INFORMATION TO USERS

This material was produced from a microfilm copy of the original document. While the most advanced technological means to photograph and reproduce this document have been used, the quality is heavily dependent upon the quality of the original submitted.

The following explanation of techniques is provided to help you understand markings or patterns which may appear on this reproduction.

1. The sign or "target" for pages apparently lacking from the document photographed is "Missing Page(s)". If it was possible to obtain the missing page(s) or section, they are spliced into the film along with adjacent pages. This may have necessitated cutting thru an image and duplicating adjacent pages to insure you complete continuity.
2. When an image on the film is obliterated with a large round black mark, it is an indication that the photographer suspected that the copy may have moved during exposure and thus cause a blurred image. You will find a good image of the page in the adjacent frame.
3. When a map, drawing or chart, etc., was part of the material being photographed the photographer followed a definite method in "sectioning" the material. It is customary to begin photoing at the upper left hand corner of a large sheet and to continue photoing from left to right in equal sections with a small overlap. If necessary, sectioning is continued again – beginning below the first row and continuing on until complete.
4. The majority of users indicate that the textual content is of greatest value, however, a somewhat higher quality reproduction could be made from "photographs" if essential to the understanding of the dissertation. Silver prints of "photographs" may be ordered at additional charge by writing the Order Department, giving the catalog number, title, author and specific pages you wish reproduced.
5. PLEASE NOTE: Some pages may have indistinct print. Filmed as received.

Xerox University Microfilms
300 North Zeeb Road
Ann Arbor, Michigan 48106

74-21,990

SARGENT, Kenneth Aaron, 1940-
CHEMICAL AND ISOTOPIC INVESTIGATION OF
STRATIGRAPHIC AND TECTONIC DOLOMITES IN
THE ARBUCKLE GROUP, ARBUCKLE MOUNTAINS,
SOUTH CENTRAL OKLAHOMA.

The University of Oklahoma, Ph.D., 1974
Geology

University Microfilms, A XEROX Company, Ann Arbor, Michigan

THE UNIVERSITY OF OKLAHOMA
GRADUATE COLLEGE

CHEMICAL AND ISOTOPIC INVESTIGATION OF STRATIGRAPHIC AND TECTONIC DOLOMITES IN THE ARBUCKLE GROUP, ARBUCKLE MOUNTAINS, SOUTH CENTRAL OKLAHOMA

A DISSERTATION
SUBMITTED TO THE GRADUATE FACULTY
in partial fulfillment of the requirements for the
degree of
DOCTOR OF PHILOSOPHY

BY
KENNETH AARON SARGENT
Greenville, South Carolina
1974

CHEMICAL AND ISOTOPIC INVESTIGATION OF STRATIGRAPHIC AND TECTONIC DOLOMITES IN THE ARBUCKLE GROUP, ARBUCKLE MOUNTAINS, SOUTH CENTRAL OKLAHOMA

APPROVED BY

Charles J Mankin

Harvey Blatt

T L Rowland

DISSERTATION COMMITTEE

DISSERTATION

CHEMICAL AND ISOTOPIC INVESTIGATION OF STRATIGRAPHIC AND TECTONIC DOLOMITES IN THE ARBUCKLE GROUP, ARBUCKLE MOUNTAINS, SOUTH CENTRAL OKLAHOMA

In the Arbuckle Mountains of south-central Oklahoma are excellent exposures of limestones and early diagenetic dolomites of Early Ordovician age. In these units are found irregular bodies of late diagenetic dolomite associated with structures produced by a Late Pennsylvanian-Early Permian deformation.

Samples of limestone, early diagenetic dolomite, late diagenetic dolomite, and vein dolomite which cuts across all other structure were analyzed for 10 trace elements in order to determine if chemical differences exist between the early diagenetic and late diagenetic dolomites. On the basis of the trace element analyses 20 samples were selected for carbon and oxygen isotopic analysis. The resulting trace element and isotopic data were studied using standard statistical techniques and the multivariate linear discriminant function technique.

Four trace elements, Na, Li, Ni, and Cu, and the isotopic values δO^{18} and δC^{13} were found to discriminate at a high level between early diagenetic and the late diagenetic dolomite in the study area. A computer program was written for the IBM 1130 to utilize the functions generated by the linear discriminant function statistical technique to test unassigned dolomite samples and place these into the correct dolomite grouping.

The limestones and early diagenetic dolomites were similar in O^{18} content with δO^{18} averages of -6.9 and -6.8 respectively. This would indicate that the early diagenetic dolomitizing solutions were similar in isotopic composition to sea water. The late diagenetic dolomites were characterized by δO^{18} values higher than for the limestones and late diagenetic dolomites indicating that the late diagenetic dolomitizing solutions differed in isotopic composition from sea water.

DEDICATION

This dissertation is dedicated to the memory of Dr. William E. Ham who initially proposed the research, guided and inspired its progress, but who unfortunately did not live to see its completion.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the help and advice of Drs. Charles J. Mankin, Thomas Rowland, Harvey Blatt, Charles Harper, and George Stone, who served on the dissertation committee and Dr. Gerald M. Friedman, who critically read the manuscript. Special recognition is due to my wife and children without whose help, encouragement and patience the work could not have been completed.

CONTENTS

TABLES

Table Page

ILLUSTRATIONS

Figure Page

Plate

CHEMICAL AND ISOTOPIC INVESTIGATION OF STRATIGRAPHIC AND TECTONIC DOLOMITES IN THE ARBUCKLE GROUP, ARBUCKLE MOUNTAINS, SOUTH-CENTRAL OKLAHOMA

INTRODUCTION

General Statement

In the Arbuckle Mountains of south-central Oklahoma (see figures 1 and 2) are many excellent exposures of carbonate rocks of the Arbuckle Group. In the southern part of the Arbuckle Mountains, the upper 5,000 feet of the Arbuckle Group is dominantly limestone of Early Ordovician age. The lower 1,500 feet consist of two

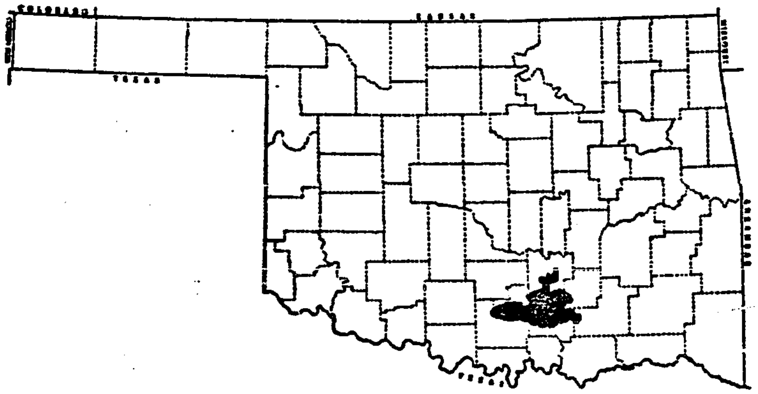


FIGURE 1. INDEX MAP OF OKLAHOMA SHOWING LOCATION OF ARBUCKLE MOUNTAINS (SOLID)

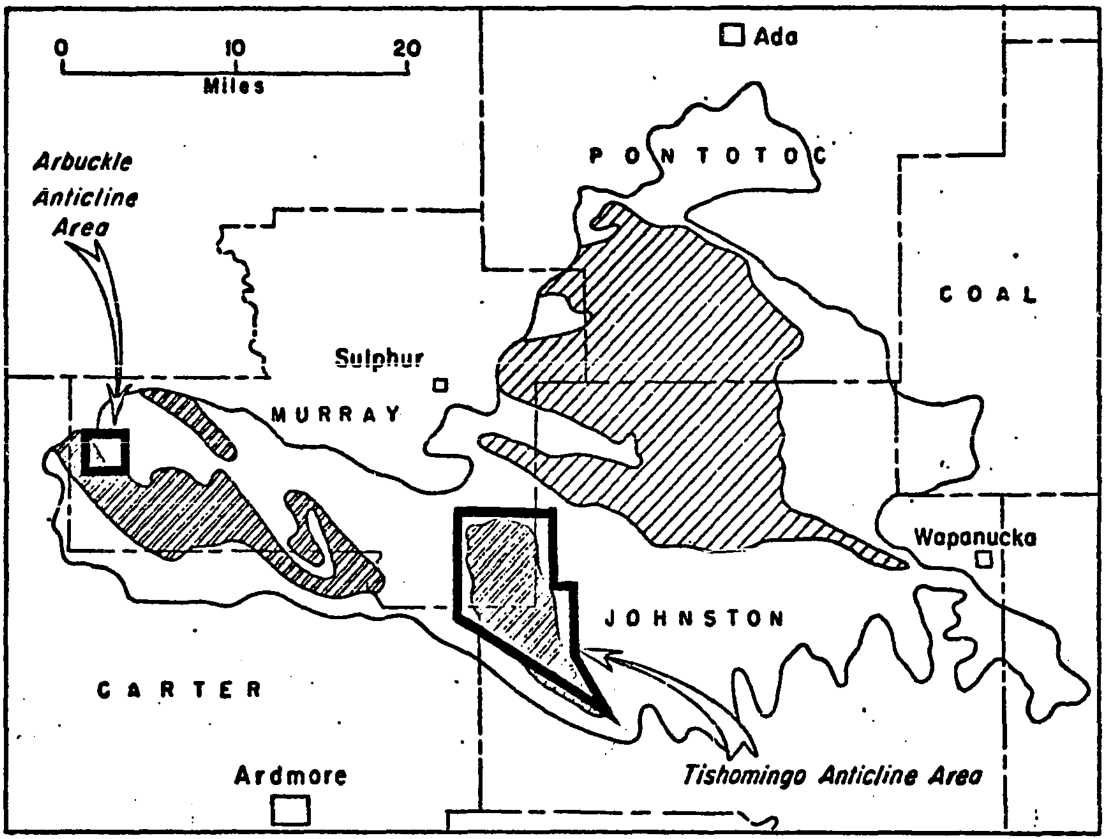


Figure 2
OUTLINE MAP OF ARBUCKLE MOUNTAINS SHOWING PRINCIPAL OUTCROPS OF ORDOVICIAN FORMATIONS OF ARBUCKLE GROUP
Investigated areas of tectonic dolomites are in Tishomingo anticline and Arbuckle anticline of southern region where the formations are thick and are composed chiefly of limestone (double-line ruling). In northern region the formations are thinner and are composed almost exclusively of dolomite (thin-line ruling).

