PETROGRAPHY AND PETROGENESIS OF THE ALIBATES

DOLOMITE AND CHERT (PERMIAN), NORTHERN PANHANDLE OF TEXAS

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by

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THESIS

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PREFACE

I was introduced to the Alibates Dolomite and associated chert during my first semester as a senior geology student at The University of Texas at Arlington in 1971. A special studies course on carbonate petrography included a petrographic study of and written report on a stratigraphic section of Alibates measured by Dr. Reaser in 1968. A spark of interest had been ignited by the Alibates flint. The lack of detailed work on the Alibates provided the incentive to continue the study.

I am very grateful to my graduate committee for their valuable guidance and assistance during the study and for critically reading the manuscript. All committee members are or were geology professors at the Department of Geology, The University of Texas at Arlington. I extend my sincerest thanks to:

Dr. Donald F. Reaser, Committee Chairman, for the countless hours, endless patience, and tireless efforts he put forth to help me in so many ways while directing this thesis, and for introducing me to the Alibates.

Dr. Burke Burkart for his suggestions concerning geochemical, mineralogical, and genetic aspects of the study.

Mr. Calvin F. Miller, Adjunct Professor at The University of Texas at Arlington and Photogeologist at Hunt Oil Company, Dallas, Texas, for his suggestions and encouragement, and for help in interpreting aerial photographs of part of the study area.

Dr. Robert W. Scott, former faculty member now with Amoco Oil Company, Tulsa, Oklahoma, for his help with the petrography and discussion of depositional environments.

I also thank other members of the Geology Department. They are: Dr. Charles F. Dodge, Department Chairman, for his interest and support of this project by providing transportation for two trips to the study area and for other departmental assistance. Professors John D. Boon, Joseph F. Fischer, David A. Kotila, and Charles L. McNulty for their interest and helpful discussions of the thesis problem. Mrs. Wanda Slagle, Departmental Secretary, for her help in administrative matters and for her warm, cheerful attitude that helped brighten many days.

Because the Lake Meredith Recreation Area and Alibates National Monument are within the most important part of the study area, the National Park Service personnel at Sanford, Texas played a major part in the completion of this thesis. They provided collecting permits for rock samples and loaned aerial photographs of the monument area. Just as valuable was their willing cooperation and friendly attitude. My special thanks to:

Mr. James M. Thomson, Superintendent through 1973; Mr. William E. Dyer, Superintendent; and Mr. Larry K. Nielson, Chief Ranger, for their project approval and administrative support.

Ms. Alice Allen and Mr. Edwin Day, Park Rangers, for their valuable assistance in the field and for sharing their knowledge of the Alibates with me. Mr. Jack Thompson and Mr. Ray Carrick, Park Rangers, for their cooperation and help in the field.

My thanks also to Mr. Edgar Blair and Mr. Fredrick Atterian, Division of Surveys, National Park Service, Denver, Colorado for their cooperation concerning photo and map coverage of the Lake Meredith Recreation Area.

Other persons residing in the project area were important to the completion of my field work. I extend my thanks to:

Dr. James R. Underwood, Jr., Professor of Geology at West Texas State University at Canyon, Texas, provided lodging for Dr. Reaser and me on two trips; and Dr. Underwood's wife, Margaret Ann, treated us to her delicious cooking. Their warm hospitality made the stay truly enjoyable.

Mr. Tom Kritser, landowner, allowed me to study Alibates exposures on his ranch north of Amarillo, Texas; Mr. Jack Brown, ranch foreman, assisted in the field.

Mr. W. V. Harlow, professional geologist at Amarillo, Texas, gave me valuable information about the Alibates in areas that were not accessible to me.

Other persons who deserve recognition and thanks are:

Dr. Charles G. Groat, Associate Director, Bureau of Economic Geology, and Mr. Daniel A. Schofield, Chemist-in-charge, Mineral Studies Laboratory at The University of Texas at Austin provided chemical analyses of fifteen Alibates samples.

Mr. Robert Phelps, Hunt Oil Company, Dallas, Texas gave helpful suggestions about illustrations.

Mr. Rey Perkins and Mr. Mark Wilson, fellow students, made several thin sections for me; Mr. Jimmy Kelley and Mr. Alan Hart, fellow graduate students, participated in stimulating conversations about the thesis problem.

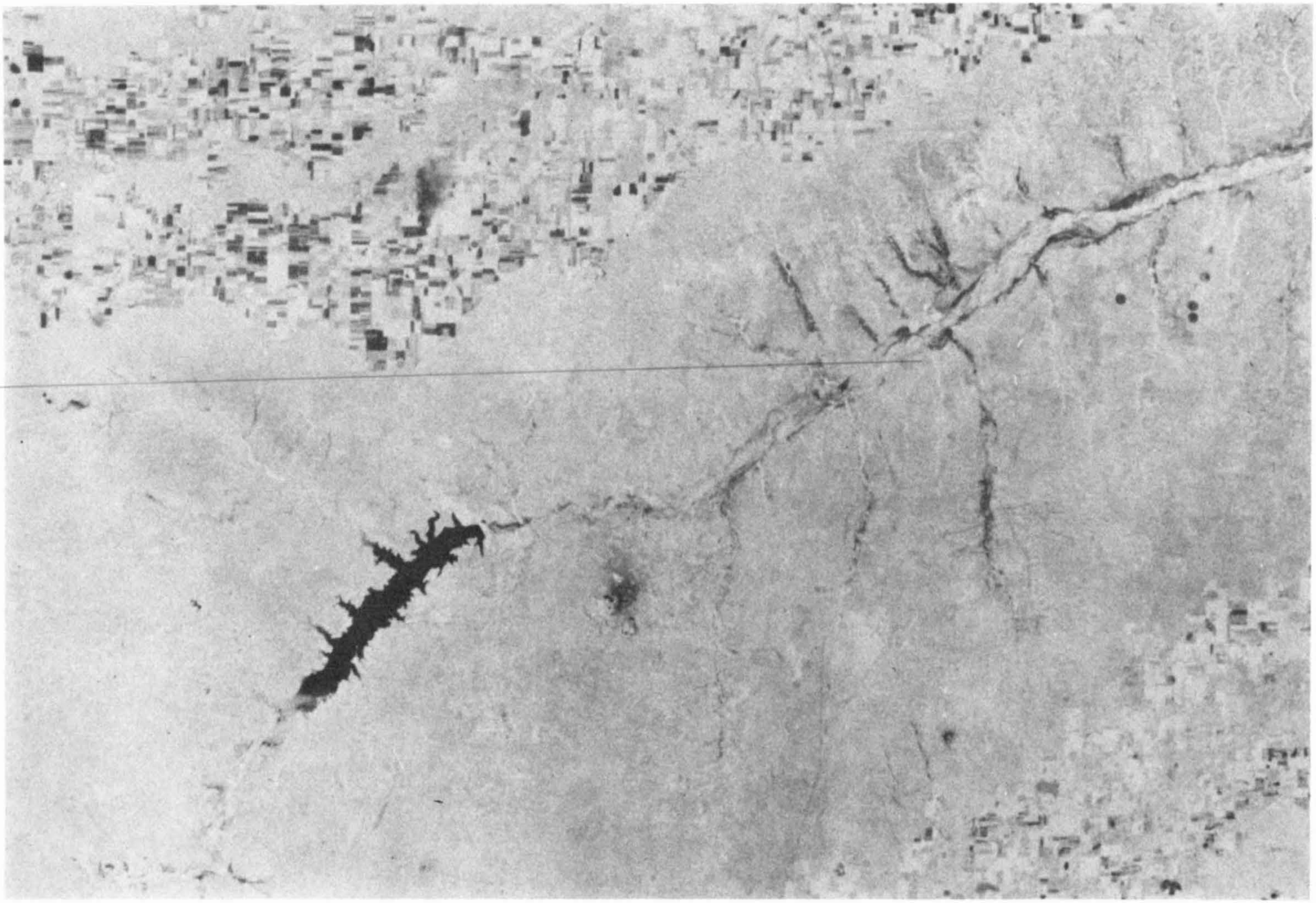
My mother, Mrs. Josephine Bowers of Salt Lake City, Utah, provided years of love and encouragement. Mr. Ralph E. Bowers, my father, saw the start of this thesis but did not live to see the finished product. To his memory, I dedicate this work in the hope that he would be proud of it.

Finally, to my wife, Susan, who worked hard to help finance my education and gave me moral support, I hope that I can now begin to repay her for her labors.

Research for this thesis was aided by a Grant-in-Aid of Research from Sigma Xi, The Scientific Research Society of North America, a Research Grant from the Southwest Section, American Association of Petroleum Geologists, and a Scholarship from the Dallas Geological Society.

This thesis was submitted to the editorial committee in March 1975.

Roger L. Bowers
May 1975



FRONTISPIECE. ERTS (Earth Resource Technology Satellite) imagery of Lake Meredith and Canadian River, northern Panhandle of Texas.

PETROGRAPHY AND PETROGENESIS OF THE ALIBATES

DOLOMITE AND CHERT (PERMIAN), NORTHERN PANHANDLE OF TEXAS

Roger Lee Bowers

A B S T R A C T

The Permian (Guadalupian) Alibates Dolomite crops out along the Canadian River in the northern Panhandle of Texas. The dolomite is underlain by the Permian Whitehorse Formation and is overlain by the Permian Quartermaster and Tertiary Ogallala formations. The 5-meter section of Alibates consists of three members: a lower gray dolomite and an upper gray dolomite separated by an interval of red to brown calcareous mudstone. The upper dolomite and middle red beds are locally absent.

Regional paleogeographic and stratigraphic studies suggest that the Alibates Dolomite was deposited in a shallow lagoonal to supratidal carbonate mudflat environment. Lamination and brecciation in the dolomite members are similar to algal laminates in other ancient rocks and in modern sabkha algal-mat environments. The three members represent a transgressive-regressive-transgressive sequence.

Extensive calcitization of both dolomite members has occurred at several places. Calcitization has formed a "boxworks" structure where it has proceeded along fractures and porous zones in the dolomite.

Chertification has occurred locally in both dolomite members forming chert beads and sporadic, irregular chert masses. Massive sheets of chert have completely replaced the upper dolomite at the Alibates National Monument. Evidence for a replacement origin for the chert

includes: 1) sharp dolomite/chert contacts, 2) clasts of dolomite floating in a chert matrix, 3) relic lamination in the chert, 4) chertified sedimentary breccia, and 5) length-slow chalcedony. Sources of silica were stratigraphically above the Alibates, and silica-bearing solutions percolated downward into the dolomite along fractures and porous zones.

Both calcitization and chertification can be related to calichification which is a common process in this climate: calcitized and chertified zones in the Alibates may have formed by this or a similar process.

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I N T R O D U C T I O N

The Permian Alibates Dolomite crops out along the Canadian River and its tributaries in Carson, Hutchinson, Moore, and Potter counties, Texas. Isolated outcrops occur along the Salt Fork of the Red River near Clarendon, Donley County, and at Lake McClellan, Gray County (fig. 1). A few exposures of the Alibates along the Canadian River are west of U. S. Highway 287 but were not included in the study because legal access to this area was not possible. The Alibates is in the subsurface throughout the rest of the Texas Panhandle. The purpose of this thesis was to interpret the origin and diagenesis of the Alibates Dolomite and associated chert by a petrographic study of samples collected from the outcrop.

PHYSIOGRAPHY

The study area lies within the southern part of the Great Plains physiographic province (Gould and Willis, 1926) and is also known as the High Plains of Texas. The northern part of the study area is drained by the Canadian River which flows northeastward and has cut a broad, shallow valley into the High Plains. This valley averages 150-200 meters deep and is 15 to 50 kilometers wide. The Canadian River has eroded the Tertiary rocks and has exposed the underlying Permian strata. Tributaries to the Canadian River trend north-south and have formed "breaks" along the sides of the valley. It is in these "breaks" that the Alibates Dolomite is best exposed. At most places, all overlying strata have been removed and the resistant Alibates caps the steep bluffs along the valley. The south-eastern part of the study area is drained by tributaries of the Red River.

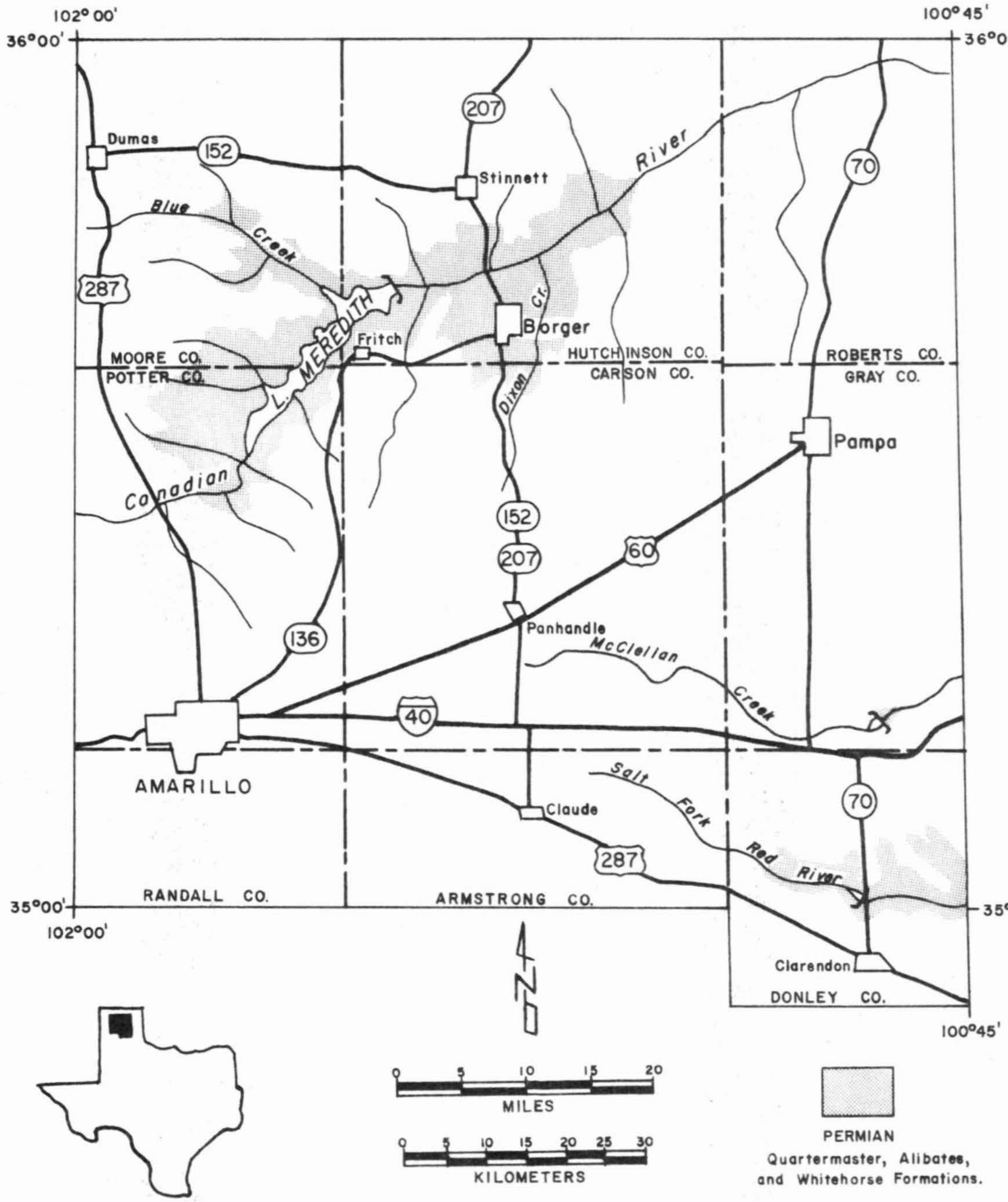

Figure 1. Map of project area and outcrop of Permian rocks (geology from Barnes, 1968 and 1969).

The Salt Fork of the Red River, Turkey Creek, and McClellan Creek flow eastward into the Red River and have exposed the Alibates Dolomite at isolated localities.

There are no significant natural lakes in the study area, but a few springs along the Canadian River provide some water in this flat, semi-arid county. Lake Meredith, behind Sanford Dam, is the largest body of water in the Texas Panhandle. Located about 50 kilometers north of Amarillo on the Canadian River, Lake Meredith is now the major source of water for this area. Two smaller man-made lakes, Greenbelt Reservoir and Lake McClellan, are on the Salt Fork of the Red River and McClellan Creek, respectively.

CLIMATE

According to Trewartha (1954, p. 283-285), the Texas Panhandle has a semiarid or steppe climate. The mean winter (January) temperature is 50°F and the mean summer (July) temperature is 80°F. The annual rainfall is from 15 to 20 inches with most of the precipitation during the late summer months. The region is characterized by a cover of short grass.

PROCEDURES

Field work was conducted during the summers of 1973 and 1974. Thirty stratigraphic sections were spaced to obtain a representative geographic distribution over the entire outcrop area. Each section was described in detail including stratigraphic and structural relationships, and samples were taken for each sequence of beds (Appendix I). Key sections and important physical characteristics or relationships were photographed.

All samples were examined and described using a hand lens or binocular microscope. Rock colors were determined by comparison with a Rock Color Chart (Goddard, 1948). A few samples of chert were sawed, and the polished surfaces were described. Thin sections of 101 selected samples of dolomite, chert, and red beds were examined under a petrographic microscope. A 100-point count was made on 96 slides which consisted of a single basic rock type; a 200-point count was made on 5 slides which contained more than one basic rock type. The following data were recorded for each slide (Appendix II):

1. Rock name and locality
2. Texture
3. Types, sizes, percentages, and characteristics of all minerals
4. Sedimentary structures
5. Weathering and alteration
6. Any unique relationships or characteristics

A few minor modifications were made to Folk's (1974) classification for this study.

Fifteen samples of dolomite and chert were chemically analyzed by the Mineral Studies Laboratory, Bureau of Economic Geology, The University of Texas at Austin. The results are shown in Table 1 and were used to interpret mineralogical relationships.

PREVIOUS WORK

Charles N. Gould (1905, p. 72), the first geologist to make a detailed geologic investigation of the Texas Panhandle, described red beds along the Canadian River in Texas. He considered these beds to be the stratigraphic equivalent of the Quartermaster Formation exposed in western Oklahoma and, therefore, applied the same name to the Texas red beds. Later, Gould (1906, p. 21) stated that dolomite beds of the Quartermaster Formation in Texas were not persistent enough laterally to name. However, further reconnaissance the next year led to the naming of the Alibates Dolomite by Gould (1907, p. 17). He named the white dolomite after Alibates Creek, along which the dolomite caps steep bluffs. Hertner (1967, p. 9) observed that the name Alibates was a corruption of the name Allen Bates, the son of local rancher W. H. Bates.

Gould (1907, p. 17-19) described the Alibates as upper and lower dolomite beds and a red-bed sequence between the two dolomite beds. He also recognized lithic similarities between the Alibates and the Day Creek Dolomite in Oklahoma, although he considered the Alibates to be a lentil in the upper part of the Quartermaster. Using the Alibates as a key horizon for mapping in 1917, Gould (1920, p. 269-275) recognized several large structural domes in the area. He recommended that the John Ray dome be drilled, and in 1918 the Masterson No. 1 was completed as a gas well. This discovery was the beginning of the petroleum industry in the Texas Panhandle.

Leroy T. Patton (1923, p. 39-42) measured stratigraphic sections of Alibates in Potter County and described characteristics of the dolomite such as lamination and brecciation. He reported the presence of minute black specks in the rock and, from a study of several thin sections and chemical analyses of four samples, concluded that the black specks were irregularly-shaped deposits of manganese dioxide disseminated throughout the rock. Patton also briefly discussed the origin of the chert; he presented three hypotheses for the genesis of the chert but did not find evidence to support any of them.

Gould (1926b, p. 420) noted that, as of May 1926, the correlation of Alibates Dolomite in Texas with the Day Creek Dolomite in Oklahoma was still an unsolved problem. Nevertheless, later the same year, Gould and Lewis (1926, p. 16-23) remarked that, in their opinion, the Alibates was the equivalent of the Day Creek and recommended that the name Alibates be dropped. They also mapped the Day Creek (Alibates) in Carson, Hutchinson, Moore, and Potter counties, Texas.

John E. Adams (1935, p. 1016-1017) correlated the Alibates with the Day Creek by tracing surface exposures and comparing well logs. He observed that the Alibates grades into gypsum to the east near the Texas-Oklahoma border; and still farther east, the gypsum grades into the Day Creek. He also stated that the Alibates appears to grade into anhydrite to the south and, as a marker for the base of the Quartermaster and the top of the Whitehorse, extends far enough to correlate with formations in the Midland basin.

Lincoln E. Warren (1946, p. 259-264) measured and described four stratigraphic sections of Alibates in Potter and Moore counties. Eight samples of dolomite were chemically analyzed. He considered the dolomite to be in the upper part of the Permian Rustler Formation.

Gus K. Eifler, Jr. of the Bureau of Economic Geology, The University of Texas at Austin, mapped the Alibates Dolomite as part of the undivided Quartermaster Formation, Cloud Chief Gypsum, and Whitehorse Sandstone (Barnes, 1969).

Bowers and Reaser (1974, p. 96) described the occurrence of Alibates chert in the Alibates National Monument and vicinity. They suggested a replacement origin for most of the chert and cited evidence to support this hypothesis.

ALIBATES NATIONAL MONUMENT

It has been purported that the extraction of flint from the Alibates quarries represents the earliest and longest-lived industry developed on the North American continent. More than 12,000 years ago, paleo-Indians (Clovis, Folsom, and others) discovered that chert from the Alibates Dolomite was superior to other cherts for making arrow heads, spear points, and other weapons and tools. Tribes that occupied the area throughout time were continually attracted to the colorful and high-quality chert. As the quarries developed, the chert apparently increased in value to the Indians. One, or perhaps several, of the more enterprising tribes turned the quarries into an industry by making "blanks" for weapons and tools. These blanks were then used to barter with other tribes. Claims have been made that Alibates chert, as trade goods, was widely distributed throughout the Southwest and eventually reached such places as the Pacific Coast and Minnesota (Anthony, 1963). A positive method of identifying the chert may greatly increase or decrease the geographic range of trading.

Today the quarries are nothing more than shallow (2-3 m) depressions along the outcrop. Most of the depressions are on the top of an Alibates-capped bluff overlooking Lake Meredith between Alibates and Turkey creeks (fig. 2). The immediate area has the appearance of an old bombing target with many of the craters partly filled. Small chips of multicolored chert blanket the ground.

In 1965, Congress established the Alibates National Monument to protect these quarries and some nearby Indian ruins. The monument borders the Lake Meredith Recreation Area, and both the monument and the recreation area are administered by the National Park Service. The monument is still in the development stage: roads, trails, and other facilities have been planned and are now being built. Several campgrounds, picnic areas, and boating facilities are already available for public use in the recreation area, but the monument area is open to the public on a limited basis. Persons are allowed in the monument only when accompanied by a park ranger; however, the rangers are readily available to guide any interested person into the area. A ranger-conducted tour to the quarries is a very interesting, informative, and thought-stimulating trip that takes one back in time to look at one of man's oldest industrial sites.

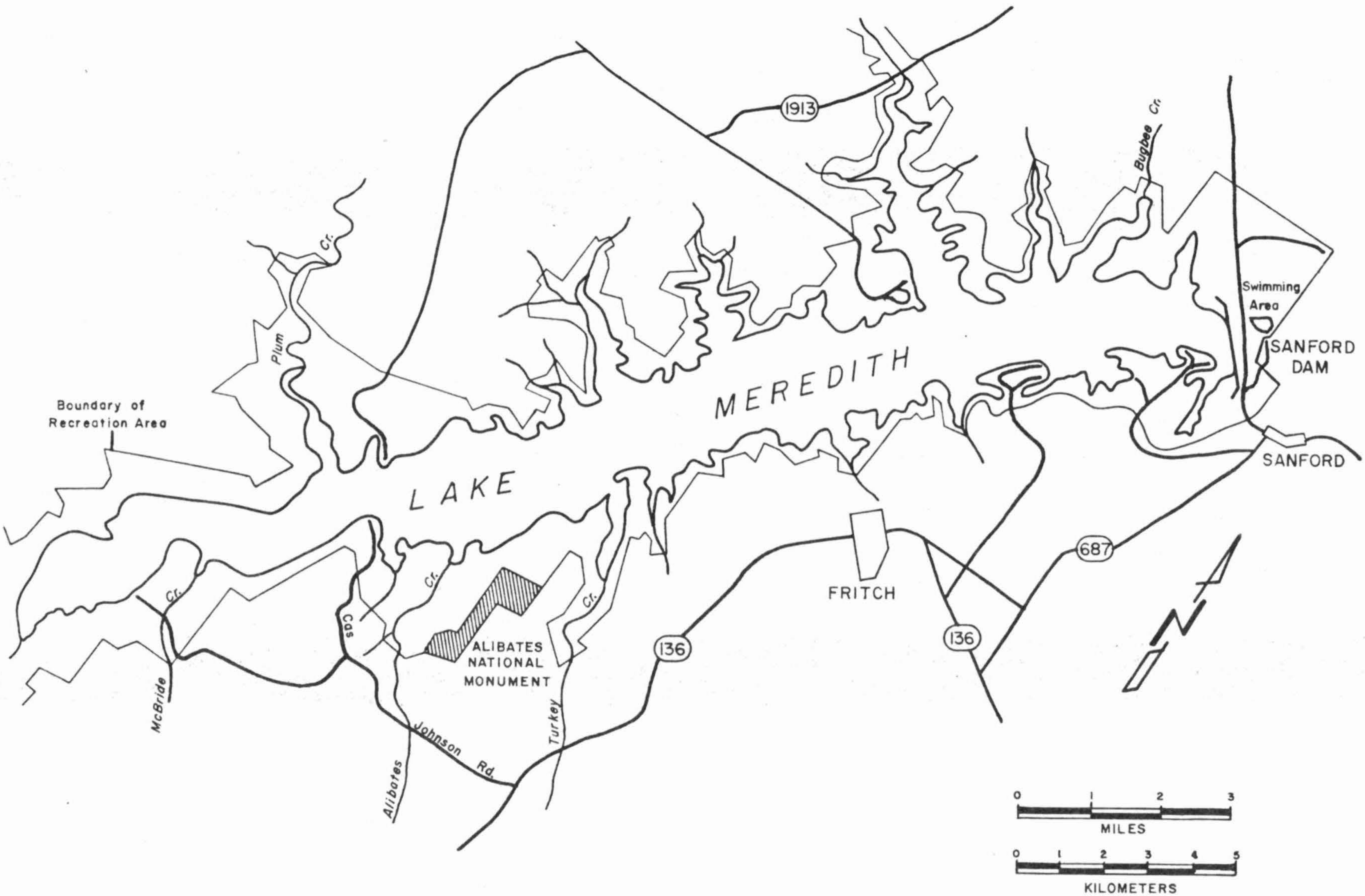

Figure 2. Lake Meredith Recreation Area and Alibates National Monument vicinity (from National Park Service flyer, 1969).

S T R U C T U R E

Pre-Cenozoic structural features of the Texas Panhandle are covered by Tertiary rocks and Quarternary sediments. Only locally, such as in parts of the Canadian River valley, has erosion exposed isolated evidence of pre-Tertiary structures, consequently, most of the structures discussed here are inferred primarily from subsurface data.

The main structural feature of the Texas Panhandle is the Amarillo Uplift (fig. 3). This uplift is formed by buried granite ridges which trend west-northwest through Wheeler, Gray, Carson, and Potter counties. Many geologists such as Abels (1959, p. 15) and Powers (1922, p. 249) consider the granite ridges as a northwest extension of the Wichita Mountains in western Oklahoma (fig. 4). According to Rascoe (1962, p. 1369), the Amarillo-Wichita Uplift came into existence during the early part of the Pennsylvanian Period (Springer and Morrow time).

North of and parallel to the axis of the Amarillo Uplift is the Anadarko Basin (fig. 3). Totten (1956, p. 1962) suggested that the basin started to form during the late Mississippian, and subsidence continued throughout most of the Permian. To the south of the Amarillo Uplift is the Palo Duro Basin, also called the Plainview Basin by some geologists. Other structural features in the Texas Panhandle include the Dalhart Basin, Cimarron Uplift, and Bravo Dome (fig. 3). Several smaller domal structures are associated with the Amarillo Uplift and include the John Ray, Bush, and X-L domes in Potter County, the Pantex Dome in Hutchinson County, and the 6666 Dome in Carson County.

