INTERPRETATION OF THE PALEOENVIRONMENT OF SEVERAL MISSOURIAN CARBONATE SECTIONS IN SOCORRO COUNTY, NEW MEXICO, BY CARBONATE FABRICS

by

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ABSTRACT

Carbonate rocks from three sections of Upper Pennsylvanian strata lying between the Zuni-Defiance and Pedernal landmasses were investigated in the field and laboratory. High percentages of clastics within these Missourian sequences suggest that the Joyita axis was an important positive element during this time.

The clay fraction of insoluble residues derived from the Zuni-Defiance, Pedernal, and Joyita landmasses is similar in the northern two sections, but different in the vicinity of the Oscura Mountains. Montmorillonite is present in all sections, but kaolinite occurs only in the central and northern part of Socorro County. High percentages of unaltered montmorillonite in rocks of this age are rare, and their common occurrence in these sections suggests that the potassium/magnesium ratio within the basin of deposition was unfavorable for its alteration to illite. Kaolinite in the carbonate rocks indicates that the source areas for the northern two sections were rich in this mineral.

Microlithologies and faunas indicate that both epineritic and infraneritic conditions existed throughout the area during the Missourian. Sea depths alternated between 50 and 150 feet, and the marine waters were warm and generally calm. Significant algal bioherms developed east of Socorro in proximity to the Joyita axis, and were situated on a shallow marine platform that was occasionally exposed to subaerial conditions.

ACKNOWLEDGMENTS

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Acknowledgment is also made to Dr. Frank E. Kottlowski of the New Mexico Bureau of Mines and Mineral Resources. As co-advisor with Dr. Balk, Dr. Kottlowski has given freely of his time both in the field and laboratory. Mr. Max Willard of the Bureau of Mines helped with the identification and interpretation of the clay minerals.

Thanks are here gratefully extended to my father, R. Waldo Hambleton, and to my uncle, F. H. Stubbs, for their generous financial assistance throughout the entire program. A grant from the New Mexico Geological Society defrayed most of the cost of thin sections, photographic materials, and typing the manuscript.

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INTRODUCTION

The subject of this thesis was chosen because of the need for detailed study of the Pennsylvanian rocks in Central New Mexico. The carbonates in these sections are classified according to Folk (1959) with some modifications. The paleoenvironment and paleogeography have been reconstructed in part based on microlithologies.

The three measured sections are all within Socorro County, New Mexico (see Figure 1). Section A (Mex-Tex Mine section) is on a steep slope about 100 yards northeast of the Mex-Tex Mine in the NE 1/4, SE 1/4, Sec. 36, T. 5 S., R. 5 E. Section B (Ojo de Amado section) is on two adjacent hills in the SE 1/4, Sec. 27, T. 2 S., R. 1 E. Section C (Mesa Sarca section) is in the NW 1/4, Sec. 18, T. 4 N., R. 3 W.

Work in this general area was done by Thompson (1942), Wilpolt and Wanek (1951), and Kelley and Wood (1946). The stratigraphic terminology used by these authors is given in Figure 2.

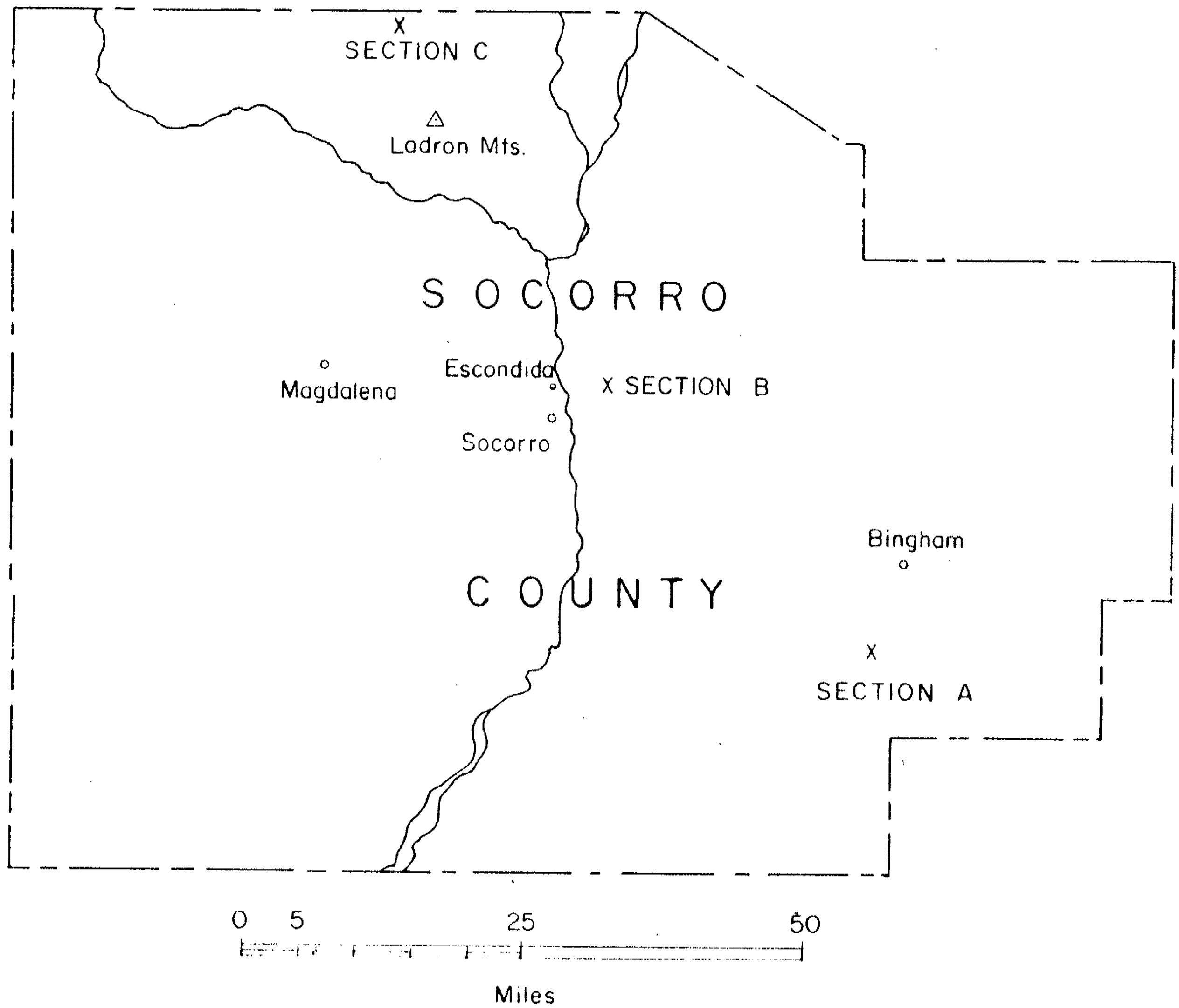
Prior to Thompson's work beginning in 1939, all of the Pennsylvanian rocks were grouped into one or two formations. Thompson recognized four series in the Pennsylvanian System of New Mexico, each represented by several groups and formations. The general tendency of present geologists is to revert to pre-Thompson classifications.

The author has found in Socorro County, that Thompson's formations within the Missourian Series are definitely usable. The various rock units can be recognized and traced on the basis of lithologies. Distinct, cliff-forming limestone units serve as excellent marker beds, persisting throughout the county, although locally specific contacts may be uncertain.

FIGURE 1

FIGURE 1

Location of the three measured sections in Socorro County, New Mexico.


SECTION C
Ladron Mts.
SOCORRO
Escondida
Magdalena
SECTION B
Socorro
Bingham
COUNTY
SECTION A
0 5 25 50
Miles

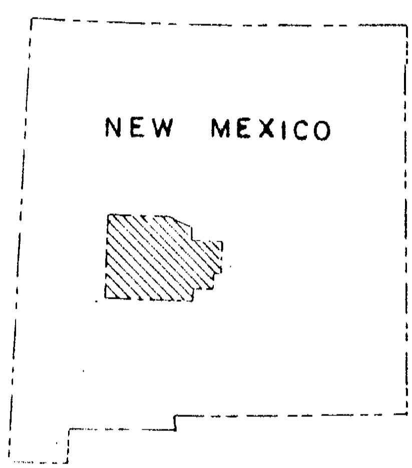

NEW MEXICO

Figure 1

FIGURE 2

FIGURE 2

Pennsylvanian nomenclature in New Mexico.

Thompson (1942), and this report				Kelly and Wood (1946)			Wilpolt and Wanek (1951)		
	SERIES	GROUP	FORMATION						
PENNSYLVANIAN	VIRGIL	Fresnal	Burton (Bruton)	MAGDALENA GROUP	MADERA LIMESTONE	Red Tanks Member	MAGDALENA GROUP	Madera Limestone	Arkosic Limestone Member
		Keller	Moya						
			Del Cuerto						
	MISSOURI	Hansonburg	Story			Atrasado Member			
			Burrego						Lower Gray Limestone Member
		Veredas	Council Springs						
			Adobe						
			Coane						
	DES MOINES	Bolander				Gray Mesa Member			
		Armendaris	Garcia						
			Whiskey Canyon						
			Elephant Butte						
	DERRY	Mud Springs	Cuchillo Negro		Sandia Formation			Sandia Formation	Upper Clastic Member
			Fra Cristobal						
		Green Canyon	Apodaca						

STRATIGRAPHY

The Missourian Series in Socorro County is a distinctive lithologic entity. All five formations defined by Thompson are easily recognized at their type locality in the Oscura Mountains. With the exception of the Coane-Adobe contact in Section B, all the formation contacts appear conformable. Detailed columnar sections (Figure 10) are located in pocket. The detailed lithologies are described in Appendix 1, and Appendix 2 gives the location of all samples collected in the field. Plate 1-A and Plate 4-A show parts of the Missourian sequence in Sections A and C respectively.

COANE FORMATION

At Section A the contact of the Coane with the underlying Bolander group of Desmoinesian age is placed at the top of massively bedded, very cherty limestones. The top of the Coane formation is placed at the base of a buff-weathering sandstone bed. The Coane formation is composed of medium to massively bedded cherty and fossiliferous limestones that weather brown. Several thin-bedded, nodular limestones occur about 20 feet above the base of the formation. The basal portion contains abundant crinoidal remains with a few scattered brachiopods. Fusulinids become more abundant upward in association with the increasingly argillaceous, nodular limestone. The thickness is about 55 feet.

At Section B the basal contact of the Coane formation is placed at the base of a well-developed nodular limestone bed overlying massively bedded limestone at the top of the Bolander group. The upper contact of the Coane formation is placed at a disconformity above a conspicuous conglomeratic sandstone bed. The formation is almost entirely clastic with a few feet of argillaceous, nodular limestone at the base. A prominent arkosic sandstone bed forms a resistant 6-foot cliff approximately in the middle of the formation. The main portion of the Coane is covered slope, and is probably shale interbedded with thin limestones. The thickness at Section B is 140 feet.

The lower contact of the Coane formation at Section C is placed at the first appearance of maroon, micaceous shales above medium-bedded cherty and fossiliferous limestones. The upper contact is concealed. The formation consists of thin argillaceous and fossiliferous limestones interbedded with maroon shales grading vertically, and laterally, into green and gray shales. Fossils within the limestone beds consist of crinoids, brachiopods, and rare fusulinids. The thickness of the formation is uncertain, but is approximately 70 feet.

ADOBE FORMATION

At Section A the lower contact of the Adobe formation is placed at the base of a buff-weathering sandstone bed. The upper contact is placed at the top of a series of nodular limestones beneath the massively bedded Council Springs formation; Plate 1-B illustrates this contact. The Adobe formation at Section A consists of thin- to medium-bedded nodular, argillaceous, cherty and non-cherty gray limestones, gray and green shales, and arkosic sandstones. Except for two horizons where fusulinids are very abundant, the formation is not fossiliferous. The thickness of the Adobe formation in the Oscura Mountains is about 60 feet.

The lower contact of the Adobe formation in Section B is placed at a disconformity below a pisolitic limestone. The upper contact is placed at the base of medium-bedded, cherty limestone of the Council Springs formation. The basal 10 feet of the Adobe formation in Section B consists of medium to light gray limestones that are profusely fossiliferous. The upper 76 feet are clastic and consist predominantly of shales interbedded with a few thin fossiliferous, argillaceous limestones. Near the middle of the Adobe, a low cliff-forming, massively bedded limestone unit is present. Representative fossils include algae, gastropods, brachiopods, pelecypods, and rare cephalopods. The thickness of the Adobe at Section B is 86 feet.

At Section C the lower contact of the Adobe is concealed. The upper contact is placed at the base of the massively bedded, non-fossiliferous limestones of the Council Springs formation. In this section the Adobe contains two 12-foot cliff-forming limestone units within a dominantly shale sequence (Plates 4-A and 4-C). The lower limestone is nodular and argillaceous at the base, grading upward into medium-bedded fossiliferous gray limestone; large productid brachiopods are visible on the weathered surfaces. The upper nodular limestone cliff, light gray and medium-bedded, contains abundant fusulinids. An accurate thickness for the Adobe could not be measured because the lower contact with the Coane falls within a covered slope.

COUNCIL SPRINGS FORMATION

The most distinctive and readily traceable formation within the Missourian Series in Socorro County is the Council Springs. Although it is relatively thin (8 to 18 feet), its massive-bedded, cliff-forming character is easily recognized.

Abrupt lithologic changes mark both the upper and lower contacts of the Council Springs formation in Section A. The lower contact is placed at the top of nodular limestones of the Adobe; the upper contact is placed at the appearance of nodular, fossiliferous limestones of the Burrego formation. The Council Springs forms an 18-foot vertical cliff of dense to coarsely crystalline, white to light gray limestone. Fossils are not visible on the weathered surfaces.

At Section B the Council Springs was measured at two localities approximately 400 yards apart. At the southern locality the lower contact is placed at the top of a thick shale sequence comprising the upper portion of the Adobe formation. The upper contact is uncertain due to faulting. The exposed part of the Council Springs is medium to massively bedded, cherty and fossiliferous, white to light gray limestone. The most abundant fossils are brachiopods and bryozoa. The thickness from the base of the formation to the fault is 9 feet.

The lower contact of the Council Springs formation at the northern locality of Section B is placed at the base of a massively bedded, lens-shaped bioherm ranging from 6 inches to 7 feet in thickness. The upper contact is placed at another abrupt lithologic change from massively bedded, cherty limestone to thin-bedded, dark gray, argillaceous limestone assigned to the Burrego formation. The bioherm is light gray to white, and consists of platy algae and very fine-grained, slightly recrystallized limestone (Plate 3-A and

3-B). The remaining portion of the formation consists of thin-bedded, medium gray, nodular limestone, draped over the bioherm, and grading upward into medium to massively bedded cherty limestone. Except for the algae within the bioherm, the Council Springs is not fossiliferous at this locality. The maximum thickness is 18 feet.

At Section C the lower contact of the Council Springs is placed at the top of a covered slope of the Adobe formation, where the sudden change to massively bedded, cliff-forming limestone occurs. The upper contact is placed at the base of a covered slope of the lower Burrego. The formation consists of massively bedded, white to light gray, unfossiliferous limestone that weathers light brown. The average thickness is 12 feet.

BURREGO FORMATION

At Section A the lower contact of the Burrego formation lies at the base of the lowest nodular, argillaceous limestone of the unit. The upper contact is placed at the first appearance of the maroon, micaceous shales in the base of the Story. The lower 20 feet of the Burrego is nodular, fossiliferous, argillaceous limestone interbedded with gray and green shale. The upper portion of the formation is medium-bedded, light to medium gray, slightly cherty limestone

(Plate 2-A). Brachiopods, bryozoa, and crinoids are abundant throughout the formation. The thickness of the Burrego is about 60 feet.

At Section B the lower contact of the Burrego formation is placed at the top of the highest massive-bedded, cherty limestone of the Council Springs; and the upper contact at the base of the lowest sandstone bed of the overlying Story. The formation is mostly clastic and consists of thin-bedded, nodular, argillaceous limestones interbedded with thick sequences of gray and green shale (Plate 3-C). Locally the limestone may grade laterally into arkosic sandstone lenses. The limestones of the Burrego at this locality are unfossiliferous. The formation is 65 feet thick.

The lower contact of the Burrego formation at Section C is placed at the base of the covered slope above the Council Springs cliff. The upper contact lies at the top of the highest low cliff of nodular, argillaceous limestones. At this locality the unit also contains much clastic material, and is quite similar lithologically to the Burrego in Section B. The thickness of the formation in Section C is about 100 feet.

STORY FORMATION

The lower contact of the Story formation at Section A is at the first appearance of maroon, micaceous shales, and the upper contact lies at the base of a distinctive green and gray shale sequence of

Virgilian age. The lower 20 feet of the formation is red to maroon micaceous shales and sandy siltstones. The upper 40 feet consists of thin- to medium-bedded, somewhat nodular and fossiliferous, medium to light gray limestone; the thickness is 60 feet.