stratigraphic dolomite units interspersed with two limestone units and are of Late Cambrian age (see figures 3 and 4.) Occurring within these limestone sequences are many irregular bodies of dolomite which originate at faults and fractures and exhibit cross-cutting relationships. The faults and fractures were formed during a period of deformation which began in Middle Pennsylvanian time and ended in Early Permian time (Ham et al., 1969, pp. 17-19.) These fault-controlled dolomite bodies have outcrop stratigraphic thicknesses of as much as

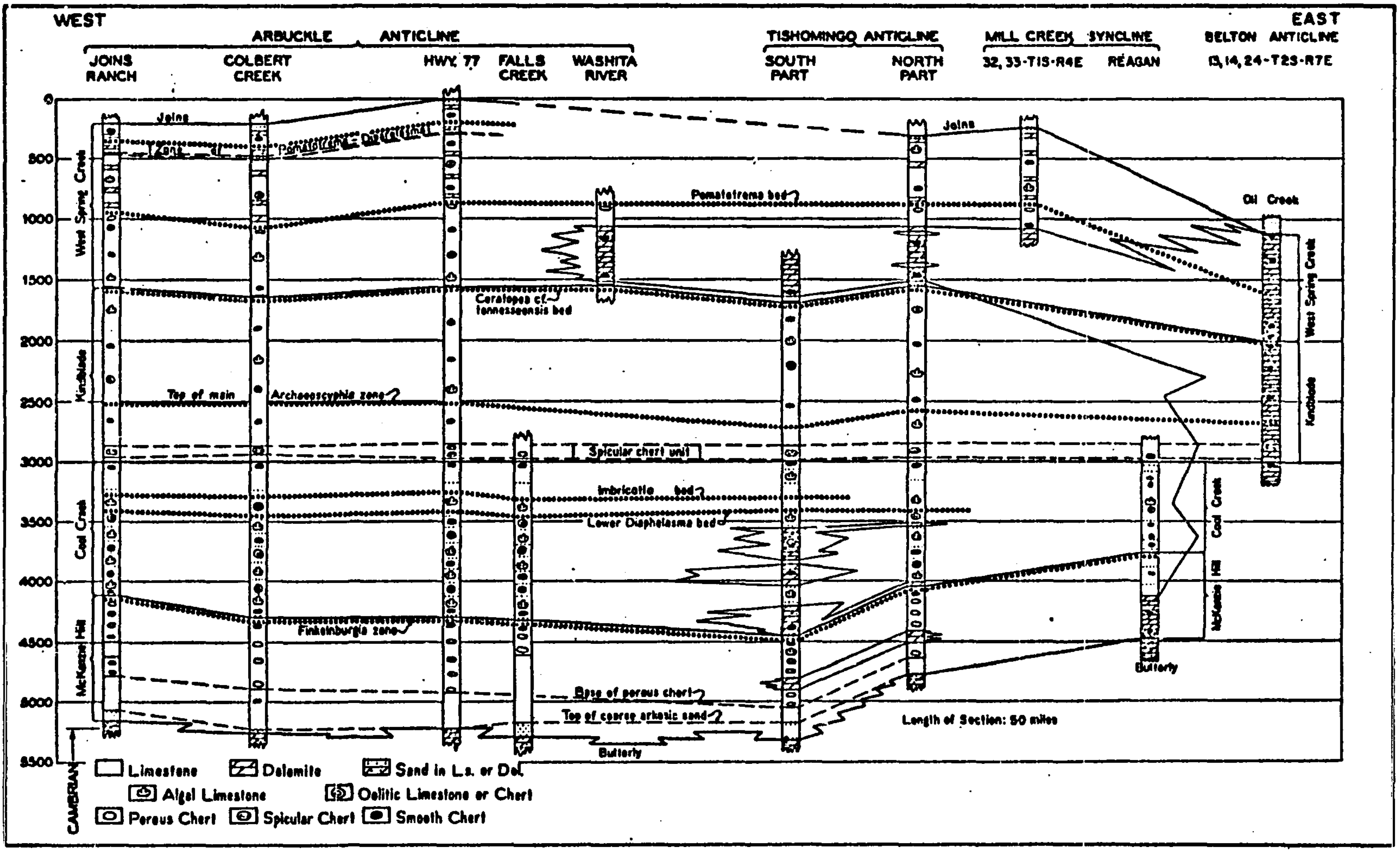


Figure 3. Measured outcrop sections of Ordovician Arbuckle strata in the Arbuckle Mountains. Note eastward thinning and gradation of limestone into dolomite.

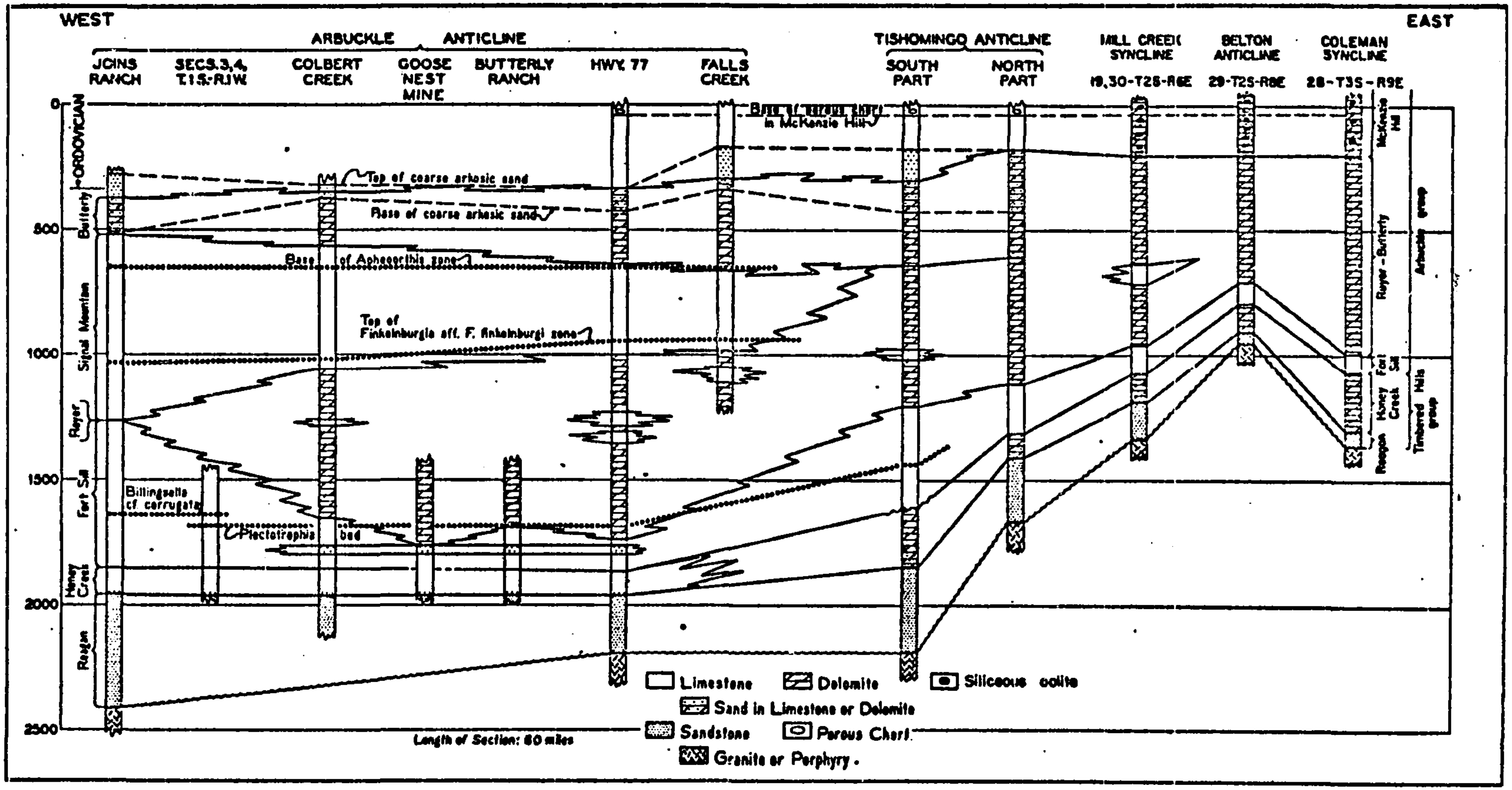


Figure 4. Measured outcrop sections of Cambrian strata in the Arbuckle Mountains. Note eastward thinning and gradation of limestone into dolomite.

1,000 feet along faults and grade abruptly into limestone at short distances away from these faults. Their outcrop dimensions reach as much as one square mile in area. In many places the faults and fractures to which the dolomite is related are filled with limonite which is inferred on the basis of pseudomorphic structures to have been originally introduced as marcasite and pyrite.

In a previous study (Sargent, 1969), eight of the localities where fault-controlled dolomite had been introduced were mapped and sampled for a petrologic study in an attempt to establish criteria for distinguishing between fault-controlled and stratigraphic dolomite. The samples obtained during this previous study were utilized in the present investigation to determine if chemical or isotopic differences exist between the fault-controlled and stratigraphic dolomite. Geologic maps of the aforementioned eight localities appear on the plate in the map pocket.

Through a discussion of the chemical and isotopic data obtained, criteria are established for distinguishing between the two dolomites. In addition, the chemical and isotopic data were analyzed by multivariate statistical techniques using an IBM 1130 computer. The results of the multivariate analyses are discussed and evaluated.

Previous Investigations

Relatively little work has been published on the variations of trace-constituents between limestones and their stratigraphically and tectonically dolomitized equivalents.

Weber (1964b) analyzed 300 "primary" and "secondary" dolostones and 150 dolomites for 20 trace and minor elements and reported on their variations in these three main dolomite types. However, these samples did not represent related carbonate samples but instead were assembled from many diverse localities. Atwood and Fry (1967) investigated the strontium and manganese variation between limestones and "coexisting" dolomites which included both stratigraphic and tectonic types. No distinction was made between stratigraphic and tectonic dolomite in reporting the analytical results.

