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The Geochemistry of the Limestone of the Shawnee Group
in Kansas, Part 1, Oread Foramtion

by

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Oread Formation

ABSTRACT

The Oread Formation, the basal formation of the Shawnee Group, was
chosen for the first report of a series of four studies on the geochemistry
of the limestones of the Shawnee Group. The four limestones of the formation (list)
were sampled along the strike of the outcrop from the Missouri River to the
Kansas-Oklahoma line. One hundred twenty chemical analyses were made and
thirty-two composite sections were measured and described.

Results of the study indicate that limestone at the northern end of the
outcrop area was deposited in deeper water. A shelf area was present in the
north central area and a general shallowing toward a land source is exhibited
at the southern end of the outcrop area during the time represented by Toronto and Kereford deposition.
The maximum transgression of the sea is represented by the Leavenworth depo-
sition, and the Plattsmouth shows evidence of reef structure at the southern
end of the outcrop area.

The tables of chemical analysis, graphs of various constituents and com-
posite measured sections are shown. The data obtained from the study and the
available geologic information were used to postulate a possible configuration
of the sea bottom as well as conditions of environment during the deposition
of the Oread Formation.

This open-file report contains additional data
not published in Kans. Geol. Survey SDP #34 (1967)
in which paper is included.

Title: The Geochemistry of the
Limestones of the Shawnee
Group, Part One: The Oread
Formation. Walle. Waugh Hill.

Introduction

The Oread Limestone, basal formation of the Shawnee Group, Upper

Virgilian Pennsylvanian Age, was chosen as the first unit of a detailed

study of the geochemistry of the limestones in the Shawnee Group. The

purpose of this ~~study~~ *investigation* was threefold: (1) *Economic —* Two of the Oread Limestones

Mv
the items that
follow are not purposes:

(Plattsmouth and Toronto) are of sufficient thickness throughout most

Study of Relation to cyclic sedimentation theory

of the outcrop area to be utilized economically; (2) Changes of chemical

composition along the outcrop are of interest in a study of lateral vari-

ations of limestone purity, variations which (if) repeated in similar over-

lying formations could be pertinent to the cyclic sedimentation theory;

Study of environmental conditions prevalent
(3) Geochemical results furnish information on conditions of environment

of deposition within the Kansas part of the midcontinent area during

Pennsylvanian time. No previous report deals exclusively with the geo-

(although
chemical aspects of the Oread Limestone, ~~but~~ some analyses of the Oread

are ?
were included in the general study of the limestone formations of the

where appropriate
eastern one-third of Kansas by Runnels and Schleicher (1956). Several

of their analyses are reproduced in this report.

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This report is the presentation of the results of a systematic

field investigation, sample collection and chemical analysis of these

limestones of the Oread Formation. The use of uniform sampling

and analytical methods to obtain information on the chemical consti-

tuents of samples collected at regular intervals along the outcrop

gives continuity to the results and makes it possible to present

analytical data in a graphic manner. This paper reports only the

observed geologic and lithologic variations of the formation and

the results of the chemical analyses. Salient geologic and chemical

trends are mentioned briefly.

A detailed interpretation of the data included in this report

will not be done until similar studies of the other limestone mega-

cyclothems of the Shawnee Group have been completed. Each megacyclo-

thems of the Shawnee Group contains the same general lithologies which

are repeated in the same order. The outcrops of all four limestone

megacyclothems extend over the same approximate area of the state

with the present day outcrops of each succeeding formation off-set

no more than a few miles to the west of the one preceding. Therefore

they share the same basin of deposition, and the same repetitive

type of cyclic sedimentation. The megacyclothems vary primarily in

that they were deposited serially through geologic time thereby

giving several constant factors with which to compare a number of

similar but discreet variables. When the results of the four studies

of similar repetitive lithologies are compared they will provide a

more comprehensive idea of the contour of the sedimenting basin and

the environment of deposition during Pennsylvanian time in the area

that is now eastern Kansas.

Methods of Investigation

Samples of each limestone were collected from outcrop and quarry

locations across the state from Doniphan to Chautauqua County. A

close spacing of locations was desired for study of lateral variations

of each limestone member. Six miles or the approximate width of

one township was chosen as an arbitrary distance (Plate 2). However,

it was found necessary to vary the spacing from 3 to 12 miles because

of inaccessability of outcrops as well as weathering characteristics

and absence of outcrops. Sample locations also deviated from the

pattern to incorporate previously analyzed samples, or samples obtained

from quarries. Ideally, a continuous vertical section of the forma-

tion at each location is desirable, but under field conditions it

was usually necessary, to group several partial sections from different

locations in order to obtain a complete section representative of

a certain area.

An analysis of the total thickness of each limestone member was

~~sought.~~ This was necessary from the standpoint of economic potential

and future utilization, because the thicknesses of the individual

beds within the limestone members are too thin to permit selective

quarrying on a sound economic basis. Each sample was taken from a

fresh surface. Depending on thickness of the unit, samples ranged

in weight from 3 to 50 pounds.

~~Each~~ sample was crushed, reduced by quartering and splitting,

and ~~was~~ ground to pass through a 60-mesh screen. ~~Samples~~ were ana-

lyzed for SiO_2, Fe_2O_3, Al_2O_3, TiO_2, K_2O, Na_2O, SO_3, S, P_2O_5, CaO,

MgO and loss on ignition for CO_2 and other volatiles, according

to the methods of Hill ~~and others~~ (1961). [Most of the constituents

are reported as the oxides and the values tabulated in tables 1-4

are calculated as weight percent.]

Due to the presence of pyrite (ferrous sulfide) [FeS] in the Leavenworth Limestone, all of the iron [Fe] is not reported as ferric oxide [Fe$_2$O$_3$].

When the iron [Fe] in pyrite is reported as ferric oxide, the summation of the percentages of all components will be low because of the molecular weight difference between ferric oxide and ferrous sulfide (Waugh and Hill, 1960). For this reason, in the Leavenworth Limestone all the sulfide is calculated as ferrous sulfide, the remaining iron as ferric oxide, and both values are used in obtaining the total. Acid insoluble iron is not included in the total because the ferric oxide and ferrous sulfide values include the acid insoluble iron.

To gain an overall comparison of the order of magnitude of excess silica and clay present in the limestones in various areas, illite with the formula $2K_2O \cdot 3MgO \cdot (Al_2O_3, Fe_2O_3)_8 \cdot 24SiO_2 \cdot 12H_2O$ (Imbrie and Poldervaart, 1959) was calculated from the percent alumina. Illite was used for the calculation because most of the shales of the Pennsylvanian System are illitic (Grim, 1963, pp. 356-357) and all X-ray diffractograms run on random samples of the shales and clay fractions of the Oread Limestones were illitic. Although

but what percentages

small amounts of other clay minerals may be present, their concen-

tration is too low to alter greatly the calculated clay value. Also,

not all of the illite present in the limestone has the formula

$2K_2O \cdot 3MgO \cdot (Al_2O_3, Fe_2O_3)_8 \cdot 24SiO_2 \cdot 12 H_2O$ because of various substitutions

in exchangeable positions. However, for purposes of comparison,

all of the alumina was used in calculating illite of the formula

shown above. Quantities of the total amount of silica in limestone

samples not used in the calculated value of clay were then reported

as excess silica.

A plot ~~of linear graphs~~ of the ~~percent constituents~~ ~~according~~

~~to~~ sample locations was used as a simple method of ~~comparing~~ the

chemical and stratigraphic properties of ~~the~~ limestones. A seven-

point moving average was chosen to smooth out minor variations but

retain major trends in the chemical composition. A seven-point

moving average is found by averaging a value with three values on

either side of it, and the process repeated for each succeeding

value. (right about start and finish).

Description of Geology

The Oread Formation, as currently defined, comprises
four limestones and three shales (Plate 1). Named from bottom to
top, these include the Toronto Limestone, Snyderville Shale, Leaven-
worth Limestone, Heebner Shale, Plattsmouth Limestone, Heumader Shale,
and Kereford Limestone. The formational boundaries are placed at the
contact of the Toronto Limestone with the underlying Lawrence Shale
Formation for the lower boundary and the contact of the Kereford
Limestone with the overlying Kanwaka Shale Formation for the upper
boundary. The Kereford Limestone is absent in certain areas in the
southern part of the state; accordingly the formational boundary in
these areas is the contact of the Plattsmouth Limestone with the
undifferentiated Heumader-Kanwaka Shales (Moore, 1935, p. 162).

The Toronto Limestone was recognized and sampled at all locations
except in the vicinity of Sedan (location 31) where no limestone
outcrop could be found in the stratigraphic position of the Toronto.
In the area around Sedan, the Snyderville Shale assumes many of the
characteristics of the Lawrence Shale. Both continuous and discon-
tinuous lenticular, and massive crossbedded sandstones are found in

both shales. Any differentiation other than an arbitrary one ~~would be~~ ~~very presumptious~~. Therefore, in the area of location 31 the Leaven-

worth Limestone is the lowest definitive member of the Oread Formation

and the lower boundary was plaCed at its base.

Between the boundaries described above, the thickness of the

Oread Formation ~~varies widely primarily~~ because of the variable

thicknesses of the shale members. Where all four limestones are

present the thickness varies from 44.0 ft. at location 2 in Doniphan

County, to 137.5 ft. at location 19 near Waverly in Coffey County

(Plate 1). In the area of location 19 the Kereford Limestone

undergoes a radical facies change and is known locally and in the

older literature as the Waverly Flags or Flagging". In this area

the Kereford is a relatively unfossiliferous light blue gray to

tan lime cemented sand or siltstone. This grades southward into a

massive wavy bedded blue gray limestone. The Kereford Limestone is

quite uniform in thickness as far south as location 9 in Douglas

County. South of location 9, the thickness becomes more variable

and is not identified south of Greenwood County (location 25).

In the area ~~from~~ between location 22 in Woodson County ~~to~~ and location 24 in Greenwood County the outcrop of the Plattsmouth Limestone appears to be an erosional remnant or possible a area of non-deposition. It appears color as a nodular limy zone with abundant fossils and, ~~in local occurrences~~ locally thickens to about one foot of bedded limestone. The Leavenworth Limestone ~~persists~~ changes very little through this area, with the same characteristics and approximate thickness exhibited farther north. The Toronto Limestone in thickness increases in the same area and becomes a lighter colored, wavy bedded limestone similar to the Plattsmouth in the north.

In southern Kansas the Toronto Limestone thins by increasing an thickness of the shale partings, and the feathering out of individual limestone strata (Plate 1). The last persistent bed was found at location 30, six miles north of Sedan, and a limy shale zone is present near Chautauqua in Chautauqua County (location 32) at approximately the same stratigraphic horizon of the Toronto Limestone.

The Snyderville Shale contains more sandstone lenses and assumes a maroon to red color in the south part of the outcrop area indicating complate oxidation of the iron present.

The Leavenworth Limestone and Heebner Shale persist in southern
Kansas and show the same gross properties as in the rest of the out-
crop area.

The Plattsmouth Limestone ~~locally is indurated into~~ forms a massive
ledge near Sedan, but ~~retains~~ remains traces of wavy bedding within the
unit. Other outcrops reveal definite thin wavy shale partings and
the wavy bedded characteristics found in the north.

~~Above~~ the Plattsmouth south of Greenwood County ~~lies~~ is overlain by the Elgin
Sandstone which was deposited on an eroded Oread surface. It con-
sists of undifferentiated massive ledges of sandstone separated by
shale partings and sandstone lenses of varying thickness. The Kere-
ford is not identifiable although locally, a thin limestone bed is
found above the Plattsmouth and may represent a remnant of the Kere-
ford. Verville (1958) states that these lenses are Kereford. In
places the Plattsmouth has been deeply eroded and Elgin Sandstone deposited,
indicating post Plattsmouth or post Oread emergence.

