A PETROLOGIC AND MECHANICAL ANALYSIS OF THE LION MOUNTAIN AND WELGE SANDSTONES OF SOUTHERN MASON COUNTY, TEXAS

By

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ABSTRACT

A Petrographic and mechanical analysis was conducted on the arenaceous beds of the Late Cambrian Lion Mountain and Welge formations in southern Mason County, Texas. The lower portion of the Lion Mountain member is composed of arenaceous limestones, calcareous sandstones and lenses of trilobite hash. The upper part of the member is composed of a glauconite-bearing, calcareous sandstone. The Welge member is a non-calcareous, non-glauconitic, quartzose sandstone. Both members are laterally persistent throughout the area.

The decrease in phi median diameter in the upper part of the Lion Mountain member suggests a regressive sea. The Lion Mountain member shows an increase in grain size toward the northern part of the area studied. This suggests that the source of detritus was to the north. In contrast to the Lion Mountain member, the Welge member is a relatively homogeneous, medium-grained, quartzose sand.

Quartz grains in the calcareous strata of the lower portion of the Lion Mountain member are etched and show partial solution. The disseminated quartz grains and fossil fragments within the limestones of the Lion Mountain member suggests that the particles were deposited penecontemporaneously in a lime mud. Evidence for recrystallization of the lime mud after deposition is suggested by gradation of irregular patches of course calcite into areas of microcrystalline calcite.

The dominant clastic mineral in both members is quartz which is moderately well-rounded and sorted. Angular overgrowths on the quartz

grains of the Welge member suggest that these grains have been subjected to authigenic processes. The authigenic process includes the enlargement of detrital quartz grains by overgrowths.

Roundness and sphericity determinations suggest that the Welge sandstone represents a more mature sand than the Lion Mountain member. The Lion Mountain and Welge members were apparently derived from the same type of terrane on the basis of similar heavy mineral content. The higher degree of mineralogical maturity of the Welge member as opposed to the Lion Mountain member is suggested by the higher percent by weight of heavy minerals in the Lion Mountain member. The higher percent by weight of heavy minerals in the Lion Mountain member may be attributed to intensive erosion of the source area as opposed to retarded erosion and prolonged chemical weathering of the source area during Welge deposition.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to Dr. K. J. Koenig of the Department of Geology and Geophysics of the Agriculatural and Mechanical College of Texas for his criticism of the manuscript and for his supervision of the study. Dr. H. R. Blank aided in identifying some of the heavy minerals. Mr. F. E. Smith gave helpful advice during the course of the field work and Dr. Peter Dehlinger read and criticized the manuscript.

The writer is grateful to Mr. H. D. Marshall and Mr. D. H. Peterson for their help in measuring the described sections.

INTRODUCTION

Statement of Problem

The principal objectives of this study are to:

1. Determine the textural and mineralogical aspects of the Lion Mountain and Welge sandstones of late Cambrian age in southern Mason County, Texas.

2. Compare the textural and mineralogical aspects of these two sandstone units.

3. Evaluate conditions of deposition which might be responsible for any observed changes in texture or mineralogy within or between these two sandstone units.

4. Determine whether or not the observed textural and mineralogical aspects may be used as an aid in the correlation of these respective sandstone units.

Location

The area is located in southern Mason County on the southwestern flank of the Llano uplift in central Texas. Five locations indicated on Figure 1, page 2, were selected for sampling.

1. Section 1 was measured in conjunction with Peterson (1959) near the type locality of the Welge sandstone in extreme southeast Mason County, Texas. The section starts in the bed of Squaw Creek approximately .60 miles from the intersection of Squaw Creek and Spring Creek.

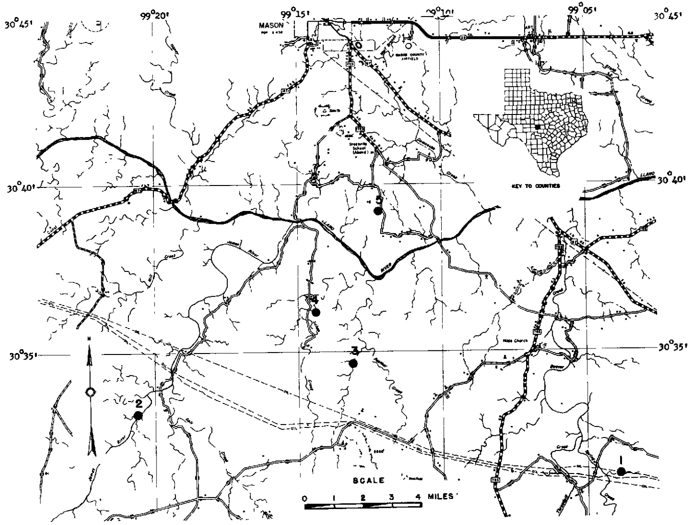


FIGURE 1. LOCATION MAP OF SAMPLING LOCALITIES IN SOUTHERN MASON COUNTY, TEXAS

Adapted from Texas State Highway Department highway map of Mason County, Texas

2. Section 2 was measured at the base of a bluff on the east side of the James River approximately 4.8 miles from the intersection of Mill Creek Road and Farm Road 1871 and 3.0 miles southeast of the Jeffreys ranch house on Mill Creek Road.

3. Section 3 was measured on Ernest Geistweidt's property in the bed of the west branch of Panther Creek approximately 1.3 miles from the point where Panther Creek divides into an eastern and western branch.

4. Section 4 was measured along Schep Creek on the Seth Martin ranch, 1.25 miles south of the Emeth Keller ranch house.

4. Section 5 is located near the eastern branch of Ridge Road approximately 1 mile from the point where Ridge Road divides into two ranch roads.

Accessibility

Public roads provide access by automobile to southern Mason County. Private ranch roads branch off the county roads and provide an excellent road net in most of southern Mason County.

Previous Investigations

Early geologic investigations of the Llano uplift were conducted by Roemer (1846, 1848); Shumard (1861); Walcott (1884); Shumard (1886); Hill (1887) and Comstock (1890). With the exception of Comstock's work in 1890, most of the above work was of a reconnaisance nature. Comstock introduced several new names such as the Riley Series and San Saba Series.

In 1911 Paige named and briefly described the Wilberns and Cap Mountain formations. The Lion Mountain sandstone member was included within the Cap Mountain formation. The Wilberns formation as defined by Paige included all the members of the present Wilberns formation with the exception of the San Saba limestone.

In 1933 Sellards presented the geologic history of the Precambrian, Cambrian, and Ordovician systems of the Llano region. The time of the initial Paleozoic uplift in the Llano uplift was dated as Mississippian by Sellards (1934). In the above report Stenzel reviewed the Precambrian structural conditions of the Llano uplift.

Bridge (1937, p. 235) named the Lion Mountain sandstone for Lion Mountain in the northwest part of the Burnet Quadrangle. Bridge defined the Lion Mountain as the upper member of the Cap Mountain formation.

All upper Cambrian units in the Llano region were subsequently described or redefined by Bridge, Barnes and Cloud (1947). The Cap Mountain was reduced to member status by the above authors and the Lion Mountain became the upper member of the Riley formation. In addition the Welge sandstone member was named by Barnes (1947, p. 34) for the Welge Land Surveys in Gillespie County.

Prior to the present study no results of a detailed petrographic and mechanical analysis of the Upper Cambrian strata in southern Mason County have been published. With the exception of Wollman's (1952) description of the fauna of the basal Welge sandstone, the present study is the first detailed investigation of the petrology of the Lion Mountain and Welge members.

Analyses similar to those proposed for the Lion Mountain and Welge sandstones have been made by Bokman (1935) on the Stanley and Jackfork formations of Oklahoma and Arkansas, Dake (1921) on the St. Peter sandstone, Graham (1930) on the Cambrian sandstones of Minnesota and Krynine (1940) on the Third Bradford Sand of Pennsylvania.

STRATIGRAPHY

General Statement

Rocks exposed in southern Mason County range in age from Precambrian to Recent. The strata of Paleozoic age are almost entirely restricted to the Cambrian and Ordovician systems. Although this study consists of a petrographic and mechanical analysis of the Lion Mountain and Welge sandstones, the stratigraphy of the Cambrian system is listed to present the relationship of the Lion Mountain and Welge members to the other units in the system. The stratigraphic column of the Cambrian system consists of the following units:

- Cambrian System
  - Upper Cambrian
    - Wilberns formation
      - San Saba limestone member
      - Point Peak shale member
      - Morgan Creek limestone member
      - Welge sandstone member
    - Riley formation
      - Lion Mountain sandstone member
      - Cap Mountain limestone member
      - Hickory sandstone member

Riley Formation

The Riley series was named for the Riley Mountains in Llano County by Comstock (1890, p. 286-289). The name Hickory series was also proposed by Comstock for strata beneath the Riley. In 1911 Paige (p. 42) renamed the Hickory series as the Hickory sandstone and named the overlying limestone beds the Cap Mountain formation. The Lion Mountain sandstone was described as a member of the Cap Mountain by Bridge (1937). Finally, Cloud, Bridge and Barnes (1945, p. 154) designated the Riley Series to be a formation.

Lion Mountain Member

Lithology. The Lion Mountain member is a grayish-green weathering to speckled brown, laminated to massive, fine - to course-grained, sub-angular to sub-rounded, glauconite rich, calcareous, quartzose sandstone containing beds of glauconite bearing, arenaceous limestone. Lenses of fine to course trilobite hash are interspersed throughout the formation. Shiny, black nodules of hematite derived apparently from the alteration of glauconite litter many of the weathered slopes of the Lion Mountain member.

Sedimentary structores. Cross-lamination is common in the granular sediments of the Lion Mountain sandstone member. The tabular cross-laminated units consist only of the foreset laminae sharply truncated at the top and tangential or nearly so at the base. Inclinations of the cross-lamination are rarely high, but directions of inclination vary widely. In general, cross-lamination is common in littorial deposits and accumulations formed in shallow water, where there is much shifting of granular sediment by current action (Shrock, 1948, p. 245).

Trilobite hash. The disarticulated trilobite tests and isolated linguloid brachiopod shells within the Lion Mountain member probably represent the remains of a fauna accidentally introduced into an environment during periods of storm activity. The assumption is made that the trilobites and some of the brachiopods lived seaward possibly in a more calcareous facies, and after death were washed into and buried in the Lion Mountain sediments. Strong waves and currents initiated by storms apparently collected the organic debris.

Glauconite. The Lion Mountain member exhibits much vertical and lateral variation in glauconite content. The average content of glauconite throughout the Lion Mountain member varies from 35 per cent in the extreme southern part of the county to 17 per cent in the south-central section of the county. The dimensions of the glauconite particles range from clay to sand size.

Much has been written on the origin of glauconite and the geological aspects of the problem are reviewed in the following paragraph.

Glauconite may be formed from the alternation of biotite (Galliher, 1935, p. 1571), from clay fillings of foraminifera, fecal pellets, fragments of volcanic glass, organic opaline silica (Takahashi, 1939, pp. 509-512) or from the alternation of illite (Light, 1952, p. 94). The presence of glauconite in the Lion Mountain member may explain the rarity of biotite, for biotite is one of the most abundant minerals in the granitic basement complex.

Glauconite commonly forms in an alkaline, anaerobic environment (Galliher, 1935, p. 1354). Kuenen (1950, p. 218) and Cloud (1955, p. 490) concluded that glauconite generally forms at shallow to moderate depths on continental shelves where a slow rate of detrital influx exists. It is difficult to establish a relationship between a reducing environment favoring glauconite deposition and the trilobite hash indicating conditions of marked turbulence and oxidation. However, Takahashi (1939) has observed glauconite in recent sediments associated with evidence of wave or current action alternating with periods of quiet water. Although glauconite is rarely associated with chemically deposited limestones (Cloud, 1955, p. 488), its presence in the lime stones of the Lion Mountain member suggests origin at greater depths. Reworking may have locally introduced the glauconite and trilobite fragments into such sediments.

