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Regressive And Transgressive Phenomena In The Gallup Sandstone In The Northwestern Part Of San Juan County, New Mexico.

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MASTER OF SCIENCE

Title **Regressive and Transgressive Phenomena in the Gallup Sandstone, in the Northwestern Part of San Juan County, New Mexico**

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July 23, 1971

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REGRESSIVE AND TRANSGRESSIVE PHENOMENA IN THE GALLUP SANDSTONE IN THE NORTHWESTERN PART OF SAN JUAN COUNTY, NEW MEXICO

BY

Francis Amrisar Kaharoeddin

B.S., The University of New Mexico, 1963

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Geology
in the Graduate School of
The University of New Mexico
Albuquerque, New Mexico

May, 1971

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ACKNOWLEDGMENTS

The writer wishes to thank Dr. R.Y. Anderson for suggesting this interesting problem, and for his guidance in the early stage of this study and in suggestions to improve this thesis. Acknowledgments are due Dr. S.A. Wengerd who has guided the entire study. He also wishes to thank Dr. P.M. Terlecky, Jr. for his guidance in laboratory methods and thesis writing. Acknowledgments are due Dr. G. Clark for correcting this thesis; Dr. L.A. Frakes for his guidance in laboratory and testing methods; Dr. A. Rosenzweig and Dr. J.P. Fitzsimmons for their suggestions on mineral identification techniques.

The writer is grateful for the grant from the New Mexico Geological Society, to cover some expenses for field work and preparing the manuscript. He is also very grateful to the Mineral Department, Navajo Tribe, Bureau of Indian Affairs for allowing access to the field and providing a guide for a certain time. Finally, thanks are due Mrs. Margarita Kaharoeddin who has helped in the field and in the laboratory.

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ABSTRACT

The sedimentary history of the Gallup Sandstone is studied through the field investigation and laboratory analysis of samples taken from four measured sections in the vicinity of the San Juan River and one section near the Red Rock Highway. In addition to field data, textural parameters and dolomite and glauconite content of sandstone samples are the basis for interpretations of the sedimentary history and environment of deposition of the Gallup Sandstone.

A plot of the mean grain-size and sorting along with stratigraphic sections reveals that most of the Gallup Sandstone was deposited in a regressive sea, and that the regression occurred in a step-like manner. Deposition of the regressive sandstone was ended because of diminishing supply of the quartzose debris to the basin. Regression was followed by erosional activity which occurred mostly at the northern part of the basin. The sediment on top of this unconformity was deposited in a transgressive sea, and consisted of medium- to coarse-grained glauconitic sandstone of Niobrara age.

In the vicinity of the New Mexico State Highway 504, the transgressive unit is found directly on top of the regressive unit. Possibly this transgressive unit is also found south of the study area. In the vicinity of the San Juan River, this

unit forms a thin sandstone blanket, sand bar, or channel-fill sandstone. There is no similarity in petrographic characteristics to the reservoir rocks in Bisti oil field.

In the vicinity of the Red Rock Highway the Gallup Sandstone was deposited under littoral conditions, whereas in the vicinity of the San Juan River it was deposited in a sublittoral to near-bathyal environment.

Because of the difference in lithology and age, the sandstone on top of the unconformity should be excluded from the Gallup Sandstone and be given a new name. The Gallup Sandstone which locally includes the transgressive unit probably terminates about three miles south of the San Juan River.

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INTRODUCTION

Purpose

The Gallup Sandstone in the San Juan basin is well known for its oil and gas production. Some geologists interpreted the oil-bearing sandstone as a sand bar deposit (Tomkins, 1957 and Sabins, 1963). The latest interpretation by McCubbin (1969) concluded that the oil-bearing sandstone was a strike-valley reservoir.

The main purpose of this study was to determine the environment of deposition of the Gallup Sandstone and the reservoir rocks associated with this sandstone. The outcrop studies, the chemical characteristics, and to a certain extent the paleontological characteristics are combined with the textural study to find the most likely environment of deposition of the sandstone.

The writer believes that an understanding of the environment of the deposition of this sandstone body, and its history of deposition, is not only of scientific interest but also may have value in the interpretation of subsurface data in the search of oil and gas in the San Juan basin.

Location and Geologic Setting

The area covered in this study is located in the northwestern part of San Juan County, New Mexico, between the Chuska Mountains and the San Juan River in the Navajo Indian Reservation (Fig. 1). More attention is given to the area north of

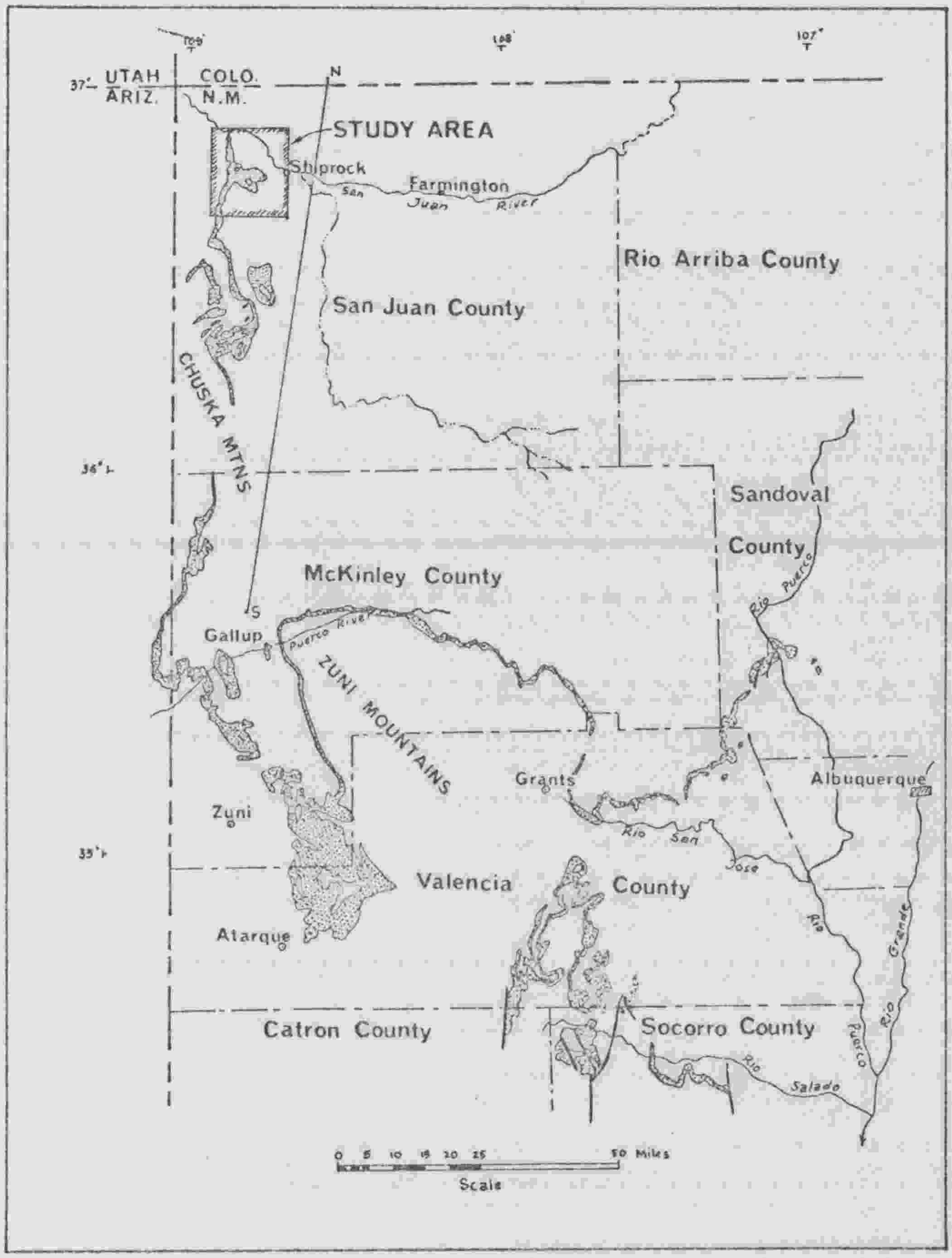

Fig. 1. Index map showing principal outcrops of Gallup Sandstone and location of study area. Cross-section S-N is shown in Figure 5.

the State Highway 504 where the Gallup Sandstone is known to pinch out.

The regional setting of the area studied is in the southeastern part of the Colorado Plateau physiographic province. It lies in the northwestern part of San Juan basin, a broad downwarped basin of the Colorado Plateau. Tectonically it lies on the Four Corners platform, which bounds the San Juan basin on the northwest.

Previous Work

The Gallup Sandstone is the basal formation of the Mesaverde Group, and was originally named by Sears (1925) for exposures in and near the town of Gallup. Sears (1934) and Hunt (1936) extended the known limits of the Gallup eastward along the southern margin of the San Juan basin.

Reeside (1924) gave a name "Tocito Sandstone lentile of the Mancos Shale" to sandstone beds of Upper Cretaceous age exposed near Tocito Trading Post, San Juan County, New Mexico. Pike (1947) established the homogenetic equivalence of the Gallup Sandstone and Tocito. Allen and Balk (1954), and Beaumont (1954) confirmed the conclusion of Pike.

The Mesaverde Group is named by Holmes (1877) after the exposures at the Mesa Verde Park, Colorado. The sandstone formations of the Mesaverde Group are known to have intertonguing relationships with the Upper Cretaceous Mancos Shale. The first detailed study by Sears, Hunt and Hendricks (1941) suggested that the Mesaverde Group was deposited in a broad, shallow sea. These authors developed a concept that the intertonguing relationships were brought about by the variation in the rate of trough subsidence and of supply of quartzose debris. This classic paper was followed by another in which Pike (1947) gave three possibilities: the rate of subsidence is faster, equal to, or slower than the rate of supply of debris. These three situations occurred during the deposition of the Mesaverde Group.

The oil discoveries between 1951 and 1955 from the Tocito or Gallup Sandstone have attracted much attention to the stratigraphy and the geometry of this sandstone. Dane, Bachman and Reeside (1957) described the Gallup Sandstone in the Gallup-Zuni embayment and along the north flank of the Zuni Mountains. Beaumont (1957) described the Gallup Sandstone on the western side of the San Juan basin. Budd (1957) discussed the facies development of the Gallup Sandstone, and Silver (1957) related the Cretaceous stratigraphy to the present coastal and marine topography along the east coast of the United States. Tomkins (1957) studied the lithological character and depositional history of the Gallup Sandstone in the Bisti oil field, and concluded that the upper producing zone in the Bisti field resembles a sand bar deposit, both in form and composition. One of the important papers in this period is the paper by Beaumont, Dane and Sears (1956), in which they revised the nomenclature of the Mesaverde Group in the San Juan basin, resulting in abandonment of Tocito in the formal nomenclature of the U.S. Geological Survey. Gallup then was elevated from a member to a formation, and the commonly used Mesaverde Formation to the Mesaverde Group.

Dane (1960) found a significant unconformity present in the northern part of the San Juan basin. The upper sandstone of the Gallup Formation of middle Niobrara age cuts sharply downward and rests directly on Carlile Shale. With this new information, several authors studied the environment of deposition of the Gallup Sandstone in more detail. Sabins (1963) worked on the geometry of the stratigraphic trap, Bisti field, New Mexico. Based on the subsurface information, along with the grain-size, glauconite and primary dolomite content, he postulated that the oil-bearing sandstone on the top part of the Gallup Sandstone is sand bar deposit. The latest interpretation of the Gallup reservoir came from McCubbin (1969). Based on the paleotopography of the erosion surface as shown by the isopach map, along with the current direction on the cross-bedded sandstone, he suggested that the deposit is a strike-valley sandstone.

Method of Study

Field Procedure

In the area where the Gallup Sandstone pinches out, the writer has measured four sections of the Gallup Sandstone down to a key bed in the underlying Mancos Shale. A five-foot Jacob staff, a brunton compass and a fifty-foot measuring tape were used in measuring the sections. The location of the measured sections is shown in Figure 2. Sandstone samples were collected at approximately every foot of the section. Another

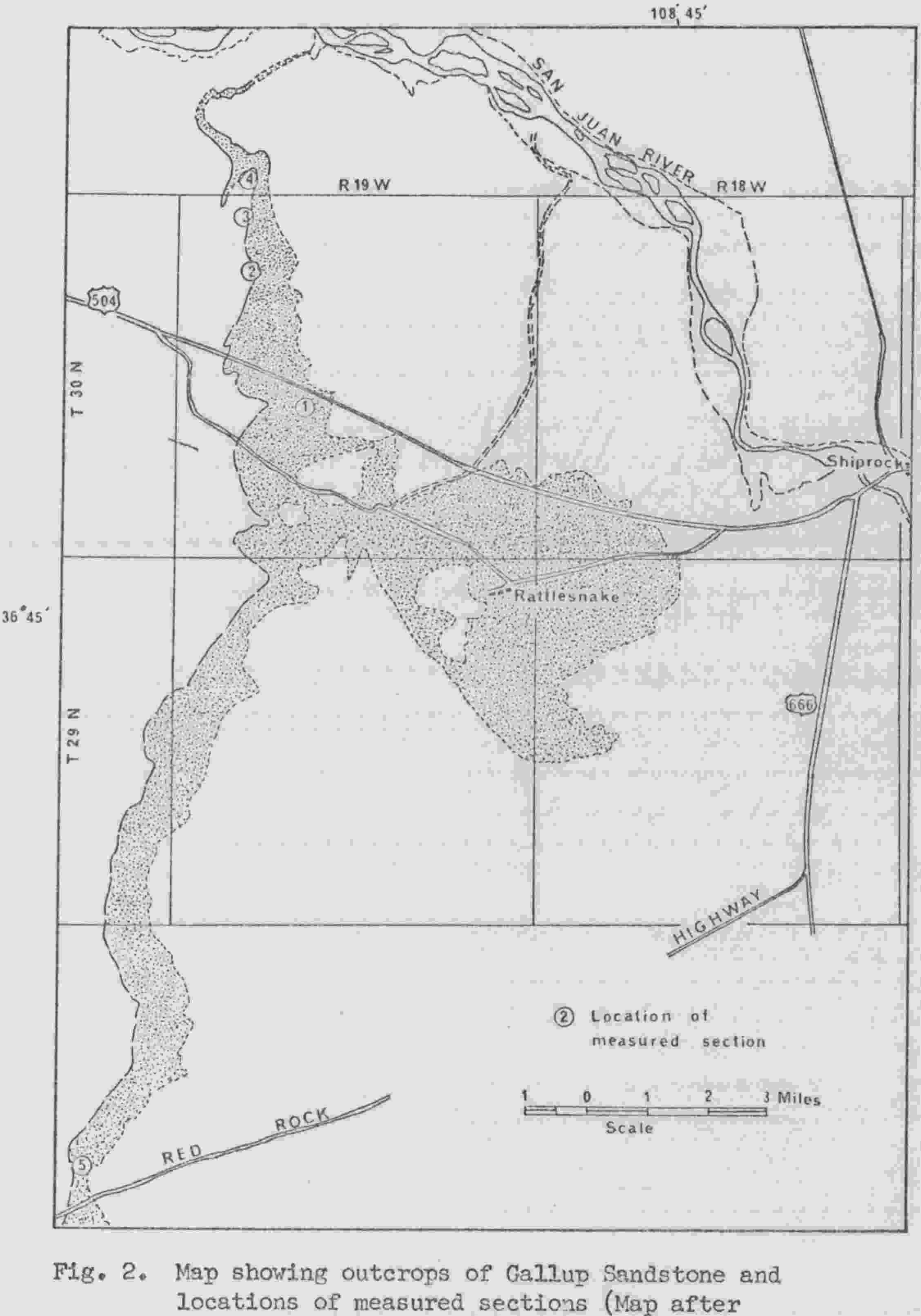

Fig. 2. Map showing outcrops of Gallup Sandstone and locations of measured sections (Map after Cooley and others, 1969).

section was also measured on the outcrops near the Red Rock Highway, and samples were collected at almost every five-foot interval.

Aerial photographs with the scale of 1 : 60,000 were used to supplement the topographic map of Rattlesnake quadrangle in studying the area. A geologic map (Cooley and others, 1969, plate I sheet 7) was also used as a guide in the field.

In measuring the sections, the bed thickness was described according to the classification of McKee and Weir (1953). The field descriptions on the textural characteristics of the sediments were modified according to the result of the analysis in the laboratory.

Laboratory Procedure

The main petrographic characteristics of the samples which are investigated are the grain-size distribution, the dolomite content and the glauconite content. Other minerals are only identified qualitatively.

All samples are calcareous, because the main cementing agent in these sandstones is calcium carbonate. Most of the sandstone samples collected are friable, and only several are strongly cemented by siliceous cement. In this study only the friable samples are sieved for grain-size analysis. A set of sieves with half phi unit intervals is used in this study. After repeated checking under the binocular microscope with a micrometer, it was found that the sieve of 230 mesh (U.S. Standard) has an opening of 0.074 mm (3.75 phi unit), instead of 0.061 mm as labelled on the sieve.

In disaggregating the calcareous sandstone for sieve analysis, the carbonate cement should be removed (Folk, 1968, Hoge, 1963). However, this standard procedure is time consuming. The present samples were merely disaggregated in a porcelain mortar with pestle or rubber cork, without being treated with the hydrochloric acid for removal of the carbonate cement. To ensure that the result would not differ greatly from the standard procedure for the carbonate-cemented rocks, a comparison test was conducted. The top ten samples from section I were used in this test. Table I shows the amount of carbonate in each sample.