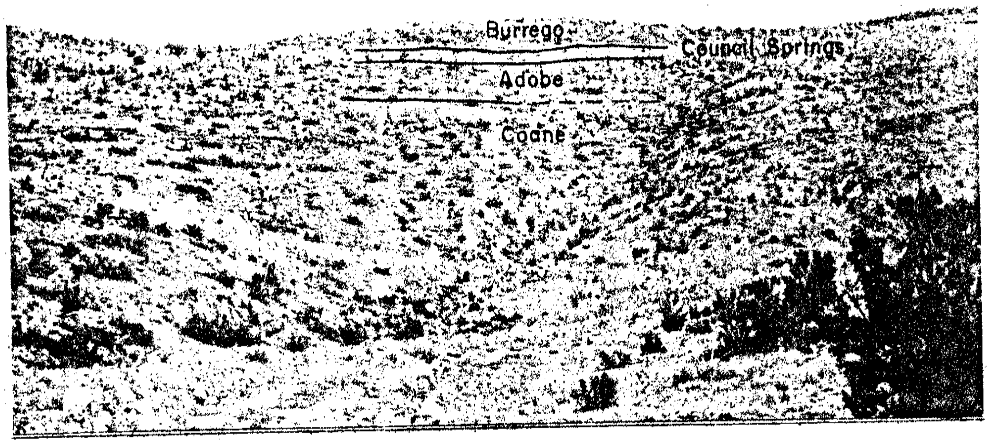
At Section B the lower contact of the Story formation is placed at the base of a thin arkosic grit; the upper contact is faulted. The basal arkosic grit grades upward into maroon micaceous shales. The remainder of the outcrop is medium- to thin-bedded, slightly nodular, extremely fossiliferous gray limestone. Fossils consist almost exclusively of pink crinoid stems and plates which weather in relief due to dolomitization. The upper beds are lost through faulting, but at least 30 feet of Story is present.

The lower contact of the Story formation in Section C is placed at the top of a nodular limestone cliff, which is overlain by a partially covered slope. The upper part of the Story has been removed by erosion. The Story at this locality is mostly clastics. Green and brown shales dominate the section. Scattered, thin-bedded, gray limestones are present and become more numerous and quite fossiliferous near the top of the measured unit. A quartz grit lens appears 44 feet above the base of the formation, and varies in thickness from 6 inches to over 4 feet (Plate 4-B). Crinoid stems, bryozoa and brachiopods are common. An incomplete section of 68 feet of Story was measured in Section C.

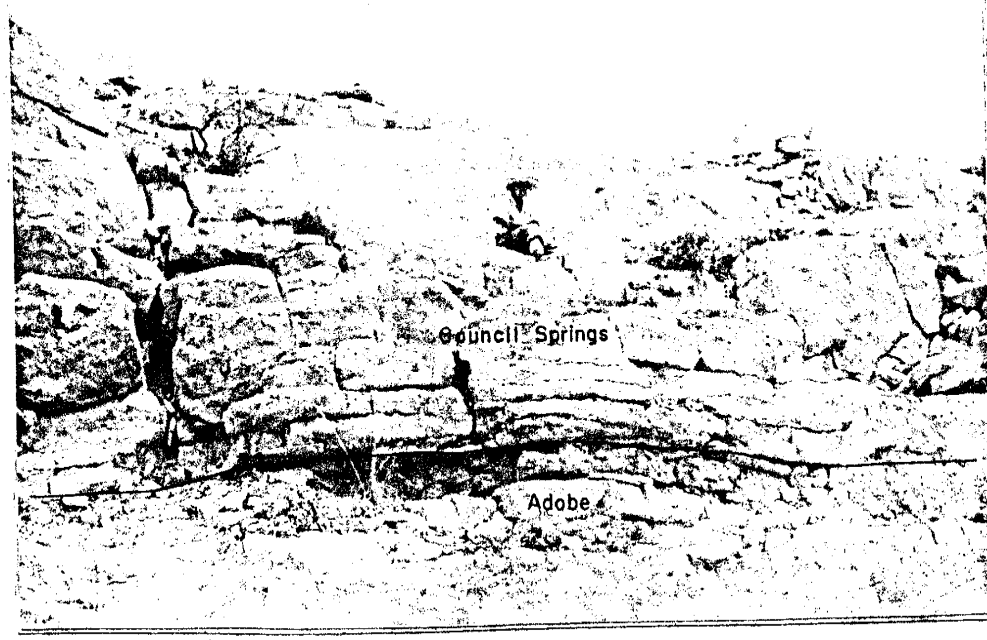
PLATE 1

A. Location of Section A in the Oscura Mountains. Upper cliff is the Council Springs Formation; lower cliff is within the Coane Formation.

B. Contact of Council Springs and Adobe Formations at Section A. The lower thin-bedded, nodular limestone is the top of the Adobe; upper massive limestone is the entire Council Springs Formation.


Burrego
Council Springs
Adobe
Coane

A


Council Springs
Adobe

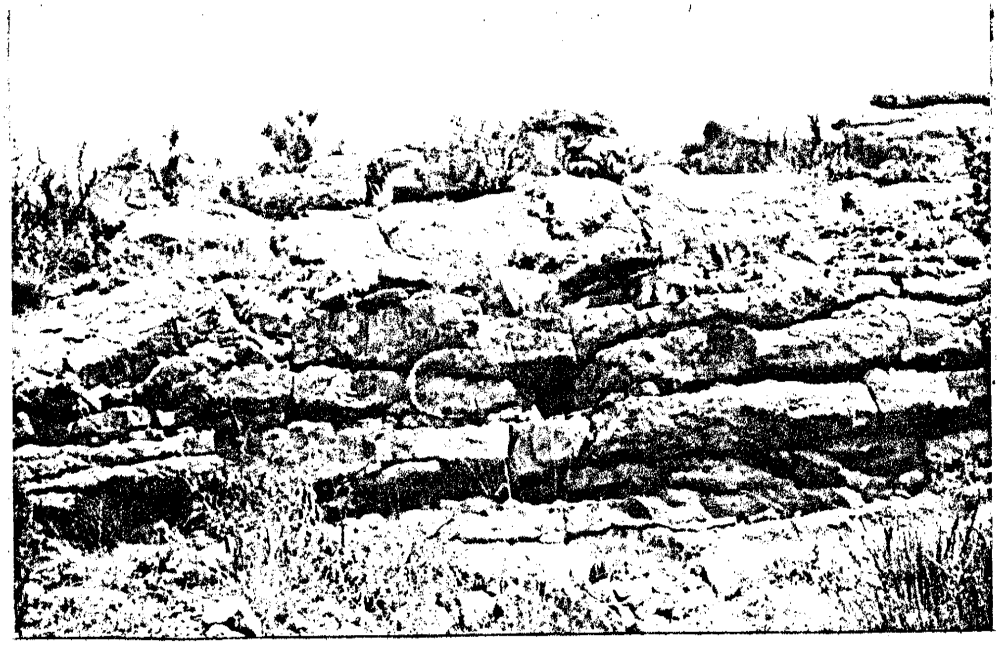
B

PLATE I

PLATE 2

A. Medium-bedded, slightly cherty fossiliferous limestone of the upper Burrego formation in Section A.

B. Weathered bedding surface in the lower portion of the Story Formation in Section A. The mottling is due to algae.



A

B

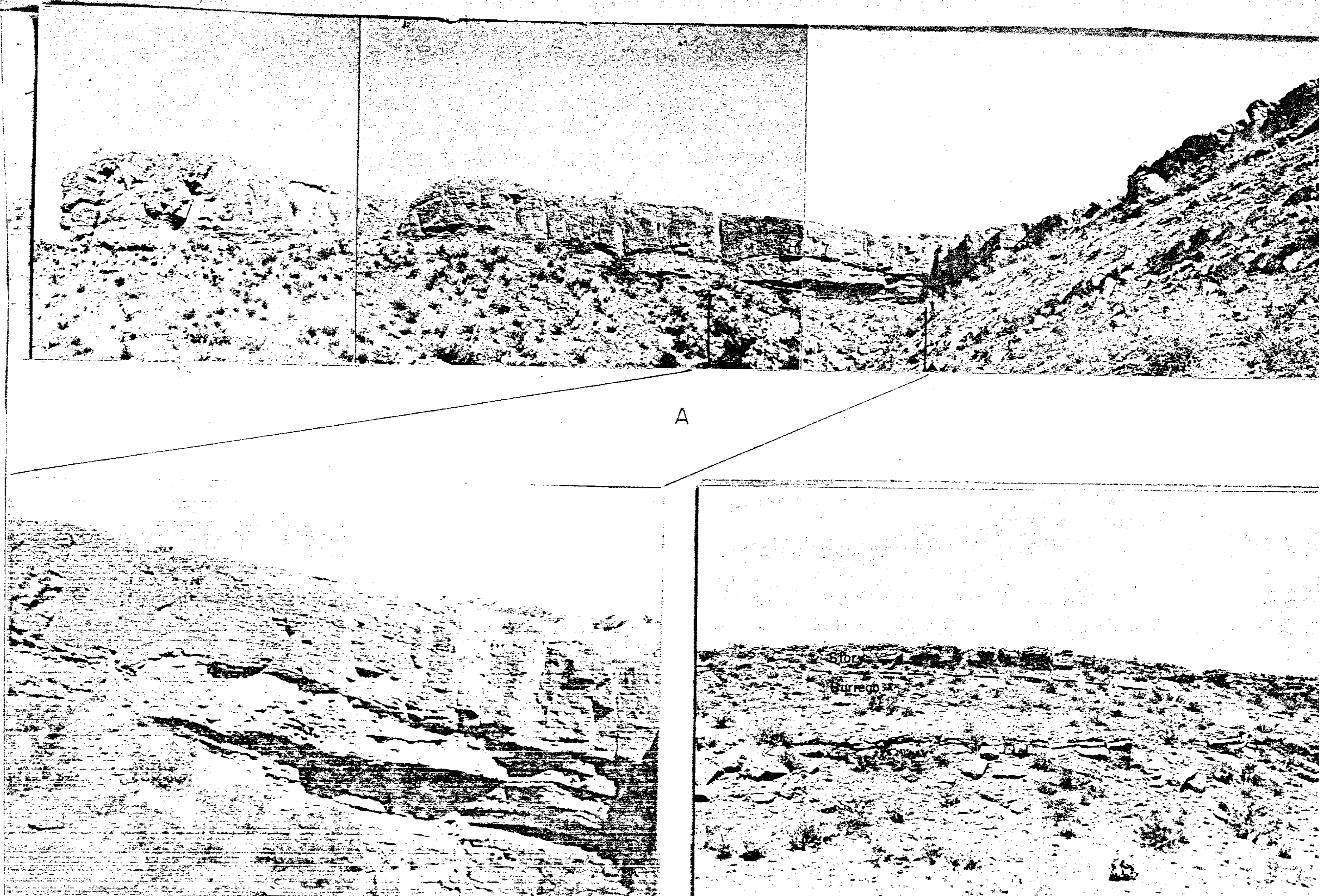
PLATE 2

PLATE 3

A. A composite picture of the bioherm within the Council Springs Formation at Section B.

B. A close-up of the same bioherm. Note thin-bedded and platy limestone above and below the massive, lens-shaped reef. The total thickness of the reef and upper limestone is 18 feet.

C. A thin, nodular limestone cropping out in covered shale slope: Burrego formation at Section B. The Story-Burrego contact lies below a quartz grit beneath the massively bedded limeston cliff within the Story formation.



A

B

C

PLATE 3

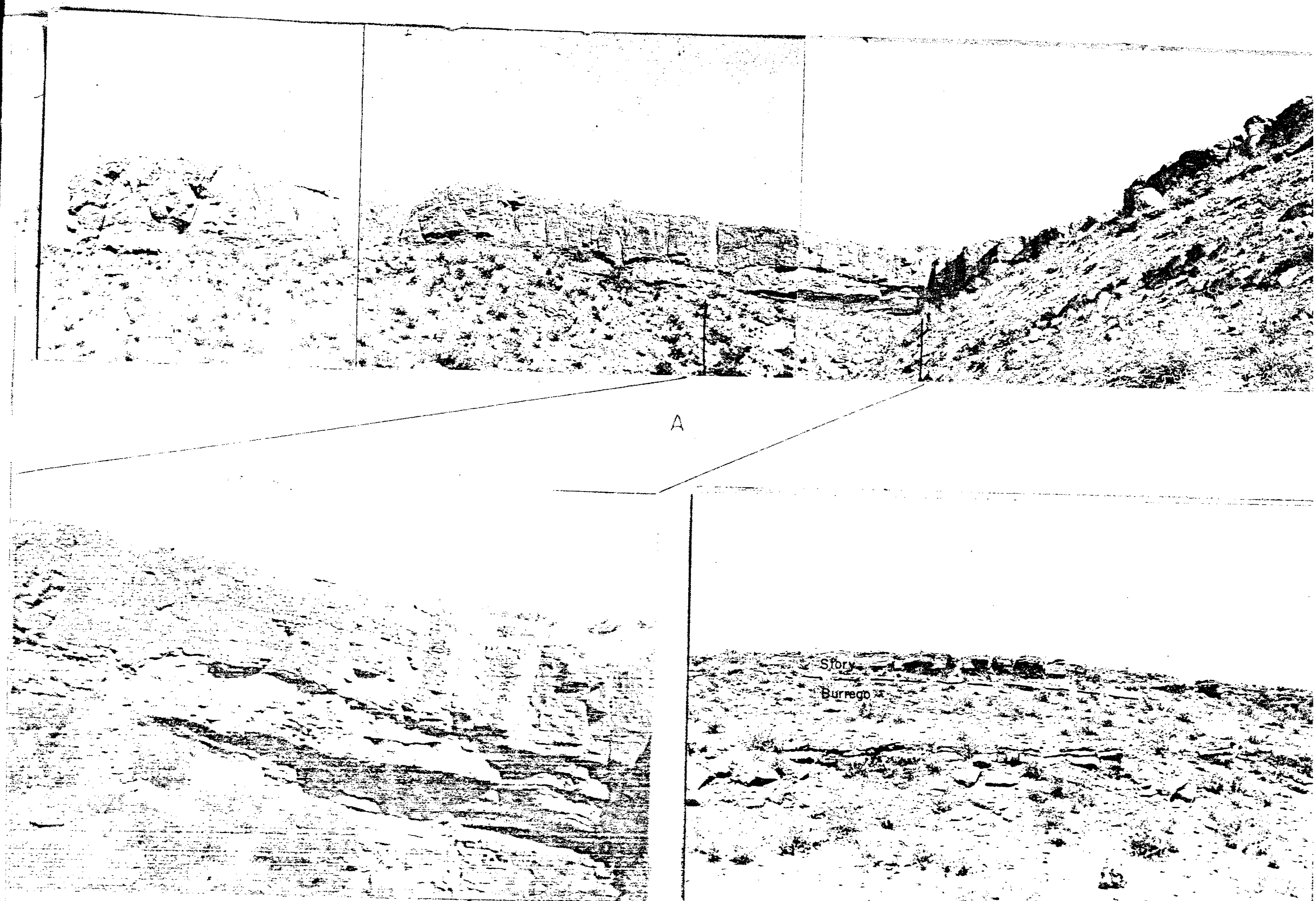


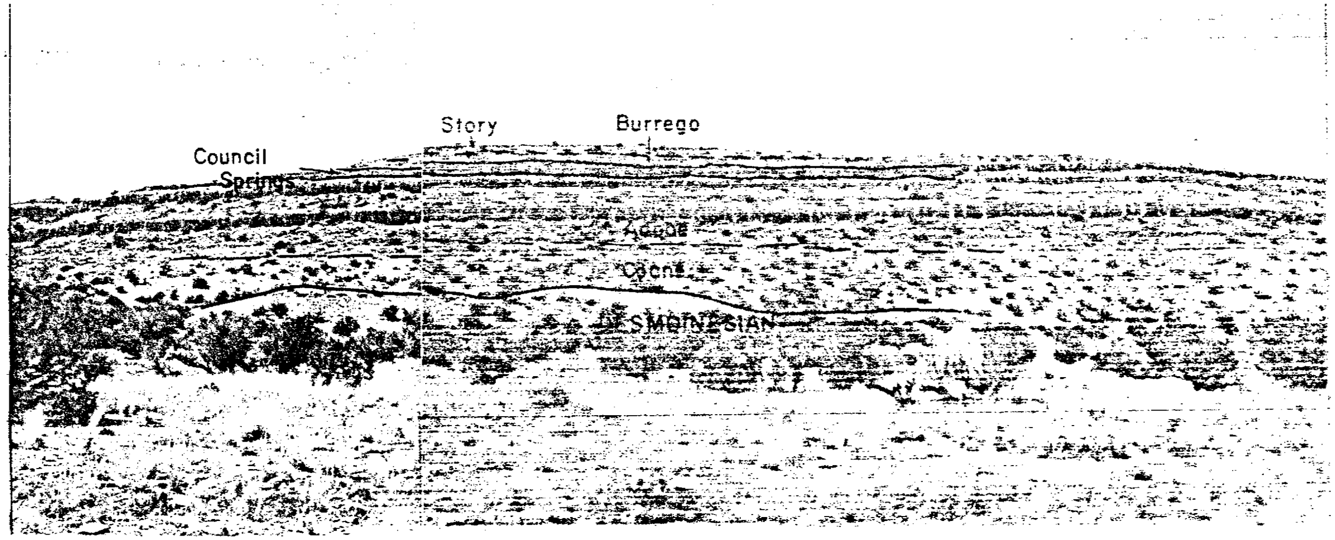
PLATE 3

PLATE 4

A. Composite picture of Section C at the north end of Mesa Sarca. The lower two cliffs are both within the Adobe formation; the upper cliff is the Council Springs formation.