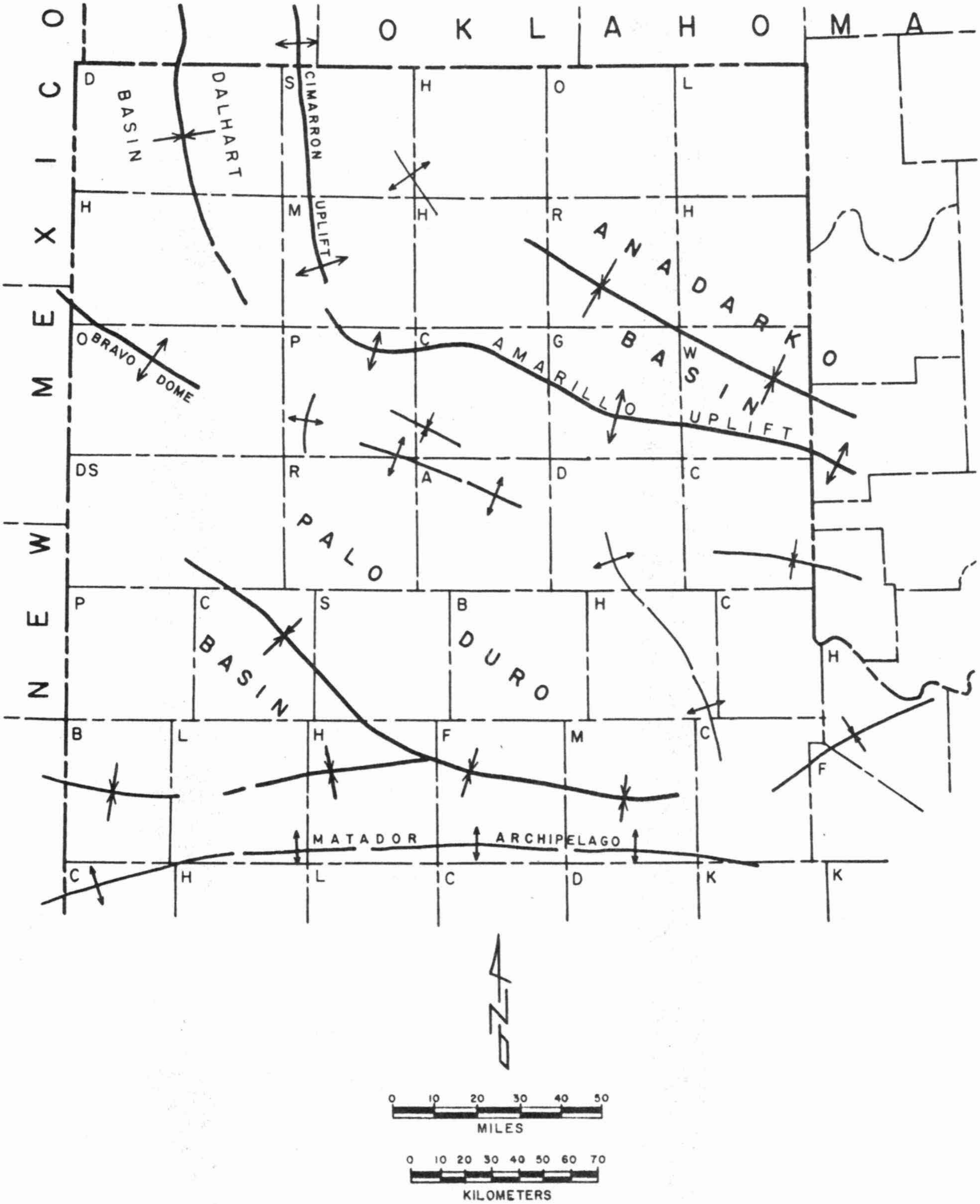

Figure 3. Structural features of the Texas Panhandle (modified from Totten, 1956, p. 1963).

Structures visible in exposed strata in the study area are relatively small and insignificant. At some places along the Canadian River valley and tributary valleys, the Alibates shows an undulating pattern of gentle, open folds. Gould (1905, p. 72) attributed these large undulations to solution of underlying evaporites.

The Bureau of Economic Geology (Barnes, 1969) mapped a normal fault on the Amarillo Sheet of the Geologic Atlas of Texas. The fault, which is downthrown to the southwest, strikes northwest and is about 2 kilometers east of U. S. Highway 287 and 1.2 kilometers north of the Canadian River in Potter County. This is approximately the same location as noted by Gould and Lewis (1926, pl. II) for the Potter County fault. Outcrops of Alibates along the breaks of the Canadian River seem to be cut by numerous faults with displacements of less than 1 meter. Most of these faults are the result of recent slumping, yet others obviously occurred before the Ogallala was deposited.

At many places, the Alibates is systematically fractured. Osburg (1968, p. 3) recognized three sets of joints in the vicinity of the Alibates National Monument. Weathering along joints has produced large rectangular slump blocks of dolomite that prominently dot the steep slopes of the river breaks.

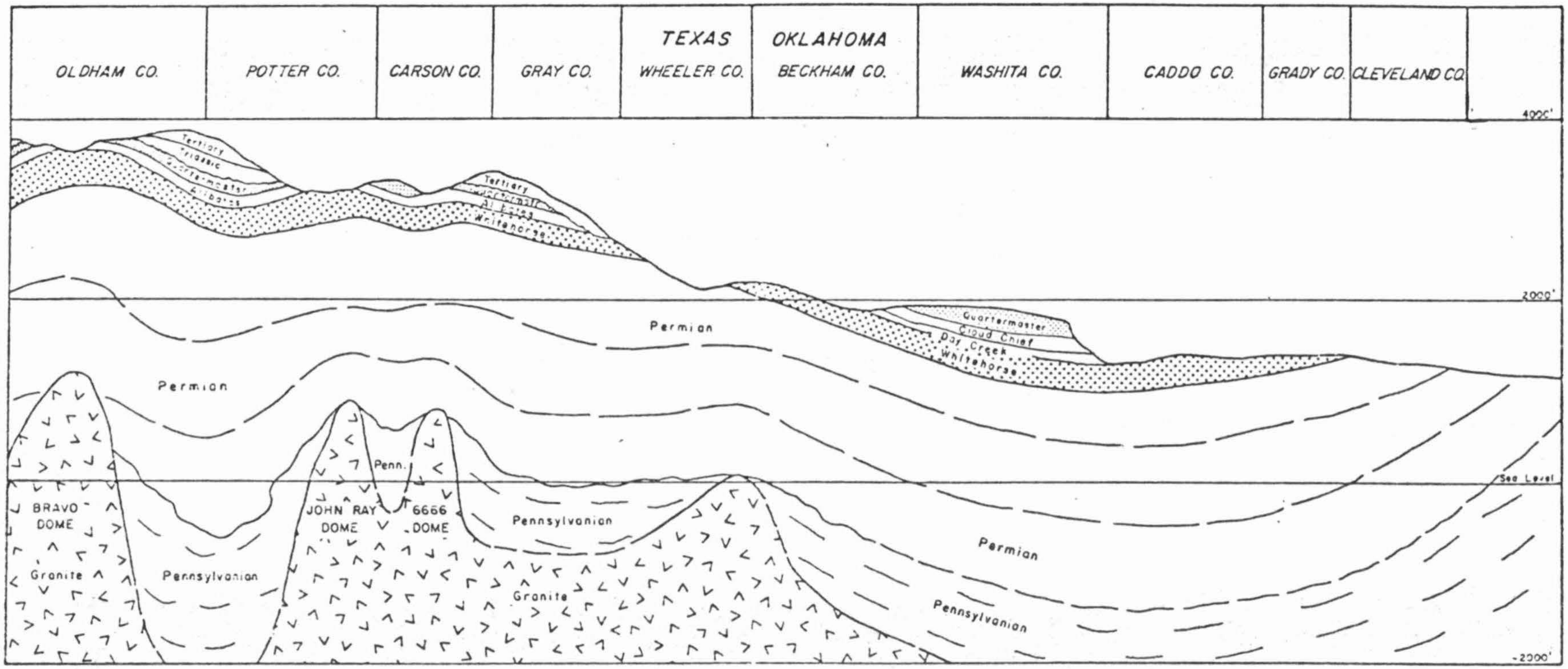

Figure 4. Generalized east-west cross section through the Texas Panhandle and western Oklahoma (modified from Freie, 1930).

S T R A T I G R A P H Y

REGIONAL

Stratigraphy of Permian rocks in the Panhandle of Texas and western Oklahoma is complex. The stratigraphic section is characterized by a thick interval of red beds with sandstone lenses and more or less persistent beds of dolomite and gypsum. Correlation of strata is difficult because of poor surface exposures, lack of well logs in some places, paucity or absence of fossils throughout, and many local unconformities and faults. Stratigraphic classifications have changed several times since 1907, and changes still fuel arguments today.

Gould's 1907 stratigraphic classification and nomenclature for the Texas Panhandle remained unchanged until the early 1920's. Then as geologists started to unravel the geologic history of the Oklahoma Permian, Gould's designations were altered. It is interesting that most changes made in the Permian stratigraphic classification of the Texas Panhandle were a result of work done in western Oklahoma. With the exception of a few workers such as Wrather (1917) and Patton (1923), Texas geologists apparently had not been concerned with the correlation of Upper Permian in the northwest part of their state. Wrather (1917, p. 95-104) discussed the Double Mountain Beds, a very large stratigraphic division of Upper Permian red beds in northern Texas (fig. 5).

Gould (1920, p. 270) noted that the Quartermaster Formation and the underlying Greer Gypsum could be considered "as the upper part of the Double Mountain formation." Gould (1924, p. 325) abandoned the name Greer after he found it was equivalent to Blaine, Dog Creek, Whitehorse, and

Cloud Chief in Oklahoma. He placed the Day Creek between the Cloud Chief and Whitehorse. Early in 1926, Gould (1926a, p. 144-153) remarked that Oklahoma nomenclature would be used in Texas because the Double Mountain Beds had not been subdivided. By the end of 1926, Gould and Willis (1926, p. 431-442) had completely revised the stratigraphic classification for the Texas Panhandle with the correlation of Alibates and Day Creek (fig. 5).

Evans (1931, p. 405-439) made a major change in the Oklahoma classification by reducing the Cloud Chief from a formation to the upper member of the Whitehorse. He placed the Day Creek above the Cloud Chief and below the Quartermaster. Evans also suggested that the Day Creek be divided into Upper Day Creek and Lower Day Creek. Green (1937, p. 1528-1529) agreed with Evans' change and concluded that "the Day Creek is a thin formation not included in either the Whitehorse group or the Quartermaster group." Although using Evans' classification, Dott (1941, p. 1679-1687) observed that the stratigraphic position of the Day Creek with respect to the Cloud Chief was still in question, and proper classification and nomenclature of the units could not be finalized until this question was resolved.

When Adams and others (1939, p. 1978) placed the Whitehorse and Day Creek in the Guadalupe Series and remarked that rocks of the Ochoa Series are not recognized in the Texas Panhandle, the age of the Quartermaster became a problem. They suggested (p. 1680) that the Quartermaster may be Triassic. Evans (1931), Green (1937), Dott (1941), and several others had noted that local unconformities and lateral changes in lithology confused the dating of strata throughout the Whitehorse-Quartermaster sequence. Finally Roth, Newell, and Burma (1941, p. 312-317) reported the

<table>
<tr><th>Gould
(1907)</th><th>Wrather
(1917)</th><th>Gould & Willis
(1926)</th></tr>
<tr><td rowspan="3">Quartermaster
Alibates
Saddlehorse</td><td rowspan="4">Double
Mountain
Beds</td><td>Quartermaster</td></tr>
<tr><td>Cloud Chief</td></tr>
<tr><td>Alibates (Day Cr.)</td></tr>
<tr><td>Greer</td><td>Whitehorse</td></tr>
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<tr><th>Evans
(1931)</th><th colspan="2">Adams & others
(1939)</th><th>Roth
(1955)</th></tr>
<tr><td rowspan="2">Quartermaster</td><td>Tri.</td><td>Quartermaster?</td><td></td></tr>
<tr><td rowspan="2">Och.</td><td rowspan="2"></td><td>Quartermaster</td></tr>
<tr><td>Day Creek</td><td>Alibates</td></tr>
<tr><td rowspan="2">Whitehorse
Cloud Chief</td><td rowspan="2">Guad.</td><td>Day Creek
(Alibates)</td><td rowspan="2">Whitehorse</td></tr>
<tr><td>Whitehorse</td></tr>
</table>

<table>
<tr><th colspan="2">Dunbar & others
(1960)</th><th colspan="2">Barnes
(1969)</th><th>Totten (1956), Rascoe
(1972), & This Paper</th></tr>
<tr><td>Ochoa</td><td>Quartermaster
(Day Creek)</td><td rowspan="4">Undivided</td><td rowspan="4">Quartermaster
Cloud Chief
Whitehorse</td><td></td></tr>
<tr><td rowspan="3">Guadalupe</td><td rowspan="3">Whitehorse</td><td>Quartermaster</td></tr>
<tr><td>Alibates</td></tr>
<tr><td>Whitehorse</td></tr>
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Figure 5. Comparison of stratigraphic classifications of Upper Permian for Texas Panhandle and western Oklahoma.

discovery of Permian pelecypods in the lower part of the Quartermaster; they stated that the Quartermaster may be either Guadalupian or Ochoan. Totten (1956, p. 1961) included the Quartermaster and Alibates (Day Creek) as part of the Whitehorse Group in the Guadalupe Series of the Texas Panhandle. Dunbar and others (1960, p. 1805) placed the Quartermaster of Oklahoma in the Ochoan Series on the advice of R. C. Moore, thus correlating the formation with the Dewey Lake and Rustler formations of West Texas. The Whitehorse was placed in the Guadalupian Series as time-equivalent to the Tansill, Yates, and Seven Rivers formations of West Texas. They did not discuss the Permian of the Texas Panhandle. Dixon (1967, p. 75-76) reviewed the problems of correlation, stated that the Quartermaster and Alibates could be either Guadalupian or Ochoan, and suggested that they may correlate with the Tansill, Seven Rivers, or Rustler formations of West Texas and New Mexico (fig. 6). The Bureau of Economic Geology (Barnes, 1969) mapped the Quartermaster, Alibates, and Whitehorse as an undivided formation. The most recent study seems to be one by Rascoe and Baars (1972, p. 144). They placed the Quartermaster, Alibates, and Whitehorse in the Guadalupian Series but did not state the reasons for doing this.

The stratigraphic classification of the Panhandle of Texas is still in a state of flux today. Most of the geologists I talked with during my study of the area and most of the more recent papers I have read agree that: 1) the Alibates is stratigraphically equivalent to the Day Creek, 2) the Alibates-Day Creek is a thin formation between the underlying Whitehorse and overlying Quartermaster formations, and 3) the three formations are probably separated by unconformities. After my limited observations from both ground and air throughout the Texas Panhandle and north-

	Eastern New Mexico and western Texas	Northern Panhandle of Texas	Western Oklahoma	Southern Kansas
Ochoa	Dewey Lake	Quartermaster?		
	Rustler	Alibates?		
	Salado			
	Castile			
Guadalupe	Tansill	Quartermaster	Quartermaster	Big Basin
	Yates	Alibates	Day Creek	Day Creek
		Whitehorse	Whitehorse	Whitehorse
	Seven Rivers			

Figure 6. Correlation of Upper Permian rocks in New Mexico, Texas, Oklahoma, and Kansas (modified after Dunbar, 1960, and Rascoe and Baars, 1972).

western Oklahoma, I agree with these three points. The age of the formations, however, is still a very speculative matter. The prevailing current opinion is to consider the Alibates and Quartermaster as Guadalupian (DeFord, 1975).

LOCAL

The formations exposed in the study area include the Permian Whitehorse, Alibates, and Quartermaster formations, and the Tertiary (Pliocene) Ogallala Formation (fig. 7). Because the Whitehorse, Quartermaster, and Ogallala are not present or not exposed at all localities, they are not considered a part of the measured sections. At some places, however, distinct characteristics were noted, and a few samples were collected.

Whitehorse Formation

The Whitehorse Formation consists of a thick interval of red beds that forms the steep slopes beneath the resistant Alibates. At most localities, only a few meters are exposed, but at Harbor Bay (MS M-2) more than 45 meters of the Whitehorse are exposed. This section consists of red to brown mudstone and silty sandstone interrupted at a few places by thin (1-2 m) beds of white gypsum or slightly more resistant red sandstone. The upper 3 meters of the section are gypsiferous or calcareous at some places; the uppermost 10-50 centimeters commonly change to green and gray mudstone immediately beneath the Alibates. The Whitehorse/Alibates contact is marked by distinct change in lithology. At places where the Alibates has been undermined, the lower surface of the dolomite is gently undulating.

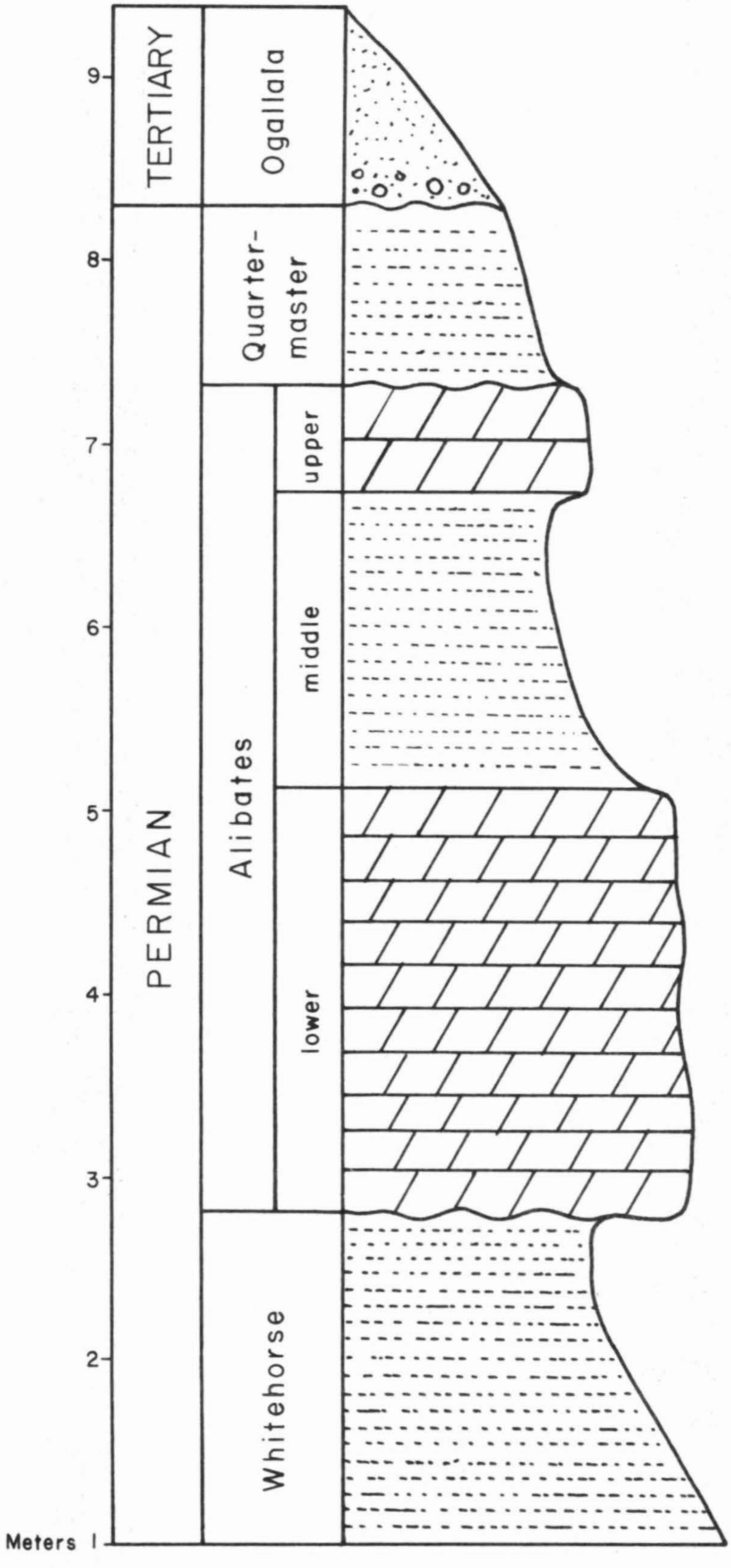


Figure 7. Generalized stratigraphic column of rocks exposed in study area showing relative resistance to weathering.

Alibates Dolomite

Because most geologists consider the Alibates Dolomite as a formation, it is herein subdivided into three informal members: lower and upper gray dolomite separated by an interval of calcareous red beds. Gould's (1907) type section of the Alibates is near the intersection of Alibates Creek and Cas Johnson Road (MS P-8) in Potter County. All three members are well exposed at this locality. Other good exposures of the formation are at Harbor Bay (MS M-2) and at North Cas Johnson Road (MS P-7).

Lower member.--The best exposure of the lower member is along Alibates Creek (MS P-8). The dolomite is also well exposed at Milligan quarries (MS P-2), Harbor Bay (MS M-2), and Sanford Dam (MS H-3). The dolomite generally ranges in thickness from 1 to 3 meters with an average thickness of about 2.5 meters. It is thickest in the western part of the study area (Potter County) and thins to the east. The lower dolomite is resistant to weathering and forms prominent ledges. The member is distinctly laminated at most places; weathering usually accentuates the laminae and may produce a rough, washboard-like surface. The upper 10-30 centimeters of the lower dolomite are commonly gradational into the overlying middle red-bed member. The contact is arbitrarily placed at the lithologic change from dominant white dolomite to dominant red mudstone.

Middle member.--The middle member is well exposed at Alibates Creek (MS P-8), Harbor Bay (MS M-2), and Sanford Dam (MS H-3). The red-bed sequence is relatively uniform in thickness and averages 1.5 meters. Lithology is chiefly red to maroon, calcareous mudstone. Bedding or lamination is not readily apparent at most localities, but the mudstone may grade into fissile shale at a few places. The contact with the upper dolomite is arbitrarily placed at the lithologic change from red mudstone to gray dolomite. The contact is marked by a sharp break in topography.

Upper member.--The most representative outcrop of the upper member is probably at Bugbee Creek (MS H-2). Other excellent exposures are at Lake Lee (MS P-1) and at Alibates Creek (MS P-8). The upper dolomite averages 60 centimeters thick and is locally absent. It is generally laminated or intensely brecciated and fractured. The dolomite is not as resistant to weathering as the lower member mainly because of this brecciation and fracturing. Like the lower dolomite, the upper dolomite thins eastward. The upper contact of the Alibates is unconformable with overlying rocks.

Chertification and calcitization have occurred sporadically in both upper and lower dolomite members. Chert and calcitized dolomite commonly occur next to each other but are rarely present in mixed assemblages. Chertification is best developed in the Alibates National Monument (MS P-9) where the upper dolomite has been completely replaced by chert. Calcitization seems to be most extensive at McBride Canyon (MS P-6).

Quartermaster Formation

The Quartermaster Formation unconformably overlies the Alibates at some localities. In the field the Quartermaster is extremely difficult to distinguish from the Whitehorse except by stratigraphic position. It is possible that, at places where the Alibates has been eroded, the Quartermaster lies directly on the Whitehorse but has not been recognized. There is little difference petrographically between the Quartermaster and

Whitehorse, however, the Quartermaster may contain more clay and mica than the Whitehorse. The thickest section of Quartermaster was found at Bugbee Creek (MS H-2) where about 7 meters of the formation are exposed above the Alibates. The section consists entirely of maroon mudstone and silty sandstone.

Ogallala Formation

All Permian formations are unconformably overlain by the Pliocene Ogallala Formation. The Ogallala is easily distinguished from other formations by its light brown to buff color and by its conglomerate lithology. Although no thick sections of Ogallala are present in the main part of the study area, it is the Ogallala that caps most of the southern Great Plains. The formation consists locally of carbonate-cemented sandstone and sandy conglomerate. Caliche deposits are well developed at some localities within the study area (Brown, 1956). Opalization has occurred sporadically in the formation and is similar to chertification in the Alibates (Harlow, 1974). At most places along the Canadian River valley where the Ogallala has been removed and the Alibates caps the bluffs, Ogallala sand has filtered down into fractures in the underlying rocks, and Ogallala pebbles and cobbles have been left behind to partially mask the Permian strata.

P E T R O G R A P H Y

CLASSIFICATION OF ROCK TYPES

Folk's (1974) classification of sedimentary rocks is used in this study. Carbonate rocks are composed of more than 50 percent carbonate minerals, and terrigenous rocks are composed of more than 50 percent terrigenous material. Carbonate rocks containing between 10 and 50 percent terrigenous material are sandy or muddy depending on the average size of the terrigenous material present. Folk (1974, p. 168) considered less than 10 percent terrigenous admixture in a carbonate rock as insignificant. This quantity is considered insignificant in this study also. Because terrigenous rocks are not a large part of this study, the classification for them will not be described (see Folk, 1974, p. 151-159).

Folk (1974, p. 166) has not provided a detailed classification of extensively recrystallized or replaced carbonate rocks. Therefore, arbitrary classifications have been developed for dolomite rocks that have been calcitized and/or chertified. I have attempted to develop classifications that are consistent, easy to use, meaningful, and descriptive. Geologic literature contains many descriptions of silicified limestone and dolostone, but contains few descriptions of calcitized dolomite (dedolomite). Any attempts to classify chertified or calcitized dolomite seem to have been avoided. To the best of my knowledge, no one has described the occurrence of both chertification (silicification) and calcitization (dedolomitization) within the same lithologic unit. This may be because such a unit has not been found, or because the processes have not been recognized in a single unit. Perhaps no one considered it important enough to classify chertified and calcitized rocks, but when these rock types constitute a large percent of all samples examined, the need to develop a classification becomes apparent.

Smit and Swett (1969, p. 379) reported that the term "dedolomitization" was first used by Von Morlot in 1848 to identify the process of dolomite being replaced by calcite. The term has remained in use to this day in geologic literature; however, geology has advanced to a level where the use of the term "dedolomitization" should be reconsidered. Swett (1965, p. 935) and Smit and Swett (1969, p. 379) listed their objections to the use of the word, namely: 1) The term is inconsistent with accepted nomenclature. If all reversible replacement processes were named accordingly, one would see terms such as "desilicification," "depyritization," and others. Dedolomitization is the only process named for the host mineral rather than the replacing mineral. 2) The term is ambiguous. Dedolomitization means removal of dolomite. Other minerals such as silica or phosphate can replace dolomite. The word only implies replacement by calcite. 3) The term is geochemically misleading. De Groot (1968, p. 1220) demonstrated that dedolomitization is not removal of dolomite, but removal of magnesium leaving an excess of the carbonate radical, CO_3. Perhaps the process is better described as "demagnesitization" (Smit and Swett, 1969, p. 379).

I agree with Smit and Swett's objections to the use of the word "dedolomitization" and add another objection to the list. The names of several samples of Alibates would be awkward and confusing if dedolomitization or other forms of the word were used. Rocks would have names such as "dedolomitized dolomite," "dedolomitic dolomite," or "dolomitic dedolomite." In place of dedolomitization, the term "calcitization" has been proposed by Swett (1965, p. 936) and Smit and Swett (1969, p. 380) to denote the process of calcite replacing dolomite. Although calcitization can also refer to calcite replacing other minerals, the calcite-after-dolomite usage of the word is applied in this thesis.

There are problems in developing a classification for calcitized dolomite rocks. Calcite occurs both as pore-fill spar and as dolomite replacement spar; however, because the amounts of pore-fill spar are generally insignificant, no differentiation is made between these two types of calcite for purposes of classification. Any dolomite rock containing 5 to 9 percent calcite is partly-calcitized dolomite. Rocks containing 10 to 50 percent calcite are calcitized rocks. In order to indicate that calcite has replaced dolomite, dolomite rocks containing 51 to 95 percent calcite-after-dolomite spar are dolomitic calcitized limestones. A rock of more than 95 percent dolomite replacement calcite is a calcitized limestone (fig. 8).

Dolomite Percent	Rock Name	Replacement Calcite Percent
0		100
	Calcitized Limestone	
5		95
	Dolomitic Calcitized Limestone	
50		50
	Calcitized Dolomite	
90		10
	Partly-calcitized Dolomite	
95		5
	Dolomite	
100		0

Figure 8. Classification of calcitized dolomite rocks.

Any carbonate rock containing 5 to 9 percent chert is a partly-chertified rock. Rocks comprised of 10 to 50 percent chert are chertified rocks. Impure cherts contain between 51 and 95 percent chert. Rocks containing more than 95 percent silica are considered pure cherts (fig. 9). Pure cherts are not divided into varieties such as flint, agate, and jasper. The term "silicified" is not used in this classification because its usage in geologic literature seems to imply a primary source of silica such as sponge spicules. Although the source of silica for the Alibates is uncertain, the origin of the chert clearly appears to be secondary rather than primary. Chertification is used to imply a replacement origin.

Dolomite Percent	Rock Name	Chert Percent
0		100
	Chert	
5		95
	Dolomitic Chert	
50		50
	Chertified Dolomite	
90		10
	Partly-chertified Dolomite	
95		5
	Dolomite	
100		0

Figure 9. Classification of chertified dolomite rocks.

DOLOMITIC ROCKS

Folk's (1974, p. 168) grain size classification for crystalline dolomite is used in this study. The crystal size is measured across the longest diagonal or diameter of each crystal. If crystals of a given size range do not constitute more than 5 percent of a rock, the crystal size is not used in the rock name.

Crystal size generally ranges from 5 to 180 microns and averages 40 microns. Any one thin section usually shows all size intervals with either finely crystalline or medium crystalline dolomite predominating. The dolomite grains are commonly anhedral to subhedral, but some euhedral crystals have developed around cavity perimeters. A few of these euhedral crystals are possibly twinned or zoned. Much of the dolomite is a homogeneous mosaic of grains with concavo-convex to sutured contacts.

Textures displayed by the dolomite in thin section include mottled or grumeleuse and porphyroid fabrics similar to Folk's (1974, p. 182) porphyroid neomorphism. This fabric is characterized by patchy concentrations or wisps of large crystals dispersed throughout the matrix of small crystals. Lamination is the most common texture in the dolomite with laminae commonly ranging in thickness from 0.1 to 1.0 millimeter and averaging about 0.3 millimeter. Much lamination is due to changes in crystal size, but in some thin sections, lamination is distinguished by: 1) faint wisps of crystal clouding, 2) concentrations of opaque or terrigenous minerals, and 3) iron oxide staining. In a few slides, the laminae are broken and appear to be microfaulted and brecciated; however, laminae in many of the lithoclasts are curved suggesting possible desiccation. Some dolomite crystals seem to be broken or shattered in brecciated laminae. Part of the very finely crystalline fraction may be fragments from larger crystals.