Although much has been published on the carbon and oxygen stable isotopic ratios found in carbonates, most reports have not considered the differences between stratigraphic and tectonic dolomites. Engel, Clayton, and Epstein (1958) studied variations in carbon and oxygen isotopic ratios between the Leadville limestone and its hydrothermally dolomitized portions, but did not consider stratigraphic dolomites. Degens and Epstein (1964) reported variations in carbon and oxygen isotopic ratios between early diagenetic and epigenetic dolomites. Weber (1964a) reported on variations of the isotopic ratios as pertain to the problem of primary vs secondary dolomitization. Although the above mentioned papers do not specifically treat the problem with which this investigation is concerned, they most closely approach the subject.

Purpose of Investigation

One objective of this study has been to establish valid compositional criteria for distinguishing epigenetic dolomite from stratigraphic dolomite in the area of study. Trace element analyses of the samples followed by carbon and oxygen stable isotopic ratio analyses of certain of these samples have provided the data for study.

A second objective was to establish the reliability of each trace element and isotopic ratio in discriminating between the dolomite types in the study area. Computer aided multivariate statistical techniques and the standard Kolmogorov-Smirnov and F-distribution tests were used to analyze the chemical and isotopic data.

Methods of Investigation

For this study 130 samples of limestone, stratigraphic dolomite, tectonic dolomite, and vein dolomite were analyzed for 16 elements using a Perkin-Elmer 303 atomic absorption spectrophotometer. Of these 16 elements, 10 gave usable results.

The data resulting from these analyses were then studied by multivariate statistical techniques with the aid of an IBM 1130 computer with a 16 K core. On the basis of these statistical tests, 20 samples were selected for carbon and oxygen stable isotopic analysis. These 20 samples included nine tectonic dolomites, five stratigraphic dolomites, three tectonic vein dolomites, and three limestones. The analyses were performed by Geochron Laboratories, Inc., of Cambridge, Massachusetts.

The results of the isotopic analyses and the most diagnostic of the trace-elements were then utilized for further multivariate statistical analysis. In addition, a computer program was written to utilize group discriminant functions produced by the multivariate discriminant test to test indeterminate samples and place them in one of the previously determined groups. This program is applicable to any discriminant testing problem.

Terminology

The following definitions are included in order to eliminate any possible confusion resulting from the author's choice of terminology.

Epigenetic dolomite refers to dolomite occurring in irregular masses and is interpreted to have been formed by solutions traveling along faults and fractures into the rocks which it replaces.

Fault-controlled dolomite is synonymous with epigenetic dolomite.

Ferroan dolomite refers to a dolomite in which no more than one-half of the magnesium is replaced by iron. In this paper it is used as a descriptive term to designate a dolomite that is noticeably high in $FeCO_3$ content and has a brown weathering color. From a preliminary chemical study the limits of $FeCO_3$ content appear to be between 2 and 13 percent.

Limonite is used in this paper to designate the undetermined brown hydrous iron oxide which occurs in faults and fractures and is inferred on the basis of pseudomorphic structures to have originally been introduced as marcasite and pyrite.

Stratigraphic dolomite defines a dolomite occurring in bedded sequences of regional extent and having pretectonic stratigraphic characteristics such as stromatolitic structures, fossils, and conformance to the local and regional structure.

Structure-controlled dolomite is synonymous with epigenetic dolomite.

Tectonic dolomite is synonymous with epigenetic dolomite.

DISCUSSION OF THE SAMPLE TYPES

Introduction

Of the 130 samples analyzed in this investigation, 25 were limestones, 17 were stratigraphic dolomites, 59 were tectonic dolomites, 24 were of uncertain origin, and 5 were tectonic vein dolomites. This section briefly discusses these sample groups. For a more complete discussion, see Sargent (1969).

Limestones

The limestones in general represent poorly fossiliferous, shallow-water marine deposits with micritic calcarenites and intraclast bearing micrites predominating. Extensive recrystallization is not common, but where it does occur, it is generally as a recrystallization of fossils or as a partial recrystallization of the micrite matrix.

Minor silicification occurs locally, generally as a replacement of fossils or as very fine grains either disseminated throughout the rock or along stromatolitic algal laminations and worm burrowings. This silicification is pre-tectonic and therefore is unrelated to the tectonic dolomitization.

Dolomite grains are common and occur as small rhombs or irregular patches scattered throughout the rock. Locally, concectrations of rhombs along worm burrowings constitute as much as 50 percent of the rock. This dolomite is most likely the result of the diagenetic action of magnesium-rich pore water entrapped in the sediment. The magnesium is probably supplied by the transformation of the high-magnesium calcite of certain skeletal grains to low-magnesium calcite soon after burial. Therefore, this dolomite is unrelated to the tectonic stage of dolomitization. This source of magnesium could not have produced locally the thick stratigraphic dolomites or the large tectonic dolomite bodies.

Of the 25 limestone samples, 16 are limestones sampled along with their tectonically dolomitized equivalents. These limestone-dolomite pairs were sampled from the same bed as close together as possible. Therefore, a comparison can be made between the limestone and dolomite compositions to see which elements were added and which were removed during the dolomitization process.

These samples all of Lower Ordovician age come from the McKenzie Hill, Cool Creek, and Kindblade Formations of the Arbuckle Group. Three were sampled from the Arbuckle anticline while the remainder came from the Tishomingo anticline.

Stratigraphic Dolomites

The stratigraphic dolomites are bedded sequences of dolomite rock of Lower Ordovician age which range from a few feet to several hundred feet in thickness. They are regional in extent and are everywhere conformable to the local and regional structure produced by a Late Pennsylvanian and Early Permian deformation. Most exhibit replacement features and consist of both fine-grained laminated dolomites and medium- to coarse-grained dolomites. They are pre-tectonic and are most likely the results of an early diagenetic replacement of limestone shortly after deposition and before deep burial. These units transect limestone formations at a low rate and are most likely the results of an early diagenesis (Ham, 1951, p. 87). Their lack of pore space developed due to dolomitization suggests that dolomitization proceeded prior to lithification of the lime precursor.

The 17 samples represent three separate stratigraphic dolomite sequences. Twelve were sampled from the Butterly Formation, a bedded sequence of dolomite ranging from 150 to 500 feet thick. Of these twelve, three are from the Arbuckle anticline, seven are from the Tishomingo anticline, and two are from along U. S. Highway 77, which is located approximately midway between the two anticlines.

Three of the samples were from the lowermost 30 feet of the Cool Creek Formation in the Tishomingo anticline. This thirty-foot basal unit is a fine-grained, partly laminated dolomite that is present along the McKenzie Hill - Cool Creek contact for a distance of about nine miles. This basal stratigraphic dolomite unit is locally a part of a much thicker dolomite unit that is judged on the basis of the field evidence to be a tectonic dolomite.

The remaining two samples were taken from a thick unit of stratigraphic dolomite occurring in the lower part of the West Spring Creek Formation in the Tishomingo anticline. This unit ranges in thickness from 400 to 600 feet and extends along the outcrop for a distance of six miles.

These dolomites are nearly ideal in composition, having only a slight excess in $CaCO_3$. Table 1 of Appendix A gives the calcium, magnesium, and ferrous iron content of four representative stratigraphic dolomites.

Tectonic Replacement Dolomite

Tectonic or fault-controlled dolomite occurs chiefly as irregular bodies replacing limestone and to a lesser extent stratigraphic dolomite and is generally closely associated with faults and fractures in the host rock. These dolomite bodies are characterized by cross-cutting relationships and by irregular and locally abrupt lateral transition into limestone or stratigraphic dolomite away from the faults and fractures. Commonly this dolomite is restricted to the immediate vicinity of a fault thus appearing as a narrow elongate body cutting across limestone or stratigraphic dolomite beds.

Limonite is commonly associated with the tectonic dolomite and locally occurs as a long narrow body restricted to the vicinity of a fault or fracture. On the basis of pseudomorphic structures, it is inferred to have originally been deposited as marcasite and pyrite, most likely in brecciated zones and fissures produced by the faulting. These deposits are small and scattered in the Tishomingo anticline area, but in the Arbuckle anticline area they are larger and locally abundant.

Two distinct types of tectonic dolomite are present in the samples: a low-iron dolomite generally containing less than 1 mole percent of $FeCO_3$ and a ferroan dolomite containing from 2 to 13 mole percent $FeCO_3$. The majority of the tectonic dolomite from the Arbuckle anticline area was ferroan. With only minor exceptions the tectonic dolomite of the Tishomingo anticline was low in iron content. The low-iron tectonic dolomites are nearly ideal in composition with only a slight excess of $CaCO_3$. The analyses for calcium, magnesium, and ferrous iron of three low-iron tectonic dolomites are included in Table 1 of Appendix A. The ferroan tectonic dolomite contains a slight excess of $CaCO_3$ with the Fe^{++} substituting for the Mg ion in the carbonate structure. The calcium, magnesium, and ferrous iron content of four ferroan tectonic dolomites appear in Table 1 of Appendix A.

In general, the tectonic dolomites have no particularly unique features by which they may be distinguished petrographically from the stratigraphic dolomites. The only valid criteria found during the previous investigation (Sargent, 1969) for distinguishing between the two dolomite types were based on field evidence. These criteria are given below.

(1) Irregular and locally abrupt lateral transitions into limestone and/or stratigraphic dolomite away from faults and fractures. This is an extremely common feature in all localities investigated.

(2) The occurrence of dolomite on only one side of a fault or fracture whereas the corresponding

limestone beds across the fault are undolomitized. This is an important point, for if the dolomite body was actually a stratigraphic unit, the corresponding beds across the fault would also consist of dolomite. Thus, a dolomite body occurring on only one side of a fault must represent the selective dolomitization of only those beds by solutions emanating from the fault. The cause of the restriction of dolomite to only one side of the fault might be a more intense fracturing on that side or possibly a drainage gradient within the limestone beds.

(3) Dolomite cutting at a high angle across the bedding of the enclosing limestones. This is one of the best and most often cited indications of fault-controlled dolomitization (Hewett, 1931; Green, 1954; Brokaw, 1950), and is common at all localities investigated for this report. Dolomitized reef structures would also cut across bedding at high angles but based on their structural configuration and fossil content, would be different from the surrounding normally bedded limestones. The dolomite bodies mapped for this study are in no way related to the occurrence of reef structures.