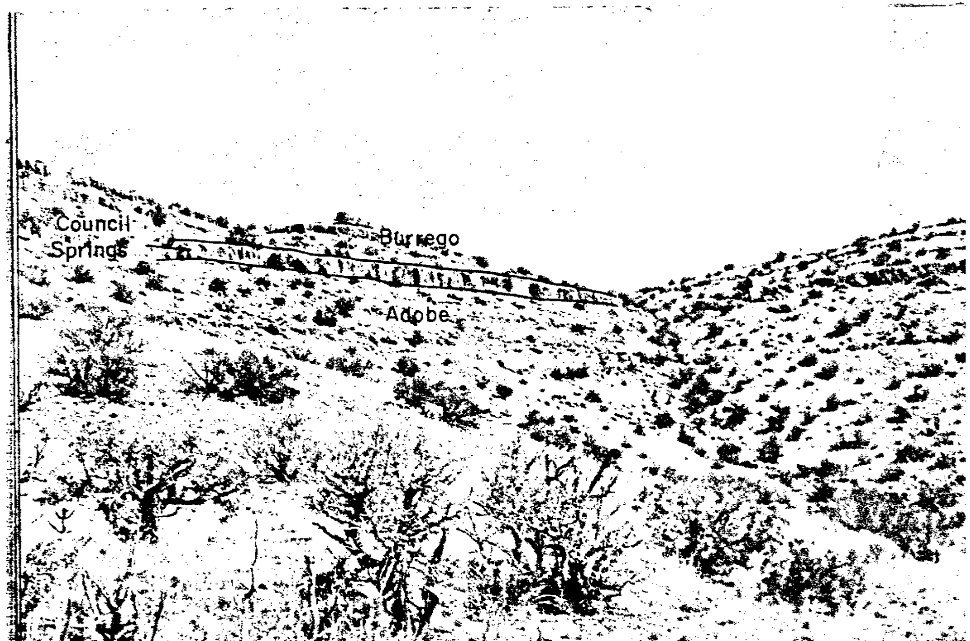
B. Exposure of a quartz grit lens within the Story formation at Section C. The lens grades laterally into nodular, argillaceous limestone.

C. Close-up of cliffs in Adobe, Council Springs, and lower Burrego formations in Section C.


Council
Springs
Story
Burrego
Adobe
Cocne
DESMOINESIAN

A

B


Council
Springs
Burrego
Adobe

C

PLATE 4

CARBONATE CLASSIFICATION

The most recent carbonate classification was proposed by Folk (1959). Folk's classification introduces new terminology for the detailed lithology of carbonate rocks; however, the writer is primarily interested in reconstructing paleoenvironments from detailed examination of the lithologies present. For this reason, Folk's classification has been modified, and his terminology adopted only where convenient.

End member classifications have been very useful in studies of sedimentary rocks (Pettijohn, 1949, p. 84). Folk employs a triangular end member diagram with allochemical constituents, microcrystalline calcite ooze, and sparry calcite cement representing the vertices. The system used in this report combines the amounts of microcrystalline calcite ooze and sparry calcite cement under the heading "orthochemical constituents"; these combined constituents represent one vertex of the triangle, while the remaining two vertices are represented by allochemical constituents and insoluble residues. This change restricts some detailed determinations of winnowed sediments, but is utilized as it brings out possible fluctuations of the strand line. Winnowed sediments are herein defined as any carbonate rock from which at least 50% of the matrix material, composed of microcrystalline calcite ooze, has been removed before final burial. During diagenesis the pore space is filled by sparry calcite. The three end members are defined as follows:

1. Allochemical constituents are composed of calcium carbonate and are clastic or detrital in nature, having undergone some form of transportation. Most carbonate rocks contain one or more of the following allochemical constituents.

   a. Lithoclasts or intraclasts. These are broken up or disturbed fragments of previously or contemporaneously formed carbonate rock, deposited with other allochemical or orthochemical material. Intraclasts may range in size from a few mm. up to many feet in length. These fragments are indicative of unstable bottom conditions or severe agitation of the bottom by waves or currents.

   b. Fossils. Sessile, planktonic, and vagrant forms are all classified as allochemical constituents. Fossils are extremely important in evaluating depositional environments.

   c. Ooliths. Both radial and concentric ooliths are considered as allochemical constituents, and indicate shallow water and agitated bottoms.

d. Pellets. Pellets are well-rounded and well-sorted particles of microcrystalline calcite. They have a wide range in size, with a maximum diameter of 0.2 mm. Pellets may represent fecal matter of invertebrates.

2. Orthochemical constituents are either microcrystalline calcite ooze or coarsely crystalline calcite cement, herein referred to as sparry calcite cement. They show little or no transportation.

a. Microcrystalline calcite ooze. These particles are chemically or biochemically precipitated within the basin of sedimentation. In thin section the ooze is cloudy to milky white, and has a particle size range of from 1 to 5 microns. Calcite ooze may be compared with the accumulation of clay particles that forms the matrix material in many immature sandstones.

b. Sparry calcite cement. Sparry calcite is usually precipitated in place as a simple pore filling. It may be distinguished from microcrystalline ooze in thin section by its larger grain size (10 microns or more) and by its optical clarity. The presence of sparry calcite not due to recrystallization is indicative of winnowing action that has removed the microcrystalline ooze.

3. Insoluble residue is defined as the material remaining after the sample has been leached with a dilute solution of hydrochloric acid. The residue, generally composed of quartz, chert, clay minerals, carbonaceous or organic matter, feldspar, and a variety of "heavy" minerals, has

a wide range in size, shape, and surface textures. Investigation of insoluble residues yields information on the location and composition of landmasses surrounding the site of deposition, and helps interpret certain environmental factors of the sea bottom at the time of deposition.

METHODS OF STUDY

Hand specimens of carbonate rock were collected in the field at distinct changes of lithology rather than at a particular interval. The samples were cut on a diamond saw, and one side etched for 30 seconds in dilute HCl. After etching, each sample was examined for possible thin section study. Twenty-seven thin sections were chosen to represent the different microlithologies from the three measured sections.

The etched samples were then painted with clove oil (any oil with an index of refraction similar to that of calcite is acceptable) and examined with a binocular microscope. The percentages of the three end members were estimated, and the amount and type of each constituent (i.e. fossils, matrix: sparry calcite or ooze, etc.) were recorded. This information, along with the environment of deposition, is recorded in Tables 1, 2, and 3.

The insoluble residues are easily estimated from the etched samples, as the non-carbonate material is left in relief. Several checks on the estimated percentages were run by standard methods, and the results agreed to within ± 1% in the samples low in insoluble residues, and to within ± 5% in the samples with a higher insoluble residue content.

Approximately six residues were obtained from each stratigraphic section measured. This material was dried and sieved, and the coarser material examined with a binocular microscope. Differential thermal analyses were run on the fine fraction, and the clay minerals identified where possible.

ANALYSES OF ETCHED SAMPLES AND THIN SECTIONS

The composition of all the carbonate samples collected for the total Missourian sequences in each location is plotted on the triangular diagrams (Figures 3, 4, and 5). Although the clastic rocks were not collected, their stratigraphic thicknesses were recorded. Clastic ratios have been determined from these measurements to show the variation of clastic and non-clastic material for all locations.

Section A has a clastic ratio of 1/3 which means there is three times as much limestone as clastic material. The triangular diagram of Section A (Figure 3) shows the composition of the carbonate rocks collected from that locality. The samples from Section A are grouped along the line joining the orthochemical and allochemical constituents. Orthochemical constituents predominate in a majority of the samples. The maximum amount of insoluble residue is 50% found in sample 25.

Section B has a clastic ratio of 4, i.e., in the total section there is 4 times as much clastic material as carbonate. In Figure 4 there is no strong grouping of the carbonate samples at any vertex. An increase in the amount of insoluble residues is reflected by the shift of the points toward that vertex.

Section C has a clastic ratio of 2.5. The distribution of the samples in Figure 5 shows that a majority have high percentages of orthochemical constituents, low percentages of insoluble residues, and low to moderate amounts of allochemical material.

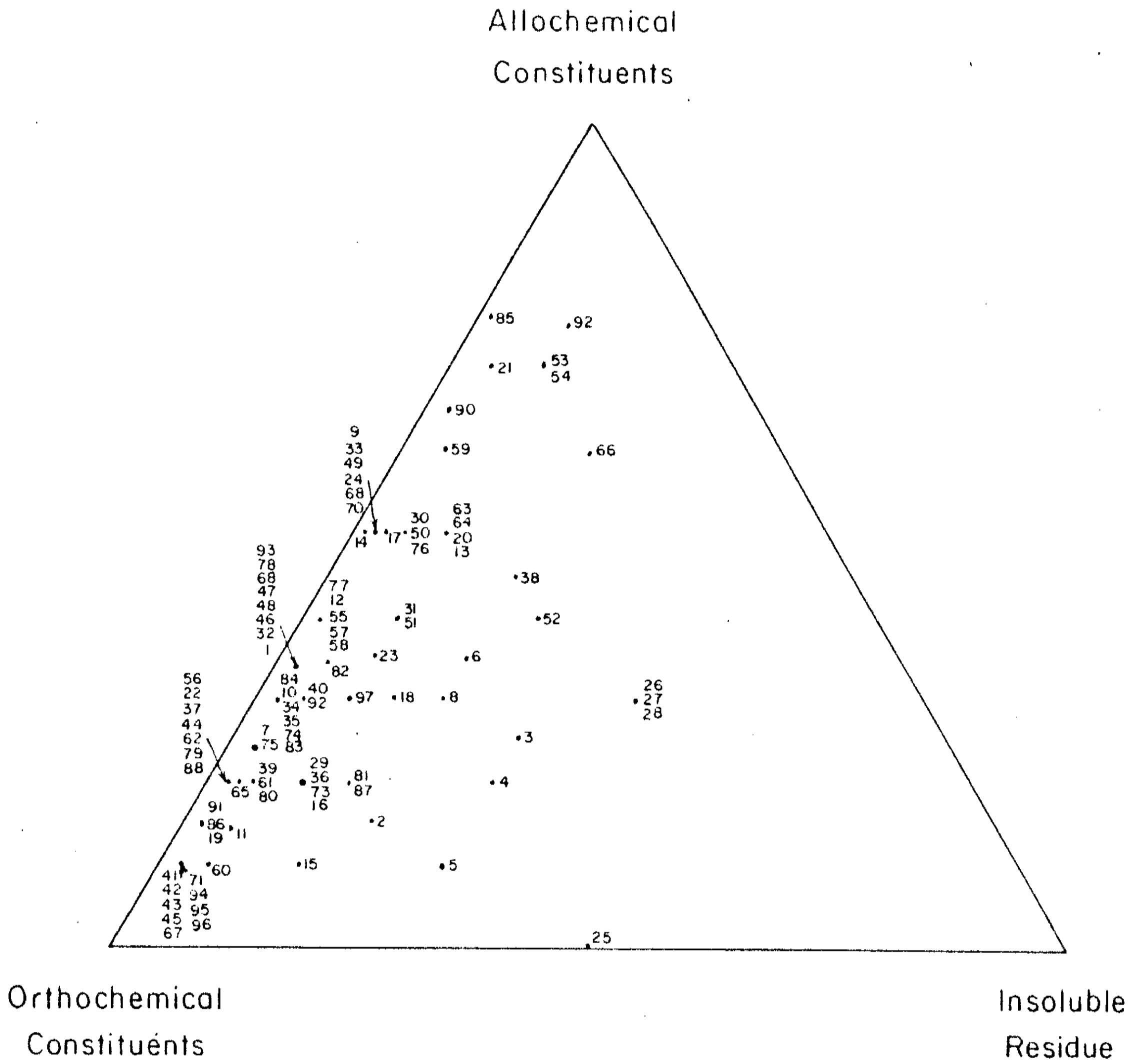
Although the triangular diagrams can express the gross lithologic changes between samples, they have certain limitations. Three samples may have identical percentages of each end member, yet the allochemical constituents of one might be predominantly fossils, another intraclasts, and the third ooliths. Their depositional environments would be different, yet they would all occupy the same position on the diagram. The necessary additional data is recorded on tables to show the variations within each end member. All this information is required for effecting a reconstruction of the depositional environment.

The letters A, M, and S within the tables abbreviate abundant, moderate, and scarce, respectively. This nomenclature pertains only to variations in each individual end member, and does not indicate their relative percentages. For example, the triangular diagram of Section A shows that sample 6 has 20% insoluble residue, 35% allochemical constituents, and 45% orthochemical constituents. Table 1 indicates that of this 20% insoluble material, clay minerals dominate but moderate amounts of quartz silt are also present. Microcrystalline calcite ooze is the sole component of the 45% orthochemical constituents. The 35% allochemical constituents is fossil detritus with a moderate amount of intraclastic material present.

FIGURE 3

FIGURE 3

Triangular diagram showing distribution of carbonate samples collected from Section A.

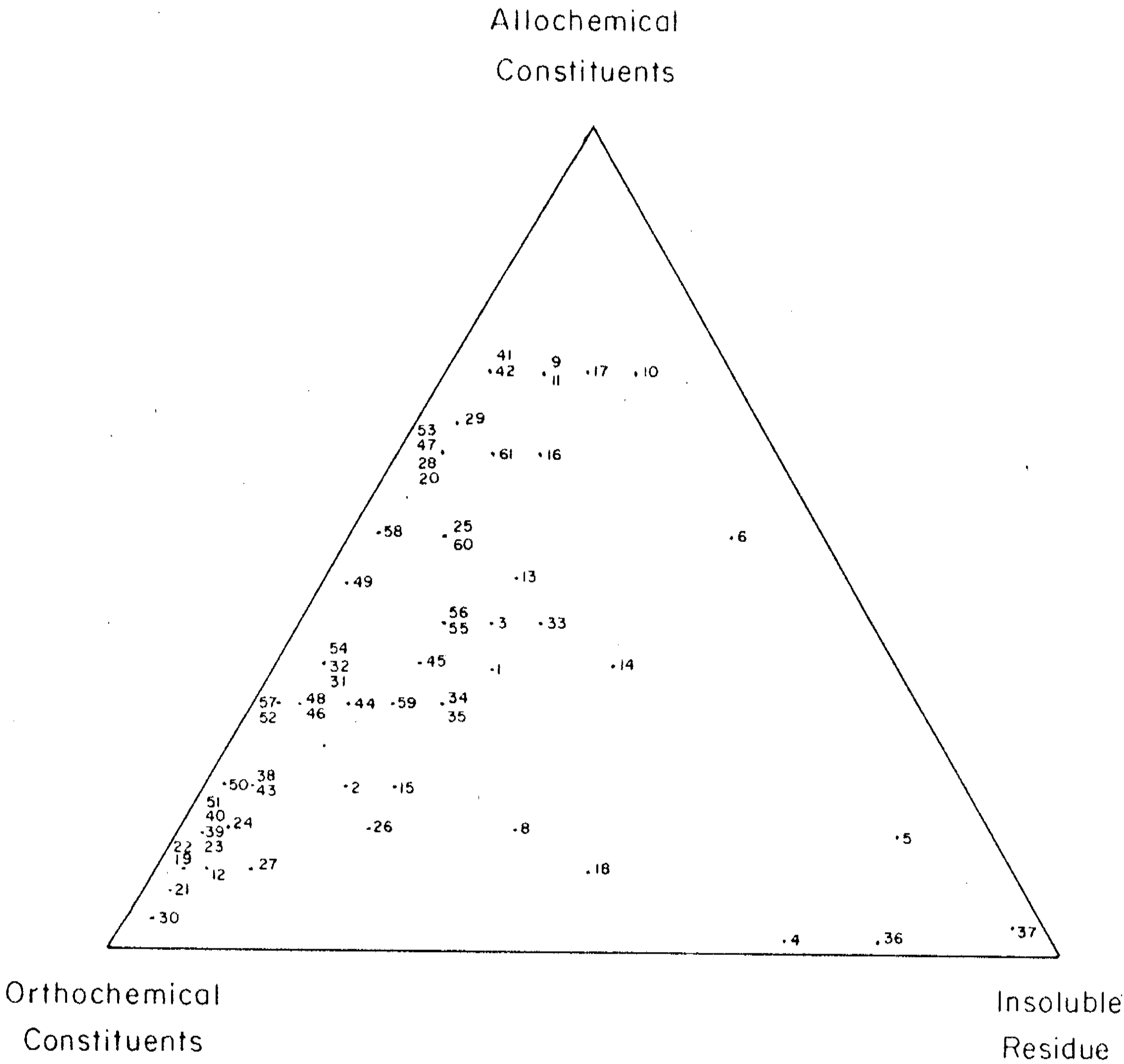

Allochemical Constituents
Orthochemical Constituents
Insoluble Residue

SECTION A

FIGURE 4

FIGURE 4

Triangular diagram showing distribution of carbonate samples collected from Section B.