Most of the dolomite is weathered and appears "moth-eaten." The crystal surfaces are pitted or dimpled and may be covered with weathered or organic residues which cloud the dolomite. Generally only the smaller crystals are clouded, and in some concentrations of very finely crystalline dolomite, the clouding obscures crystal boundaries. Laminae of larger dolomite grains are usually more porous than laminae of smaller grains. Cavities may be as large as 1.0 millimeter, and porosity in some thin sections is as much as 30 percent. Less than 5 percent of the porosity is due to fractures or partings.

CALCITIC ROCKS

Calcite occurs in almost half of the thin sections examined. Using Folk's (1974, p. 168) classification for crystal size, the crystals are predominantly medium crystalline. Other crystal sizes of calcite seem to be rare in the Alibates. Calcite in the Alibates occurs as: 1) pore-fill spar, 2) dolomite replacement spar (dedolomite), and 3) sparry cement.

Spar-filled Vugs and Fractures

As pore-fill spar, the calcite is medium to coarsely crystalline and generally has straight crystal boundaries and distinct rhombohedral cleavage. Crystals are best developed in large cavities, whereas subhedral to anhedral crystals are more common in fracture fillings. Pore-fill calcite spar is present in both dolomite and chert-lined cavities.

Calcitized Limestone

Calcite spar which has replaced dolomite (dedolomite) is common in several thin sections of Alibates Dolomite. Most of this spar is similar to the dedolomite pseudospar described by Moore (1971, p. 371), but is different from Folk's (1965b) recrystallized pseudospar. The recognition of replacement spar from pore-fill spar or recrystallized spar (pseudospar) can be difficult and is certainly subjective. Many of Bathurst's (1971, p. 484-490) criteria, in addition to the presence of remnant dolomite crystals in the spar, can be used to differentiate replacement spar from neomorphic and psuedospar.

Replacement spar is the predominant type of calcite in the Alibates; it constitutes more than 80 percent of the calcite counted. Most dolomite-replacing spar is medium crystalline with subordinate amounts of finely crystalline spar. Crystal shape is extremely variable and ranges from almost circular or equant to very elongate. In some thin sections, the crystals form a mosaic of two distinctly different size groups. Crystal boundaries range from slightly curved to sutured. Individual crystals and crystal aggregates of very finely to finely crystalline dolomite are disseminated throughout the spar matrix. These crystals of dolomite commonly give the spar a cloudy or pitted appearance. Blebs of opaque minerals and iron oxides dot the spar in many slides.

Spar-cemented Sandstone

At places where the Ogallala is in contact with the Alibates, wide fractures in the Alibates are filled with Ogallala calcitic sandstone. Thus, sparry calcite cement does not occur in the Alibates as such, but has been mobilized from the overlying Tertiary Ogallala Formation. In slide P-3-L, the calcite comprises 36 percent of the thin section and is finely to medium crystalline spar cement among the "floating" sand grains.

CHERT ROCKS

The word "chert" is used carelessly by many geologists and, to some, the word is nothing more than a "garbage can" name for any highly siliceous rock. Whether a rock is igneous, metamorphic, or sedimentary, chert is a handy name to use. To a sedimentary petrographer, however, the definition of chert is very restrictive. Folk (1965a, p. 80) defined chert as:

> ...a chemically-precipitated sedimentary rock, essentially monomineralic and composed chiefly of microcrystalline and/or chalcedonic quartz, with subordinate megaquartz and minor amounts of impurities.

This definition is used in this study, and the following types of authigenic quartz (chert) are recognized:

Megaquartz: equant to elongated grains larger than 35μ.

Microcrystalline quartz: equant grains which commonly form pinpoint-birefringent aggregates, smaller than 35μ.

Chalcedonic quartz (chalcedonite): radiating fibers, length-fast, extinction parallel to fibers.

Quartzine: fibrous, length-slow, extinction parallel to fibers.

Lutecite: pseudofibrous, length-slow, oblique extinction.

McBride and Thompson (1970, p. 46) modified Folk's (1965a, p. 80) chert classification by changing the arbitrary, larger size limit of microcrystalline quartz from 20 to 35 microns, and subdivided microcrystalline quartz into coarse-, medium-, fine-, very fine-, and ultra fine-grained size ranges. Petrographically, there is a distinct difference in the appearance of megaquartz and microcrystalline quartz, although the forms may be transitional. In thin sections of Alibates rocks, much of the quartz has the pinpoint-birefringent characteristic of microcrystalline quartz, but the crystal aggregates are larger than 20 microns. There seems to be a more natural division of megaquartz and microcrystalline quartz at 35 microns than at 20 microns; therefore, McBride and Thompson's size classification is used.

Megaquartz

Megaquartz occurs in more thin sections of Alibates than any other type of chert. The anhedral to subhedral crystals are equidimensional to elongated and generally range in size from 35 to 200 microns. The average size is about 40 microns. The megaquartz occurs as clusters of crystals which fill some cavities in the dolomite and microquartz. The crystals generally have smooth to concavo-convex boundaries.

The absence of inclusions is a noticeable characteristic of most of the megaquartz, however, clasts of the surrounding carbonate are found in a few crystals. Opaque minerals are sandwiched between crystals in a few clusters. The megaquartz is generally clear but may be lightly stained by iron oxide in some thin sections.

Another distinguishing characteristic of megaquartz is straight extinction. Aggregates of two or more crystals may have the appearance of a large composite detrital quartz grain with each sub-individual having straight extinction. Folk (1974, p. 73) reported that in a composite grain, each sub-individual has a different optical orientation; however, in megaquartz aggregates, all sub-individuals tend to show nearly the same optical orientation. This optical continuity is another criterion that can distinguish megaquartz from composite quartz grains.

Microcrystalline Quartz

Microcrystalline quartz is the most abundant type of chert in thin sections of Alibates rocks. Distribution of grain sizes varies with each slide, but generally all sizes are present in any one thin section. No distinction is made between very fine and ultra fine sizes because the optical limits of the microscope do not readily permit it, and the differentiation of such a small size is considered insignificant to this study.

In thin section, microcrystalline quartz occurs as: 1) veinlets, 2) cavity or fracture linings, 3) cavity or fracture fillings, and 4) masses of complete replacement of carbonate. As veinlets in the carbonate, the quartz is generally fine to medium grained. The veinlets commonly appear to be the advance "feelers" of a massive replacement front or stringers from a fracture fill. As cavity or fracture linings, the fine- to coarse-grained quartz generally forms colloform bands around the void. Iron staining commonly accentuates the colloform structure. Cavity or fracture fillings are ultra fine- to coarse-grained microcrystalline quartz that usually grades into megaquartz or chalcedonite. In thin sections of massive chert samples the quartz is predominantly very fine to fine grained. Alternating bands of very fine- and fine- to medium-grained quartz occur in a few slides of massive chert rocks. These bands average 0.2 to 0.3 millimeter wide and are wavy or wispy. Iron oxide staining and trace concentrations of opaque minerals vary from band to band. At dolomite-chert contacts, bands in the chert are continuous with laminae in the dolomite.

Chalcedonite

Chalcedonite (chalcedonic quartz) occurs primarily as a cavity or fracture filling; however, it also exists as a cavity or fracture lining and less commonly in a vein or cement-like habit. Fibers may be as long as 1.0 millimeter. Folk (1974, p. 80) set an arbitrary short-length limit of 20 microns, but a shorter fibrous structure can be recognized in many thin sections. Chalcedonite fibers shorter than 20 microns were counted as microcrystalline quartz.

The fibrous structure of chalcedonite under crossed nichols is distinctive and can be beautiful. The fibers are length-fast and form radiating bundles that have been compared to a fan of feathers, a squirrel's tail, or a peacock's tail. The longest fibers occur in the largest cavity fillings. In slide P-9A-F5 the fibers have formed complete circles (spheres?) within a cavity. As a cavity or fracture lining, the fibers radiate from points along the wall and are generally normal to the wall. The result is a colloform structure which is commonly outlined by iron oxide staining. Where a void is both lined and filled with chalcedonite, the fibers may transgress the colloform lining and show a completely different arrangement.

Quartzine and Lutecite

Quartzine and lutecite are the least common varieties of chert in Alibates thin sections. Unlike the other types of chert, quartzine and lutecite rarely occur with the other varieties. The size range of these varieties is approximately the same as chalcedonite. Quartzine and lutecite are considered together because they are transitional and are generally difficult to tell apart. They both appear to have a fibrous structure identical to chalcedonite, but the fibers are length-slow rather than length-fast. Quartzine fibers have parallel extinction like those of chalcedonite, but lutecite is pseudofibrous. These pseudofibers have oblique extinction and are commonly shorter and less distinct than quartzine or chalcedonite fibers.

These two types of length-slow chert are present as cavity linings and as small nodules or beads disseminated throughout the dolomite. The nodules or beads average about 1.0 millimeter in diameter and, in hand sample, have the appearance of BB shot peppered into the rock. Most of the beads do not have any particular shape and many display concentric bands of staining. Under crossed nicols, these bands are distinct layers of quartzine-lutecite with different fiber length and orientation. Where there is no iron oxide staining, the clear quartzine-lutecite may exhibit flowlike lines which bend around carbonate crystals and parallel cavity perimeters.

ACCESSORY MINERALS

Quartz

Detrital quartz is present in many thin sections of the Alibates. The quartz grains range in size from 5 to 600 microns; however, most slides contain grains of only one size group such as very fine sand or medium silt. Distribution of detrital quartz ranges from scattered single grains to lenses in the dolomite to homogeneous masses in the red-bed sandstone or mudstone.

The shape of the grains ranges from equant to very elongate, and most of the grains are angular to subrounded. Sorting is very poor. The predominate grain size in most slides seems to be very fine sand, followed by minor quantities of silt and fine to medium sand. A textural inversion exists in slides M-1-7 and M-1-8 where the quartz is subangular, subequant silt and rounded coarse sand.

Types of quartz include common (plutonic), volcanic, vein, recrystallized metamorphic, and stretched metamorphic. Common quartz probably accounts for at least 99 percent of all detrital quartz counted; the other types comprise the remaining 1 percent. Some quartz grains show signs of solution or have overgrowths. This alteration of grains occurs chiefly in sandy or silty fracture fillings in the dolomite (slide P-2A-2b). A few grains show possible recrystallization (replacement?) into fibrous chert around grain borders and other grains are partly cemented with chert. Most grains examined in thin section appear to be relatively fresh rather than pitted, fractured, or abraded.

Feldspar

Feldspars comprise no more than 3 percent of all detrital silt and sand grains. Size and shape are the same as the quartz, although feldspar is more easily identified in the larger sizes. Feldspar seems to be more abundant in the upper dolomite member and in fractures filled with Ogallala. Orthoclase is the predominant type of feldspar present and accounts for at least 97 percent of all feldspar counted. Microcline ranks next in abundance at almost 3 percent. Plagioclase (types not determined) and possible sanidine are present in trace quantities. Most of the feldspar shows little alteration or weathering.

Mica

Biotite and muscovite are found in many thin sections, but rarely account for more than 1 percent in any one slide. Most flakes are small and average 10-50 microns long. Mica commonly occurs in the silt or sand lenses in the dolomite or in mud clasts in the red beds. It is also present in some chert samples where it appears to have been trapped in cavities or detritus lenses before chertification. The mica appears weathered or altered in most thin sections. In slides of red beds, much of it has been altered to clay and may form a micaceous hash. In some thin sections of dolomite, biotite seems to be in various stages of alteration or weathering. As an end-stage, only a green stain remains, giving a glauconite-like appearance to some carbonate grains.

Clay

Types of clay were not determined because only minor amounts occur in Alibates rocks. Most of the terrigenous rocks examined contain less than 5 percent clay-size material, some of which may be micaceous hash or ferruginous carbonate. In a few thin sections of dolomite, clay-size material is concentrated in cavities, fractures, and some laminae. It is commonly associated with opaque minerals and possible organic material.

Opaque Minerals

Opaque minerals are abundant in the Alibates dolomite and chert. The dolomite commonly appears as if it has been sprinkled with pepper. This appearance is due to minute black specks occurring throughout the rock. Although not as obvious in the chert as in the dolomite, the black specks seem to be present in most parts of the Alibates. In thin section, the black specks are irregular-shaped blebs which generally range in size from 5 to 150 microns. These opaque specks are commonly concentrated along laminae or in and around cavities and fractures.

Patton's (1923, p. 39-40) chemical analyses indicated that the black specks were manganese oxide. Results of chemical analyses for this study also show the presence of manganese along with iron (table 1). Most of the opaque specks are pyrolusite and display a microdendritic form in some thin sections. Some blebs are blood red to yellowish brown and are obviously iron oxides. With all the intermediate colors and lusters present, it is logical to assume that many of the opaque specks are mixtures of iron and manganese oxides.

Iron oxides are present in most thin sections as red, brown, and yellow stains. Coloration is most common in chert samples where the staining usually accentuates relic lamination and colloform vug linings. In slides P-4-6b (Ogallala) and M-1-8 (Quartermaster), the oxides cement sand grains to form a ferruginous sandstone.

Trace quantities of other opaque minerals such as magnetite, pyrite, and possibly graphite were found in a few thin sections, but these minerals are part of the detrital sand and silt fraction of red-bed samples. Ilmenite and leucoxene were suspected in some dolomite samples, but chemical analyses showed no titanium present in the dolomite.

Other Minerals

The only other minerals present in the Alibates are apatite and zircon. Apatite is present in trace quantities as a part of the terrigenous fraction. Zircon occurs as microlites in detrital quartz grains. Other heavy minerals such as tourmaline or rutile could be present but were not identified in thin section. Magnesite could occur in dolomite samples that have been extensively calcitized. This was suggested by Powell (1975) after examination of several Alibates thin sections. A few carbonate crystals with brown edges and high relief could be ankerite, but high concentrations of iron oxide and small crystal size (less than 10 microns) make identification only speculative. Other minerals may be suggested by chemical analyses.

ORGANIC(?) CONSTITUENTS

According to available published reports, no fossils have been found in the Alibates Dolomite. After examination of many outcrops and 101 thin sections, evidence has been found that suggests certain organisms may be preserved in the Alibates. Presence of fossil organisms is only <u>suggested</u> because dolomitization, calcitization, chertification, and many other processes have probably destroyed any fossils that may have once existed. Hence only fossil ghosts survive, and true identities remain hidden in mysteriously clouded dolomite.

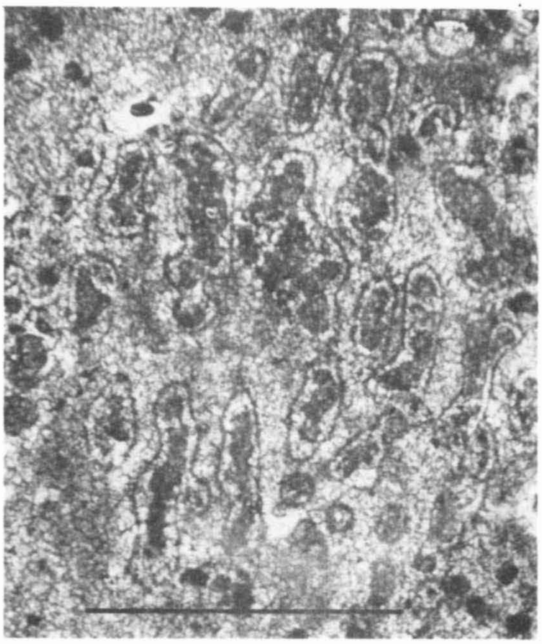
The smaller sized dolomite crystals are commonly clouded. This clouding is generally concentrated in laminae which alternate with clearer, coarser crystalline dolomite laminae. If the clouding of the crystals is caused by organic residues, repetitious (seasonal?) cycles may be implied. Possible algal structures are present in slides H-3-6, H-3-7, and C-1-4. These structures occur in certain laminae and could be the remains of algal mats. The general shape of the structures suggests the presence of individual filaments that are approximately 0.5 millimeter long and 0.1 millimeter wide (pl. 1). The structures are commonly filled with coarser crystals and are outlined by smaller, clouded crystals. Orientation is generally normal to bedding surfaces, and there is slight grading of crystal size throughout the length of the structures.

Some thin sections (P-2-1, P-2A-5, P-7-3, and others) contain possible organic pellets. They are small (average 40 microns), structureless, and uniform in size and shape. All are circular or slightly elliptical and appear as round, clouded blebs of very finely crystalline dolomite. These blebs are generally concentrated along certain laminae, although a grumeleuse texture is developed in a few slides. Dark clouding of the blebs suggests the presence of organic material. Textures are similar to those described and illustrated by Beales (1965) for pelleted limestones.

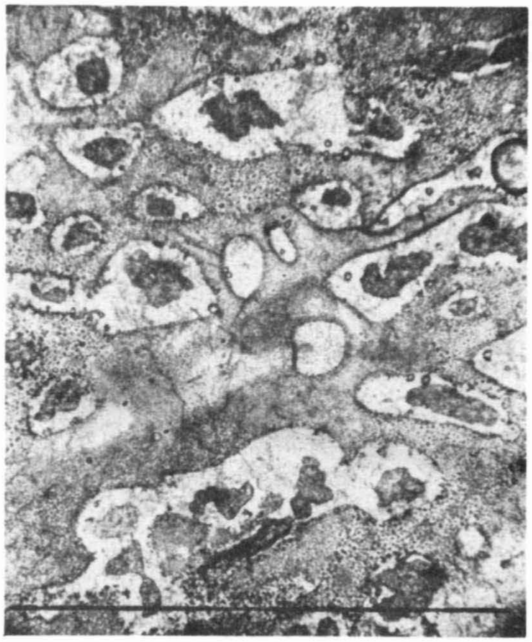
Elliptical structures ranging in size from about 0.5 to 2.3 millimeters were observed in the clouded, finely crystalline carbonate matrix of slides G-1-5a and G-1-5b (pl. 1). The objects are outlined by a thin rim of dark gray amorphous material and are generally filled with coarser crystalline carbonate or chert. McNulty (1975) and Powell (1975) have both suggested that these structures could have once been ostracods.

CHEMICAL ANALYSES

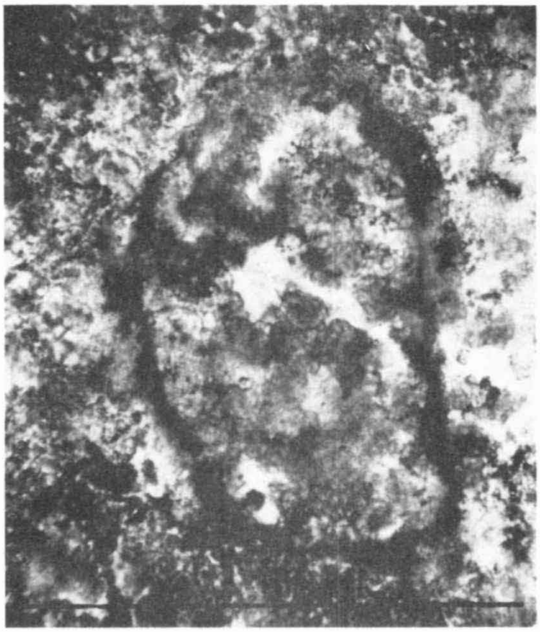
Fifteen samples of Alibates dolomite and chert were chemically analyzed by the Mineral Studies Laboratory, Bureau of Economic Geology, The University of Texas at Austin. Samples for analysis were chosen to obtain the best geographical distribution over the outcrop area and the most typical or representative rock types from each measured section. The objective of the analyses was to find out if any unusual elements or



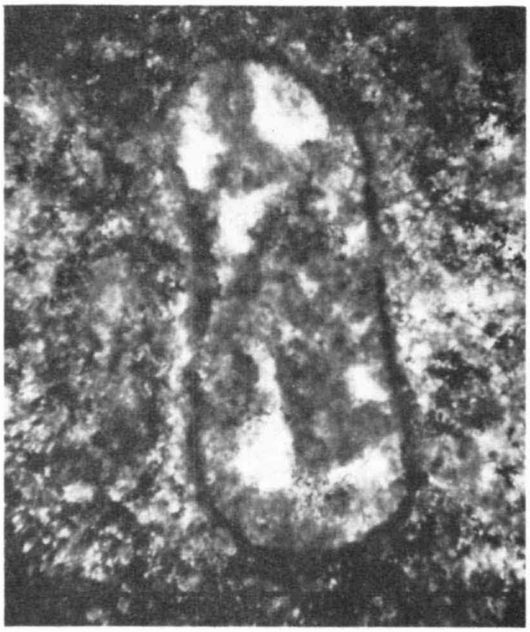
A. Algae, slide H-3-7.



B. Algae, slide C-1-4.



C. Ostracode, slide G-1-5b.



D. Ostracode, slide G-1-5b.

Plate 1. Possible fossils in the Alibates Dolomite.
Photomicrographs: scale = 1.0 millimeter.

elemental relationships exist in the dolomite and chert. Two chert, one upper dolomite, and two lower dolomite samples were selected from the Alibates National Monument. Eight more samples of the lower dolomite were picked to give the widest possible geographic coverage. The lower dolomite was used because it is more continuous over a large geographic area, whereas the upper dolomite is absent at some places. Two samples of the upper dolomite were randomly chosen to complete the limit of 15 samples.

The samples were analyzed by chemical, semiquantitative spectrochemical, and qualitative spectrochemical methods. Elements analyzed for included: aluminum, calcium, iron, gallium, germanium, magnesium, manganese, nickel, silicon, strontium, and titanium. Results are shown in table 1. Total iron content is reported as ferric oxide; ferrous and ferric iron were not differentiated because the total iron content did not exceed 0.3 percent in any of the samples.

Several conclusions or assumptions can be inferred from the analyses. Chert samples (P-9-F1 and P-9A-F1) are relatively pure silica and contain no unusual impurities. Calcium and magnesium are expected "leftovers" from the dolomite. Colors in the chert are easily attributed to aluminum, iron, titanium, and manganese. It is interesting, however, that the manganese concentrations are much lower in chert than in dolomite. This suggests that many of the opaque minerals in the chert are iron and titanium oxides rather than manganese oxides. Iron concentrations are generally higher in silica-rich samples (P-2-F1, P-9-F1, and P-9A-F1) than in other samples thus agreeing with thin section observations that chert is commonly stained by iron oxides.

A "true" dolomite would consist of 54.26 percent calcium carbonate and 45.74 percent magnesium carbonate by weight which gives a calcium/

Sample	Member	Al_2O_3	CaO	Fe_2O_3	MgO	MnO_2	SiO_2	SrO	TiO_2	H_2O	Ig.Ls.	Total
P-1-6	Upper	0.150	30.200	0.060	20.500	0.060	1.590	tr	0.000	0.240	46.890	99.690
P-2-3	Lower	0.150	30.100	0.100	21.300	0.080	0.850	tr	0.000	0.160	47.130	99.870
P-2-F1	Lower	0.150	20.100	0.200	13.900	0.055	33.500	tr	0.000	0.230	31.440	99.575
P-4-4	Lower	0.250	31.400	0.080	19.400	0.150	1.850	tr	0.000	0.190	46.070	99.390
P-9-4	Lower	0.150	30.000	0.120	20.900	0.060	1.180	tr	0.000	0.180	46.780	99.370
P-9-9	Upper	0.250	52.800	0.070	1.500	0.120	2.160	tr	0.000	0.190	42.080	99.170
P-9-F1	Upper	0.200	0.130	0.195	0.020	0.003	98.100	0.000	0.015	0.230	0.940	99.833
P-9A-1	Lower	0.200	29.700	0.130	21.000	0.025	1.910	tr	0.000	0.240	45.980	99.185
P-9A-F1	Upper	0.200	0.130	0.140	0.020	0.007	98.300	0.000	0.020	0.390	1.030	100.237
M-2-3	Lower	0.250	29.500	0.110	21.200	0.060	2.280	tr	0.000	0.180	46.250	99.830
M-2-5	Upper	0.250	26.700	0.080	19.900	0.040	12.900	tr	0.000	0.210	39.770	99.850
H-5-2	Lower	0.150	35.500	0.090	15.800	0.060	2.260	tr	0.000	0.160	45.420	99.440
H-10-2	Lower	0.150	29.900	0.090	21.100	0.045	1.180	tr	0.000	0.190	46.870	99.525
C-1-2	Lower	0.200	29.500	0.120	21.100	0.060	1.460	tr	0.000	0.180	46.250	98.870
D-1-4	Lower	0.050	24.200	0.050	17.400	0.075	17.000	tr	0.000	0.210	38.960	97.945

Table 1. Chemical analyses of selected Alibates dolomite and chert samples (Mineral Studies Laboratory, Bureau of Economic Geology, University of Texas at Austin, 1974). Ig. Ls.=Ignition Loss.

magnesium ratio of 1.186. The calcium/magnesium ratios of dolomite samples range from 1.341 to 2.246 indicating an excess of calcium in all samples (table 2). These results also agree with thin section observations. Excess calcium would be expected in dolomite that contains cavity-filling spar or has been calcitized (or, perhaps never completely dolomitized?).

Aluminum content is relatively constant in the dolomite and chert samples. Although aluminum concentrations are generally higher than iron and manganese, no aluminum minerals were recognized. The aluminum most likely exists in clay minerals and as hydrous oxides. Hydrous aluminum oxides could account for some of the staining attributed to iron and manganese oxides.

Sample Number	Member	Percent CaO	Percent MgO	Ca/Mg Ratio
P-1-6	Upper	30.2	20.5	1.473
P-2-3	Lower	30.1	21.3	1.413
P-2-F1	Lower	20.1	13.9	1.446
P-4-4	Lower	31.4	19.4	1.618
P-9-4	Lower	30.0	20.9	1.435
P-9A-1	Lower	29.7	21.0	1.414
M-2-3	Lower	29.5	21.2	1.391
M-2-5	Upper	26.7	19.9	1.341
H-5-2	Lower	35.5	15.8	2.246
H-10-2	Lower	29.9	21.1	1.417
C-1-2	Lower	29.5	21.1	1.398
D-1-4	Lower	24.2	17.4	1.390

Table 2. Calcium and magnesium concentrations and calcium/magnesium ratios of Alibates Dolomite samples.

P E T R O G E N E S I S

Although the term "petrogenesis" is commonly used in reference to igneous rocks, it is applied in this thesis in its broadest sense -- the origin and formation of rocks. Perhaps some would prefer to use the term "lithogenesis" because this is a study of sedimentary rocks. On the other hand, possibly the best word to use is simply genesis. This simple word looks even better when one realizes the conflicts involved in the definitions of diagenesis, syndiagenesis, anadiagenesis, epigenesis, and many other forms of the word "genesis." With simplicity and clarity of understanding as objectives, the following topics will be discussed in this section: 1) the depositional environment of the Alibates, 2) calcitization of the dolomite, and 3) chertification of the dolomite.

ENVIRONMENT OF DEPOSITION

It is difficult to describe the sedimentary environment of a dolomite when the time of dolomitization is not known. Naturally, the intent here is to describe the depositional environment of the carbonate rock unit; the dolomitization process will be discussed later. Fitting the local environmental indicators into a regional picture is not without problems. Regional stratigraphic correlation of the Alibates is uncertain, and possible lithologic changes in the subsurface are suggested by a few well logs. Because of these and other problems, the environment is inferred primarily from local rock characteristics.

Regional Paleogeography

Many papers have been written about the Permian paleogeography of the southwestern United States, but in most studies, the area is confined to the well-known Permian strata of western Texas and southeastern New Mexico. Gould and Lewis (1926) reported on paleogeographic interpretations for the Permian of Oklahoma, and there are a few general papers on Kansas. Once again, the Texas Panhandle has been generally ignored.

Hills (1942, 1963, and 1972) constructed a series of paleogeographic maps of western Texas and eastern New Mexico which may be projected to include the Panhandle area. According to these maps, during early and middle Permian, marine seas covered most of the Panhandle and western Texas. The Amarillo Mountains, which had been a source of sediments for the Anadarko and Palo Duro basins for much of the Pennsylvanian, had been worn down and were now being covered by shallow marine carbonate deposits. According to Hills (1963, p. 1720), during late Permian the seas became more constricted and saline as they slowly retreated to the southwest. Lang (1937, p. 885) reported that the saline environment gradually migrated from Kansas, through western Oklahoma and the Texas Panhandle, and into western Texas. This migration is marked by progressively younger evaporite deposits to the south (Hills, 1963, p. 1720). Constriction and regression of the seas eventually turned most of the Texas Panhandle into a vast mudflat environment. Localized saline lagoons became sites of carbonate and evaporite deposition with red-bed deposition around the margins of the lagoons. Beds and lentils of evaporites and carbonates within the Whitehorse red beds are the deposits of this mudflat-lagoonal environment. Gould and Lewis (1926, p. 28) suggested that the Ancestral Rocky Mountains in New Mexico and Colorado furnished most of the sediments that are now Whitehorse strata.