(4) The occurrence of dolomite along the walls of a single fault. This is a clear indication of fault control because the dolomite must be the result of solutions moving along the fault.

(5) The occurrence of coarse crystalline dolomite in veins and cavities of brecciated rocks of tectonic origin represents a phase of dolomite formation occurring at the same time or soon after the brecciation.

(6) The absence of typical cave deposits such as dripstones, flowstones, or travertine-like cement in tectonic dolomite or wall rock. If solution-collapse had occurred before the dolomitization of the limestone, some or all of the above features would have been preserved in the resulting dolomites.

(7) In the Arbuckle anticline area, the dolomites that can be shown from field relations to be of tectonic origin generally contain from 2 to 13 percent ferrous carbonate, whereas the pre-tectonic dolomites of the same area are normal low-iron dolomites. Thus the occurrence of ferroan dolomite is locally an important supplemental feature of tectonic origin, although in the Tishomingo anticline no such distinction can be applied.

Of the 59 samples of tectonic dolomite, 38 were from the Tishomingo anticline area and 21 from the Arbuckle anticline area. The Tishomingo anticline samples came from six irregular bodies of tectonic dolomite which were mapped in detail by Sargent (1969). Two of the six localities have stratigraphic dolomite associated with the tectonic dolomite. Except for five samples, all were low-iron dolomites.

The Arbuckle anticline samples came from two mapped bodies of tectonic dolomite of which one was directly associated with stratigraphic dolomite. All of these samples were ferroan having from 2 to 13 percent $FeCO_3$. Along with five ferroan samples from the Tishomingo anticline area, they were placed into a separate grouping for the computer analyses of the chemical data.

Tectonic Vein Dolomites

The five samples of vein dolomite were all found in the Tishomingo anticline area where they occur as vein-fillings of coarse-crystalline pink or white dolomite in brecciated tectonic dolomite. It is obviously post-brecciation and therefore is younger than the tectonic dolomite host. This dolomite may have resulted from the direct precipitation of dolomite from the solutions responsible for the tectonic dolomitization of the host limestone.

Indeterminate Dolomites

Twenty-four samples that had some degree of doubt associated with their origins were placed in a separate grouping.

Although these samples were associated with tectonic dolomite bodies, they possessed either field relationships, such as local stratigraphic continuity, or textural characteristics, such as finely-grained and laminated textures, which are more typical of stratigraphic dolomites. Of the 24 samples, one came from the Arbuckle anticline area and the remainder from three of the six mapped tectonic dolomite bodies of the Tishomingo anticline area.

Table 1. Stratigraphic units from which the samples were taken.

Formation	Limestones	Stratigraphic Dolomites	Tectonic Dolomites	Ferroan Tectonic Dolomites	Vein Dolomites	Indeterminate Dolomites
West Spring Creek	-	2	-	-	-	-
Kindblade	7	-	12	1	-	2
Cool Creek	12	3	13	3	5	21
McKenzie Hill	6	-	3	18	-	1
Butterly	-	12	-	4	-	-

METHODS OF CHEMICAL ANALYSIS

Sample Preparation

Each sample was slabbed and trimmed to remove all external weathered material. The remaining fresh material was crushed and then milled in a Spex mixer-mill to produce a fine powder. The samples were dryed at 95° C for one hour and cooled in a dessicator before weighing.

Approximately one gram portions of the dryed samples were weighed analytically and opened in 25 ml of 20% hydrochloric acid. After gentle heating on a hot plate for ten minutes, the solutions were filtered quantitatively. The filtered residue was ashed, weighed and reported as insoluble residue. The filtrate was collected in a 100 ml volumetric flask, diluted to volume and retained for chemical analysis.

Major and Minor Element Analysis

Selected representative samples were analyzed using titrimetric methods for calcium, magnesium, and ferrous iron. The results are reported in Table 1 of Appendix A. Calcium and magnesium were determined using the procedure given on pages 12 and 13 of Hill, Waugh, Galle, and

Runnels, 1961. The ferrous iron was determined using the method outlined in Furman (1962, p. 544).

Trace Element Analysis

Using a Perkin-Elmer 303 atomic absorption spectrophotometer, all samples were analyzed for the following carbonate-forming cations: Li, Na, K, Rb, Sr, Ba, Tl, Pb, Mn, Fe, Co, Zn, and Cd; and in addition the following commonly encountered elements: Cr, Ni, and Cu. These elements were chosen because they most commonly appear in reported chemical analyses of carbonate rocks (see Graf, 1960a, and Ostrom, 1957). Of these sixteen elements, Cd, Tl, Rb, Ba, Co, and Cr could not be detected due to calcium interferences. The limits of detectability for these six elements with the methods used are given in Table 2. Analytical conditions for all elements are given in Table 3. The accuracy of the Na, K, Sr, Mn, and Fe analyses was checked using the G. Frederick Smith Company standards 400 (dolomite) and 401 (limestone), and the NBS 1A dolomite standard. The accuracy of the Li, Ni, Pb, Zn, and Cu analyses was checked using a previously analysed sample. All elements were determined with precisions of ±10% or better. Additionally, a standard sample was used periodically during the analyses as a check against changing analytical conditions.

Table 2. Limits of detectability based on standard solutions for the elements not detected.

Cd	50 ppm
Tl	50 ppm
Rb	20 ppm
Ba	20 ppm
Co	20 ppm
Cr	20 ppm

Table 3. Analytical conditions.

Element	Analytical Line	Fuel	Burner
Li	3360 Å	air-acetylene	Boling three slot
Na	2955	"	"
K	3831	"	"
Sr	2309	"	"
Pb	2828	"	"
Mn	2795	"	"
Fe	2480	"	"
Zn	2132	"	"
Ni	2311	"	Single slot
Cu	3241.5	"	Boling three slot
Rb	3903	"	"
Ba	2774	N_2O-acetylene	Nitrous oxide burner
Tl	2761	air-acetylene	Boling three slot
Co	2400	"	"
Cr	3587	"	"
Cd	2280	"	"

Isotopic Analysis

Twenty selected samples were analyzed for the stable isotope ratios O^{18}/O^{16} and C^{13}/C^{12}. The analyses were performed by Geochron Laboratories, Inc., of Cambridge, Massachusetts. They report the precision of the mass spectrometer method used as usually better than ± 0.02%. The results are reported in Table 7 of Appendix A.

STATISTICAL ANALYSIS OF THE CHEMICAL DATA

Introduction

The chemical data were subjected to analysis by two well-known statistical techniques: the nonparametric Kolmogorov-Smirnov method and the multivariate discriminant function. The former was used to test each variable in the multivariate groups while the latter was to establish group parameters and test each sample within the groups. Both methods are further explained in this section.

The Kolmogorov-Smirnov Statistic

The Kolmogorov-Smirnov statistic is a nonparametric test in that it requires no knowledge of the distribution function of the data. It can be used to test the null hypothesis that two populations have the same distribution.

First a frequency histogram is drawn for each group and then a cumulative-percentage histogram is plotted from the data in the frequency histogram. (See figures 5 and 6.) The cumulative-percentage histograms for both groups are drawn on the same graph so they may be compared. The maximum vertical separation of the two histograms, d_n, can then be measured directly from the graph. More simply, d_n

Figure 5. Frequency Histogram.

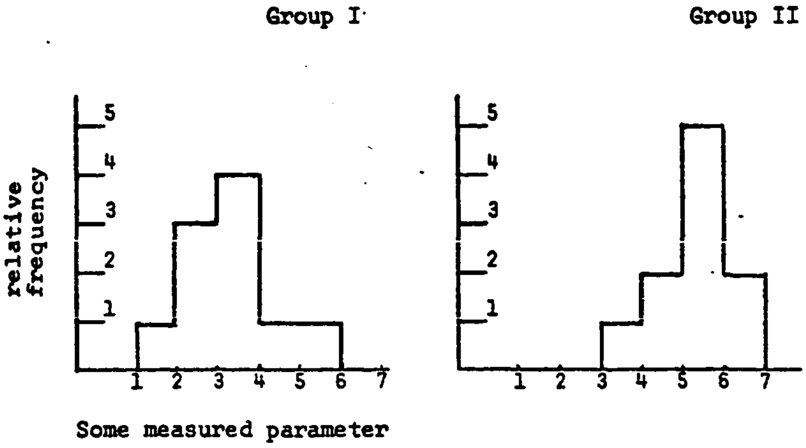
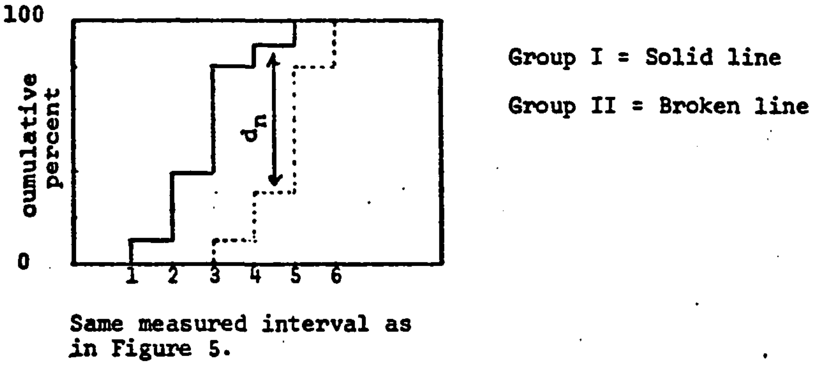


Figure 6. Cumulative-percentage Histogram.



can be obtained by subtracting the cumulative percent columns of the tabulated data. This value, d_n, is then compared with the value ε_N, either read from approximation charts such as those in Miller and Kahn, 1962, p. 468-469, or calculated by formulas such as those given in Dixon and Massey, 1951, p. 348. The larger the value for d_n, the greater the confidence that the two groups have different distributions and are thus unique. The value ε_N for any given confidence level depends on the sizes of the two sample groups n_1 and n_2. The parameter N is introduced to compensate for the groups sizes and is calculated from the equation

$$N = n_1 n_2/(n_1+n_2).$$

The approximation charts in Miller and Kahn are given in figures 7 and 8. The parameter N is plotted along the abscissa of these charts and the value ε_N is plotted on the ordinate. The two curves delineate the 95 and 99% confidence regions. For small values of N (i.e., small group sizes), the value ε_N and correspondingly the value d_n must be greater than for larger values of N. Intuitively, the frequency histograms of groups containing small numbers of

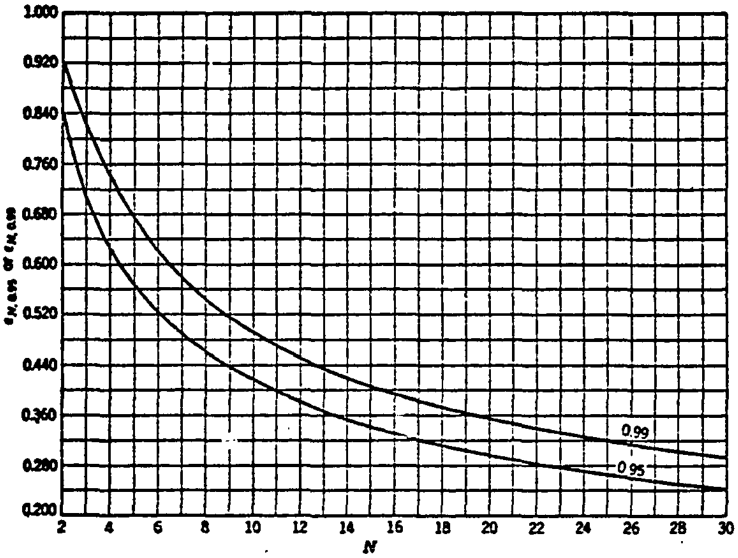


Figure 7. Approximation Chart for Kolmogorov-Smirnov Distribution Function (N < 30).