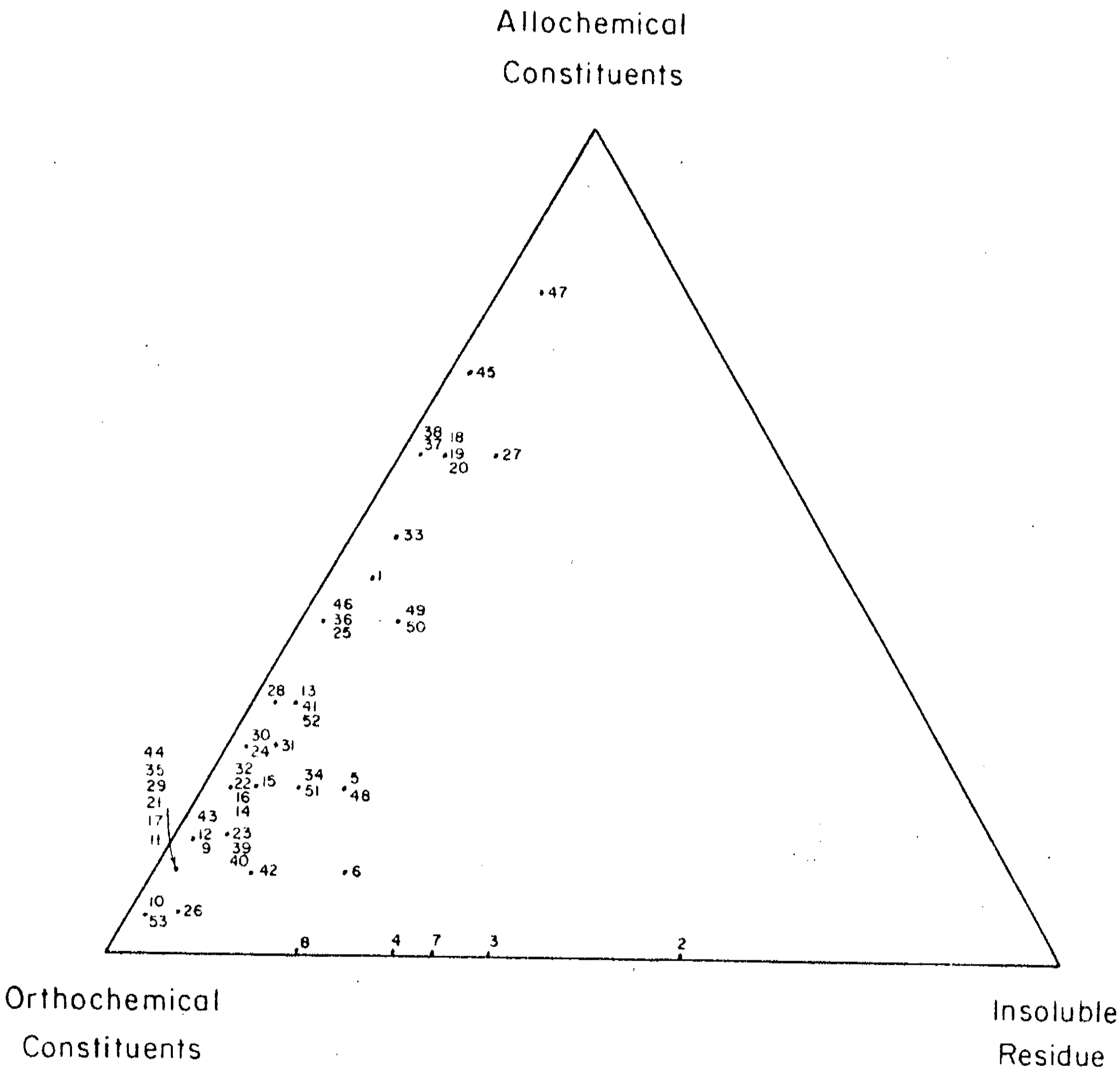

Allochemical Constituents
Orthochemical Constituents
Insoluble Residue

SECTION B

FIGURE 5

FIGURE 5

Triangular diagram showing distribution of carbonate samples collected from Section C.


Allochemical Constituents
Orthochemical Constituents
Insoluble Residue
47
45
38
37
18
19
20
27
33
1
46
36
25
49
50
28
13
41
52
30
24
31
44
35
29
21
17
11
32
22
16
14
15
34
51
5
48
43
12
9
23
39
40
42
6
10
53
26
8
4
7
3
2

SECTION C

Abbreviations:

Allochems:	Allochemical constituents
Orthochems:	Orthochemical Constituents
Insol. Res:	Insoluble Residue
S.:	Scarce
M.:	Moderate
A.:	Abundant
Winn.:	Winnowed
Unwinn.:	Unwinnowed
Intracl.:	Intraclastic
Biocl.:	Bioclastic
Intraform.:	Intraformational
Congl.:	Conglomerate
SS.:	Sandstone
Part.:	Partially

SECTION A

TABLE 1

Sample number		Allochems				Orthochems		Insoluble residue				Environment
Laboratory Sample No.	Field Sample No.	Fossils	Intraclasts	Ooliths	Pellets	Microcrystal-line calcite	Sparry calcite cement	Quartz	Chert	Clay minerals	Feldspar	
1	A1	S	A			A		M		M		Unwinn. intracl.
2	A2	M	M			A		M		M		Unwinn. intracl.
3	A3	M	M			A	S	M		S		Unwinn. intracl.
4	A4	A				A		M		A		Unwinn.
5	A5	M			S	A	S	M		A		Unwinn. biocl.
6	A6	A	M			A		M		A		Unwinn. biocl.
7	A7	M	M			A		S		S		Part. winn. intracl.
8	A8	A				A		M		A		Unwinn. biocl.

TABLE 1 (Cont.)

Sample number		Allochems				Orthochems		Insoluble residue				Environment
Laboratory Sample No.	Field Sample No.	Fossils	Intraclasts	Ooliths	Pellets	Microcrystal-line calcite	Sparry calcite cement	Quartz	Chert	Clay minerals	Feldspar	
9	A9	A				M	A	S		S		Winn. biocl.
10	A10	M	S			A	S	M		S		Part. win. biocl.
11	A11	M	S			A	S	M		M		Part. win. biocl.
12	A12	A				S	M	S		S		Winn. biocl.
13	A12A	A				S	M	M		M		Winn. biocl.
14	A12B	A				S	M	M		M		Winn. biocl.
15	A13	M				A		M		M		Unwinn.
16	A14	A				A		M		M		Unwinn.
17	$A14_1$	S	A			M	M	S		S		Part. winn. intracl.
18	$A14_2$	A				A		M		M		Unwinn.
19	A15	A				A		S		S		Unwinn.
20	A16	S	A			A	S	M		M		Part. winn. intracl.
21	A17A	S	A			S	A	M		M		Winn. intracl.
22	A17B	A				A	S	S		S		Unwinn. biocl.
23	A17C	M	A			A		M		M		Unwinn. biocl. & intracl.
24	A18	S	A			A	S	S		S		Unwinn. biocl. & intracl.
25	A19A						A	A		M		Winn. ss.
26	A19B						A	A		M		Winn. ss.
27	A19C						A	A		M		Winn. ss.
28	A19D						A	A		M		Winn. ss.
29	A20A	A				A	M	M		M		Unwinn. biocl.
30	A20B	A				A		S		S		Unwinn.
31	A21	A				M	M	M		M		Part. winn. biocl.
32	A22	A				A		S		S		Unwinn.
33	A23	A				A	S	S		S		Part. winn.
34	A24A	A				A		S		S		Unwinn. biocl.
35	A24B	A				A		S		[illegible]		Unwinn. biocl.
36	A24C	M				A		M	M	S		Unwinn. biocl.
37	A24D	A				A	S	S		S		Part. winn. biocl.
38	A25	A				S	A	M		M		Win. biocl.

TABLE 1 (Cont.)

Sample number		Allochems				Orthochems		Insoluble residue				Environment
Laboratory Sample No.	Field Sample No.	Fossils	Intraclasts	Oolliths	Pellets	Microcrystal-line calcite	Sparry calcite cement	Quartz	Chert	Clay minerals	Feldspar	
39	A26A	A				A	M	S		S		Part. winn. biocl.
40	A26B	S	A			A		S		S		Unwinn. intracl.
41	A27A	S				A		S		S		Unwinn.
42	A27B	S				A		S		S		Unwinn.
43	A27C	S				A		S		S		Unwinn.
44	A27D	S				A		S		S		Unwinn.
45	A28A	S				A		S		S		Unwinn.
46	A28B	M	S		S	A		S		S		Unwinn. biocl.
47	A28C	M	M		S	A		S		S		Unwinn. biocl. & intracl.
48	A28D	M	M		S	A		S		S		Unwinn. biocl. & intracl.
49	A28E	S	A			M	A	S		S		Winn. intracl.
50	A29A	M	M			S	A	M		M		Winn.
51	A29B	A				S	A	M		M		Winn.
52	A29C	A	S			M	M	A		M		Unwinn.
53	A29D	A					A	M		M		Winn.
54	A29E	A					A	M		M		Winn.
55	A29F	A	M			A	S	M		S		Unwinn.
56	A29G	M	S			A	S	M		S		Unwinn.
57	A29H	M	M		S	A	S	S		S		Unwinn.
58	A29I	M	M		S	A	S	S		S		Unwinn.
59	A29K	A	S			S	A	M		S		Winn.
60	A30A	S				A		S		S		Unwinn.
61	A30B	M	S			A	S	S		S		Unwinn.
62	A30	M	S			A		A		M		Unwinn.
63	A31A	A				A		M		M		Unwinn.
64	A31B	A				A		M		M		Unwinn.
65	A31C	M	M			A	S	M		S		Unwinn.
66	A31	A				A	S	A		M		Unwinn.
67	A31D	M				A		S		S		Unwinn.
68	A31E	A				A		S		S		Unwinn.

TABLE 1 (Cont.)

Sample number		Allochems				Orthochems		Insoluble residue				Environment
Laboratory Sample No.	Field Sample No.	Fossils	Intraclasts	Oolites	Pellets	Microcrystal-line calcite	Sparry calcite cement	Quartz	Chert	Clay minerals	Feldspar	
69	A32A	A				A	S	S		S		Unwinn.
70	A32B	A				A		S		S		Unwinn.
71	A32C	S	M			A	S	S		S		Unwinn.
72	A32D	M	M			A	M	M		M		Unwinn. intracl.
73	A32E	A	S			M	M	M		M		Part. winn.
74	A33A	A				A	S	S		S		Unwinn.
75	A33B	A				A	S	S		S		Unwinn.
76	A33C		A				A	S		S		Winn. intracl.
77	A33D	A	M			A		M		S		Unwinn. intracl.
78	A35A	A				A		M		S		Unwinn.
79	A35B	A				A		M		S		Unwinn.
80	A35C	A				A		M		S		Unwinn.
81	A35D	A				A		M		S		Unwinn.
82	A36A	A	M			A		M		S		Unwinn.
83	A36B	M	M			A		S		S		Unwinn.
84	A36C	M	M			A		S		S		Unwinn.
85	A36D	A				A		S		S		Unwinn.
86	A36E	M	S			A	S	S		S		Unwinn.
87	A37A	A				A		M		M		Unwinn.
88	A37B	A				A		S		S		Unwinn.
89	A37C		A				A	S		S		Winn. intracl.
90	A37D	A					A	S		S		Winn. biocl.
91	A37E	A				A	S	S		S		Unwinn.
92	A38A	A				A	S	S		S		Unwinn.
93	A38B	A	S			M	M	S		S		Part. winn.
94	A38C	A				M	M	S		S		Part. winn.
95	A38D	M				M	M	S		S		Part. winn.
96	A38E	M	M			M	M	S		S		Winn. intracl.
97	A38 F	A					A	M		M		Winn. biocl.

SECTION B

TABLE 2

Sample number		Allochems				Orthochems		Insoluble residue				Environment
Laboratory Sample No.	Field Sample No.	Fossils	Intraclasts	Ooliths	Pellets	Microcrystalline calcite	Sparry calcite cement	Quartz	Chert	Clay minerals	Feldspar	
1	B1	A	M			S	M	A		M		Winn. biocl.
2	B1A	A				A		A		M		Unwinn.
3	B1B	A				S	M	A		M		Winn.
4	B2A					M		A	M	A	M	Near-shore
5	B2B					M		A	M	A	M	Near-shore
6	B2C	A				A		A	S	A		Back-reef
7	B2D	A				A		M		A		Back-reef
8	B2E	M	M			A		M		M		Back-reef
9	B2F	A					A	S		M		Back-reef
10	B2G	A					A	S		M		Back-reef
11	B3A	A				A		S		S		Back-reef
12	B3B	M				A		S		S		Unwinn.
13	B4A	A					A	A		A		Reef-flank
14	B4B	A				A		M		M		Back-reef
15	B4C	A				A		M		M		Back-reef
16	B5	A				A		M		M		Back-reef
17	B5A	A				A		M		M		Back-reef
18	B5B	M				A		A		M		Unwinn.
19	B6A	M				A		S		S		Unwinn.
20	B7	A					A	M		S		Back-reef
21	B7A	M				A		S		S		Unwinn.
22	B7B	M				A		S		S		Unwinn.
23	B7C	M				A		S		S		Unwinn.
24	B7D	M				A		S		S		Unwinn.
25	B8A	A				A		A		M		Back-reef
26	B8B	M					A	A		M		Winnowed
27	B8C	M	M			A		M		M		Unwinn. intracl.
28	B8D	A					A	M		M		Back-reef
29	B8D'	A					A	M		M		Back-reef
30	B8E					A		S		S		Lagoonal

TABLE 2 (Cont.)

Sample number		Allochems				Orthochems		Insoluble residue				Environment
Laboratory Sample No.	Field Sample No.	Fossils	Intraclasts	Ooliths	Pellets	Microcrystal-line calcite	Sparry calcite cement	Quartz	Chert	Clay minerals	Feldspar	
31	B8F	A				A		M		M		Lagoonal
32	B8G	A				A		M		M		Lagoonal
33	B9A	A				A		M		M		Lagoonal
34	B9B	M	M			A		M		M		Unwinn. intracl.
35	B9C	M	M		S	A		M		M		Intracl.
36	B10A					M		A	M	A		Near-shore
37	B10B	A				A		M		M		Unwinn.
38	B10C	M				A		S		S		Unwinn.
39	B10D	M	M			A		S		S		Unwinn.
40	B10E	A					A	M		M		Winn. back-reef
41	B10F	A	S				A	M		M		Winn. back-reef
42	B10F'	A	A				A	M		M		Winn. back-reef
43	B10G	S	A			A		M		M		Unwinn. intracl.
44	B10H	A				S	A	M		M		Part. winn. biocl.
45	B10K	A	M	M			A	M		M		Shallow winn.
46	B10L	M	A			A	M	M		S		Biocl. intracl.
47	B10M	A	M				A	M		S		Winn. intracl.
48	B10N	A					A	M		S		Winn. biocl.
49	B11A		A				A	M		S		Winn. intracl.
50	B11B	M	A				A	M		S		Winn. intracl.
51	B11C	A	M			A		M		S		Unwinn. intracl.
52	B11D	A	S		S	A		S		S		Unwinn. biocl.
53	B12A	A					A	M	M	S		Winn. biocl.
54	B12B	A				M	M	M		M		Part. winn. biocl.
55	B12C	A				M	M	M		M		Part. winn. biocl.
56	B12D	A				A	S	M		M		Part. winn. biocl.
57	B12E	A				A		S		S		Unwinn. biocl.
58	B12F	A					A	S		S		Near-shore winn.
59	B13A	A				M	M	M		M		Shallow biocl.
60	B13B	A				A		M		M		Unwinn.
61	B13C	A					A	M	M	S		Winn. biocl.

SECTION C

TABLE 3

Sample number		Allochems				Orthochems		Insoluble residue				Environment
Laboratory Sample No.	Field Sample No.	Fossils	Intraclasts	Ooliths	Pellets	Microcrystal-line calcite	Sparry calcite cement	Quartz	Chert	Clay minerals	Feldspar	
1	C1A	A	S			S	A	S		S		Winn. biocl.
2	C2A					A		A		A		
3	C2B					A		A		A		
4	C2C					A		A		A		
5	C2D	A				A		M		M		Unwinn. biocl.
6	C2E	M				A		A		M		Unwinn. biocl.
7	C2F					A		A		A		
8	C2G					A		A		A		
9	C3A	M				A		S		S		
10	C3B	M				A		S		S		
11	C3C	M				A		S		S		
12	C3D	M				A		M		M		Unwinn. biocl.
13	C3E	A				A		M		S		Unwinn. biocl.
14	C3F	A				A		S		S		Unwinn. biocl.
15	C3G	A				A		S		S		Unwinn. biocl.
16	C4A	A				A		M		S		Unwinn. biocl.
17	C4B	M				A		S		S		Unwinn. biocl.
18	C4C		A			M	M	M		S		Intracl.
19	C5A	A	S				A	M		M		Winn. biocl.
20	C5B	A					A	M		M		Winn. biocl.
21	C5C	M				A		S		S		
22	C5D	A				A		S		S		Unwinn. biocl.
23	C5E	A				A		S		S		Unwinn. biocl.
24	C5F	A				A		S		S		Unwinn. biocl.
25	C5G	A				A		S		S		Unwinn. biocl.
26	C6A	S				A		M		M		
27	C6B	A					A	M		M		Winn. biocl.
28	C7A	A				A		S		S		Unwinn. biocl.
29	C7B	M	S			A		S		S		Unwinn. biocl.

TABLE 3 (Cont.)

Sample number		Allochems				Orthochems		Insoluble residue				Environment
Laboratory Sample No.	Field Sample No.	Fossils	Intraclasts	Oolites	Pellets	Microcrystal-line calcite	Sparry calcite cement	Quartz	Chert	Clay minerals	Feldspar	
30	C7C	A				A		S		S		Unwinn. biocl.
31	C7D	A				A		S		S		Unwinn. biocl.
32	C7[illegible]	A				A		S		S		Unwinn. biocl.
33	C7F	A					A	M		M		Shallow winn.
34	C8A	A				A		M		M		Unwinn. biocl.
35	C8B	A				A		S		S		Unwinn. biocl.
36	C8C	M	A			M	A	S		S		Winn. intracl.
37	C8D	M	A				A	S		S		Intraform. congl.
38	C8E	M	A			S	A	S		S		Intraform. congl.
39	C9A	A				A		M		S		Unwinn. biocl.
40	C9B	A				A		M		S		Unwinn. biocl.
41	C9C	A				A	S	M		M		Unwinn. biocl.
42	C9D	A				A		M		M		Unwinn. biocl.
43	C9E	A				A		S		S		Unwinn. biocl.
44	C9F	A				A		S		S		Unwinn. biocl.
45	C9G	A					A	S		S		Shallow winn. biocl.
46	C10A	A	M				A	S		S		Shallow winn. biocl.
47	C10B	A				M	M	M		S		Shallow winn. biocl.
48	C10C	A				A		M		M		Unwinn. biocl.
49	C11A	A				A		M		M		Unwinn. biocl.
50	C11B	A				A		M		M		Unwinn. biocl.
51	C11C	A				A		M		M		Unwinn. biocl.
52	C11D		A			A		M		S		Intraform. congl.
53	C11E	M				A		S		S		Unwinn. biocl.