The Alibates Dolomite represents the last, or one of the last, encroachments of a saline sea into the Panhandle of Texas during the Permian. The full geographic extent of this sea has not been completely determined, but outcrops and well logs suggest that it covered most of the northern part of the Texas Panhandle. Correlation of the Alibates with the Day Creek in Oklahoma and Kansas considerably increases the size of the sea. Adams (1935, p. 1016-1017) reported that the dolomite grades into gypsum in the subsurface to the east near the Texas-Oklahoma border; the gypsum grades back into dolomite (Day Creek) in Oklahoma and Kansas. Adams further stated that the Alibates also grades into gypsum and anhydrite in the subsurface to the south and may extend as far as the Midland Basin. Assuming that the dolomites, gypsums, and anhydrites are time equivalent, this lateral gradation of lithology suggests that the depositional sites of the Alibates and Day Creek dolomites may have been areas of slightly lower relief or the centers of shallow basins. Irwin (1965, p. 446) established a sequence of time equivalent, epeiric sediments in which dolomite is deposited seaward of evaporite. Although he applied his model primarily to ancient rocks, the same lithologic sequence has been observed in the modern sabkha of the Trucial Coast by Wood and Wolfe (1969). The evaporite between the Alibates and Day Creek may represent a shallower, shoal-like area that separated the Alibates and Day Creek carbonate "basins".

The section at Lake McClellan (G-1) in Gray County imples at least a local change in depositional environment. The lower dolomite, middle red beds, and upper dolomite have been thoroughly "mixed" with each other into a single interval of interlaminated dolomitic red beds and dolomite. The continuous influx of terrigenous sediments combined with a marked increase in organic material and possible fossils (ostracods?) suggests that this section may have been near shore, possibly near the site of a river delta. There is no evidence of evaporite in this section, and much of the carbonate is calcite rather than dolomite. A river emptying into the saline basin would provide the terrigenous sediments and could dilute the brine sufficiently enough to produce an environment hospitable to organisms. The absence of sedimentary structures such as cross bedding, and the fine grain size of the sediments imply that: 1) the mouth of the river may have been a considerable distance away, and currents carried the sediments to this site of deposition, or 2) the river was near base level and could no longer carry coarser-grained sediments. The latter may be favored by the other environmental indicators which all suggest that the entire Texas Panhandle was a large, flat region. No other Alibates outcrops of this "mixed" lithology were found.

The Alibates rock interval, dolomite-red beds-dolomite, certainly implies a transgressive-regressive-transgressive sequence. Because the upper dolomite and parts of the middle red-bed member have been eroded away at many places and are unconformable with overlying strata, one can only speculate that the last transgression (upper dolomite) was followed by a regression. The areal extent of the Alibates transgression-regression-transgression has not been determined.

Environmental Indicators

Compared to most carbonate rocks, the Alibates Dolomite is practically barren of paleoenvironmental indicators such as fossils and many diagnostic sedimentary structures. Perhaps the best indicator in the Alibates is the rock type: a finely crystalline carbonate with detrital quartz sand and silt. The only other dependable environmental indicators in the rock are lamination and brecciation; if other sedimentary structures were present at one time, they have been obliterated by diagenetic alteration. Until organisms can be found within the rock and can be positively identified, the source of the organic material will remain speculative at best.

Kendall and Skipwith (1968) studied a Persian Gulf lagoon, and later, Kendall (1969) related the study to interpretation of paleoenvironments of the Permian carbonates and evaporites of western Texas. Kendall's (1969, p. 2517-2519) description of lagoonal facies is very similar to the Alibates facies. Fine-grained laminated dolomite containing small quantities of quartz silt and sand is the chief rock type of the lagoonal facies. The relative absence of terrigenous clay in the fine-grained carbonates indicates that energy levels were high enough to winnow the clay out of the sediments; the lenses of silt and sand throughout the carbonate may have been concentrated by weak currents. Scattered individual quartz grains suggest that at least some of the silt and sand could have been blown or washed into the area by storms. Modern calcilutites have been described in Florida Bay, Persian Gulf, and several other places. Bathurst (1971) summarized many of these descriptions. Comparing the Alibates to these descriptions, the grain size distribution and mineral associations are most indicative of a shallow lagoonal to tidal-flat environment.

Lamination is the most common and easily recognized sedimentary structure in the Alibates Dolomite. Both the upper and lower dolomites are laminated, but the laminae are usually more distinct in the upper dolomite. Wolf (1965), Friedman, Amiel, Braun, and Miller (1973), Gebelein (1969), Logan, Rezak, and Ginsburg (1964), Fischer (1964), and others have described and classified many occurrences of algal laminates. Lamination in the Alibates suggests an algal-mat origin. This origin was proposed by Smith (1963, p. 10-11). Laminae and pelletoid or granuloid textures of the Alibates are similar to the algal products described by Wolf (1965, p. 18-21) and Beales (1965). Possible algae are preserved in the upper dolomite, and suspected organic material is found throughout the upper and lower dolomites. Shearman and Skipwith (1965, p. 1310-1311) suggested that kerogen or organic matter of ancient carbonates is the derivative of algal secretions. These secretions are found in several modern and Pleistocene algal environments.

Sedimentary brecciation of laminae is common at many places in the Alibates and is especially characteristic of the upper dolomite. Geologists have described breccias in carbonate rocks but have suggested origins other than algal. Kendall (1969, p. 2518), in his study of Permian carbonates, observed breccias near contacts between supratidal evaporites and bedded dolomites. He attributed these breccias to solution of evaporites followed by collapse of surrounding carbonates into the void. Other carbonate breccias supposedly formed by solution of evaporites have been observed in Cretaceous rocks of Texas (Moore, 1971) and in Mississippian carbonates of Montana (Middleton, 1961). It is possible that some of the breccia in the upper dolomite had this origin. At some localities, the dolomite is overlain by gypsiferous red beds, however, the unconformable dolomite/red bed contact would suggest that some of the breccia was a result of reworking. On the other hand, the upper part of the dolomite could represent a regressive lithologic sequence to an evaporite and red-bed environment similar to parts of the Whitehorse Formation.

It is doubtful that most of the breccia in the dolomite (especially in the lower dolomite) is due to evaporite solution. Although the presence of quartzine and lutecite may imply that evaporites were once present, there is no evidence that evaporite minerals occurred in large enough quantities to produce the volumes of breccia in the Alibates. Gebelein (1969), Kendall and Skipwith (1968), Bathurst (1971), and several others have documented that desiccation of algal mats commonly produces a laminar breccia of mat fragments. Gebelein (1969, p. 66) reported that laminar brecciation also occurs in subtidal environments. The breccia consists of flat algal chips, but there is no evidence of desiccation. It is laminar brecciation that is most common in the Alibates. At some places, these breccias have been partly masked by recrystallization or dolomitization(?) of the carbonate, but they are especially well preserved in the chert. The lack of recognizable desiccation features may imply a subtidal environment.

A very common characteristic of the dolomite is laminae of organically(?) clouded, finer-grained dolomite alternating with laminae of clearer, coarser-grained dolomite. The coarser-grained laminae are usually quite vuggy; the finer-grained laminae have a very low porosity. The vugs are commonly less than 0.2 mm in longest dimension but may be as large as 5 mm. Shinn (1968) suggested that many vugs or birdseye structures in carbonate rocks are the result of gas bubbles and desiccation in a supratidal environment. Smaller, bubble-shaped cavities are formed by gas bubbles trapped in algal mats. Lenticular cavities elongated parallel to bedding planes are formed by desiccation. Both bubble-shaped and lenslike cavities are present in the Alibates. At a few localities, some of the cavities have been filled with length-slow chalcedony suggesting that evaporite crystals or nodules may have existed in the carbonate beds. Wood and Wolfe (1969, p. 179) described poikilotopic anhydrite in lagoonal dolomites in the sabkha deposits of the Trucial Coast. The anhydrite crystals are randomly scattered throughout the laminated dolomite. The same fabric exists in the Alibates except that anhydrite has been replaced by chert.

Cavities are not dependable environmental indicators; but, in addition to lamination and brecciation, no other definite sedimentary structures were found. Possible ripple marks, mud cracks, cross bedding, and fossils -- all were found at some places, and all have been distorted beyond definite recognition assuming that they did exist at one time. Schlanger (1957, p. 186) stated, "The final stage of dolomitization is the complete obliteration of all organic remains and original textures."

Perhaps the Alibates is better described as a cryptalgalaminate. This term was proposed by Aitken (1967, p. 1170) for carbonate rocks having distinctive, generally planar lamination formed by algae. He listed 13 characteristics which may be displayed by a cryptalgalaminate. The Alibates shows more than half of the characteristics including the following:

1) The laminations are not explained by settling of sediments, deposition from currents, or periodic chemical precipitation.

2) The laminae do not pinch-and-swell to compensate for underlying surface relief.

3) Small-scale "disconformities" are common.

4) Bubbles on the scale of a few millimeters are common.

5) "Birdseyes" are common.

6) Thin breccias in association with laminations are present.

7) The carbonate is more commonly dolomite than limestone.

8) Traces of poorly preserved filaments may be present.

Aitken (1967, p. 1171) further stated that cryptalgalaminates form in "protected intertidal carbonate mudflat environments."

Lucia (1972) summarized characteristics of modern supratidal and intertidal sediments and applied these sedimentary features to the interpretation of ancient carbonate and evaporite rocks. Most of his criteria for the recognition of supratidal and intertidal environments in ancient rocks are the same as Aitken's (1967) criteria for cryptalgalaminates. Lucia (1972, p. 173-177) also listed irregular or wispy laminations, lithoclasts, and lack of fossils as characteristics of a supratidal environment. All of these characteristics are common in the Alibates Dolomite.

The best environmental indicators in the Alibates are: 1) regional stratigraphic and lithologic relationships; 2) general lithology: rock types, textures, and mineral associations; and 3) sedimentary structures: lamination and brecciation. From the study of these indicators, I conclude that:

1) The Alibates Dolomite was deposited in a shallow lagoonal to supratidal, carbonate mudflat environment.

2) The lateral change from dolomite to gypsum and anhydrite indicates a transition from an intertidal to a supratidal, evaporitic environment.
3) The middle red beds represent a minor regression of the sea.
4) The chemical environment was generally highly saline, thus prohibiting existence of most organisms except algae and promoting sporadic formation of gypsum and other evaporite salts.
5) Much of the deposite was similar to modern sabkha environments.

The environmental indicators found in the Alibates support most inferred Permian (Guadalupian) paleoenvironments for the Texas Panhandle region. The exact stratigraphic relationship of the Alibates with the Day Creek in Oklahoma and Kansas, and with other formations in Texas, New Mexico, and Colorado would, nevertheless, be of great value to future interpretations of paleoenvironments.

DOLOMITIZATION

The word "dolomitization" seems to automatically suggest a lagoonal, intertidal, or supratidal environment to many geologists. This is probably because dolomite has been found in these modern environments, and this discovery has received much publicity. Occurrences of dolomite formed by hydrothermal alteration, ground water, and other natural methods have also been documented, but the chief problem is to find an environment or process that can produce large volumes of dolomite like the thick sequences of the Paleozoic. Many pages could be filled with discussion of the different theories of dolomitization, but this is not the purpose here. Instead, a few problems and conflicts in some of the theories will be explored and applied to the Alibates.

Friedman (1964, p. 811) observed that dolomite forms in at least three environments: 1) in intertidal pellet muds and algal mats (Bahamas), 2) at the sediment/water interface in deep marine waters (Bermuda), and 3) as a replacement of calcite and aragonite soon after burial of the sediment. Chilingar and Bissell (1963) reported that dolomite also forms in sulfate-rich environments like those found in the Persian Gulf and the Great Salt Lake. Zenger (1972, p. 8) suggested that dolomite forms in a supratidal environment under evaporitic conditions, and Friedman and Sanders (1967, p. 338) proposed that dolomite be considered as an evaporite mineral. In relation to ancient carbonates, Kendall (1969) found dolomite in lagoonal facies with algal stromatolites and in supratidal evaporite facies in Permian rocks. Thompson (1970) observed that dolomite was most abundant in supratidal facies in some Ordovician rocks. Fischer (1964, p. 131) observed that dolomite was generally restricted to intertidal facies in the Triassic Lofer cyclothems. He suggested that the dolomite formed in a sabkha like environment.

Folk (1974, p. 182) stated that dolomite grains finer than 10 microns were likely to be of primary origin. This idea concurs with most recent discoveries of dolomite in sabkha, supratidal, and intertidal environments. Whether the dolomite is a direct precipitate or the result of rapid calcite and aragonite replacement soon after burial is not known. Schlanger (1957) suggested an organic origin for dolomite after he found it "growing" in coralline algae. Murray and Lucia (1967) observed that dolomitization may be selective by occurring in finer-grained lime muds first. In the sabkha of the Trucial Coast, Butler (1969, p. 81) found that dolomitization and gypsum precipitation were concurrent processes. He also postulated that dolomitization may cause gypsum precipitation. Other less-significant theories have been presented for, what can be considered as, primary origins of dolomite.

Theories which consider dolomitization as a secondary process have also been popular. Degens and Epstein (1963, p. 42) undoubtedly excited a few geologists when they reported that isotope studies suggested that calcite had to be recrystallized before it could be dolomitized. In a later study, Degens (1965, p. 121) concluded that

> All sedimentary dolomites, independent of age (at least for the last 1000 million years), environment, and mode of formation (whether syngenetic, diagenetic, or epigenetic) are products of $CaCO_3$ metasomatism.

This statement supported an earlier theory proposed by Adams and Rhodes (1960). In their study of Permian Basin carbonates, Adams and Rhodes (p. 1917-1919) explained that dolomitization of calcite and aragonite took place when hypersaline brines seeped through the carbonate beds of the lagoon floor. Other studies such as the one by Hanshaw and Back (1969) have shown that normal marine waters and even ground waters have sufficient magnesium concentrations to dolomitize calcite. This study contradicts theories which state that high salinities and high magnesium/calcium ratios are necessary for dolomitization.

Folk and Land (1975) reported that crystallization of dolomite is possible in a wide range of salinities and magnesium/calcium ratios. In a hypersaline environment, the magnesium/calcium ratio must exceed 5-10:1 for dolomite to form. However, in reduced salinities, dolomite may form with magnesium/calcium ratios as low as 1:1. Dilution of a brine promotes dolomitization by retaining high magnesium/calcium ratios and reducing foreign ions which would hinder dolomite crystallization. Folk and Land (1975) also reported that two environments are most conducive to dolomitization: 1) a schizohaline environment such as a floodable sabkha or a shallow lagoon in which the salinity can fluctuate rapidly, and 2) a subsurface zone where saline water is diluted by contact with meteoric water. These environments are also suggested by environmental indicators in the Alibates.

Field and petrographic study strongly implies that the Alibates carbonate body, both upper and lower members, has been completely dolomitized at some time. I suggest that dolomitization occurred relatively early in the history of the Alibates. The primary evidence for this conclusion is that most dolomite is, or appears to have been, very fine grained. The laminae are formed by anhedral dolomite grains and may contain organic matter (algae). Dolomitization occurred before chertification because clasts of laminated dolomite are enclosed in the chert. Close stratigraphic proximity to evaporite beds also suggests the existence of an environment conducive to dolomitization.

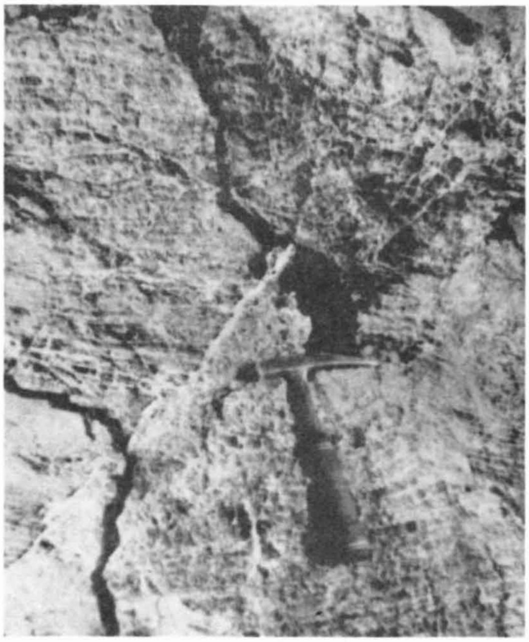
CALCITIZATION

Calcitization (dedolomitization) has occurred at several localities in the Alibates Dolomite and is best seen at McBride Canyon (MS P-6). At this outcrop, calcitization has developed as "boxworks" fabric that extends over several hundred square meters (pl. 2). "Boxes" generally range in size from about 3 to 50 centimeters, and the box walls average 1-5 centimeters thick. The walls are composed of dense, hard, gray calcite spar; the boxes are filled with leached, friable, sucrosic, white dolomite. Extensive "boxworks" calcitization has also taken place at Harbor Bay (MS M-2). At Bear Creek (MS H-10) calcitization has produced a brecciated appearance.

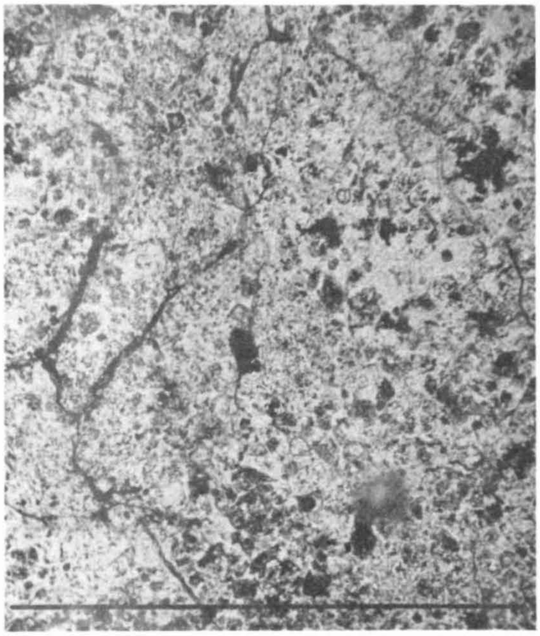
Calcitization is a secondary process and follows fractures and porous laminae in the dolomite. Stringers or veinlets of the spar spread out from a massive source along a fracture. The veinlets penetrate into the dolomite along porous laminae and gradually capture and consume dolomite individuals and clusters (pl. 2).

Few papers have been written on calcitization. Chilingar (1956, p. 763) suggested that the primary reason for this lack of papers is that most geologists simply do not recognize "dedolomite." Lucia (1961), Goldberg (1967), and Folkman (1969) reported occurrences of calcitized dolomite in ancient rocks, but in all instances, the replacement spar was rare and extremely localized. Evamy (1967) and Katz (1971) discussed

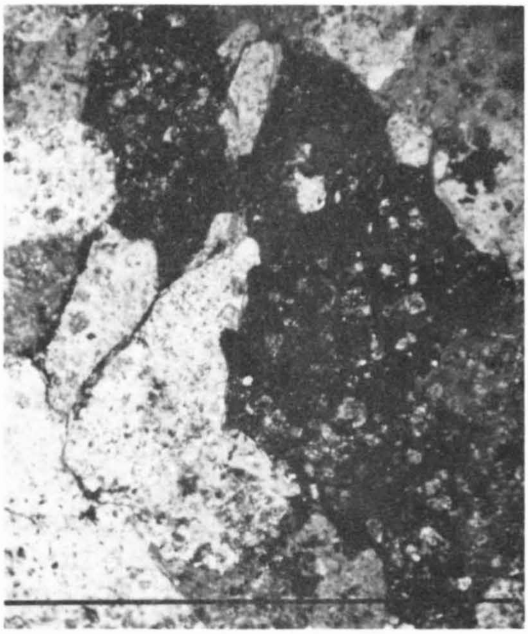
A. "Boxworks", McBride Canyon.



B. "Boxworks", Big Creek.



C. Calcitized dolomite, slide P-6-X, plane polarized light.



D. Calcitized dolomite, slide P-6-X, crossed nicols.

Plate 2. Calcitization in the Alibates Dolomite.
Photomicrographs: scale = 1.0 millimeter.

possible criteria for the recognition of calcitization; however, the features they described, such as zoned crystals and rhombohedral pores, were not found in the Alibates.

Katz (1968) discussed three methods of calcitization. He proposed that the formation of replacement spar is: 1) a surface weathering feature, 2) a reaction of dolomite in sulfate solutions forming calcite and magnesian sulfate, or 3) an early diagenetic process resulting from a changing water system. Katz concluded that most occurrences of calcitized dolomite were the result of early diagenetic processes because little evidence was found to support the first two hypotheses. Moore (1971), however, related the formation of calcitized dolomite to sulfate solutions. He reported that the spar (dedolomite) formed as a cement in evaporite solution collapse breccias. The breccias consist of large dolomite clasts floating in a calcite spar matrix. Some of the calcitized dolomite breccia at Bear Creek (MS H-10) may be of this origin.

Lucia's (1972, p. 178-180) report that calcitization of dolomite produces breccia supports Moore's (1971) findings. Lucia states that calcitization is the reverse of reflux dolomitization. Fresh water dissolves sulfate evaporite and produces a low magnesium/calcium ratio solution which can calcitize dolomite. Compared to Folk and Land's (1975) study which suggested dolomite formation at low salinities and magnesium/calcium ratios, the controlling factor between dolomitization and calcitization seems to be the amount of sulfate present. Perhaps evaporite concentrations were responsible for localizing calcitization in the Alibates.

My field observations suggest that most calcitization in the Alibates is the result of surface weathering. Katz (1968, p. 440), although not favoring this idea, did suggest that the spar could form by weathering along fractures in dolomite. He stated that calcitization could be a "product" of calichification. Calichification involves dissolution, migration, and reprecipitation of both calcite and quartz. It is interesting to note that in the Alibates, replacement spar and chert commonly occur adjacent to each other, but the two are rarely mixed. Only trace quantities of chert are found in zones of calcitization. Most "boxworks" are barren of chert, but large chert masses may be present just a meter away from the calcitized zone. This relationship suggests that minor fluctuations of pH and/or sulfate concentration may localize calcitization and chertification.

Friedman (1975) supported the ideas of calcitization in the Alibates and sulfate control of the process. He stated that "boxworks", along with breccias, are predictable characteristics of calcitized dolomites. He added that calcitization-dolomitization processes may have reversed many times in the history of the rock and that calcitization is not necessarily a weathering process.

There are other theories to explain calcitization, but most of the evidence that I found implies:

1. Calcitization in the Alibates is secondary.
2. Calcitization may be localized in the dolomite by changes in pH or sulfate concentrations.
3. Most calcitization in the dolomite can be related to calichification as a part of the weathering process.

CHERTIFICATION

The Alibates is best known for its chert because of the ancient flint quarries, and yet, the chert accounts for probably no more than 2-3 percent of the total Alibates exposed. The chert is in both dolomite members, but it is more abundant in the upper dolomite. Chert can be found in most outcrops of the Alibates. It is not confined to any particular bed or stratigraphic horizon in the dolomite. The three main habits of chert in the outcrop are: 1) small beads, 2) nodular and podlike masses, and 3) massive sheets.

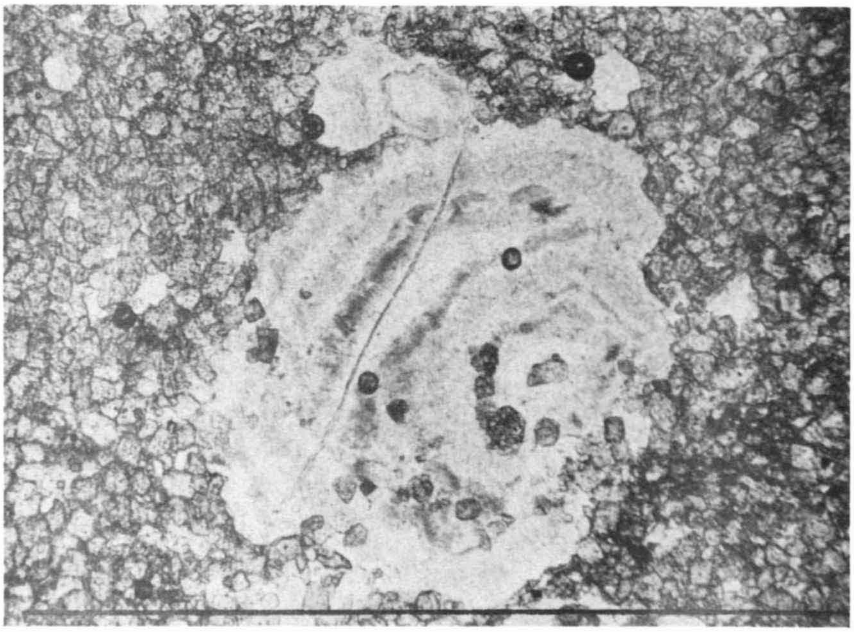
Chert Beads

Beads of chert average 1-2 millimeters in diameter and commonly weather dark brown. Although they occur in both dolomite members, the beads seem to be more abundant in the lower dolomite where they are concentrated along some laminae. Most beads are composed of chalcedonite; some consist of megaquartz or quartzine and lutecite. Chalcedonite and megaquartz beads are cavity fillings in the dolomite and are similar to birdseye structures described by Folk (1973, p. 716). All stages of cavity filling were observed in thin section. An empty or partly-filled cavity may be less than 5-6 millimeters away from a completely filled cavity, thus showing extreme localization or selectivity of the chertification. There is no evidence to suggest that silica precipitation was selective of certain cavities because of pre-existing chemical or mineralogical conditions. Instead, most cavity fillings show a direct spatial relationship to fractures and porous laminae in the dolomite.

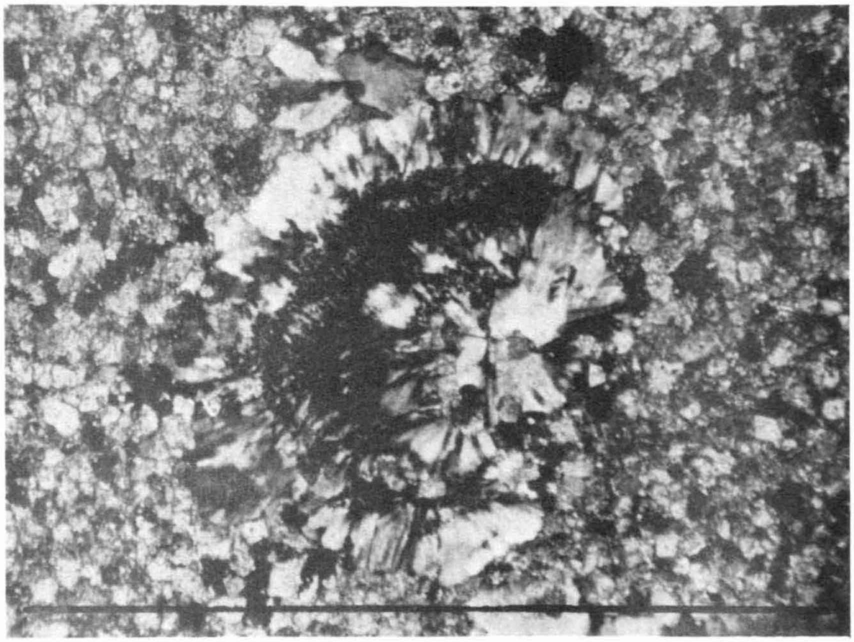
Some quartzine beads are obviously cavity fillings, but others may have formed by replacement of evaporite minerals. A few beads have shapes that resemble "ghosts" of gypsum or anhydrite crystals. Folk (1972) described characteristics of length-slow chalcedony replacement of evaporite minerals. There are marked similarities between his descriptions and the Alibates quartzine beads. Structures similar to flow lines in a few clear quartzine beads are further evidence of sulfate mineral replacement. Although no sulfate microlites were found in the quartzine, the "flow lines" are probably the relic fibrous texture of gypsum crystals. This relic gypsum texture in the quartzine is identical to that described and illustrated by Siedlecka (1972) from Permian beds on Bear Island, Svalbard.

The random distribution of length-slow chalcedony beads in the laminated dolomite is similar to anhydrite crystals scattered throughout dolomite beds in the modern sabkha environment (Wood and Wolfe, 1969, p. 179). They observed that poikilotopic anhydrite is common in lagoonal dolomite sediments but suggested that anhydrite did not form until after the dolomite was lithified. The lithologic textures are identical to those of the Alibates: only the mineralogy has changed. Quartzine and lutecite have replaced the anhydrite.

Concentric growth rings similar to those described by King and Merriam (1969, p. 1144) occur in some chalcedonite and quartzine beads and are commonly accentuated by iron oxide staining (pl. 3). Many rings have an appearance similar to growth rings in the cross section of a tree and are jagged or crenulated. Under crossed nicols, the chalcedony fibers may or may not transect these rings. Multiple generations of silica precipitation are suggested by these rings and by a few cavities filled with both



A. "Growth rings" in quartzine-lutecite bead, slide M-1-F1, plane polarized light.



B. Quartzine-lutecite bead, slide M-1-F1, crossed nicols.

Plate 3. "Growth rings" in chert beads, Alibates Dolomite, Photomicrographs: scale = 1.0 millimeter.

length-fast and length-slow chalcedony. Some cavities show successive layers of chalcedonite, quartzine, and chalcedonite or megaquartz. This transition of chert types strongly suggests changes in the chemical environment during the different stages of vug filling. (Folk (1972 and 1974) showed that length-slow chalcedony can form in a sulfate-rich environment and replace evaporite minerals. Quartzine interlayered with chalcedonite in the cavity fillings therefore implies a chemical change in the interstital waters. This periodic(?) change to a sulfate-rich environment also supports the theories of dolomitization and calcitization proposed by Adams and Rhodes (1960), Lucia (1972), and Folk and Land (1975).

Many beads have inclusions of finely crystalline or very finely crystalline dolomite. These carbonate microlites in the chert are generally near the quartz-carbonate boundary and appear to be grains that were trapped in the silica precipitate. Opaque minerals, iron oxides, and trace quantities of mica and clay are other impurities in the chert beads.