Table I. The carbonate cement content of 10 samples tested for comparison of methods of samples preparation

Sample No.	% of Carbonate Cement
I-36	2.26
I-35	2.77
I-34	1.70
I-33	4.77
I-32	4.04
I-31	1.64
I-30	2.84
I-29	2.92
I-28	3.25
I-27	1.65

Comparison of the mean of paired samples can be achieved by using the t-test (Simpson, Roe and Lewontin, 1960). To get a reliable value for this comparison, the mean size of each sample in phi unit was obtained by using the formulas of moment method (Friedman, 1961). The formulas of the graphic method (Folk, 1968) were used to find the parameters for the environmental studies. Moment measures of the 10 tested samples for comparison purposes are listed in Table II. Incorporated in this table is the value of F which is the value of s^2/s_t^2 or s_t^2/s^2 such that F is bigger than 1.

Table II. Moment measure of the untreated and the HCl-treated samples

Sample No.	Untreated Samples $\bar{x}$	s^2	s	Treated Samples $\bar{x}_t$	s_t^2	s_t	F
I-36	2.11	0.24	0.49	2.18	0.26	0.51	1.08
I-35	2.03	0.27	0.52	2.01	0.28	0.53	1.04
I-34	1.98	0.22	0.47	2.00	0.24	0.49	1.09
I-33	2.03	0.25	0.50	2.06	0.25	0.50	1.00
I-32	2.09	0.26	0.51	2.09	0.22	0.47	1.18
I-31	2.05	0.24	0.49	2.05	0.23	0.48	1.04
I-30	1.72	0.37	0.60	1.70	0.34	0.58	1.08
I-29	1.53	0.40	0.63	1.51	0.46	0.68	1.15
I-28	1.68	0.21	0.45	1.66	0.20	0.45	1.05
I-27	1.64	0.42	0.65	1.68	0.42	0.65	1.00

Table II shows that at least two different populations exist. The first population has a mean grain-size around 2.05 phi unit, and the second population has around 1.65 phi unit.

Figure 3 shows these two different populations more clearly, and the difference between the parameters of the paired samples (untreated vs. treated) is very small. This insignificant difference is proven further by the statistical method; i.e. the t-test for paired samples and the F test as explained in Simpson, Roe and Lewontin (1960, p. 172 - 212). The caluclations of t in Appendix II and F in Appendix III show that there is no significant difference of the means obtained from the treated and the untreated samples.

To compare the variance of each untreated sample and its pair of treated sample, the variance ratio F can be used. Because the sum of frequency in each sample is 100, one can assume that the degree of freedom (d.f.) is 100. The degree of freedom as (n - 1) applied only for small n. From the table of F (Shelby, 1968), with 100 d.f. in numerator and denominator for 5 percent level of significance, F is 1.41. The value of F for each pair in Table II is less than 1.41. The conclusion is that there is no significant difference in the variance obtained from the treated or untreated samples.

The above observations show that the grain-size parameters obtained from the untreated samples are nearly indistinguishable from the treated samples, and can be used in the analysis of environment. This conclusion is based on the assumption that none of the remaining samples has a high carbonate cement content. Visual comparison of the carbonate cement content of all samples with the 10 tested samples was conducted by comparing the degree and duration of effervescence. The

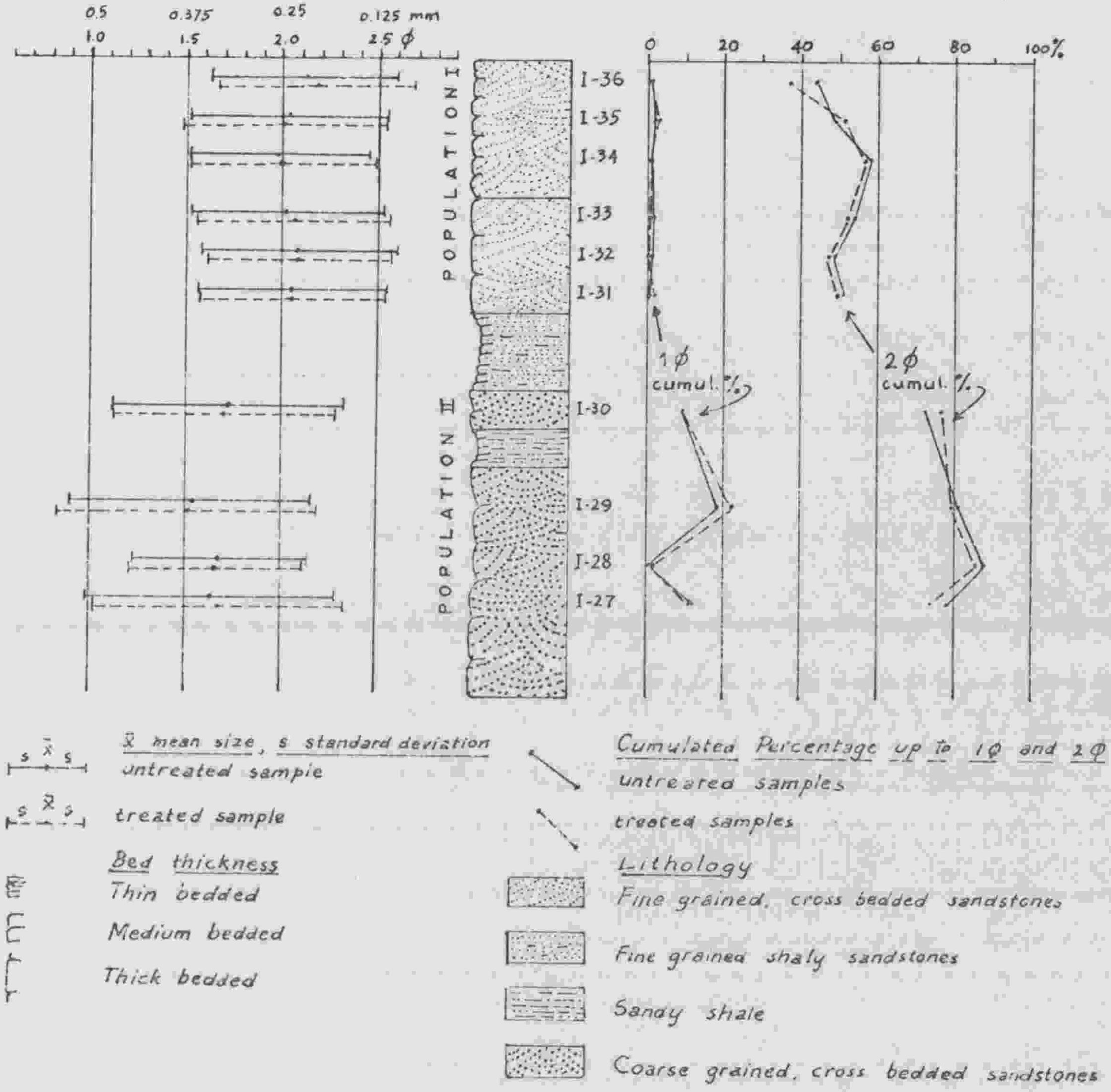

Fig. 3 The top part of the Gallup Sandstone from section I, showing two different populations with different mean size and standard deviation.

result of this test is that none of the samples has a high carbonate cement content, generally between 1 - 5 percent for the samples from the vicinity of San Juan River, and probably less than 1 percent for the samples from near the Red Rock Highway.

Most of the samples were also studied for their primary dolomite content as defined by Sabins (1962). As an aid for identification of dolomite, the samples were stained by alizarin red S. The outline of procedure for preparation of samples and chemicals and the staining treatment is described in Appendix IV. In this paper ankerite is included in dolomite because they belong to the same series of chemical composition. The dolomite percentage was estimated by use of the visual estimation chart (Wengerd, 1957, p. 60). A percentage less than one percent is denoted as trace.

All samples were studied for their glauconite content. The binocular microscope was used to distinguish the glauconite, and a visual estimation chart (Wengerd, 1957, p. 60) was used for percentage estimation. After studying all samples, the following verbal classification was used:

less than 1% - (T) trace
1% or more, but less than 3% - (P) present
3% or more, but less than 5% - (C) common
5% or more, but less than 7% - (A) abundant
more than 7% - (VA) very abundant.

In most cases the upper boundary of "very abundant" is 10 percent; in two or three samples this upper limit became almost 15 percent.

The same verbal classification was used by Sabins (1963); however, he did not mention the limitation of each class, except that the upper limit was 10 percent. Although some differences may occur, the above limitation should be very close to his limitation.

GEOLOGIC SETTING OF THE SAN JUAN BASIN

Regional Setting

The San Juan basin is a structural depression roughly circular in outline, occupies the southeastern part of the Colorado Plateau physiographic province. It is one of the three prominent structural basins in the Four Corners area. Geographically, the San Juan basin lies in the northwest part of New Mexico and extends slightly into southwestern Colorado.

The basin is bounded on the north by the San Juan dome, on the east by the Archuleta arch and Nacimiento uplift, on the south by the Zuni uplift, and on the west by the Hogback monocline and Four Corners platform. The southern part of the basin is generally called the Chaco slope (Fig. 4), where the overall regional dip of the beds is about one degree to the northeast. Along the other margins of the basin, the Upper Cretaceous beds dip steeply into the basin.

The earliest development of the San Juan basin appeared to occur during the Late Paleozoic time when it was an elongate northwest-southeast marine sedimentary trough on the southeast flank of the Paradox basin. This general shape was maintained through most of Late Paleozoic time. During the Late Mesozoic, this region was a south flank of the Rocky Mountains geosyncline. Its present shape was essentially the result of Late Cretaceous-Tertiary Laramide folding (Kelley, 1957).

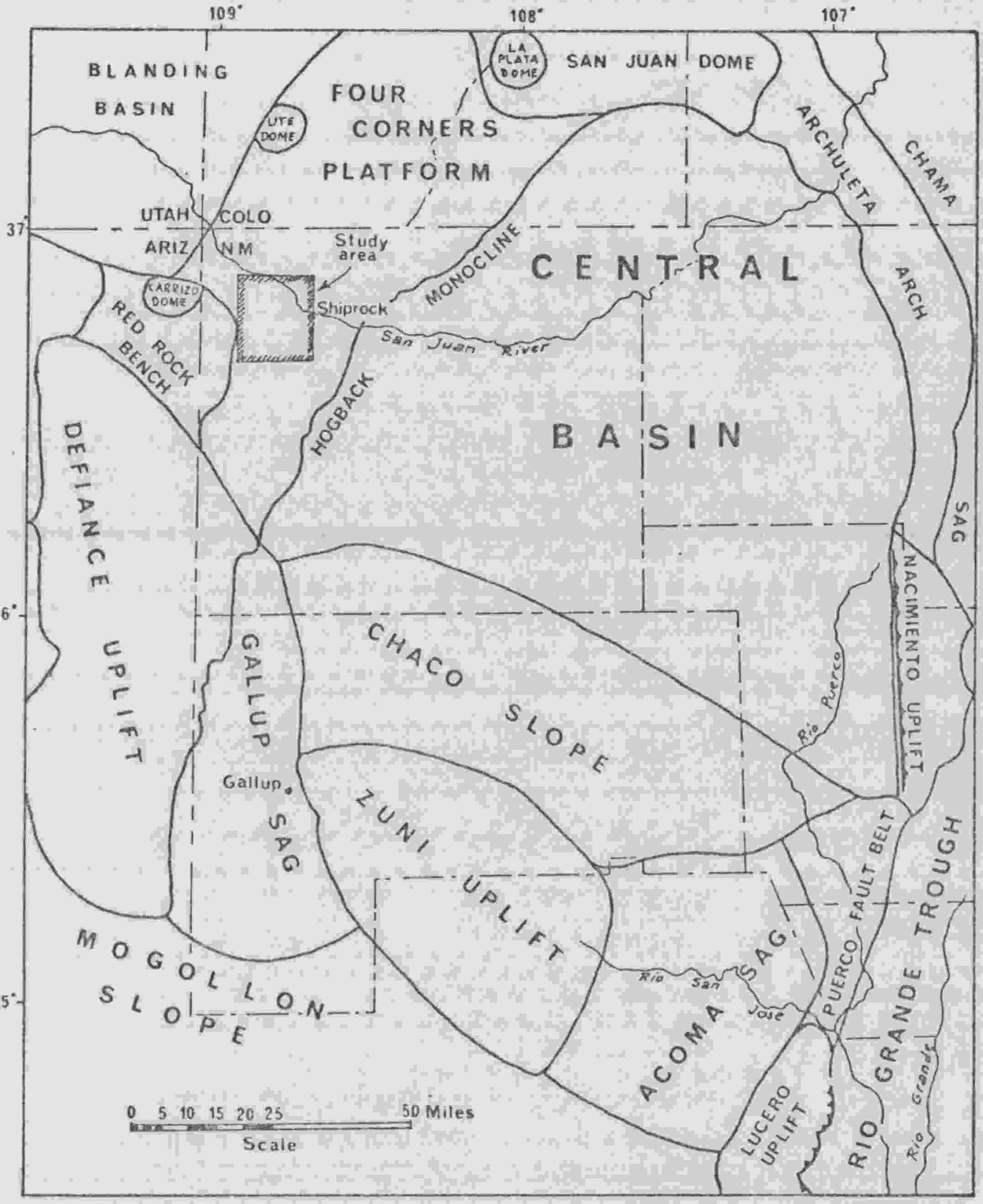

Fig. 4. Tectonic map of San Juan basin with major tectonic features (after Kelley, 1957).

Stratigraphy

From a sedimentary viewpoint, the present structural basin was the shelf area of an epicontinental sea which covered the Western Interior throughout most of Late Cretaceous time (Pike, 1947, and Budd, 1957). The Upper Cretaceous deposits filled this sea, and the Laramide orogeny has separated this broad belt of Upper Cretaceous deposits into several unconnected structural basins.

Older rocks are known to underlie the Upper Cretaceous deposits of the San Juan basin and are found in wells drilled in the basin, and they crop out on the surrounding uplift. These pre-Cretaceous rocks are summarized in Table III.

Lower Cretaceous rocks have not been positively identified in the San Juan basin. The Upper Cretaceous rocks in the basin consist of intertonguing marine and non-marine strata. Previous works by Sears, Hunt and Hendricks (1941), Pike (1947), Budd (1957), and Silver (1957) concluded that the main source area of sediments lie to the south and southwest of the basin. In the southwestern part of the basin the Upper Cretaceous strata are predominantly continental deposits, and in the northeast they are predominantly offshore marine deposits. As a result of sea level fluctuation, these two facies intertongue. The sea repeatedly transgressed to the southwest and retreated to the northeast. The nomenclature of the Upper Cretaceous and Lower Tertiary strata are summarized in Table IV. The

Table III. Nomenclature chart of pre-Cretaceous of the San Juan basin (modified from Peterson and others, 1965)

ERA	PER.	EPOCH	NORTH		SOUTH
MESOZOIC	JURASSIC	UPPER		Morrison Fm (sh, ss)	Morrison Fm (sh, ss)
		MIDDLE	SAN RAFAEL GROUP	Bluff (ss)	
				Summerville Fm (sh)	Summerville Fm (sh)
				Todilto (ls)	Todilto (ls)
				Entrada (ss)	Entrada (ss)
				Carmel Fm (sh)	Carmel Fm (sh)
		LOWER	GLEN CANYON GROUP	Navajo (ss)	Wingate (ss)
				Kayenta Fm (sh)	Chinle Fm (sh)
	TRIASSIC	UPPER		Wingate (ss)	
				Chinle Fm (sh)	
				Shinarump (cgl)	Shinarump (cgl)
		MIDDLE			
		LOWER		Moenkopi Fm (sh)	Moenkopi Fm (sh)
PALEOZOIC	PERMIAN	OCHOA			
		GUADALUPE			
		LEONARD		De Chelly (ss)	San Andres (ls)
					Glorieta (ss)
					Yeso Fm (ss, evap)
		WOLFCAMP		Cutler Fm (ark ss)	Abo Fm (ark, ss)
	PENN.	VIRGIL	HERMOSA GROUP	Honaker Trail (ls)	Madera (ls)
		MISSOURI		Paradox Fm (evap)	
		DES MOINES		Pinkerton Trail Fm (ls)	
		ATOKA		Molas Fm (sh)	Sandia Fm (ls, sh, ss)
		MORROW			
	MISS.	CHESTER			
		MERAMEC		Leadville (ls)	Arroyo Penasco (ls)
		OSAGE			
		KINDERHOOK			
	DEVONIAN	UPPER		Ouray (ls)	
				Elbert (dol, ss)	
				Aneth (sh, dol)	
		MIDDLE			
		LOWER			
	SILURIAN				
	ORDOVICIAN				
	CAMBRIAN	UPPER		Ignacio (qtzte)	
		MIDDLE			
		LOWER			
PRECAMBRIAN				Igneous & Metamorphics	Igneous & Metamorphics

Table IV. Nomenclature chart of Upper Cretaceous and Lower Tertiary of San Juan basin (modified from Hollenshead and Pritchard, 1961 and Peterson and others, 1965).