Toronto Limestone Member

Lithology

The thickness of the Toronto Limestone Member ranges from

0 to 13.6 feet. It thickens and thins locally, but there are two

areas (location 4 through 12 and location 20 to 24) of fairly con-

stant thickness (4 to 7 feet). The thickness of the limestone

diminishes to the south until the last recognizable bed of Toronto

is lost near Sedan in Chautauqua County and a thin calcareous shale

replaces it in the same stratigraphic position.

In the northern one-half of the outcrop area the Toronto Lime-

stone normally consists of two massive beds separated by a persistent

shale parting. Locally in the same area (location 2 and 17) the

Toronto is represented by an extremely calcareous shale containing

nodules of limestone. In the area of location 20 to 24, it assumes

a wavy bedded appearance. South of location 24 the Toronto separates

into several thin beds of limestone separated by 6 to 12 inch shale

partings and is represented by a calcareous shale at the southern

end of the outcrop area.

on a fresh surface

The color of the Toronto Limestone is white to light gray (dark

gray at the southern end of the outcrop area), and weathers dark

red brown to yellow brown. The weathered zone is very thick in

places, ranging from 1 to 4 inches in recent exposures to 12 inches

or more in older outcrops. The limestone contains small vugs lined

with calcite crystals and filled with powdery red hematite or limo-

nite or both. The depth of oxidation and uniform dispersion of the

limonite in the weathered zone may be due to the high porosity of the

rock. Chert is found locally in the northern part of the outcrop

area as far south as Douglas County. The chert is orange in color *and*

matches closely

very closely matching the weathered color of the Toronto Limestone.

containing

This chert is very impure and contains large quantities of $CaCO_3$ and

Fe_2O_3 (finely dissemenated) through-out and encloses large irregular

limestone fragments.

Chemical Characteristics

The reddish-brown color of the Toronto Limestone is due to the

high percentage of iron oxide (Fe_2O_3, Table 1). The iron-oxide con- *Fe_2O_3*

tent of the 31 samples of Toronto analysed ranges from 0.54 to 8.34

percent and averages 3.71 percent. There are several theories

have been

~~which could~~ be advanced to explain the original source of the iron

in *~~none satisfactorily~~*

~~content of~~ the Toronto Limestone. However, ~~additional information~~

explains the presence of the Fe

~~such as the oxidation state of the iron at the time of deposition~~

~~and a more detailed petrographic analysis of the limestone is~~

~~needed before these theories can be advanced.~~ It ~~does seem~~

possible, however, that a ~~position~~ *portion* of the iron content could be

derived in part from the red and green ironstained Lawrence Shale

Formation immediately underlying the Toronto (Goldschmidt, 1954,

p 665). [Where a shale formation containing terrestrial plant remains

was inundated by sea water and a marine limestone deposited, some

leaching and reprecipitation of iron minerals is indicated.] *confusing*

The average phosphate content of all the samples of Toronto

Limestone analyzed is 0.09 percent. The average phosphate content

for most limestones and carbonate sediments is about 0.04 percent

(Rankama and Sahama, 1950, p. 590; Mason, 1958, p. 147). The

higher overall average phosphate content in the Toronto can be

attributed to an increase in the phosphate content toward the

southern edge of the state. It increases from 0.05 percent at

location 24 in Greenwood County to 0.36% at location 32 in Chautauqua.

County (Table 1). This increase appears to be of some significance

because the phosphate content of the Toronto Limestone in the

northern part of the state as well as for other members of the Oread

Limestone is very close to the average quoted by Rankama and Sahama.

The increase in phosphate at the southern end of the outcrop area

is a possible indication of shallow water and even a near shore

area. The abundance of shell fragments along with some phosphatic

brachiopods, would substantiate the theory of shallower water and/or

near shore conditions. While it is true that phosphate can be

formed and deposited in deep water environments, the presence of

sand lenses in the adjacent shales, the feathering out of the Toronto

Limestone, and increased coarse clastics in the adjacent shales indicates

that southern Kansas was probably a shallow area of offshore bars or

sandy beaches and underwent minor transgressive and regressive fluc-

tuations of sea level with a resultant shift of shore line between

late Douglas and middle Oread deposition. Wilson (1957, p. 125)

states that a shoreline existed in this area from late Lansing to

early Shawnee time.

Location 12 in Douglas County appears to be a ~~point~~ *from an area* which

separates the north *ern* and south *ern* parts of the outcrop area into different *two*

environment*s* ~~of deposition~~. *This is shown clearly in table I* The ~~table of analyses of the various~~

~~elements shows the contrasts of the two areas.~~ Table 1 indicates

a larger magnesium oxide content north oflocation 12. South of

that point the magnesium oxide content is nearer the average of the other

limestones of the Oread megacyclothems. Calculation of $CaCO_3$ and

$MgCO_3$ using the method outlined by Galle and Runnels (1960) indi-

cates a higher amount of dolomite present north of location 12. X-ray

analysis confirmed the presence of dolomite in the *sample from this* area. In the area

from location 12 north to the state line, the average $MgCO_3$ content

is 6.03 percent while the average $MgCO_3$ content south of that point

is 1.34 percent.

<center>Snyderville Shale Member</center>

not needed

Moore, Frye, and Jewett (1944, p. 182) describe the Snyder-

ville Shale as "under-clay-like" from the lack of easily discernible

bedding in outcrops in northern Kansas. The shale is a greenish-gray

claystone characterized locally by dark diagonal bands in the northern

16

half of the outcrop area. Near the center of the outcrop area the

thickness of the Snyderville increases, and the upper part of the

member is red to maroon. The basal part remains gray-green and con-

tains lenticular, massive cross-bedded sandstones locally. As

the Snyderville Shale increases in thickness, the red part also

increases and becomes more sandy and silty. Very fossiliferous

limestone and sandy limestone in beds generally less than 4 inches

are present locally. The Snyderville ranges in thickness from 5.8

to 81.2 feet in the outcrops measured. North of the Kansas River

the member has a relative constant thickness of from 11 to 18.9

feet. South of the river the same proportional thickness exists

for about 30 miles. South of location 18 in southwestern Franklin

County shale begins to thicken until it reaches the center of

Chautauqua County, where the Toronto Limestone feathers out and the

Snyderville Shale could not be differentiated from the Lawrence

Shale.

Leavenworth Limestone Member

Lithology

The Leavenworth Limestone ranges from 1 to 2 feet in thickness

and is present along the outcrop of the Oread Formation throughout

Kansas. The limestone commonly is a single bed but locally in Doni-

phan County occurs as two beds of limestone separated by a thin shale.

The Leavenworth is vertically jointed, extremely dense and breaks

with a conchoidal fracture. It is fine grained, dark blue-gray in

color and weathers to light yellow-gray. The principle weathering

feature is the rounding of sharp corners into subangular blocks.

A weathering notch fig. _____ parallel to the bedding plane commonly

is evident in weathered exposures. The Leavenworth Limestone contains

fossils commonly replaced by dark calcite and microscopic crystals of

pyrite. Pyrite crystals are finely disseminated throughout the Leaven-
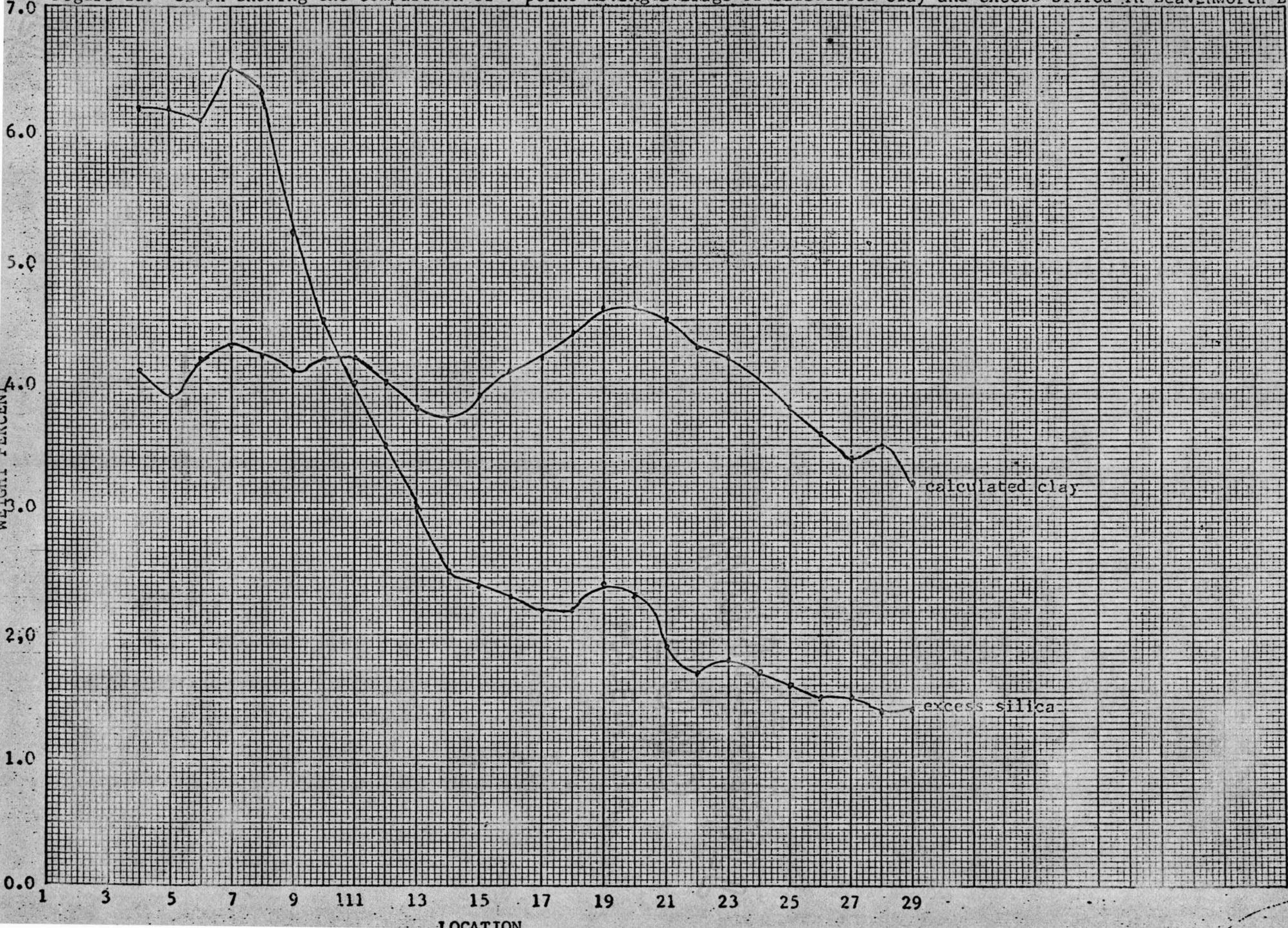
worth over much of the outcrop area.

Chemical Characteristics

The results of the chemical analysis showed that samples taken

from the northern 1/4 of the state have a higher silica (SiO_2) content

than the samples collected from the southern 3/4 of the state. The

section of the outcrop area where the Leavenworth Limestone contains

a greater amount of silica extends from location 1 in Doniphan County

to location 11 in Jefferson County. This area is bounded on the north

by the Missouri River and on the south by the Kansas River. The

average silica content of samples taken from eleven locations in this

area is 7.37 percent with a low of 5.57 percent at location 3 in

Doniphan County to a high of 11.74 percent at location 5 in Atchison

County (Table 2). In the area which extends from location 12 in

Douglas County to location 32 in Chautauqua County, the average silica

content of samples taken from 22 locations is 3.19 percent. This

average includes a high of 5.52 percent and a low of 1.80 percent.

The lack of a correspondingly high alumina (Al_2O_3) value in

relation to the higher silica value for the samples from the northern

indicates
part of the state (Table 2) is a good indication that only part of

the silica present is incorporated in clay minerals. Figure II shows,

how calculated
in a graphic form, the comparison between the calculated clay content

and the excess silica present in some other form. It must be remembered

that the values representing the amount of clay in this particular

how
limestone are empirical and were calculated for purposes of comparison.

found?
The excess SiO_2 in the Leavenworth Limestone is present in a finely

disseminated form in the insoluble residues run on the samples of this

limestone. No visible chert nodules were found in the Leavenworth as

Figure II. Graph showing the comparison of 7 point moving average of calculated clay and excess silica in Leavenworth Lime.

were found in the Plattsmouth and Toronto members.