Geologic contacts and thickness. The Cap Mountain - Lion Mountain contact is gradational. The contact was picked at the base of the first quartz sandstone encountered above the Cap Mountain limestone member. The contact of the Lion Mountain member with the overlying Welge sandstone is rather abrupt. There is a noticeable change from the highly glauconitic sands of the Lion Mountain member to the yellowish-brown, non-glauconitic sands of the Welge member. The Lion Mountain - Welge contact is believed to represent a disconformity and will be discussed in detail later in this report.

According to Bridge, Barnes, and Cloud (1947, p. 114) the Lion Mountain member has a maximum measured thickness of 50 feet in the Llano region. The thickness of the Lion Mountain sandstone in southern Mason County compares favorably with that noted by Bridge, Barnes and Cloud.

Wilberns Formation

The Wilberns formation was named by Paige (1911, p. 23) for Wilberns Glen in Llano County. The Wilberns was redefined by Cloud, Barnes, and Bridge (1946, p. 155) and the upper boundary placed at the top of the Cambrian system. The Wilberns was subsequently divided into four members which are:

San Saba limestone member

Point Peak shale

Morgan Creek limestone

Welge sandstone.

Welge Sandstone Member

Lithology. The Welge member is a white to buff, massive, medium-grained, sub-angular to sub-rounded, friable, siliceous quartzose sandstone which weathers to a light reddish-brown color. The sandstone is non-glauconitic and is generally non-calcareous. Some recomposed quartz grains were observed; joint fillings of hematite protrude noticeably from the weathered surfaces of some beds within the Welge member.

<u>Sedimentary structures</u>. Poorly preserved ripple marks with rounded crests and troughs were observed in the Welge member. According to Lahee (1941, p. 49) such structures are wave ripple marks which are common on beaches. However, conditions favorable for the formation of ripple marks have been found at depths as great as 800 meters (Shrock, 1948, p. 55).

Another structural feature of the Welge sandstone member was observed at Squaw Creek. In the above locality, slumping has occurred and exposed the undersides of several massive sandstone beds. The undersides of these blocks show an anastomosing pattern of tubular burrows which have been subsequently filled with a buff colored sandstone. The periphery of the fillings is a dark brown clay. The above structures are embedded in argillaceous silt.

Wollman (1952) attributed the above features to be the product of annelid worm tracks. McKee (1938, p. 154) has described similar structures on the bottom sides of massive sandstone beds in the Kaibab formation of the Grand Canyon and attributed the structures to be trails of annelid worms.

<u>Geologic contacts and thickness</u>. The Welge - Morgan Creek contact is gradational and was picked at the base of the first purplish-brown to rust-colored calcareous sandstone bed encountered above the Welge lithology. The thickness of the Welge member varied from 15 to 23 feet in southern Mason County

METHODS OF FIELD WORK

Measured Sections

The field work was accomplished between July 20, 1958, and August 10, 1958. Five sections were measured throughout southern Mason County, Texas in areas previously mapped by graduate students of the Texas A. and M. College. The sections described in the Appendix of this report were measured at sites chosen for good exposures of the Lion Mountain and Welge sandstone members.

Measurements were made by sighting on a self-reading rod with a Brunton compass, which was set on the average dip of the strata. All stratigraphic contacts were walked out or determined by traverses made roughly perpendicular to the strike of the contacts.

Collection of Samples

Eighty samples of the two sandstone members were collected at five localities depicted on Figure 1, page 2. Due to vertical and lateral lithologic variations within the two sandstone members, a series of spot samples were collected. The related set of spot samples may be defined as serial samples (Krumbein, 1938, p. 14). The serial samples were selected vertically at each lithologic break across the thickness of the two members. The above procedure enabled the writer to obtain a wide range of the material to be tested, so that both average composition and size variations could be determined.

PREPARATION OF SAMPLES FOR ANALYSIS

Laboratory Procedures for Mechanical Analysis

Disaggregation. Initially, each individual sample was examined under a binocular microscope to determine the nature of the cementing agent. The common cementing material in the Lion Mountain member is calcite, which was removed by placing the rock fragments in .8N HCl. Thin sections of the Lion Mountain member revealed that no detrital calcite grains other than fossil fragments are present in the arenaceous limestone. Glauconite grains in the Lion Mountain member were only slightly affected by the acid treatment. No calcite or glauconite grains were observed in the Welge sandstone member.

Disaggregation of the friable and loosely cemented Welge sandstone member was accomplished by rubbing the individual rock fragments between two wooden boards. The grains were examined before and after disaggregation to determine whether changes had occurred. No appreciable change in the roundness or size of the particles was noted.

Splitting. Each sample was split down to a representative analytical sample of 50 to 100 grams, using a Jones sample splitter.

Separation of sand from silt and clay. A weighed quantity of the sample, disaggregated in accordance with the above techniques was placed in a 250 cc. Erlenmeyer flask with 100 cc. of N/100 sodium oxalate solution and allowed to soak. The N/100 sodium oxalate, $Na_2C_2O_4$, was used as a peptizer to prevent flocculation. The suspended sample was then passed through a .062 mm. sieve. The silt and clay particles were left in suspension as a final test for complete dispersion.

Sand analysis by sieving. The dry sand above .062 mm. was sieved through a nest of Tyler Standard Screen Scale Sieves. The Tyler automatic "Ro-Tap" shaker equipped with an automatic clock agitated the sieves for twenty minutes. The concentrates from each sieve were weighed on an analytical balance, and the material in the pan was added to the silt-clay suspension.

Silt-clay analysis by the hydrometer method. The silt-clay suspension of each sample was diluted to 1000 ml. in a graduated liter cylinder. The suspension was observed over a 48 hour period, and if no flocculation occurred, the analysis was continued. A fine-grained analysis of the Welge sandstone member was not conducted due to the negligible amount of clay and silt in the Welge member.

If flocculation of the finer particles of the Lion Mountain member occurred during the period of observation, the suspension was heated to the boiling point. This treatment was sufficient to produce complete dispersion.

Once it was apparent that no flocculation would occur, the silt and clay sizes were determined according to Wadell's law

$$\left(v_p = \frac{(1/7)(d_1-d_2)gr_p^2)}{N}\right.$$

where:

d_1 density of the sphere
d_2 density of the fluid
g acceleration due to gravity
N viscosity of the fluid
V_p practical settling velocity
r_p practical sedimentation radius.

The above law involved the settling velocity of particles of a fluid. A natural gradation or sorting of particles vertically according to size occurred, both in the fluid, and in the deposit at the bottom of the cylinder as heavier particles settle faster than lighter particles.

In this study the suspension was stirred well with a stirring rod. After a given period of time, from the moment when the sediment was stirred, all particles greater than a certain size settled to a given depth, and the suspension above contained only smaller particles. A hydrometer, calibrated to read grams of soil per liter, was introduced into the suspension at intervals, and readings were taken in time sequence according to the following schedule:

Time			Diameter	Diameter
Hr	Min	Sec	mm.	Ø Scale
0	3	1	1/32	5
0	11	59	1/64	6
0	47	51	1/128	7
0	12	--	1/256	8

From the above procedure the distribution of sizes by weight was determined.

Preparation of Samples for Petrographic Analysis

Sampling technique. The .125 mm. fraction of the Lion Mountain sandstone and the .125-.175 mm. fraction of the Welge were selected for heavy mineral identification. All of the spot samples within the grade range of each locality were combined to form an aggregate single sample or compound sample. Compound samples were used in this study, because they afford average values of the heavy minerals at each locality. Five composite samples of the Lion Mountain and Welge members respectively were selected for heavy mineral preparation.

Removal of iron oxides. The composite samples for each locality were placed in 5-500 ml. beakers and covered with about 100 ml. of 2.4N HCl. The beakers were covered with a watch glass and heated slowly on a hot plate. When the supernatent liquid attained a yellow color, solid oxalic acid was slowly added until the yellow color disappeared. This procedure was repeated as often as the yellow color reappeared. The glauconite grains which were relatively unaffected by the dilute .8N HCl in the disaggregation of the Lion Mountain member were completely destroyed in the stronger acid solution.

Separation methods. The heavy minerals of the two members were separated from the lighter fraction according to standard techniques as utilized by Krumbein and Pettijohn (1938, p. 335). The heavy fraction was subsequently spread on a sheet of paper and a horseshoe magnet was passed slowly over the fraction. Magnetite was not observed in the heavy mineral suite. The light and heavy mineral fractions were then mounted in a synthetic resin (Arochlor 4456) and the slides examined separately under a petrographic microscope.

STATISTICAL PARAMETERS

Quartile Deviation

Quartile deviation, which is a measure of sorting or the spread of a curve, is defined by the following equation:

$$Qd_{\phi} = \frac{Q_{3\phi} - Q_{1\phi}}{2}$$

where: $Q_{3\phi}$ is that diameter which has 25 per cent of that distribution smaller than itself and 75 per cent larger than itself, and

$Q_{1\phi}$ is that diameter which has 75 per cent of the distribution smaller than itself and 25 per cent larger than itself.

According to Trask (1930) a value of So less than 1.35 (ϕ scale) indicates a well sorted sediment.

Quartile Skewness

Quartile skewness, which measures the degree of asymmetry, or the departure of the quartile average from the median, is defined by the following equation:

$$QD_{\phi} = \frac{Q_{1\phi} + Q_{3\phi}}{2} - Md_{\phi}$$

where: Md_{ϕ} is the phi median diameter which is a measure of the central tendancy. It is that diameter which is larger than 50 per cent of the diameters in the distribution and smaller than the other 50 per cent.

PRESENTATION OF DATA

General Statement

The particle size is expressed in the Ø scale. The phi notation of Krumbein (1936), where $\phi = -\log_2$ of the diameter in millimeters, is used in this paper because a logarithmic diameter scale is more convenient in depicting the statistical relations of sediments.

The mechanical analyses data are compiled in a series of tables and figures. The basic data are presented in Table 1 and on Figs. 2 thru 17. In addition to basic data, Table 1 contains sediment parameters which include a measure of the median diameter, the coefficient of sorting and skewness.

Grain Size Variation

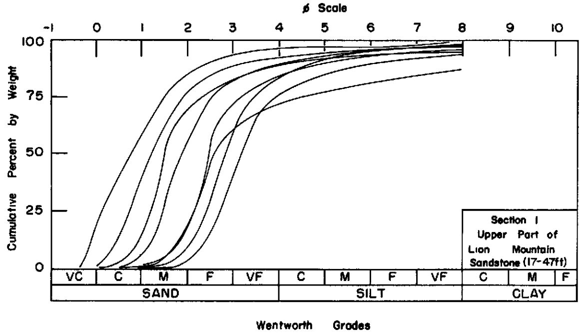
Figures 2 thru 17 summarize variations of size characteristics in the Lion Mountain and Welge sandstone members. In general, the particle size of the Lion Mountain sandstone member increases from the bottom to the top of the unit. Cumulative frequency curves shown on Figures 2 thru 6 graphically illustrate this change in grain size within the Lion Mountain member.

Figures 15 and 16 show the variation of the phi median diameter in the Lion Mountain member. The phi median diameter decreases gradually from the bottom part of the Lion Mountain member to the upper part of the unit. Figure 16 represents a composite of sections 1, 3, 4, 5 and also a partial section of the Lion Mountain member in Locality 2. Faulting has removed approximately 20 feet of the Lion Mountain member in section 2. The upper 5 feet of Lion Mountain sediments in sections 2, 3 and 5 become slightly finer than the upper middle part (Figures 15 and 16)

Figure 14 indicates that the Lion Mountain sediments become coarser to the north. This suggests that the source of detritus was to the north.