PERIOD	EPOCH	LITHOLOGIC UNITS	
TERTIARY	EOCENE	San Jose Fm. (ss)	
	PALEOCENE	Nacimiento Fm. (sh) Animas Fm. (ss)	
CRETACEOUS	MONTANAN	Ojo Alamo Fm. (ss)	
		McDermot Fm. (cgl)	
		Kirtland (sh)	
		Fruitland Fm. (sh, ss, coal)	
		Pictured Cliffs (ss)	
		Lewis (sh)	
		Mesaverde Group	Cliff House (ss)
			Menefee Fm. (sh, ss, coal)
	COLORADOAN		Point Lookout (ss)
			Crevasse Canyon Fm. (sh, ss, coal)
			Gallup (ss)
		Mancos (sh)	
	DAKOTAN	Dakota (ss)	

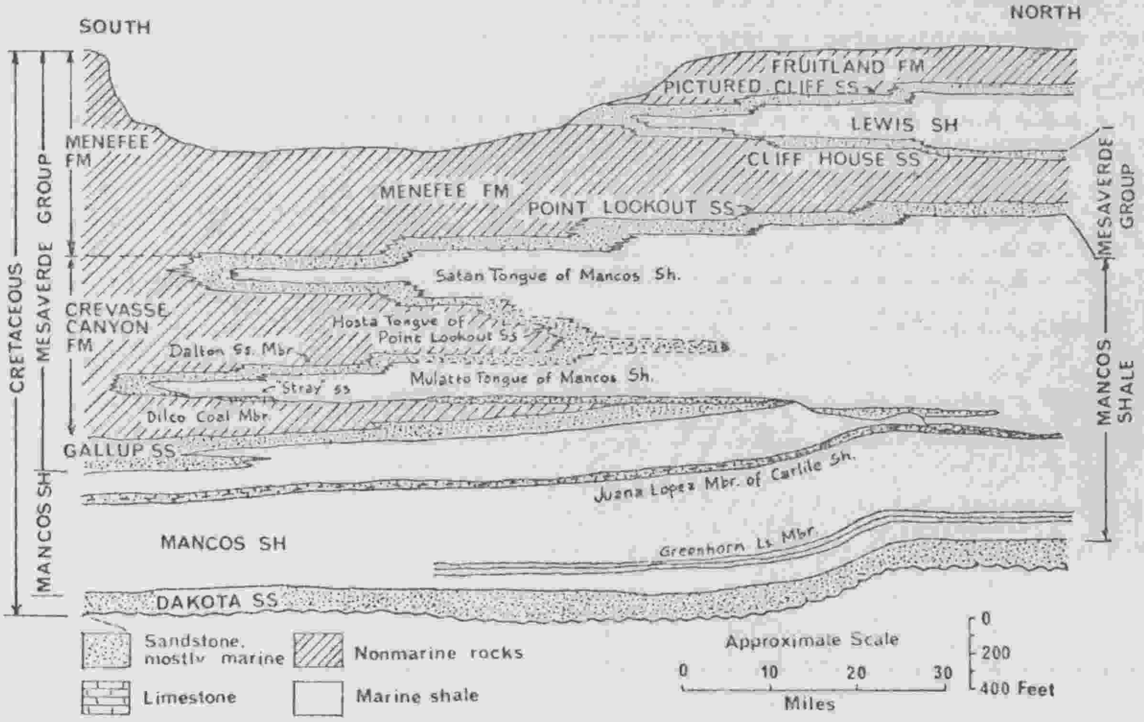

Fig. 5. Semi-diagramatic section of Upper Cretaceous rocks in San Juan basin (after McCubbin, 1969). Line of section is shown in Figure 1.

intertonguing relationships of the Upper Cretaceous strata are shown in Figure 5. Late Tertiary rocks are represented by dikes and volcanic plugs which are present in the southern, northeastern and northwestern part of the basin.

STRATIGRAPHY AND LITHOLOGY OF THE GALLUP SANDSTONE

The Gallup Sandstone which is the basal section of the Mesaverde Group, was laid down in a regressive sea (Sears, Hunt and Hendricks, 1941). It is exposed in the western, southern and southeastern rim of the San Juan basin (Fig. 1).

In the south and southwestern San Juan basin, the Gallup Sandstone underlies the continental deposit, the Dilco Member of the Crevasse Canyon Formation. To the north, the Dilco thins out, and partly interfingers with the Gallup Sandstone. In the study area, near the San Juan River, the known Gallup Sandstone is overlain by the upper part of Mancos Shale and there is no Dilco Member present.

In the study area, the Juana Lopez Sandstone in the Lower Mancos Shale is present about 250 feet below the Gallup Sandstone. To the south, Pike (1947) has included the Juana Lopez Sandstone in the Gallup section. Many previous studies have concluded that the age of the Gallup in the southern part is middle to late Carlile, while in the northern part it is latest Carlile age.

The thickness of the Gallup Sandstone in the south is almost 600 feet in Puertecito area and about 500 feet in the Atarque area (Dane, Bachman and Reeside, 1957). To the north it gradually thins and pinches out into the Mancos Shale. The wedge edge of this sandstone has been mapped by many authors, but varies from one to the other. In this study the Gallup Sandstone is considered to wedge out about four miles south of the San Juan River, where a distinct unconformity is present, on top of which a younger distinctive unit of sandstone was deposited.

The depositional strike of the Gallup Sandstone is known to be northwest-southeast. The outcrop of the Gallup Sandstone along the western margin of the San Juan basin is nearly perpendicular to this depositional strike. Therefore, major changes in the character of the sandstone can be expected to occur in a relatively short distance. In the study area the changes occur within 1,000 feet or less.

At the type locality in the Hogback, three miles east of the town of Gallup, according to Sears (1925) the Gallup Sandstone consisted of three massive sandstone and interbedded shale and coal. In the measured section V, about 0.3 miles north of the Red Rock Highway, the Gallup Sandstone still formed a conspicuous tripartite division, however, the interbedded shale contains carbonaceous materials which were very thin. The upper part formed small ridges along the east slope of the main ridge and in places was obscured on the soil covered slope. Detail description of this section is found in Appendix I, and the generalized stratigraphic section in Figure 6. The mean grain-size of sandstone in section V is progressively coarser toward the top. This phenomena can be observed in the field by direct comparison of the samples.

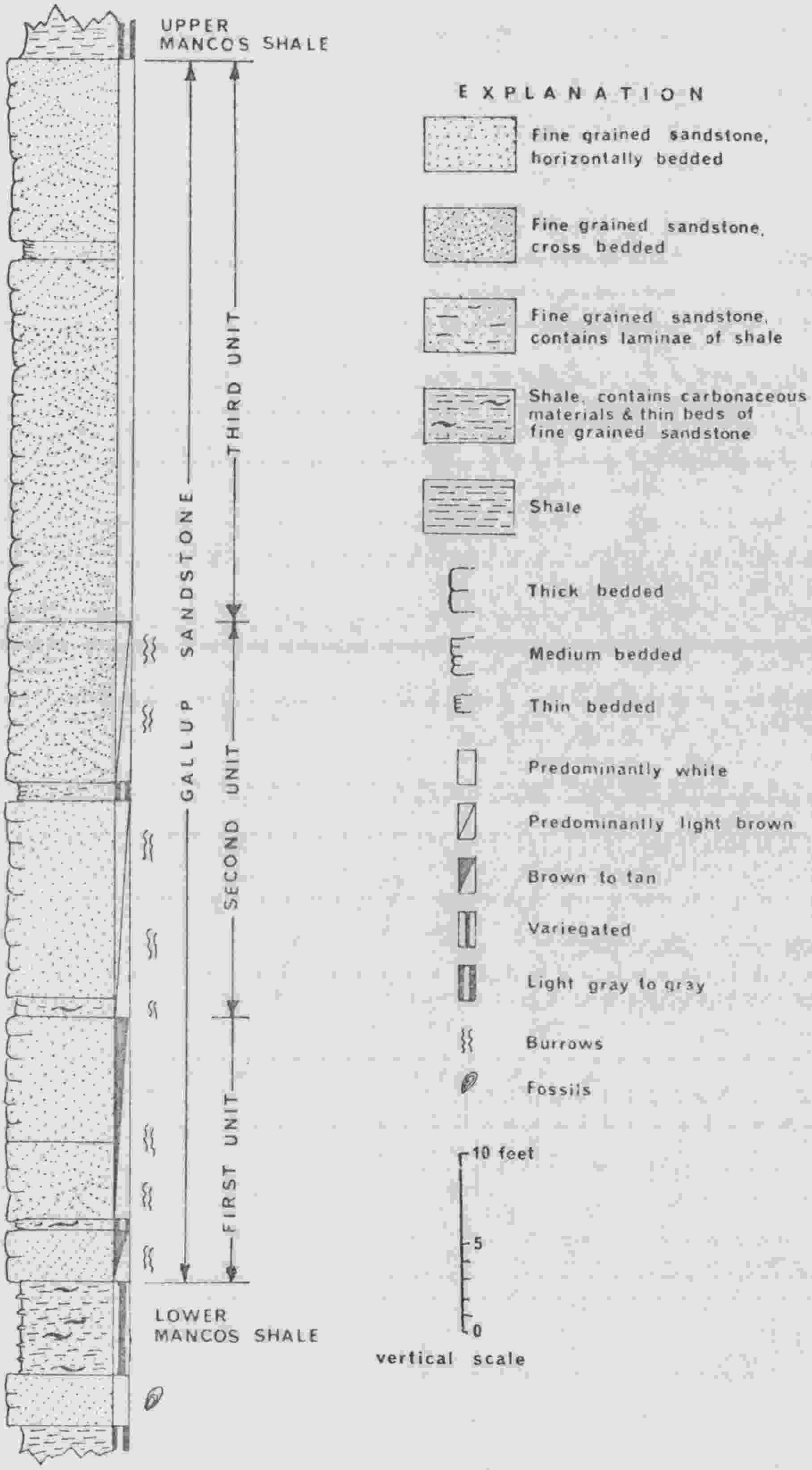

Fig. 6. Generalized stratigraphic section of the Gallup Sandstone near the Red Rock Highway.

In the vicinity of the San Juan River, the topography does not provide an easy way to divide the section into benches or ledges. Near the Red Rock Highway the angle of the dip is 20°, which causes a certain unit or bench to crop out in the form of a ridge. In the vicinity of the San Juan River, the dip ranges from 2° to 8°, which makes the section easily recognizable on the bluff or on the cliff of the wash. Here the abrupt change of grain-size, the glauconite content and nature of bedding facilitates division of section into units. Detail description of these measured sections is found in Appendix I and the correlation of these sections is shown in Figure 7, in pocket.

Within the length of the line of section I, which is less than a half mile, the character and thickness of sandstone units change. Within 300 yards, a unit almost at the bottom part of this section, changes from medium bedded sandstone into thin bedded sandstone with shale intercalations (Fig. 8 and Fig. 9). At section II this unit changes completely into shale.

There is 44.5 feet of Gallup Sandstone in section I, with some intercalations of shaly sandstone. According to its grainsize this section can be divided into four units. The bottom three units show that the grain-size is progressively coarser toward the top. The fourth unit, however, is finer than the second and third units. This top unit contains flat cavities parallel to the bedding, in places filled with shale (Fig. 10). There is a possibility that these cavities have

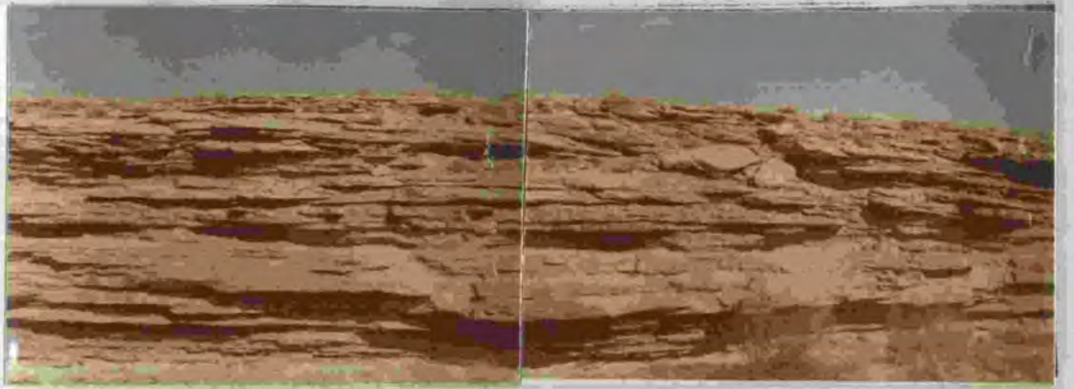

Fig. 8. Bottom part of the Gallup Sandstone in section I, about 100 yards north of the New Mexico State Highway 504.

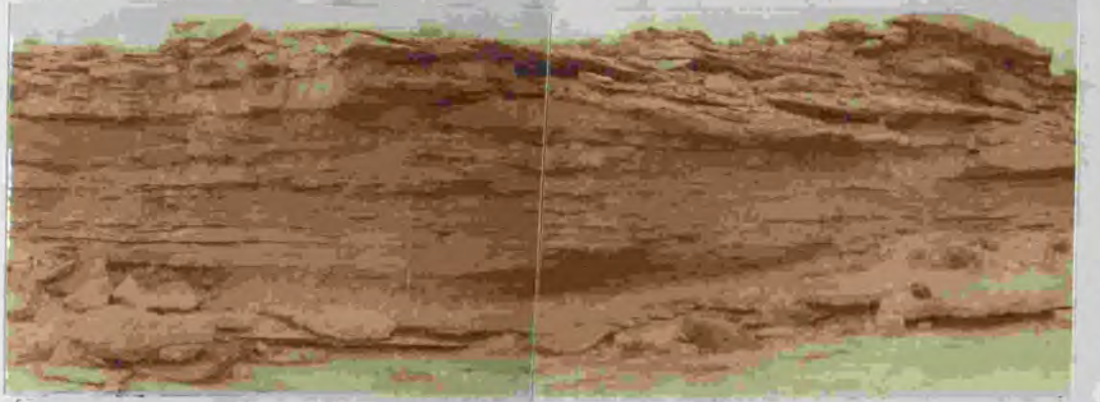

Fig. 9. Middle ledge in Figure 8 as exposed at a site about 400 yards northeast of above locality.

Fig. 10. Sample from the fourth sandstone unit in section I, showing cavities connected by thin cavity which is filled by shale. The scale is six inches long.

been formed by the leaching out of calcareous or gypseous lentils; however, the size and the form of the cavities suggests that they are cavities produced by weathering of fossils. No fossil was found preserved in this sandstone unit.

In a small wash between section I and II, very fine-grained, thin-bedded and ripple-marked sandstone can be observed, equivalent to the first unit in section I (Fig. 11). Large concretions in this wash lie almost at the same stratigraphic level as the concretion horizons in section I and II. These concretions are septaria (Fig. 12) and they are remnant in "box work" forms known as melikaria. Thin-bedded sandstone containing casts of fossils occur beneath this horizon. Most of the fossils are weathered, thus making their identification difficult.

In section II, about 3 miles north of section I, there is a 12 foot section of sandstone on top of sandy shale containing carbonaceous materials. The bottom 10 feet of this sandstone is equivalent to the third unit sandstone in section I. The grain-size is finer than that in section I, but the glauconite is more common, and the beds are not cross-bedded. The sandstone on the top part of section II is medium-grained sandstone, containing coarse-grained sand and some granules. This top unit is equivalent to the sandstone in section III which lies above an unconformity. McCubbin (1969) has called this sandstone the "Basal Niobrara Sandstone."

The unconformity cannot be detected clearly in section II. The medium to coarse-grained sandstone forms an irregular

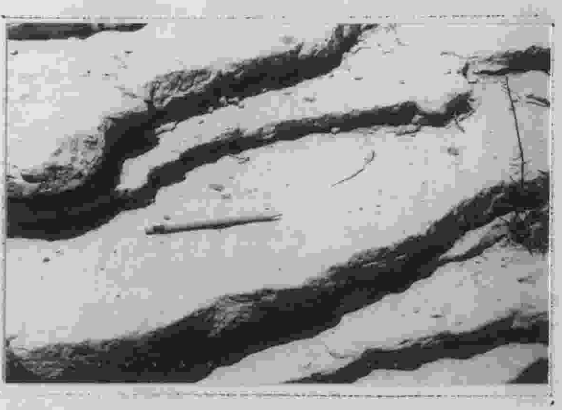

Fig. 11. Ripple-marked sandstone in the wash between section I and section II. Pencil pointing to the direction of flow, N 45 E. Length of pencil is six inches.

Fig. 12. Close view of a septarian concretion in the wash between section I and II.

Fig. 13. Horizon of concretions, probably weathered cone-in-cone structure, in the slope below the Gallup Sandstone in section II, as viewed to the east-northeast.

blanket on top of the bluff (Fig. 14). Farther north where the thickness of this sandstone is greater (Fig. 15), the sandstone is clearly cross-bedded, and the geometry of the outcrop suggests that it is bar sand. About a half mile north of section II another feature (Fig. 16) of this sandstone suggests that it has been deposited in a channel. The direction of the channel is parallel to the known direction of the strand line; that is southeast to northwest. In this locality and its surroundings, the unconformity is evident. Many big gravels, cobbles up to 30 cm in diameter present in the coarse-grained sandstone, which indicates a higher energy level than in the bar sand deposits.

The unconformity in section III is evident (Fig. 17). The sandstone above the unconformity is medium-grained and contains coarse-grained particles up to 2 mm and pebbles up to 1 cm. This sandstone which contains shell-fragments and shark teeth strongly cemented in the sandstone has many vertical burrows, which adds to the porosity of the medium to coarse sandstone.

