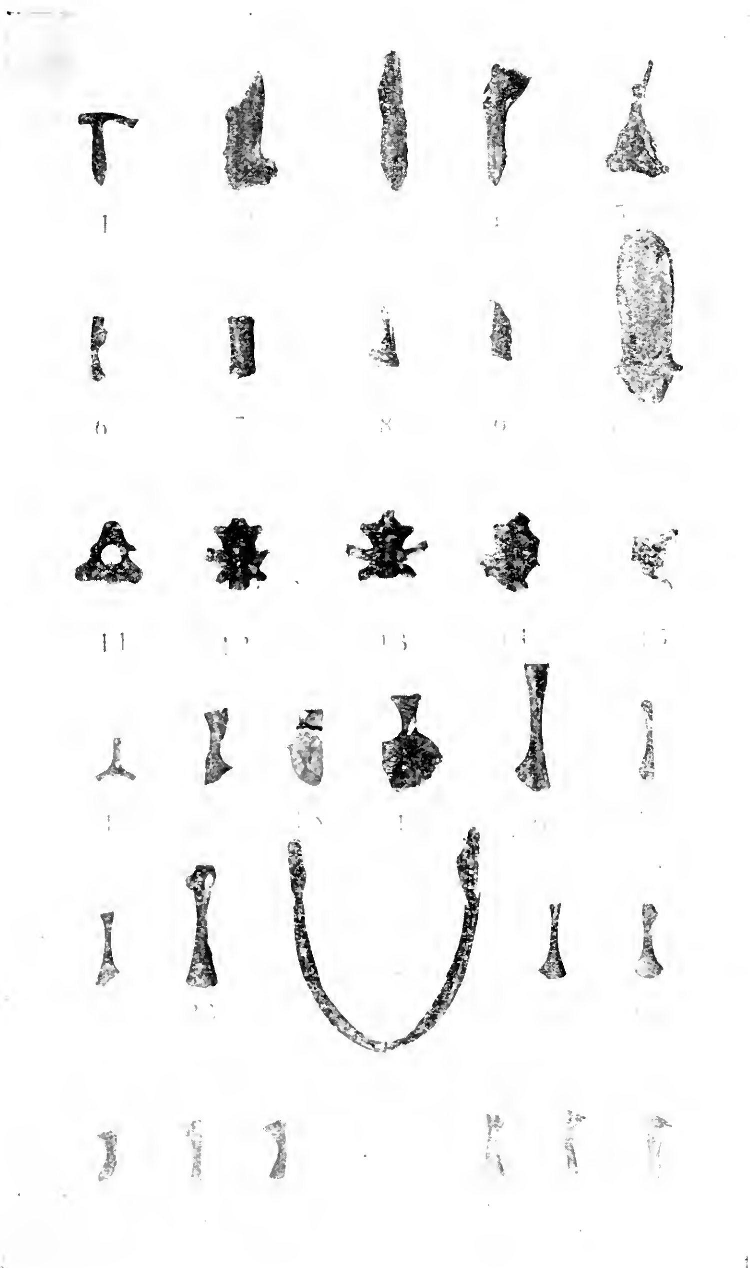
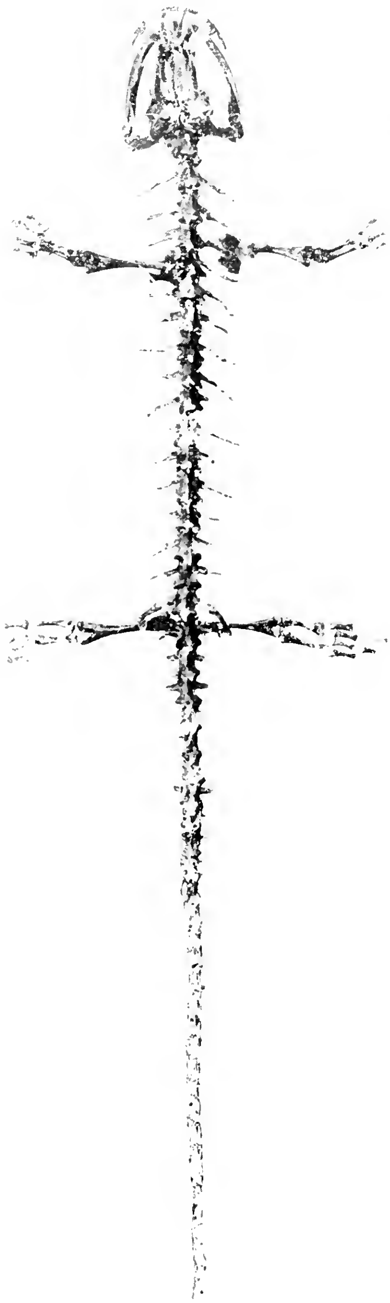


PLATE XXXII.

Restoration of the skeleton of *Plioambystoma kansasense* from elements shown on Plate XXXI, *ante*. Nine inches long.

PLATE XXXII.



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