Figures 7 thru 11 summarize the grain size variations of the Welge sandstone member. In contrast to the Lion Mountain sandstone member the Welge member appears to be a relatively homogeneous, medium-grained, quartzose sand. The cumulative curves of the Welge indicate no significant variation in grain size. The curves fluctuate within a very small range. The absence of silt and clay within the sandstone member suggests vigorous wave and current action.

Figure 17 shows the variation of the phi median diameter in the Welge member, as determined from the five principal sections in which the member is exposed. A trend to coarser sizes in the northern part of Mason County was observed for samples taken 1 foot from the base of the Lion Mountain - Welge contact (Figure 17). The remainder of the data indicates the slight oscillatory nature of the Welge seas.



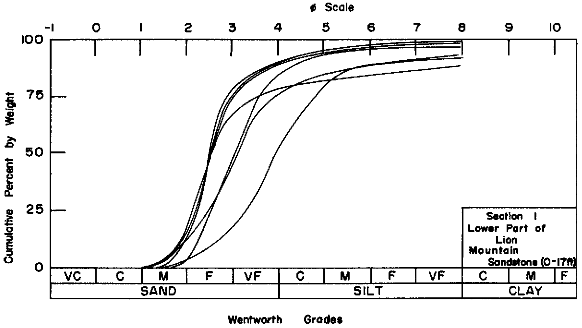


Fig. 2- Cumulative curves of the Lion Mountain sandstone, plotted with ø as independent variable

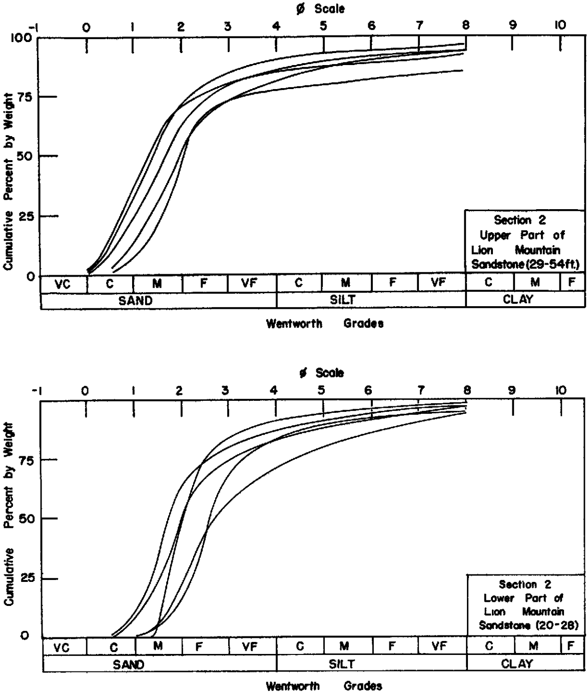
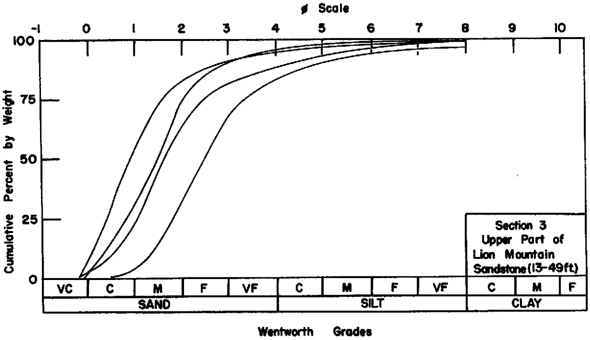


Fig. 3 - Cumulative curves of the Lion Mountain sandstone, plotted with ø as independent variable.



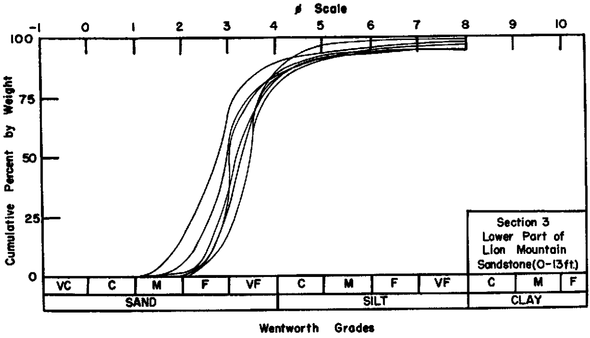


Fig. 4 - Cumulative curves of the Lion Mountain sandstone, plotted with ø as independent variable.

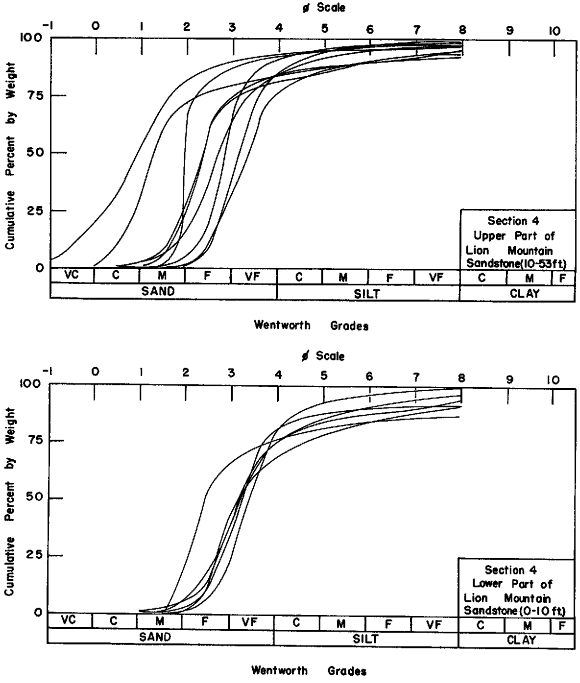
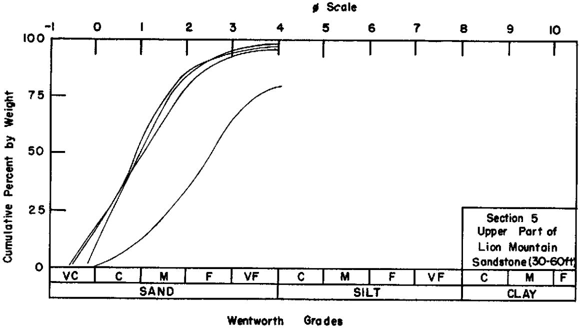


Fig.5- Cumulative curves of the Lion Mountain sandstone, plotted with ø as independent variable



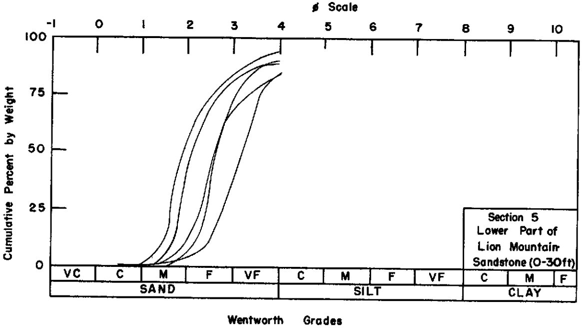


Fig. 6 - Cumulative curves of the Lion Mountain sandstone, plotted with ø as independent variable

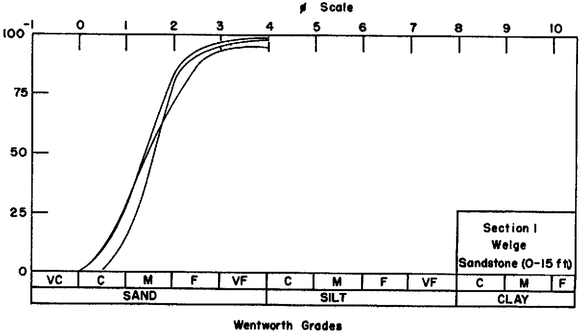


Fig. 7 – Cumulative curves of the Welge sandstone, plotted with ø as independent variable.

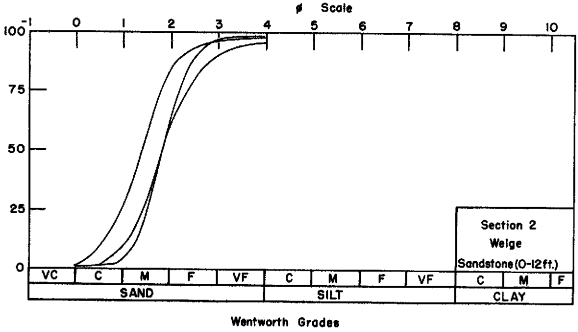


Fig. 8 – Cumulative curves of the Welge sandstone, plotted with ø as independent variable.

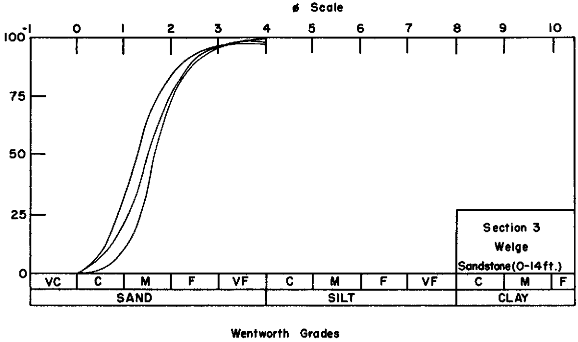


Fig. 9 — Cumulative curves of the Welge sandstone, plotted with ø as independent variable.

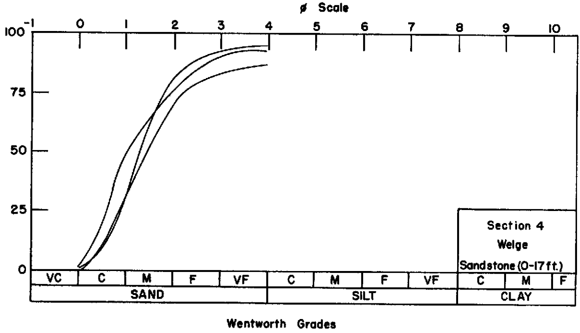


Fig. 10 — Cumulative curves of the Welge sandstone, plotted with ø as independent variable.

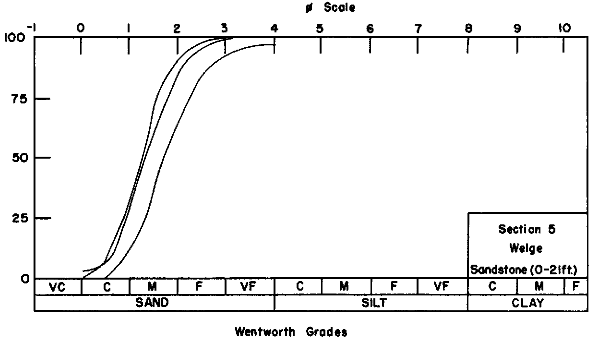


Fig. 11 - Cumulative curves of the Welge sandstone, plotted with ø as independent variable.

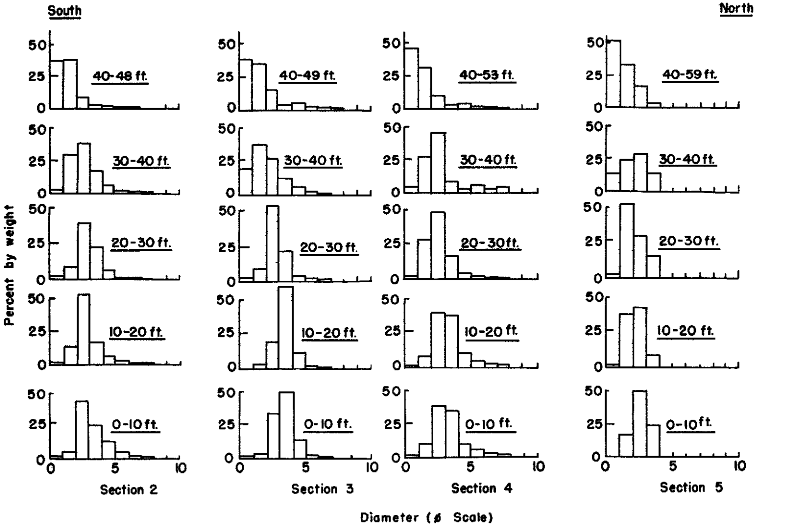


Fig. 12- Histograms indicating lateral and vertical variation in grain size of the Lion Mountain sandstone. Distance in feet above the Lion Mountain-Cap Mountain contact is indicated adjacent to each graph.