North of section III the unconformity cuts downward steeply (7° to 9°) into the lower part of the Mancos Shale (Fig. 18). In section IV, about one mile north of section III, approximately 75 feet of strata which are present in section III have been removed. About 300 yards farther north the sandstone lies on and cuts into carbonaceous shale containing <u>Inoceramus</u> fossils. This locality is only about 200 yards from where the sandstone dips to the north underneath the wash.

Fig. 14. Medium-grained sandstone containing some granules as found on top of the bluff in section II (view north).

Fig. 15. Sandstone equivalent to the "Basal Miobrara Sandstone" of McCubbin, showing a bar-like outcrop in a SE-NW direction, about 300 yards north of section II, as viewed to the northeast.

Fig. 16. Outcrop about half a mile north of section II, showing a small and shallow channel cutting into the Gallup Sandstone.

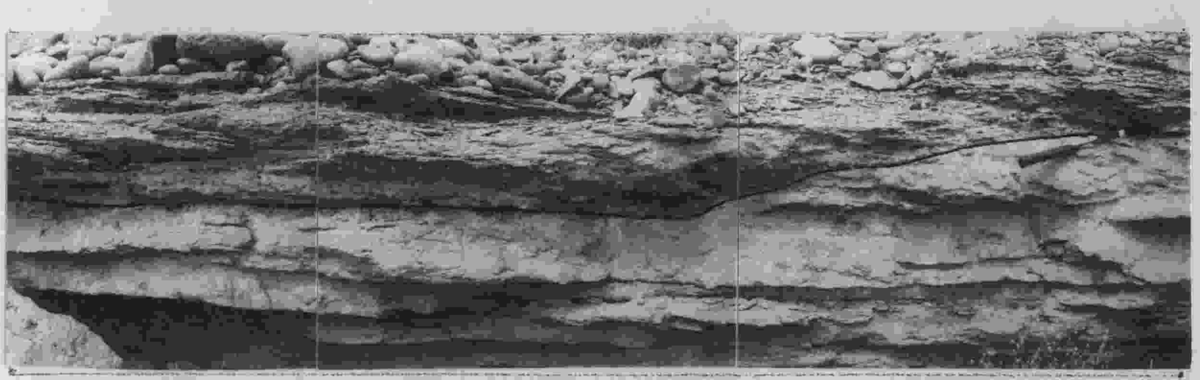

Fig. 17. Unconformity at the point of hammer, in section III.

Fig. 18. Unconformity cuts downward into the marker beds in the lower part of Mancos Shale, about 500 yards north of section III. Direction of view is east-northeast.

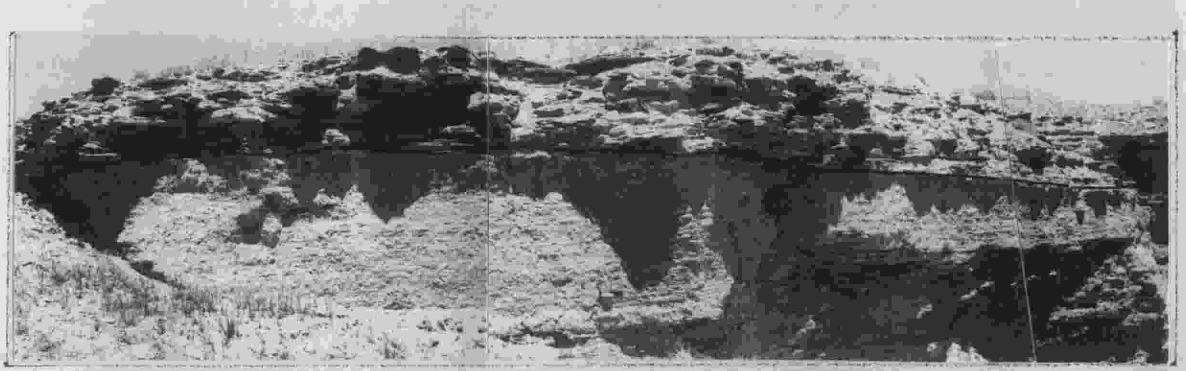

Fig. 19. Medium-grained sandstone in section IV lies above an unconformity. Direction of view is north-northwest.

Fig. 20. Broken piece of the sandstone above the unconformity in section IV, as viewed on the bedding surface, showing ripple marks, casts of fossils, horizontal burrows and tracks.

At Towaoc, Colorado, according to Dane (1960), the coarse-grained glauconitic quartz sandstone rests directly on top of the Juana Lopez Sandstone Member of Carlile age. The age of the glauconitic sandstone, based on the occurrences of *Inoceramus involutus*, according to Dane (1960) is middle Niobrara.

The glauconitic sandstone on top of the unconformity in the study area is equivalent to the reservoir rocks in the Horseshoe, Many Rocks, and Verde oil fields in northwestern part of San Juan County. The outcrop studies indicate that this sandstone was deposited as bar sand or marine channel sand.

PETROGRAPHY OF THE GALLUP SANDSTONE

Regressive and transgressive phenomena have been studied by means of grain-size analysis. In general, grain-size becomes coarser toward the top in a regressive sea, and the opposite is true in a transgressive sea (Visher, 1965). The environment of deposition may be recognized through the textural characteristics of the sandstone. In this petrographic study grain-size analysis is stressed more than the other petrographic characteristics of sediments.

The writer did not attempt to conduct a complete petrographic study of the Gallup Sandstone. Under the binocular microscope the following minerals were identified: quartz, feldspar, glauconite, mica, chert, zircon, tourmaline, iron oxide minerals, carbon and clay minerals. A complete petrographic study of the Gallup Sandstone from subsurface samples has been done by Williams (1956). Besides those minerals, Williams found garnet and pyrite. He found that the iron oxide minerals are hematite, limonite, magnetite and ilmenite, and the micas are chlorite and sericite.

The staining method reveals that some of the Gallup Sandstone contains dolomite and ankerite grains. The cementing materials of the sandstone are mainly carbonates and some silicious materials. The carbonate cement is mainly calcium carbonate and sometimes contains high Mg-calcite.

Quartz in the samples is usually greater than 90 percent, and the amount of feldspar is usually around 5 percent. According to Pettijohn's classification (1957) this sandstone can be classified as orthoquartzite. In some samples, especially those of the bottom part of the sections, the amount of quartz is less than 90 percent, sometimes only up to 70 percent and the amount of feldspar in places is as great as 25 percent; thus, the reason for calling them the feldspathic or arkosic sandstone. The grain-size analysis shows that the Gallup Sandstone in the study area is medium-grained to fine-grained sandstone. Most of the grains are subangular, only the coarser grains are subrounded.

The petrographic criteria studied in the laboratory are the textural parameters, the dolomite content and the glauconite content. The results are tabulated in Tables V, VI and VII. The graphic parameters are calculated by using the formulas of the graphic method (Folk, 1968). Other parameters are calculated for comparing the data with Sabins' data (1963). The maximum grain diameter is found by direct measurement under the binocular microscope, and the millimeter values obtained are converted to phi units by using the phi-millimeter conversion chart (Folk, 1968).

The glauconite grains occur as dark green pellets or aggregates with irregular rounded shapes. Comparison with the type of glauconite according to its form (Burst, 1958, Fig. 5, p. 318), shows that the glauconite in the samples are the altered fecal pellets and clay agglomerations.

Table V. Graphic parameters, dolomite content, and glauconite content of Gallup Sandstone from section I.

Sample No.	M_z in ϕ	σ_I in ϕ	Sk_i	K_g	Max in ϕ	Md in ϕ	σ_G in ϕ	Dol %	Glauc cont.
I-36	2.07	0.40	0.21	1.32	0.05	2.04	0.36	0	P
I-35	2.01	0.48	0.05	1.54	0.05	2.01	0.45	-	P
I-34	1.95	0.41	0.16	1.01	0.25	1.93	0.38	T	T
I-33	1.99	0.42	0.18	1.35	0.20	1.96	0.38	2	P
I-32	2.06	0.43	0.23	1.30	0.20	2.01	0.40	-	T
I-31	2.01	0.43	0.15	1.28	0.02	1.99	0.39	T	T
I-30	1.69	0.56	0.06	1.11	-1.85	1.68	0.54	1	T
I-29	1.52	0.56	0.01	1.06	-1.90	1.52	0.55	T	T
I-28	1.63	0.32	0.20	1.42	-0.45	1.61	0.29	-	T
I-27	1.60	0.57	0.17	1.28	-0.90	1.56	0.53	1	T
I-26	1.67	0.40	0.10	1.15	-1.30	1.66	0.38	-	T
I-25	1.68	0.39	0.14	1.28	-0.40	1.67	0.36	T	T
I-24	1.63	0.38	0.00	1.09	0.15	1.63	0.36	-	T
I-23	1.61	0.40	0.05	1.09	0.20	1.61	0.38	T	P
I-22	1.53	0.42	0.10	1.08	-0.05	1.51	0.41	-	T
I-21	1.62	0.49	0.04	1.18	-0.30	1.62	0.46	T	P
I-20	1.54	0.49	0.10	1.24	-1.35	1.54	0.46	1	P
I-19	1.85	0.23	0.19	1.33	0.30	1.83	0.22	-	P
I-16	1.79	0.38	0.10	1.38	-2.30	1.78	0.33	T	T
I-14	1.92	0.37	0.22	1.39	0.55	1.89	0.32	T	P
I-10	2.06	0.33	0.23	1.33	0.05	2.03	0.30	-	P
I-9	2.06	0.38	0.16	1.36	-1.25	2.05	0.33	-	P
I-8	2.22	0.33	0.05	1.46	0.05	2.23	0.28	-	T

Table VI. Graphic parameters, dolomite content, and glauconite content of Gallup Sandstone and associated rocks from sections II, III and IV.

Sample No.	M_z in Ø	σ_I in Ø	Sk_i	K_g	Max in Ø	Md in Ø	σ_G in Ø	Dol %	Glauc cont.
II-22	1.89	0.47	0.18	1.49	-0.35	1.85	0.39	3	A
II-21	2.33	0.59	0.21	1.49	0.10	2.30	0.50	2	C
II-20	2.45	0.46	0.07	1.37	0.10	2.44	0.39	-	C
II-19	2.19	0.51	0.40	1.29	-0.35	2.08	0.47	1	P
II-18	2.33	0.45	0.22	1.20	0.22	2.29	0.50	-	P
II-17	2.38	0.64	0.44	1.26	0.09	2.25	0.56	1	C
II-16	2.58	0.51	0.31	1.28	1.00	2.49	0.48	5	P
II-15	2.32	0.61	0.25	1.25	-100	2.26	0.55	3	P
II-14	2.49	0.57	0.25	1.63	0.31	2.46	0.46	-	T
II-13	2.66	0.89	0.52	2.31	0.81	2.50	0.63	5	T
II-12	2.54	0.89	0.62	1.64	0.31	2.33	0.77	-	0
II-11	2.60	0.60	0.31	1.64	0.06	2.56	0.50	3	0
III-20	1.31	1.00	-0.04	1.05	-2.46	1.35	0.89	5	C
III-19	2.11	0.49	0.12	1.22	-0.15	2.10	0.45	5	VA
III-18	1.95	0.41	0.12	1.26	-0.26	1.94	0.37	-	VA
III-17	2.21	0.38	0.09	1.14	0.41	2.20	0.36	-	A
III-16	2.25	0.42	0.29	1.46	0.46	2.19	0.38	10	A
III-15	2.20	0.50	0.36	1.18	0.42	2.09	0.49	10	VA
III-13	3.37	0.29	0.27	2.22	0.59	3.37	0.18	15	0
III-11	3.40	0.33	0.37	2.43	0.71	3.38	0.22	15	0
IV-7	2.03	0.47	0.21	1.24	-0.16	1.98	0.44	5	C
IV-6	2.07	0.58	0.21	1.22	-0.42	2.01	0.55	10	C

Table VII. Graphic parameters, dolomite content, and glauconite content of Gallup Sandstone from section V.

Sample No.	M_z in Ø	σ_I in Ø	Sk_i	K_g	Max in Ø	Md in Ø	σ_G in Ø	Dol %	Glauc cont.
V-20	2.28	0.45	0.01	1.10	-0.02	2.28	0.44	0	0
V-19	2.24	0.41	-0.03	1.15	-0.15	2.25	0.39	-	0
V-18	2.34	0.39	-0.02	1.06	0.47	2.38	0.38	T	T
V-17	2.14	0.39	-0.03	0.96	-0.04	2.18	0.40	-	0
V-16	2.12	0.50	0.01	1.08	0.01	2.11	0.48	T	T
V-15	2.02	0.61	-0.11	1.01	-0.42	2.06	0.60	0	0
V-14	2.59	0.45	-0.05	1.04	-0.42	2.60	0.44	0	T
V-13	2.70	0.40	-0.07	1.08	-0.55	2.71	0.39	-	0
V-12	2.77	0.37	-0.13	1.12	-0.80	2.89	0.36	T	T
V-11	2.56	0.40	-0.05	1.06	-0.02	2.57	0.39	-	0
V-10	2.55	0.42	-0.01	0.92	-0.75	2.55	0.43	-	0
V-8	2.85	0.27	-0.15	1.22	0.98	2.87	0.26	0	0
V-7	2.88	0.31	-0.20	0.92	0.90	2.92	0.32	-	0
V-6	2.88	0.32	-0.06	1.03	0.95	2.90	0.32	0	0
V-4	2.74	0.34	-0.05	0.94	0.85	2.75	0.35	0	0
V-3	2.84	0.31	-0.08	1.12	0.81	2.84	0.30	-	T

INTERPRETATION

Sets of data in Tables V, VI and VII can be interpreted in a general way. Samples from section V show that almost all of them have negative skewness, which tends to indicate beach deposits (Friedman, 1961). This interpretation is similar to the interpretation derived from the Visher (1969) method. In the Visher method, the grain-size distribution curves themselves are used, instead of the textural parameters.

The log-probability plot is found to exhibit two or three straight line segments and according to Visher (1969), these phenomena have been observed in nearly 2,000 grain-size distributions. These line segments are related to the modes of transportation: surface creep, saltation and suspension. As a conclusion of his study, Visher (1969) has tabulated the classification of grain-size curves according to environment of deposition. In the present study, a direct comparison with the curves from Visher's paper is used along with his table.

Figure 21 shows the cumulative curves of samples from section V. Almost all samples clearly show two sub-populations in the saltation population. From the table of Visher, and comparing the cumulative curves with those of recent sediments and the known ancient deposits (Fig. 22), it may be concluded that samples from section V are beach deposits. According to Visher (1969), in the beach deposits the saltation

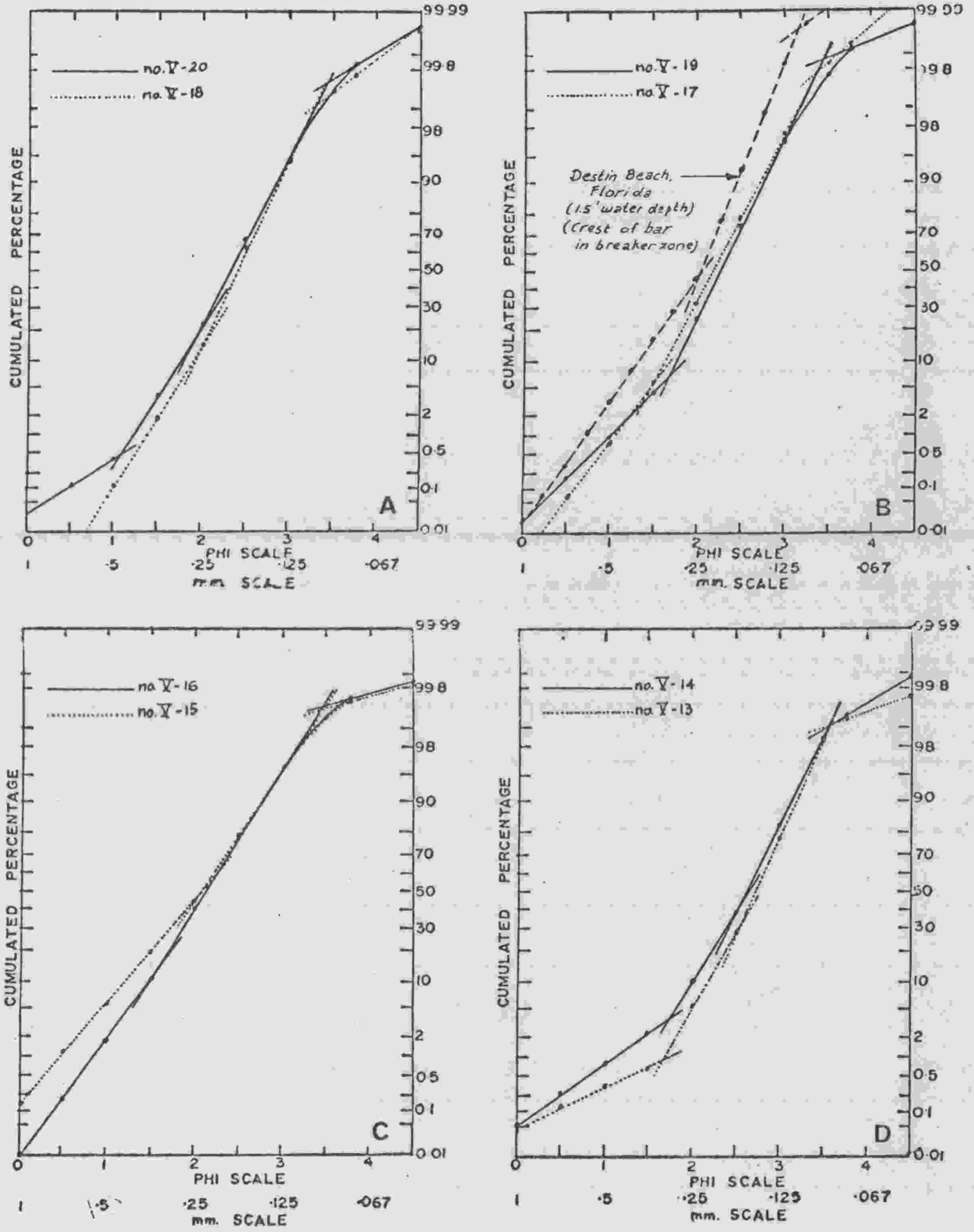

Fig. 21. Cumulative curves of samples from section V, near Red Rock Highway.