The other minerals present in the Leavenworth Limestone which appear to have significance are the sulfide minerals. As can be seen in the tables of analysis, the other three limestones of the Oread Formation show sulfide sulfur (S) to be present in only trace amounts or not at all. By direct contrast, the Leavenworth Limestone shows sulfide sulfur present in amounts which range from 0.06 percent to 1.00 percent. The average sulfide sulfur content of 33 samples analyzed is 0.26 percent. The sulfide sulfur present in the Leavenworth was found to be in the form of pyrite (FeS_2). Figure III is a graph of the values of pyrite as calculated from the amounts of sulfide present in the samples analyzed. The major peak, locations 2 to 25 includes the Worden fault zone in southern Douglas and northern Franklin counties. O'Conner (1960) dates the first movement of the Worden fault as post-Toronto, pre-Leavenworth. In southern Douglas county some galena and sphalerite are found locally in the lower shales of the Oread Formation and is a possible indication of some sulfide mineralization associated with the fault. The sulfide minerals in the Leavenworth Limestone in the area of locations 14 and 15 were partially accounted for if it is

assumed that sulfurous gases of solutions were released from the fault,

thereby causing the iron in solution to be reduced and precipitated

as pyrite. The samples of Leavenworth from the northern one-half of

the outcrop area were found to contain relatively large percentages of

sulfide (Table II). The area near the Worden fault shows up in the

graph of the pyrite (Fig III) as a distinct peak on the side of the

major peak.

The fine grained, pyritic, Leavenworth Limestone exhibits a very

uniform lithology in the outcrops examined and was probably deposited from

deeper less agitated water than the other limestones of the Oread

Formation. The Heebner Shale, which overlays the Leavenworth, contains

a large percentage of carbon and carbonaceous material in the lower fissle

part of the shale and indicates that the relatively quiet water and

reducing conditions continued after the deposition of limestone

terminated. Evidence collected during this investigation indicates

that the deposition of the Leavenworth Limestone and lower Heebner

Shale represent the deepest water environment of deposition in the

Oread megacycle.

Heebner Shale

The Heebner Shale Member is present throughout the entire out-
crop area of the Oread Limestone in Kansas. The shale ranges in
thickness from 2 to 8.6 feet and consists of four beds. Named in
ascending orders they are as follows: (1) One-half to 3 inches of
yellow calcareous clay shale that is in contact with the underlying
Leavenworth Limestone; (2) One to 4 feet of dark mahogany brown to
black fissile shale containing some phosphate nodules; (3) One to
6 feet of relatively unfossiliferous yellow and gray clay shale that
locally shows rudimentary bedding; (4) A yellow nodular calcareous
contact zone at the top averaging a few inches in thickness.

The thicknesses of the various components thicken and thin
across the state. In the north the black fissile zone averages 41.77
percent of the total thickness, 46.77 percent in the center and 34.98
percent in southern Kansas while the upper tan to gray shale thickens
and thins accordingly. The contact zones at the top and bottom of
the Heebner maintain the same relative thickness.

Plattsmouth Limestone Member

Lithology

The Plattsmouth Limestone Member is a persistent member of

the Oread Limestone Formation within the boundaries of the state

and generally the thickest limestone member of the formation.

Measured thicknesses range from 0.5 feet to 20 feet. The individual

strata of the limestone are irregular in thickness and wavy-bedded,

composed mostly of thin (4 to 8 inch) undulating beds separated by

thin shale partings. These shale partings locally thicken to several

inches. At locations 22 through 24 the Plattsmouth Limestone occurs as

a nodular calcareous shale zone or one or two thin limestone strata.

The top of the member in extreme southern Kansas and the base of the

member in the northern one-half of the state is a massive bed of lime-

stone. In northern Kansas dark wavy bands of shale or carbonaceous

material occur within the massive basal part of the Plattsmouth.

Yellow and gray shale partings are found in central and southern Kansas.

The color of the Plattsmouth Limestone on a fresh exposure is

light gray and weathers light yellow to a light gray. The induration

and weathering characteristics of the outcrops in the central and southern

parts of the state show a softer more easily eroded limestone.

Limonite staining ~~as a part of the weathering~~ is common in these

sections.

Black or gray chert, spotted with white or gray siliceous replace-

ments of fossils, north of the Kansas river in Douglas County, and

found in lesser amounts southward into Coffey County. The chert

nodules are 1 to 12 inches in greatest dimension, do not cross bedding

planes and are completely surrounded by the limestone and carbonate

material. Fossils are abundant. Fusulinids, brachiopods, crinoid

columnals, gastropods, cephalopods, corals and fenestrate and rhombopor-

ate bryozoa are found at many outcrops. Over the entire area the

Plattsmouth shows localized zones which are extremely fossiliferous.

One very fossiliferous area extends from location 22 through 24. In

this area the Plattsmouth is present as a nodular calcareous shale zone

and the outcrops examined contained large numbers of brachiopods,

bryozoa, crinoid columnals and shell fragments. In Elk and Chautauqua

Counties the Plattsmouth Limestone contains a profusion of horn corals.

Of special interest are the dark wavy bedding planes of shale

and carbonaceous material within the Plattsmouth which, upon weathering,

are the parting planes. A high carbonaceous content of the thin

shale bedding planes is usually found in the northern part of the

outcrop area but also found locally well into the central part of

the outcrop area. They give way to yellow and gray shale partings

in central and southern Kansas.

Chemical Characteristics

Based on purity or the percentage of calcium carbonate the

Plattsmouth Limestone is arbitrarily divided into four distinct areas

from north to south across the state. (Table 3 and Fig. IV). In

the northernmost area from location 1 through 11 the average calculated

calcium carbonate is 80.80 percent and the average magnesium carbonate

is 2.92 percent. In the area from locations 12 through 20 the calcium

carbonate average is 89.44 percent and the average magnesium carbonate

is 1.14 percent. At locations 21 through 24 the Plattsmouth exhibits

its greatest chemical and lithologic change within the state. The

limestone at location 21 is 12 feet thick and at location 22 and 23 it

is a 6-inch calcareous fossiliferous zone. At location 24 the thick-

ness is two feet. The percentage of calcium and magnesium carbonate

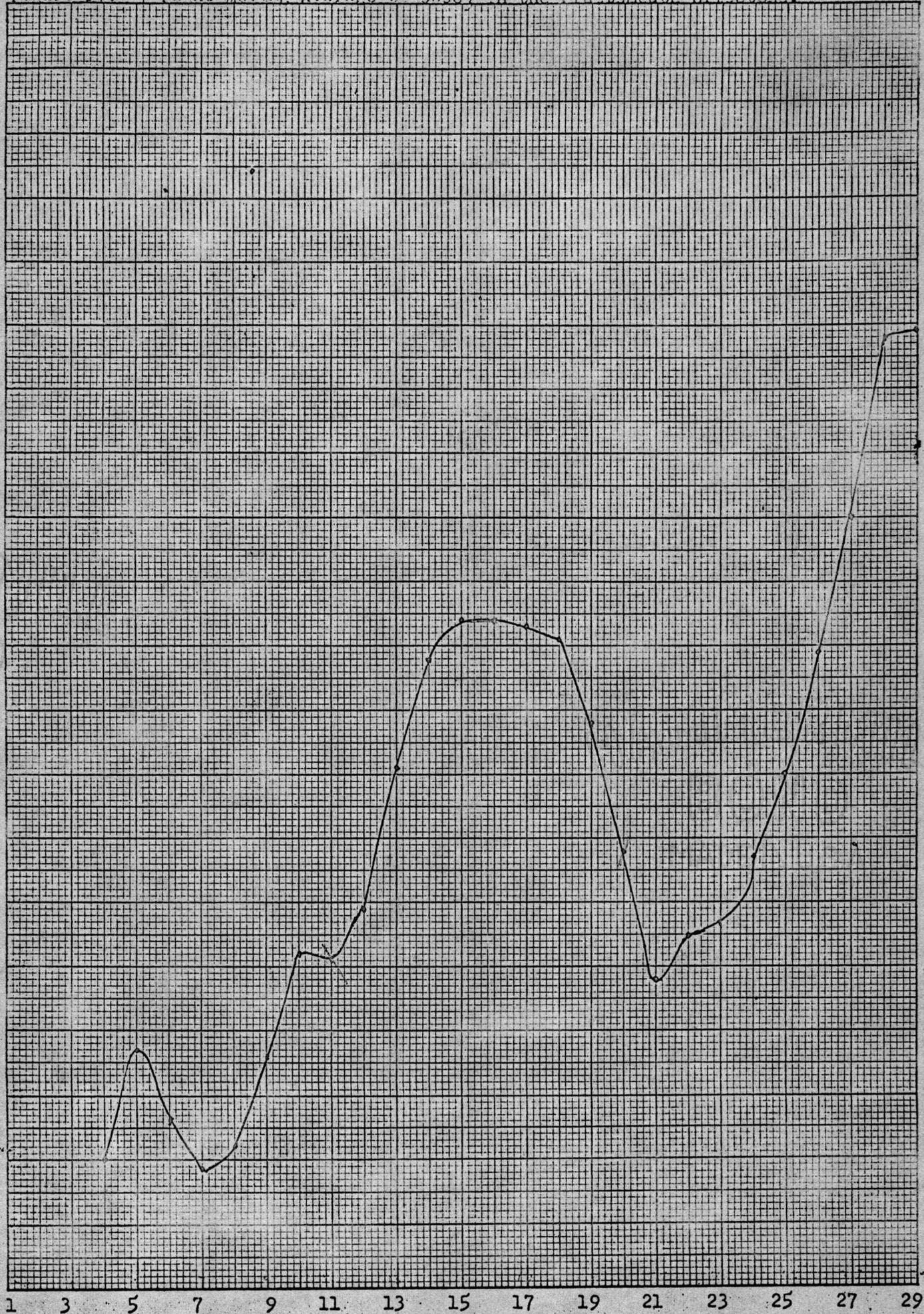at these locations is, in general, less than that found at other

Figure IV. 7 Point Moving Average of $CaCO_3$ in the Plattsmouth Limestone.

LOCATION

locations in the state. The average calculated calcium carbonate is

80.25 percent and the average magnesium carbonate is 2.61 percent. In

the southernmost area, location 25 through 32, the Plattsmouth gradually

thickens to a maximum of 20 feet at location 31. The calcium carbonate

shows a marked increase to an average of 93.63 percent, and the magnesium

carbonate decreases to 0.81 percent.

Wilson (1957) states that reefs and lagoons were present in

southeastern Kansas during early Shawnee deposition. The general

thickening of the Plattsmouth in the area of location 26 through

31 along with the increase in the calcium carbonate content and the

abundance of horn corals indicates possible reef structure in the

area. Cooley (1952) states that there is abundant evidence of a

biostrome in the Plattsmouth in the area of Sedan (Central Chautauqua

County). He also suggests a lagoon southeast of Elgin (southern

Chautauqua County).

Heumader Shale Member

In northern Kansas the Heumader Shale Member is very thin.

On the Missouri river bluff in Doniphan County it is about 2 feet

thick. The shale thickens gradually southward into Douglas County

where it is 41 feet thick and varies from yellow to dark gray.

Bedding is indistinct over most of the area. However, locally some platy bedding was observed just above the contact of the Heumader with the Plattsmouth.

In south-central Kansas the Heumader thickens to a maximum of 75 feet. Southward from northeastern Elk County the overlying Kereford Limestone Member is missing and the Heumader could not be differentiated from the Kanwaka Shale.

Kereford Limestone Member

Lithology

The thickness of the Kereford Limestone Member ranges from 1.5 feet in Atchison County to 25.2 feet in Osage County. The Kereford Limestone has a discontinuous character along the outcrop in Kansas and undergoes a series of facies changes which makes it the most variable of the limestones of the Oread Limestone Formation.