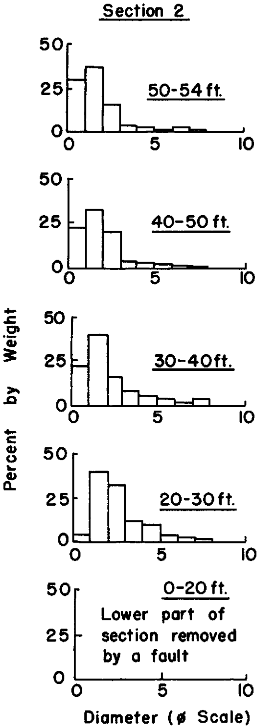


Fig 13— Histograms indicating vertical variation in grain size of the Lion Mountain sandstone. The lower part of the section has been removed by a fault.

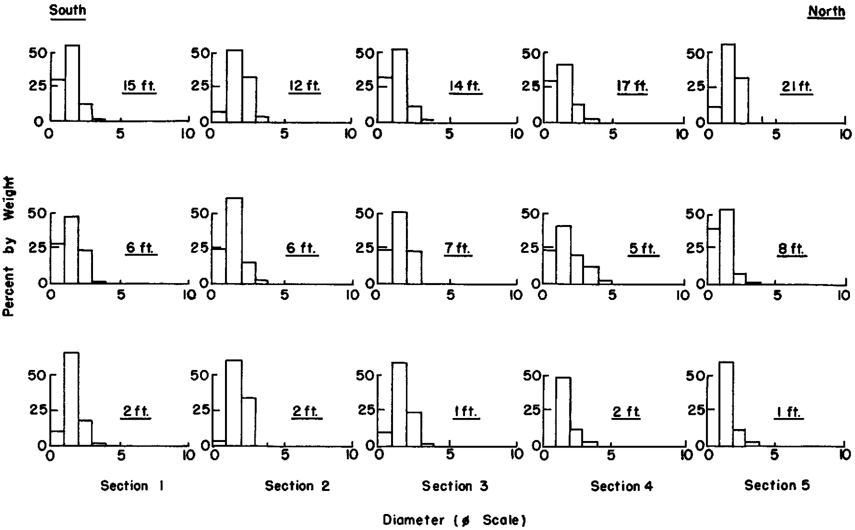


Fig. 14- Histograms indicating lateral and vertical variation in grain size of the Welge sandstone. Distance in feet above the Lion Mountain-Welge contact is indicated adjacent to each graph.

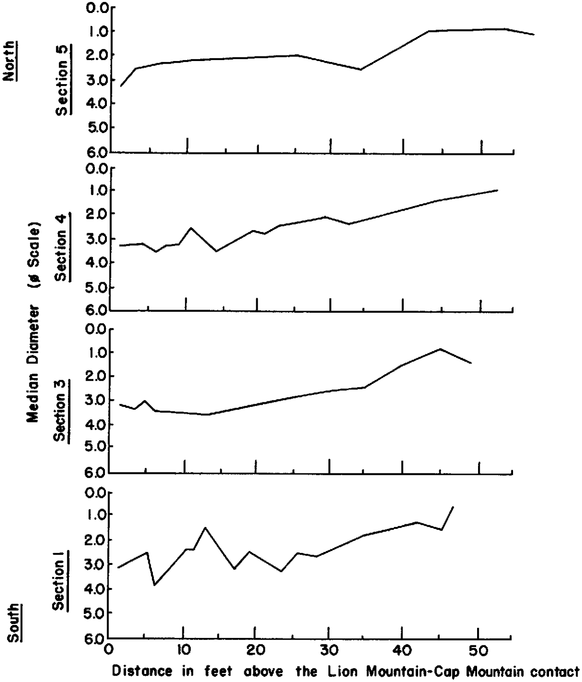


Fig. 15 —Size variation diagram of the Lion Mountain sandstone.

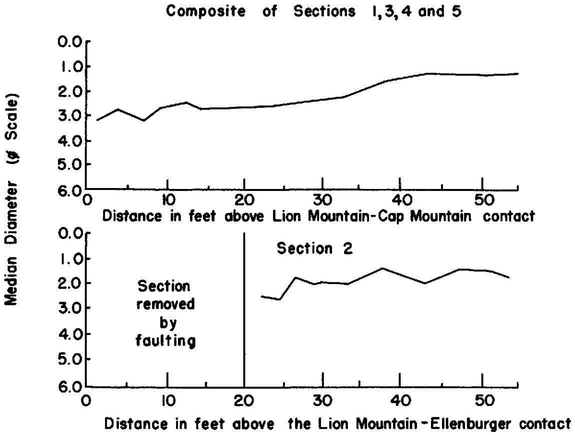


Fig 16- Size variation diagram of the Lion Mountain sandstone.
The lower part of the section has been removed by a fault

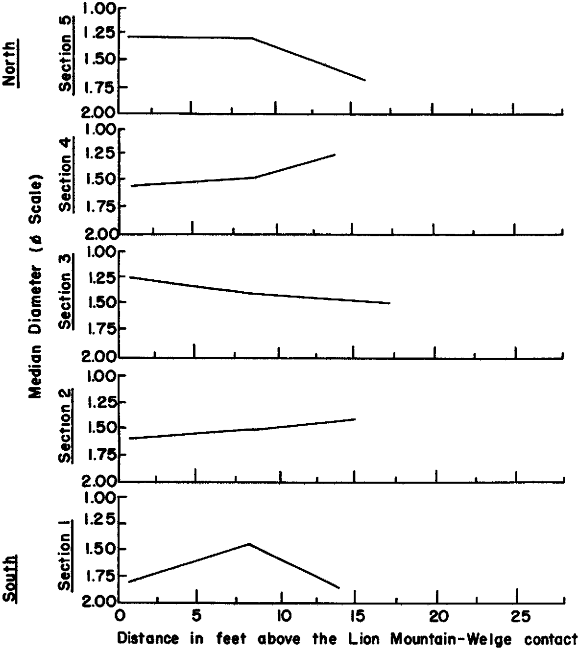


Fig. 17- Size variation diagram of the Welge sandstone.

TABLE 1

SIZE CHARACTERISTICS OF THE LION MOUNTAIN AND WELGE SANDSTONES IN SOUTHERN MASON COUNTY, TEXAS

Legend:
Sec. - Section number.
S - Sample number.
SP - Stratigraphic position from base of respective member in feet.

Sec.	S	SP	Percent by weight in Wentworth grades (Ø scale)									Sediment Parameters		
			0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8	MdØ	QdØ	SkØ
								Welge sandstone						
1	18	15.0	27.02	57.68	13.42	.40	---	---	---	---	---	1.40	.45	.00
1	17	7.0	26.84	45.05	21.50	1.34	---	---	---	---	---	1.50	.58	.03
1	16	1.0	10.83	69.35	16.51	1.23	---	---	---	---	---	1.60	.35	.00
								Lion Mountain sandstone						
1	15	47.0	60.52	26.68	7.55	1.57	1.33	.33	.66	.33	1.33	.75	.70	-.05
1	14	45.0	14.96	56.32	12.69	5.69	3.43	2.06	1.03	.69	3.78	1.50	.53	.23
1	13	42.0	41.79	37.65	10.97	2.72	2.34	.78	1.56	.39	1.95	1.20	.60	.10
1	12	35.0	4.65	52.05	27.75	5.87	1.84	1.23	1.23	1.23	4.30	1.85	.50	.15
1	11	30.0	.30	6.67	51.11	26.13	7.14	2.75	1.65	1.10	3.28	2.80	.53	.18
1	10	25.5	.18	20.23	41.15	10.44	5.98	3.42	3.42	2.57	12.00	2.60	1.18	.73

Sec.	S	SP	Percent by weight in Wentworth grades (Ø scale)									Sediment Parameters		
			0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8-	MdØ	QdØ	SkØ
1	9	23.5	.16	2.68	37.95	36.85	8.35	3.51	3.36	1.76	4.82	3.20	.53	.08
1	8	19.0	.34	18.29	55.60	8.50	7.32	2.74	1.83	.92	3.66	2.50	.50	.20
1	7	17.0	.55	13.26	34.38	29.95	7.09	4.92	1.09	2.18	6.54	3.10	.58	.03
1	6	13.0	.56	15.44	64.50	10.77	4.31	2.69	.54	1.08	2.69	2.50	.35	.05
1	5	11.5	.70	11.31	61.90	16.26	4.42	2.21	.89	.44	1.78	2.55	.48	.13
1	4	10.0	.17	12.44	65.00	13.39	4.22	1.69	.84	.84	1.69	2.55	.38	.03
1	3	6.0	1.18	4.45	13.00	38.50	22.82	9.90	1.57	2.28	4.62	3.90	.75	1.10
1	2	5.0	.76	12.15	55.88	10.54	3.02	2.26	3.02	1.51	12.0	2.56	.67	.28
1	1	1.0	.01	1.61	45.80	34.48	7.23	2.20	.31	.31	2.52	3.10	.50	-.05
								Welge sandstone						
2	14	12.0	6.67	52.08	32.50	4.66	----------					1.85	.43	.08
2	13	6.0	24.45	60.18	12.29	1.18	----------					1.45	.38	-.02
2	12	2.0	3.07	61.68	31.40	1.85	----------					1.80	.35	.05

Sec.	S	SP	Percent by weight in Wentworth grades (Ø scale)									Sediment Parameters		
			0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8-	MdØ	QdØ	SkØ
								Lion Mountain sandstone						
2	11	34.0	23.79	39.30	17.01	4.73	3.64	1.46	2.19	1.46	4.38	1.70	.78	.13
2	10	32.0	35.66	35.92	13.69	4.07	4.57	.76	.76	1.52	3.05	1.35	.70	.10
2	9	27.0	38.65	32.58	10.12	3.89	4.27	1.70	.85	1.72	5.12	1.30	.78	.23
2	8	23.0	6.36	40.18	28.22	2.36	2.87	2.14	2.16	.71	14.28	2.00	.83	.43
2	7	18.0	33.46	38.08	10.42	2.76	2.77	2.22	.56	2.22	7.78	1.40	.73	.13
2	6	13.0	10.48	43.55	19.75	9.00	4.67	3.11	1.56	1.56	4.67	1.95	1.20	.60
2	5	10.0	6.74	46.00	16.97	12.80	7.68	3.08	2.30	2.30	1.53	1.95	.88	.43
2	4	9.0	.49	50.27	35.88	4.80	3.94	1.47	1.47	1.47	1.47	1.00	.40	.05
2	3	6.0	8.37	56.44	15.48	5.25	4.96	3.32	1.66	1.66	3.32	1.70	.55	.25
2	2	4.6	.45	23.16	35.99	12.47	10.48	3.48	4.64	3.48	6.95	2.65	1.08	.53
2	1	2.0	.17	13.84	54.75	14.59	7.35	1.57	1.57	1.05	3.15	2.60	.55	.20
								Welge Sandstone						
3	14	14.0	32.33	53.15	11.53	.79	-------	-------	-------	-------	-------	1.25	.43	.07
3	13	7.0	24.39	51.63	20.85	.81	-------	-------	-------	-------	-------	1.50	.43	.02