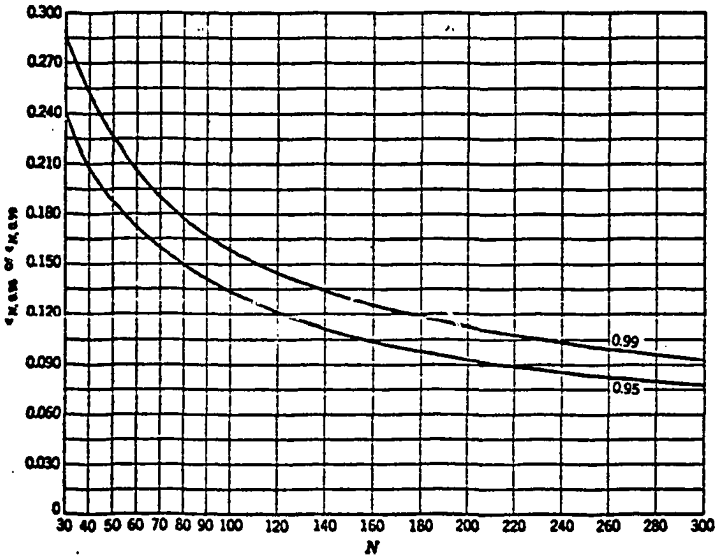


Figure 8. Approximation Chart for Kolmogorov-Smirnov Distribution Function (N > 30).

samples are more subject to variability due to changes in the class intervals along the abscissa.

Alternatively, the value of ϵ_N may be computed using the formulas given by Dixon and Massey and reproduced in Table 4. The formulas given are for the 80, 85, 90, 95, and 99% confidence regions. (See Table 5.) The values for the numerators in these formulae are taken from the asymptotic Kolmogorov-Smirnov distribution table appearing in Table 6. The use of the formulae is more versatile and more accurate than the approximation charts. In Table 7 there is a comparison of selected calculated values with those taken from the approximation charts.

Table 4. Formulas for calculating ϵ_N.
(Taken from Dixon and Massey, 1951.)

Confidence region	.80	.85	.90	.95	.99
Formula for calculating Confidence Region	$\frac{1.07}{\sqrt{N}}$	$\frac{1.14}{\sqrt{N}}$	$\frac{1.22}{\sqrt{N}}$	$\frac{1.36}{\sqrt{N}}$	$\frac{1.63}{\sqrt{N}}$

Table 5. Values for ϵ_N calculated using the formulas in Table 3.

Confidence level	.80	.85	.90	.95	.99
N					
10.6	.33	.35	.37	.42	.50
3.9	.54	.58	.62	.69	.83
3.2	.60	.64	.68	.76	.91
2.5	.68	.72	.77	.86	1.00
2.2	.72	.77	.82	.92	1.00

x	P	x	P	x	P	x	P	x	P	x	P
.35	1.000	.65	.792	.95	.327	1.25	.088	1.55	.016	1.85	.002
.36	.999	.66	.776	.96	.315	1.26	.084	1.56	.015	1.86	.002
.37	.999	.67	.760	.97	.304	1.27	.079	1.57	.014	1.87	.002
.38	.999	.68	.744	.98	.292	1.28	.075	1.58	.014	1.88	.002
.39	.998	.69	.728	.99	.281	1.29	.072	1.59	.013	1.89	.002
.40	.997	.70	.711	1.00	.270	1.30	.068	1.60	.012	1.90	.001
.41	.996	.71	.695	1.01	.259	1.31	.065	1.61	.011	1.91	.001
.42	.995	.72	.678	1.02	.249	1.32	.061	1.62	.011	1.92	.001
.43	.993	.73	.661	1.03	.239	1.33	.058	1.63	.010	1.93	.001
.44	.990	.74	.644	1.04	.230	1.34	.055	1.64	.009	1.94	.001
.45	.987	.75	.627	1.05	.220	1.35	.052	1.65	.009	1.95	.001
.46	.984	.76	.610	1.06	.211	1.36	.049	1.66	.008	1.96	.001
.47	.980	.77	.594	1.07	.202	1.37	.047	1.67	.008	1.97	.001
.48	.975	.78	.577	1.08	.194	1.38	.044	1.68	.007	1.98	.001
.49	.970	.79	.560	1.09	.186	1.39	.042	1.69	.007	1.99	.001
.50	.964	.80	.544	1.10	.178	1.40	.040	1.70	.006	2.00	.001
.51	.057	.81	.528	1.11	.170	1.41	.038	1.71	.006	2.01	.001
.52	.950	.82	.512	1.12	.163	1.42	.035	1.72	.005	2.02	.001
.53	.941	.83	.496	1.13	.155	1.43	.033	1.73	.005	2.03	.001
.54	.933	.84	.481	1.14	.149	1.44	.032	1.74	.005	2.04	.000
.55	.923	.85	.465	1.15	.142	1.45	.030	1.75	.004		
.56	.912	.86	.450	1.16	.136	1.46	.028	1.76	.004		
.57	.901	.87	.435	1.17	.129	1.47	.027	1.77	.004		
.58	.890	.88	.421	1.18	.123	1.48	.025	1.78	.004		
.59	.877	.89	.407	1.19	.118	1.49	.024	1.79	.003		
.60	.864	.90	.393	1.20	.112	1.50	.022	1.80	.003		
.61	.851	.91	.379	1.21	.107	1.51	.021	1.81	.003		
.62	.837	.92	.366	1.22	.102	1.52	.020	1.82	.003		
.63	.822	.93	.353	1.23	.097	1.53	.019	1.83	.002		
.64	.807	.94	.340	1.24	.092	1.54	.017	1.84	.002		

Table 6. Asymptotic Kolmogorov-Smirnov Distributions.

Table 7. Comparison of ϵ_N values calculated from the formulas with values taken from the approximation charts.

Confidence level .95			Confidence level .99		
N	Formula	Chart	N	Formula	Chart
10.6	.42	.40	10.6	.50	.47
3.9	.69	.64	3.9	.83	.75
3.2	.76	.70	3.2	.91	.80
2.5	.86	.76	2.5	1.00	.86
2.2	.92	.77	2.2	1.00	.89

Multivariate Analysis

Populations that are characterized by three or more variables may be compared through the use of multivariate statistical methods. These methods enable the researcher to check for dependence between variables within a group, to eliminate extraneous variables, to evaluate similarities and differences between groups, to evaluate the "goodness" or fit of samples that are in a group, and to characterize groups so that new samples may be placed in the proper group. A brief explanation of the method utilized in the present investigation follows.

Discriminant Analysis

The linear discriminant function is essentially a classification method that defines populations containing n variables in n-dimensional space. Just as one-variable systems occupy one-dimensional space (line) and two-variable systems occupy two-dimensional space (plane), n-variable systems occupy n-dimensional space (hyperspace). The multivariate discriminant analysis studies the dispersion of the points (i.g., sample values) in the n-dimensional cluster by constructing (n-1) hyperplanes to subdivide n-dimensional space in such a way that most effectively separates the populations. The hyperplanes are chosen so as to maximize the separation between groups while minimizing the dispersion of points within the groups. Discriminant functions for each group can then be calculated. Vectors are constructed from the discriminant planes to the group means and the common means. These vectors give rise to the discriminant coefficients, k_n, for each variable in the discriminant function.

Previous studies (see Chayes and Velde, 1965; Mellon, 1964; Potter, Shimp, and Witter, 1963) utilized the two-group discriminant function of the form

$$\text{D.F.} = k_1X_1 + k_2X_2 + \cdots + k_nX_n .$$

When the common means for all the variables of both groups are substituted into the equation, a number results that discriminates between the two groups. When the data for an unassigned sample are substituted into the equation, the resulting number is either higher or lower than the mean value and is thus assigned to one or the other group.

The present study uses a multigroup program listed in the IBM Scientific Subroutine Package Programmer's Manual (see IBM, 1967). The only restriction on this program is that the number of groups cannot exceed the number of variables considered. In the two-group method, one discriminant function is calculated which discriminates into one or the other group. With a multigroup method, a discriminant function of the form

$$D.F._{k_g} = k_1X_1 + k_2X_2 + \cdots + k_nX_n + C,$$

where C is a constant and k_g = groups 1 to g, is calculated for each group. An unassigned sample can then be substituted into each discriminant function and assigned to the group having the discriminant function that produces the highest value.

The discriminant analysis program utilizes the following three subroutines in sequence:

1. DMATX - to compute means of the variables in each group and a pooled dispersion matrix.
2. MINV - to invert the pooled dispersion matrix.
3. DISCR - to compute the common means of the variables, the discriminant coefficients, evaluate the function for each sample, and calculate the probability associated with the largest function.