A replacement origin for the chert beads is suggested by:

1. All stages of cavity filling are present.
2. Filled cavities are in close proximity to porous zones in the dolomite.
3. Length-slow chalcedony (quartzine) can be a replacement of evaporite minerals.
4. Relic gypsum textures may occur in quartzine beads.
5. Concentric growth rings show successive generations of silica precipitation.
6. Possible "ghost" crystal outlines of evaporites are present.
7. Alternating concentric layers of length-slow and length-fast chalcedony in the same cavity indicate chemical changes during

stages of cavity filling.

8. Clasts of dolomite, opaque minerals, and other impurities are enclosed in the chert.
9. Beads are not confined to any particular stratigraphic horizon.

Sporadic Chert Masses

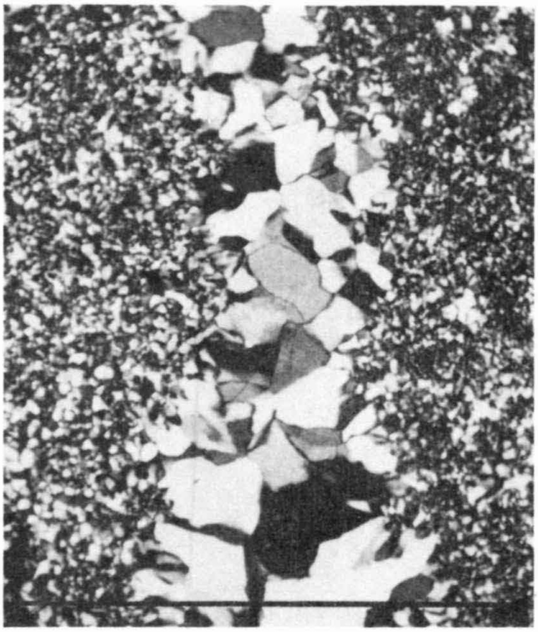
Irregular masses of chert occur sporadically in both dolomite members but are more abundant in the lower dolomite. These masses are not localized geographically and may be found in any Alibates outcrop. There is no predominant size or shape of these masses. The size ranges from a few millimeters to a few meters, and characteristic shapes include spherical nodules, elongate pods, and interbedded stringers (pl. 4). Fresh surfaces of the chert are multicolored and contrast strongly with the gray dolomite. The chert weathers to various shades of brown.

Nodular and podlike masses are best developed in the Milligan quarries in the northern part of the Kritser Ranch. There the chert masses average 25-75 centimeters in longest dimension and are commonly elongated normal to bedding planes and parallel to near-vertical fractures in the rock. At some localities, chert extends from large central masses along fractures and forms embayments and stringers in the dolomite. In the Alibates National Monument and vicinity, these stringers have penetrated the dolomite 2-3 meters along bedding surfaces.

Excluding size and shape, these masses have the same characteristics. In outcrop, the chert-dolomite contact appears to be sharp rather than gradational, and iron oxide staining in the chert readily delineates

A. Irregular chert mass in dolomite (MS P-2).

B. "Bedded" chert, Alibates National Monument.



C. Megaquartz vein in microquartz, slide P-9A-F4, crossed nicols.

D. Chalcedonite cavity filling in dolomite, slide P-7-3, crossed nicols.

Plate 4. Chertification in the Alibates Dolomite. Photomicrographs: scale = 1.0 millimeter.

the contact on fresh surfaces. The dark, resistant chert is most obvious on weathered surfaces. At many places, lamination is continuous from the dolomite into the chert, and is more distinctive in the chert because of iron oxide coloration. Clasts of laminated dolomite as large as 10 centimeters can be found floating in many chert masses. At a few localities, sedimentary breccias are preserved in the chert.

Thin sections of some chert masses show that most of the chert is fine- to coarse-grained microcrystalline quartz with minor amounts of chalcedonite and megaquartz. The microcrystalline quartz commonly appears as an anastomosing network of stringers invading the dolomite along laminae. Massive chert fronts of microcrystalline quartz form along fractures and send out advance veinlets to infiltrate the dolomite. As chertification proceeds, the chert veinlets surround and capture individual dolomite crystals thus forming a chert-cemented dolomite. The final stage of chertification is complete replacement of the dolomite. The entire invasion of chert or the complete transition from dolomite to chert may be displayed in less than 1 centimeter.

A replacement origin for sporadic, irregular chert masses is suggested by:

1. Sharp chert-dolomite contacts.
2. Chert stringers and embayments into the dolomite.
3. Relic laminae in the chert.
4. Sedimentary breccia preserved in chert.
5. Dolomite clasts floating in a chert matrix.
6. Microscopic gradation from dolomite to chert.

Massive Sheets

Massive sheet chert occurs at two places: the Alibates National Monument and the Devil's Canyon-Cactus Flats vicinity. The areal extent of this massive replacement has not been determined but may cover a combined area as large as 50 square kilometers (about 20 square miles). Only the upper dolomite has been completely replaced in these areas; the lower dolomite contains minor chert as in all other Alibates outcrops. Although no dolomite has been found in the massive sheets, the dolomite features are well preserved in the chert. Laminations are colorfully preserved as alternating bands of red, gray, brown, and several other colors. Chertified breccias are usually preserved as white fragments in a red and brown matrix.

The massive chert is predominantly fine-grained microcrystalline quartz. Minor quantities of chalcedonite and megaquartz appear as patches within the microcrystalline quartz. These patches may have been dolomite clasts in the massive chert that were replaced during a later stage of silica precipitation. At several places, the massive chert has been fractured. The fractures are filled with chalcedonite and indicate multiple generations of chertification.

The massive sheets have replaced the upper dolomite, and the evidences for replacement origin are basically the same as those cited for the sporadic masses. The controlling factors for such complete yet localized replacement are, however, not as obvious. Occurrences of chert beads and sporadic masses can be related to chertification along joints, faults, and porous zones in the dolomite. Field observatons coupled with evaluation of maps and air photos suggest that there are no significant structural controls for localizing the massive chert. It is apparent from chert-dolomite spatial relationships that chertification has proceeded downward from the top of the Alibates. Because all overlying rocks have been removed by erosion, any stratigraphic or lithologic controlling factors are hypothetical. However, it is possible that the upper dolomite acted as a filter to remove silica from descending solutions. At some localities, this filter failed to remove all the silica from the solution, and the silica leaked into the lower dolomite. There is no evidence to suggest topographic controls for localization of the chert.

Sources of Silica

The theory of silica entering the Alibates from overlying strata concurs with a theory proposed by Norton (1939, p. 1811). He described similar chert occurrences in the Day Creek Dolomite in Kansas and concluded:

> ...the preponderance of evidence favors the theory of replacement by silica from percolating ground water from overlying strata, the commonest source being the sandy conglomerate of the Tertiary Ogallala 'mortar beds.'

Assuming that the source of silica was always stratigraphically above the Alibates, multiple generations of chert may suggest multiple sources of silica. It is reasonable to assume that the Alibates was once overlain by Mesozoic strata. Triassic rocks are exposed in western Potter County (Patton, 1923, p. 47-76), and other studies (King and Merriam, 1969, and others) suggest that Jurassic and Cretaceous rocks may have once covered the Texas Panhandle. The Triassic rocks are predominantly terrigenous and contain chert and petrified logs (Barnes, 1969). Silica may have been derived from bentonites, tuffaceous rocks, and many silicate minerals.

Because terrigenous rocks have probably overlain the Alibates since the Triassic, a direct source of silica has been provided. Extensive opalization at some places in the Pliocene Ogallala Formation (Harlow, 1974 and Norton, 1939) indicates recent sources of silica. The fresh appearance of some chert along fractures in the Alibates gives the impression that chertification is still taking place today.

The only sources of silica within the Alibates are detrital sand, silt, and clay in the dolomite and middle red beds. Some chert in the lower dolomite may have been derived from the red-bed member. Silicate detritus in the dolomite is a possible but extremely limited source. Walker (1960 and 1962) proposed that chert-carbonate replacement is a reversible process. Calcite replaces the silica (primarily detrital quartz), and the silica is then transported in solution and reprecipitated nearby. Walker (1962, p. 239) stated that the probable cause of such replacement reversals is fluctuation of pH in interstitial water.

Walker's (1960 and 1962) ideas have been supported by Krauskopf (1956 and 1967), Siever (1957 and 1962), and others who have reported that the solubility of silica is relatively low and constant at pH's below 9, but greatly increases at pH's above 9. Krauskopf (1967, p. 170) also speculated that changes in pH and silica concentration were controlling factors for the reversible silica-calcite replacement. Walton (1973, p. 854) proposed that concentrations of aluminum coupled with pH changes may be important factors in the solubility and localization of silica; however, the uniform aluminum concentrations revealed by the chemical analyses do not support this theory.

Brown (1956) and Reeves (1970) documented the formation of caliche in the Ogallala Formation in the study area. According to Reeves (1970, p. 353), one result of the calichification process is oversaturation of solutions with silica because of high pH. It is a simple matter for these solutions to percolate a relatively short distance downward into the Alibates and precipitate in the dolomite.

There are other possible sources and controls for localization of chert in the Alibates Dolomite; nevertheless, most evidence supports the following conclusions:

1. Most of the silica came from sources outside the Alibates Dolomite.
2. The sources of silica were stratigraphically above the Alibates Dolomite.
3. Most of the chert was localized in the dolomite by fractures and porous zones.
4. Precipitation of silica was probably caused by variations of pH which can be related to changes in lithology.

Dolomitization, calcitization, chertification, and calichification are closely related processes. The first three can be a product of calichification. Only slight changes in pH, salinity, magnesium/calcium ratio, and silica and sulfate concentrations seem to be necessary to cause a reversal in any one process. All of these processes can operate in the present and suggested ancient environments of the Alibates Dolomite.

A P P E N D I X

MEASURED SECTIONS

Numbering System

Example: P-9A-6b or M-2-F3

first letter (P, M) = county (C=Carson, D=Donley, G=Gray, H=Hutchinson, M=Moore, P=Potter).

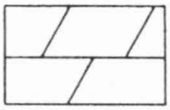
first number (9, 2) = measured section (numbered from west to east in each county).

second letter (A) = continuation or sub-section measured near primary section.

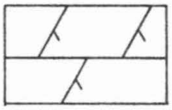
second number or third letter (6, F) = sample or thin section (F=float, L=fracture fill, X=boxworks).

last number or letter (b, 3) = multiple samples from same stratigraphic horizon or unit.

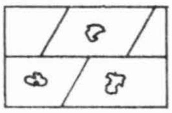
Lithologic Symbols



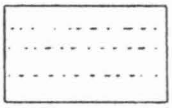
Dolomite



Calcitized Dolomite



Chertified Dolomite



Red Beds

MEASURED SECTION LOCALITIES

Section Number	County	Locality
P-1	Potter	Ranch Creek, Kritser Ranch
P-2, 2A, 2B	Potter	J. Milligan Quarry, Kritser Ranch
P-3	Potter	Hackberry Canyon, Kritser Ranch
P-4	Potter	Devils Canyon, Weymouth Ranch
P-5	Potter	Plum Creek
P-6	Potter	McBride Canyon
P-7	Potter	Cas Johnson Road
P-8	Potter	Alibates Creek, Cas Johnson Road
P-9	Potter	Bivins Ranch
P-9A	Potter	Alibates National Monument
P-10, 10A	Potter	Short Creek, State Highway 136
M-1	Moore	Chimney Hollow, Blue West
M-2	Moore	Harbor Bay, Fritch
H-2	Hutchinson	Bugbee Creek
H-3	Hutchinson	Sanford Dam
H-4	Hutchinson	Antelope Creek, State Highway 136
H-5	Hutchinson	Big Creek, State Highway 687
H-6	Hutshinson	Bunavista
H-7	Hutchinson	Electric City, Farm Road 1559
H-8	Hutchinson	State Highway 152 (207), North of Canadian River
H-9	Hutchinson	Dixon Creek, State Highway 152
H-10	Hutchinson	Bear Creek, State Highway 280
H-11	Hutchinson	Plemons

Section Number	County	Locality
C-1	Carson	West Dixon Creek, Burnett #2
G-1	Gray	Lake McClellan
D-1	Donley	Salt Fork of Red River, State Highway 70
D-2	Donley	Turkey Creek

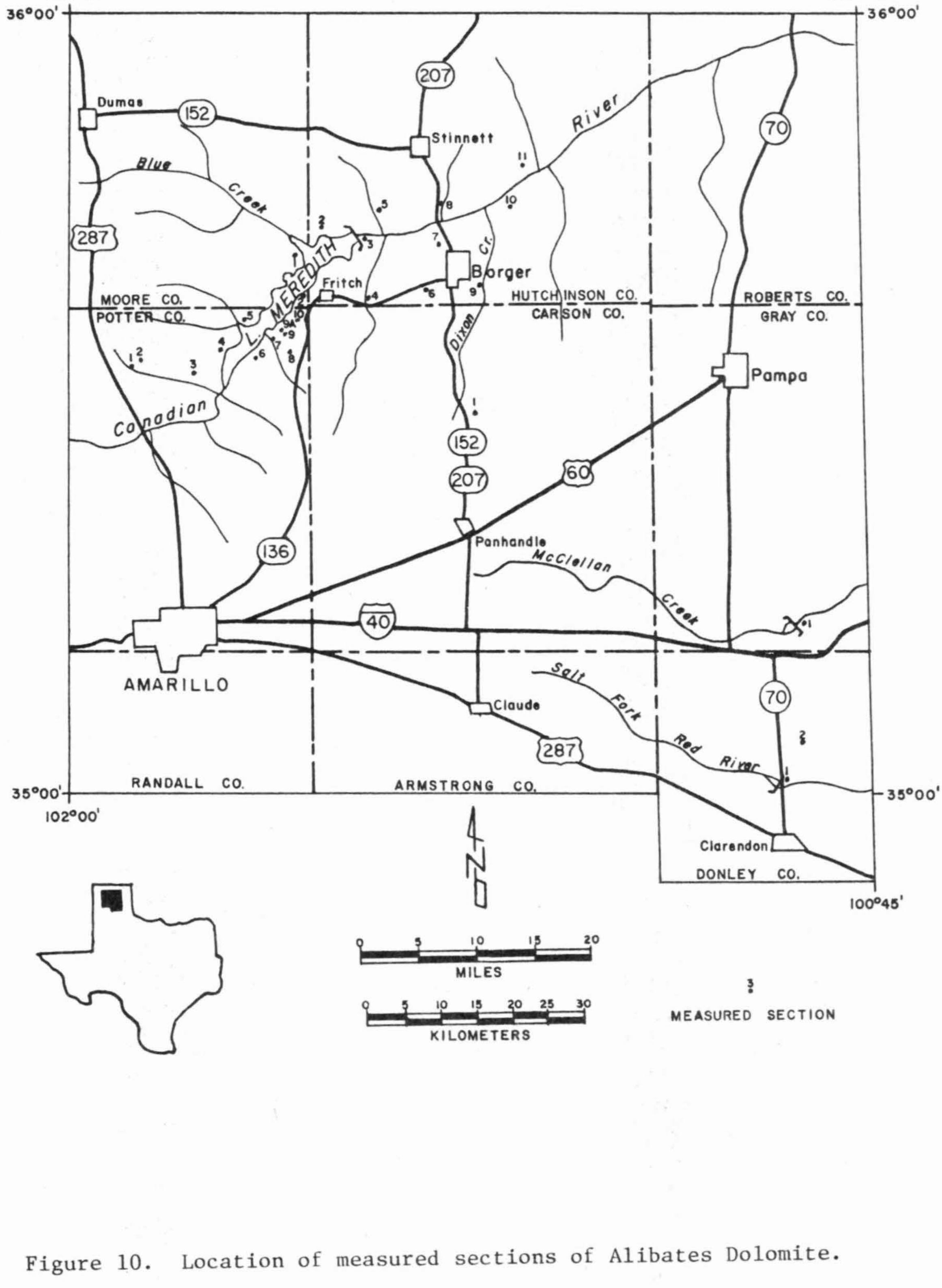


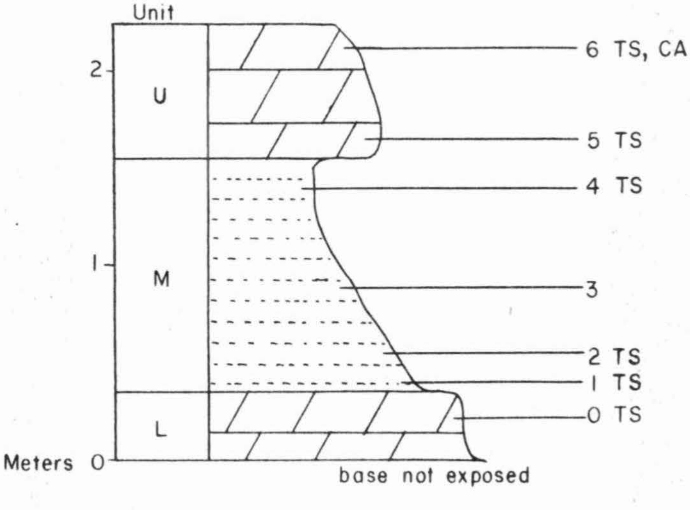
Figure 10. Location of measured sections of Alibates Dolomite.

Measured Section P-1

Section of Alibates Dolomite measured on exposure in creek bed of Ranch Creek, 100 m downstream (south) of Lake Lee, 3.5 km (2.2 mi) east on gravel road from gate 4 at U. S. Highway 287, northern Kritser Ranch, Potter County, Texas

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Upper Member		
	Finely crystalline dolomite: very pale orange (10YR8/2) to pinkish gray (5YR8/1) weathers light brown (5YR6/4) to grayish orange (10YR7/4), laminated, fractured, possible desiccation cracks near top, forms ledge	0.70
Middle Member		
	Dolomitic mudstone: yellowish gray (5Y8/1) to light brown (5YR6/4) weathers same, laminated to very thinly bedded, calcareous at some places, grades into fissile mud-shale at some places, forms slope	1.20
Lower Member		
	Finely crystalline dolomite: very pale orange (10YR8/2) to pinkish gray (5YR8/1) weathers yellowish gray (5Y8/1), laminated, fractured, sucrosic, possible ripple marks at some places, undulating surface, base not exposed	0.35
	Total exposed section	2.25

Measured Section P-1

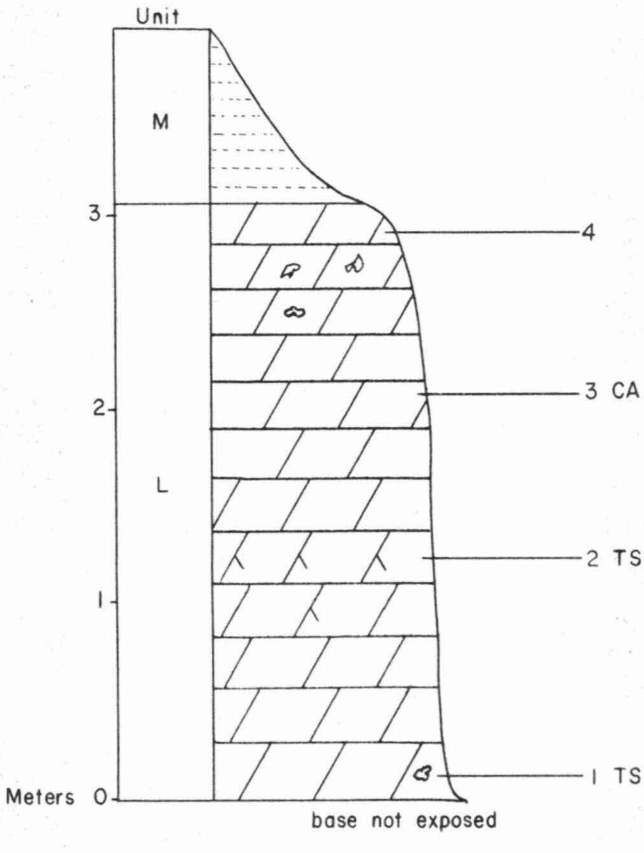


Measured Section P-2

Section measured in abandoned quarry of J. Lee Milligan Rock Quarry, 350 m east of rock crusher and office, 4.3 km (2.7 mi) east on gravel road from gate 4 and U. S. Highway 287, northern Kritser Ranch, Potter County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Middle Member		
	Calcareous mudstone: yellowish gray (5Y8/1) to light brown (5YR6/4) weathers same, laminated, grades into green claystone in lower part, forms slope.	0.90
Lower Member		
	Finely crystalline dolomite: yellowish gray (5Y7/2) weathers same, laminated, fractured, calcitized "boxworks" at some places, chertification along fractures away from calcitized zones, chert nodules containing dolomite clasts, sucrosic and friable in lower 20 cm. base not exposed	3.05
	Total exposed section	3.95

Measured Section P-2

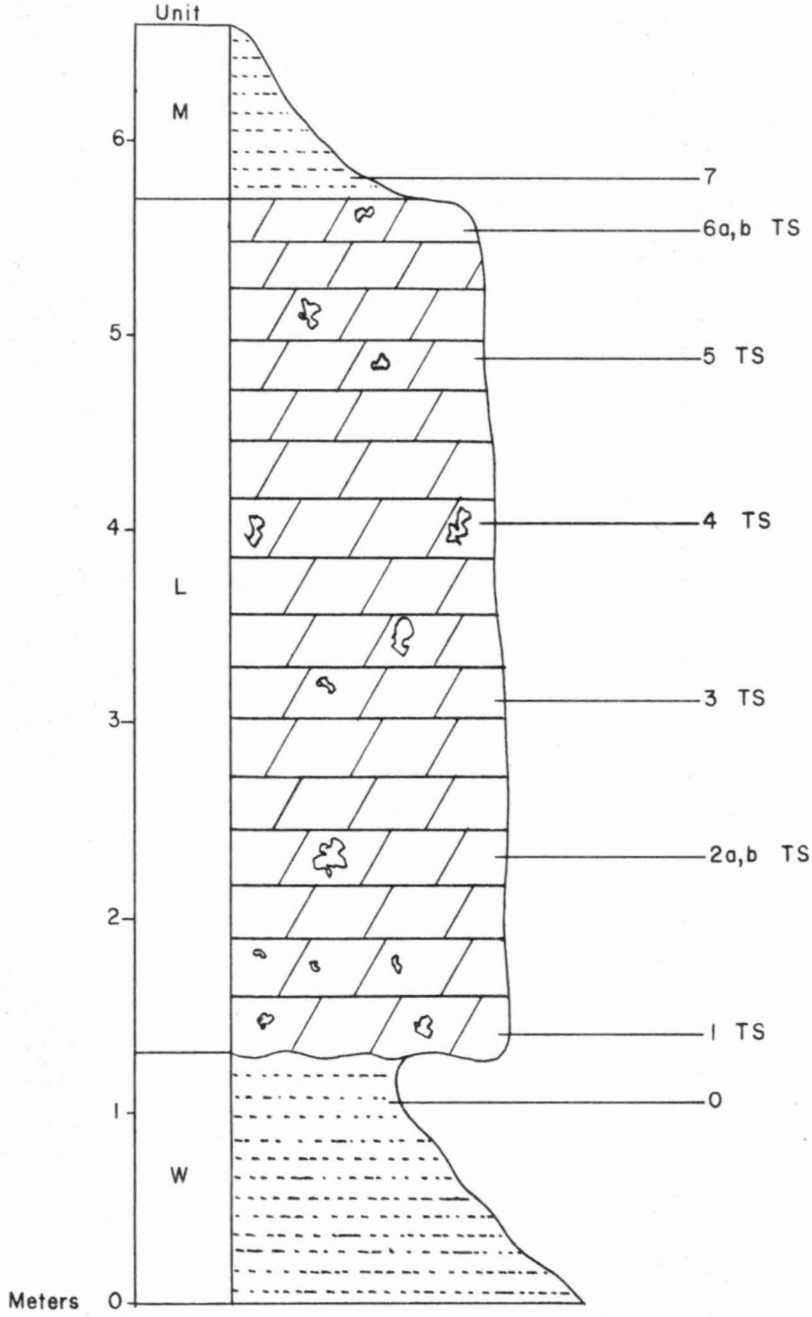


Measured Section P-2A

Section measured in operating quarry of J. Lee Milligan Rock Quarry, 1.6 km (1.0 mi) east of rock crusher and office, northern Kritser Ranch, Potter County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Middle Member		
	Calcareous mudstone: yellowish gray (5Y8/1) to light brown (5YR6/4) weathers same, covered by soil and vegetation, forms slope. . . .	0.90
Lower Member		
	Medium to finely crystalline dolomite: grayish orange pink (10YR8/2) to pinkish gray (5YR8/1) weathers same, laminated, intensely fractured at some places, some fractures filled with buff, calcareous sandstone, irregular chert pods at some places, chertification follows fractures in dolomite, pale brown (5YR5/2) chert beads in lower half concentrated along laminae	4.40
Whitehorse Formation		1.30
	Total exposed section	6.60

Measured Section P-2A

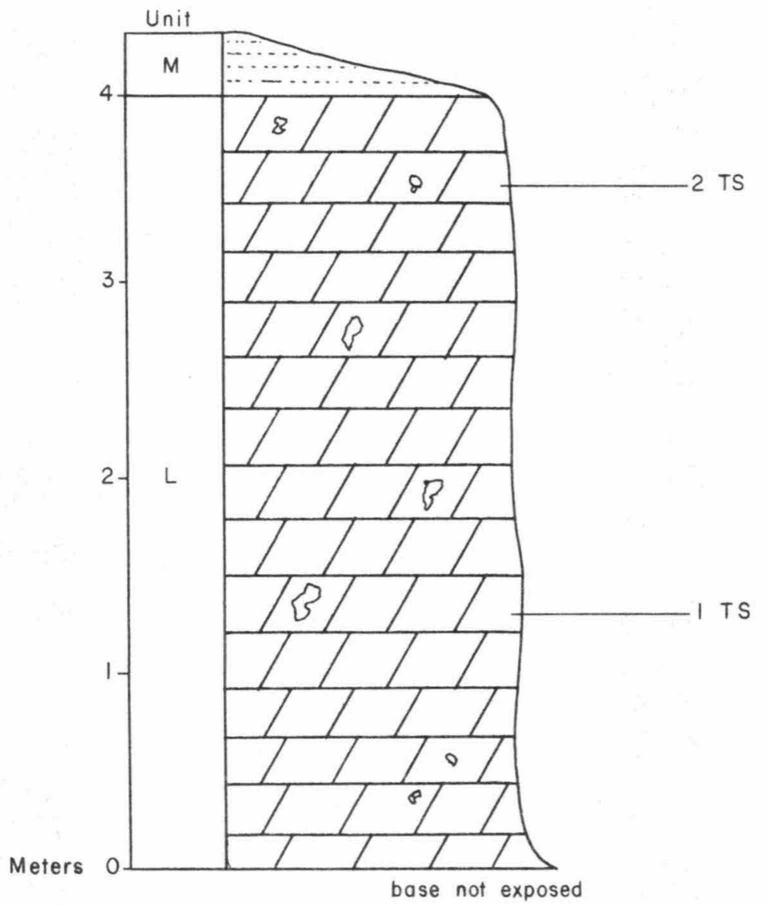


Measured Section P-2B

Section measured in operating quarry of J. Lee Milligan Rock Quarry, 10 m east of MS P-2A, 1.6 km (1.0 mi) east of rock crusher and office, northern Kritser Ranch, Potter County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Middle Member		
	Calcareous mudstone: yellowish gray (5Y8/1) to light brown (5YR6/4) weathers same, covered by soil and vegetation	0.35
Lower Member		
	Medium to finely crystalline dolomite: grayish orange pink (10YR8/2) to pinkish gray (5YR8/1) weathers same, laminated, fractured, brecciated at some places, some fractures filled with buff calcareous sandstone, chertification along some fractures, small (5-10 cm) pods of red opaline chert in dolomite near fracture fill dolomite friable and sucrosic at some places, base not exposed	4.00
	Total exposed section	4.35

Measured Section P-2B

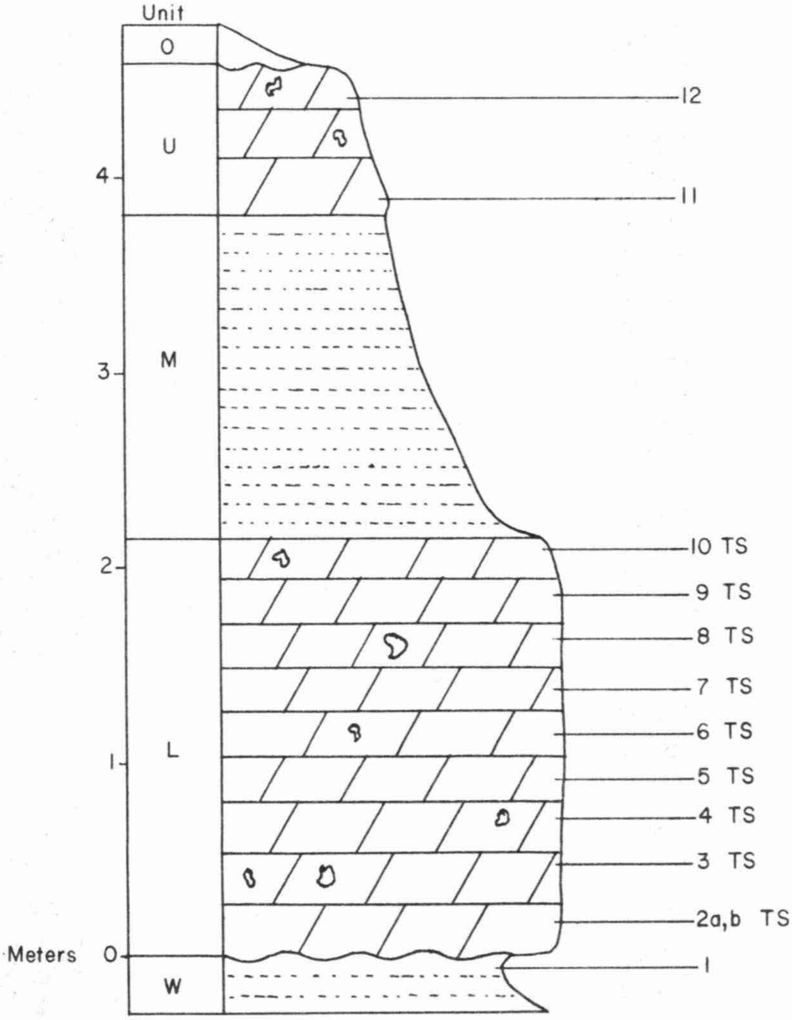


Measured Section P-3

Outcrop of Alibates Dolomite on south rim of bluff at head of Hackberry Canyon, 20 m south of gravel road, 5.4 km (3.4 mi) east southeast of J. Lee Milligan Rock Quarry office, northeastern Kritser Ranch, Potter County, Texas.