In northern Kansas the Kereford is a single massive dark blue gray fossiliferous limestone located only a few feet above the Plattsmouth Limestone. Southward to the Kansas river (location 11) it

separates into several beds and lightens to a light gray. From

location 12 through 14 the Kereford becomes very shaley and less

indurated and weathers to an almost unrecognizable nodular calcareous

shale. This area extends into Franklin County where the Kereford

is present as a single bed at location 15.

A few miles south of location 15 the "Waverly Flags" appears in

the same approximate stratigraphic horizon, a relatively thick lime-

stone unit 8 to 25 feet thick, composed of thin evenly bedded very

fine grained limestone and lime cemented siltstone. Sand lenses

are found locally at the top and bottom of the KEreford and thin sand

lenses are often found interbedded with limestone. Most beds range from

2 to 5 inches in thickness and are light gray to blue gray, weathering

to a yellow tan. The "Waverly Flag" facies of the Kereford extends

about 24 miles along the outcrop and grades into a dark blue gray

thin bedded limestone at location 19 where the total thickness is

approximately 7 to 9 feet. The Kereford maintains this thickness

for about 40 miles to the south with the exception of a small area

at location 21 where it thins to a nodular shaley zone. Within the

area from location 20 to 24 the Kereford is a light gray coarsely

crystalline wavy bedded limestone similar in appearances to the

normal lithofacies exhibited by the Plattsmouth Limestone in the

north. This facies extends over the area between the Neosho and

Verdigris Rivers where the full thickness of the Plattsmouth is

not present. The Kereford and Plattsmouth are separated by 40 to

70 feet of Heumader Shale in this area. In the area of location

20 thru 24 the Kereford is very fossiliferous containing large

productid brachiopods in the upper strata and profuse fusilinids

in the lower strata. Locally a sandstone is present at the base,

and in places the top beds, are deeply eroded and filled with a

sandstone, indicating exposure and erosion after deposition. It

is possibly a northern extension of the erosional cycle that re-

moved the upper Oread and implaced the Elgin Sandstone in southern

Kansas. Southward into Elk County the Kereford thins and becomes

dark blue and flaggy containing primarily a brachiopod and mollus-

can faunal assemblage. In central Elk County the Kereford Limestone

disappears as a definite stratigraphic member of the Oread Formation.

Locally in southern Elk County and Chautauqua County one or more

thin fossiliferous limestone strata are found above the Plattsmouth

Member b ut below the overlying Elgin Sandstone.

Chemical Characteristics

The calculated calcium carbonate of the Kereford Limestone

(Table 4) ranges from 90.86 to 38.35 percent. The amount of

calcium carbonate decreases generally to the south as the Kereford

thins and becomes more arenaceous. The areas containing the high-

est percentages of calcium carbonate (Fig. V) are from location

2 through location 9 and location 13 through 19. In the southern

half of the Kereford outcrop ~area~ the percent of calcium carbonate is ~decreases~

less because sand was deposited ~along~ with the limestone. Silica in the

form of quartz comprises more than 21 percent of the members at ~what members?~

locations 22 through 24 (Fig. VI). Clay (Fig. VII) occurs in appre-

ciable amounts in the area between location 9 and 15 and between

locations 21 and 24.

The amount of potassium oxide and sodium oxide in the Kere-

ford Limestone is relatively constant; [however an increase in ~not a sentence~

the amount of both oxides from locations 11 through 14 and loca-

tions 19 through 21.] ~A positive correlation exists~ The areas where there is an increase in the

~the~ potassium and sodium oxide ~content~ corresponds to the areas where clay is ~content~ ~between~ ~and~

more abundant in the Kereford. The greater ratio of potassium

Figure V. 7 Point Moving Average of the CaCO₃ in the Kereford Limestone.

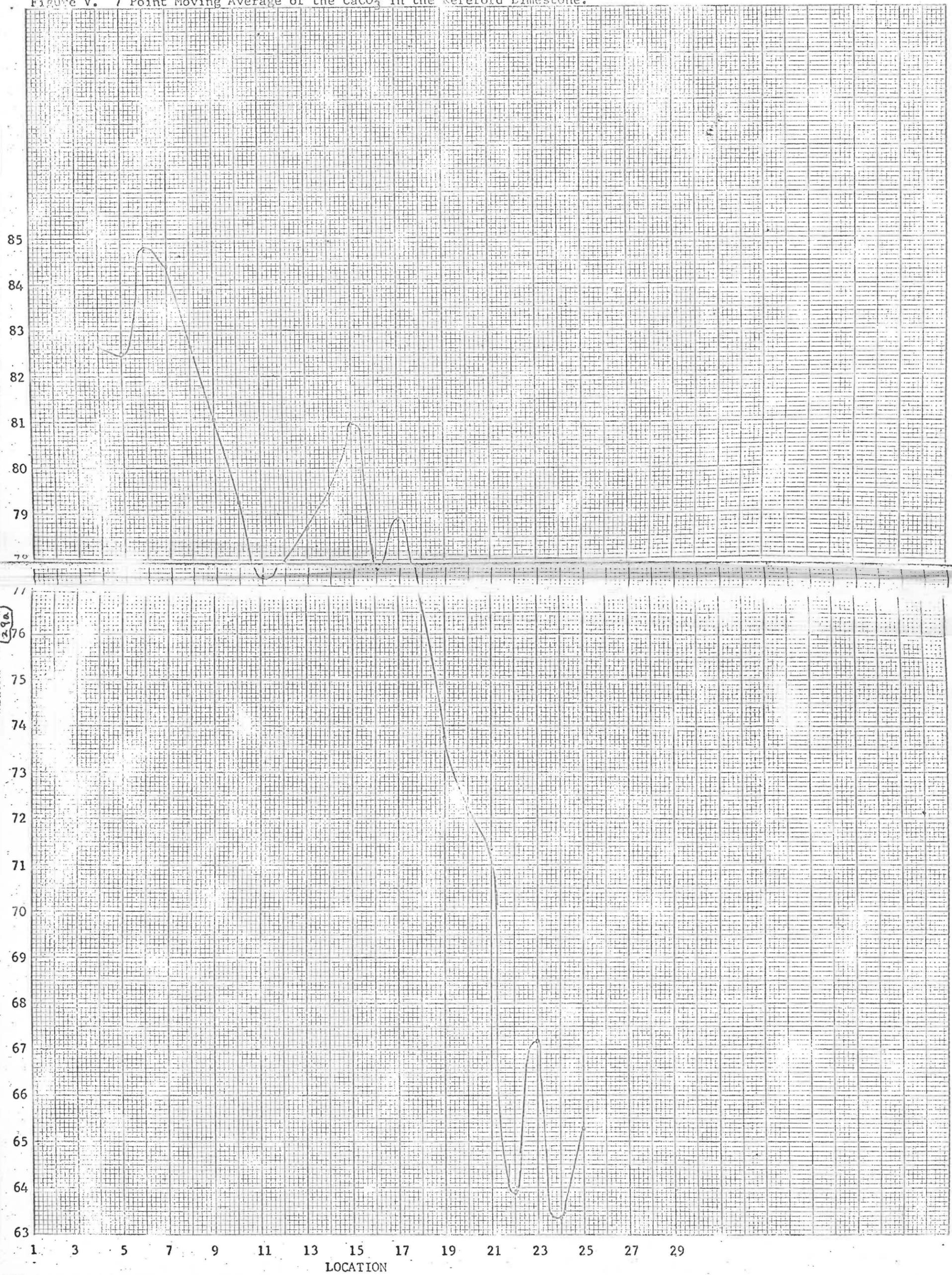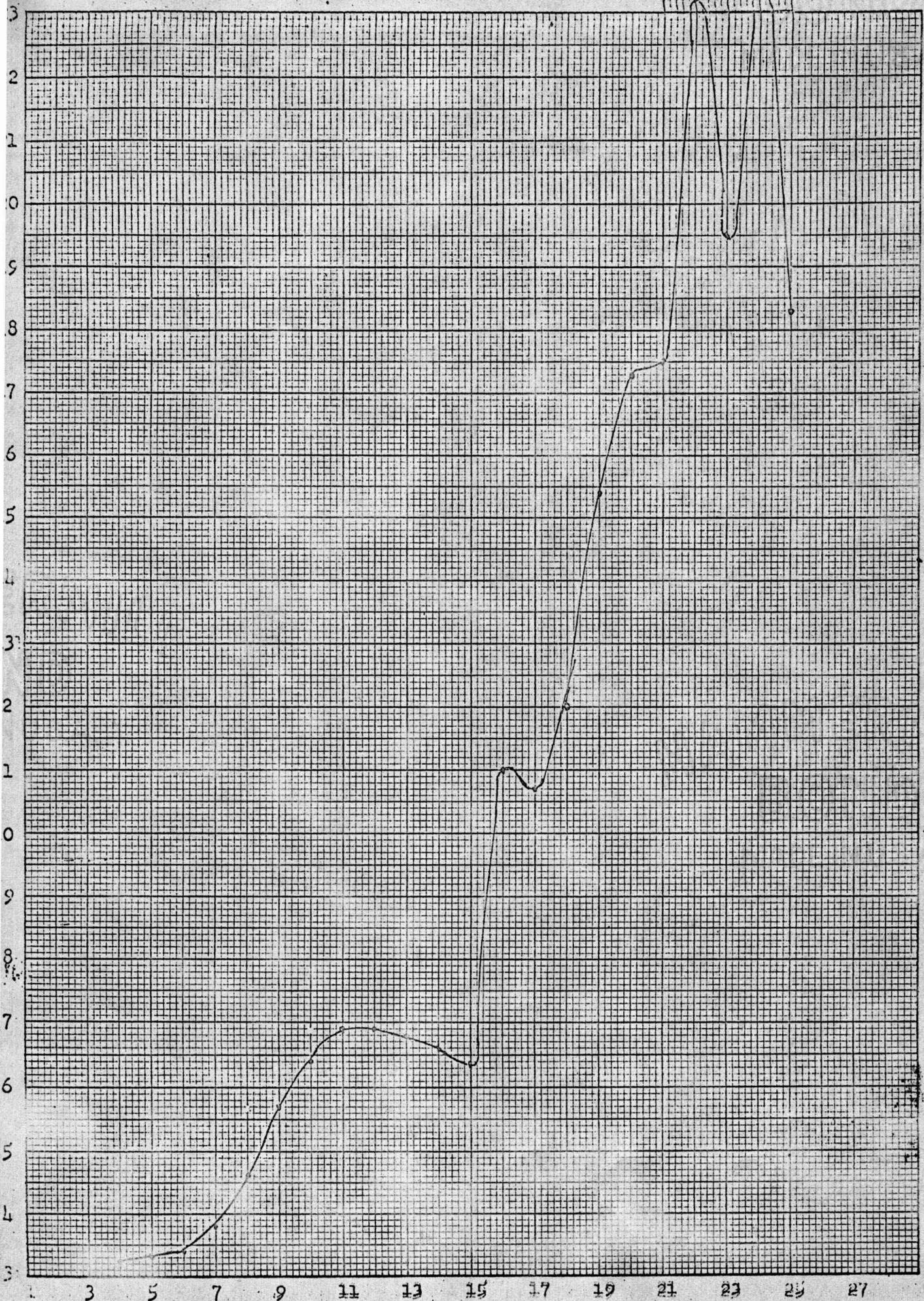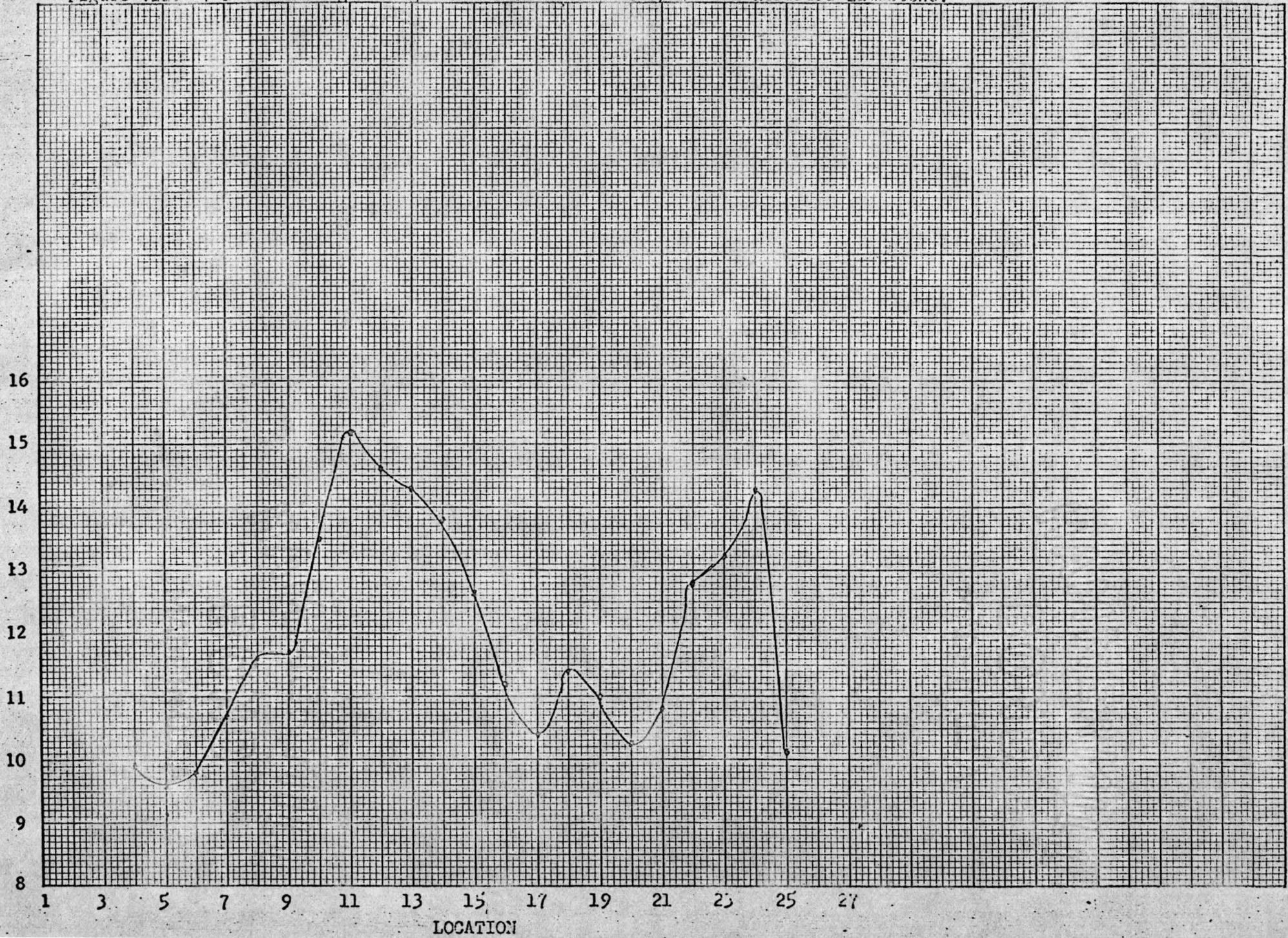Figure VI. 7 Point Moving Average of the Excess Silica in the Hereford Limestone