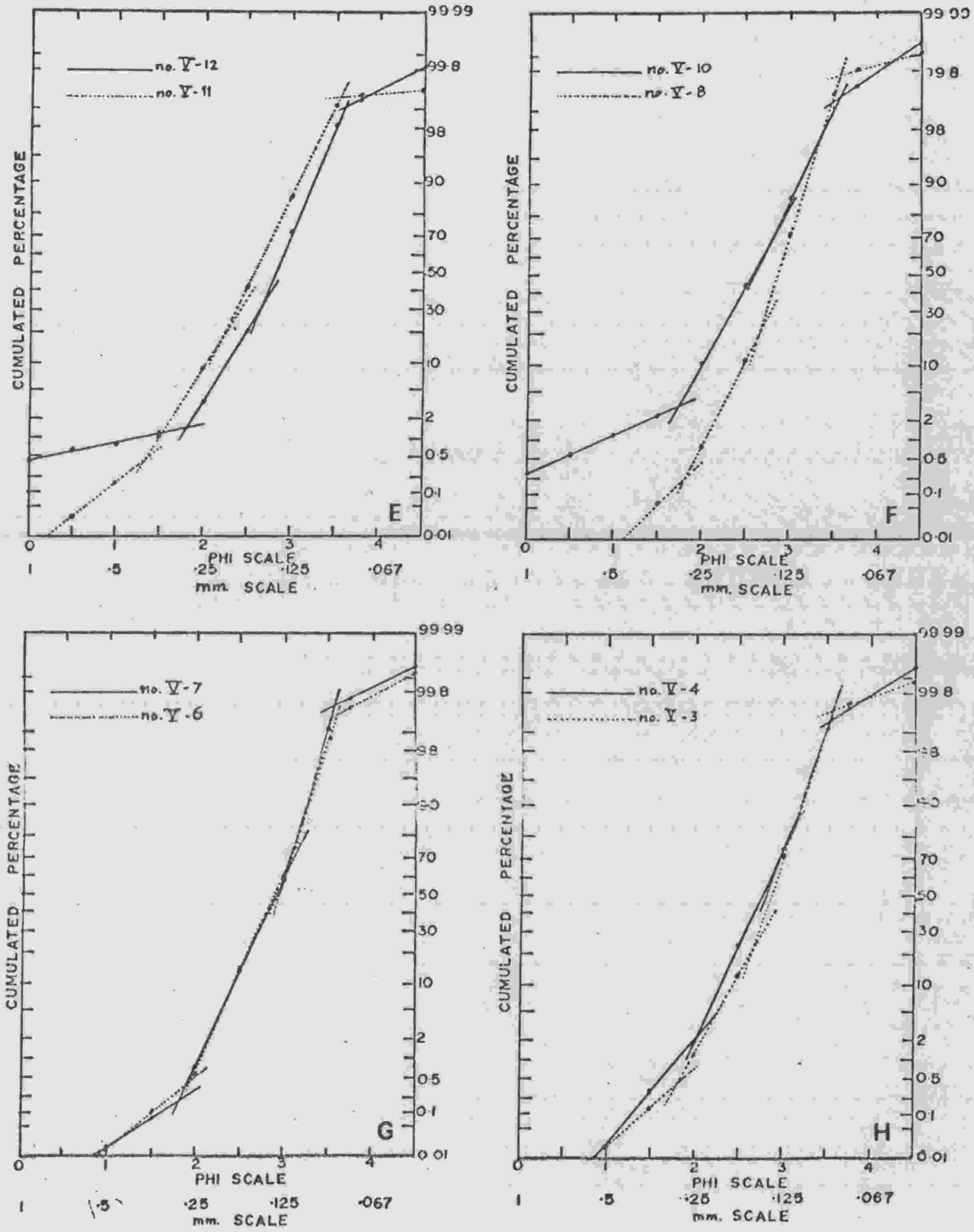

Fig. 21. (contd.) Cumulative curves of samples from section V, near Red Rock Highway.

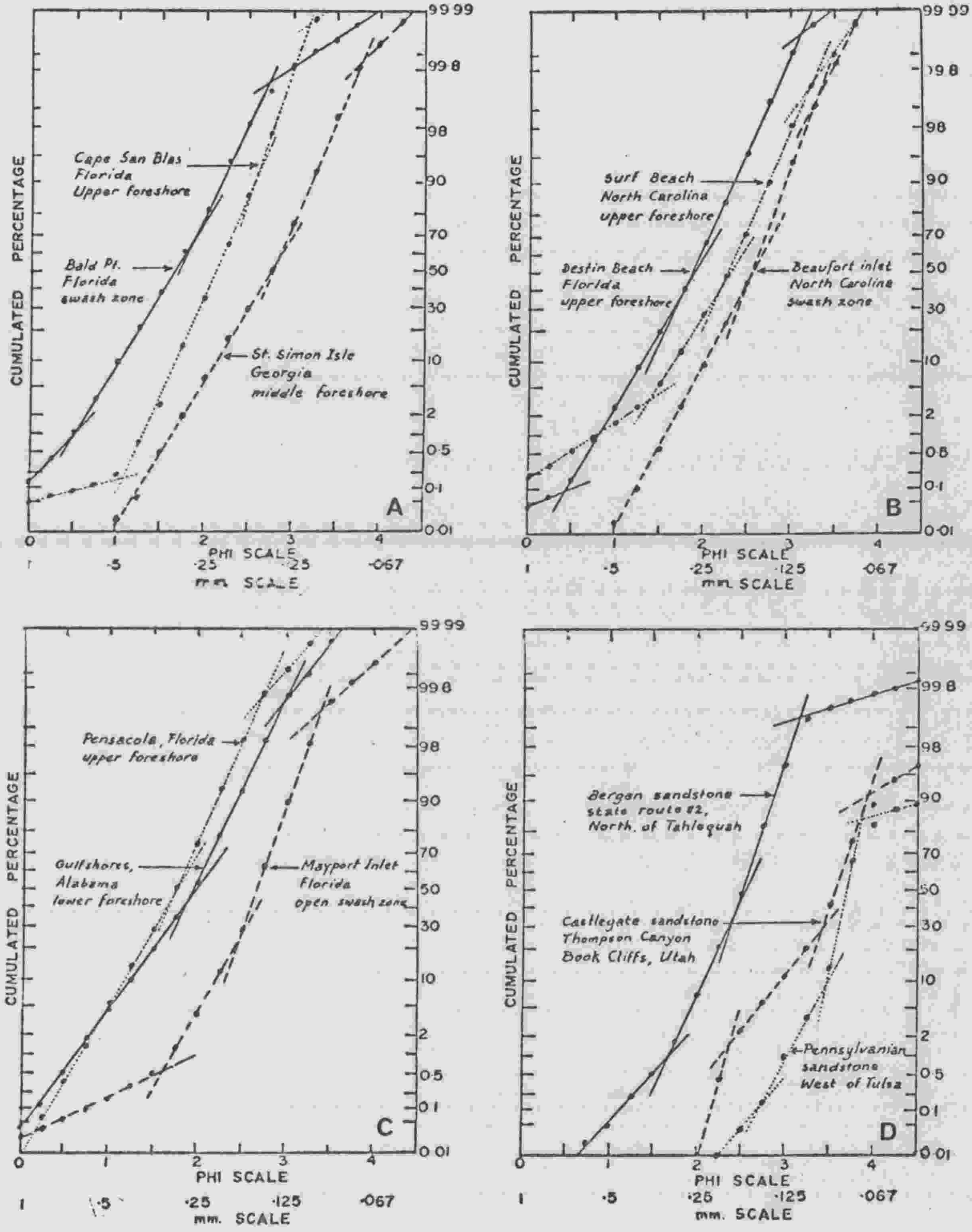

Fig. 22. Example of recent beach foreshore sands (A, B, and C) and ancient known beach sands (From Visher, 1969).

populations are divided into two sub-populations with excellent sorting.

The saltation and the surface creep populations of the samples from section V are comparable to those of present samples, but the suspension population is comparable to those of ancient sandstones; that is, making an almost horizontal line. This infers that the suspension population is poorly sorted, and an appreciable amount of finer particles existed in the ancient sediment. This phenomena might really exist in ancient sediments, but it may also be postulated that the diagenetic process has changed the grain-size distribution at the fine tail of the cumulative curve. Another possible explanation is that during disaggregation of ancient sediment, the cementing materials and some of the broken grains accumulated and were added to the existing fine particles to form the almost horizontal fine tail of the cumulative curve.

Visher (1969) has included in the beach sands those from lower foreshore, middle foreshore, upper foreshore and swash zone (Fig. 22A, B and C). Comparison of the surf zone sands with beach sands indicated that the coarser population is more poorly sorted. However, some exceptions seem to occur, depending on the energy of the waves. A cumulative curve of Recent sand from the breaker zone at Destin Beach, Florida, has been incorporated in Figure 21 B for direct comparison. A great similarity exists between this curve and the curves of samples No. V-19, V-17, V-16 and V-15. These samples show a higher concentration of finer particles than those of the sample from Destin Beach, Florida. Consulting the table of Visher (1969), it may be concluded that the above samples are from the surf or plunge zone.

It may be concluded that the Gallup Sandstone in section V was deposited in beach and very near shore environment. How far this environment extends to the north can not be said definitely. The presence of small quantity of glauconite in samples from section I (Table V), and the fact that the sandstone is mostly medium-bedded and cross-bedded, suggest that the sandstone in section I was deposited in shallow marine environment.

The cumulative curves of samples from section II (Fig. 24) resemble the cumulative curves of white sandstone at the base of the Almond and Lance Formations (Fig. 25 A and B). The difference is that the samples in section II are coarser than the samples in Almond Formation. These sandstones have been described by Weimer, according to Visher (1969), as having deltaic origin. The cumulative curve of the Wann Formation (Fig. 25 C) also resembles those of samples in sections II and III. The difference is also in the grain-size, the samples in sections II and III are coarser than the sample from the Wann Formation. Concerning this sample, Visher stated that it may be related to marine parts of ancient deltas rather than to near shore environments associated with beaches. Uncertainty on the interpretation of the cumulative curves of marine

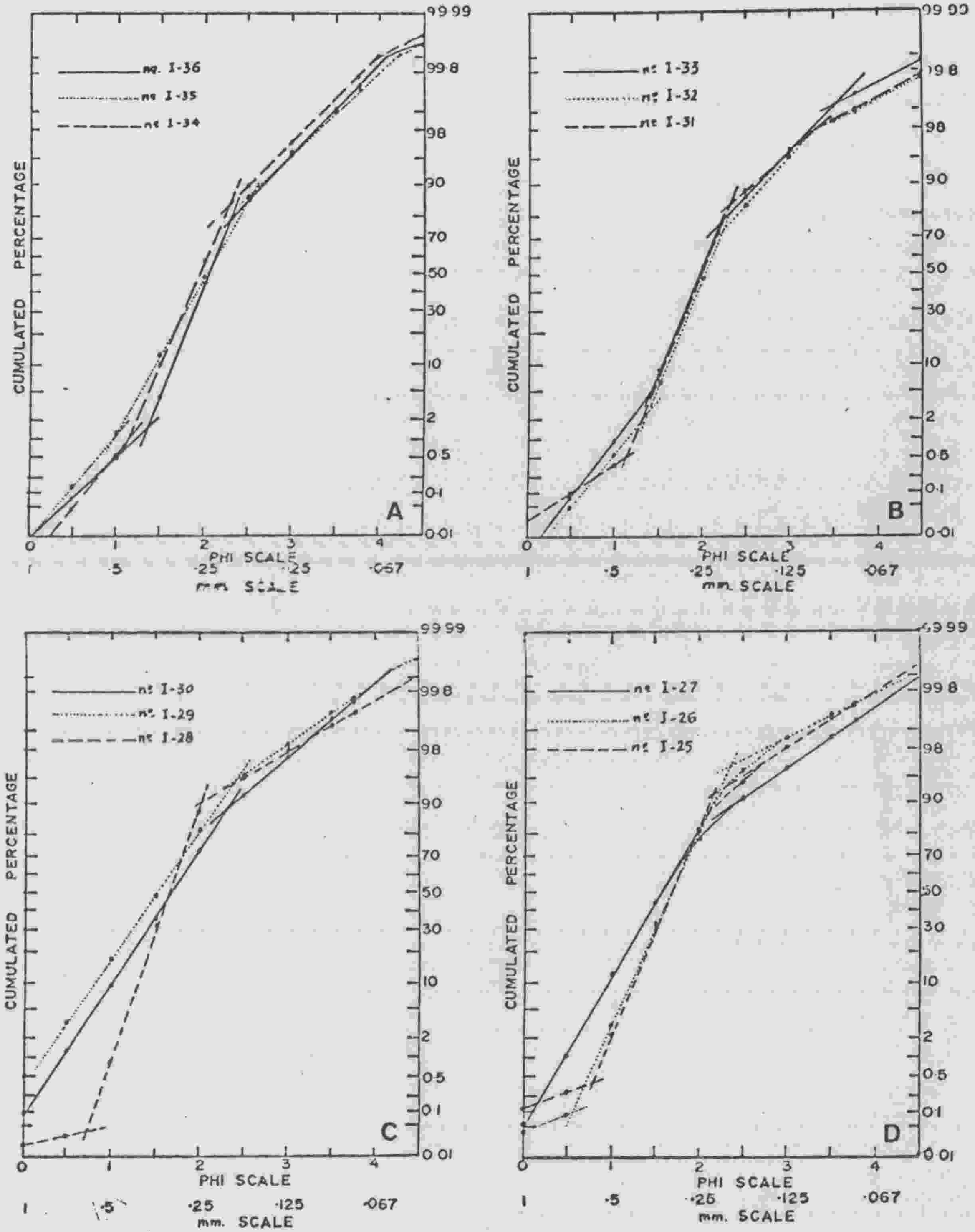

Fig. 23. Cumulative curves of samples from section I.

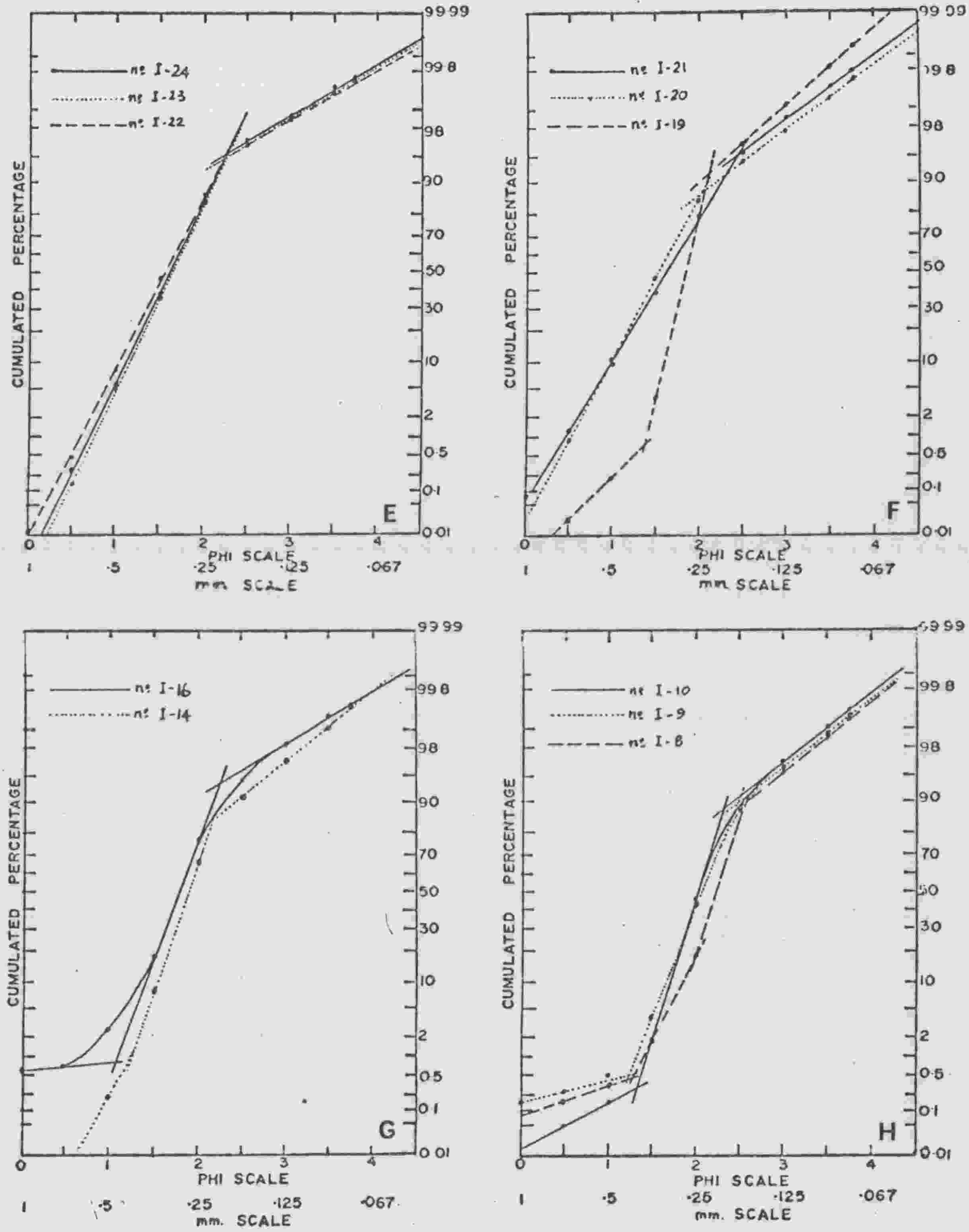

Fig. 23. (contd.) Cumulative curves of samples from section I.