PLATE 5

A. Thin section, sample A24C; Adobe formation, Section A. X 25

Fossiliferous calcarenite; grains show poor sorting and little transportation. Particles consist of fusulinids and recrystallized brachiopod fragments. Some areas of clear calcite may be the result of recrystallization. Matrix is predominantly microcrystalline calcite ooze with some quartz silt and clay minerals. Note the sparry calcite precipitated as primary pore filling within the chambers of the fusulinid.

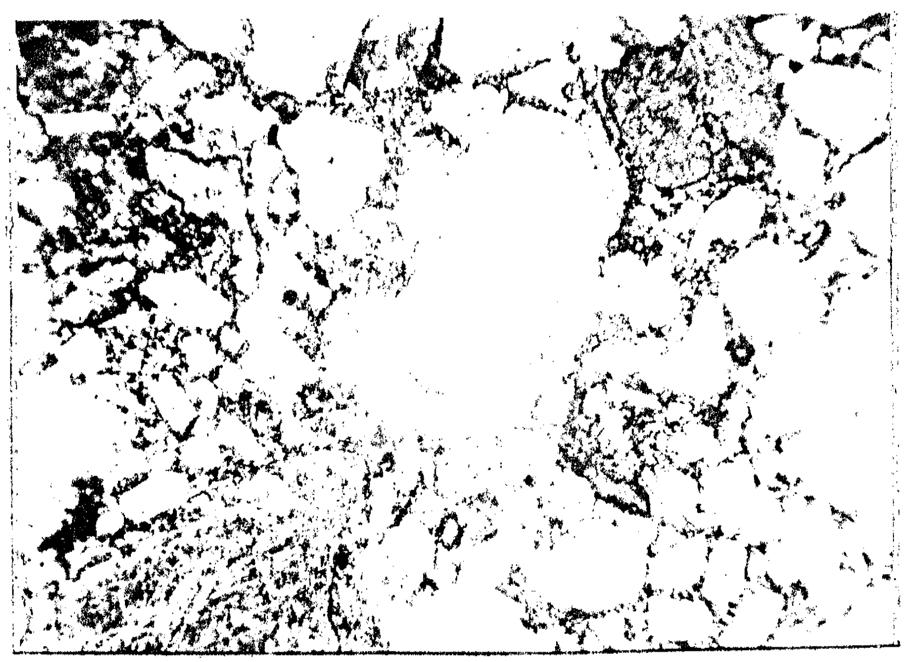
Interpretation: From the amounts of fine lime ooze matrix, one may infer a lack of winnowing currents. Brachiopod and fusulinid shells indicate normal salinity, and calm, warm waters. Sediments of this type have been interpreted as deposited in the infraneritic zone.

B. Thin section, sample B2B; base of Adobe formation, Section B. X 25

Quartz grit; particles are dominantly poorly sorted, coarse quartz grains. Rounded intraclasts of calcilutite are visible in upper right corner of photograph. Some altered feldspar and muscovite grains are present. Note the replacement of quartz by lime matrix in largest quartz grain. Such a sutured boundary could not have been retained during transportation. Matrix is predominantly recrystallized calcite ooze rather than sparry calcite precipitated as pore filling.

Interpretation: This material lies directly above the unconformity in Section B. It probably represents rapid erosion of the source area coupled with moderate transportation and fairly rapid burial. Since the sediments above are highly algal, this unit was probably deposited in the shallow, epineritic zone.

A



B

PLATE 5

PLATE 6

A. Thin section, sample A29B; base of Burrego formation, Section A. X 25

Bioclastic calcarenite. Particles consist of foraminifera, bryozoa, crinoids, brachiopod spines, and large grains of recrystallized calcite showing polysynthetic twinning. Dark gray patch at left is an intraclast of calcilutite. Matrix is almost entirely sparry calcite. This may represent recrystallization of microcrystalline ooze.

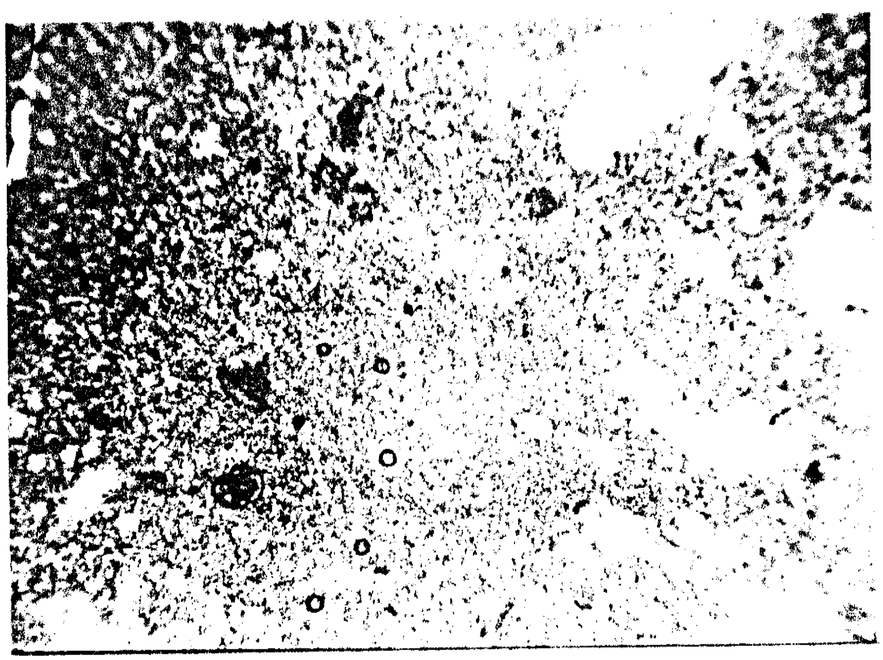
Interpretation: Typical winnowed bioclastic calcarenite of the epineritic zone.

B. Thin section, sample A28A; base of Council Springs formation, Section A, X 25

Typical calcilutite or micrite (Folk, 1959). Scarce allochems consist of foraminifera and brachiopod(?) fragments. Irregular patches of mosaic calcite probably represent recrystallization. Matrix contains moderate amounts of quartz silt, clay minerals, and organic material. Most of the rock consists of microcrystalline calcite ooze with minor pellets.

Interpretation: This sediment probably represents low turbulence in the epineritic zone.

A



B

PLATE 6

PLATE 7

A. Thin section, sample A32D; Burrego formation, Section A. X 25

Lithoclastic and finely bioclastic limestone. Fragments show poor sorting but good rounding. Lithoclasts are composed of fine bioclastic material that is coarser than the lime ooze matrix. Fossils are fusulinids, foraminifera, and fine brachiopod detritus. Irregular white patches are recrystallized calcite.

Interpretation: Sediment was probably developed in the infraneritic zone. Although the fragments show good rounding, the poor sorting and high percentage of ooze indicates a lack of winnowing currents.

B. Etched section, sample B4A; Adobe formation, Section B. X 5

Typical reef-flank fossiliferous limestone. Fauna consists of pelecypods, gastropods, cephalopods, brachiopods, crinoids, bryozoa, and algae. Small, oolitic algae, formed around shell or quartz grains, are abundant throughout. The matrix is predominantly "reef milk" derived from the abrasion of the reef wall by waves. Although this sediment was deposited in proximity to severe agitation, the protective nature of the bioherm is indicated by the presence of lime ooze.

Interpretation: Shallow water deposit developed on the lee side of a bioherm. The molluscan fauna represents predators dwelling around and on the biohermal mass.

A

B

PLATE 7

PLATE 8

Etched section, sample B2G; Adobe formation, Section B. X 40

Sponge-algal pisolitic limestone. Algae generally incorporate a shell fragment as a nucleus, and in some instances whole gastropod shells have been used. Matrix is sparry calcite cement.

Interpretation: Sediment accumulated in shallow water less than 90 feet, and shows partial winnowing. From associated sediments, this may represent a lagoonal facies of a reef complex.

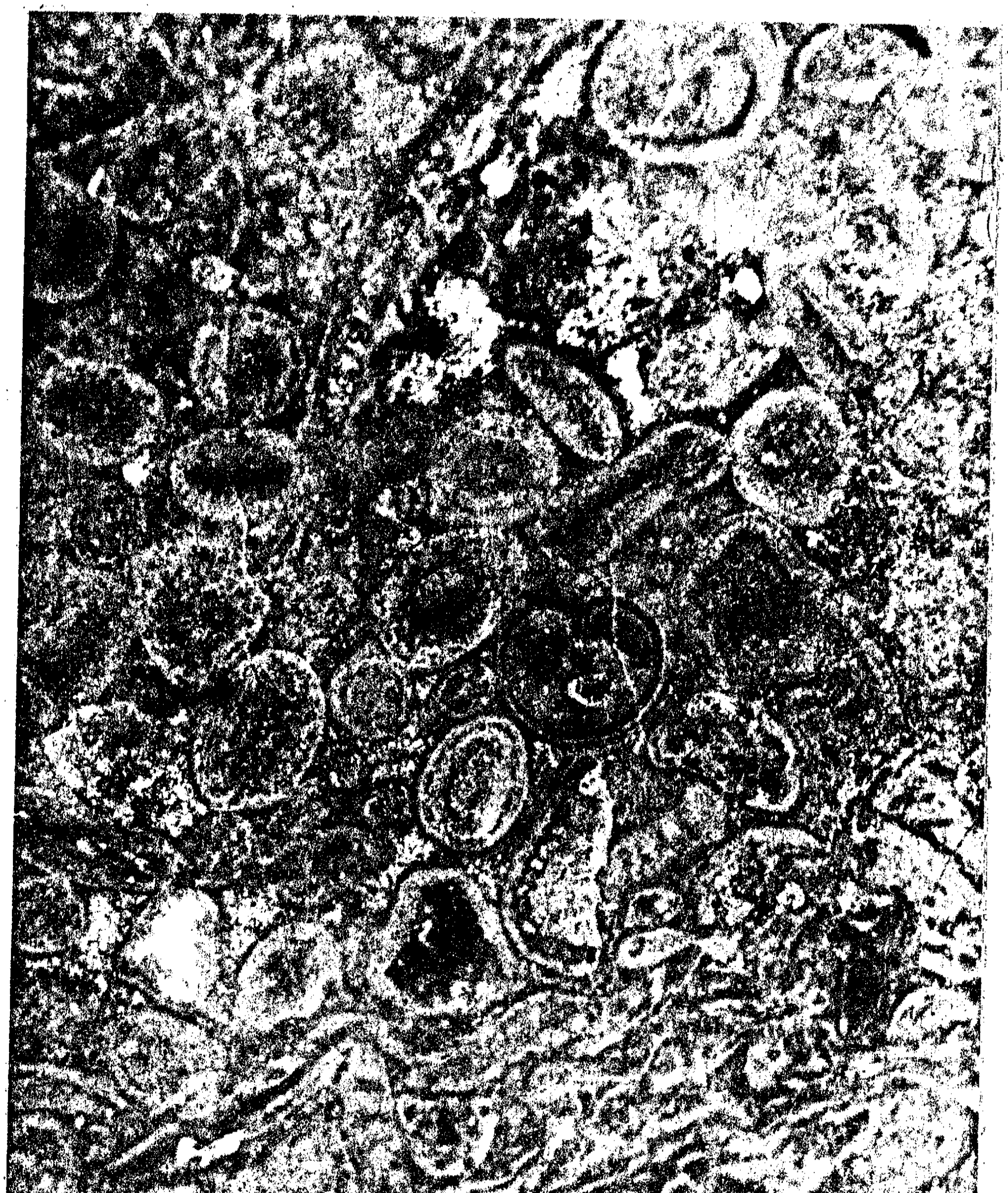


PLATE 8

DIFFERENTIAL THERMAL ANALYSES

Several samples of insoluble residues obtained from the carbonate rocks were analyzed by differential thermal methods. The location of samples within the three sections and the thermal curves obtained are shown in Figures 6, 7, and 8.

The endothermic peaks (Section A, Figure 6) at 120-175° C are given by the dehydration of the clay mineral montmorillonite (Kerr, Kulp, and Hamilton, 1949). The slight variations of these particular peaks may be due to dilutents or different crystal size. The broad exothermic portion of the curves is a characteristic reaction following the endothermic peak. The curve obtained from sample A37A shows the endothermic reaction of montmorillonite. However, the character of the exothermic peak is quite different than all other samples. The residue contained large quantities of carbonaceous material, lacking in other samples, and this curve may be a result of the burning off of the carbon. Shales were sampled in Section A, and DTA's were run on some of them. High percentages of montmorillonite are present in these samples also. The sharp endothermic peak at 800° C obtained from the shale samples is due to carbonate; this has been removed by leaching in sample 2'. The low endothermic peak at 600° C in sample 5 is interpreted as kaolinite.

Differential thermal curves obtained from samples in Section B show more or less well-developed endothermic peaks at 100-150° C, and in general a strong endothermic peak at 550-600° C. This is interpreted as low to moderate amounts of montmorillonite (120° peak), and medium to high percentages of kaolinite. The kaolinite peaks from the insoluble residues are slightly lower than normal (600° C), but x-ray measurements verified its common occurrence in these samples.

The clays from Section C are similar to those in Section B. The kaolinite peaks obtained from samples in Section C are not as well-developed, but this is probably due to lower percentages of the mineral.

The occurrence of both kaolinite and montmorillonite presents an interesting problem in genesis. Montmorillonite is the normal clay mineral formed in alkaline marine waters. However, with time, and the addition of potassium ions, this mineral usually alters to a mica type (poorly crystallized illite) or to K-bentonite. Grim (1953, p. 356) states ". . . montmorillonite is generally absent in sediments older than the Mesozoic". There are three possible reasons that montmorillonite has not altered to illite. If the montmorillonite was introduced into the basin of deposition from a volcanic origin (montmorillonite is generally the clay mineral formed under these conditions), and the potassium magnesium ratio was less than 1.0 (i.e. magnesium greater than potassium), montmorillonite would be the stable form. Secondly, "An acid igneous rock containing considerable quantities of potassium as well as magnesium, under weathering conditions permitting the potash and magnesia to remain in the weathering environment after breakdown of the parent minerals, will yield illite and montmorillonite as the alteration products. If the content of magnesium is low, illite will be the only product, and if the content of potash is low, montmorillonite will be the only product." (Grim, 1953, p. 342). Finally, the montmorillonite may form in situ within the basin of deposition, and if the magnesium ions exceed the potassium ions, (as is the case in present-day sea water) this mineral will be the only persistent and stable form. Since there is no known volcanic activity in the area during the Missourian, and abundant kaolinite is present in two sections, suggesting that potassium and magnesium were removed from the weathering zone, the third possibility appears to be the most satisfactory.

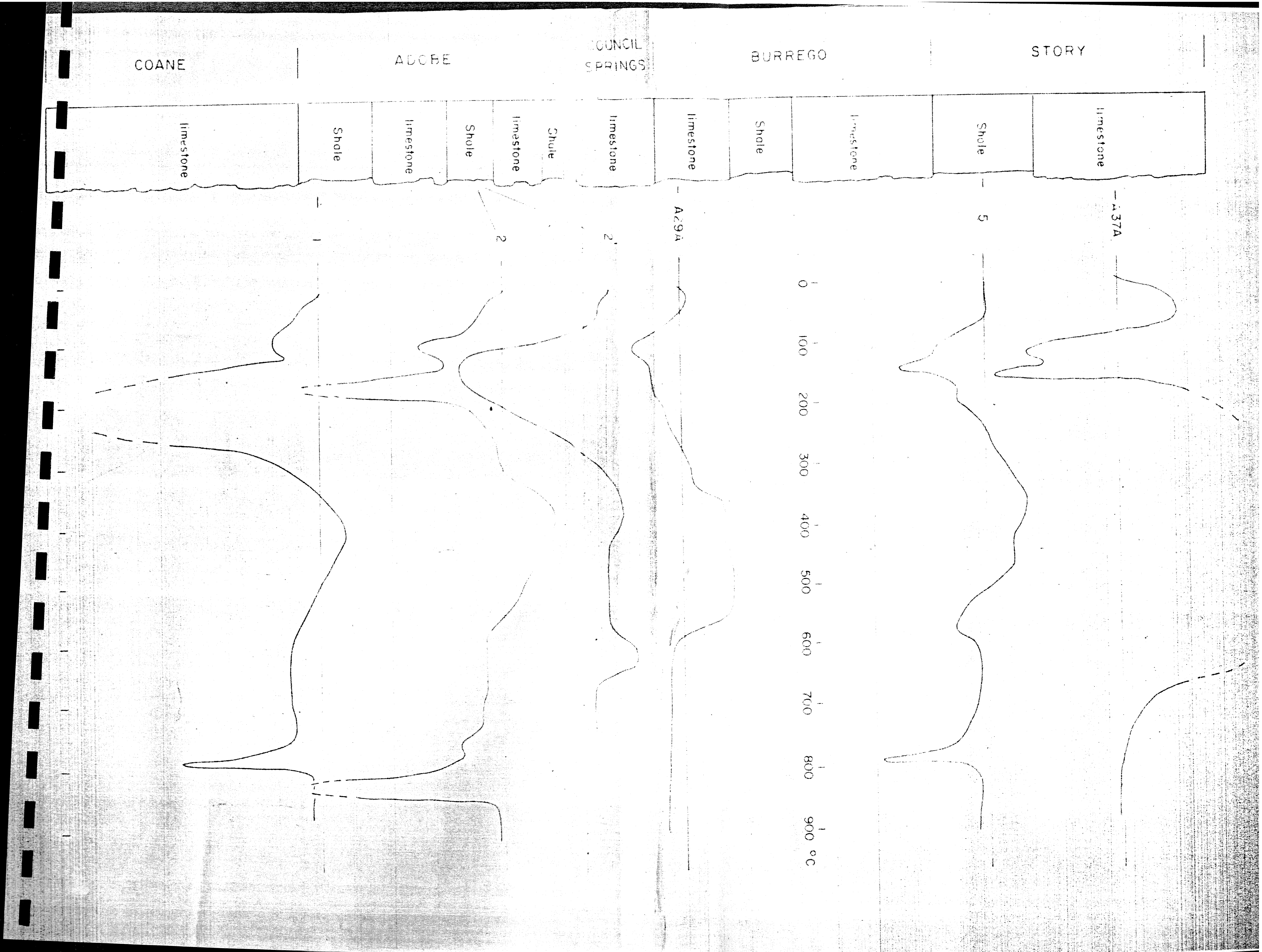
Millot has presented evidence that high percentages of calcium ions will block the formation of kaolinite (Grim, 1953, p. 351). It would appear that the kaolinite present in these residues could not have formed in situ within the basin of deposition, but must have come from a source area rich in this mineral. Millot (1952, p. 108) has postulated that the mineral kaolinite is transported from the source area to the basin of deposition by fresh, acid streams (pH 2.8 to 6.2). The formation of kaolinite is favored by rapid leaching of an acid terrain and the consequent removal of magnesium and potassium from the weathered zone by high rainfall coupled with good drainage.