Figure VII. 7 Point Moving Average of the Calculated Clay in the Kereford Limestone.

to calculated clay in this area suggests the possibility of

deposition of potassium-substituted clays. *was this suggested also by the x-ray patterns*

Elgin Sandstone

The Elgin Sandstone member of the Kanwaka Shale named

from outcrops in the vicinity of Elgin in Chautauqua County, Kansas

is a sequence of undifferentiated massive crossbedded, and thin sand

layers separated by shales of varying thickness. The Elgin Sand-

stone is present in the Heumader-Kanwaka Shale in extreme southern

Kansas and feathers out to the north. The exact extent of the

Elgin was not determined but persistent lenses may extend into

Central Kansas. In Elk County and part of Chautauqua County the

Elgin was deposited over an erosional surface that cut the Platts-

mouth Limestone Member locally.

Discussion and Comparison of Results

In northern Kansas the shales of the Oread Limestone formation

are fine grained and of relatively uniform thickness indicating a

distant source *for the* of sediments. (Plate 1) The uniformity of the Oread

in this area indicates a relatively quiet environment and non-emer-

gence during the Oread megacycle. The limestones in this area show

the least change from one location to another than at any other

area along the outcrop. Low relative purity indicates slow but contin-

uous deposition of fine clastics during the cycles of limestone depo-

sition. This area also is the primary area of chert deposition in

the Plattsmouth Limestone. Lane (1957) and Hattin (1957) postulate

the deposition of chert in deeper water facies in other limestones

in Kansas. The Leavenworth Limestone also shows an excess of silica

in this area.

The many facies changes of the upper and lower members indicate

the periods of greatest change of environments of deposition created

by shallow water. Both the Toronto and the Kereford seem to attain

a similar facies, corresponding to the middle members at some point

along the outcrop. Yet each retains at least one lithofacies

exclusive of the other. The Toronto exhibits the high iron

massive facies possibly supporting the theory of transgressing

seas leaching iron from the ferruginous terrestrial shale immediately

below it. This can also be seen in the Clay Creek Limestone of the Kan -

waka Shale which also rests on a terrestrial shale. The Kereford

Limestone's exclusive facies is a fine grained lithographic limestone as

shown by Waverly flags and sandstone lenses adjacent or incorporated

into the limestone strata.

Does not necessarily do

The uniform character of the Leavenworth Limestone indicates

deposition under reducing conditions in deeper water. The high

content of carbonaceous matter in the lower Heebner Shale also

supports this postulation. Deposition of the Leavenworth probably occurred

in two periods with an increased deposition of fine clastics between *no!*

periods. Dixon (1960) points out this zone and designates it as

his middle Leavenworth. This zone is very pronounced in weathered *?*

outcrops, being more easily removed than the upper and lower portions

of the limestone resulting in a weathering notch. If deeper water

is involved the Leavenworth and Heebner probably mark the greatest

transgression of the sea during Oread time. This is further supported
not mentioned in text
by evidence of onlap in the south. The enormous amount of carbonaceous *?*

material in the Heebner can hardly be satisfied either in quantity *o*

or distribution by the inundation of marginal shelf areas. Rather

the unundation of adjacent coal basins might more nearly explain the

amount but not the extremely fine particle size. Hornbaker (personal

communication) states that the Heebner Shale is greatly deficient

in spores compared to the carbonaceous matter of coals. This would

indicate deposition a great distance from land, and would favor the

emplacement of the organic material by soft bodied marine animals,

plants and bacteria. The change of conditions beginning in middle

Heebner time reflects a resurgance of shellfish and other animal life

producing the cycle of lime deposition which resulted in the Plattsmouth

Limestone. The wavy bedded characteristics of the Plattsmouth Limestone

indicates increased wave action, periodicy of lime and clastic depo-

sition, accentuating the beginning of the regressive cycle of the mega-

cyclothem.

Comparison of graphs of some compounds for all four limestones

show repetition of peaks and depressions. These similarities probably

indicate the effect of the contour of the bottom on environment of

deposition and consequently on the chemical constituents. From this

information similarities in chemical variation between superposed lime-

stones, supported by litholgoy, should allow the prediction of the

contour of the floor of the epicontinental sea. Dissimilarities point

out changes due to environment of deposition such as the deposition

of varying thicknesses of shale interposed between the limestones,

and the varying depth of water during transgressive and regressive

cycles. Varying the depth of water effects a lateral shift in facies
as the faunal belts and lithologies migrate in relation to depth of
water, and the new shore line.

Assuming reasonably contemporaneous deposition of limestone at
all points along the outcrop with respect to time, the impurities
incorporated in the limestone can be taken as the amount of clastics
deposited during the periods of formation and lithification of the
limestone. Increased size of clastics is interpreted as the approach
to a positive area. Areas of increased amounts of fine clastics are
construed to be 1. A distant source of sediments, 2. a depression
of the sea floor with quiet water conditions allowing the settling of
fine clastics, or 3. the quiet conditions as in #2 behind a reef or
irregularity on the sea floor. In contrast, areas of high purity
limestone are interpreted as shallow areas of wave and current action
keeping fine clastics in suspension.

The postulated contour of the bottom implies a general shallowing
of water from north to south. Two major breaks occur in this shallowing.
The area in southern Douglas and northern Franklin County appears
anomalous. An east-west fault zone crosses this area (O'Connor, 1960).

In addition significant chemical changes in element concentrations and purity are noted in graphs of the area. The second break of this nature occurs in the Coffey, Woodson, Greenwood sector where although no fault zone is proven, chemical change and the extreme variation in lithology indicate the possibility of a fault.

The Worden fault can be dated both geologically and chemically as post Toronto-pre Leavenworth. The analyses of sulfide sulfur indicate the continued escape of sulfurous gasses or solution during Leavenworth deposition. The Worden fault was, therefore, most active during Snyderville-Leavenworth time reaching equilibrium during Plattsmouth time.

The contour of the sea floor along the outcrop appears to be a tangential cross section of a shelf area with land to the south and east. Graphs of chemical constituents and lithology of the sediments indicate a number of environmental changes along the outcrop. The Ozark area was active during Pennsylvanian time and the chemical changes in the limestone seem to indicate that the Bourbon and Chautauqua arches and Forest City basin although deeply buried may still affect the contour of the sea bottom during Oread time.

The adjacent shales above and below the Oread contain persistent thin lime units in northern Kansas but these feather out to the

south indicating deeper water in the northern outcrop area. The Clay

Creek Limestone in the Kanwaka Shale extends well into Greenwood County

before losing its identity. The Amazonia Limestone in the Lawrence

Shale is well developed in northern Kansas but feathers out to the

south. The deepest water in the area probably occurred in the northern

1/4 of the outcrop where a persistent body of water occurred throughout

Oread time and was present at least periodically during deposition

of the Lawrence and Kanwaka Shales.

The shale units above and below the Oread contain the Tonganoxie

and Ireland channel sandstones in north central Kansas, and massive sand-

stones are present in the Lawrence Shale in southern Kansas. These

southern sandstones persist into the Snyderville Member of the lower

Oread and extend well into central Kansas. This probably represents

shore and delta development of a persistant river. Some wandering

of the river mouth and distributaries could easily be responsible

for a large part of their serial extent. The sand lenses were

probably deposited by longshore currents reworking beach and delta

deposits. The two areas of sand deposition mentioned above are

probable indicators of the primary sources of clastic material during

Oread time.

The chemical and geological results indicate the following:

(1) the lateral variation of purity of the limestone is very great and in the southern 2/3 of the state is relatively unpredictable from location to location. (2) Parallelisms appear in the graphs of chemical constituents of superimposed limestones deposited under different *not necessarily* environments which probably indicate contour of the bottom. (3) The increase of coarse clastics to the south is interpreted as an approach to a positive area. The same is true in the north central outcrop area during regressive stages. (4) Facies changes are gradational but almost continuous along the outcrop.

Similar facies appear in three of the four limestones *members* indicating a similarity of environmental conditions at the time of deposition. Wavy bedded limestone, characteristic of the Plattsmouth over most of the outcrop area, is present locally in both the Toronto and Kereford *not necessarily so.* members, indicating the same relative depth of water and other conditions of deposition. Also the Toronto, Plattsmouth, and Kereford show calcareous shale facies intermittently along the outcrop which are indicative of either the contour of the sea floor or selective implacement of clastics or both. Black shale partings in the Plattsmouth Limestone are taken as an indication of greater depth as are the areas of

greater thicknesses of interposed shale in the central part of the state.

CONCLUSIONS

Comparison and contrast of dissimilar units can point out and delineate some similarities and differences but comparison with other similar strata in other unstudied formations are necessary for any attempted correlation of similar units occurring in consecutive mega-cyclothems. However, it is possible to make some valid conclusions concerning the Oread Limestones using the chemical and geologic information obtained in this study.