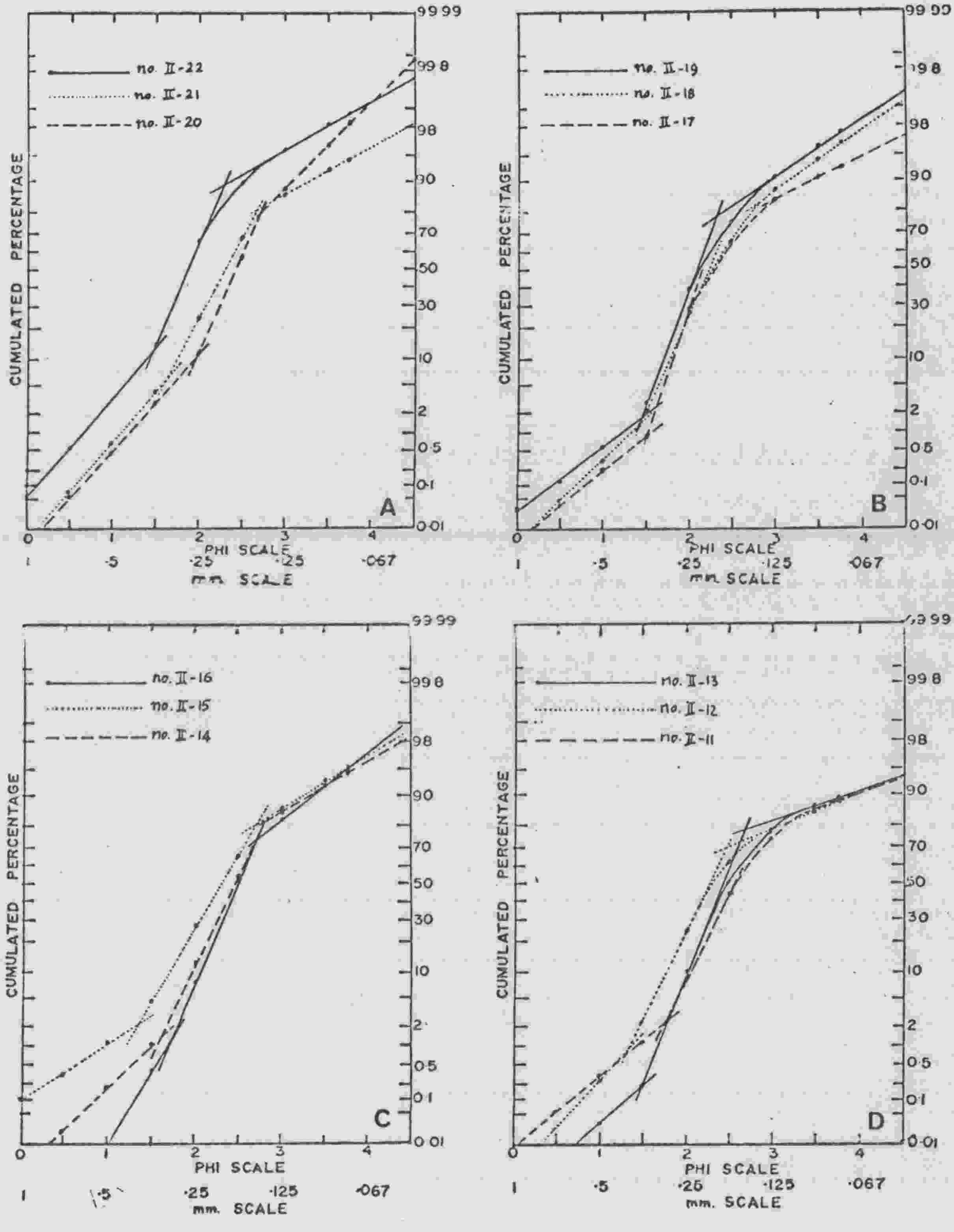

Fig. 24. Cumulative curves of samples from section II.

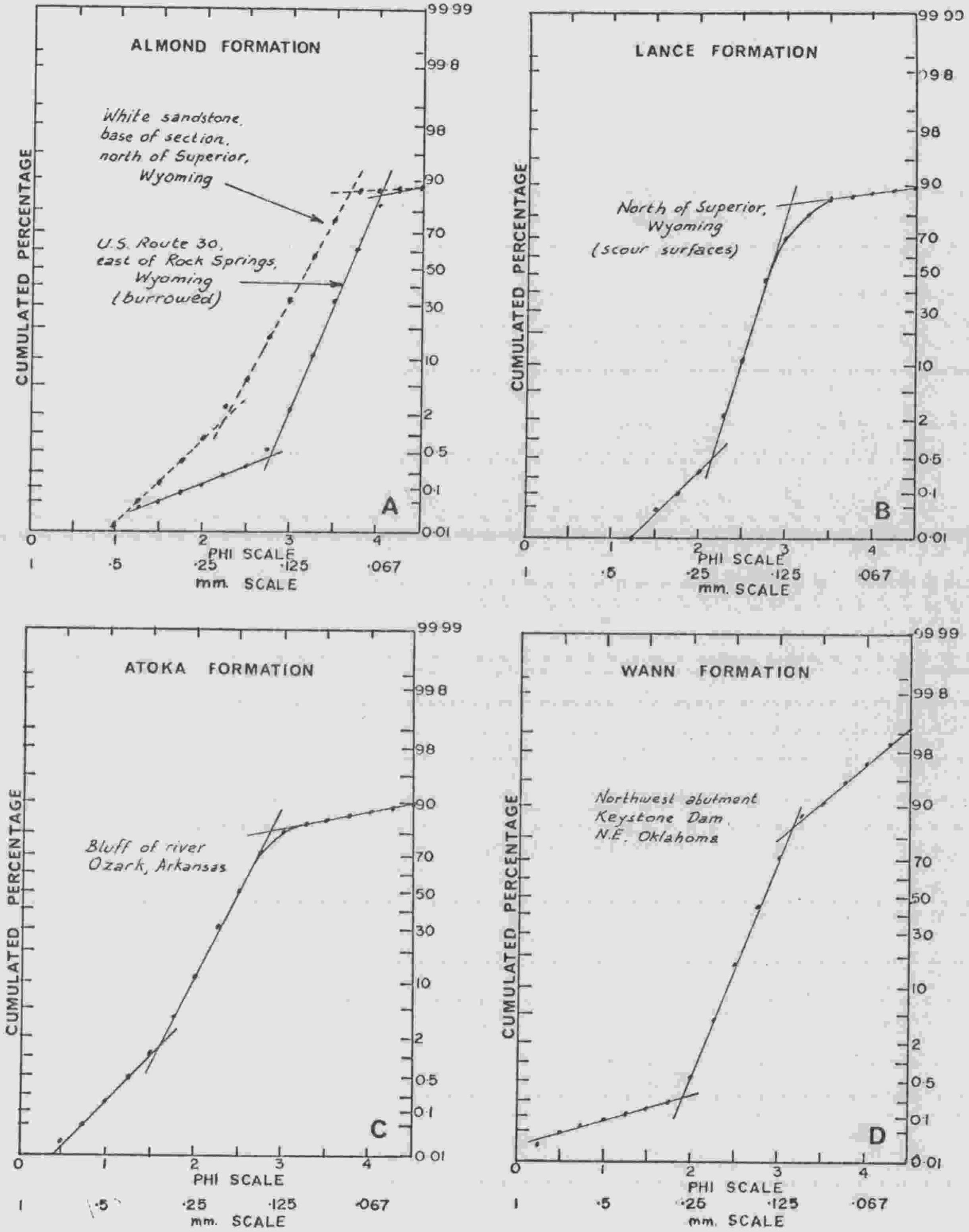

Fig. 25. Example of ancient deltaic sediments and probable marine environment related to ancient deltas.

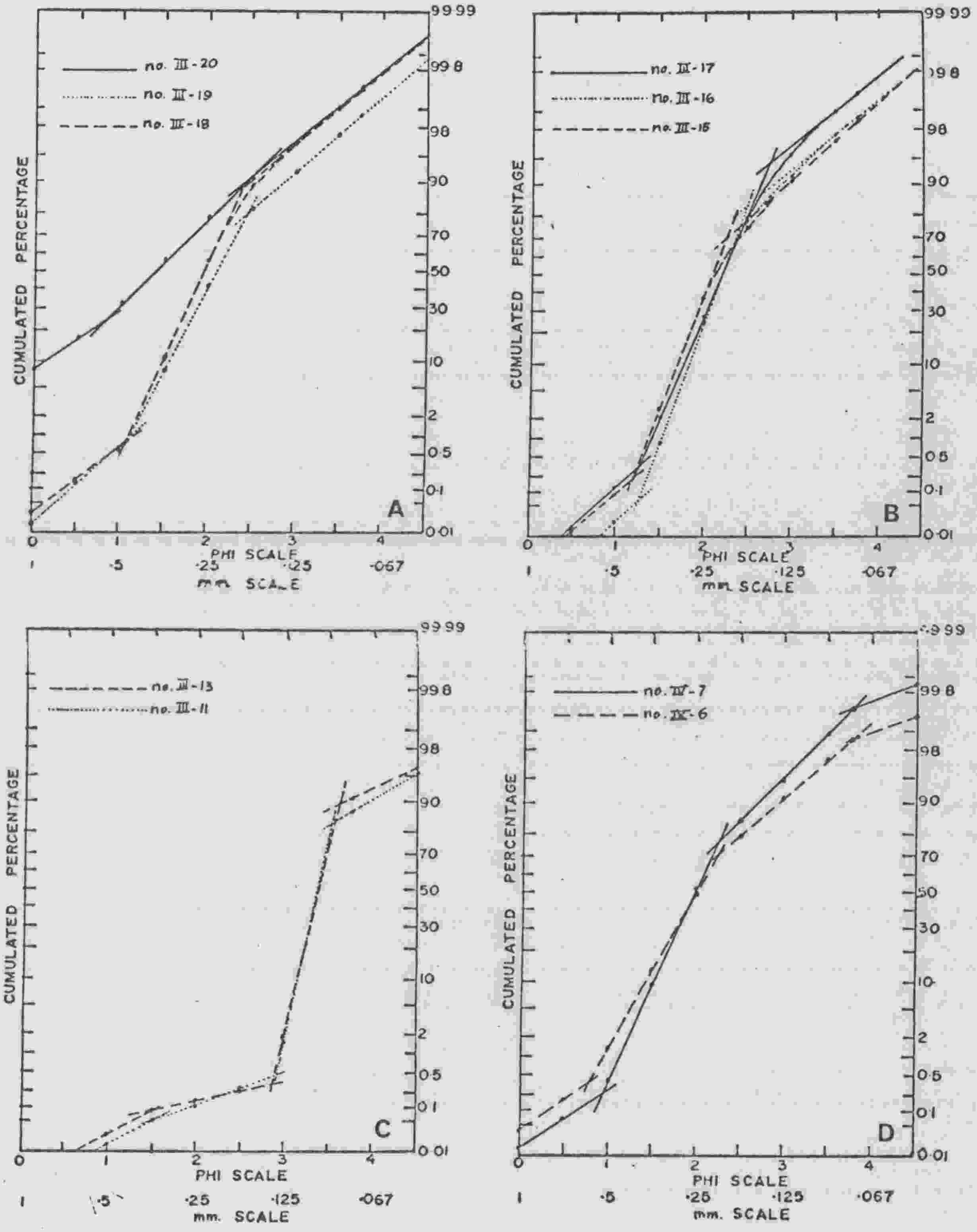

Fig. 26. Cumulative curves of samples from section III and IV.

sediments inevitably exists. Many samples from present marine environment are needed for analysis before firm conclusions can be made.

Direct interpretation from the data in Tables V, VI and VII is difficult. Patterns of the changes in the values of parameters which occur vertically in all sections can be investigated better in stratigraphic columns. The changes of skewness and kurtosis vertically do not follow a definite pattern. In all sections, except in section IV, the mean grain-size changes vertically according to a definite pattern. The sorting in some layers changes with the change of mean grain-size. From the plot of the mean grain-size and sorting (inclusive graphic standard deviation) in the stratigraphic section (Fig. 7, in pocket) several patterns can be seen:

1. In sections V and I the grain-size changes in step-form.
2. In section V and in major portion of section I the grain-size is coarser toward the top.
3. In section I the top part is finer than the underlying sandstone.

The above observations agreed with the field observations in sections V and I. In a regression one can expect the grain-size to become coarser toward the top of the section and the reverse is true for transgression (Twenhofel, 1950; Visher, 1965). It may be concluded that the Gallup Sandstone in section V and the major part of the sandstone in section I were deposited in a regressive sea. A transgression has occurred after the regression, as shown by the finer sandstone on top part of section I. The regression and the transgression have occurred in step-like nature. This step-like nature was also observed by Hollenshead and Pritchard (1961) in the Point Lookout Sandstone and the Cliff House Sandstone of the Mesaverde Group.

Farther north in section III the abrupt change of grain-size coincides with the unconformity. The field studies have established that the medium-grained sandstone on top part of section II is equivalent to the sandstone above the unconformity in section III. The abrupt change of grain-size on the top part of section II then is not the same regressive phenomena as in sections V and I. However, the regressive phenomena can be observed in section II as shown by the grain-size in this section which is gradually coarser toward the upper part. It may be concluded that the regression of the sea was followed by an erosional activity, which then followed by a transgression of the sea to the south. This also allows the inference that a hiatus present in between the third and fourth units in section I and between the medium-grained and the fine-grained sandstone in the section II.

The fine-grained sandstone in section II is relatively finer and poorly sorted in comparison with the sandstone in section I. This allows the inference that the sediment was deposited in deeper water. However, not much of this sandstone was preserved, because this seaward portion of the Gallup Sandstone was eroded and truncated by an unconformity.

It seems that after the last "bench" of the Gallup Sandstone was deposited in a stabilized sea level, there was no further addition of clastic materials into that part of the basin. This allowed the currents and waves to attack the sediments within their energy range. There is no evidence of soil profile having been developed, which suggests that the Gallup Sandstone was probably not subject to subaerial erosion. But erosion and removal of about 300 feet of sediments just south of Ute Mountains (Dane, 1960) by marine processes alone seems unlikely. Some thinning out of sediments below the unconformity also occurred. A unit of carbonaceous shale in the vicinity of section IV is thinner toward the north, from 2 feet into 1 foot thick, within a distance of 100 yards.

Channeling into the Gallup Sandstone, as observed in Figure 16, could have been the result of under-sea erosion or by river action. The sandstone in this channel indicates that it has been deposited under marine conditions, as shown by the presence of shark teeth, broken shell fragments and glauconite. The remnants of river deposits, if present, can only be revealed by detailed sampling in this channel. The presence of boulders up to 30 cm in this channel and its vicinity indicates that they have been deposited under a high energy conditions. The irregular cross-bedding in the channel might indicate that turbulent flow has passed in the channel.

The sandstone unit above the unconformity in sections II, III and IV was deposited in a transgressive sea, the same as the fourth sandstone unit in section I. Sporadic floods brought coarse sediments up to the vicinity of the channel (Fig. 16). In a rapid rise of sea level the coarse particles are left behind, and the finer particles carried away toward the land (Twenhofel, 1950). This explains the decreasing grain-size at the top part of sections III to I. At a certain depth, the formation of bar-sand (Fig. 13) was favorable and deposited a thicker sandstone than those in section II.

The presence of strike valley topography produced by the erosion in pre-Niobrara time is not observed in the study area. McCubbin (1969) found from his subsurface study, several strike-valleys parallel to each other, but at different levels. Most of the strike-valleys occurred very close to the Juana Lopez Member or cut into it. In the study area the unconformity cannot be traced far enough because the San Juan River has removed the evidence.