The cursory examination of the clays suggests that the basin of sedimentation had high concentrations of calcium and magnesium ions, a low concentration of potassium ions, and a pH range of 7.2 to 8.8. The source area or areas for the two northern sections supplied kaolinite derived from an acid terrain.

FIGURE 6

FIGURE 6

Differential thermal curves of clay minerals obtained from shales and insoluble residues collected from Section A.



COANE
ADOBE
COUNCIL SPRINGS
BURREGO
STORY
limestone
Shale
limestone
Shale
limestone
Shale
limestone
limestone
Shale
limestone
Shale
limestone
A29A
5
A37A
0
100
200
300
400
500
600
700
800
900 °C

FIGURE 7

FIGURE 7

Differential thermal curves of clay minerals from insoluble residues of carbonate rocks collected from Section B.

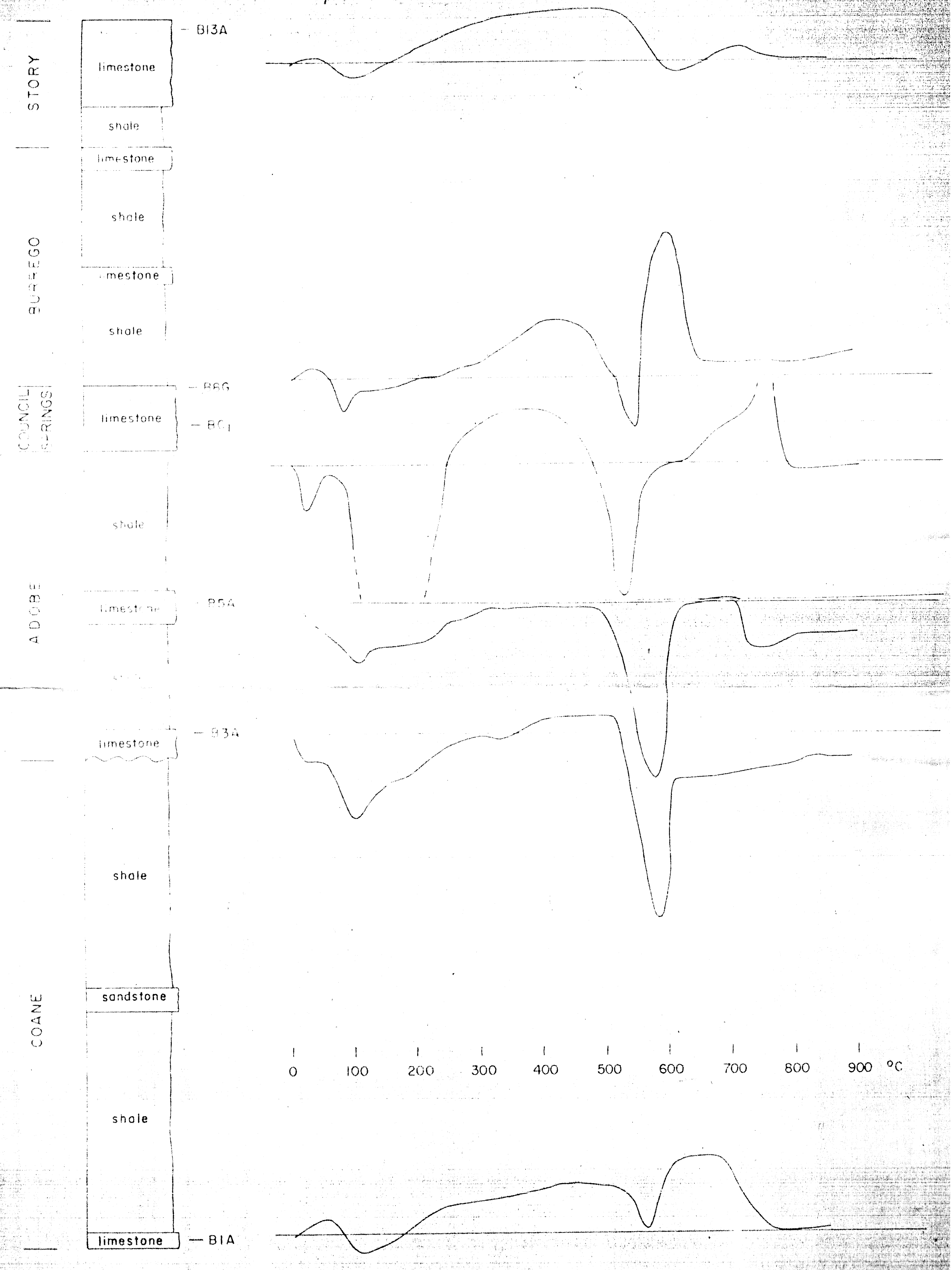
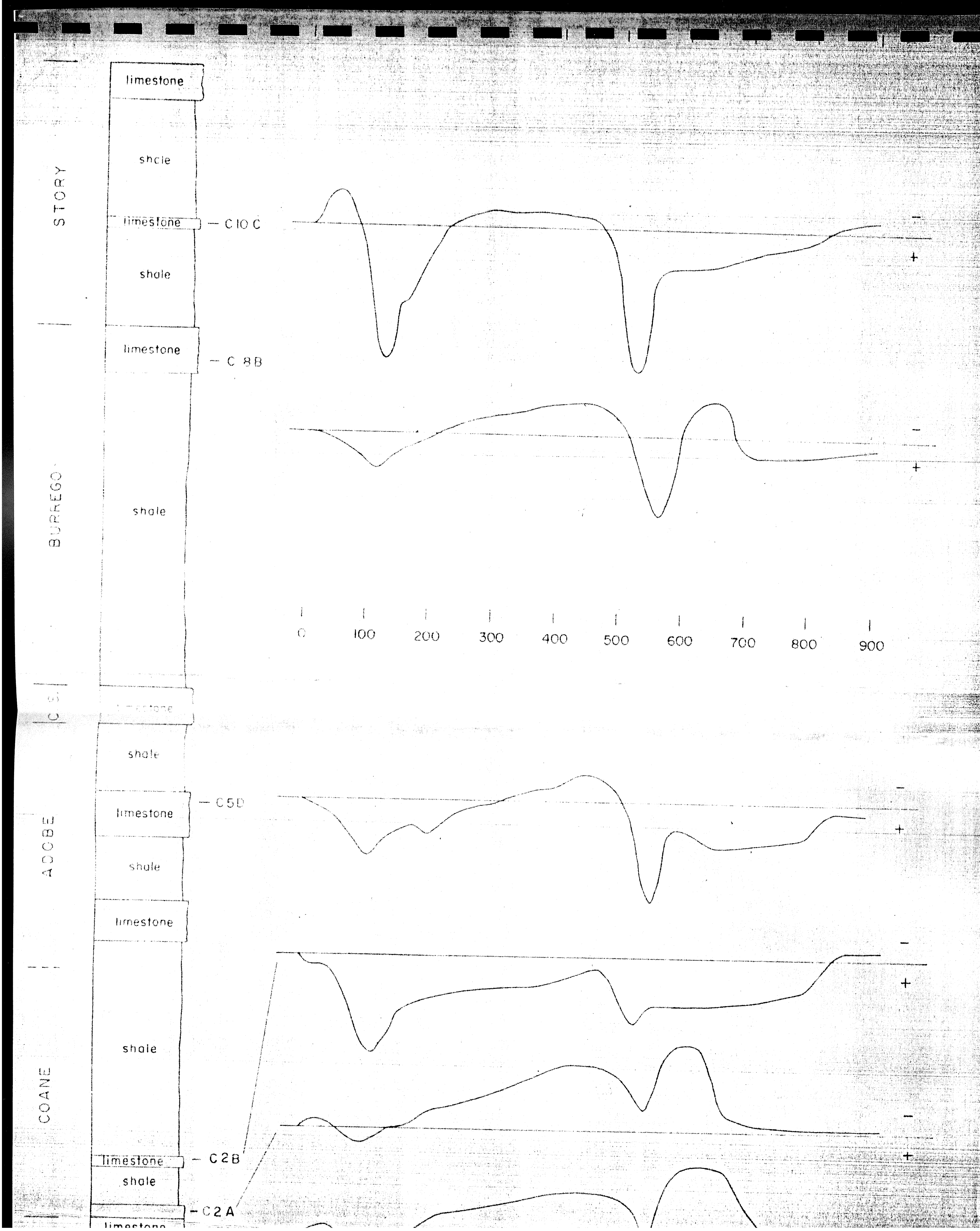

STORY
BURREGO
COUNCIL SPRINGS
ADOBE
COANE
limestone
shale
limestone
shale
limestone
shale
limestone
shale
limestone
limestone
shale
sandstone
shale
limestone
B13A
B8G
BC1
B5A
B3A
B1A
0
100
200
300
400
500
600
700
800
900 °C

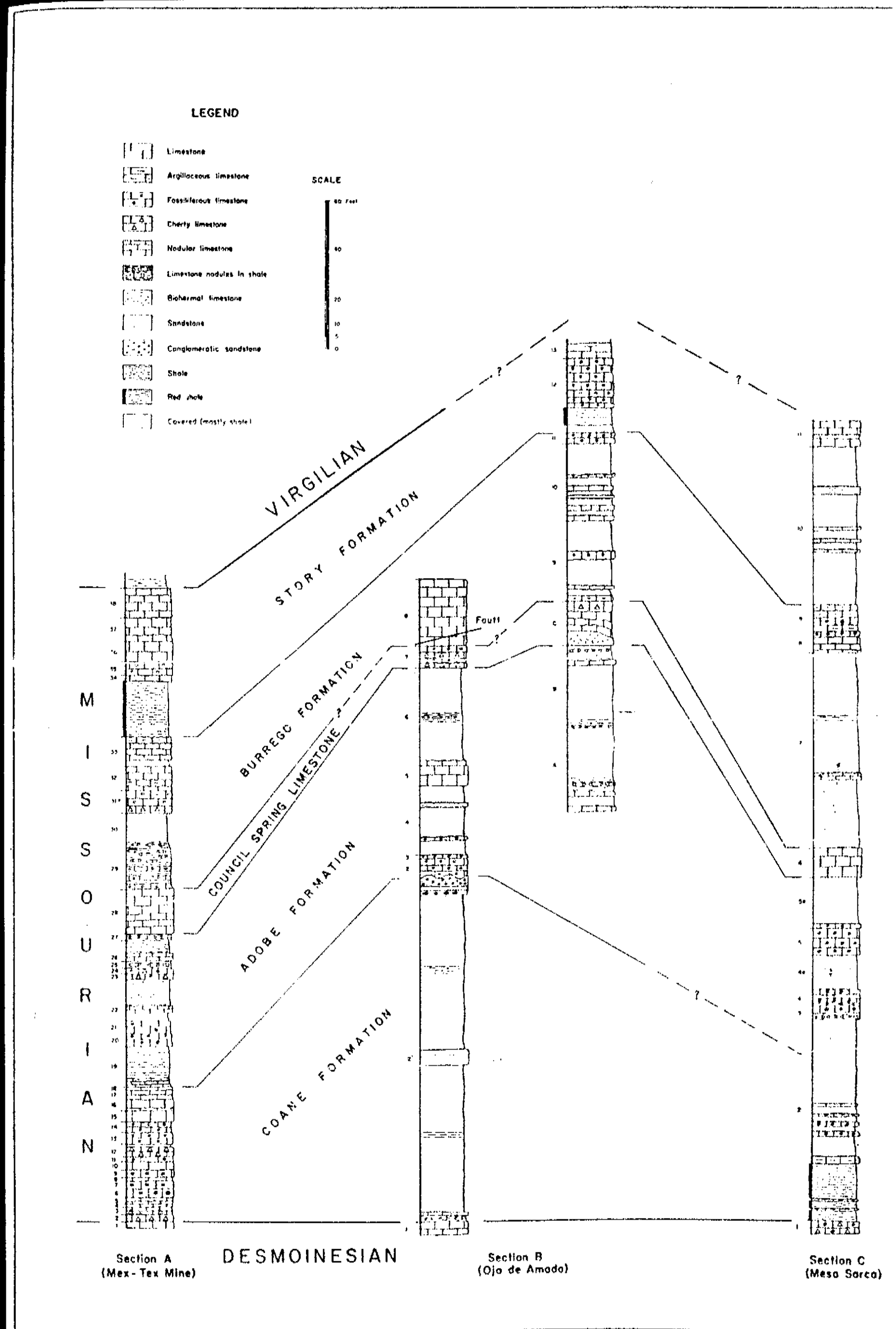
FIGURE 8

[illegible]

FIGURE 8

Differential thermal curves of clay minerals from insoluble residues of carbonate rocks collected from Section C.


STORY
BURREGO
C.S.
ADOBE
COANE
limestone
shale
limestone
shale
limestone
shale
shale
limestone
shale
limestone
shale
limestone
shale
limestone
C10C
C8B
C5D
C2B
C2A
0
100
200
300
400
500
600
700
800
900
-
+



LEGEND
Limestone
Argillaceous limestone
Fossiliferous limestone
Cherty limestone
Nodular limestone
Limestone nodules in shale
Biohermal limestone
Sandstone
Conglomeratic sandstone
Shale
Red shale
Covered (mostly shale)
SCALE
VIRGILIAN
STORY FORMATION
BURREGO FORMATION
COUNCIL SPRING LIMESTONE
ADOBE FORMATION
COANE FORMATION
Fault
M I S S O U R I A N
DESMOINESIAN
Section A (Mex-Tex Mine)
Section B (Ojo de Amado)
Section C (Mesa Sarca)

ENVIRONMENTS OF DEPOSITION

The field and laboratory data is integrated to ascertain the environments of deposition for each formation at each locality. Where a paucity of definitive foss ls and carbonate microtextures is present within the section (notably the thick clastics of Sections B and C), environmental conditions are determined primarily from the amount and nature of the clastic material. In general, however, a wealth of information may be obtained from the microtextures, fossils, and nature of the insoluble residues within the carbonate rocks.

The Coane formation in Section A is represented by both epineritic and infraneritic sediments (Krumbein and Sloss, 1951, p. 209). A brachiopod-crinoid fauna alternates with a fusulinid fauna. The sediments associated with the brachiopod-crinoid fauna are moderately bioclastic, poorly winnowed to unwinnowed, low in lithoclasts and insoluble residues. These sediments were probably deposited in the epineritic zone at depths of less than 100 feet. The marine waters were characterized by normal salinity and oxygen content. The paucity of intraclasts, and the slight amount of sorting or abrasion due to transportation indicates a lack of strong current or wave movements. The sea bottom was soft calcareous mud favorable to a burrowing and vagrant benthos fauna. The sediments associated with the fusulinids and cate deposition in the slightly deeper water of the infraneritic zone (100-150 feet), where currents and wave action are minimized. These sediments lack lithoclasts, exhibit no winnowing, and contain much fine clastic material. Where currents were absent, the finest clastic material settled out and was incorporated with the calcareous ooze. The top of the Coane formation is a typical intraformational conglomerate which grades upward into arkosic sandstone. An uplift of the source area accompanied by shallowing of the adjoining sea bottom is postulated to account for this abrupt coarsening of the deposits. The shallowing of marine areas adjacent to the landmass caused the earlier formed calcareous sediments to be exposed to the disintegrating effects of wind, water, and temperature variations (phenomena typical of present tidal flats). The resulting fragments were transported into deeper water, and deposited as an intraformational conglomerate. Continued uplift of the source area increased stream gradients, and an influx of coarse clastics blanketed the carbonate layers.

The Coane formation is similar in Sections B and C. Both sections contain a large proportion of fine clastics which are interbedded with thin argillaceous limestones. The limestones contain brachiopod-crinoid faunas like those found in Section A. It is reasonable to assume essentially comparable depositional conditions for these limestones. An epineritic zone where rapid deposition of fine clastics inhibited the formation of limestone is postulated for the northern portion of Socorro County during Coane time. Occasional clearing of the waters allowed thin, fossiliferous limestones to form from accumulating fossil detritus. The Coane formation at Section B was deposited close to the strand line at this time. Uplift of the source area and partial subaerial exposure of the adjoining shoals is reflected in this section by coarse clastics, and the disconformity at the Coane-Adobe contact.

The Adobe formation at Section A shows some similarities to the Coane at the same location, but fine clastics dominate the unit. The faunas alternate between brachiopod-crinoid and fusulinid suggesting oscillations of the epineritic and infraneritic zones across the site. The absence of lithoclasts and sparry calcite cement indicate a lack of currents; the sediments were accumulating at water depths not exceeding 50 to 150 feet.