The Oread Limestone formation in eastern Kansas was deposited in a shallow marine basin, restricted in part by the Nemaha Ridge on the west, and by the Ozark Dome on the southeast and east during all but the maximum periods of transgression. The outcrop area in north and northeast Kansas lies in a remnant of the Forrest City Basin. On the south a shore area of reefs and lagoons during middle Oread time is reported by Tanner (1956).

The upper and lower Oread Limestones studied along the outcrop underwent many lithofacies changes and from chemical and lithological evidence were deposited over an irregular sea floor, ranging from relative deeps to emergent areas or promontoreis of land. The

limestones of middle Oread in general are quite uniform over most

of the outcrop area and the lack of lithofacies change is probably

the result of deposition from deeper water.

The limestones of the middle Oread vary least, the lower and

super limestones of the megacyclothem show the greatest variation.

The Toronto Limestone locally in southern Kansas exhibits a litho-

facies similar to the Leavenworth. In central Kansas in the area

of the type section of the Toronto in Woodson County, the bedding, color,

and general appearance of the Toronto is similar to that of the Platts-

mouth Limestone at most locations investigated. The Leavenworth does

not undergo a major lithofacies change at any point along on the outcrop.

The Plattsmouth varies primarily in degree of induration, weathering

characteristics, the presence of chert, and the color of the shale

partings. The Kereford is discontinuous and more variable than any

of the other limestones. It resembles the Leavenworth and Plattsmouth

Limestone in specific areas with the addition of the unique possibly

lagoonal facies exemplified by the Waverly Flags.

A positive area existed to the south or southeast of the present

Oread outcrop during Oread deposition and many minor transgressive and

regressive fluctuations are in evidence in southern Kansas in the Snyder-

ville and Heumader Shales. In southern Kansas deposition took place

in relatively shallow seas and a shallow shelf area may have extended

into the central part of the present outcrop area in Kansas.

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in southeast Kansas: Guide Book K.G.S. Field Conference in Eastern
Kansas, p. 123-126.

Table 1 Results of Chemical Analysis and Other Pertinent Data of the Toronto Limestone

Loc. No.	Lab. No.	County	Thickness	Locality Sec. T.S. R.E.	Calc. CaCO₃	Calc. MgCO₃	CaO	MgO	L.O.I. 105/550	550/1000	SiO₂	Al₂O₃	Fe₂O₃	Acid Insol. Iron	TiO₂	K₂O	Na₂O	SO₃	S	P₂O₅	Total
1.	59268	Doniphan	3.1	SW 28-2-22	75.82	6.34	42.83	3.74	1.02	36.65	9.60	2.34	2.69	0.18	0.10	0.41	0.16	0.01	0.03	0.26	99.81
2.	58243	Doniphan	0.8	SW 21-3-22	69.12	0.92	38.80	1.01	1.42	30.87	19.50	4.86	2.11	0.11	0.02	0.34	0.24	trace	nil	0.05	99.72
3.	59253	Doniphan	4.5	SW 5-4-22	72.60	10.40	40.77	4.99	1.07	37.35	9.63	2.01	3.05	0.10	0.11	0.30	0.13	trace	0.02	0.07	99.48
4.	607	Atchison	6.5	NE 18-5-21	82.08	0.90	46.17	1.18	1.23	36.56	9.43	2.11	2.67	0.16	0.03	0.20	0.02	trace	nil	0.14	99.74
5.	58183	Atchison	3.8	SW 32-6-21	76.89	2.05	43.11	1.96	1.83	34.88	8.88	2.15	6.37	0.20	0.08	0.37	0.06	trace	nil	0.02	99.71
6.	58247	Leavenworth	4.5	NE 34-7-21	85.12	1.82	47.82	1.25	1.39	38.38	5.63	1.57	3.66	0.08	0.04	0.17	0.05	0.06	nil	0.10	100.02
7.	58127	Leavenworth	5.2	N 36-8-22	78.10	2.66	43.83	1.78	1.30	35.73	8.98	1.85	5.53	0.16	0.11	0.20	0.10	0.03	0.02	0.04	99.28
8.	58303	Leavenworth	5.0	SE 15-9-21	71.03	12.65	40.41	6.12	1.69	38.23	4.87	0.92	7.47	0.10	0.03	0.11	0.01	trace	0.02	0.08	99.94
9.	58286	Leavenworth	6.0	NW 7-10-21	81.05	0.48	45.54	1.63	2.49	35.89	6.29	1.24	6.49	0.08	0.07	0.22	0.05	trace	trace	0.10	100.01
10.	6160	Leavenworth	8.6	W 8-11-21	85.38	2.91	48.05	2.19	1.17	39.06	4.94	0.67	3.84	0.06	0.01	0.04	0.03	trace	nil	0.08	100.08
11.	58119	Jefferson	13.6	E 31-11-20	78.65	3.03	44.14	2.33	1.13	36.16	12.42	1.11	2.49	0.08	0.18	0.12	0.04	trace	0.04	0.05	100.17
12.	52353	Douglas	8.0	SW 25-12-19	78.58	5.00	44.08	3.19	1.42	37.16	8.56	1.47	3.83	0.09	0.06	0.19	0.09	nil	nil	0.04	100.09
13.	54372	Douglas	3.6	NW 35-13-19	92.70	0.04	51.97	0.73	0.67	40.78	3.62	0.79	1.53	0.06	0.06	0.07	0.03	nil	trace	0.02	99.89
14.	54371	Douglas	4.2	SE 19-14-20	94.24	0.10	52.81	0.52	0.76	41.50	3.16	0.79	0.54	0.05	0.03	0.06	0.04	nil	trace	0.01	100.02
15.	58159	Franklin	11.0	NW 32-15-18	88.17	0.04	49.51	0.62	0.75	38.79	5.57	1.12	3.00	0.10	0.19	0.06	0.02	trace	0.03	0.08	99.71
16.	59587	Osage	5.0	N 16-17-17	87.24	0.10	48.93	0.70	1.12	38.41	5.77	1.19	3.32	0.10	0.04	0.11	0.02	trace	nil	0.04	99.65
17.	58182	Osage	2.9	SW 6-18-17	73.48	0.25	41.22	0.71	0.84	32.44	17.70	3.62	2.12	0.31	0.13	0.69	0.13	trace	nil	0.04	99.64
18.	58160	Anderson	9.0	NE 24-19-17	87.11	0.15	48.88	0.97	1.03	38.38	5.14	1.00	4.16	0.12	0.19	0.05	0.01	trace	nil	0.05	99.86
19.	5959	Coffey	2.9	N 15-20-17	85.69	0.40	48.04	1.22	1.61	37.89	4.20	0.73	5.70	0.08	0.02	0.07	trace	nil	nil	0.02	99.50
20.	58249	Anderson	6.0	C 1-21-17	58.83	1.30	33.07	1.01	2.22	26.55	24.00	4.38	7.07	0.31	0.28	0.61	0.22	0.03	nil	0.07	99.49
21.	5960	Coffey	7.8	W 36-22-15	84.99	4.73	47.71	2.58	1.02	39.84	3.54	0.82	4.00	0.09	0.03	0.07	0.01	trace	nil	0.07	99.69
22.	5914	Woodson	7.9	NW 4-24-15	86.49	3.08	48.50	2.14	0.92	39.64	4.13	0.76	4.10	0.04	nil	0.07	0.03	trace	trace	0.03	100.32
23.	5915	Woodson	7.6	SE 18-25-15	84.54	2.78	47.49	1.85	1.17	38.72	5.78	1.34	3.14	0.08	0.05	0.14	0.06	trace	0.01	0.09	99.83
24.	52294	Greenwood	9.0	NW 10-26-13	89.29	0.17	50.10	0.61	1.00	39.35	4.56	0.92	3.04	0.07	0.02	0.08	0.03	nil	nil	0.05	99.76
25.	52301	Wilson	4.0	W 25-27-13	89.10	0.36	49.92	0.80	0.93	39.37	5.85	1.60	1.34	0.09	0.07	0.18	0.03	nil	0.02	trace	100.09
26.	58310	Elk	6.5	SE 1-29-12	84.20	0.60	47.35	0.76	1.20	37.23	8.55	2.02	2.50	0.15	0.08	0.17	0.04	0.06	0.02	0.13	100.09
27.	58299	Elk	0.3	S 25-29-12	84.74	2.22	47.59	1.72	1.16	38.42	6.32	1.76	1.92	0.21	0.11	0.24	0.06	0.09	0.15	0.04	99.53
28.	58300	Elk	1.2	SW 27-30-12	82.55	0.90	46.64	0.99	1.73	36.77	7.43	2.02	2.72	0.19	0.13	0.31	0.07	0.17	0.14	0.21	99.24
29.	58350	Elk	1.0	SE 16-31-12	78.46	1.78	44.31	1.05	1.67	35.43	10.17	3.22	3.40	0.18	0.07	0.41	0.09	0.12	nil	0.21	100.05
30.	5916	Chautauqua	0.6	E 36-32-12	76.69	0.63	43.53	0.95	1.90	34.05	11.51	3.49	2.97	0.21	0.09	0.50	0.13	0.13	0.03	0.36	99.61
32.	59367	Chautauqua	1.0	NE 3-35-11	62.89	0.98	35.80	0.90	3.05	28.15	16.72	5.34	8.34	0.37	0.16	0.80	0.15	0.13	nil	0.36	99.90
					80.83	2.26	45.44	1.68	1.3?	36.73	8.47	1.91	3.71	0.14	0.08	0.25	0.07	0.03	0.02	0.09	

Table 2 Results of Chemical Analysis and Other Pertinent Data of the Leavenworth Limestone