Sec.	S	SP	Percent by weight in Wentworth grades (Ø scale)									Sediment Parameters		
			0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8-	MdØ	QdØ	SkØ
3	12	1.0	8.93	64.70	22.75	.88	----------------------------------					1.60	.30	.10
								Lion Mountain Sandstone						
3	11	49.0	24.67	41.78	16.93	5.57	5.45	2.73	1.36	.70	.70	1.60	.73	.13
3	10	45.0	55.91	29.04	6.83	1.70	3.41	2.05	.68	.68	.68	.90	.56	.08
3	9	39.5	31.39	43.50	17.84	2.36	3.22	1.28	.00	.00	.00	1.45	.60	-.05
3	8	34.0	4.04	29.14	34.52	16.40	6.76	3.08	1.85	.62	.60	2.50	.78	.08
3	7	30.0	.43	14.00	57.21	17.65	3.84	1.92	.98	.97	.95	2.75	.43	-.08
3	6	25.0	.14	5.36	52.58	26.67	5.85	2.50	1.68	.84	.89	2.95	.43	.08
3	5	13.0	.06	1.06	18.48	67.30	9.78	1.23	.58	.58	.58	3.45	.25	.10
3	4	6.5	.05	.95	21.24	57.42	11.22	2.00	1.35	.66	2.66	3.40	.33	.03
3	3	5.0	.02	.37	47.46	36.80	7.00	1.16	1.16	.39	2.74	3.00	.30	.20
3	2	3.50	.05	.65	31.46	50.82	9.78	1.83	.61	.61	1.22	3.25	.40	-.05
3	1	1.50	.10	1.15	37.12	42.78	10.02	1.33	.67	1.33	2.68	3.15	.48	.12
								Welge sandstone						
4	18	17.0	28.92	41.48	13.94	2.20	----------------------------------					1.50	.65	.05

Sec.	S	SP	Percent by weight in Wentworth grades (Ø scale)									Sediment Parameters		
			0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8-	MdØ	QdØ	SkØ
4	17	5.0	30.28	45.38	15.28	3.25	------------------------------					1.25	.45	.10
4	16	2.0	32.68	48.08	12.21	2.33	------------------------------					1.25	.45	.10
							Lion Mountain sandstone							
4	15	53.0	54.70	27.52	8.28	3.00	1.36	1.36	.45	.45	.45	.90	1.60	.65
4	14	46.0	36.10	36.28	8.05	2.28	4.32	1.96	1.57	1.18	6.64	1.35	.70	.25
4	13	32.0	2.71	25.94	46.18	7.94	2.04	6.14	2.04	4.10	2.04	2.35	.58	.18
4	12	29.0	.42	52.27	35.25	4.49	2.21	1.39	.60	.58	3.00	2.00	.18	.03
4	11	22.5	.79	24.57	49.72	8.90	4.34	1.63	2.17	1.63	4.34	2.40	.50	.10
4	10	21.0	.46	4.18	61.68	25.97	3.64	1.37	1.37	.46	.46	2.85	.28	.02
4	9	19.0	2.00	13.12	48.28	21.58	5.00	3.00	2.00	2.00	3.00	2.75	.55	.10
4	8	15.0	.19	.95	38.50	45.27	9.20	2.12	1.42	.71	.71	3.15	.43	.03
4	7	13.8	.00	1.81	32.16	44.22	9.42	2.57	2.56	2.57	1.70	3.35	.53	-.03
4	6	10.0	.24	19.32	49.02	6.91	7.34	2.94	1.47	1.47	11.78	2.50	.95	.55
4	5	9.0	.14	1.74	40.27	30.20	8.50	4.56	3.93	2.62	4.00	3.20	.85	.35
4	4	7.5	.92	4.65	34.95	35.52	8.30	3.70	2.78	4.60	2.78	3.25	.65	.10

Sec.	S	SP	Percent by weight in Wentworth grades (Ø scale)									Sediment Parameters		
			0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8-	McØ	QdØ	SkØ
4	3	6.5	.07	.70	21.84	58.90	12.20	2.68	2.02	1.35	.00	3.40	.43	.08
4	2	4.5	.47	6.80	33.23	35.54	10.00	5.25	2.34	2.34	2.92	3.20	.63	.18
4	1	1.0	.04	2.65	32.23	47.52	5.34	1.78	2.22	.44	6.25	3.25	.44	-.02
								Welge sandstone						
5	11	21.0	9.65	56.35	27.50	3.41	----------	----------	----------	----------	----------	1.70	.45	.10
5	10	8.0	36.39	57.65	5.17	.41	----------	----------	----------	----------	----------	1.25	.35	-.10
5	9	1.0	27.44	61.62	9.85	1.09	----------	----------	----------	----------	----------	1.30	.40	.05
								Lion Mountain Sandstone						
5	8	59.0	49.57	31.69	12.84	2.81	----------	----------	----------	----------	----------	1.00	.78	-.02
5	7	53.0	54.85	32.00	7.94	1.41	----------	----------	----------	----------	----------	.90	.65	.00
5	6	43.0	52.79	32.71	9.36	1.91	----------	----------	----------	----------	----------	.95	.58	.03
5	5	29.8	12.35	23.40	27.00	12.68	----------	----------	----------	----------	----------	2.50	.95	.05
5	4	11.0	2.25	37.97	44.02	6.01	----------	----------	----------	----------	----------	2.25	.43	.08
5	3	5.0	.07	5.14	68.15	18.29	----------	----------	----------	----------	----------	2.65	.30	.10
5	2	3.0	.40	9.50	58.62	15.42	----------	----------	----------	----------	----------	2.60	.55	.20
5	1	1.0	.64	3.34	33.07	48.20	----------	----------	----------	----------	----------	3.25	.40	-.05

Skewness

Examination of Table 1 indicates that positive skewness prevails for the Lion Mountain sandstone member. This implies that $Q_{3\phi}$ is much closer to Md_{ϕ} than $Q_{1\phi}$, or, that the finer sizes are more closely grouped to the median than the coarser sizes, which are spread over a wide range.

Although the Welge member is also characterized by positive skewness, the average value is uniformly small in comparison with the Lion Mountain member.

Coefficient of Sorting

Table 1 indicates the phi quartile deviation measure of the Lion Mountain and Welge sandstones. The phi quartile deviation measure, in the five sections analyzed, has a greater value for the Lion Mountain member than the Welge member. This indicates that the Welge member is better sorted than the Lion Mountain member.

There is some question regarding the sorting coefficient of the calcareous strata in the lower 25 to 30 feet of the Lion Mountain member. An analysis of thin sections indicates that the non-calcareous clastics were deposited simultaneously in a lime mud. The widely spaced quartz grains within the calcite cement imply poor sorting, although a consideration of non-calcareous material alone indicates good sorting. It is apparent that an erroneous picture of environmental conditions is presented when the calcareous material is neglected. Thus, thin sections were required to give a more accurate analysis of environmental conditions.

ROUNDNESS AND SPHERICITY

General Statement

Caution was exercised in the selection of quartz grains for roundness and sphericity determinations, as much of the quartz in the lower level of the Lion Mountain member had been corroded by partial solution. In addition secondary overgrowths on the quartz grains of the Lion Mountain and Welge members impeded roundness and sphericity determinations.

Roundness

Roundness is a measure of the sharpness of the edges and corners of a clastic fragment. The roundness of fifty random quartz grains from representative samples of the Lion Mountain and Welge sandstone members was determined by utilizing the Powers (1953, p. 118) visual scale. The roundness grades for each class interval is given by Table 2. A representative fraction within the medium sand grade size (1-2 Ø) and the very fine sand grade size (2-3 Ø) was selected for roundness studies of the Lion Mountain member. A representative fraction within the coarse sand grade size (0-1 Ø) and the fine sand grade size (1-2 Ø) was selected for the determination of roundness of the Welge sandstone member. The differences in sizes chosen for roundness determinations of the two members were based on the cumulative frequency curves shown on Figures 2 thru 11. The greatest percentage of material transported lies between the limits of the observed grade sizes.

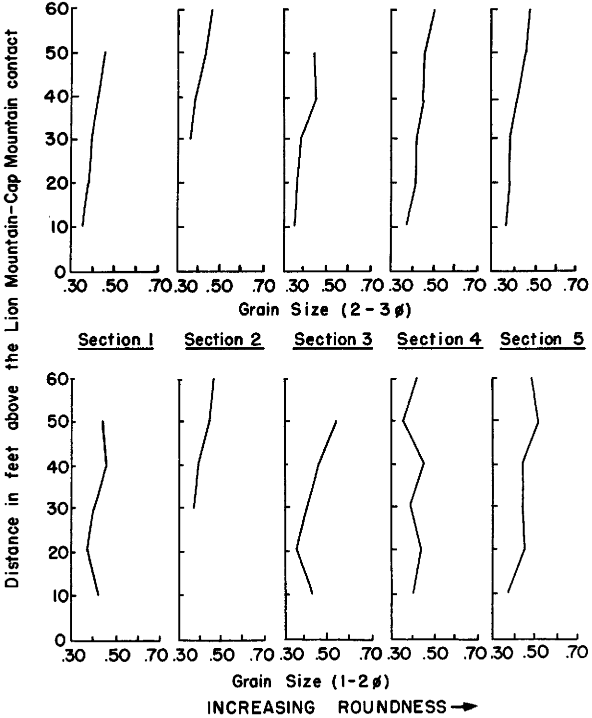


Fig. 18— Plot of roundness values of the Lion Mountain sandstone versus stratigraphic position.

The relationship between roundness and stratigraphic position is indicated by Figures 18 and 20. Both size classes of the Lion Mountain and Welge sandstones show a definite, though fluctuating, increase in average roundness from the bottom to the top of the unit. The average roundness values of the Welge sandstone member are higher than the Lion Mountain sandstone member (Figures 18 and 20).

A well-defined relationship exists between the size and roundness of the Welge sandstone member. The larger sizes are much better rounded than the smaller grades. The roundness values of the Lion Mountain sandstone member, however, show no relationship between size and degree of rounding. The values obtained fluctuate within a very small range and are not significant.

Table 2: Roundness Grades (after Powers, 1953)

Class Term	Class Interval	Geometric Mean
Very Angular	0.12-0.17	0.14
Angular	0.17-0.25	0.21
Subangular	0.25-0.35	0.30
Subrounded	0.35-0.49	0.41
Rounded	0.49-0.70	0.59
Well Rounded	0.70-1.00	0.84

Sphericity

The sphericity of 50 randum quartz grains was determined from projected grain images by the Riley Method (Riley, 1941). This method involves the measurement of the diameter of the inscribed and circumscribed circles. The sphericity is given by $\sqrt{\frac{di}{dc}}$, where d_1 and

d_c are the diameters of the inscribed and circumscribed circles, respectively. The same grades utilized in the roundness determinations were used for obtaining average sphericity.

The sphericity values of the Welge sandstone member obtained by measurements on grain projection show a definite, though fluctuating, increase in sphericity from the bottom to the top of the unit, as illustrated by Figure 21. The sphericity values of the Lion Mountain sandstone member show no clear trend with stratigraphic position and the values fluctuate within a very small range.

A definite relationship exists between the size and sphericity of the Welge sandstone member. The average sphericity of the coarser fraction (0-1 Ø) is .88, whereas the sphericity of the finer fraction (1-2 Ø) is .82. The average sphericity values of the Lion Mountain sandstone member are similar for both grade sizes.