Above the disconformity in Section B, the Adobe formation is characterized by reef-flank and back-reef facies. The reef site is not known, but its proximity (to the southwest) can be inferred from the fauna and lithology. An abundance of pisolitic, sponge-like algae (Dasycladaceae) indicates very shallow depths (possibly as shallow as 10 feet) for those sediments accumulating in the lagoonal or in the back-reef facies. These facies are characterized by abundant algae, soft mud bottoms, moderate amounts of fine clastics, and generally clear and calm water. The dominant matrix material of the back-reef facies is microcrystalline calcite ooze and "reef milk" (very fine, white and opaque microcrystalline calcite), derived from abrasion of the reef core and reef flank. The reef-flank deposits contain a profusion of gastropods, brachiopods, pelecypods, and cephalopods. These sediments were collecting on the lee side of the reef where the faunas were protected by the wave-resistant bioherm. A sparry calcite matrix cementing the fossil allochems suggests that although these sediments were protected from violent wave action, strong local currents removed much of the microcrystalline calcite ooze.

Above the reef sediments, the Adobe grades into fine clastics. A downwarping of the sea floor brought the area into the infraneritic zone, and the influx of clay and silt inhibited further growth of the reef.

The Adobe formation at Section C is lithologically similar to the Adobe in Section A. Higher percentages of clastics in the northern section suggest that this site of deposition was closer to the source area, but otherwise the lithologic and faunal characteristics are identical to those of the Adobe in Section A. Depositional environment of the site alternated between the epineritic and infraneritic zones.

The faunas and microlithologies of the Council Springs formation at Section A suggest that this formation was deposited in relatively shallow water. Brachiopods and crinoids are most abundant, but algae and foraminifera (exclusive of fusulinids) are present in significant quantities. Sparry calcite cement and lithoclasts indicate shallow depths where currents agitated the bottom (lithoclasts), and winnowed the sediments (sparry calcite). The very minor quantities of non-carbonate clastics (less than 2%) point to the stable nature of the source area during this time. The sea floor was soft, calcareous mud.

The Council Springs formation at Section B was measured in two locations about 400 yards apart. The basal portion of the formation at the northern locality consists of a massive bioherm composed of recrystallized platy algae and the microcrystalline calcite ooze trapped by these plants. One may infer from the algae that the sea bottom at this site was very shallow, and was subjected to severe attack by waves. However, the known sediment-trapping ability of the reef algae precluded the removal of the fine calcite ooze. The sediments overlying the bioherm are unfossiliferous argillaceous limestones. This abrupt change is believed caused by sinking of the area below wave base; a site where fine clastics winnowed from near-shore environments prevented further growth of the bioherm.

Carbonate rocks of the same age (Council Springs formation) outcrop 400 yards to the south of the area described above. These limestones were deposited in back-reef sites to the lee of, and protected by, the adjacent reef. A molluscan fauna is dominant, but pisolitic algae, indicating very shallow water depths, are also present. The sediment is partially winnowed to unwinnowed and lacks intraclasts. The sporadic occurrence of minor currents produced some winnowing and occasional development of pisolites and oolites. The Council Springs formation in this area exhibits all the rapid facies changes characteristic of the variable environments developed at a typical biohermal site.

Although the megascopic appearance of the Council Springs formation is homogeneous in Section C, the microtextures indicate changing environmental conditions over the site as deposition continued. The basal portion of the formation is characterized by a meager brachiopod fauna in calcite ooze. The sediment was undisturbed, and environmental conditions were apparently unfavorable for abundant life. Whether this phenomena was produced by abnormal salinities or is due to other conditions is uncertain. The upper portion of the formation contains abundant brachiopod and crinoid remains, and the matrix material is predominantly sparry calcite. The sediment is a typical well-washed and well-sorted bioclastic limestone. An epineritic environment with clear, shallow waters, well oxygenated by moderate currents, is postulated.

The Burrego formation has similar lithologies, faunas, and environments throughout the area of investigation. The formation becomes more clastic to the northwest. The greater influx of clastics is attributed to steeper gradients of streams on the Zuni-Defiance landmass (see Figure 9). Depositional environments alternated between epineritic and infraneritic types. Abundant brachiopods, bryozoa, and crinoids characteristic of the epineritic environment alternate with fusulinid faunas of the infraneritic environment in Sections A and C. Although the existence of infraneritic conditions is also postulated for Section B, the preponderance of clastics apparently prevented the development of a fusulinid facies.

The red color of the shales at the base of the Story formation in both Sections A and B is interpreted as predepositional coloration. Evidence of oxidation during deposition is absent. Unaltered arkosic grits at the base of these red shales suggest that these sediments were rapidly buried and thus protected from additional weathering.

After the deposition of the basal shales of the Story formation in Section A, waters cleared. Fusulinids are moderately abundant in the lower limestone beds, indicating warm, calm waters of the infraneritic zone. Crinoids, algae, sparry calcite cement, and intraclasts become more abundant upward. The sea floor became shallower, currents stronger, and conditions favorable for the growth of crinoids and algae in the epineritic zone.

The limestone portion of the Story formation in Section B is similar to the upper beds of the same formation in Section A. Crinoids are profusely abundant throughout the formation, with pelecypods, brachiopods, and gastropods present in significant numbers. The presence of pisolitic algae (Dasycladaceae) indicates periods when water was quite shallow (30 feet or less). Moderate currents winnowed the fine lime ooze (sparry calcite is abundant), and the sediments are well-washed and sorted. Epineritic conditions are postulated for this location throughout most of the deposition of the Story.

In the northern section (Section C), the Story is predominantly clastic. Discontinuous arkosic sandstone lenses indicate the local influx and rapid burial of coarse sediments on a downwarping, uneven sea floor. These sediments were probably deposited in channels produced by current scour. Clay and silt were distributed over adjacent areas. Thin, argillaceous limestones represent short periods of clear water, and normal epineritic conditions. The limestones at the top of the section contain abundant crinoidal fragments and bryozoa. The fossils have undergone little or no transportation, and the sediments are unwinnowed. The weakening of currents permitted the limestones to form in the clearer, warm water of the epineritic zone.

SUMMARY OF ENVIRONMENTS

The environment of deposition alternated between epineritic and infraneritic throughout most of Socorro County during Missourian time. The depth of water fluctuated between approximately 50 feet and 150 feet. The waters were warm, mostly clear, and were generally well oxygenated. Currents were moderate to absent, and the bottom was soft calcareous or argillaceous mud most of the time. The sea bottoms overlying sandstones, reef-core, and reef-flank material were considerably harder. The wealth and distribution of faunas suggests waters of normal salinity.

Sporadic uplifts of the source areas caused shoaling of adjoining sea sites, and introduced high percentages of coarse to fine clastics into the depositional basins.

During the formation and existence of the bioherms in the central portion of the county, a variety of environments developed. The reef core was characterized by shallow, turbulent waters, a hard calcareous bottom, and algal flora. Reef-flank deposits, adjacent to, and in the lee of the reef core, were characterized by strong winnowing currents, a hard calcareous bottom, relatively shallow waters, and an abundant and varied molluscan fauna. The back-reef sediments were deposited in shallow, warm, and well-oxygenated waters. Winnowing currents were moderate in the back-reef areas, and the bottoms of soft calcareous mud supported a mixture of algal, brachiopodal, and crinoidal faunas. The lagoonal sites lacked currents, had slightly deeper waters, and supported a dominantly algal flora. The floor of the lagoons was soft calcareous and argillaceous mud.

PALEOGEOGRAPHY

Wedge-shaped arkosic sandstones and red sandstones and shales incorporated within rocks of Pennsylvanian age in New Mexico attest the near presence of positive land areas during this time. These ancient landmasses have been generally termed the Colorado Mountains (Schuchert and Dunbar, 1933, p. 246). Thompson (1942) named and described several land areas that existed during Pennsylvanian time and continued into Permian time; these were inundated by progressive on-lap of Permian seas or buried by Permian terrestrial deposits. Thompson's paleogeographic map of Pennsylvanian time in New Mexico (1942, p. 8) is very schematic, but more detailed studies have been stimulated by his work (Brill, 1952).

The Pedernal landmass, named from the Pedernal Hills, Torrance County, was a north-south trending area, and was connected to the Sierra Grande Arch during part of the Pennsylvanian (Brill, 1952). Permian formations (Yeso and Abo) rest directly on Precambrian metamorphic and igneous rocks throughout this area, and adjacent Pennsylvanian sediments are characterized by an abundance of coarse clastics.

The Zuni-Defiance landmass was a linear positive area extending from west-central New Mexico northwest into Arizona

(Thompson, 1942). This landmass was named from the Zuni Mountains and Fort Defiance areas. The Zuni-Defiance landmass extended into west-central New Mexico during Missourian time, and the eastern shore was located adjacent to Section C of this report.

A third prominent positive area existing in New Mexico during the Pennsylvanian, the Uncompahgre landmass, did not greatly influence the Missourian sediments of Socorro County. The maximum extension of the uplift during the Missourian was about 100 miles south of the present New Mexico-Colorado State line (Brill, 1952).

The positive area most profoundly influencing sedimentation in north-central Socorro County during the Missourian was the Joyita axis (Read and Wood, 1947). This axis may have existed as several small islands situated on a shallow marine platform. The islands contributed large quantities of coarse and fine clastic material to surrounding areas (Section B and probably Section C). Section B of this report is located about 13 miles southeast of the Joyita island area, and on the southern end of the marine platform.

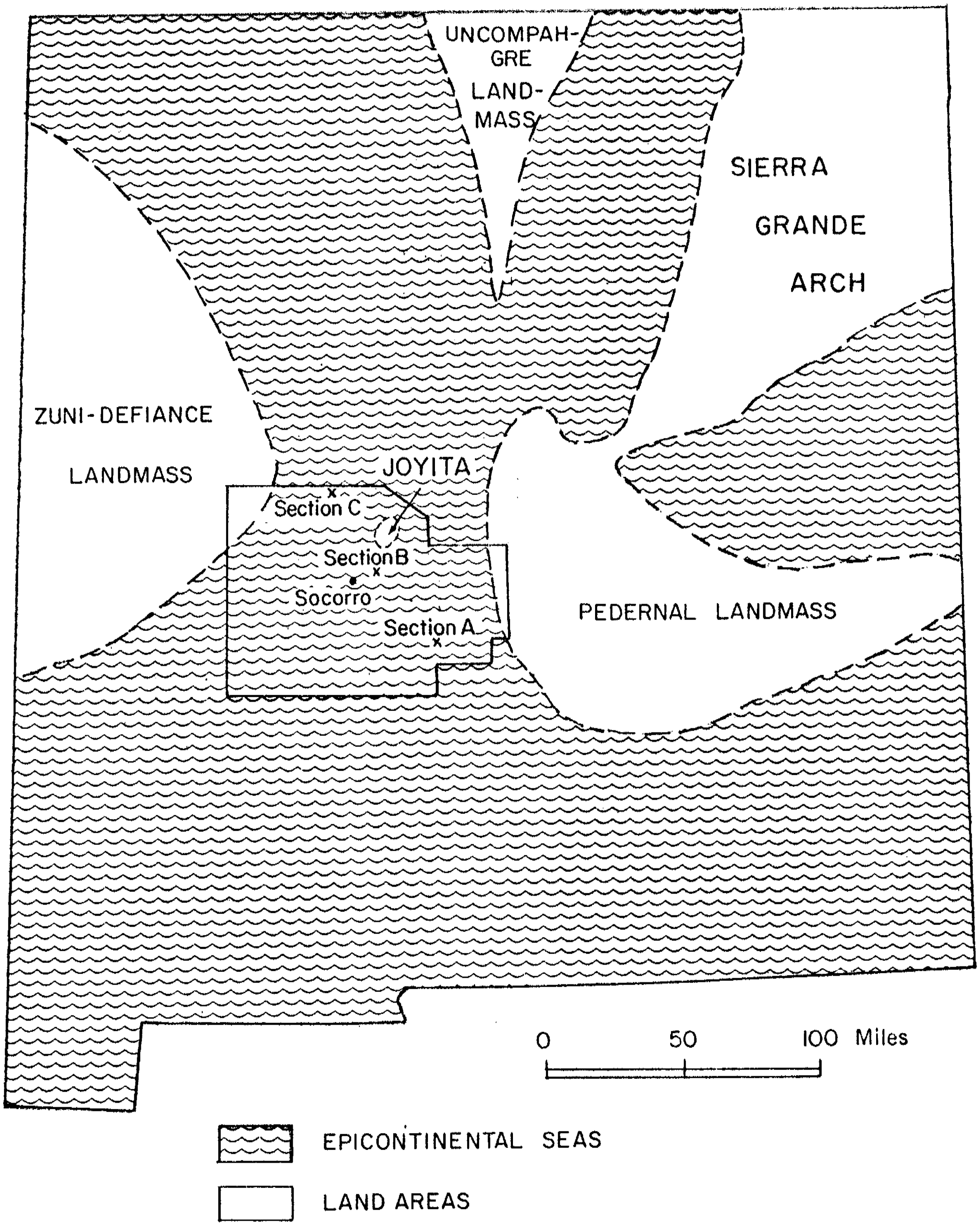
Minor uplifts of the Joyita axis occasionally exposed the platform to subaerial conditions.

The paleogeographic map (Figure 9) is compiled from information obtained from this study. It should be compared with the map constructed by Brill (1952, p. 817) depicting the paleogeography of Colorado and New Mexico during the Desmoinesian.

FIGURE 9

FIGURE 9

Paleogeographic map of New Mexico during Missourian time.


UNCOMPAH-
GRE
LAND-
MASS
SIERRA
GRANDE
ARCH
ZUNI-DEFIANCE
LANDMASS
JOYITA
Section C
Section B
Socorro
Section A
PEDERNAL LANDMASS
0
50
100 Miles
EPICONTINENTAL SEAS
LAND AREAS

SUMMARY

The lithology of Missourian strata in Socorro County varies from predominantly carbonate in the Oscura Mountains to predominantly clastic in the central portion of the county. In comparison to other areas, the northern section has lithologies intermediate between the clastic and carbonate extremes.

Microlithologies and microtextures of the carbnnte rocks also attest to the higher amounts of clastics in sediments of the central and northern sections. Both the carbonate clastic material (allochemical constituents) and the non-carbonate clastic material (insoluble residue) of the limestones parallel the increase of total clastic sediments within the various sequences.

The microtextures are similar in all sections although the percentages of allochemical constituents, orthochemical constituents, and insoluble residues show considerable variation from sample to sample; typical reef textures are developed in a portion of Section B. Allochemical material is distributed between fossils and intraclasts, with minor oolites and pellets scattered throughout the sections. Of the orthochemical constituents, sparry calcite cement in large quantities is rare, and the dominant cementing agent is microcrystalline calcite ooze. In proximity to the bioherms, abundant fossil material is present, and is generally cemented by sparry calcite.

Two distinct faunal assemblages are present in all sections. In Sections A and C, these assemblages alternate between dominantly crinoid-brachiopod faunas and dominantly fusulinid. The assemblages of Section B alternate between a molluscan fauna (associated with the bioherms) and algae flora. In the non-biohermal portion of Section B, the dominant faunas are brachiopoda, crinoidea, and the only flora is algae. Fusulinids are extremely rare in Section B.

The coarse fraction of the insoluble residues is similar in all three sections, and consists of varying amounts of quartz, chert, mica, scarce magnetite and pyrite, and scattered concentrations of feldspar.

The clay minerals present consist of moderate to abundant quantities of montmorillonite in all sections, and generally abundant quantities of kaolinite in Sections B and C. In addition to clay minerals, the fine fraction of the insoluble residues includes finely divided carbonaceous material and organic remains.

CONCLUSIONS

From the distribution of the clastics within the three sections measured, it is concluded that the Joyita axis was an active positive element during the Missourian.

The fauna and microtextures indicate that the depositional environments alternated between epineritic and infraneritic types. The water depth varied from between 50 to 150 feet, except where local reefs existed in water depths possibly as shallow as 10 feet. Abundance of fusulinids in two sections indicates that the water was generally warm. Currents were moderate to absent, and the sea floors, except in the vicinity of the bioherms, were soft lime or clay muds throughout the area. From the presence of well-developed faunas, it is concluded that the marine waters were well oxygenated and of normal salinity.

The clay analyses and the thin sections of the clastic rocks suggest that the source areas were composed of igneous and metamorphic rocks. The large percentages of kaolinite in the northern sections require source areas rich in silica, slightly acid weathering conditions, and rapid transportation by fresh waters. The presence of unaltered montmorillonite suggests that the potassium/magnesium ratio in the marine waters was such as to favor the formation of the mineral, and preclude its alteration to illite.

APPENDIX 1

Measured sections

MEASURED SECTIONS

Section A located on a steep slope about 100 yards northeast of the Mex-Tex Mine in the NE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 36, T. 5 S., R. 5 E., Socorro County. The base of the Coane formation is faulted here, and was measured in the NW $\frac{1}{4}$, Sec. 31, T. 5 S., R. 6 E. All sections were measured upward from the Desmoinesian contact with hand level and steel tape.