Unit	Description	Thickness (meters)
TERTIARY		
Ogallala Formation		not measured
PERMIAN		
Alibates Dolomite		
Upper Member		
	Medium to finely crystalline dolomite: pale yellowish brown (10YR6/2) to pinkish gray (5YR8/1) weathers light brownish gray (5YR6/1), laminated, brecciated at some places, sporadic chertification, chert opalline at a few places, weathers easily, forms slope	0.75
Middle Member		
	Calcareous mudstone: moderate reddish orange (10R6/6) to grayish yellow green (5GY7/2), weathers same, fractured, fissile at some places, forms slope.	1.67
Lower Member		
	Medium to finely crystalline dolomite: grayish orange pink (10R8/2) to pale red (10R6/2) weathers same, laminated, intensely fractured at some places, some fractures filled with moderate orange pink (5YR8/4) calcareous sandstone (from Ogallala?), incipient chertification follows fracture fills and small faults due to slumping of member, chertification varies laterally (controlled by faults?), forms ledge	2.15
Whitehorse Formation		
	Red beds: form slope	not measured
	Total measured section	4.57

Measured Section P-3

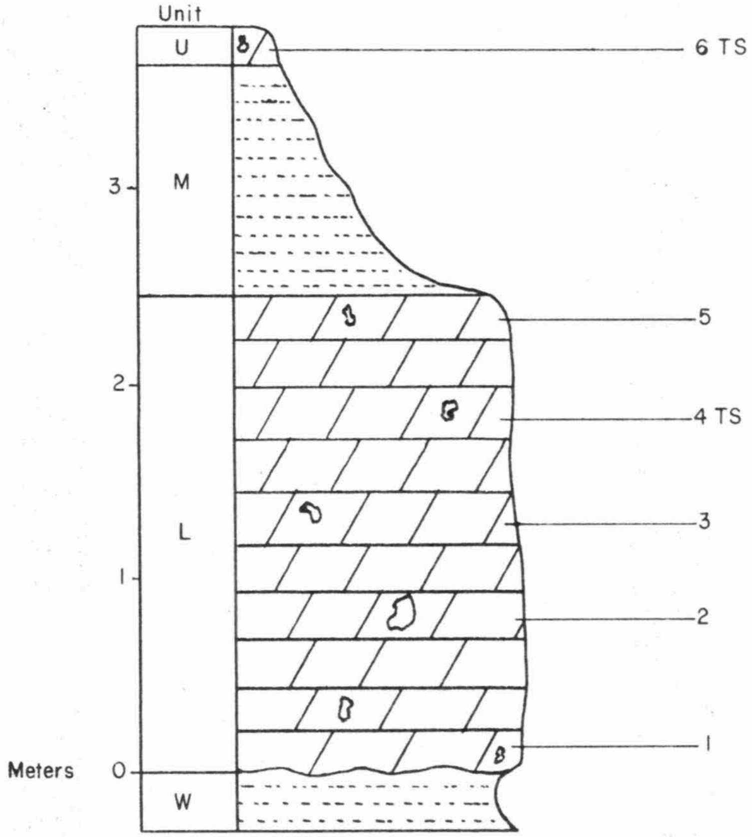


Measured Section P-4

Outcrop on the southern point of Cactus Flats along Colorado Interstate Gas Company gravel road, near National Park Service Boundary Marker 153, east rim of Devil's Canyon, Potter County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Upper Member		
	Chert: pale red (5R6/2) to light brown (5YR5/6) weathers moderate brown (5YR4/4), banded, fractured, relic sedimentary breccia at some places, small (1-2 mm) dolomite clasts floating in chert at a few places, forms ledge.	0.20
Middle Member		
	Covered by vegetation, forms slope, estimated thickness.	1.20
Lower Member		
	Medium to finely crystalline dolomite, grayish orange pink (10R8/2) to pale orange (10YR8/2) weathers light brown (5YR6/4) to moderate orange pink (10R7/4), distinctly laminated, irregular masses of chert throughout, some large quartz crystals lining cavities in chert, forms ledge.	2.45
Whitehorse Formation		
	Red beds: form steep slope.	not measured
	Total measured section	3.85

Measured Section P-4

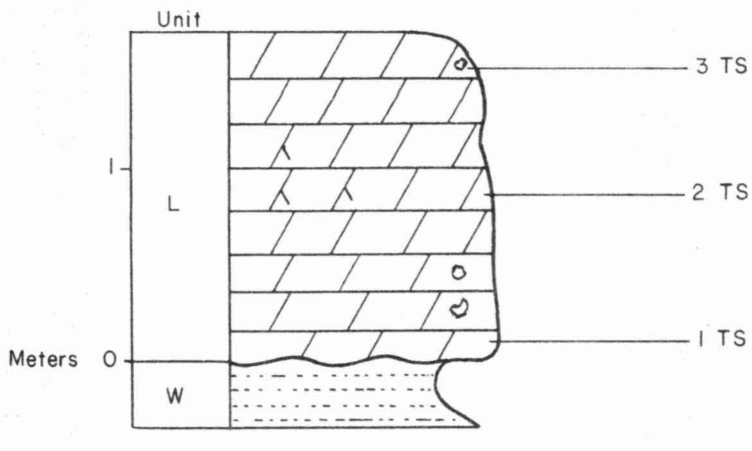


Measured Section P-5

Exposure of Alibates Dolomite along north side of road to Plum Creek boat ramp, at the top of a steep grade, 10.0 km (6.3 mi) south of intersection with Farm Road 1913, and 2.2 km (1.4 mi) north of Plum Creek boat ramp, Lake Meredith Recreation Area, Potter County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Lower Member		
	Medium to finely crystalline dolomite: grayish orange pink (5YR7/2) to yellowish gray (5Y7/2) weathers light brown (5YR5/6), laminated, intensely fractured, brecciated at some places, calcitized "boxworks" at a few places, calcitized dolomite box wall harder than friable dolomite box filling, small (less than 2 cm) chert nodules isolated at a few places, covered by thin (10-20 cm) soil and vegetation, forms ledge. . . .	1.70
Whitehorse Formation		
	Red beds: form steep slope.	not measured
	Total measured section	1.70

Measured Section P-5

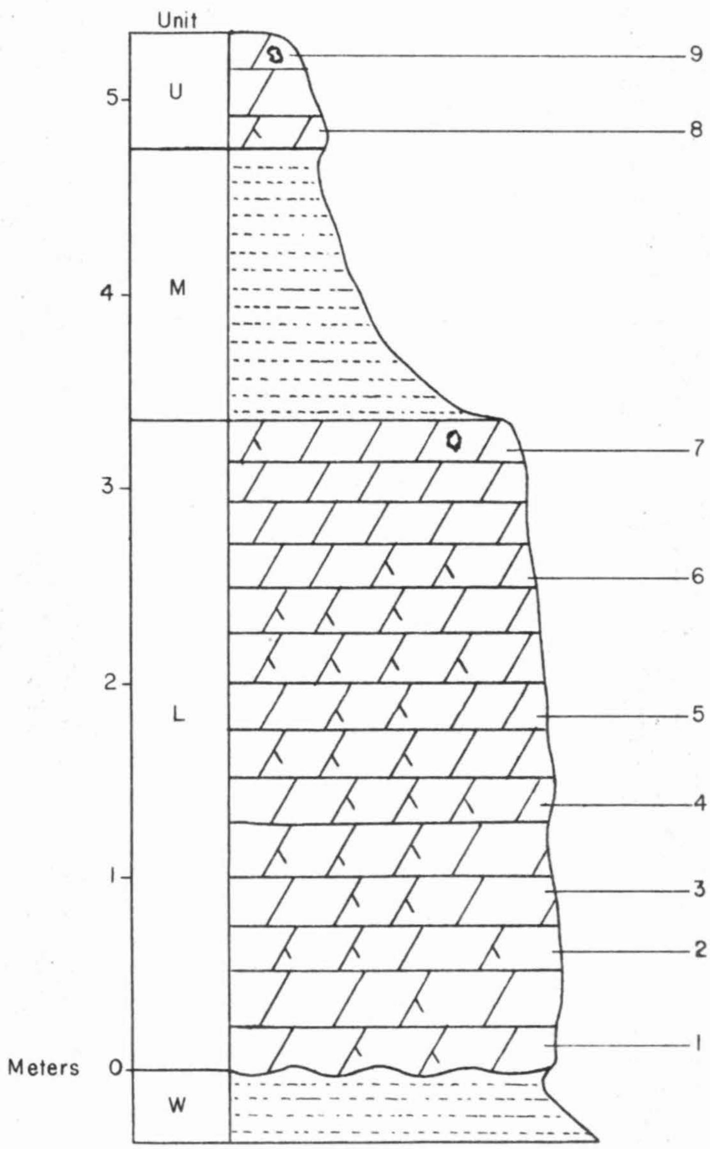


Measured Section P-6

Outcrop measured on both sides of McBride Canyon road at the top of grade and sharp turn near boundary of Lake Meredith Recreation Area, 4.5 km (2.8 mi) west of the fork of McBride Canyon and Cas Johnson roads, Potter County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Upper Member		
	Medium to finely crystalline dolomite: grayish orange pink (5YR7/2) to pinkish gray (5YR8/1) weathers very pale orange (10YR8/2) to pale yellowish brown (10YR6/2), laminated, fractured, isolated brecciation, localized calcitization, small (less than 5 cm) chert nodules in upper 20 cm, soft, sucrosic, friable, 8 cm bed about 17 cm above base, lower 5 cm interbedded with maroon siltstone, forms steep slope.	0.60
Middle Member		
	Red beds, covered with vegetation.	1.40
Lower Member		
	Medium to finely crystalline dolomite: colors same as upper member, laminated, intensely fractured, calcitized throughout, "boxworks" well developed, box walls of hard, medium crystalline limestone, boxes filled with soft, friable, leached(?), finely crystalline dolomite, boxes range in size from 5 to 50 cm, calcitization follows fractures and possible porous zones in dolomite, forms ledge.	3.35
Whitehorse Formation		
	Red beds: form slope.	not measured
	Total measured section	5.35

Measured Section P-6

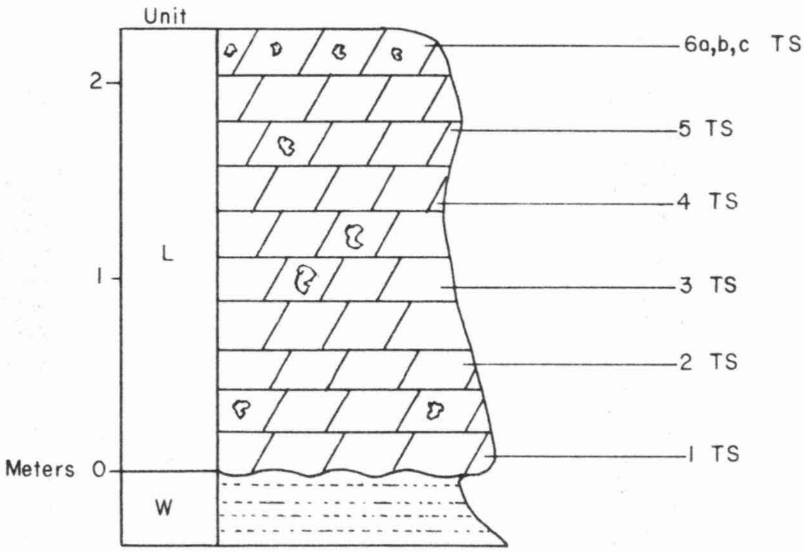


Measured Section P-7

Outcrop at the top of hill on the east side of Cas Johnson Road about 100 m north of Pioneer Natural Gas Company pipeline, 8.0 km (5.0 mi) west of the intersection of Cas Johnson Road and State Highway 136, Potter County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Lower Member		
	Medium to finely crystalline dolomite: grayish orange pink (5YR7/2) to pinkish gray (5YR8/1) weathers very pale orange (10YR8/2) to pale yellowish brown (10YR6/2), laminated, fractured, jointed, sucrosic at some places, brown chert common in upper 10 cm, chert pods (5-30 cm) in middle part, chertification follows fractures and vuggy laminae, forms ledge	2.30
Whitehorse Formation		
	Red beds: form steep slope.	not measured
	Total measured section	2.30

Measured Section P-7

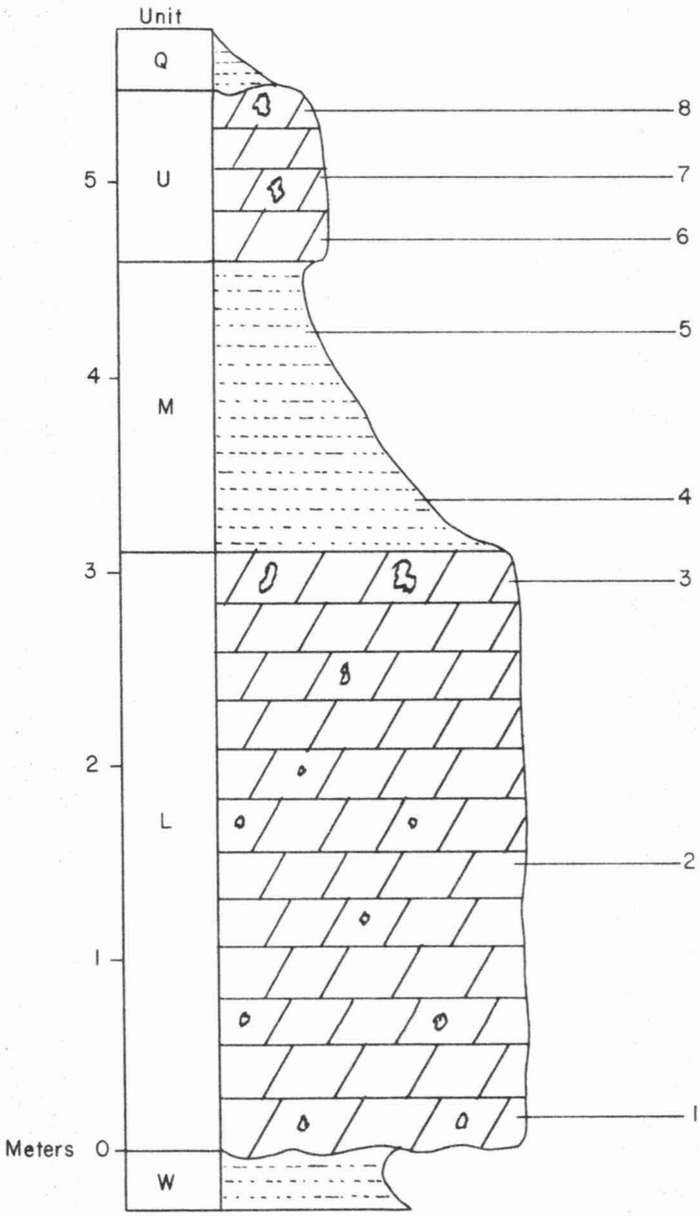


Measured Section P-8

Exposure in creek bed of Alibates Creek on the north side of Cas Johnson Road at the Alibates Creek crossing, 3.5 km (2.2 mi) west of the intersection of Cas Johnson Road and State Highway 136, Potter County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Quartermaster Formaion		
	Red beds	not measured
Alibates Dolomite		
Upper Member		
	Medium to finely crystalline dolomite: pinkish gray (5YR8/1) weathers grayish orange pink (5YR7/2) to pale yellowish brown (10YR6/2), laminated, intensely fractured at some places, sporadic brown chert nodules 5-40 cm in longest dimension, gently undulating exposed lower surface, forms ledge	0.90
Middle Member		
	Calcareous mudstone: moderate reddish orange (10R6/6) to moderate orange pink (10R7/4) weathers same, sand and silt lenses at some places, upper 10 cm interbedded with gray dolomite, forms slope.	1.50
Lower Member		
	Medium to finely crystalline dolomite; pinkish gray (5YR8/1) weathers light brownish gray (5YR6/1) to light brown (5YR5/6), laminated, intensely fractured, appears brecciated at some places, brown chert beads throughout, chert nodules up to 25 cm long in upper 50 cm, undulating exposed upper and lower surfaces, forms prominent ledge.	3.10
Whitehorse Formation		
	Red beds: upper 50-75 cm grade into greenish gray (5GY6/1) claystone, fractured, calcareous, forms slope.	not measured
	Total measured section	5.50

Measured Section P-8

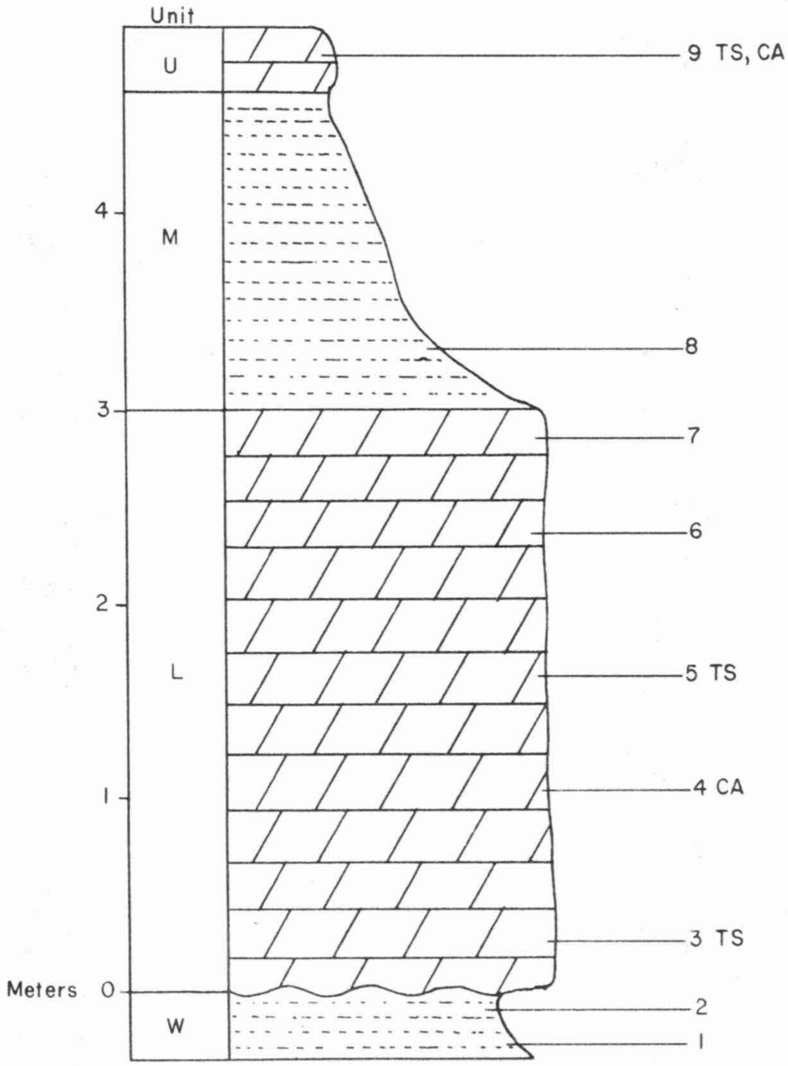


Measured Section P-9

Outcrop measured at the rim of a bluff about 225 m east of the Alibates National Monument boundary (fence) and about 1,000 m south of the Alibates Flint Quarries ridge, Bivins Ranch, Potter County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Upper Member		
	Chert: dusky red (5R3/4) to pale red purple (5RP6/2) weathers same, banded, fractures filled with white to gray quartz, some cavities lined with quartz crystals, covered by soil and vegetation	0.33
Middle Member		
	Red beds: covered with vegetation, estimated thickness.	1.65
Lower Member		
	Medium to finely crystalline dolomite: pinkish gray (5YR8/1) to light brownish gray (5YR6/1) weathers pale yellowish brown (10YR6/2), laminated, fractured, sporadic chertification along fractures in upper 50-60 cm, forms prominent ledge	3.00
Whitehorse Formation		
	Red beds: pale reddish brown (10R5/4) weathers same, upper 30-75 cm grade into light greenish gray (5GY8/1) claystone, forms steep slope	not measured
	Total measured section	4.98

Measured Section P-9

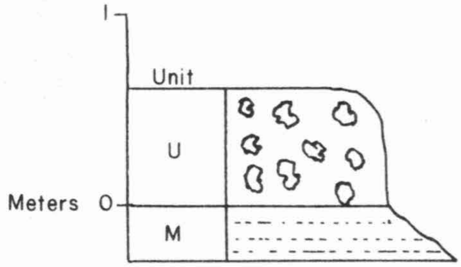


Measured Section P-9A

Section measured on top of ridge in several quarry depressions at the Alibates Flint Quarries, Alibates National Monument, Potter County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Upper Member		
	Chert: pinkish gray (5YR8/1), grayish orange pink (5YR7/2), grayish red purple (5RP4/2), dark reddish brown (10R3/4), and brownish gray (5YR4/1) weathers same, multicolored bands, fractured, some fractures filled with gray quartz, relic sedimentary breccia at some places, covered with thin (5-20 cm) soil and vegetation.	0.60
Middle Member		
	Red beds: exposed only in isolated quarry pits	not measured
	Total measured section	0.60

Measured Section P-9A



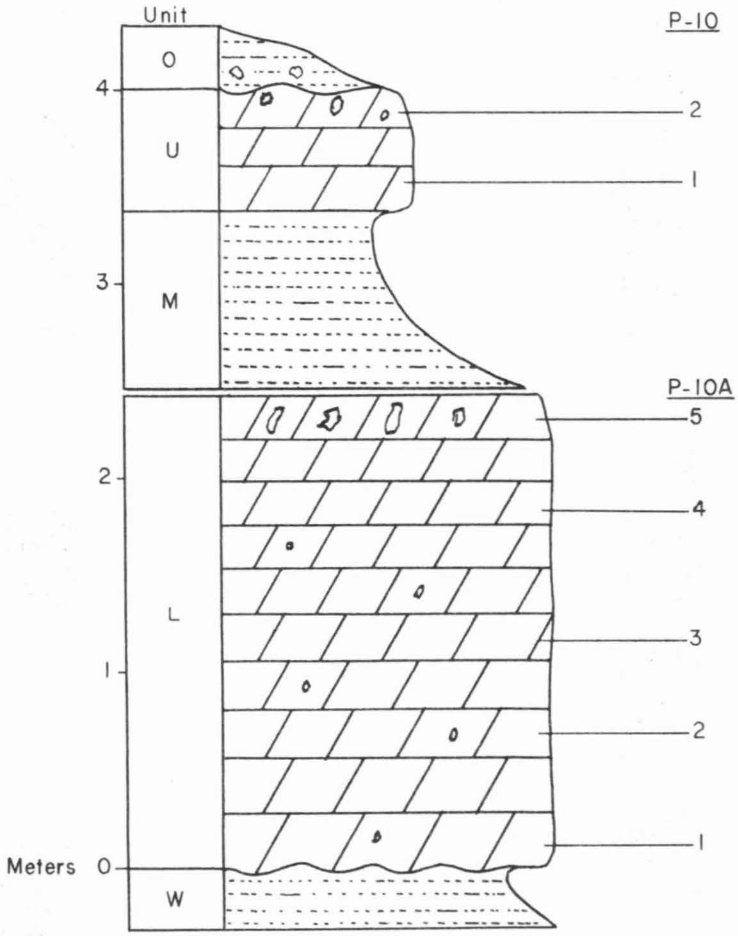
Float samples only

Measured Sections P-10 and P-10A

Upper and middle members measured in creek bed of Short Creek about 0.4 km (0.25 mi) downstream (northwest) from Short Creek bridge on State Highway 136; lower member measured approximately 0.8 km (0.5 mi) downstream from bridge, near confluence of Short Creek and two tributaries from northeast, Potter County, Texas.

Unit	Description	Thickness (meters)
TERTIARY		
Ogallala Formation		
	Sandstone: light brown (5YR6/4), calcareous . . .	not measured
PERMIAN		
Alibates Dolomite		
Upper Member		
	Medium to finely crystalline dolomite: pinkish gray (5YR8/1) to yellowish gray (5Y8/1) weathers same, laminated, fractured, hard, sporadic chertification in upper 10-15 cm, forms ledge.	0.62
Middle Member		
	Red beds: form slope, estimated thickness	0.95
Lower Member		
	Medium to finely crystalline dolomite: pinkish gray (5YR8/1) weathers same, laminated, intensely fractured at some places, distinctly jointed, brown chert nodules (5-7 cm long) in upper 50 cm, scattered chert beads throughout, covered with grass, forms ledge.	2.45
Whitehorse Formation		
	Red beds: form slope and creek bed	not measured
	Total measured section	4.02

Measured Sections P-10 and P-10A

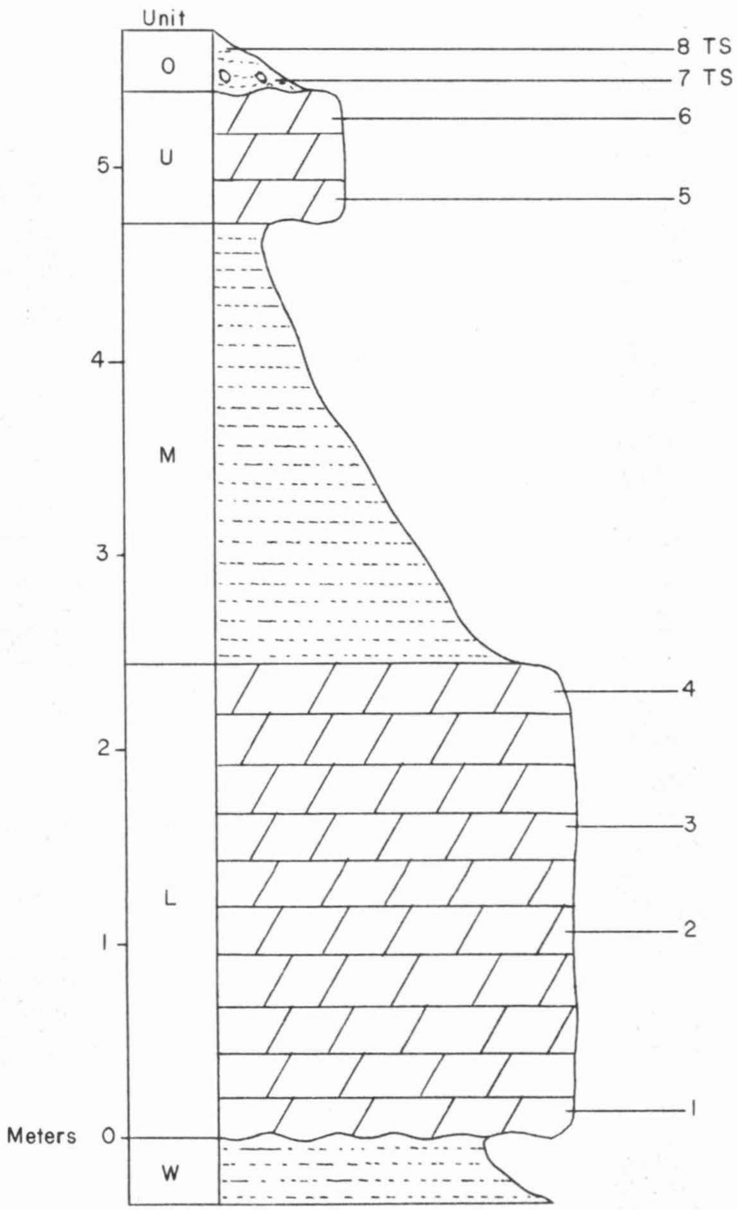


Measured Section M-1

Outcrop measured about 50 m east of Blue West road near the top of the hill on the northwest side of Chimney Hollow Creek, 4.8 km (3.0 mi) from the intersection of Blue West road and Farm Road 1913, Lake Meredith Recreation Area, Moore County, Texas.