Comparing the data in Tables V, VI and VII with the petrographic characteristics of the facies in the Bisti oil field (Sabins, 1963), it was found that none of the characteristics of beach, offshore, back-bar and fore-bar facies, as listed by Sabins, are similar to the samples studied here. The main difference arises from the value of sorting (σ_G) of these samples, in general being half of the sorting of samples listed by Sabins (1963). High sorting values might be the result of a high percentage of finer particles in sandstone in the Bisti area. By comparing only the median grain-size, dolomite content and glauconite content, these conclusions seem logical:

1. Sandstone below the unconformity in section II is equivalent to beach facies in Bisti area;
2. Sandstone lenses in the lower part of Mancos Shale in section III are equivalent to offshore facies in Bisti area;
3. Sandstone above and below the unconformity in section III, and sandstone above the unconformity in section IV is equivalent to bar sands in Bisti area.

The first two conclusions are probably valid, but the third conclusion is false because samples in section IV and samples below the unconformity in section III are definitely not bar sand. As a consequence of this conclusion, what has been called bar sand in the Bisti area most probably is not bar sand. A comparison of petrographic characteristics of modern bar sand and the "bar sand" in the Bisti area should be made to assure the presence of bar sand in that area.

The chemical aspect of the sediments may reveal some more information about the facies or the environment of the Gallup Sandstone in its associated rocks. The presence of glauconite does not always indicate to a marine environment, however, the presence of primary dolomite shows a marine environment (Kukal, 1971).

The depth of deposition of sandstone, unfortunately cannot be revealed definitely by the glauconite content. According to Cloud (1955) the presence of glauconite of as much as 5 - 10 percent implies depth between 10 - 400 fathoms, which embraces the sublittoral and the upper part of the bathyal environments. However, a careful use of this figure combined with the textural and bedding characteristics of the sediments, suggests that sandstone in section I was deposited in sea water in less than 10 fathoms deep. Farther to the north the sandstone below the unconformity shows an increasing glauconite content. The presence of 5 - 10 percent glauconite in the sandstone below the unconformity in section III implies a depth on the upper part of 10 - 400 fathoms. Considering the distance between section I, II and III, and the bedding characteristics of the sandstones, it may be concluded that the Gallup Sandstone below the unconformity in section III was deposited in the sublittoral environment or the upper part of bathyal environment. The sandstone above the unconformity has glauconite very near to 5 percent or between 5 - 10 percent, which also implies the sublittoral or the upper part of bathyal environment.

The source material for the formation of glauconite is probably micaceous minerals, illite or bottom muds of high iron content (Cloud, 1955). The biotite-glauconite transformation in Monterey Bay, California seem exceptional (Burst, 1958). Although the glauconite has an illite-montmorilonite type clay structure (Burst, 1958), there is little possibility that illite-glauconite transformation has occurred. According to Kukal (1971) illite minerals in marine environment are the most stable and montmorilonite may be perfectly stable or susceptible to alteration. Apparently the glauconite and illite are the end member of chemical transformation in marine environment.

According to Burst (1958) the requirements for the forming of glauconite are (1) the presence of layered silicate lattice, (2) enough supplies of iron and potassium, and (3) favorable environmental oxidation potential. Micaceous minerals were observed in the samples, but in very small quantity. The presence of iron was observed in all sandstones, as proven by the test with potassium ferricyanide. The mafic igneous rock particles in the conglomeratic sandstone might serve as the source of iron in the sea and sediments.

The third requirement apparently is contradictory to Burst's (1955) opinion, which requires reducing condition for the forming of glauconite. According to Kukal (1971) glauconite can be formed in neutral to slightly reducing environment. The reducing condition can be the result of decaying organic matter. The presence of burrows and other organic markings in the Gallup Sandstone and associated rocks shows that this condition for the forming of glauconite existed.

The formation of glauconite is believed to be favored by slow deposition or non-deposition (Cloud, 1953; Kukal, 1971). Obviously, the glauconitic sandstone on top of the unconformity was deposited under these conditions. This allows an inference that the transgression was the result of a slow rate of detrital influx in relation to the rate of the basin subsidence. The amount of detritus supplied to the basin during this transgression was very small so that only thin sandstone beds were deposited. The fourth sandstone unit in section I which was shown as transgressive unit, cannot be trace up to section II. This shows that there may be several unconnected transgressive sandstone units on top of the regressive Gallup Sandstone. Without a careful field determination of the grain-size changes up the section of the Gallup Sandstone, this phenomena cannot be detected. The unconformity which separated the transgressive and the regressive units could not be detected south of the New Mexico State Highway 504.

A continuous deposit of transgressive sandstone is found from the vicinity of section II, which is about 3 miles south of the San Juan river, up to the San Juan River. North of the San Juan River this unit is still present, but its continuity is not known, although Dane (1960) mentioned that this same unit is exposed near Towaoc, Colorado.

Because of the difference in lithology and age, the Gallup Sandstone is considered to terminate about 3 miles south of the San Juan River. Although most of the Gallup Sandstone is regressive sandstone of middle to late Carlile age, locally it might have included the transgressive unit, which has a middle Niobrara age.

CONCLUSIONS

1. The Gallup Sandstone is mostly a regressive deposit which locally might include an upper transgressive unit. The regression has occurred in step-like movement, producing benches. Each bench has formed in a subsiding basin which was apparently in equilibrium with the rate of sedimentation. A lowering of sea level, which was caused by a slight decrease of rate of subsidence in relation to sedimentation, caused the strand line to move seaward. After the strand line was stabilized again, as a result of equilibrium of the rate of subsidence with the rate of sedimentation, another bench was deposited.

2. Most of the regressive Gallup Sandstone was deposited in the littoral environment. Farther to the north, in the vicinity of the San Juan River, the sandstone was deposited in a sublittoral or possibly in a near-bathyal environment.

3. The deposition of the last bench of the Gallup Sandstone was ended when the supply of quartzose detritus was diminished and probably completely stopped, which resulted in non-deposition. This was followed by erosional activity at the northern part of the San Juan basin. There is no evidence of subaerial erosion. However, the absence of Late Carlile sediment by erosion as much as 300 feet near the Ute Mountains, Colorado (Dane, 1960), cannot be attributed to marine erosion alone. Apparently a non-depositional activity also has taken place. A strong sea current or river did scour the Gallup

Sandstone at one locality (Fig. 16) to form a channel.

3. Subsidence occurred after the formation of the erosional surface. Lack of materials introduced to the basin during this subsidence resulted in a transgression over the Gallup Sandstone and the deposition of the Dilco Formation. Sediments deposited on top of the unconformity formed a thin blanket on the erosional surface, sometimes as bar sand and also as channel-filling sand. This sandstone is the reservoir rock in several oil fields in the northern part of the San Juan basin.

4. In mapping, the Gallup Sandstone should be considered as terminated about 3 miles south of the San Juan River. From this point to the north, only a definite glauconitic sandstone is found on top of an unconformity. A new nomenclature for the sandstone of Niobrara age is needed.

APPENDIX I

DESCRIPTIVE STRATIGRAPHIC SECTIONS

Section I

Along an arroyo, from south to north of the
bridge on New Mexico State Highway 504,
in secs. 20 and 21, T. 30 N, R. 19 W.

Sample No.	Description	Thickness in feet
	UPPER PART OF MANCOS SHALE	
	Shale, light gray to tan, sometimes sandy.	
	GALLUP SANDSTONE	
I-36 I-35 I-34	Sandstone, white to light-gray, fine-grained, well sorted, subrounded grains; friable, medium-bedded, cross-bedded; contains small amount of glauconite; contains flat cavities parallel to bedding plane; the bottom part contains some laminae of soft shaly siltstone; weathers brown; forms the top of cliff.	3.5
I-33 I-32 I-31	Sandstone, white to light-gray, fine-grained, well sorted, subrounded grains; friable, thick-bedded, cross-bedded; contains small amount of glauconite; contains some vertical burrows and other organic markings on the top and bottom part; weathers brown; forms cliff.	3
	Sandstone, light-brown, fine-grained, well sorted, subangular to subrounded grains; soft, thin-bedded; contains laminae of shale; weathers grayish-brown, smooth; forms soft part of cliff.	2
I-30	Sandstone, white, medium-grained, moderately well sorted, subangular to subrounded grains; soft, friable, medium-bedded, cross-bedded; contains small amount of glauconite; weathers light-gray to light-brown, rather smooth; forms cliff.	2
	Shaly sandstone, light-gray, soft, thin-bedded; weathers gray; forms soft part of cliff.	1

Sample No.	Description	Thickness in feet
I-29 I-28 I-27 I-26 I-25	Sandstone, white to light-gray, medium-grained, well sorted, subangular to subrounded grains; friable, thick-bedded, cross-bedded; contains small amount of glauconite; the upper part contains some shale partings; the middle part contains vertical burrows and other organic markings; weathers light-brown to light-tan, rather smooth; forms cliff.	6
I-24 I-23 I-22 I-21 I-20	Sandstone, white, medium-grained, well sorted, subangular to subrounded grains; friable, thick-bedded, cross-bedded; contains small amount of glauconite; contains some vertical and horizontal burrows and other organic markings; weathers brown to gray, rather smooth; forms cliff.	5
	Shaly sandstone, light-gray, fine-grained; soft, friable, thin-bedded; contains some carbonaceous materials; weathers gray, rather smooth; forms soft part of cliff.	0.3
I-19 I-18	Sandstone, light-gray, medium-grained, very well sorted, subangular to subrounded grains; occasionally contains some granules; rather hard, slightly friable, thick-bedded, cross-bedded; contains small amount of glauconite; contains many vertical burrows and other organic markings; weathers light-brown to tan; forms cliff.	2
I-17 I-16	Alternating light-gray sandstone and shale, soft, thin-bedded; sandstone is medium-grained, well sorted, subangular to subrounded grains; contains small amount of glauconite and shale partings; shale and sandstone contain granules; weathers gray to brown, smooth; forms cliff.	2.7
I-15 I-14 I-13	Sandstone, white to light-gray, medium-grained, well sorted, subangular grains; friable, medium-bedded, cross-bedded; contains small amount of glauconite; contains many vertical burrows and other organic markings; weathers brown to tan, smooth; forms cliff.	5

Sample No.	Description	Thickness in feet
I-12 I-11	Sandstone and interbedded shale, light-gray, soft, friable, thin-bedded; sandstone is fine-grained, well sorted, subangular grains; contains small amount of glauconite and shale partings; sandstone and shale contains granules; weathers gray to brown; forms soft part of cliff.	2
I-10 I-9	Sandstone, light-gray, fine-grained, well sorted, subangular to subrounded grains; friable, medium-bedded, cross-bedded; contains small amount of glauconite; contains vertical burrows and other organic markings; contains 6 inches of shaly sandstone in the middle part; weathers brown to tan, rather smooth; forms cliff.	5.5
	Shaly sandstone, gray, soft, friable, thin-bedded; contains small amount of glauconite, weathers brown.	0.5
I-8	Sandstone, light-brown to light-gray, fine-grained, subrounded grains; friable, medium-bedded, cross-bedded; contains small amount of glauconite; contains vertical burrows and other organic markings; weathers brown to tan, smooth; forms cliff.	2
	Shaly sandstone, light-gray, fine-grained, soft, thin-bedded; contains small amount of glauconite; contains some granules at the bottom part and some carbonaceous materials; weathers gray.	0.5
I-7	Sandstone, light-gray, fine-grained, well sorted, subrounded to rounded grains; hard, not very friable, medium-bedded, cross-bedded; contains small amount of glauconite; contains small amount of glauconite; contains some gravels up to 2 cm at the bottom part and the top part; contains some vertical and horizontal burrows and other organic markings; weathers brown to gray; forms cliff.	1.5
	Total thickness of Gallup Sandstone	44.5 feet

Sample No.	Description	Thickness in feet
	LOWER PART OF MANCOS SHALE	
	Alternating sandstone and shale, gray, thin-bedded; sandstone is fine-grained, poorly sorted; sandstone and shale contain gravels and some carbonaceous materials; weathers brown; forms the soft part of cliff.	1
I-6	Shaly sandstone, light-brown, fine-grained; rather hard, friable, medium-bedded and thin-bedded; contains abundance of glauconite; contains gravels up to 2 cm; weathers brown; forms cliff.	1.5
	Shaly sandstone, light-gray and light-brown, fine-grained, gravelly; soft, thin-bedded and laminated; contains limestone concretions up to 15 cm in the upper part and up to 30 cm in the bottom part; contains carbonaceous materials; weathers gray; forms the softer part of cliff.	2.3
I-5	Shaly sandstone, light-gray, fine-grained; rather hard, thin-bedded; contains carbonaceous materials and gravels; contains abundance of glauconite; contains limestone concretions up to 15 cm; weathers brown; forms cliff.	1
	Alternating sandstone and shale, gray, thin-bedded and laminated; sandstone is fine-grained; sandstone and shale are soft; contain carbonaceous materials and some concretions up to 12 cm; contain some gravels up to 15 mm; weather brown and dark gray; form softer part of cliff.	2
I-4	Sandstone, gray to light-brown, fine-grained; soft, friable, thin-bedded; the bottom part is more shaly sandstone; contains burrows, tracks and other organic markings; weathers brown; forms cliff.	3
	Shale, gray, laminated, sometimes sandy; mostly covered; forms slope.	13

Sample No.	Description	Thickness in feet
I-3	Sandstone, gray to light brown, fine-grained; soft, friable, thin-bedded; weathers brown; forms small bench on the slope.	3
	Shale, gray, laminated; forms slope.	7
I-2	Sandstone, gray to light-brown, fine-grained; soft, friable, thin-bedded; contains shale partings; weathers brown; forms small bench on the slope.	2
	Shale, gray, the top part is sandy, laminated and thin-bedded; weathers dark-gray to brown; forms slope.	5
I-1	Sandstone, light-brown, fine-grained, well sorted; soft, friable, thin-bedded; weathers brown; forms cliff. (This sandstone is used as marker in correlation, because of its distinct nature; forms the top of small cliff closer to the bottom of arroyo.)	2
	Shale, gray, laminated, occasionally with thin-bedded sandstone, fine-grained; contains limestone concretions; weathers dark gray; forms soft part of the cliff.	more than 15

Section II

From the bottom of an arroyo to the top of the cliff and beyond, about 3 miles north of section I, in sec. 8, T. 30 N,R. 19 W.

UPPER PART OF MANCOS SHALE

Shale, light gray to tan, sometimes sandy; forms the top soil and slope to the east.

Sample No.	Description	Thickness in feet
	GALLUP SANDSTONE	
II-22	Sandstone, white to light-brown, medium-grained, some grains up to 2 mm, well sorted, subrounded grains; contains some granules, especially at the bottom part; friable, medium-bedded, cross-bedded; contains very abundant galuconite; contains vertical burrows, trails, tracks and other organic markings; the top 1 foot is highly weathered, forms soil; weathers brown to dark gray; forms top of cliff.	2
II-21	Sandstone, white to light-brown, fine-grained, moderately well sorted, subrounded grains; friable, medium-bedded; glauconite is common; contains some burrows; weathers tan to brown; forms top of cliff.	2
II-20	Sandstone, light-brown, fine-grained, well sorted, subrounded grains; friable, rather soft, thin-bedded; glauconite is common; contains some shale partings; weathers tan to brown; forms cliff.	1
II-19 II-18	Sandstone, light-brown, fine-grained, moderately well sorted, subrounded grains; friable, medium-bedded; contains small amount of glauconite; contains some vertical burrows; weathers tan to brown; forms cliff.	2
	Sandstone, light-brown, medium-grained, well sorted, subangular to subrounded grains; friable, thin-bedded; glauconite is common; contains many vertical burrows; weathers brown; forms cliff.	0.8
II-17 II-16 II-15 II-14	Sandstone, light-brown, fine-grained, moderately well sorted, subangular to subrounded grains; slightly friable, medium-bedded; glauconite is common at the top part but decreases toward the bottom part; contains some carbonaceous materials at the bottom part; especially along the bedding plane; contains vertical burrows and other organic markings; weathers tan; forms cliff.	4
	Total thickness of Gallup sandstone.	11.8

Sample No.	Description	Thickness in feet
	LOWER PART OF MANCOS SHALE	
II-13	Shaly sandstone, light-brown, fine-grained, moderately sorted, subangular to subrounded grains; friable, rather soft, medium-bedded; contains very small amount of glauconite; contains carbonaceous materials, weathers tan and gray; forms the soft part of the cliff; forms the transition of the Mancos shale and the overlying Gallup sandstone.	1
II-12 II-11	Shale, gray, laminated, sometimes sandy; interbedded with shaly sandstone, gray, soft, thin-bedded; both shale and shaly sandstone contain carbonaceous materials; content of sand particles is increasing toward the top; forms the soft part of the cliff.	10
	Covered interval, most probable shale and some thin-bedded sandstone; only 1 foot of shale outcropping in the bottom part; about 12 feet from the bottom occurred many big concretions, mostly cone-in-cone structure, some are weathered septaria.	39
	Sandstone, light-brown, fine-grained, rather hard, not so friable, thin-bedded; contains some vertical burrows and tubes; weathers brown.	0.3
	Shale, gray, laminated, contains carbonaceous materials; only the top and the bottom part are well exposed; forms slope.	4.5
	Sandstone, light-brown, fine-grained, with shale fillings, some horizontal grooves, soft, thin-bedded, weathers brown.	0.3
	Shale, gray, laminated, contains carbonaceous materials.	1
	Sandstone, light-brown to light-gray, fine-grained, thin-bedded; contains carbonaceous materials; weathers brown to gray.	1
	Shale, gray to dark-gray, laminated, sometimes sandy, contains carbonaceous materials.	6

Sample No.	Description	Thickness in feet
	Sandstone, light-brown, fine-grained, well sorted; rather hard, thin-bedded, contains few burrows and tracks; the middle part contains some laminae of shale, carbonaceous; contains some concretions in the bottom part; weathers gray to brown; forms a conspicuous top part of a small cliff. (used as marker bed in correlation)	3
	Alternating shale and sandstone, light-gray to light-brown, laminated and thin-bedded, contains carbonaceous materials; sandstone is fine-grained, contains burrows.	more than 15

Section III

From the bottom of an arroyo to the top of the cliff and beyond, about 1 mile north of section II, in sec. 5, T. 30 N, R. 19 W.