Section A

Missourian Series - Hansonburg Group

Top Unit		Thickness Feet	Inches
Story Formation	. . . .	61	2
38	Base of unit is fossiliferous, nodular, light to medium gray limestone with irregular bedding. Unit becomes dense and fine-grained upward, grading into nodular, medium bedded limestone, and then into green shales. These shales are within the Virgil group, and are conformable with the Story.	12	0
37	At base is dark gray limestone nodules in a light gray argillaceous matrix; top bedding surfaces are quite uneven. Unit grades into partially covered loose ledges of coarsely crystalline, brecciated gray limestone, and then into covered shales. Next limestone beds are dense, sandy, and have a sugary texture. Top of unit is coarsely crystalline, crinoidal limestone.	9	5

36	Massively bedded, buff weathering limestone, with irregular patches of fine-grained, sugary-textured limestone. Chert is absent. Unit remains massive, fine-grained, buff limestone throughout.	8	6
35	Dense, fine-grained gray limestone, massively bedded and bioclastic in places. Unit becomes more sugary-textured and nodular upward. Brachiopods are abundant throughout. . . .	6	0
34	Base of unit consists of 23 feet of dark red to maroon micaceous shale. Above the shale is 2 feet 3 inches of very nodular, irregularly bedded, medium gray, argillaceous limestone.	25	3
Burrego Formation		62	7
33	Basal 2 feet are conspicuously irregular-bedded, nodular limestone, grading into medium to massively bedded, solution weathering light gray limestone. Top of unit is nodular with fine laminae of calcareous shale.	9	10
Covered		2	8
32	Lower 2 feet medium-bedded, fine-grained, gray nodular limestone. Unit remains nodular, but becomes fossiliferous (brachiopods) and mottled near the top.	9	3
31	Base is gray to greenish gray limestone with fusulinids weathering in relief in lighter patches. Unit contains a chert bed at the base of a low cliff, and above this the unit is argillaceous and fossilferous with large spiriferid brachiopods abundant.	9	3

30	Several feet of gray weathering, limestone nodules in a shale matrix form the base of this unit. The remainder is covered and probably shale. . . .	14	1
29	Base is medium-bedded, light gray, bioclastic limestone with gray to green shale separating the limestone beds. Upper portion becomes more argillaceous, with horizons of discontinuous nodular limestone.	17	6

Veredas Group

Council Springs Formation.		18	4
28	Base of cliff is medium-bedded and irregular buff weathering limestone. The formation becomes more massively bedded upward, but the color and lithology remain the same. Chert is scattered over the surface which is very irregular due to solution weathering. Fossils are not visible, and stylolites and thin silt partings are the only hints of bedding. .	18	4
Adobe Formation		62	1
27	Medium-bedded, fine-grained gray limestone nodules in a caliche and shale matrix mark the conformable contact between the Council Springs and Adobe formations.	2	5
26	Basal portion of this unit is dense, even-bedded, gray limestone. The upper 5 feet consists of green and yellow shales.	8	8
25.	Dark to medium gray, argillaceous limestone nodules in a weathered shale matrix.	3	0

24	Even-bedded cherty and fossiliferous (fusulinids), medium-grained, gray limestone.	2	0
23	Coarsely crystalline algal limestone similar to above unit.	2	9
22	Brecciated gray bioclastic limestone at base. Upper portion is very nodular and grades into shales and arkosic sandstones.	13	6
21	Smooth-weathering, massively bedded, light gray limestone that grades laterally into nodular limestone. Fusulinids are present. Top 3 feet of unit is covered.	8	4
20	Light gray, dense, finely crystalline fossiliferous limestone. Fossils are brachiopods, corals, and an horizon of fusulinid coquina. Some thin shales are interbedded with the limestone. . .	4	11
19	Buff to yellow weathering, coarsely crystalline limestone that is fossiliferous at the base. Unit becomes progressively sandier upward, until the topmost beds are coarse quartz grits. This unit marks the conformable contact between the Adobe and Coane formations.	16	6
Coane Formation		53	9
18	Medium to fine-grained, crystalline, evenly bedded, medium to light gray limestone.	1	2
17	Medium-grained, granular limestone; weathers yellow to buff with solution pits. Irregular vertical joints filled with dark brown chert.	4	1

16	Interbedded nodular and fine-grained light to medium gray, solution-weathered limestone.	4	6
15	Fine-grained, crystalline, light gray limestone. These beds form a low ledge with irregular, solution-pitted surface.	4	6
14	Basal beds consist of black-weathering re-entrant limestone. Top of lowest unit is very fossiliferous, light gray and coarsely crystalline. The entire unit is nodular, and the upper beds become less fossiliferous and weather pink to pale gray.	4	0
13	Limestone: dense, dark gray, fine-grained and fossiliferous. Brachiopods and fusulinids are abundant. Horizontal patches parallel to weathering planes are more resistant. This unit passes laterally into lenses of light gray, solution-weathered limestone.	4	9
12	The basal beds are medium-grained, crystalline limestone with some irregular solution weathering. Unfossiliferous chert is present and is white to gray, weathering black. Bedding blocky and massive near the base, becoming medium-bedded, lighter gray, and more crystalline upward. The top 1 foot of the unit covered.	4	8
11	Limestone: medium gray, crystalline, somewhat crinoidal, weathering in solution pits. Bedding surfaces mottled..	2	4
10	Limestone: massive-bedded and blocky; medium grained, gray, weathers in irregular cliff.	3	0
9	Similar to unit 10, but very fossiliferous containing fusulinids and composita brachiopods.	3	0

8	Limestone: argillaceous and dark gray; thin-bedded.	1	4
7	Massively bedded, crystalline, medium gray to light gray limestone containing fusulinids and algae.	3	1
6	Massively bedded, crystalline limestone containing fusulinids, <u>Composita</u> brachiopods, and crinoidal debris.	3	6
5	Medium to dark gray, argillaceous, fine-grained limestone; very nodular with irregular bedding surfaces.	2	6
4	Medium to massively bedded, cherty limestone.	1	3
3	Limestone: nodular and massively bedded, gray to light brown, with abundant chert. Shale and caliche form matrix material around the nodules . .	3	1
2	Limestone: light to medium gray, very cherty, and coarsely crystalline. . . .	3	0

Desmoinesian Series

1	Limestone: dense, fine-grained, sampled 3 feet below Missourian-Desmoinesian contact. Upper Desmoinesian is extremely cherty.		

Total thickness for Missourian series at this location 257 11

Section B is located on two adjacent hills (near Ojo de Amado) in the SE 1/4, Sec. 27, T. 2 S., R. 1 E.

Missourian Series - Hansonburg Group

Top

Unit		Thickness Feet	Inches
Story Formation		30(?)	2
13	Limestone: bioclastic, medium to light gray with abundant pink crinoids weathered in relief. Upper portion is discontinuous laterally, and grades into green, crystalline, sandy limestone. This unit may be a repeated sequence of unit 12, and the total thickness of the Story is uncertain here.	10	0
12	Base of unit (basal 10 feet) comprised of green and gray micaceous and arkosic sandstone grading into dark maroon and red micaceous sandy shales. Upper portion is medium to light gray bioclastic limestones with abundant pink crinoids and chert nodules.	20	2
Burrego Formation		67	8
11	Irregularly bedded gray, fossiliferous limestone interbedded with thin laminae of shale.	4	8
10	Interbedded thin, buff-weathering limestones and shale: limestone bed 5 feet from base of unit grades laterally into quartz conglomerate. The remaining limestones are nodular and argillaceous	31	0
9	Thin-bedded, argillaceous and nodular limestone interbedded with thick, micaceous shales. The upper limestone beds are fossiliferous, and weather medium gray to buff.	32	0

Veredas Group

Council Springs Formation	18	0
C — Upper portion thinly and irregularly bedded dark gray, argillaceous limestone, chert increasingly abundant upward. Basal portion massively bedded limestone bioherm. The reef is lens-shaped, and varies in thickness from a few inches to over 6 feet within a distance of 40 feet.	18	0
Adobe Formation	incomplete section	
B — Thin-bedded, nodular and argillaceous, dark gray limestones interbedded with shale.	30	0
A — Similar to unit B, but limestones weather to a buff color, and are usually more fossiliferous.	38	0

Units A, B, and C were measured to correlate the two sections measured in this same locality. Unit C, the Council Springs formation, correlates with unit 7 in the following description. See columnar sections in pocket of report.

Burrego Formation (?)		
8 — Medium to massively bedded, light gray non-cherty limestone at base of unit. Upper beds are similar, but become oolitic and pisolitic.	27	0
FAULT — Veredas Group		
Council Springs Formation	8	9
7 — Limestone: medium, irregularly bedded, dark gray, nodular and fossiliferous. Unit grades vertically into fine-grained, crystalline limestone with prominent bands of brown-weathering chert.	8	9

Adobe Formation		84	7
6	Base of this unit contains a thin bed of pellet limestone. Remainder of unit is mostly covered shale.	40	0
5	Prominent cliff-forming, yellow to buff-weathering, medium grained crystalline limestone.	8	0
4	Thin-bedded and nodular, fossiliferous limestone interbedded with shale and thin sandstones; poorly exposed.	28	0
3	Yellow-weathering, fossiliferous, and medium- to fine-grained crystalline limestone which grades upward into pellet and oolitic limestone.	1	4
2	Medium to dark gray bioclastic and oolitic limestone.	7	3
	Disconformity		
Coane Formation		140	0
2!	Basal 4 feet is nodular, argillaceous and fossiliferous, medium to dark gray, thin-bedded limestone. This is overlain by 60 feet of covered shale, which is capped by a 7 foot, buff-weathering, quartz sandstone bed. The sandstone is overlain by 62 feet of covered shale, and this shale sequence is capped by 7 feet of coarse, cross-bedded conglomerate composed of quartz, chert, and limestone pebbles	140	0
	Desmoinesian Series		
1	Limestone: medium to massively bedded, medium to light gray, irregular bedding surfaces.		
Thickness of Missourian at this locality.		362	4

Section C is located at the north end of Mesa Sarca in the NW $\frac{1}{4}$, Sec. 18, T. 4 N., R. 3 W.

Missourian Series - Hansonburg Group

Top Unit		Thickness Feet	Inches
Story Formation		73+	11
11	Limestone: medium to light gray, interbedded with thin shale laminae; abundant bryozoa and crinoids. Unit forms a low, resistant ledge.	10	1
10	Interbedded thin, dark gray, argillaceous limestone and micaceous shales. A buff-weathering, coarse sandstone lens is present locally, but is not persistent.	63	10
Burrego Formation		97	6
9	Limestone: dark gray, nodular and argillaceous with prominent fusulinid horizon. Unit forms a low, non-resistant cliff.	11	0
8	Limestone: irregularly bedded, green to gray, fossiliferous. Unit becomes more massively bedded upward. Crinoids are abundant near the top.	8	6
7	Shales, mostly covered, interbedded with thin, nodular, fossiliferous limestones.	78	0
Veredas Group			
Council Springs Formation		12	0

6	Limestone: massively bedded, cliff-forming, medium to light gray, weathering buff to light brown, consistently fine-grained and crystalline.	12	0
Adobe Formation		thickness uncertain	
5a	Covered shale slope with thin bed of dark gray-weathering limestone containing productids at base.	21	0
5	Limestone: dark gray, fine-grained, and mottled. Fusulinids are abundant throughout	11	0
4a	Covered shale slope.	13	6
4	Limestone: non-resistant, fossiliferous, nodular, medium to dark gray, interbedded with thin shales.	6	7
3	Limestone: gray, nodular, argillaceous. Large productid brachiopods abundant on weathered surfaces.	5	7
Coane Formation		thickness uncertain	
2	The contact of the Coane and Adobe formations lies somewhere within the upper portion of the shales of this unit. Fissile green-gray to maroon shales interbedded with 7 or more argillaceous, dark gray limestones with scattered crinoids and brachiopods	83	0
	Desmoinesian Series		
1	Limestone: dark gray, cherty, abundantly fossiliferous		
Total thickness of Missourian at this location . . .		324	1

APPENDIX 2

Location of samples

The following list gives the position of all samples collected from the measured sections.

SECTION A

Unit	Sample	Distance from base of unit (feet)	(inches)	Thickness of unit (feet)	(inches)
38	A38F	12	0	12	0
	A38E	9	6		
	A38D	8	0		
	A38C	7	3		
	A38B	6	8		
	A38A	2	0		
37	A37E	9	5	9	5
	A37D	7	5		
	A37C	6	3		
	A37B	1	3		
	A37A	0	9		
36	A36E	8	6	8	6
	A36D	7	4		
	A36C	5	0		
	A36B	3	3		
	A36A	at base			
35	A35D	6	0	6	0
	A35C	4	3		
	A35B	1	0		
	A35A	at base			
34	A34	24	3	25	3
33	A33D	9	10	9	10
	A33C	6	0		
	A33B	4	2		
	A33A	1	3		

Unit	Sample	Distance from base of unit (feet)	(inches)	Thickness of unit (feet)	(inches)
32	A32E	9	3	9	3
	A32D	7	7		
	A32C	4	8		
	A32B	2	0		
	A32A	at base			
31	A31E	9	3	9	3
	A31D	8	2		
	A31C	6	0		
	A31B	2	5		
	A31A	at base			
30	A30B	3	0	14	1
	A30	1	6		
	A30A	at base			
29	A29K	17	6	17	6
	A29I	15	0		
	A29H	13	8		
	A29G	11	0		
	A29F	9	3		
	A29E	7	2		
	A29D	4	9		
	A29C	2	6		
	A29B	1	0		
	A29A	at base			
28	A28E	18	4	18	4
	A28D	13	7		
	A28C	6	0		
	A28B	2	9		
	A28A	at base			
27	A27D	2	5	2	5
	A27C	1	10		
	A27B		9		
	A27A	at base			

Unit	Sample	Distance from base of unit (feet)	(inches)	Thickness of unit (feet)	(inches)
26	A26B	2	8	8	8
	A26A	at base			
25	A25	1	3	3	0
24	A24D	2	0	2	0
	A24C	1	8		
	A24B	0	10		
	A24A	at base			
23	A23	1	3	2	9
22	A22	2	5	13	6
21	A21	3	0	8	4
20	A20B	4	0	4	11
	A20A	1	3		
19	A19D	16	2	16	6
	A19C	10	4		
	A19B	3	0		
	A19A	at base			
18	A18	0	9	1	2
17	A17C	4	1	4	1
	A17B	1	10		
	A17A	at base			
16	A16	2	3	4	6
15	A15	2	3	4	6
14	$A14_2$	4	0	4	0
	$A14_1$	1	9		
	A14	at base			

Unit	Sample	Distance from base of unit (feet)	(inches)	Thickness of unit (feet)	(inches)
13	A13	2	7	4	9
12	A12B	3	2	4	8
	A12A	1	4		
	A12	at base			
11	A11	1	5	2	4
10	A10	1	6	3	0
9	A9	1	2	3	0
8	A8	at base		1	4
7	A7	2	0	3	1
6	A6	2	4	3	6
5	A5	at base		2	6
4	A4	0	9	1	3
3	A3	2	7	3	1
2	A2	1	6	3	0
1	A1	3 feet below Missourian-Desmoinesian contact			

SECTION B

13	B13C	10	0	10	0
	B13B	4	8		
	B13A	at base			

Unit	Sample	Distance from base of unit (feet)	Distance from base of unit (inches)	Thickness of unit (feet)	Thickness of unit (inches)
12	B12F	20	2	20	2
	B12E	16	5		
	B12D	11	0		
	B12C	7	9		
	B12B	3	4		
	B12A	at base			
11	B11D	4	8	4	8
	B11C	3	2		
	B11B	1	10		
	B11A	at base			
10	B10N	17	8	31	0
	B10M	14	0		
	B10L	13	4		
	B10K	12	0		
	B10H	9	6		
	B10G	6	0		
	B10F	5	4		
	B10E	4	9		
	B10D	4	0		
	B10C	2	0		
	B10B	1	2		
	B10A	at base			
9	B9C	19	2	32	0
	B9B	6	0		
	B9A	at base			
8	B8G	27	0	27	0
	B8F	22	3		
	B8E	14	9		
	B8D	9	11		
	B8C	6	3		
	B8B	2	10		
	B8A	at base			
7	B7B	8	9	8	9
	B7A	4	2		
	B7	at base			

Unit	Sample	Distance from base of unit (feet)	(inches)	Thickness of unit (feet)	(inches)
6	B6A	1	5	40	0
5	B5B	8	0	8	0
	B5A	3	11		
	B5	at base			
4	B4C	20	3	28	0
	B4B	7	6		
	B4A	6	4		
3	B3B	1	4	1	4
	B3A	at base			
2	B2G	7	3	7	3
	B2F	6	5		
	B2E	5	0		
	B2D	3	10		
	B2C	2	4		
	B2B	1	2		
	B2A	at base			
1	B1B	1 foot below Desmoinesian-Missourian contact			
	B1A	2 feet below Desmoinesian-Missourian contact			

SECTION C

11	C11E	10	1	10	1
	C11D	8	3		
	C11C	5	5		
	C11B	3	0		
	C11A	at base			
10	C10C	30	0	63	10
	C10B	25	0		
	C10A	21	0		

Unit	Sample	Distance from base of unit (feet)	(inches)	Thickness of unit (feet)	(inches)
9	C9G	11	0	11	0
	C9F	9	5		
	C9E	7	7		
	C9D	4	11		
	C9C	3	2		
	C9B	1	8		
	C9A	at base			
8	C8E	8	6	8	6
	C8D	6	0		
	C8C	3	5		
	C8B	1	9		
	C8A	at base			
7	C7F	30	10	78	0
	C7E	30	4		
	C7D	29	11		
	C7C	29	3		
	C7B	28	8		
	C7A	28	0		
6	C6B	10	5	12	0
	C6A	4	7		
5	C5F	11	0	11	0
	C5E	8	8		
	C5D	7	2		
	C5C	4	0		
	C5B	1	11		
	C5A	at base			
4	C4C	6	7	6	7
	C4B	3	3		
	C4A	at base			
3	C3G	5	7	5	7
	C3F	5	0		
	C3E	4	2		
	C3D	3	8		
	C3C	3	2		
	C3B	1	5		
	C3A	at base			

Unit	Sample	Distance from base of unit (feet)	Distance from base of unit (inches)	Thickness of unit (feet)	Thickness of unit (inches)
2	C2G	47	0	83	0
	C2F	42	4		
	C2E	38	10		
	C2D	35	0		
	C2C	24	10		
	C2B	8	6		
	C2A	4	5		
1	C1A	1 foot 5 inches below Desmoinesian-Missourian contact			

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This thesis is accepted on behalf of the graduate faculty of the Institute by the following committee:

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