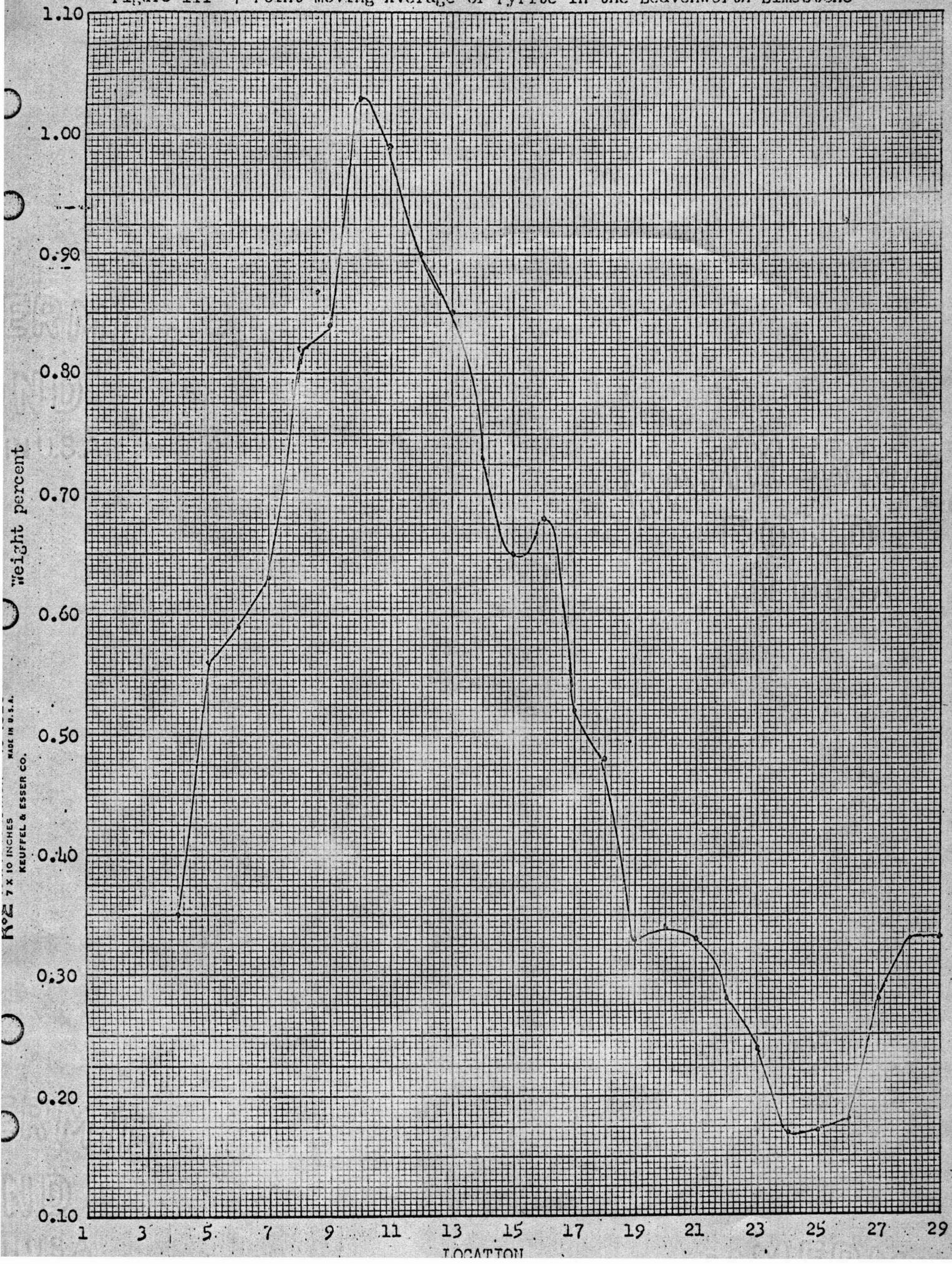| Loc. No.	Lab. No.	County	Thickness	Locality Sec. T.S. R.E.	Calc. CaCO₃	Calc. MgCO₃	CaO	MgO	D.L.O.I. 105°/550°	550°/1000°	SiO₂	Al₂O₃	Fe₂O₃	Acid Insol. Iron	TiO₂	K₂O	Na₂O	SO₃	S	FeS₂	P₂O₅	Total	Fe₂O₃ and FeS₂ as Fe₂O₃
1.	58122	Doniphan	2.5	SW 28-2-22	88.27	0.38	49.61	1.22	1.01	39.02	6.33	1.08	0.85	0.27	0.09	0.09	trace	0.01	0.19	0.20	0.37	99.88	1.10
2.	58123	Doniphan	1.7	SW 21-3-22	90.15	0.08	50.52	0.55	0.63	39.66	7.00	0.69	0.79	0.06	0.09	0.01	0.01	trace	0.12	0.22	0.01	100.18	0.94
3.	59257	Doniphan	1.0	SW 5-4-22	89.51	0.98	50.24	1.39	0.52	39.87	5.57	0.73	0.67	0.32	trace	0.08	0.03	0.05	0.22	0.41	0.04	99.60	0.94
4.	605	Atchison	1.9	SW 18-5-21	87.83	0.84	49.28	0.98	0.82	38.86	7.22	0.98	1.10	0.07	0.08	0.04	0.01	0.04	0.06	0.11	0.03	99.55	1.17
5.	58183	Atchison	1.7	C 31-6-21	82.85	1.42	46.50	0.85	0.78	37.17	11.74	0.88	1.41	0.12	0.06	0.08	0.04	0.05	0.15		0.03	99.74	1.51
6.	58184	Leavenworth	1.3	SW 25-7-21	86.77	0.80	48.72	0.53	0.64	38.57	9.50	0.84	0.92	0.20	0.01	0.08	0.03	0.10	0.18	0.34	0.02	100.30	1.15
7.	58120	Leavenworth	2.0	NW 31-8-22	88.99	1.67	49.98	1.26	0.77	39.98	5.86	0.55	0.57	0.50	0.10	0.05	0.02	0.13	0.44	0.82	0.02	100.??	1.12
8.	58311	Leavenworth	1.4	SE 15-9-21	86.90	1.80	48.80	1.50	0.70	39.13	6.22	0.88	0.90	1.13	0.03	0.11	0.05	0.10	1.00	1.87	0.03	100.??	2.14
9.	58313	Leavenworth	1.7	C 18-10-21	88.83	0.02	49.82	0.45	1.00	39.07	7.26	1.02	0.79	0.21	0.03	0.15	0.04	0.03	0.23	0.43	0.02	100.11	1.08
10.	58130	Leavenworth	2.0	W 8-11-21	84.15	2.68	47.24	1.74	0.90	38.40	8.66	1.06	1.22	0.51	0.03	0.13	0.02	0.12	0.38	0.71	0.01	100.24	1.69
11.	58129	Jefferson	1.5	E 31-11-20	89.81	0.94	50.35	1.02	0.36	39.99	5.70	0.80	0.13	0.39	0.02	0.08	0.03	0.03	0.77	1.44	0.01	99.96	1.09
12.	606	Douglas	1.2	NW 36-12-15	92.41	0.19	51.96	1.25	0.57	40.73	3.62	0.57	0.82	0.18	0.05	0.05	0.01	0.21	0.15	0.28	0.02	100.14	1.01
13.	58128	Douglas	1.5	NE 14-14-18	87.24	3.08	48.97	1.55	0.85	39.97	4.43	0.99	1.11	1.05	0.06	0.13	0.04	0.09	0.90	1.68	0.02	99.88	2.23
14.	58121	Douglas	1.9	NW 4-15-19	93.74	0.40	52.62	0.33	0.62	41.43	2.63	0.63	0.88	0.35	0.09	0.02	0.01	0.27	0.51		0.03	99.89	1.12 / 1.22
15.	58131	Franklin	1.1	NW 5-16-18	91.97	1.76	51.58	1.24	0.72	41.36	2.06	0.57	0.74	0.60	nil	0.02	trace	trace	0.66	1.23	0.04	99.56	1.56
16.	5953	Osage	1.4	N 16-17-17	93.02	0.82	52.13	0.76	0.67	41.33	3.08	0.69	0.84	0.12	0.01	0.06	0.02	trace	0.06	0.11	0.01	99.71	0.91
17.	58161	Osage	1.3	SW 6-18-17	88.68	0.74	49.85	1.14	0.66	39.38	5.52	1.00	1.24	0.27	0.18	0.05	0.01	0.22	0.10	0.19	0.03	99.45	1.37
18.	58162	Franklin	1.2	SW 13-19-17	88.68	1.92	49.75	1.32	0.84	39.99	5.02	1.03	1.44	0.36	0.11	0.05	0.02	0.03	0.28	0.51	0.03	100.15	1.79
19.	5953	Coffey	0.9	S 8-20-17	90.99	0.86	51.06	1.08	0.61	40.46	3.41	0.89	0.93	0.28	0.10	0.09	trace	0.05	0.27	0.51	trace	99.25	1.27
20.	58183	Coffey	0.6	E 11-21-16	91.09	0.67	51.12	0.50	0.81	40.40	4.25	1.14	0.91	0.42	0.02	0.15	0.05	0.08	0.30	0.56	0.01	100.00	1.28
21.	5957	Coffey	0.7	NE 27-22-15	91.29	1.88	51.20	1.14	0.65	41.07	3.12	0.80	1.42	0.17	0.09	0.06	0.02	0.06	0.11	0.21	0.01	99.85	1.56
22.	5917	Woodson	1.3	NW 6-24-15	88.52	3.26	49.75	1.58	0.90	40.62	3.57	0.89	1.78	0.15	0.03	0.11	0.03	0.12	0.11	0.21	0.05	99.64	1.92
23.	58312	Woodson	1.4	SW 16-25-14	90.40	2.53	50.77	1.21	0.74	41.19	2.46	0.70	1.70	0.15	nil	0.07	0.01	0.11	0.11	0.21	0.03	99.20	1.84
24.	59266	Greenwood	1.2	SW 8-26-13	89.11	1.21	50.06	1.06	1.06	39.81	3.88	0.90	2.20	0.10	0.11	0.06	0.01	0.07	0.06	0.11	0.06	99.39	2.27
25.	58313	Greenwood	1.4	NW 15-27-13	89.70	3.26	50.37	1.62	0.75	41.14	3.00	0.79	1.84	0.20	0.05	0.08		0.22	0.12	0.22	0.05	99.98	1.99
26.	58314	Elk	1.8	SW 25-28-12	89.02	2.07	50.00	1.15	0.97	40.22	3.41	0.64	2.44	0.10	0.09	0.06	trace	0.07	0.08	0.15	0.05	99.25	2.47
27.	58295	Elk	1.7	C 25-29-12	92.08	1.03	51.66	1.09	0.75	41.03	2.89	0.68	1.64	0.07	nil	0.06	0.03	0.05	0.04	0.07	0.02	99.97	1.69
28.	58296	Elk	1.9	SW 22-30-12	93.47	0.48	52.49	0.93	0.73	41.50	2.31	0.53	1.18	0.12	0.05	0.05	0.02	0.11	0.21	0.28	0.03	100.14	1.32
29.	5919	Elk	2.0	S 15-31-12	92.65	1.16	52.08	1.26	0.62	41.35	2.29	0.48	0.84	0.18	0.06	0.06	0.01	0.23	0.15	0.28	0.01	99.57	1.02
30.	58315	Chautauqua	2.0	NW 31-32-12	89.79	1.97	50.53	1.47	0.81	40.51	2.40	0.87	1.32	0.46	nil	0.13	0.02	0.26	0.50	0.94	0.02	99.29	1.95
31.	58297	Chautauqua	1.8	C 33-33-11	93.84	1.28	52.69	1.07	0.63	41.93	1.80	0.55	0.81	0.21	nil	0.05	trace	0.12	0.22	0.41	0.02	100.08	1.08
32.	58293	Chautauqua	1.8	NW 14-35-10	91.11	0.50	51.22	0.77	0.68	40.32	3.16	1.04	1.57	0.07	0.03	0.08	trace	0.19	0.12	0.22	0.03	99.61	1.72
					88.78	1.33	50.40	1.09	0.75	40.17	4.67	0.81	1.16	0.29	0.05	0.07	1.02	0.10	0.26	0.49	0.23		1.48

Table 3 Results of Chemical Analysis and Other Pertinent Data of the Plattsmouth Limestone