The probability associated with the largest discriminant function is calculated from the equation

$$P_L = \frac{1}{\sum_{k=1}^{g} e^{(D.F._k - D.F._L)}}$$

where g = number of groups, k = group number from 1 to g, $D.F._L$ = the value of the largest discriminant function, and

L = the subscript of the largest discriminant function.

Thus the greater the difference between the largest discriminant function and all others, the higher the probability that the sample has been correctly assigned. With two groups the lowest probability (both functions producing the same number) would be 0.50000, with three groups 0.33333, and with four groups 0.25000. Table 8 gives the probabilities for a two-group discriminant. Table 9 gives probabilities for a three-group discriminant. The values for the largest discriminant function in this study vary approximately from 5 to 30. Thus probabilities can be converted to percentages and used as a direct measure of the "goodness" or fit of a sample into it assigned group. The listing for this program is given in Appendix B. The language used is FORTRAN IV.

Table 8. Probabilities for the two-group discriminant function.

Difference between functions ($D.F._{k_g} - D.F._L$)	Probability associated with largest function (P_L)
0	.50000
0.005	.50125
0.01	.50250
0.05	.51249
0.1	.52498
0.5	.62246
1.0	.73106
2	.88079
3	.95257
4	.98201
5	.99331
6	.99753
7	.99909
8	.99966
9	.99988
10	.99995
11	.99998
12	.99999
13	.10000

Table 9. Probabilities for the three-group discriminant function.

Difference between largest function and the other two functions		Probability associated with largest function
$(D.F._A - D.F._L)$	$(D.F._B - D.F._L)$	(P_L)
0	0	.33333
0.1	0.1	.35591
0.5	0.5	.45186
1	1	.57612
2	2	.78699
3	3	.90944
4	4	.96466
5	5	.98670
6	6	.99507
7	7	.99818
8	8	.99933
9	9	.99975
10	10	.99991

Discriminant Identification Program

In order to utilize the data derived from the discriminant analysis, a program was written for the IBM 1130 to evaluate ungrouped samples and assign them to one of the groups set up by the discriminant analysis. This program is called discriminant identification, code name DSCID, and is capable of handling any number of samples, groups, and variables, subject only to the limitation of the particular computer utilized. As listed in Appendix B, it is dimensioned for up to 100 samples, 20 groups, and 25 variables.

The discriminant coefficients for each group under study are entered along with the sample data. The program calculates for each sample a discriminant function, $D.F._k$, for each group involved from one to k groups. It then assigns each sample to the group whose discriminant function produced the highest value and computes the probability for this assignment using the formula previously given on page 28. The program output lists for each sample the group assignment, the value of the largest discriminant function, and the probability for this assignment. The listing for this program is given in Appendix B. The language used is FORTRAN IV.

STATISTICAL EVALUATION OF THE ANALYTICAL RESULTS

Introduction

A total of 16 computer runs were made with the discriminant analysis program using various combinations of variables and sample groupings. Table 10 lists the runs and the sample groupings as they will be discussed here. In addition, eight computer runs were made with the discriminant identification program and are listed in Table 11.

Computer runs MDISC 1 through 9 and 14 through 16 involved only trace element data while computer runs 10 through 13 involved isotopic data as well. The discriminant identification programs, DSCID 1 through 8, involved only trace element data.

The frequency histograms and cumulative frequency plots used in the Kolmogorov-Smirnov test of all variables are reported in figures 1 through 3 of Appendix C. The results of this test appear in Tables 1 through 3 of Appendix C.

Table 10. Discriminant analysis computer runs.

Run No.	No. of variables	Groups*
MDISC 1	10	$1_{(17)}$, $2_{(33)}$, $3_{(24)}$, $4_{(26)}$
" 2	10	$1_{(17)}$, $2_{(33)}$, $3_{(24)}$
" 3	10	$1_{(17)}$, $2_{(33)}$, $4_{(26)}$
" 4	10	$1_{(17)}$, $2_{(28)}$, $4_{(26)}$
" 5	10	$1_{(17)}$, $2_{(33)}$
" 6	10	$1_{(17)}$, $2_{(28)}$
" 7	6	$1_{(17)}$, $2_{(28)}$, $4_{(26)}$
" 8	6	$1_{(17)}$, $2_{(28)}$, $3_{(24)}$
" 9	6	$1_{(17)}$, $2_{(28)}$
" 10	8	$1_{(5)}$, $2_{(5)}$
" 11	8	$1_{(5)}$, $2_{(9)}$
" 12	8	$1_{(5)}$, $2_{(5)}$, $4_{(4)}$
" 13	5	$1_{(5)}$, $2_{(18)}$
" 14	4	$1_{(17)}$, $2_{(28)}$
" 15	10	$1_{(17)}$, $2_{(22)}$
" 16	4	$1_{(17)}$, $2_{(22)}$

Sample groupings

Stratigraphic dolomites - Groups $1_{(17)}$ and $1_{(5)}$

Tectonic dolomites - Groups $2_{(33)}$, $2_{(18)}$, $2_{(28)}$, $2_{(22)}$, $2_{(5)}$, and $2_{(9)}$

$2_{(33)}$ includes 5 vein dolomites
$2_{(28)}$ excludes the 5 vein dolomites
$2_{(18)}$ consists of 5 low-iron; 4 ferroan; and 10 unspecified tectonic dolomites analyzed by Gerald M. Friedman
$2_{(22)}$ excludes 6 samples having bad group fit
$2_{(9)}$ consists of 5 low-iron and 4 ferroan tectonic dolomites

Indeterminate dolomites - Group $3_{(24)}$

Ferroan tectonic dolomites - Groups $4_{(26)}$ and $4_{(4)}$

* Numbers within parentheses indicate the number of samples in each group.

Table 11. Discriminant identification program computer runs.

Run No.	No. of variables	Discriminant function from runs
DSCID 1	10	MDISC 4
" 2	6	" 7
" 3	10	" 6
" 4	6	" 9
" 5	4	" 14
" 6	10	" 15
" 7	4	" 16
" 8	10	" 15

Evaluation of Trace Element Data

Discriminant Analyses

At first the discriminant program was used to study all ten of the analyzed trace elements as variables. In subsequent computer runs, certain elements were eliminated on the basis of their unreliability as shown by the Kolmogorov-Smirnov test, their standard deviations within the groups, and the values of their discriminant coefficients.

Computer runs MDISC 1, 2, and 8 were made in order to determine whether or not considering the indeterminate samples as a group along with the others would produce meaningful results. However, this arrangement proved to be of only limited use. In each of the runs, eight samples from the indeterminate group were assigned to one of the other groups. Of the eight samples, five were common to all the runs and were assigned to the same group by all three runs. These group assignments also agreed with those produced by the discriminant identification program. This information is reported in Table 12.

Table 12. Group assignments of indeterminate samples from MDISC 1, 2, and 8.

	Sample Designation	MDISC 1	P(%)	MDISC 2	P(%)	MDISC 8	P(%)	Final Assignment
1	TA 1-5-3	4	99					T
2	TA 1-5-5							?
3	TA 3-1-1					2	40	S
4	TA 3-2-1	2	65	2	63	2	56	T
5	TA 3-6-1	2	63	2	73	2	73	T
6	TA 4-1-1							S
7	TA 4-2-1							S
8	TA 4-7-2							T
9	TA 4-7-3							T
10	TA 4-10-1							T
11	TA 4-10-1A			2	60			T
12	TA 4-11-1							T
13	TA 4-12-1	2	66	2	61	2	51	T
14	TA 4-13-1							T
15	TA 4-14-1							?
16	TA 4-15-1			1	44	1	38	?
17	TA 4-16-1	2	62	2	68	2	54	T
18	TA 4-17-1							T
19	TA 4-19-1	1	45	1	50	1	43	S
20	TA 4-20-1	2	52					?
21	TA 4-22-2							S
22	TA 4-24-2			2	42			T
23	TA 4-24-3							T
24	AA 2-17-1	1	80			1	94	S
	Lowest possible P(%)		25		33		33	

T = Tectonic
S = Stratigraphic

1 = Stratigraphic dolomite
2 = Low-iron tectonic dolomite
4 = Ferroan tectonic dolomite

Runs MDISC 3, 4, 5, and 6 were made to determine if the inclusion of the five vein dolomites with the tectonic dolomite group would affect the results. In runs MDISC 5 and 6 only the probabilities varied. In runs MDISC 3 and 4, the only change other than changes in the probabilities was in the assignment of one sample in the ferroan tectonic dolomite group. With the vein dolomites included, sample number 5 was assigned to the stratigraphic dolomite group. With the veins excluded it was assigned to the low-iron tectonic dolomite group. Although this mixed assignment was a minor change, it was decided to exclude the vein dolomites from the low-iron tectonic dolomites for the remainder of the discriminant analyses. The vein dolomites were formed by precipitation from solution rather than by replacement of a precursor limestone and thus truly constitute a separate group.

Furthermore, it was decided that since the ferroan tectonic dolomites constitute a relatively unique group both in this study and in the literature (see Sargent, 1969, p. 29), little could be gained by including this group in the remaining discriminant analyses that used only trace elements. It should be noted that in the majority of cases (see runs MDISC 3, 4, and 7, Tables 4, 5, and 8 of Appendix B) these samples were classified either in their own group or with the low-iron tectonic dolomites. They will become more important later in the discussion of the isotopic data.

The most useful statistical results came from runs MDISC 6, 9, 14, 15, and 16. The discriminant coefficients from these runs appear in Tables 13 and 14. MDISC 6 and 15 involved the discrimination between the stratigraphic and low-iron tectonic dolomite groups using all ten trace elements. MDISC 9 involved the same discrimination, but with four of the ten elements excluded. MDISC 14 and 16 likewise involved the same discrimination, but with only the four best discriminating elements.

Discriminations using Ten Variables

MDISC 6, using ten variables, produced good discrimination between the two dolomite groups. All 17 samples

Table 13. Evaluation of variables for MDISC 6, 9, and 14.