Geologic Significance

It is difficult to evaluate the geologic significance of roundness and sphericity with any degree of certainty. However, a high degree of roundness apparently indicates the index of maturity of a sediment (Pettijohn, 1952, p. 66). According to Pettijohn, only well-washed, many times reworked sands are well-rounded or even moderately rounded. Pettijohn determined the degree of maturity of a sediment from the relationship between size and roundness. He advocated that sediment derived from pre-existing sediments would show marked

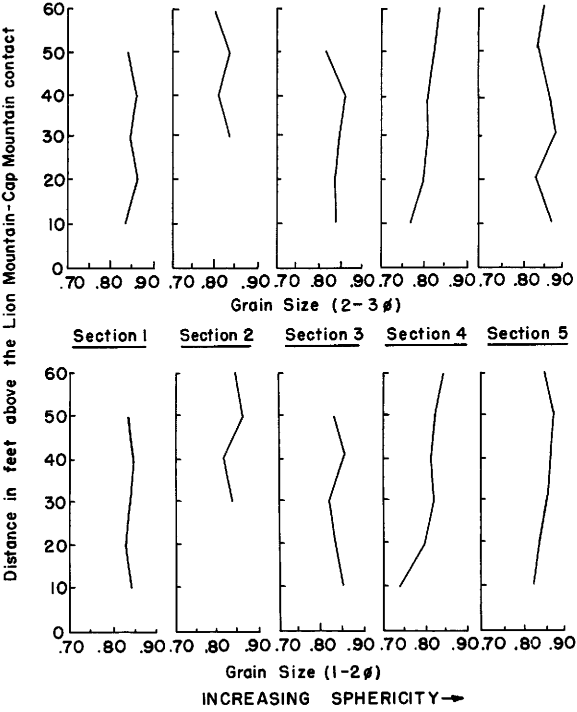


Fig. 19 - Plot of sphericity values of the Lion Mountain sandstone versus stratigraphic position.

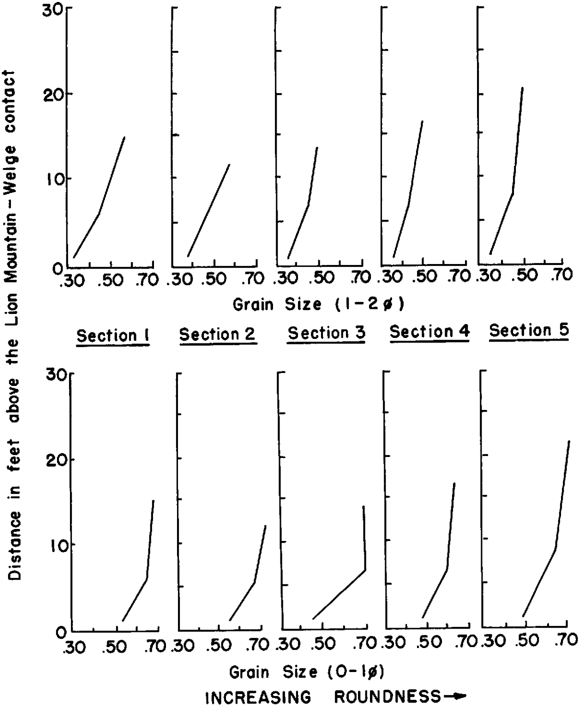


Fig. 20 – Plot of roundness values of the Welge sandstone versus stratigraphic position.

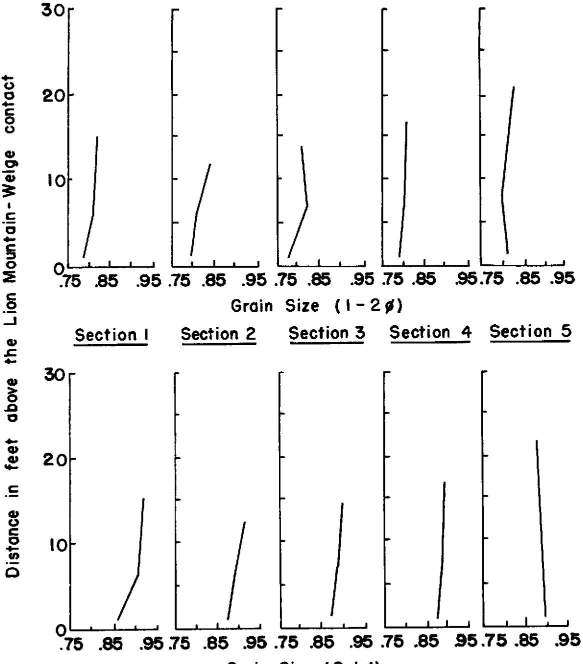


Fig. 21— Plot of sphericity values of the Welge sandstone versus stratigraphic position.

differences between rounding of the several grade sizes as opposed to the same roundness for different sizes of sediments derived from a basement complex. Therefore, the Welge sand would represent a more mature sand in contrast to the Lion Mountain which exhibits no marked difference in roundness for different grade sizes.

The textural maturity of the Welge member is marked by (1) the absence of clay (2) good sorting of the nonclay fraction, and (3) rounding of the quartz grains. According to Pettijohn (1949, p. 522), the first two conditions occur soon after erosion; however, the last stage is attained only after prolonged transport.

A sand grain apparently gets smaller, more spherical and better rounded as a result of abrasion (Pettijohn and Lundahl, 1943, p. 75). If the Welge sandstone member represents reworked sedimentary deposits, it would apparently exhibit the above characteristics. An examination of Table 1 illustrates the smaller phi median diameter of the Welge quartz grains as opposed to the higher phi median diameter of the upper portion of the Lion Mountain sandstone member. In addition Figures 18 thru 21 illustrate the higher roundness and sphericity of the Welge sandstone member in contrast to the lower roundness and sphericity values of the Lion Mountain sandstone member. The logical deduction, therefore, is that the sand grains of the Welge sandstone member may have been derived from pre-existing sediments.

An exception to the abrasion process as described above was observed by Marshall (1927). Marshall maintained that the presence of abundant coarse material would tend to split and fracture the smaller grains yielding low values of roundness and sphericity. However, the above explanation is inadequate for the Lion Mountain and Welge sandstone members, as the coarse materials needed for sand destruction are absent.

Additional evidence for the secondary origin of the Welge sandstone member is the pitted and frosted nature of the Welge quartz grains. Laboratory experiments conducted by Kuenen (1950, p. 280) indicate that only quartz grains larger than 1 mm. collide in water with sufficient force to become frosted. Twenhofel (1945, p. 59) states that grains of this size will be rounded and frosted by aeolian transportation due to the velocity and lesser viscosity of the wind.

Thus, the Welge sandstone member may represent the remnants of a sandy-dune complex derived from pre-existing sediments and consequently invaded and redistributed by a transgressing sea. The absence of glauconite in the Welge sandstone member may be attributed to the mature decomposition of the reworked sediments which were apparently subjected to extreme oxidizing conditions.

PETROGRAPHIC STUDY

Thin Section Analysis

The lower stratigraphic level (0-30 ft.) of the Lion Mountain member consists predominantly of trilobite hash beds and arenaceous limestones. Four thin sections taken at 8 foot intervals from section 1 were analyzed. In the following paragraphs a petrographic description of the limestones is discussed.

The calcite occurs as a granular mosaic, generally subtranslucent with a faint brownish-gray tint in thin section. The individual grain size varies from 1 to 3 microns for the smaller sizes and 10 or more microns for larger sizes. Quartz, microcline, orthoclase, plagioclase, glauconite and other non-calcareous terrigeneous material are unevenly distributed throughout the microcrystalline and coarse calcite matrix. The wide spacing between the individual quartz grains indicates poor sorting and initial deposition within an ooze matrix. Fossil fragments are also unevenly distributed throughout the calcite cement.

Evidence for recrystallization of the finer calcite matrix is suggested by the gradation of irregular patches of coarse calcite into areas of microcrystalline calcite (Folk, 1953). In some cases the coarser calcite has grown around detrital quartz grains with the detrital grains serving as a nucleus.

The size distribution of the initial calcite particles in the sediment should be reflected in the size distribution of sediment. However, a mechanical analysis of the discrete sizes of the initial calcite particles is impossible by ordinary mechanical methods. Any attempt to determine the size of the calcite particles must be dependent upon thin-section analysis. Thin-sections of selected samples within the Lion Mountain member indicate that recrystallization of the fine particles has taken place and that all gradations in size of the particles can be observed.

Replacement of Quartz

In all of the thin sections of the Lion Mountain sandstone member some of the detrital quartz grains appear to have been corroded and replaced by the calcite cement. Such replacement has been reported previously by Krynine (1940, p. 24); Pettijohn (1949, p. 484); and others, but is generally recognized as uncommon.

Many of the quartz grains appear to be well-rounded on one edge, whereas a very jagged or irregular-shaped outline can be observed on other edges. It is doubtful that grains with very angular edges could have been transported without such edges being broken off. It is apparent that the present shape is a result of post-depositional replacement. The well-rounded shape of some grains suggests that these grains have undergone abrasion prior to deposition.

Locally, small quartz grains often appear in the midst of larger calcite grains which are completely surrounded by a fine-crystalline calcite cement. It is possible that these small quartz grains represent the remnants of larger quartz grains which have been replaced by the calcite cement. The replacement of the quartz grains by the carbonate cement may be responsible for the wide spacing of the quartz grains observed in thin section. It is conceivable that given sufficient time, in a lime mud environment, all of the quartz grains would be replaced.

Heavy Mineral Study

The heavy mineral suite of both the Lion Mountain and Welge sandstone members is characterized by a pronounced concentration of leucoxene, ilmenite and zircon with brookite occurring as a trace mineral in both members. The Welge sandstone member differs essentially from the Lion Mountain member in that it contains a higher percentage of zircon. Pyrite is present in variable amounts within the Lion Mountain sandstone member but is absent in the Welge sandstone member. Table 3 illustrates the minor heavy mineral fraction within the Lion Mountain and Welge sandstone members. The heavy mineral content of the Lion Mountain sandstone member appears to increase from south to north, whereas the heavy mineral content of the Welge sandstone member indicates no definite relationship with geographic position.

Table 3

Percent of Heavy Minerals

South	Section Number					North
Stratigraphic Unit	1	2	3	4	5	
Lion Mountain member	.04	.10	.04	.62	1.35	
Welge member	.49	.10	.07	.36	.02	

Description of heavy minerals. The zircon of the Lion Mountain and Welge sandstone members ranges in color from clear to a faint pinkish-white tinge and occurs as long slender or oval-shaped grains with well-rounded terminations. The strong birefringence, high relief and parallel extinction were distinctive features in the identification of zircon. Next to ilmenite, zircon is the most abundant mineral and like ilmenite, it maintains a very uniform character in all samples.

The ilmenite grains of the Lion Mountain and Welge sandstone members are quite common. They occur as opaque, blue-gray black, subrounded to rounded particles with a metallic luster and a deep purplish-black sheen in reflected light. (Many of the grains are covered by opaque leucoxene.)

Brookite occurs as a trace mineral in both the Lion Mountain and Welge sandstone members. The distinctive features of Brookite are its straw-yellow color, tabular habit, incomplete extinction and marked striations parallel to the edges of the individual grains.

The pyrite grains of the Lion Mountain member are characterized by their metallic luster and pale brass-yellow color in reflected light.

The distinctive features of the heavy mineral suite of both the Lion Mountain and Welge sandstone members are the persistence of a few minerals such a ilmenite, leucoxene and zircon and also the well rounded, abraded nature of the individual grains.

Description of light minerals. Quartz is the chief light mineral in the Lion Mountain and Welge sandstone members, generally comprising 98 - 100 percent of the light mineral fraction excluding glauconite. A negligible amount of feldspar was observed in the Lion Mountain and Welge sandstone members. No definite identification of the feldspars could be obtained from an examination of the individual grains.

The Lion Mountain and Welge sandstone members contain quartz grains showing secondary enlargement, with the later quartz in optical continuity with the original grain. The secondary quartz is characterized by its clarity and the development of nearly perfect pyramidal faces.

A rather large percentage of the quartz grains in the Lion Mountain member exhibit thin, parallel or subparallel lamellae. In addition to the platy quartz a white chert-like material was also observed. This chert-like material is rare in the Welge sandstone member.