Unit	Description	Thickness (meters)
TERTIARY		
Ogallala Formation		
	Sandstone: light brown (5YR5/6) weathers same, calcareous, covered by vegetation.	not measured
PERMIAN		
Alibates Dolomite		
Upper Member		
	Medium to finely crystalline dolomite: pinkish gray (5YR8/1) to very pale orange (10YR8/2) weathers same, laminated, intensely fractured, brecciated at some places, possible desiccation cracks on undulating upper surface, chert beads scattered in upper 10 cm, forms ledge.	0.70
Middle Member		
	Red beds: covered by Ogallala float, forms slope, estimated thickness	2.26
Lower Member		
	Medium to finely crystalline dolomite: color same as upper member, distinctly laminated, fractured, chert beads in upper 5 cm, incipient calcitization at some places, isolated gray siltstone lenses in upper 35-40 cm, forms prominent ledge.	2.44
Whitehorse Formation		
	Red beds: form steep slope.	not measured
	Total measured section	5.40

Measured Section M-1

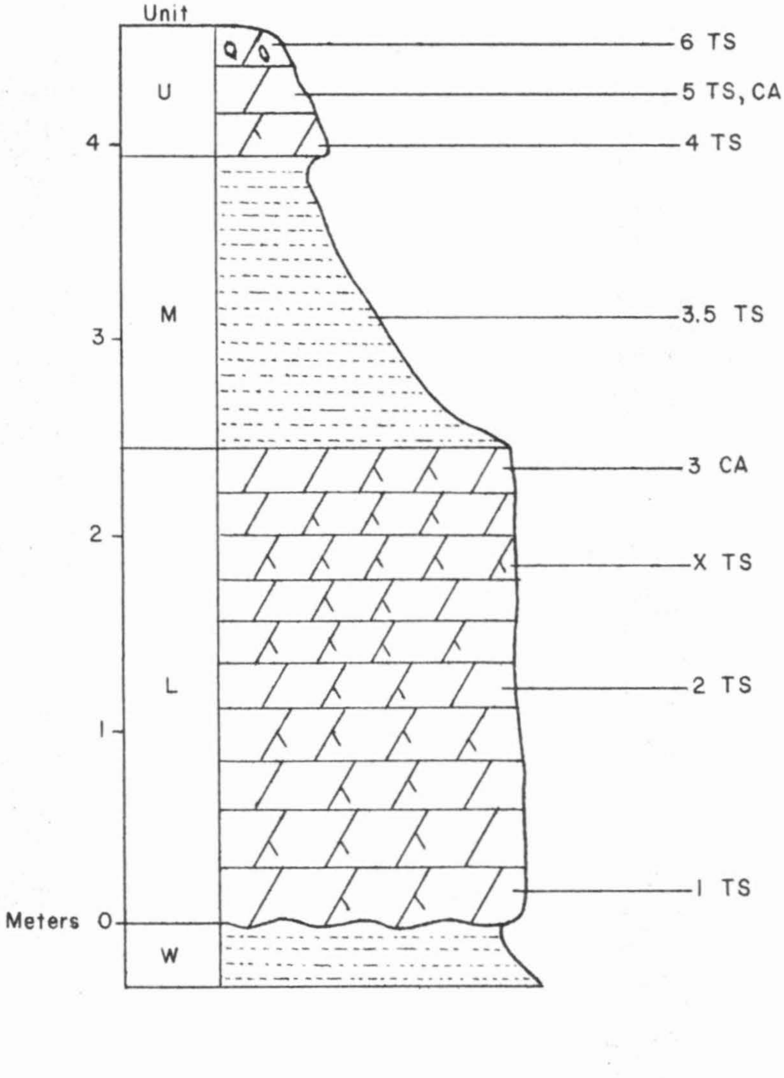


Measured Section M-2

Section measured on rim of the bluff east of and overlooking Harbor Bay campground and Lake Meredith, 2.7 km (1.7 mi) west of Fritch, Lake Meredith Recreation Area, Moore County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Upper Member		
	Medium to finely crystalline dolomite: grayish orange pink (10R8/2) to light gray (N7) weathers light brown (5YR6/4), laminated, intensely fractured, sporadic chertification in upper 25 cm, badly weathered, covered by vegetation	0.68
Middle Member		
	Red beds: calcareous, fractured, several thin (2-10 cm) beds of sandstone and sandy dolomite in lower 75 cm, forms slope	1.50
Lower Member		
	Medium to finely crystalline dolomite: pinkish gray (5YR8/1) weathers same, laminated, fractured, distinctly jointed, brecciated in upper 50-60 cm, extensively calcitized, "boxworks" throughout, limestone resembles mortar on dolomite bricks, boxes filled with sucrosic, friable dolomite, forms prominent ledge.	2.45
Whitehorse Formation		
	Red beds: contains beds (30-75 cm thick) of gypsum, dolomite, and sandstone, forms steep slope.	not measured
	Total measured section	4.63

Measured Section M-2

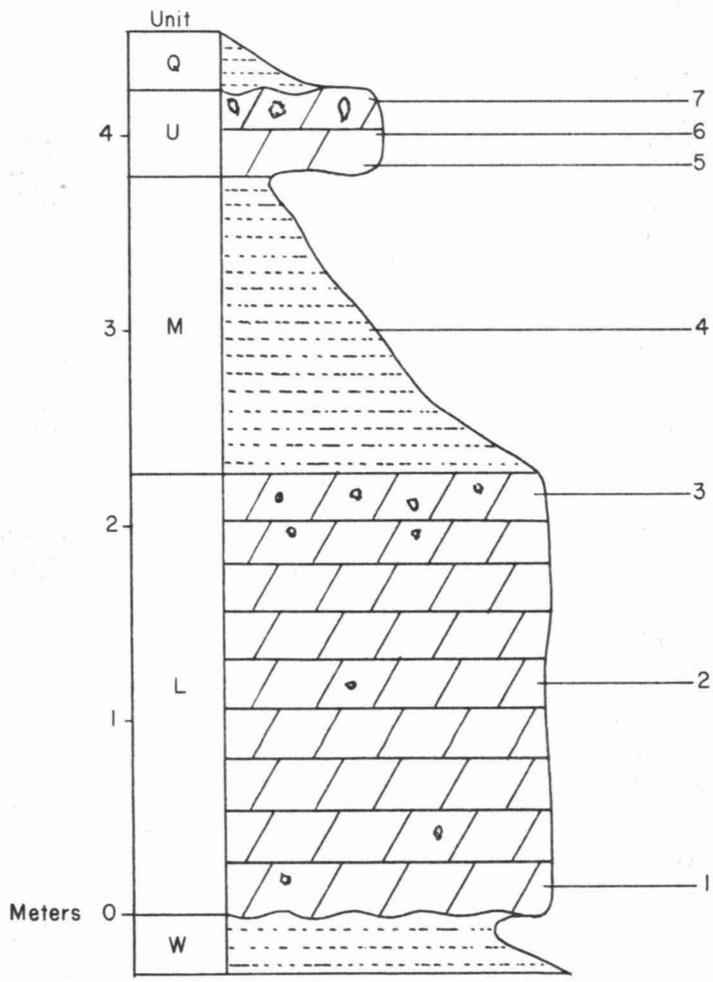


Measured Section H-2

Outcrop measured in creek bed of Bugbee Creek about 50 m downstream (south) from dirt road crossing and dam, 3.2 km (2.0 mi) west on Bugbee Shores road from intersection of Ranch Road 687, Hutchinson County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Quartermaster Formation		
	Red beds	not measured
Alibates Dolomite		
Upper Member		
	Medium to finely crystalline dolomite: yellowish gray (5Y8/1) weathers same, laminated, intensely fractured, brecciated at some places, brown chert beads and nodules in upper 10-15 cm, top and bottom surfaces irregular and undulating, forms prominent ledge.	0.45
Middle Member		
	Mudstone: pale reddish brown (10R5/4) weathers same, thinly bedded, calcareous, forms slope.	1.52
Lower Member		
	Medium to finely crystalline dolomite: pinkish gray (5YR8/1) to yellowish gray (5Y8/1) weathers same, laminated, chert beads in upper 30 cm, upper surface broadly undulating, forms ledge.	2.28
Whitehorse Formation		
	Red beds: exposed in creek bed.	not measured
	Total measured section	4.25

Measured Section H-2

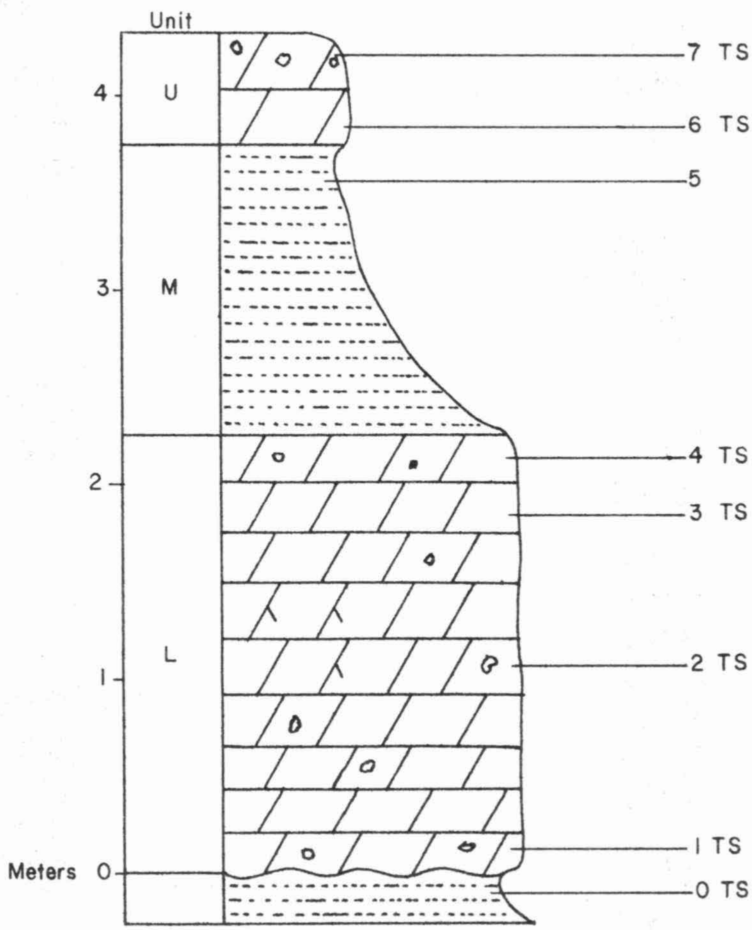


Measured Section H-3

Outcrop at top of the bluff on the west side of gravel road to swimming area at the base of Sanford Dam, 1.0 km (0.65 mi) from intersection with Ranch Road 687, Lake Meredith Recreation Area, Hutchinson County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
	Upper Member	
	Medium to finely crystalline dolomite: yellowish gray (5Y8/1) weathers pinkish gray (5YR8/1) laminated, fractured, sporadic chertification in upper 10-20 cm, upper surface undulating, forms ridge.	0.58
	Middle Member	
	Red beds: covered with vegetation	1.50
	Lower Member	
	Medium to finely crystalline dolomite: yellowish gray (5Y8/1) weathers pale yellowish brown (10YR6/2), distinctly laminated, fractured, chert beads throughout, incipient calcitization at some places, forms ledge.	2.28
Whitehorse Formation		
	Red beds: form steep slope.	not measured
	Total measured section	4.36

Measured Section H-3

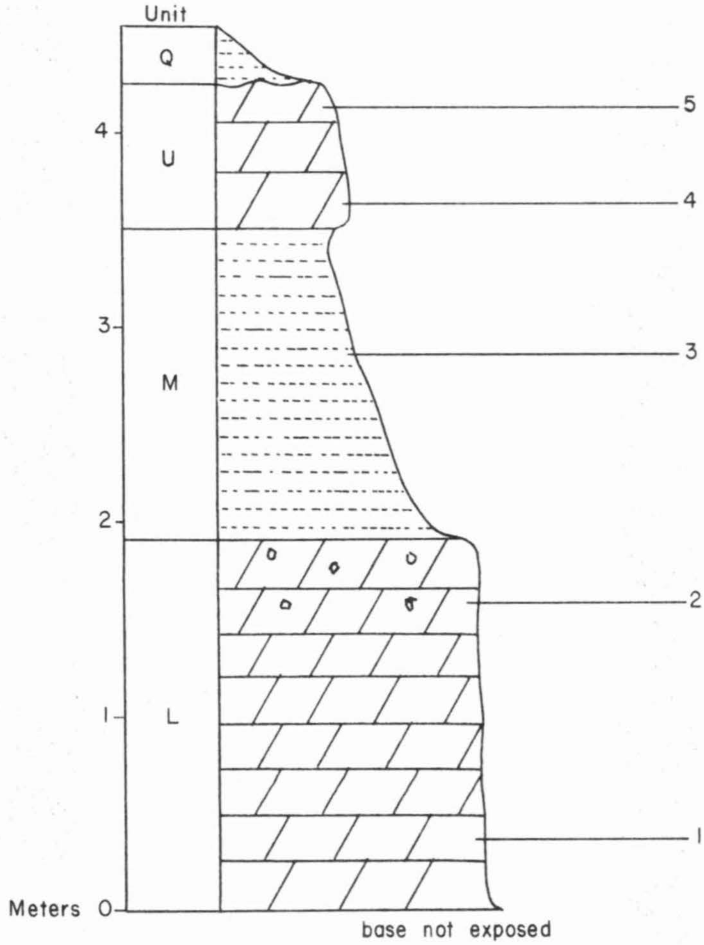


Measured Section H-4

Outcrop in creek bed of Antelope Creek, about 100 m downstream (north) from Antelope Creek bridge on State Highway 136, Hutchinson County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Quartermaster Formation		
	Red beds	not measured
Alibates Dolomite		
Upper Member		
	Medium to finely crystalline dolomite: pinkish gray (5YR8/1) to yellowish gray (5Y8/1) weathers same, laminated, fractured, brecciated at some places, undulating top surface, forms ledge	0.76
Middle Member		
	Red beds: form slope.	1.60
Lower Member		
	Medium to finely crystalline dolomite: pinkish gray (5YR8/1) to yellowish gray (5Y8/1) weathers same, laminated, fractured, brecciated at a few places, chert beads in upper 30-50 cm, forms ledge, base not exposed. . .	1.90
	Total measured section	4.26

Measured Section H-4

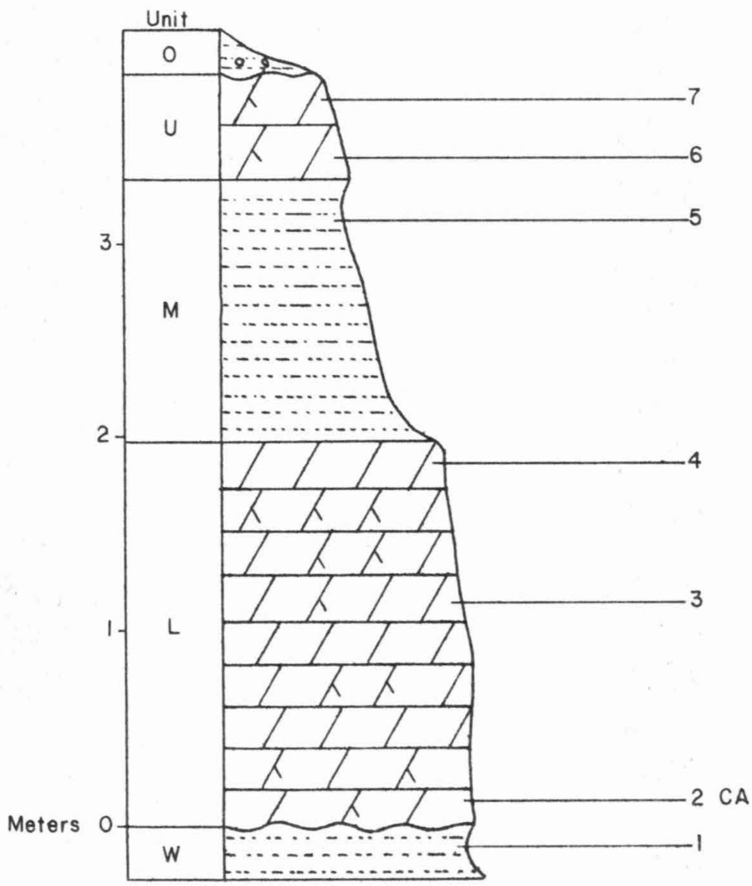


Measured Section H-5

Exposure along east side of Big Creek, about 100 m north of intersection of Ranch Road 687 and small tributary to Big Creek, 0.56 km (0.35 mi) northeast of Big Creek bridge, Hutchinson County, Texas.

Unit	Description	Thickness (meters)
TERTIARY		
Ogallala Formation		
	Sandstone.	not measured
PERMIAN		
Alibates Dolomite		
Upper Member		
	Medium to finely crystalline dolomite: pinkish gray (5YR8/1) to very pale orange (10YR8/2), laminated, intensely fractured, brecciated at many places, calcitized "boxworks" at some places, forms ledge	0.55
Middle Member		
	Red beds: calcareous, form slope.	1.37
Lower Member		
	Medium to finely crystalline dolomite, yellowish gray (5Y8/1) to very pale orange (10YR8/2) weathers dark yellowish brown (10YR4/2), laminated, fractured, calcitized "boxworks" well developed at many places, forms ledge.	1.98
Whitehorse Formation		
	Red beds: calcareous, form slope.	not measured
	Total measured section	3.90

Measured Section H-5

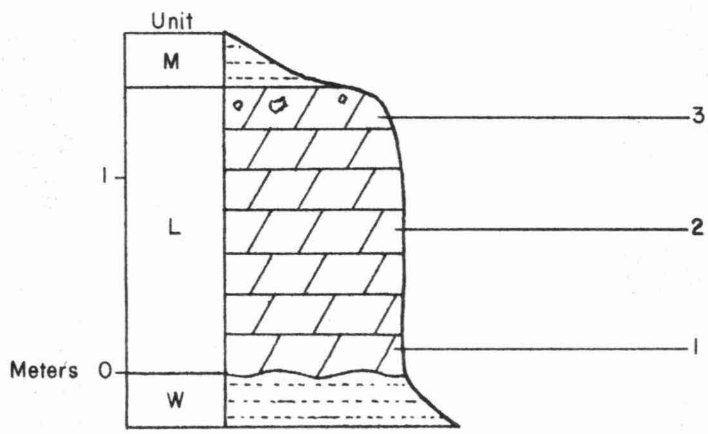


Measured Section H-6

Exposure in road cut on the south side of State Highway 136 at the west city limit of Bunavista, Hutchinson County, Texas

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Middle Member(?)		
	Red beds: covered with vegetation	not measured
Lower Member		
	Medium to finely crystalline dolomite: very pale orange (10YR8/2) to pinkish gray (5YR8/1) weathers same, laminated, fractured, scattered chert beads in upper 10-15 cm, forms ledge.	1.47
Whitehorse Formation		
	Red beds: form slope.	not measured
	Total measured section	1.47

Measured Section H-6

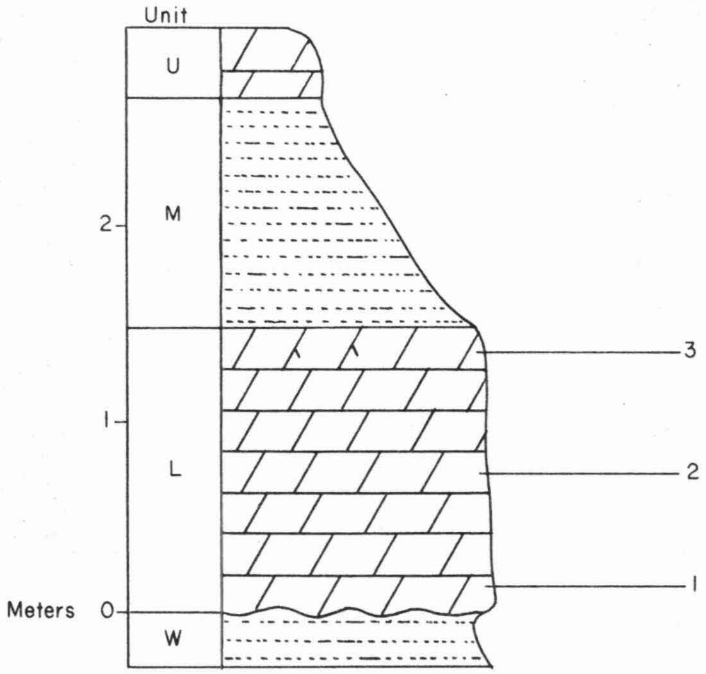


Measured Section H-7

Section measured at the top of hill near power lines on the south side of FM Road 1559, 0.6 km (0.4 mi) northwest of the intersection of FM 1559 and State Highways 136, 152, and 207, Electric City, Hutchinson County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
	Upper Member	
	Dolomite, not accessible	not measured
	Middle Member	
	Red beds: thickness estimated	1.20
	Lower Member	
	Medium to finely crystalline dolomite: pinkish gray (5YR8/1) to very pale orange (10YR8/2) weathers same, distinctly laminated, fractured, brecciated at some places, possible incipient calcitization in upper 20 cm, forms ledge	1.47
Whitehorse Formation		
	Red beds: form slope	not measured
	Total measured section	2.67

Measured Section H-7

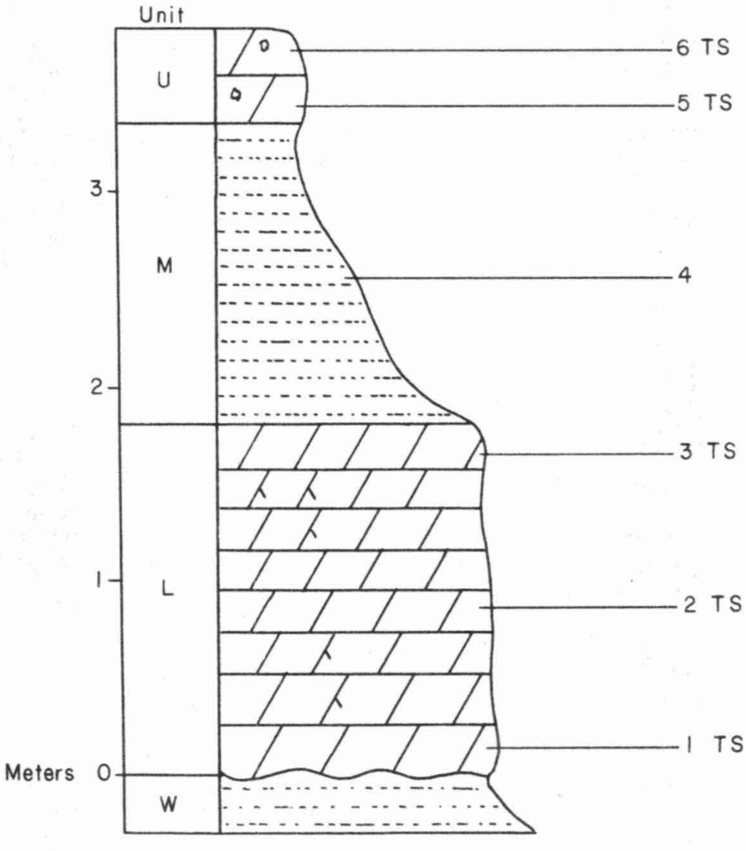


Measured Section H-8

Outcrop near the top of hill on the east side of State Highway 207 (also 136 and 152), 2.2 km (1.4 mi) north of Canadian River bridge, Hutchinson County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Upper Member		
	Medium to finely crystalline dolomite: grayish orange pink (10R8/2) to very pale orange (10YR8/2) weathers same, intensely brecciated, sucrosic, numerous solution cavities, sporadic chert nodules and beads, forms ledge	0.50
Middle Member		
	Red beds: covered with vegetation	1.52
Lower Member		
	Medium to finely crystalline dolomite: colors same as upper member, laminated, fractured, brecciated at some places, localized zones of calcitization, sucrosic, friable, forms ledge	1.80
Whitehorse Formation		
	Red beds: covered with vegetation, form slope	not measured
	Total measured section	3.82

Measured Section H-8

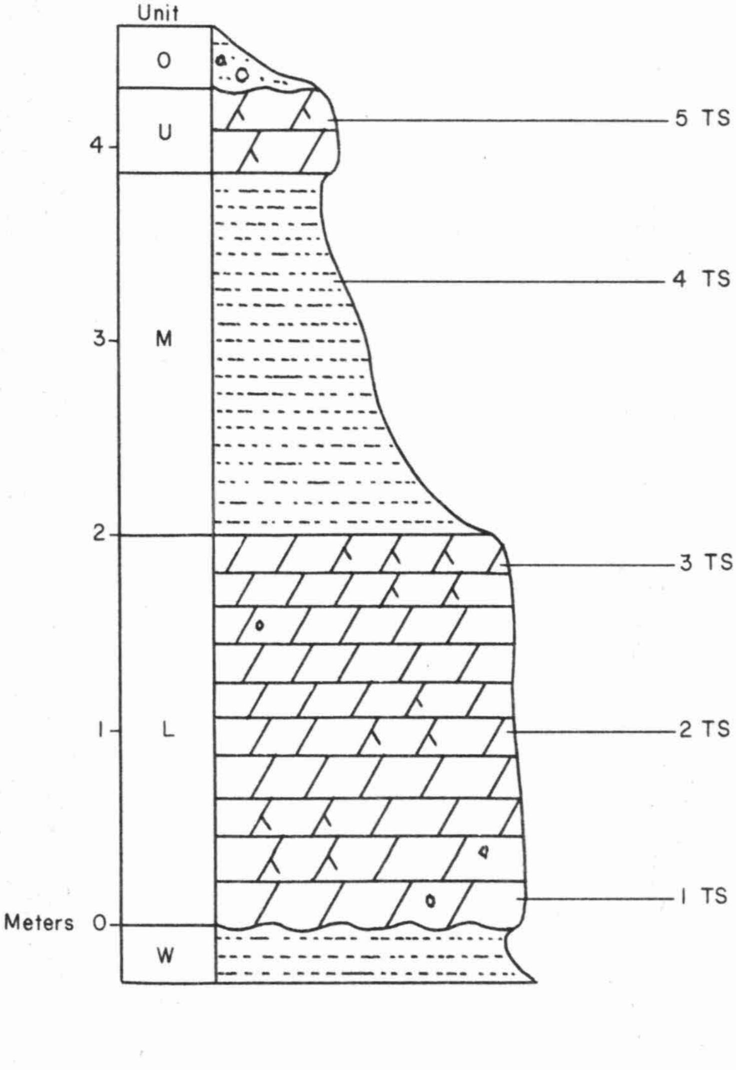


Measured Section H-9

Section measured on hillside southwest of the intersection of State Highway 152 and Dixon Creek, Hutchinson County, Texas.