		Pb	Zn	Na	Li	Ni	K	Cu	Sr	Mn	Fe	
1	$\bar{x}$(17)	1.00	0.12	222.24	0.24	0.94	206.18	3.12	26.65	176.24	1,231.24	MDISC 6
	s	4.12	0.49	51.15	0.44	1.43	143.95	0.93	17.02	191.61	1,000.58	
	k	0.28584	-0.02778	0.06005	0.19333	-0.30267	0.01620	1.04597	0.04771	0.01894	-0.00089	
	k $\bar{x}$	0.29	-0.003	13.35	0.05	-0.29	3.34	3.26	1.27	3.34	-1.10	
	% of DF	1.2	(-) 0.01	56.8	0.2	(-) 1.2	14.2	13.9	5.4	14.2	(-) 4.7	
2	$\bar{x}$(28)	0.21	1.46	169.61	2.50	6.46	162.68	6.57	40.25	94.57	858.11	
	s	0.96	3.67	68.83	4.26	4.82	90.76	2.36	24.32	72.70	760.13	
	k	0.21919	0.18268	0.04579	0.30497	0.19991	0.00763	1.75316	0.07999	0.00941	-0.00025	
	k $\bar{x}$	0.05	0.27	7.77	0.76	1.29	1.24	11.52	3.22	0.89	-0.22	
	% of DF	[illegible]	1.0	29.0	2.8	4.8	4.6	43.0	12.0	3.3	(-) 0.8	
1	k			0.06171	0.09531	[illegible]	0.01130	1.03697	0.02160			MDISC 9
	k $\bar{x}$			13.71	0.03	0.19	2.33	3.24	0.58			
	% of DF			69.6	0.2	(-) 1.0	11.8	16.4	2.9			
2	k			0.04701	0.31673	0.23570	0.00518	1.75606	0.06152			
	k $\bar{x}$			7.97	0.79	1.52	0.84	11.54	2.48			
	% of DF			31.7	3.1	6.0	3.3	45.9	9.9			
1	k			0.06507	0.14054	-0.18624		1.08373				MDISC 14
	k $\bar{x}$			14.46	0.03	-0.18		3.38				
	% of DF			81.7	0.2	(-) 1.0		19.1				
2	k			0.05181	0.37257	0.24735		1.75482				
	k $\bar{x}$			8.79	0.93	1.60		11.53				
	% of DF			38.5	4.1	7.0		50.5				
3	d_n	0.06	0.19	0.50	0.40	0.69	0.24	0.69	0.21	0.21	0.22	
	P(%)	0	16	99	93	100	42	100	27	27	30	

1 = Stratigraphic dolomites
2 = Low-iron tectonic dolomites
3 = Kolmogorov-Smirnov Test (N = 10.6)

k = discriminant coefficient
P(%)= Probability

Table 14. Evaluation of variables for MDISC 15 and 16.

		Pb	Zn	Na	Li	Ni	K	Cu	Sr	Mn	Fe	
1	$\bar{x}$ (17)	1.00	0.12	222.24	0.24	0.94	206.18	3.12	26.65	176.24	1,231.24	MDISC 15
	s	4.12	0.49	51.15	0.44	1.43	143.95	0.93	17.02	191.61	1,000.58	
	k	0.41136	-0.11160	0.07808	0.41261	-0.21821	0.00867	1.08108	0.04722	0.01824	-0.00125	
	k $\bar{x}$	0.41	-0.01	17.35	0.10	-0.21	1.79	3.37	1.26	3.22	-1.54	
	% of DF	1.6	(-) 0.1	67.4	0.4	(-) 0.8	6.9	13.1	4.9	12.5	(-) 6.0	
2	$\bar{x}$ (22)	0.05	1.68	161.00	2.68	7.36	156.64	7.27	42.55	103.55	995.18	
	s	0.21	4.05	58.58	4.57	4.89	88.71	2.12	23.64	78.21	803.35	
	k	-0.13432	0.93134	0.03398	-0.14419	1.18386	-0.02097	3.58503	0.16548	-0.02496	0.00675	
	k $\bar{x}$	-0.01	1.57	5.47	-0.39	8.71	-3.29	26.06	7.04	-2.59	6.72	
	% of DF	(-)0.01	3.2	11.1	(-) 0.8	17.7	(-) 6.7	52.9	14.3	(-) 5.2	13.6	

		Pb	Zn	Na	Li	Ni	K	Cu	
1	k			0.08139	0.22444	-0.09836		1.18730	MDISC 16
	k $\bar{x}$			18.09	0.05	-0.09		3.70	
	% of DF			83.1	0.02	(-) 0.4		17.0	
2	k			0.05677	0.46757	0.62303		2.66338	
	k $\bar{x}$			9.14	1.25	4.59		19.36	
	% of DF			26.6	3.6	13.4		56.4	

		Pb	Zn	Na	Li	Ni	K	Cu	Sr	Mn	Fe
3	d_n	0.06	0.21	0.55	0.41	0.76	0.24	0.85	0.23	0.18	0.15
	P(%)	0	16	99	92	100	36	100	30	9	3

1 = Stratigraphic dolomites
2 = Low-iron tectonic dolomites
3 = Kolmogorov-Smirnov Test (N = 9.6)

k = discriminant coefficient
P(%)= Probability

of the stratigraphic dolomite group were assigned to that group with high probabilities. Only two probabilities were below 90% and the group average was 95.338% with a standard deviation of 4.714%. Of the 28 tectonic dolomite samples, three were assigned to the stratigraphic dolomite group. For the remaining 25 samples assigned to the tectonic dolomite group, three were assigned probabilities lower than 60%, while the remainder received probabilities of 80% or higher. The group average, excluding the three assigned to the stratigraphic dolomites, was 92.399%, with a standard deviation of 14.038%. If in addition the three samples receiving probabilities below 60% are excluded, the group average becomes 97.265% with a standard deviation of 4.083%.

A run was then made with the above-mentioned six samples excluded. In this run, MDISC 15, all of the 17 samples in the stratigraphic dolomite group were assigned to that group. The group average probability was 99.99% with a standard deviation of 0.025%. Of the 22 samples remaining in the tectonic dolomite group, all were assigned to that group. The average probability for the group was 99.789% with a standard deviation of 0.803%. These two groups were clearly differentiated by this run, with all samples fitting their group with a very high degree of confidence. However, the discrimination may be biased by the exclusion of the six samples as the tectonic dolomite group may no longer be as representative of all tectonic dolomites.

This possible bias is discussed further in the section Distinguishing Tectonic and Stratigraphic Dolomites.

Discriminations using Six Variables

MDISC 9, 14, and 16 were run after certain variables were excluded in an attempt to increase the reliability of the discrimination. In MDISC 9, Pb, Zn, Mn, and Fe were excluded on the basis of group means, overlap of standard deviations between groups, and percentage contribution of each variable to the discriminant function of each group. (See Table 13.) Later, Kolmogorov-Smirnov tests of these variables confirmed that each discriminated at below the 30% level of confidence. The discrimination and probabilities of this run were comparable to those produced in run MDISC 6.

Discriminations using Four Variables

A Kolmogorov-Smirnov test of the 6 variables used in MDISC 9 indicated that while Ni and Cu discriminate at the 100% confidence level, Na at the 99% level, and Li at the 93% level, K and Sr discriminate at below the 45% confidence level. In two subsequent runs, MDISC 14 and 16, K and Sr were excluded, leaving only the four variables Na, Li, Ni, and Cu.

For MDISC 14 the tectonic dolomite group containing 28 samples was used while the 22 sample group was used for MDISC 16. For both runs the average probabilities decreased when only four variables were used. For MDISC 14 these were 93.520% for the stratigraphic dolomites and

89.992% for the tectonic dolomites, both approximately 2% lower than when six and ten variables were used.

Comparing MDISC 14 and 16, there were significant increases in probabilities when the six badly fitting samples were excluded from the tectonic dolomite group. For MDISC 16 the average probabilities increased by 6% for the stratigraphic dolomites and by 3.5% for the tectonic dolomites.

Discriminant Identifications

Eight computer runs were completed with the DSCID program using the discriminant functions from seven of the MDISC runs as listed in Table 11. DSCID 1 through 7 were used to test the 24 indeterminate dolomite samples, while DSCID 8 tested the five tectonic vein dolomites and the six samples excluded from the low-iron tectonic dolomites. The computer print-outs of these runs appear in Tables 19 through 26 of Appendix B. The DSCID 1 through 7 group assignments and probabilities for the 24 indeterminate dolomites are summarized in Table 15 of the text. The results of DSCID 8 appear in Table 16.

DSCID 1 used the ten variable discriminant functions from MDISC 4. DSCID 2 used the six variable discriminant functions from MDISC 7. Both MDISC 4 and 7 discriminated between three groups: the stratigraphic dolomites, the low-iron tectonic dolomites, and the ferroan tectonic dolomites. As has been discussed earlier, the ferroan dolomites constitute a unique case. In addition, the

Table 15. Group Assignments for the Indeterminate Dolomite Group from the Discriminant Identification Runs.

	Sample Designation	DSCID 1		DSCID 2		DSCID 3		DSCID 4		DSCID 5		DSCID 6		DSCID 7		Subj. Assign.	Final Assign.
		Gr.	P(%)	Gr.	P(%)	Gr.	P(%)	Gr.	P(%)	Gr.	P(%)	Gr.	P(%)	Gr.	P(%)		
1	TA 1-5-3	4	100	2	96	2	100	2	100	2	99	2	100	2	100	2	T
2	TA 1-5-5	1	58	2	51	1	88	1	84	2	86	1	100	2	96		T
3	TA 3-1-1	1	95	1	90	1	85	1	80	2	50	1	93	1	62	1	?
4	TA 3-2-1	2	99	2	94	2	98	2	98	2	99	2	100	2	100	2	T
5	TA 3-6-1	2	94	2	80	2	99	2	97	2	98	2	100	2	100		T
6	TA 4-1-1	1	100	1	100	1	100	1	100	1	76	1	100	1	99		S
7	TA 4-2-1	1	56	2	47	1	83	1	75	2	58	1	100	1	58		?
8	TA 4-7-2	2	100	2	97	2	99	2	99	2	98	2	100	2	100	2	T
9	TA 4-7-3	2	100	2	99	2	99	2	100	2	99	2	100	2	100	2	T
10	TA 4-10-1	2	100	2	99	2	100	2	100	2	100	2	100	2	100		T
11	TA 4-10-1A	2	100	2	100	2	100	2	100	2	100	2	100	2	100		T
12	TA 4-11-1	2	95	2	85	2	92	2	91	2	95	2	89	2	99		T
13	TA 4-12-1	2	100	2	80	2	99	2	99	2	97	2	100	2	100		T
14	TA 4-13-1	2	100	2	95	2	96	2	98	2	95	2	100	2	99		T
15	TA 4-14-1	2	93	2	88	2	80	2	89	2	88	1	86	2	92		T
16	TA 4-15-1	1	88	1	86	1	63	1	61	2	61	1	82	1	55		?
17	TA 4-16-1	2	100	2	99	2	100	2	100	2	100	2	100	2	100		T
18	TA 4-17-1	2	100	2	98	2	100	2	100	2	100	2	100	2	100		T
19	TA 4-19-1	2	51	4	91	1	82	1	81	1	90	1	100	1	99	2	S
20	TA 4-20-1	2	99	2	56	2	91	2	91	2	80	1	61	2	83	2	T
21	TA 4-22-2	1	77	4	69	1	96	1	95	1	90	1	100	1	99	2	S
22	TA 4-24-2	2	93	2	80	2	90	2	89	2	75	2	67	2	63	2	T
23	TA 4-24-3	2	98	2	91	2	98	2	95	2	71	2	100	2	58	2	T
24	AA 2-17-1	1	93	1	78	1	100	1	99	1	98	1	100	1	100	1	S
Lowest P(%) possible			33		33		50		50		50		50		50		

1 = Stratigraphic dolomite 2 = Low-iron Tectonic dolomite 4 = Ferroan Tectonic dolomite

Table 16. Results of DSCID 8.