Loc. No.	Lab. No.	County	Thickness	Locality Sec. T.S. R.E.	Calc. CaCO₃	Calc. MgCO₃	CaO	MgO	D.L.O.I. 105°/550°	550°/1000°	SiO₂	Al₂O₃	Fe₂O₃	Acid. Insol. Iron	TiO₂	K₂O	Na₂O	SO₃	S	P₂O₅	Total
1.	6130	Doniphan	19.8	NW 24-2-21	72.89	6.48	41.07	3.43	1.03	35.43	14.44	1.34	1.89	0.17	0.16	0.21	0.11	0.16	0.11	0.09	99.36
2.	58163	Doniphan	16.5	SW 21-3-22	86.26	0.31	48.41	0.66	0.86	38.09	9.46	1.12	1.14	0.06	0.08	0.09	0.02	trace	0.01	0.06	99.99
3.	6129	Doniphan	17.5	SE 26-4-21	81.37	0.52	45.66	0.79	0.81	36.05	14.11	1.19	1.04	0.07	0.13	0.09	0.03	trace	0.02	0.05	99.95
4.	604	Atchison	16.0	SW 18-5-21	80.21	1.72	45.08	1.31	1.11	36.17	12.77	1.40	1.60	0.13	0.05	0.10	0.03	0.09	0.06	0.06	99.77
5.	6170	Atchison	13.0	NW 32-6-21	80.55	5.75	45.27	3.17	0.98	38.42	9.30	1.28	1.50	0.17	0.01	0.15	0.09	0.14	0.12	0.03	100.34
6.	58252	Leavenworth	14.0	SW 25-7-21	78.39	1.49	44.09	1.01	0.89	35.25	15.32	1.11	1.18	0.16	0.16	0.05	0.01	trace	trace	0.13	99.20
7.	58254	Leavenworth	11.0	C 33-8-22	87.56	0.98	49.17	0.57	0.74	39.01	7.97	0.86	1.12	0.15	0.10	0.02	0.01	trace	0.01	0.08	99.65
8.	6166	Leavenworth	13.5	SE 14-9-21	84.67	0.84	47.55	1.14	0.63	37.67	10.74	0.86	1.28	0.04	0.01	0.07	0.03	trace	0.02	0.08	100.11
9.	58251	Leavenworth	14.0	NW 7-10-21	78.08	5.17	43.82	2.75	0.81	37.04	11.47	1.28	1.87	0.25	0.14	0.11	0.05	trace	0.16	0.06	99.40
10.	6167	Leavenworth	16.5	NW 7-11-21	77.01	6.09	43.40	3.01	0.99	37.04	11.45	1.21	1.80	0.23	0.07	0.18	0.20	0.20		0.08	99.72
11.	6171	Douglas	16.0	NE 1-12-19	82.44	2.78	46.39	1.87	0.85	37.70	9.80	1.09	1.56	0.15	0.01	0.13	0.07	0.11	0.10	0.09	99.67
12.	6168	Douglas	15.0	SW 4-13-19	90.01	0.86	50.48	1.16	0.85	40.03	5.47	0.74	0.92	0.09	0.01	0.10	0.05	trace	0.06	0.04	99.85
13.	54370	Douglas	10.3	C 22-14-18	89.83	0.00	50.44	0.97	1.00	39.47	6.41	1.43	0.44	0.07	0.01	0.10	0.13	0.10	0.02		100.45
14.	59112	Douglas	14.0	NE 15-15-18	86.72	2.57	48.69	1.41	0.61	39.47	6.52	1.10	1.24	0.13	0.01	0.08	0.05	0.09	0.08	0.07	99.34
15.	59113	Franklin	6.0	SW 7-16-18	89.95	0.00	50.47	0.43	0.65	39.55	6.04	0.83	1.06	0.06	0.03	0.05	0.04	trace	0.02	0.05	99.20
16.	5993	Osage	10.6	SW 6-17-17	94.24	0.71	52.83	0.34	0.51	41.44	3.00	0.64	0.95	0.08	0.02	0.03	0.02	trace	nil	0.02	99.80
17.	54224	Osage	20.2	SW 3-18-16	88.32	2.87	49.59	2.15	0.95	40.34	3.89	1.00	1.32	0.26	0.04	0.11	0.20	0.16	0.20	trace	99.59
18.	5999	Franklin	3.0	NW 14-19-17	86.83	0.28	48.69	0.84	1.12	38.33	5.85	1.49	3.12	0.09	0.05	0.11	0.03	nil	trace	0.03	99.66
19.	59100	Coffey	3.7	S 8-20-17	89.93	0.10	50.44	0.63	0.91	39.59	4.88	1.09	2.05	0.08	0.04	0.08	0.02	trace	nil	0.04	99.77
20.	52278	Coffey	13.0	SW 14-21-15	89.11	2.84	49.99	1.92	0.69	40.67	4.04	1.08	1.29	0.18	0.06	0.15	0.06	nil	0.12	0.05	100.00
21.	52316	Coffey	12.0	SE 2-22-15	85.24	2.26	47.85	1.64	1.02	38.66	6.48	1.28	2.77	0.10	0.13	0.18	0.06	nil	nil	0.07	100.14
22.	59265	Woodson	0.5	NW 6-24-15	80.62	1.19	45.27	1.12	1.67	36.07	8.41	3.22	3.11	0.19	0.08	0.25	0.05	0.02	0.04	0.07	99.32
23.	59263	Woodson	0.5	S 17-25-14	80.35	0.96	45.14	0.90	1.80	35.83	8.79	3.15	3.68	0.20	0.11	0.24	0.06	0.02	0.05	0.08	99.80
24.	59262	Greenwood	2.0	NW 1-26-12	74.78	6.04	42.13	2.89	1.50	36.11	9.05	3.59	3.20	0.36	0.25	0.42	0.12	0.15	0.24	0.09	99.50
25.	52205	Wilson	3.0	SW 23-27-13	91.56	0.57	51.30	0.72	0.90	40.56	3.64	1.23	1.35	0.08	0.07	0.13	0.01	nil	trace	trace	99.91
26.	53174	Greenwood	7.1	NE 3-28-12	91.29	1.55	51.24	1.28	0.82	40.95	3.36	0.97	1.30	0.11	0.07	0.09	0.03	0.05	0.06	0.05	100.19
27.	52301	Elk	9.0	SE 21-29-12	96.29	0.08	53.96	0.43	0.44	42.38	1.61	0.41	0.64	0.04	0.01	0.07	0.03	nil	trace	0.01	99.98
28.	58293	Elk	17.5	SW 22-30-12	94.50	0.71	53.04	0.34	0.73	41.58	2.45	0.61	0.92	0.07	0.01	0.05	0.01	trace	trace	0.03	99.77
29.	58286	Elk	18.0	NE 29-31-12	94.15	0.02	52.78	0.34	0.86	41.39	2.55	0.63	1.23	0.04	0.03	0.10	0.01	trace	trace	0.02	99.94
30.	58294	Chautauqua	6.0	NE 36-32-11	94.70	0.42	53.19	0.30	0.50	41.90	2.54	0.67	0.61	0.09	0.01	0.05	trace	trace	trace	trace	99.83
31.	52270	Chautauqua	20.0	C 33-33-11	94.00	2.49	52.67	1.44	0.41	42.63	1.15	0.30	1.51	0.03	0.07	0.06	0.04	nil	nil	trace	100.28
32.	58293	Chautauqua	17.4	NW 14-35-10	92.58	0.65	51.91	0.41	0.74	41.04	3.45	0.75	0.94	0.16	0.18	0.02	trace	trace	0.01	0.02	99.47
					86.39	1.94	48.49	1.29	0.89	38.93	7.08	1.22	1.55	0.13	0.07	0.12	0.04	0.04	0.06	0.05	

Table 4 Results of Chemical Analysis and Other Pertinent Data of the Hereford Limestone

Loc. No.	Lab. No.	County	Thick-ness	Locality Sec. T.S. R.E.	Calc= CaCO₃	Calc MgCO₃	CaO	MgO	D.L.O.I. 105°/550°	550°/1000°	SiO₂	Al₂O₃	Fe₂O₃	Acid Insol. Iron	TiO₂	K₂O	Na₂O	SO₃	S	P₂O₅	Total
1.	59254	Doniphan	2.0	NW 24- 2-21	64.07	13.47	36.26	7.19	1.39	36.20	10.01	2.91	4.20	0.34	0.20	0.47	0.15	0.34	0.36	0.09	99.41
2.	59255	Doniphan	2.0	SW 21- 3-22	84.40	1.09	47.38	0.73	1.11	37.68	7.45	2.31	2.42	0.11	0.20	0.22	0.07	trace	0.03	0.07	99.64
3.	6128	Doniphan	1.6	SE 26- 4-21	86.94	0.80	49.09	1.06	1.34	38.65	4.18	1.06	3.58	0.07	0.30	0.11	0.03	0.06	0.01	0.26	99.72
4.	602	Atchison	1.5	SW 6- 5-21	90.86	1.30	50.96	0.81	0.76	40.63	3.51	1.20	1.73	0.15	0.08	0.04	0.01	trace	0.08	0.04	99.77
5.	59253	Atchison	3.5	NE 32- 6-21	79.06	1.13	44.44	11.00	1.33	36.35	11.05	3.12	2.56	0.19	0.17	0.47	0.10	trace	0.01	0.11	99.70
6.	59252	Leavenworth	3.0	SW 27- 7-21	90.27	0.68	50.84	0.70	0.94	40.44	2.66	0.75	2.67	0.05	0.01	0.06	0.02	0.14	0.01	0.12	99.35
7,8.	59251	Leavenworth	2.0	SW 32- 8-21	82.92	1.44	46.57	0.63	1.12	37.21	8.60	2.54	2.07	0.14	0.16	0.26	0.09	trace	0.02	0.08	99.53
9.	59250	Leavenworth	3.7	NW 34- 9-20	80.78	2.70	45.38	1.71	0.92	36.93	9.41	2.56	1.72	0.18	0.16	0.33	0.17	0.07	0.02	0.05	99.41
10.	59249	Jefferson	6.6	NE 12-11-19	82.76	1.19	46.48	0.62	1.07	36.90	9.49	2.32	2.20	0.12	0.11	0.14	0.08	trace	0.05	0.08	99.49
11.	59260	Douglas	6.8	NW 2-12-18	79.58	0.69	44.64	0.83	1.31	35.35	11.53	2.46	2.86	0.13	0.22	0.47	0.15	trace	0.02	0.04	99.86
12.	60109	Douglas	2.2	SW 31-12-19	68.27	1.02	38.51	1.09	1.25	30.55	18.94	3.36	2.76	0.17	0.28	0.26	0.26	trace	0.02	0.20	100.41
13.	60132	Douglas	0.8	SW 18-14-19	77.78	0.71	43.67	0.85	1.47	34.57	12.08	3.28	2.57	0.19	0.18	0.44	0.15	0.06	0.01	0.04	99.32
14.	60111	Douglas	2.0	C 3-15-18	70.77	1.51	39.74	0.88	1.70	31.91	16.07	4.85	2.93	0.23	0.19	0.76	0.13	trace	0.01	0.07	99.23
15.	59101	Osage	12.0	NE 15-16-17	86.61	0.23	48.54	0.80	0.88	38.31	7.35	1.89	1.72	0.13	0.06	0.10	0.04	trace	0.03	0.01	99.68
16.	59102	Osage	8.2	SW 35-16-16	85.79	0.82	48.11	0.64	0.71	38.15	7.84	1.90	1.94	0.13	0.10	0.10	0.06	nil	0.02	0.03	99.58
17.	60110	Osage	25.2	E 4-18-16	88.04	0.57	49.36	0.80	0.72	39.01	6.74	1.63	1.21	0.11	0.28	0.14	0.06	0.05	0.06	0.02	100.02
18.	59103	Osage	12.2	W 36-18-16	90.01	0.17	50.47	0.56	0.53	39.67	6.21	0.88	1.17	0.07	0.14	0.06	0.04	trace	0.06	0.03	99.76
19.	59104	Coffey	11.0	E 11-20-16	44.96	0.36	25.23	0.36	0.79	19.96	48.91	1.97	2.12	0.11	0.22	0.24	0.12	nil	nil	0.03	99.95
20.	60114	Coffey	8.6	SW 11-21-15	86.28	0.46	48.38	0.72	1.06	38.18	6.93	1.52	2.88	0.07	0.09	0.14	0.06	trace	nil	0.03	99.99
21.	60113	Coffey	0.5	SW 2-22-15	55.58	0.90	31.40	0.76	2.48	24.91	27.23	6.21	4.76	0.29	0.45	0.89	0.12	trace	0.01	0.20	99.41
22.	60115	Woodson	6.3	C 14-24-14	65.57	0.08	36.78	0.27	0.71	28.87	29.99	1.37	1.48	0.08	0.10	0.10	0.05	trace	nil	0.03	99.75
23.	5912	Woodson	2.9	S 8-25-14	75.41	0.34	42.29	0.43	0.88	33.34	19.22	0.82	2.56	0.05	0.15	0.05	0.02	trace	nil	0.03	99.79
24.	58307	Greenwood	7.0	SW 8-26-13	81.81	1.21	45.92	0.65	1.23	36.60	10.11	2.45	2.55	0.23	0.03	0.24	0.02	0.03	0.06	0.05	99.92
25.	59261	Greenwood	2.0	C 6-27-13	38.35	0.46	21.74	0.45	1.21	17.10	51.32	3.49	2.42	0.10	0.45	0.33	0.52	trace	0.03	0.19	99.27
					78.86	1.39	43.01	1.03	1.12	34.44	14.45	2.32	2.46	0.14	0.18	0.39	0.10	0.03	0.04	0.08	

Figure III 7 Point Moving Average of Pyrite in the Leavenworth Limestone

Weight percent

LOCATION