Unit	Description	Thickness (meters)
TERTIARY		
Ogallala Formation		
	Sandstone: covered with vegetation.	not measured
PERMIAN		
Alibates Dolomite		
Upper Member		
	Medium to finely crystalline dolomite: pinkish gray (5R8/2) to very pale orange (10YR8/2) weathers same, brecciated throughout, extensively calcitized, weathers to rough, pitted surface, forms ledge.	0.45
Middle Member		
	Red beds: covered with vegetation	1.87
Lower Member		
	Medium to finely crystalline dolomite: colors same as upper member, laminated, upper 20 cm brecciated, calcitized "boxworks" at a few places, chert beads scattered throughout, lower 50 cm friable, forms ledge.	2.00
Whitehorse Formation		
	Red beds: form steep slope, covered with vegetation	not measured
	Total measured section	4.32

Measured Section H-9

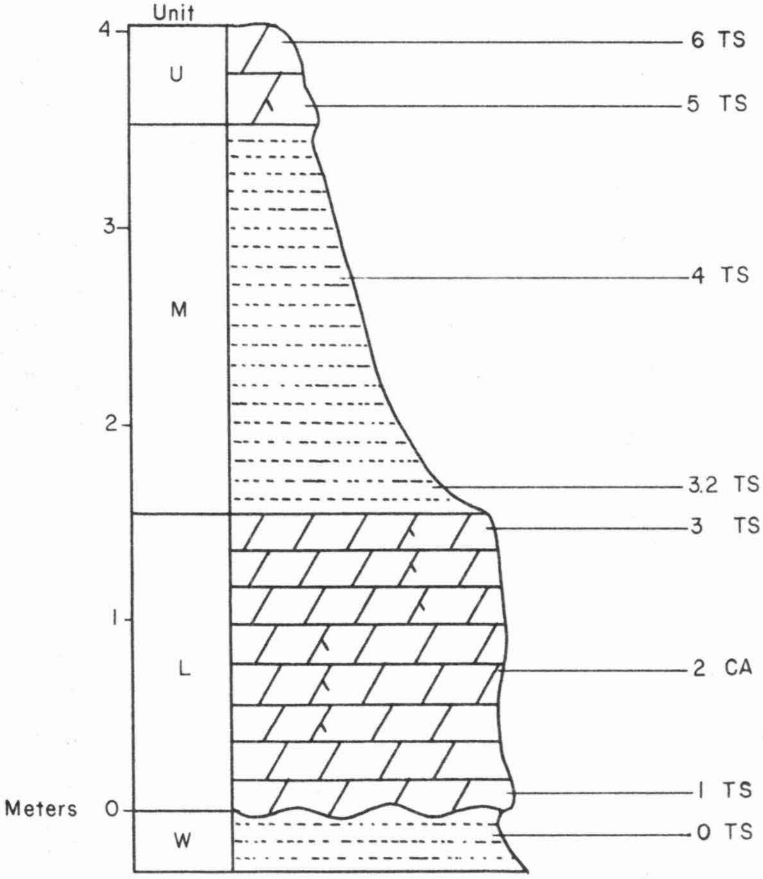


Measured Section H-10

Outcrop on the northeast side of the intersection of Bear Creek and Farm Road 280, 1.3 km (0.8 mi) northwest of the end of pavement on Farm Road 280, Hutchinson County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Upper Member		
	Medium to finely crystalline dolomite: very pale orange (10YR8/2 weathers light brown (5YR6/4), intensely fractured and brecciated, weathers easily, breccia possible result of calcitization, forms small ledge.	0.50
Middle Member		
	Mudstone: pale reddish brown (10R5/4) weathers same, calcareous, interbedded dolomite in lower 20-30 cm, forms slope.	2.00
Lower Member		
	Medium to finely crystalline dolomite: very pale orange (10YR8/2) to pinkish gray (5R8/2) weathers same, laminated, fractured, brecciated at many places, breccia includes clasts of brown claystone, calcitization at some places along fractures, forms ledge.	1.53
Whitehorse Formation		
	Red beds: form slope.	not measured
	Total measured section	4.03

Measured Section H-10

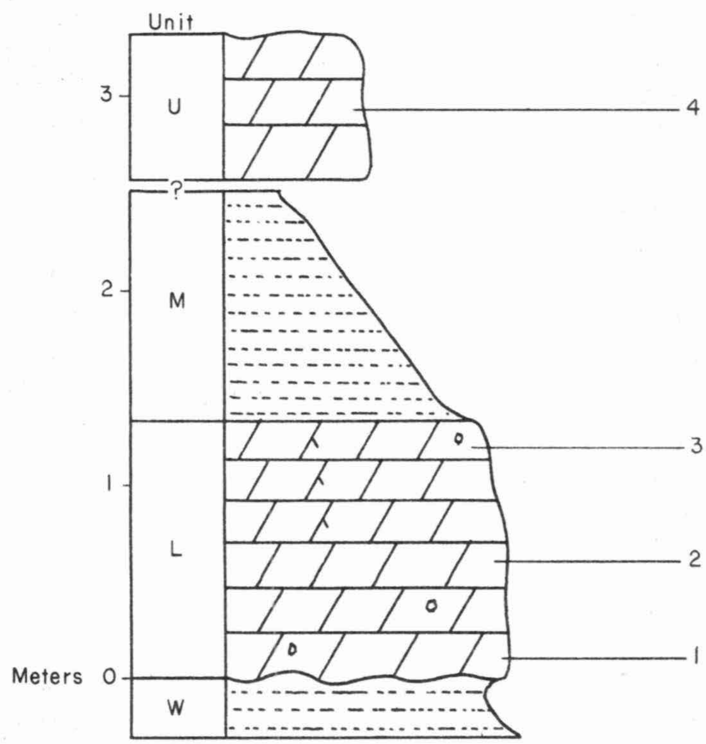


Measured Section H-11

Exposure of Alibates Dolomite capping a small butte, 0.8 km (0.5 mi) east northeast of Plemons, Hutchinson County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Upper Member(?)		
	Medium to finely crystalline dolomite: very pale orange (10YR8/2) weathers same, distinctly laminated, fractured, slump blocks, estimated thickness.	0.80
Middle Member		
	Red beds: erosion surface, estimated thickness.	1.20
Lower Member		
	Medium to finely crystalline dolomite: very pale orange (10YR8/2) to pale yellowish brown (10YR6/2) weathers same, laminated, fractured, brecciated at many places, possible calcitization along some fractures, scattered chert beads and nodules, forms ledge.	1.32
Whitehorse Formation		
	Red beds: covered with vegetation, form slope . .	not measured
	Total measured section	3.32

Measured Section H-11

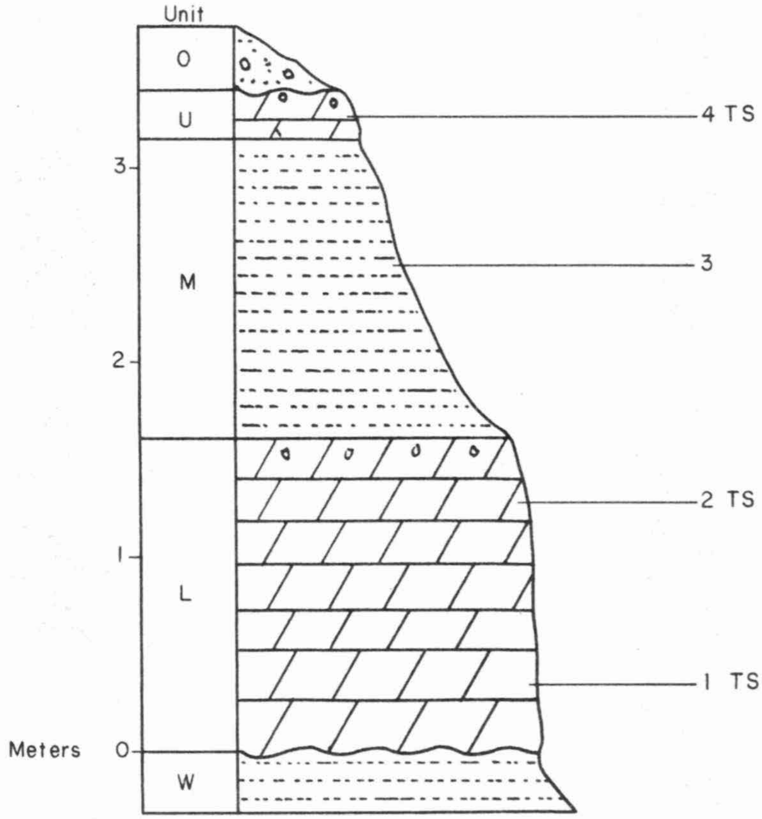


Measured Section C-1

Exposure on west hillside, about 100 m north of Perkins-Prothro Company well, Burnett #2, 2.4 km (1.5 mi) east of State Highway 207 and Burnett Camp, Carson County, Texas.

Unit	Description	Thickness (meters)
TERTIARY		
Ogallala Formation		
	Sandstone: covered with vegetation, forms slope.	not measured
PERMIAN		
Alibates Dolomite		
Upper Member		
	Medium to finely crystalline dolomite: pale pink (5RP8/2) weathers grayish orange pink (10R8/2), distinctly laminated, fractured, scattered chert beads in upper 10 cm, possible calcitization at some places, solution along some fractures, forms ledge	0.25
Middle Member		
	Red beds: covered with vegetation, forms slope.	1.55
Lower Member		
	Medium to finely crystalline dolomite: pale red (10R6/2) to very pale orange (10YR8/2) weathers grayish orange pink (5YR7/2), distinctly laminated, some fracturing, chert beads in upper 5 cm, hard resistant, forms ledge	1.60
Whitehorse Formation		
	Red beds: forms slope	not measured
	Total measured section	3.40

Measured Section C-1

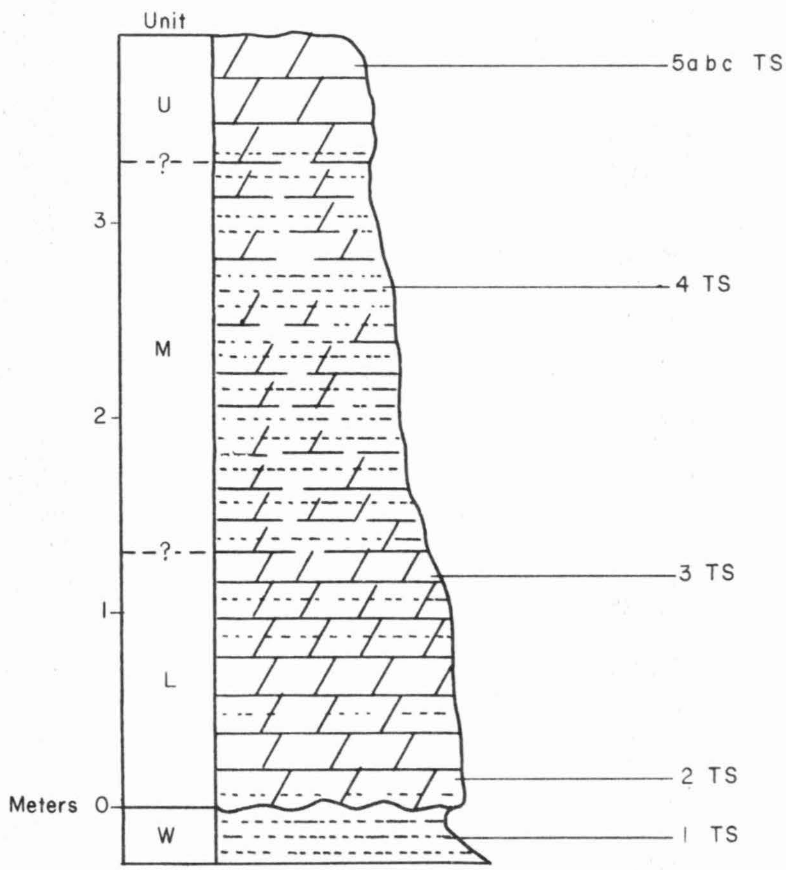


Measured Section G-1

Section measured along steep rim of the bluff about 200 m east of Lake McClellan dam, Gray County, Texas.

Unit	Description	Thickness (meters)
PERMIAN		
Alibates Dolomite		
Upper Member		
	Medium to finely crystalline dolomite: pale yellow brown (10YR6/2) to moderate orange pink (5YR8/4) weathers same, laminated, fractured, brecciated at some places, chert nodules in upper 10-20 cm, grades vertically downward into interlaminated dolomite and maroon mudstone, forms ledge, estimated thickness	0.65
Middle Member(?)		
	Medium to finely crystalline dolomite: moderate orange pink (5YR8/4) weathers same, laminated to thinly bedded, fractured, interbedded with gray to green siltstone and claystone, calcitized(?) "boxworks" throughout, distinct "lumpy" weathered surface, dolomite beds increase vertically downward, forms ledge, estimated thickness.	2.00
Lower Member(?)		
	Medium to finely crystalline dolomite: moderate orange pink (5YR8/4) weathers same, laminated, fractured, brecciated at some places, clasts and lenses of darker brown mudstone and claystone throughout dolomite, forms ledge, estimated thickness.	1.30
Whitehorse Formation		
	Red beds: covered with vegetation, forms slope. .	not measured
	Total measured section	3.95

Measured Section G-1

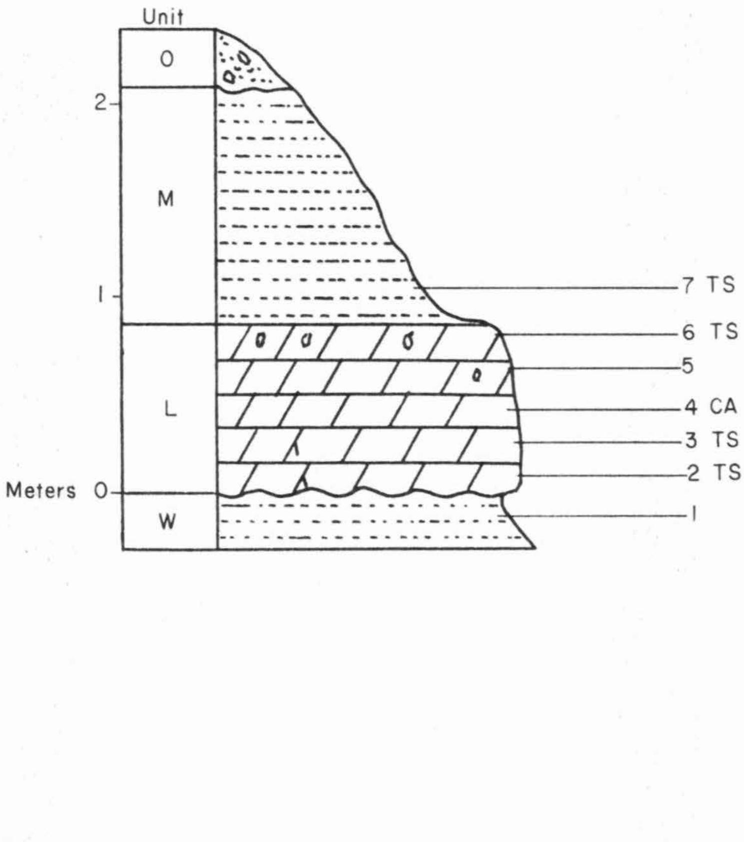


Measured Section D-1

Outcrop and roadcut on the east side of State Highway 70, 0.6 km (0.4 mi) north of bridge over the Salt Fork of the Red River, Donley County, Texas.

Unit	Description	Thickness (meters)
TERTIARY		
Ogallala Formation		
	Sandstone: covered with vegetation.	not measured
PERMIAN		
Alibates Dolomite		
Middle Member?		
	Covered slope, estimated thickness	1.20
Lower Member		
	Medium to finely crystalline dolomite: pinkish gray (5YR8/1) to grayish orange pink (5YR7/2) weathers moderate orange pink (5YR8/4) to light brown (5YR6/4), faintly laminated, fractured sporadic chertification along fractures in upper 15-20 cm, exposed upper surface undulating and marked with abundant dendrites, possible calcitization at some places, forms ledge.	0.87
Whitehorse Formation		
	Red beds: calcareous, gypsiferous, form steep slope.	not measured
	Total measured section	2.07

Measured Section D-1

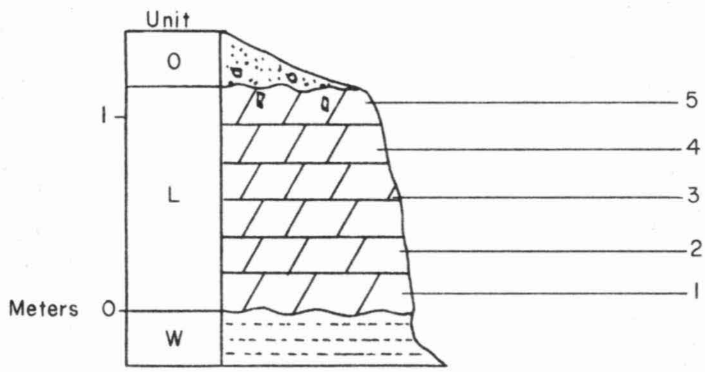


Measured Section D-2

Section measured in rock quarry on the west side of Turkey Creek along dirt road to Hip O Ranch, 2.6 km (1.6 mi) east of intersection with State Highway 70. Intersection is 7.4 km (4.6 mi) north of the Salt Fork of the Red River bridge, Donley County, Texas.

Unit	Description	Thickness (meters)
TERTIARY		
Ogallala Formation		
	Sandy conglomerate: covered with vegetation . . .	not measured
PERMIAN		
Alibates Dolomite		
Lower Member		
	Medium to finely crystalline dolomite: pinkish gray (5YR8/1) to moderate orange pink (5YR8/4) weathers same, faintly laminated, fractured, possible incipient chertification in upper 10-15 cm, lower 10 cm grade into dolomitic mudstone, forms ledge.	1.15
Whitehorse Formation		
	Red beds: sandy, calcareous, form slope	not measured
	Total measured section	1.15

Measured Section D-2



PETROGRAPHIC DATA

Slide Number	Unit	Rock Name
P-1-6	U	Finely crystalline dolomite
P-1-5	U	Finely to very finely crystalline dolomite
P-1-4	M	Dolomitic immature orthoquartzite mudstone
P-1-2	M	Dolomitic immature orthoquartzite mudstone
P-1-1	M	Finely crystalline dolomite
P-1-0	L	Medium to finely crystalline dolomite
P-2-2	L	Medium to finely crystalline dolomite
P-2-1	L	Medium to finely crystalline dolomite
P-2A-6b	L	Finely crystalline dolomite
P-2A-6a	L	Chertified medium to finely crystalline dolomite
P-2A-5	L	Medium to finely crystalline dolomite
P-2A-4	L	Medium to finely crystalline dolomite
P-2A-3	L	Partly-chertified medium to very finely crystalline dolomite
P-2A-2b	L	Partly-chertified medium to finely crystalline dolomite
P-2A-2a	L	Chertified medium to finely crystalline dolomite
P-2A-1	L	Medium to finely crystalline dolomite
P-2B-2	L	Medium to finely crystalline dolomite
P-2B-1	L	Partly-chertified, partly-calcitized finely to very finely crystalline dolomite

Unit: O=Ogallala, Q=Quartermaster, U=Upper Alibates, M=Middle Alibates, L=Lower Alibates, W=Whitehorse

SLIDE NUMBER	DOLOMITE			CALCITE		CHERT							DETRITUS					OPAQUE MINERALS
				PORE-FILL SPAR	REPLACEMENT SPAR	MEGAQUARTZ	MICROCRYSTALLINE QUARTZ				CHALCEDONITE	QUARTZINE - LUTECITE	SAND	SILT	CLAY	FELDSPAR	MICA	
	MC	FC	VFC				CG	MG	FG	VFG-UFG								
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
P-1-6	1	96	2			1												
P-1-5		95	5			tr												
P-1-4			29	tr										21	50	tr	tr	tr
P-1-2		3	8											24	64	tr	tr	tr
P-1-1		100	tr			tr								tr			tr	
P-1-0	6	93	tr			1												tr
P-2-2	38	55	2					2	2		1			tr				tr
P-2-1	8	88	4															tr
P-2A-6b	1	95	3			1			tr		tr		tr				tr	tr
P-2A-6a	51	30	2			tr		1	2		14		tr					tr
P-2A-5	15	82	3	tr									tr					tr
P-2A-4	6	91	3	tr							tr		tr					tr
P-2A-3	9	65	15					2	3				2	tr				2
P-2A-2b	6	81	4	tr					1		5		3	tr	tr			tr
P-2A-2a	13	65	4			3			2		13							tr
P-2A-1	25	71	4															tr
P-2A-2	36	59	1						3	1			tr					tr
P-2B-1	2	72	5	tr	8				5	3	tr	5	tr		tr			tr

Slide Number	Unit	Rock Name
P-3-L	L	Silty fine sandstone; calcitic, submature, subarkose
P-3-10	L	Medium to finely crystalline dolomite
P-3-9	L	Medium to very finely crystalline dolomite
P-3-8	L	Medium to finely crystalline dolomite
P-3-6	L	Medium to finely crystalline dolomite
P-3-5	L	Medium to finely crystalline dolomite
P-3-4	L	Medium to finely crystalline dolomite
P-3-3	L	Medium to finely crystalline dolomite
P-3-2b	L	Medium to finely crystalline dolomite
P-3-2a	L	Partly-chertified finely to very finely crystalline dolomite
P-4-6b	O	Fine sandstone: ferruginous, submature, quartzarenite
P-4-6a	U	Banded chert
P-4-4	L	Medium to finely crystalline dolomite
P-4-F1	L	Dolomitic banded chert
P-5-3	L	Medium to very finely crystalline dolomite
P-5-2	L	Medium to finely crystalline dolomite
P-5-1	L	Medium to very finely crystalline dolomite

SLIDE NUMBER	DOLOMITE			CALCITE		CHERT							DETRITUS					OPAQUE MINERALS
				PORE-FILL SPAR	REPLACEMENT SPAR	MEGAQUARTZ	MICROCRYSTALLINE QUARTZ				CHALCEDONITE	QUARTZINE - LUTECITE	SAND	SILT	CLAY	FELDSPAR	MICA	
	MC	FC	VFC				CG	MG	FG	VFG-UFG								
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
P-3-L				36									46	14	tr	3	1	tr
P-3-10	19	78	3										tr					tr
P-3-9	14	80	6										tr		tr			tr
P-3-8	47	50	3										tr		tr			tr
P-3-6	52	47	1										tr					tr
P-3-5	26	74	tr										tr					tr
P-3-4	31	69	tr															tr
P-3-3	66	34	tr										tr					tr
P-3-2b	22	78	tr										tr					tr
P-3-2a	4	84	6					1	3	2			tr					tr
P-4-6b				2									92			5	tr	tr
P-4-6a						1	15	20	25	31	8		tr				tr	tr
P-4-4	71	28	tr	1									tr				tr	tr
P-4-F1	2	7	tr			7	9	33	35	3	3	?	1				tr	tr
P-5-3	49	42	5	4									tr		tr			tr
P-5-2	64	34	tr	1									tr		tr			1
P-5-1	36	59	5			tr							tr				tr	tr

Slide Number	Unit	Rock Name
P-6-X	L	Dolomitic medium crystalline calcitized limestone
P-7-6c	L	Chertified medium to finely crystalline dolomite
P-7-6b	L	Chertified medium to very finely crystalline dolomite
P-7-6a	L	Chertified medium to finely crystalline dolomite
P-7-5	L	Medium to finely crystalline dolomite
P-7-4	L	Medium to very finely crystalline dolomite
P-7-3	L	Chertified medium to finely crystalline dolomite
P-7-2	L	Medium to finely crystalline dolomite
P-7-1	L	Calcitized medium to very finely crystalline dolomite
P-9-F	U	White chert
P-9-9	U	Medium to finely crystalline dolomite
P-9-6	L	Medium to finely crystalline dolomite
P-9-5	L	Medium to finely crystalline dolomite
P-9-3	L	Medium to finely crystalline dolomite
P-9A-F5	U	Banded chert
P-9A-F4	U	Banded chert
P-9A-F3	U	Banded chert
P-9A-F2	U	Banded chert

SLIDE NUMBER	DOLOMITE			CALCITE		CHERT							DETRITUS					OPAQUE MINERALS
				PORE-FILL SPAR	REPLACEMENT SPAR	MEGAQUARTZ	MICROCRYSTALLINE QUARTZ				CHALCEDONITE	QUARTZINE-LUTECITE	SAND	SILT	CLAY	FELDSPAR	MICA	
	MC	FC	VFC				CG	MG	FG	VFG-UFG								
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
P-6-X		23	9		68								tr					tr
P-7-6c	60	12	tr			tr		4	11		13							tr
P-7-6b	21	57	6			1	1	7	4		3		tr					tr
P-7-6a	19	65	4			tr	1	2	6		3		tr		tr			tr
P-7-5	61	39	tr												tr			tr
P-7-4	26	67	7										tr					tr
P-7-3	33	37	tr			tr		12	8	1	9							tr
P-7-2	78	18	4										tr				tr	tr
P-7-1	5	59	6		25	3						2	tr					tr
P-9-F									tr	100								tr
P-9-9	79	13	tr	2									5			tr		1
P-9-6	29	67	1															3
P-9-5	23	74	3															tr
P-9-3	30	67	3															tr
P-9A-F5				tr		1	51	33	4	1	9	1	tr		tr		tr	tr
P-9A-F4				1		10	47	33	9	tr	tr						tr	tr
P-9A-F3						1	22	56	15	tr	5				?		tr	1
P-9A-F2						7	37	47	7	tr	2				tr		tr	tr

Slide Number	Unit	Rock Name
M-1-8	Q	Calcitic immature orthoquartzite mudstone
M-1-7	U	Finely to very finely crystalline dolomite
M-1-Fl	L	Partly-chertified medium to finely crystalline dolomite
M-2-6	U	Medium to very finely crystalline dolomite
M-2-5	U	Chertified finely to very finely crystalline dolomite
M-2-4	U	Finely to very finely crystalline dolomite
M-2-3.5	M	Medium to finely crystalline dolomite
M-2-2	L	Medium to finely crystalline dolomite
M-2-1	L	Medium to very finely crystalline dolomite
M-2-X	L	Calcitized medium to finely crystalline dolomite
H-3-7	U	Medium to very finely crystalline dolomite
H-3-6	U	Medium to very finely crystalline dolomite
H-3-4	L	Medium to finely crystalline dolomite
H-3-3	L	Medium to finely crystalline dolomite
H-3-2	L	Partly-calcitized medium to finely crystalline dolomite
H-3-1	L	Calcitized medium crystalline dolomite
H-3-0	W	Very fine sandstone: micaceous, immature, quartzarenite

SLIDE NUMBER	DOLOMITE			CALCITE		CHERT							DETRITUS					OPAQUE MINERALS
				PORE-FILL SPAR	REPLACEMENT SPAR	MEGAQUARTZ	MICROCRYSTALLINE QUARTZ				CHALCEDONITE	QUARTZINE - LUTECITE	SAND	SILT	CLAY	FELDSPAR	MICA	
	MC	FC	VFC				CG	MG	FG	VFG-UFG								
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
M-1-8				4									34	52	2	8	tr	
M-1-7		79	14										6	tr	tr	1	tr	tr
M-1-F1	30	58	3			7						2	tr				tr	tr
M-2-6	12	69	16	tr									2		tr	tr		1
M-2-5		48	16			11	25	tr							tr			tr
M-2-4	2	83	14	tr									1		tr		tr	tr
M-2-3.5	11	83	tr			tr						tr		4	tr		2	tr
M-2-2	27	69	4									tr	tr					tr
M-2-1	14	73	13												tr			tr
M-2-X	27	29	tr	tr	42								tr					2
H-3-7	12	76	10	2									tr		tr			tr
H-3-6	10	63	14										8	3	1		1	tr
H-3-4	75	25	tr			tr						tr	tr		tr		tr	tr
H-3-3	89	11	tr			tr						tr	tr		tr			tr
H-3-2	81	10	tr	9									tr	tr			tr	tr
H-3-1	74	1	tr	16	9								tr		tr			tr
H-3-0				tr									37	41	7	5	10	tr

Slide Number	Unit	Rock Name
H-8-6	U	Medium to finely crystalline dolomite
H-8-5	U	Calcitized medium to finely crystalline dolomite
H-8-3	L	Finely crystalline dolomite
H-8-2	L	Finely to very finely crystalline dolomite
H-8-1	L	Partly-calcitized medium to very finely crystalline dolomite
H-9-5	U	Calcitized medium to finely crystalline dolomite
H-9-4	M	Sandy to muddy dolomitic medium crystalline calcitized limestone
H-9-3	L	Partly-chertified medium to finely crystalline dolomite
H-9-2	L	Medium to very finely crystalline dolomite
H-9-1	L	Medium to finely crystalline dolomite
H-10-6	U	Dolomitic medium crystalline calcitized limestone
H-10-5	U	Partly-calcitized medium to finely crystalline dolomite
H-10-4	M	Sandy to muddy partly-calcitized medium crystalline dolomite
H-10-3.2	M	Muddy dolomitic medium crystalline calcitized limestone
H-10-3	L	Partly-chertified dolomitic medium crystalline calcitized limestone
H-10-1	L	Medium to very finely crystalline dolomite
H-10-0	W	Sandy calcitized medium to finely crystalline dolomite

SLIDE NUMBER	DOLOMITE			CALCITE		CHERT							DETRITUS					OPAQUE MINERALS
				PORE-FILL SPAR	REPLACEMENT SPAR	MEGAQUARTZ	MICROCRYSTALLINE QUARTZ				CHALCEDONITE	QUARTZINE - LUTECITE	SAND	SILT	CLAY	FELDSPAR	MICA	
	MC	FC	VFC				CG	MG	FG	VFG-UFG								
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
H-8-6	25	71	3		tr							1					tr	tr
H-8-5	35	21	1	tr	40							3			tr		tr	tr
H-8-3	tr	95	3						tr				tr		1		tr	1
H-8-2	4	81	12		3													tr
H-8-1	7	77	10		6													tr
H-9-5	34	53	tr	tr	13													tr
H-9-4	10	tr	tr	55									14	15	6		tr	tr
H-9-3	23	67	2			tr			8						tr			tr
H-9-2	15	78	7	tr														tr
H-9-1	56	44	tr										tr		tr			tr
H-10-6	13	8	tr	tr	79	tr							tr		tr			tr
H-10-5	72	19	tr	tr	9								tr		tr			tr
H-10-4	57	4	tr	?	5								11	16	4	tr	2	1
H-10-3.2	8	4	tr	tr	70	2						1	3	9	2		1	tr
H-10-3	7	21	tr	1	66							5						tr
H-10-1	17	75	8	tr									tr				tr	tr
H-10-0	28	19	tr	2	30								10	8	2		1	tr

Slide Number	Unit	Rock Name
C-1-4	U	Dolomitic medium crystalline calcitized limestone
C-1-2	L	Medium to finely crystalline dolomite
C-1-1	L	Medium crystalline dolomite
D-1-7	M	Muddy calcitized medium to finely crystalline dolomite
D-1-6	L	Chertified calcitized finely crystalline dolomite
D-1-3	L	Medium to finely crystalline dolomite
D-1-2	L	Medium to finely crystalline dolomite
G-1-5c	U	Partly-chertified calcitized medium to finely crystalline dolomite
G-1-5b	U	Chertified medium to very finely crystalline dolomite
G-1-5a	U	Medium to very finely crystalline dolomite
G-1-4	M	Medium to finely crystalline dolomite with clasts of ferruginous mudstone
G-1-3	L	Sandy medium to finely crystalline dolomite
G-1-2	L	Sandy partly-calcitized medium to very finely crystalline dolomite
G-1-1	W	Muddy calcitized medium to finely crystalline dolomite

SLIDE NUMBER	DOLOMITE			CALCITE		CHERT							DETRITUS					OPAQUE MINERALS
				PORE-FILL SPAR	REPLACEMENT SPAR	MEGAQUARTZ	MICROCRYSTALLINE QUARTZ				CHALCEDONITE	QUARTZINE - LUTECITE	SAND	SILT	CLAY	FELDSPAR	MICA	
	MC	FC	VFC				CG	MG	FG	VFG-UFG								
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
C-1-4	2	24	tr	1	70	tr						3	tr		tr			tr
C-1-2	78	20	tr			1						1	tr					tr
C-1-1	95	4	tr		1	tr							tr					tr
D-1-7	20	51	2	11									1	11	2		1	1
D-1-6	3	41	4	tr	30							21						1
D-1-3	9	87	3						1		tr		tr					tr
D-1-2	87	13	tr												tr			tr
G-1-5c	34	9	1	2	47							6	tr		tr		tr	1
G-1-5b	5	39	20	1			7	5			16		tr		4			3
G-1-5a	68	23	8	1														tr
G-1-4	47	17	1	3									7	8	3		1	13
G-1-3	71	11	1	2									10	3	1		1	tr
G-1-2	6	40	11	18									21	2	1		1	tr
G-1-1	30	9	tr	25	10								8	15	2			1

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