Possible source area. While not conclusive, the persistence of approximately the same heavy minerals in the sediments of the Lion

Mountain and Welge members suggests that the two members were derived from the same type of terrane. However, the higher percent by weight of heavy minerals in the Lion Mountain sediments in contrast to the Welge sediments suggests that the weathering process affected the sediments of the Welge to a greater extent than the Lion Mountain member. The rate of uplift possibly determined the time or duration of the formative processes and hence the magnitude of maturity or immaturity of the sediment and the extent to which the processes of sedimentary differentiation were carried.

The source area during Lion Mountain deposition was apparently characterized by a terrane of moderate to low relief, and by comparatively slow continuous uplift. The rate of uplift probably was accelerated during the deposition of the upper part of the Lion Mountain member (Fig. 15). The accelerated rate of uplift is a possible explanation for the higher percent by weight of heavy minerals in the Lion Mountain member as the rate of burial of the sediments would also be increased.

The high degree of mineralogical maturity of the Welge member suggests retarded erosion of the source in an area of low relief. Under conditions of retarded erosion, the weathering goes to completion so that only the most stable species appear in the sediments.

Although the heavy mineral suite suggests that the Lion Mountain and Welge sandstone members were originally derived from an acid to intermediate plutonic terrane, the presence of only the very stable minerals in the detrital suite suggests that the sandstone members have passed through more than one cycle of erosion and deposition.

The Welge sandstone may represent a dune deposit, subsequently partially reworked by a transgressive sea. The uniformity of grain size, and the frosting and pitting of the grains suggest that at one time the grains were subjected to wind transport.

DISCONFORMITY

A disconformity may be defined as a temporal break in a stratigraphic sequence in which two units of stratified rock are parallel but the surface of unconformity represents and old erosion surface. One of the most satisfactory criteria for a disconformity between the Lion Mountain and Welge members is the evidence of an erosion surface between the two members. Such evidence is present in the physical form of the irregularity of the contact between the two members.

The absence of fossils in the Welge member as opposed to the fossiliferous nature of the Lion Mountain member of southern Mason County suggests a hiatus but the unfossiliferous nature of the Welge member may be attributed to a change in bottom ecology.

Roundness and sphericity determinations offer additional evidence that the Welge member represents a more mature sand than the Lion Mountain member. As both members have approximately the same heavy mineral suite, the evidence points strongly to derivation from the same terrane. Thus, the higher degree of maturity of the Welge member suggests possible secondary derivation from pre-existing deposits.

ENVIRONMENT OF DEPOSITION

General Statement

Cambrian strata of southern Mason County, Texas were apparently deposited in shallow water, as is attested by the general sedimentary structures. The differences that exist in the character of the strata may only in part be referred to depth of water, and other factors of the environment of deposition must be sought. The problem of environment will be considered separately for each formation in the succeeding paragraphs.

Lion Mountain Environment

The rate of deposition of the Lion Mountain member appears to have occurred under quiet conditions, the assumption being based on the numerous thin, low-angle cross-laminated units. However, local zones of turbulence probably interrupted the quiet conditions of deposition of the Lion Mountain member at periodic intervals. Evidence for the above statement is based on the occurrence of lenses of trilobite hash within the member.

The sandy calcareous facies of the lower part of the Lion Mountain member appears to be the product of sedimentation marginal to a very low-lying land area. The presence of a microcrystalline calcite matrix signifies a lack of vigorous currents and the gradation of irregular patches of coarse calcite into areas of microcrystalline calcite suggests possible recrystallization of the cementing material.

The presence of trilobite lenses inclined at angles of 35 degrees or more with the bedding plane suggests that local zones of turbulence often disturbed the normal conditions of quiet-water deposition. Thin sections of the trilobite hash indicate that the carbonates are composed predominately of coarse-grained calcite as opposed to the microcrystalline and coarse calcite cement of the arenaceous limestones.

An abrupt rise in the source area apparently brought the lime deposition to an end except for brief invasions by the sea depositing thin limestone beds. The amount of non-calcareous material would apparently increase in proportion to uplift in the source area. A source area to the north is indicated by an increase in grain size to the north and also by an increase in percent by weight of heavy minerals to the north. Initially, the sea apparently covered an area of low relief but during Lion Mountain deposition uplift occurred as attested by the decrease in phi median diameter in the upper level of the member.

The rather abrupt decrease in phi median diameter in the upper part of the Lion Mountain member (Fig. 15) supports the concept of uplift and regression. The decrease of phi median diameter in the upper part of the Lion Mountain member may be attributed to removal of the fine material by wave action.

The absence of shale in the Lion Mountain member is difficult to explain. If the carbonates were composed of initial coarse-grained calcite, then the lower part of the unit could be the product of deposition in a turbulent environment. The finer material would be removed by current action and by-passed into deeper areas of less turbulence. However, as the arenaceous limestones are presumably in part lime muds, it is difficult to understand by-passing of the argillaceous material. It is possible that the finer material was winnowed out in an earlier cycle and the detrital quartz grains associated with the carbonates are second-cycle or multi-cycle grains.

Another possible explanation for the absence of shale in the Lion Mountain member may be attributed to reverse by-passing (Hjulstrom's diagram., Sloss, 1955, p. 160). The silt and clay size particles derived from the source area may have been deposited in a tidal flat which is possibly located to the north of the area studied. The mud flat would become firm by cohesion or partial compaction soon after deposition and greater energy factors would be required to initiate transportation of the particles. However, sand grains could be moved slowly across the tidal flat without seriously disturbing the surface.

Welge Environment

The uniformity of composition and the occurrence of the Welge member as a thin, widespread stratigraphic unit over southern Mason County indicates that the Welge sediments represent stable conditions of sedimentation with considerable transport and winnowing action before final accumulation.

The high degree of textural and mineralogical maturity of the Welge member is indicated by the high quartz content and the excellent sorting and rounding exhibited by the quartz grains. The textural and mineralogical maturity of the Welge member are obviously the product of prolonged weathering, sorting and abrasion. The absence or negligible amount of feldspar within the Welge member supports the above assumption, as prolonged erosion and chemical weathering will slowly eliminate feldspar and tend to round the quartz grains.

The quartz grains of the Welge member were apparently not in chemical equilibrium with one another or with the interstitial fluid at the time of deposition. Angular overgrowths on quartz grains of the Welge member suggest that these grains have been subjected to authigenic processes in an attempt to establish chemical equilibrium. The authigenic process includes the enlargement of detrital quartz grains by overgrowths. The relative clarity of the majority of the overgrowths suggests that secondary growth occurred after deposition of Welge sediment. However, some secondary overgrowths are pitted and frosted indicating growth prior to the deposition of the Welge sediment.

The textural and mineralogical studies of the Welge sandstone suggest that (1) the source area and the site of deposition were tectonically stable, or that (2) the sand had gone through several cycles of deposition, or (3) that a combination of these two factors existed during the deposition of the Welge member. The paucity of shale in the Welge member may be attributed to the winnowing out of the finer material in an earlier cycle.

Perhaps, the land areas were arid at the close of Lion Mountain deposition and the clay fraction was removed by wind transport and only a sandy dune complex remained. This dune complex was then invaded and redistributed by a transgressing sea. The similar heavy mineral suite in both the Lion Mountain and Welge sandstone members suggest derivation from the same terrane.

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A P P E N D I X

The following sections of the Lion Mountain and Welge sandstone members were measured at five localities in southern Mason County.

SECTION 1

Section 1 was measured in conjunction with Peterson (1959) near the type locality of the Welge sandstone in extreme southeast Mason County, Texas. The section starts in the bed of Squaw Creek approximately .60 miles from the intersection of Squaw Creek and Spring Creek.

	Thickness in feet
Wilberns formation:	
Welge sandstone member:	
14. Sandstone; buff to light brown with darker streaks, weathering yellowish-brown with dark brown blotches, massive, friable, medium-grained, sub-rounded to rounded, non-calcareous, non-glauconitic, siliceous quartzose sandstone. Some of the quartz grains have recomposed faces. .	18
Riley formation:	
Lion Mountain sandstone member:	
13. Sandstone; gray, speckled green, weathering to dull greenish-brown, massive, friable, medium- to coarse-grained, sub-rounded to rounded, glauconite bearing, calcareous,	

	Thickness in feet
quartzose sandstone. Lenses of trilobite hash are interspersed throughout the sandstone beds	12.9
12. Limestone; greenish-gray, 2 to 6 inch ledges of glauconitic, arenaceous limestone	4.5
11. Interbedded sandstone and oimestone; orange to brown, 6 to 12 inch ledges of fine- to medium-grained, shaly sandstones and orange to brown, 2 to 6 inch ledges of arenaceous limestone	12.4
10. Limestone; orange-gray, weathering to dirty brown, massive, fine- to coarsely-crystalline, glauconitic, arenaceous limestone. Trilobite hash is the main constituent of the limestone	3
9. Sandstone; purplish-gray, weathering to orange-brown, laminated, medium-grained, glauconite bearing, calcareous, quartzose sandstone	1.5
8. Limestone; gray, speckled green, weathering to orange-brown, massive, fine- to coarse-	

	Thickness in feet
grained, glauconitic, arenaceous limestone.	1.8
7. Sandstone; gray speckled green, weathering to orange-brown, laminated, fine-grained, glauconitic, non-calcareous, siliceous, quartzose sandstone	1
6. Limestone; orange-green, weathering to reddish-brown, medium-bedded, fine- to coarsely-crystalline, glauconite bearing, arenaceous limestone	.5
5. Sandstone; orange-brown, weathering to dirty brown, cross-bedded, thin- to medium bedded, glauconite bearing, calcareous, quartzose sandstone	5
4. Limestone; orange-gray, weathering to orange-brown, medium-bedded, glauconitic, arenaceous limestone	.5
3. Sandstone; gray speckled green, weathering to orange-brown, laminated, fine-grained, glauconite bearing, calcareous, quartzose sandstone	1
2. Limestone; gray, weathering to reddish-gray, massive, fine- to coarsely-crystalline,	

	Thickness in feet
slightly glauconitic, arenaceous limestone.	3.2
1. Sandstone; gray speckled green, weathering to orange-green, cross-bedded, laminated, fine-grained, glauconite bearing, calcareous sandstone	.5
Total thickness of Lion Mountain measured	47.8
Total thickness of section	65.8

SECTION 2

Section 2 was measured at the base of a bluff on the east side of the James River approximately 4.8 miles from the intersection of Mill Creek Road and Farm Road 1871 and 3.0 miles southeast of the Jeffreys ranch house on Mill Creek Road.