	UPPER PART OF MANCOS SHALE	
	Shale, light gray to tan, sometimes sandy; forms the slope.	
	GALLUP SANDSTONE	
	The top part is covered by terrace gravels.	2
III-20	Sandstone, white to light-gray, medium-grained, moderately sorted, contains coarse grains up to 2 mm and pebbles up to 1 cm, subrounded grains; slightly friable, medium-bedded, cross-bedded; glauconite is common to abundant; contains shell fragments and shark teeth; contains many vertical and horizontal burrows; weathers gray, rough; forms cliff.	1
	---------Unconformity---------	
III-19	Sandstone, very light-gray to white, fine-grained, well sorted, subrounded grains; slightly friable, medium-bedded; glauconite is very abundant; contains vertical burrows; weathers gray; forms cliff.	2
	Total thickness of Gallup sandstone	3 - 5

Sample No.	Description	Thickness in feet
	LOWER PART OF MANCOS SHALE	
	Alternating shale and fine-grained sandstone, light-brown to light-gray, laminated and thin-bedded; contains carbonaceous materials; weathers gray to brown; forms soft part of the cliff.	9
III-18 III-17 III-16 III-15	Sandstone, light-greenish-gray to gray, medium-grained, well sorted; friable, medium-bedded; as a lens, not continuous to the south and cut by unconformity to the north; glauconite is very abundant; contains very few vertical burrows; the middle part is softer; weathers brown to gray; forms cliff. (not considered as part of Gallup sandstone, because to the south it becomes shale)	5
	Shale, gray, laminated, forms slope.	1.5
III-14	Sandstone, light-gray, fine-grained, well sorted, subangular to subrounded grains; friable, medium-bedded; not very well exposed, probably is also a lens.	0.5
	Covered interval, most probably shale, which is only exposed on the top and bottom part.	20
	Sandstone, light-gray, very fine-grained, thin-bedded, contains some shale partings and carbonaceous materials; contains some vertical burrows; weathers brown.	0.3
	Shale, gray, laminated, highly weathered.	1
III-13	Sandstone, light-gray, very fine-grained, very well sorted, subangular to subrounded grains; rather hard, thin-bedded; contains carbonaceous materials and very few glauconite; top part contains some burrows and other organic markings; weathers light gray to light brown; forms benches on the slope.	1
	Covered interval, most probably shale.	8
	Shale, gray, laminated; at the top and the bottom part is sandstone, thin-bedded, very fine-grained, contains some burrows; weathers gray to brown.	3.5

Sample No.	Description	Thickness in feet
	Covered interval, most probably shale.	6
III-12	Sandstone, light-brown, very fine-grained, very well sorted; rather hard, thin-bedded; contains limestone concretions; weathers brown, forms benches on the slope.	1
	Shale, gray, laminated, contains carbonaceous materials; with a thin bed of very fine grained sandstone at 3 feet from the bottom; mostly forms slope.	5
III-11	Sandstone, light-brown, very fine-grained, well sorted; rather hard, thin-bedded; contains some shale partings and some carbonaceous materials at the bedding plane; contains some small limestone concretions at the upper part; contains some burrows; weathers brown to gray; forms a conspicuous small cliff bordering the arroyo. (used as marker bed for correlation)	3
	Alternating shale and very fine-grained sandstone, laminated and thin-bedded, the sandstone mostly ripple-marked; contains carbonaceous materials; the sandstone contains some burrows and other organic markings; contains cone-in-cone structure at 23 feet from the top; contains Inoceramus and other shale fragments at 15 and 20 feet from the top and below the cone-in-cone structure; weathers gray to dark gray.	more than 30

Section IV

From the bottom of an arroyo to the top of the cliff and beyond, about 1 mile north of section III, in sec. 32, T. 30 N, R. 19 W.

UPPER PART OF MANCOS SHALE

Shale, light-gray to tan, sometimes sandy; forms slope.

Sample No.	Description	Thickness in feet
IV-7	Sandstone, light-gray to light-brown, medium-grained, moderately well sorted, with some grains up to 1.5 mm, subangular to subrounded grains; friable, medium-bedded, cross-bedded; glauconite is common; contains chert nodules; contains burrows and other organic markings; as a lens, not continuous to the south; weathers brown, rough; forms cliff.	3
	Shale, gray, laminated, not well exposed, forms slope.	9
	GALLUP SANDSTONE	
IV-6	Sandstone, white to light-brown, medium-grained, moderately well sorted, some grains up to 1.5 mm, subangular grains; friable, medium-bedded, cross-bedded; glauconite is common; contains chert nodules; contains burrows; weathers tan to gray; forms cliff.	5
	---------Unconformity---------	
	Alternating shale and sandstone, gray to brown, laminated and thin-bedded; contains carbonaceous materials, locally in high concentration; forms part of the cliff.	10
	Alternating shale and sandstone, gray to brown, laminated and thin-bedded; contains carbonaceous materials; the sandstone is ripple marked; contained limestone concretions, some definitely cone-in-cone structure; contains Inoceramus and other shell fragments.	10
	Sandy shale, red, laminated and thin-bedded; contains carbonaceous materials; contains cone-in-cone structure up to 2 feet in diameter.	3
	Shale, dark-gray,,laminated, highly carbonaceous.	more than 5

Section V

About 0.3 miles north of Red Rock Highway
in sec. 1, T. 27 N, R. 20 W.

Sample No.	Description	Thickness in feet
	UPPER PART OF MANCOS SHALE	
	Shale, light-gray to tan, sometimes sandy.	
	GALLUP SANDSTONE	
V-20 V-19	Sandstone, white to light-brown, fine-grained, well sorted, subrounded to subangular grains; friable, thick-bedded, cross-bedded; weathers tan to brown; forms small ridges.	10
	Sandstone, white to light brown, fine-grained, contains laminae of shale; soft, thin-bedded; weathers brown, forms small valley between ridges.	1
V-18 V-17 V-16	Sandstone, white to light-brown, fine-grained, well sorted, subrounded grains; friable, thick-bedded, cross-bedded; the top part contains trace of glauconite; weathers tan to brown; forms cliff or small ridges.	17
V-15	Sandstone, light-brown, fine-grained, moderately well sorted, subrounded grains; friable, thick-bedded, cross-bedded; weathers brown to gray, top part brown; forms cliff.	4
V-14 V-13	Sandstone, light-brown to light-gray, fine-grained, well sorted, subrounded to subangular grains; friable, thick-bedded, cross-bedded; on the top part contains trace of glauconite; the bottom part contains some burrows and other organic markings; weathers brown; forms small ridges between other ridges.	9
	Sandstone, light-gray, fine-grained, well sorted, contains laminae of shale; soft, rather friable, medium-bedded; weathers gray; forms small valley between ridges.	1

Sample No.	Description	Thickness in feet
V-12	Sandstone, light-brown, fine-grained, well sorted, subangular to subrounded grains; slightly friable, medium-bedded; contains trace of glauconite; weathers tan to brown; forms cliff or ridges.	4
V-11 V-10	Sandstone, light-brown, fine-grained, well sorted, subrounded to subangular grains; friable, thick-bedded; contains some burrows on the top and in the middle part; weathers brown; forms cliff or ridges.	7
V-9	Sandstone, light-brown, fine-grained, well sorted, subrounded to subangular grains; friable, medium-bedded; contains some shale partings and carbonaceous materials; contains some burrows and other organic markings; weathers brown to tan; forms cliff.	1
V-8 V-7 V-6	Sandstone, light brown, fine-grained, very well sorted, subangular to subrounded grains; friable, thick-bedded; contains some burrows in the bottom part; weathers brown to tan; forms cliff or ridges.	7
V-5 V-4	Sandstone, light-brown, fine-grained, very well sorted, subangular to subrounded grains; friable, thick-bedded, cross-bedded; contains burrows on the bottom part; weathers tan; forms cliff.	4
	Shaly sandstone, gray, fine-grained; soft, medium-bedded, contains some carbonaceous materials; weathers gray; forms soft part of cliff.	0.5
V-3	Sandstone, light-brown, fine-grained, very well sorted, subangular to subrounded grains; friable, thick-bedded; contains trace of glauconite; weathers brown to tan; forms cliff.	3
	Total thickness of Gallup sandstone	68.5

Sample No.	Description	Thickness in feet
	LOWER PART OF MANCOS SHALE	
V-2	Alternating sandstone and shale, light-brown and light-gray; medium-bedded, thin-bedded and laminated, soft, friable; sandstone is fine-grained, well sorted, contains shale partings and stringer of mica; contains trace of glauconite; sandstone and shale contain carbonaceous materials; weather gray to brown; form the soft part of cliff.	5
V-1	Sandstone, light-brown to white, fine-grained, very well sorted, subangular to subrounded grains; friable, thick-bedded and medium-bedded; contains trace of glauconite; contains casts of fossils, probably brachiopodes; weathers brown; forms bottom part of cliff or small ridges on the slope of shale.	3
	Shale, gray, laminated, sometimes sandy; forms slope.	more than 30

APPENDIX II

Calculation of Student t for Paired Samples

Population I

Sample No.	$\bar{x}_t$	$\bar{x}$	d	d^2
I-36	2.18	2.11	0.07	0.0049
I-35	2.01	2.03	-0.02	0.0004
I-34	2.00	1.98	0.02	0.0004
I-33	2.06	2.02	0.04	0.0016
I-32	2.09	2.09	0.00	0.0000
I-31	2.05	2.05	0.00	0.0000
			0.11	0.0073

$N = 6$ $d = 0.00183$

$$s_d^2 = \frac{\Sigma d^2 - (\Sigma d)^2/N}{N - 1} = \frac{0.0073 - (0.11)^2/6}{6 - 1} = 0.00106$$

$$t = \frac{\bar{d}}{(s_d^2/N)^{1/2}} = \frac{0.00183}{(0.00106/6)^{1/2}} = 1.38$$

degree of freedom. d.f. = N - 1 = 5

From the table of t (Simpson, p. 422), t = 1.38 occurs between P = 0.2 and P = 0.3, which means that between 20 % and 30 % of the time, a value of t as large or larger than 1.38 would be expected. In other words, the differences between the means are insignificant. As a general rule, according to Folk (1968), if P is over 0.20, differences are insignificant.

Population II

Sample No.	$\bar{x}_t$	$\bar{x}$	d	d^2
I-30	1.70	1.72	-0.02	0.0004
I-29	1.51	1.53	-0.02	0.0004
I-28	1.66	1.68	-0.02	0.0004
I-27	1.68	1.64	0.04	0.0016
			-0.02	0.0028

$N = 4$ $\bar{d} = -0.005$

$$s_d^2 = \frac{0.0028 - (-0.02)^2/4}{4 - 1} = 0.0009 \text{ and } t = \frac{-0.005}{(0.0009/4)^{1/2}} = -0.33$$

degree of freedom. d.f. = 3

From the table of t (Simpson, p. 422), t = -0.33 occurs between P = 0.8 and P = 0.7, which is fairly high. Conclusion from this test is that there is no significant differences between the means of the treated and untreated samples.

APPENDIX III

Computation of Variance Analysis

Population I

Sample No.	Mean grain-size treated $\bar{x}_t$	 untreated $\bar{x}$	$\bar{x}_t^2$	$\bar{x}^2$
I-36	2.18	2.11	4.7524	4.4521
I-35	2.01	2.03	4.0401	4.1209
I-34	2.00	1.98	4.0000	3.9204
I-33	2.06	2.02	4.2436	4.0804
I-32	2.09	2.09	4.3681	4.3681
I-31	2.05	2.05	4.2025	5.2025
N = 6	12.39	12.28	25.1444	25.1444

Correction term, CT = $(\Sigma\bar{x}_t + \Sigma\bar{x})^2/2N$

$$= (12.39 + 12.28)^2/12 = 50.7174$$

Total of sum of squares, $SS_{tot} = \Sigma\bar{x}_t^2 + \Sigma\bar{x}^2 - CT$

$$= 25.6067 + 25.1444 - 50.7174 = 0.0337$$

Between techniques sum of squares, $SS_{bt} = \frac{1}{N}(\Sigma\bar{x}_t)2 + (\Sigma\bar{x})^2 - CT$

$$= \frac{1}{6}(12.39^2 + 12.28^2) - 50.7174 = 0.0010$$

Within techniques sum of squares, $SS_{wt} = SS_{tot} - SS_{bt}$

$$= 0.0337 - 0.0010 = 0.0327$$

One way variance analysis to test the technique:

No. of items	Source of variation	degree of freedom	Sum of squares	Mean square	Variance ratio	$F_{5\%}$
2	Between techniques	1	0.0010	0.0010	0.3	4.96
6	Within techniques	10	0.0327	0.0033		
12	Total	11	0.0337			

The variance ratio is smaller than the tabulated value of $F_{95,1,10}$ (Selby, 1968), hence the hypothesis is accepted; i.e., the means of grain-size obtained from these two techniques do not vary, and therefore both techniques are yielding the same set means.

Population II

Mean grain-size

Sample No.	treated $\bar{x}_t$	untreated $\bar{x}$	$\bar{x}_t^2$	$\bar{x}^2$
I-30	1.70	1.72	2.8900	2.9584
I-29	1.51	1.53	2.2801	2.3409
I-28	1.66	1.68	2.7556	2.8224
I-27	1.68	1.64	2.8224	2.6894
N = 4	6.55	6.57	10.7481	10.8113

Correction term, CT = $(\Sigma\bar{x}_t + \Sigma\bar{x})^2/2N$

$$= (6.55 + 6.57)^2/8 = 21.5168$$

Total of sum of squares, $SS_{tot} = \Sigma\bar{x}_t^2 + \Sigma\bar{x}^2 - CT$

$$= 10.7481 + 10.8113 - 21.5168 = 0.0426$$

Between techniques sum of squares, $SS_{bt} = \frac{1}{N}(\Sigma\bar{x}_t)^2 + (\Sigma\bar{x})^2 - CT$

$$= 1/4(6.55^2 + 6.57^2) - 21.5168 = 0.0001$$

Within techniques sum of squares, $SS_{wt} = SS_{tot} - SS_{bt}$

$$= 0.0426 - 0.0001 = 0.0425$$

One way variance analysis to test the technique:

No. of items	Source of variation	degree of freedom	Sum of squares	Mean square	Variance ratio	$F_{5\%}$
2	between techniques	1	0.0001	0.0001	0.014	5.99
4	within techniques	6	0.0425	0.0071		
8	Total	7	0.0426			

The variance ratio is smaller than the tabulated value of $F_{95,1,10}$ (Selby, 1968), hence the hypothesis is accepted; i.e., the means of grain-size obtained from these two techniques do not vary, and therefore both techniques are yielding the same set means.

APPENDIX IV

Staining Procedure for Dolomite Identification

A. <u>Sample preparation</u>

1. Sample is cut into one-inch cube forms and each face was roughly polished on top of a glass plate with very little water.
2. Boiled the sample for 5 minutes in hot epoxy.
3. Polished one surface of the sample with very fine carborundum until it is free of epoxy. Most of the samples are porous and the spaces have been filled with epoxy, but the polished grains are exposed.

B. <u>Preparation of chemicals</u> (Friedman, 1959; Warne, 1962)

1. For etching purposes, 8 to 10 ml concentrated HCl were diluted with water to 100 ml.
2. Dissolved 0.1 g alizarin red S in 100 ml of 0.2% HCl. (0.2 ml of concentrated HCl in 100 ml of water.)
3. Prepared 30% NaOH by dissolving 30 g of NaOH pellets into 100 ml of water. Also prepared 5% NaOH by dissolving 5 g of NaOH into 100 ml of water.

C. <u>Treatment before and after staining</u> (Warne, 1962)

1. Before staining, the sample was etched in hot dilute HCl for 15 - 20 seconds.
2. After staining, the sample was washed in water containing strongly diluted NaOH.

D. Staining (Friedman, 1959; Warne, 1962)

1. The freshly etched sample was placed for 5 minutes in boiling alizarin red S and equal parts of 30% NaOH. (Dolomite, ankerite, high Mg-calcite, rhodochrosite, magnesite, gypsum and smithsonite should stain purple.)
2. The freshly etched sample was placed for 5 minutes in boiling alizarin red S and equal parts of 5% NaOH. (Only magnesite, gypsum and smithsonite should be stained purple, while dolomite stains very faintly or not at all.)
3. The freshly etched sample was immersed in 1 - 3% NaOH for 1-1/2 minutes and exposed to air for 1-1/2 minutes, and then covered by benzidine reagent cold. (Rhodochrosite should immediately have a blue stain while dolomite should be unaffected.)

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Figure 7

Figure 7. Stratigraphic sections of the Gallup Sandstone and associated rocks near Red Rock Highway, and between New Mexico State Highway 504 and San Juan River, New Mexico.

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