	Thickness in feet
Wilberns formation:	
Welge sandstone member:	
14. Sandstone; tan to brown, weathering to reddish-brown, massive, friable, medium-grained, sub-rounded to rounded, non-calcareous, non-glauconitic, siliceous quartzose sandstone. Some of the quartz grains have recomposed faces	18
Riley formation:	
Lion Mountain sandstone member:	
13. Sandstone; gray speckled green, weathering to dull gray, massive, medium- to coarse-grained, glauconite bearing, calcareous, quartzose sandstone. Sandstone beds crop out as 2 foot ledges. Lenses of trilobite hash are interspersed throughout the sandstone	10

	Thickness in feet
12. Sandstone; dark green, weathering to dull gray, massive, medium-grained, very glauconitic, calcareous, quartzose sandstone	5
11. Sandstone; reddish-green, weathering to reddish-brown, medium-bedded, friable, medium-grained, glauconite bearing, limonite stained, calcareous, quartzose sandstone .	1.2
10. Limestone; white speckled green, weathering to dull gray, massive, fine- to coarsely-crystalline, glauconitic, arenaceous limestone. Shells of linguloid brachiopods are scattered throughout the limestone which grades laterally into a sandstone unit . .	3.5
9. Sandstone; dark green, weathering to creamy gray, thin-bedded, friable, fine- to medium-grained, glauconite bearing, calcareous, quartzose sandstone. The bed grades laterally into a limestone unit	2.8
8. Limestone; gray speckled green, weathering to dull brownish-green, medium-bedded, fine- to coarsely-crystalline, glauconitic,	

		Thickness in feet
	arenaceous limestone. The sandstone beds crop out as 1 to 2 foot ledges. Linguloid brachiopods are quite common . .	3.5
7.	Sandstone; dark green, weathering to orange-brown, cross-bedded, laminated, fine- to medium-grained, glauconite bearing, limonite stained, calcareous, quartzose sandstone. Ellipsoidal hematite nodules are present within the sandstone	.5
6.	Sandstone; brownish-green, weathering to dull brown, cross-bedded, laminated, fine- to medium-grained, glauconite bearing, slightly calcareous, quartzose sandstone. The sandstone grades laterally into a limestone unit	1.8
5.	Greensand; dark green, weathering to light green, laminated, friable, medium-grained, very glauconitic, quartzose sandstone. Ellipsoidal hematite nodules are in place within the unit	1.2
4.	Limestone; grayish-white, weathering to dull gray, thin-bedded, fine- to coarsely-	

	Thickness in feet
crystalline, glauconitic, arenaceous limestone. The limestone beds grade laterally into a sandstone unit	.7
3. Sandstone; grayish-green, weathering to orange-gray, laminated, fine- to medium-grained, glauconite bearing, calcareous, quartzose sandstone	.4
2. Sandstone; gray speckled green, weathering to grayish-green, laminated, fine- to medium-grained, glauconite bearing, calcareous quartzose sandstone. Lenses of trilobite hash are interspersed throughout the sandstone	1
1. Sandstone; dark green, weathering to dull gray, laminated, fine-grained, glauconite bearing, calcareous, quartzose, sandstone.	2.9
Total thickness of Lion Mountain measured.	34.5
Total thickness of section	52.5

SECTION 3

Section 3 was measured on Ernest Geistweidt's property in the bed of the west branch of Panther Creek approximately 1.3 miles from the point where Panther Creek divides into an eastern and western branch.

	Thickness in feet
Wilberns formation:	
Welge sandstone member:	
2. Sandstone; buff to light brown, weathering to reddish-brown, massive, friable, medium-grained, sub-angular to sub-rounded, non-clacareous and non-glauconitic, siliceous, quartzose sandstone	14
1. Sandstone; yellow-brown, massive, medium-grained, sub-rounded to rounded, slightly glauconitic, siliceous, quartzose sandstone.	1
Riley formation:	
Lion Mountain sandstone member:	
17. Siltstone; reddish-brown, weathering to dirty brown, fissile, siltstone containing large sub-angular to sub-rounded quartz grains in the siltstone matrix	1
16. Sandstone; dark green, weathering to reddish-brown, laminated, friable, very	

		Thickness in feet
	glauconite bearing, non-calcareous, siliceous, quartzose sandstone	3
15.	Sandstone; gray speckled green, weathering to orange-brown, fine- to coarse-grained, sub-rounded to rounded, glauconite bearing, slightly calcareous, quartzose sandstone. .	8
14.	Limestone; gray speckled green, medium-bedded, arenaceous, glauconitic limestone. The limestone grades laterally into a cross-bedded, sandy faces	1.5
13.	Sandstone; gray speckled green, weathering to dull orange-brown, laminated, fine- to medium-grained, glauconite bearing, calcareous, quartzose sandstone	3
12.	Limestone; white speckled green, weathering to dirty gray, medium-bedded, glauconitic limestone composed predominantly of trilo-bite fragments	1
11.	Sandstone; orange-brown, weathering to reddish-brown, cross-bedded, laminated. fine- to medium-grained, glauconite bearing, quartzose sandstone	2.5

		Thickness in feet
10.	Limestone; gray, weathering to orange-brown, medium-bedded, finely-crystalline, glauconitic limestone	1
9.	Sandstone; gray speckled green, weathering to buff brown, thin- to medium-bedded, fine- to medium-grained, glauconite bearing, very calcareous, quartzose sandstone . . .	9.5
8.	Limestone; orange-brown, weathering to brown, thin-bedded, coarsely-crystalline, glauconitic, arenaceous sandstone	1
7.	Sandstone; greenish-gray, weathering to reddish-brown, cross-bedded, medium-bedded, medium-grained, very calcareous, glauconite bearing, quartzose sandstone	7
6.	Limestone; orange-brown, weathering to grayish-brown, massive, fine- to coarsely-crystalline, glauconitic, arenaceous limestone	1.5
5.	Sandstone; dark gray, weathering to light brown, massive, fine-grained, glauconite bearing, very calcareous, quartzose sandstone	3

	Thickness in feet
4. Limestone; light-gray, weathering to buff brown, thin-bedded, oolithic, glauconitic, arenaceous, limestone	1.5
3. Sandstone; gray, weathering to orange, fine-grained, medium-bedded, glauconite bearing, calcareous, quartzose sandstone .	2.5
2. Limestone; gray, weathering to orange-brown, thin-bedded, finely-crystalline, glauconitic, arenaceous limestone	1.5
1. Sandstone; gray speckled green, weathering to creamy brown, fine-grained, glauconite bearing, calcareous, quartzose sandstone .	1.5
Total thickness of Lion Mountain measured .	48.5
Total thickness of section	63.5

SECTION 4

Section along Schep Creek on the Seth Martin ranch, 1.25 miles south of the Emeth Keller ranch house.

	Thickness in feet
Wilberns formation:	
Welge sandstone member:	
19. Sandstone; buff to light brown, weathering reddish-brown, sub-angular to sub-rounded, medium- to coarse-grained, ferruginous, non-glauconitic, non-calcareous, siliceous, quartzose sandstone	20
Riley formation:	
Lion Mountain sandstone member:	
18. Sandstone; light green, weathering to greenish-brown, cross-bedded, laminated, medium-grained, glauconite bearing, calcareous, quartzose sandstone. Small lenses of coarsely-crystalline limestone are interbedded within the unit. The limestone is composed predominantly of trilobite fragments	13.4
17. Limestone; gray speckled green, weathering to buff brown, medium-bedded, coarsely-	

	Thickness in feet
crystalline, slightly limonitic and glauconitic limestone. Individual beds varying in thickness from 1 to 2 feet crop out through a thick soil cover. Trilobite hash is the main constituent of the limestone	7.0
16. Sandstone; gray speckled green, weathering to dirty brown, medium-bedded, medium-grained, glauconite bearing, calcareous, quartzose sandstone. Thin lenses of limestone are interspersed throughout the sandstone	8.4
15. Interbedded limestone and sandstone; alternating cross-bedded laminae of grayish-brown, medium-grained, glauconite bearing, calcareous, quartzose sandstone with gray, weathering to yellowish-brown, limestone composed mainly of trilobite fragments . .	1
14. Sandstone; dirty reddish-brown, weathering to brownish-gray, laminated, silty, siliceous, quartzose sandstone which contains small grains of limonite	2.2

		Thickness in feet
13.	Limestone; gray speckled green, thin-bedded, coarsely-crystalline, sandy, glauconitic, ferruginous limestone containing minor amounts of limonite. The unit grades laterally into a cross-bedded, fine- to medium-grained, quartzose sandstone	1.8
12.	Sandstone; purplish-gray, weathering to buff brown, thin to medium-bedded, fine-grained, glauconite bearing, calcareous, quartzose sandstone	3.7
11.	Limestone; brownish-gray, weathering to buff brown, massive, finely-crystalline, very glauconitic, partially limonitic limestone. The unit grades laterally into a sandstone .	.5
10.	Sandstone; gray speckled green, weathering to brownish-green, medium-bedded, fine- to medium-grained, glauconite bearing, calcareous, quartzose sandstone stained with specks of limonite	2.2
9.	Limestone; greenish-gray, weathering to brown, medium-bedded, finely-crystalline, sandy, slightly glauconitic limestone	

	Thickness in feet
which also contains trilobite fragments . .	2
8. Sandstone; grayish-green, weathering to dark brown, laminated, fine-grained, glauconite bearing, clacareous, quartzose sandstone	.6
7. Limestone; gray, weathering to grayish-brown, medium-bedded, finely-crystalline, very glauconitic, limonitic limestone. The unit is partially composed of trilobite fragments	1
6. Sandstone; grayish-green, weathering to dark grayish-brown, laminated, very fine-grained, glauconite bearing, calcareous, quartzose sandstone	.6
5. Sandstone; dirty gray, weathering to buff brown, laminated, fine-grained, glauconite bearing, calcareous, quartzose sandstone. Small veins of calcite are interspersed throughout the unit	.9
4. Limestone; greenish-gray, weathering to light brown, medium-bedded, finely-crystalline, very glauconitic, slightly	

	Thickness in feet
sandy limestone composed primarily of trilobite fragments	1.1
3. Sandstone; gray speckled green, weathering to dirty orange-brown, laminated, very fine-grained, glauconite bearing, limonite stained, calcareous, quartzose sandstone .	.9
2. Limestone; greenish-gray, weathering to buff gray, medium-bedded, coarsely-crystalline, glauconitic, sandy, limonitic limestone. Fresh surface glitters due to the calcite cleavage fragments. Small seams of sandstone cut the limestone at irregular intervals .	3.2
1. Sandstone; greenish-gray, weathering to brown, laminated, fine-grained, glauconite bearing, calcareous, quartzose sandstone. The sandstone grades laterally into a finely-crystalline limestone	1
Total thickness of Lion Mountain measured.	51.5
Total thickness of section	71.5

SECTION 5

Section 5 is located near the eastern branch of Ridge Road approximately 1 mile from the point where Ridge Road divides into two ranch roads.

Thickness in feet

Wilberns formation:

Welge sandstone member:

10. Sandstone; gray, weathering to light brown, massive, friable, medium-grained, subrounded, non-calcareous, ferruginous, non-glauconitic, siliceous, quartzose sandstone. Some quartz grains have recomposed faces . . 23

Riley formation:

Lion Mountain sandstone member:

9. Sandstone; gray speckled green, weathering to dirty brown, massive, extremely friable, coarse-grained, glauconite bearing, calcareous, quartzose sandstone. Linguloid brachiopod shells are abundant 7

8. Sandstone; gray speckled green, weathering to orange-brown, massive, medium-grained, glauconite bearing, calcareous, quartzose sandstone. Lenses of trilobite hash are

	Thickness in feet
interspersed throughout the unit	10
7. Interbedded sandstone and limestone; gray, weathering to reddish-brown, massive, glauconitic, arenaceous limestone alternating with 1/8 to 1/2 foot ledges of glauconite bearing, calcareous, quartzose sandstone beds. Lenses of greensand several inches thick are interspersed throughout the limestone. The limestone is composed predominantly of trilobite fragments. Individual beds crop out through a thick soil cover . .	23
6. Limestone; white speckled green, weathering to reddish-brown, massive, fine- to coarsely-crystalline, glauconitic, arenaceous limestone. Trilobite fragments are the predominant constituent of the unit	2
5. Sandstone; gray speckled green, weathering to dull brown, massive, ferruginous, glauconite bearing, calcareous, quartzose sandstone . .	3
4. Limestone; orange-gray, weathering to dull brown, massive, fine- to coarsely-crystalline, glauconitic, arenaceous limestone	2.7

	Thickness in feet
3. Sandstone; gray speckled green, weathering to blotchy gray, thin-bedded, fine-grained, glauconite bearing, calcareous, quartzose sandstone	3
2. Limestone; gray, weathering to orange-gray, massive, glauconitic, limonitic, arenaceous limestone	3
1. Sandstone; gray speckled green, weathering to buff brown, laminated, fine-grained, glauconite bearing, calcareous, quartzose sandstone. Calcite veins approximately 1/8 inch thick cut the sandstone parallel to the bedding planes	4
Total thickness of Lion Mountain measured.	57.7
Total thickness of section	80.7