	Sample Designation	Group Assignment	P(%)
1	TA 5-2-1	1	100
2	TA 5-5-1	1	99
3	TA 6-1-1	1	100
4	TA 6-1-4	1	93
5	TA 7-1-1	1	97
6	TA 7-2-1	1	100
7	TA 1-1-1v	2	100
8	TA 3-4-1v	2	100
9	TA 4-1-1v	2	100
10	TA 4-9-1v	2	100
11	TA 4-18-1v	2	100
	Lowest possible probability		50

concentrations in that group of four of the trace elements are different from either the stratigraphic or the low-iron tectonic dolomites. The concentration trends of Zn, K, Cu, and Sr for the ferroan dolomites more closely resemble the low-iron tectonic dolomites, but those of Na, Li, and Ni more closely resemble the stratigraphic dolomites. Because of these considerations the results of DSCID 1 and 2 were not used when making the final group assignments. However, it is important to note that these two runs jointly agreed with 18 of the final group assignments for the 24 indeterminate dolomites.

DSCID 3, 4, and 5 used the ten, six, and four variable discriminant functions respectively from MDISC 6, 9, and 14. In all three MDISC runs, only the stratigraphic dolomites and the 28 sample low-iron tectonic dolomite groups were involved. The group assignments made by DSCID 3 and 4 were identical, with very close correlation between the probabilities. On the other hand, DSCID 5 disagreed on five group assignments.

DSCID 6 and 7 utilized the ten and four variable discriminant functions from MDISC 15 and 16 respectively. In these two MDISC runs the tectonic dolomite group contained 22 samples. These two identification runs disagree on only three of the 24 indeterminate samples. In four other samples there is a significant difference in probabilities with DSCID 6 assigning probabilities that range from 27 to 42% higher than those given by DSCID 7.

Final Group Assignments of Indeterminate Dolomite Samples

The runs chosen for determining the final group assignments for the 24 indeterminate samples were DSCID 5 and 7. Where the group assignments of DSCID 5 disagreed with those of DSCID 7, the final assignments were left in question.

DSCID 5 and 7 were based on the four best variables -- Na, Li, Ni, and Cu -- which discriminated on the 99%, 93%, 100%, and 100% levels respectively. DSCID 5 was based on the 28 sample tectonic dolomite group while DSCID 7 was based on the 22 sample tectonic dolomite group.

The final group assignments for the indeterminate samples appear in the last column of Table 15 along with the original subjective group assignment that was made before the chemical analyses. These subjective assignments where made were based on the field relationships. Those for which no assignments were made at that time were dolomites that were very fine-grained showing very little recrystallization, were non-fossiliferous, and which were associated with dolomite beds having some continuity. It could not be objectively decided whether these samples represented fine-grained limestones that were tectonically dolomitized or thin and discontinuous lenses of stratigraphic dolomite already in the limestone prior to the tectonic dolomitization. Such lenses are commonly found within the limestone beds of the Arbuckle Group.

Of the 11 samples that were given a subjective group assignment, eight were confirmed by the discriminant analysis, two were assigned to a different group, and one was left undecided. Of the 13 samples that were not given subjective group assignments, two remained undecided after the discriminant identifications, while the 11 others were assigned to groups by the analyses.

Evaluation of Isotopic Data

The results of the isotopic analyses appear in Table 7 of Appendix A. In order to study these data with the discriminant program, three groups were established, characterized by six trace elements and the carbon and oxygen isotopic ratios. These groups are listed in Appendix A and consist of five stratigraphic dolomites, five low-iron tectonic dolomites, and four ferroan tectonic dolomites. These 14 samples were originally selected from their respective groups for isotopic analysis on the basis of their high probabilities as computed in run MDISC 3 using ten variables. These probabilities appear in the last column of the group listing in Appendix A. Since these samples already had a high group probability, when separated as a group and given the added discriminating power of the isotopic ratios it would be expected that they would be assigned very high probabilities. Indeed all samples were assigned probabilities of 100% in all three computer runs (MDISC 10, 11, and 12.)

In Table 17 appear the means, standard deviations, the discriminant coefficients resulting from runs MDISC 10 and 11, and the results of the Kolmogorov-Smirnov test of the variables. MDISC 10 discriminated between the group of five stratigraphic dolomites and the group of five low-iron tectonic dolomites, MDISC 11 between the five stratigraphic dolomites and the group of nine tectonic dolomites formed by including the four ferroan tectonic dolomites. While differences in trace element content did exist between the low-iron and ferroan tectonic dolomites, there were no significant differences in the carbon and isotopic ratios. This permitted the merger of these two groups to strengthen the results of the discrimination. As indicated by the Kolmogorov-Smirnov test, the discriminating power of K, Ni, Cu, δO^{18}, and δC^{13} were improved by the inclusion of the ferroan dolomites while those of Na, Li, and Sr were decreased. For MDISC 11 the Kolmogorov-Smirnov test indicated that the carbon and oxygen isotopic ratios should discriminate at the 99.7 and 96% levels respectively. This evaluation is strengthened by the relatively large values of their coefficients in the discriminant function. Thus, both tests

Table 17. Evaluation of variables for MDISC 10 and 11.

		Na	K	Li	Ni	Cu	Sr	δO^{18}	δC^{13}	
1	$\bar{x}$ (5)	234.40	346.00	0.20	0.20	2.80	29.00	-6.80	0.18	MDISC 11
	s	47.62	159.59	0.45	0.45	0.45	16.00	1.99	0.79	
	k	0.36286	0.03528	0.60395	1.06064	1.45624	-0.06473	-12.64708	18.80735	
	$k\bar{x}$	85.05	12.21	0.12	.21	4.08	-1.88	86.00	3.39	
	% of DF	45.0	6.5	0.1	0.1	2.1	(-)1.	45.4	1.8	
2	$\bar{x}$ (9)	174.33	125.00	2.11	4.56	7.89	49.11	-4.12	-2.02	
	s	73.09	69.64	2.57	3.43	2.26	32.95	1.15	0.92	
	k	0.17756	0.00168	-0.20940	1.25890	2.66595	0.04728	-6.48513	4.65487	
	$k\bar{x}$	30.95	0.21	-0.44	5.74	21.03	2.32	26.72	-9.40	
	% of DF	40.1	0.3	(-)0.6	7.4	27.3	3.0	34.6	(-)12.2	
3	d_n	0.47	0.69	0.47	0.78	1.00	0.44	0.78	1.00	
(N=3.2)	P(%)	52	90	52	96	99.7	44	96	99.7	
1	k	3.66486	0.65013	-12.73588	66.32724	-29.49274	0.10836	-107.84199	-1.31633	MDISC 10
	$k\bar{x}$	859.04	224.94	-2.55	13.27	-82.58	3.14	733.33	-0.24	
	% of DF	49.1	12.9	(-)0.1	0.8	(-)5	0.2	41.9	(-)0.01	
4	$\bar{x}$ (5)	141.40	140.00	3.60	7.00	9.20	54.80	-4.28	-1.80	
	s	46.87	82.54	2.61	2.12	2.28	29.54	1.24	0.35	
	k	2.38278	0.44613	-7.12272	59.55704	-13.40285	0.74709	-76.58708	-11.64408	
	$k\bar{x}$	336.93	62.46	-25.64	416.90	-123.31	40.94	327.79	20.96	
	% of DF	31.9	5.9	(-)2.4	39.4	(-)11.7	3.9	31.0	2.0	
3	d_n	0.60	0.60	0.80	0.60	1.00	0.60	0.80	1.00	
(N=2.5)	P(%)	67	67	92	67	98.6	67	92	98.6	

1 = Stratigraphic dolomites
2 = All tectonic dolomites
3 = Kolmogorov-Smirnov Test
4 = Low-iron tectonic dolomites

k = discriminate coefficient
P(%)= Probability

confirm the importance of the isotopic ratios as group discriminators. Unfortunately, the small number of samples in each group hampers the effectiveness of both the Kolmogorov-Smirnov test and the discriminant analysis. Larger sample sizes would greatly increase the confidence of this discrimination. It would also be especially informative to test the discriminating power of the isotopic ratios against that of the trace elements alone. This could be done by analyzing isotopically the indeterminate samples that have already been assigned to groups on the basis of the trace element data alone.

In 1965, Dr. Gerald M. Friedman visited one of the localities (see Sargent, 1969, locality TA-4) from which samples for this study were collected. Friedman at that time collected 10 limestone and 13 tectonic dolomite samples. He attempted to collect these samples along a single horizon, but while the limestone bedding was easily traced, individual beds could not be traced in the dolomite due to fracturing and lack of topographic expression. The locality map for this area is reproduced in part from Sargent, 1969, in figure 9. On this map is placed the approximate location of Friedman's collecting area. Figure 10 is an enlarged view of this area and contains the sample locations as provided by Friedman.

Friedman analyzed his 23 samples for Ca, Mg, Sr, Mn, Cr, Fe, Cu, Ba, δO^{18}, and δC^{13}. The results of these analyses appear by permission in Table 8 of Appendix A. In

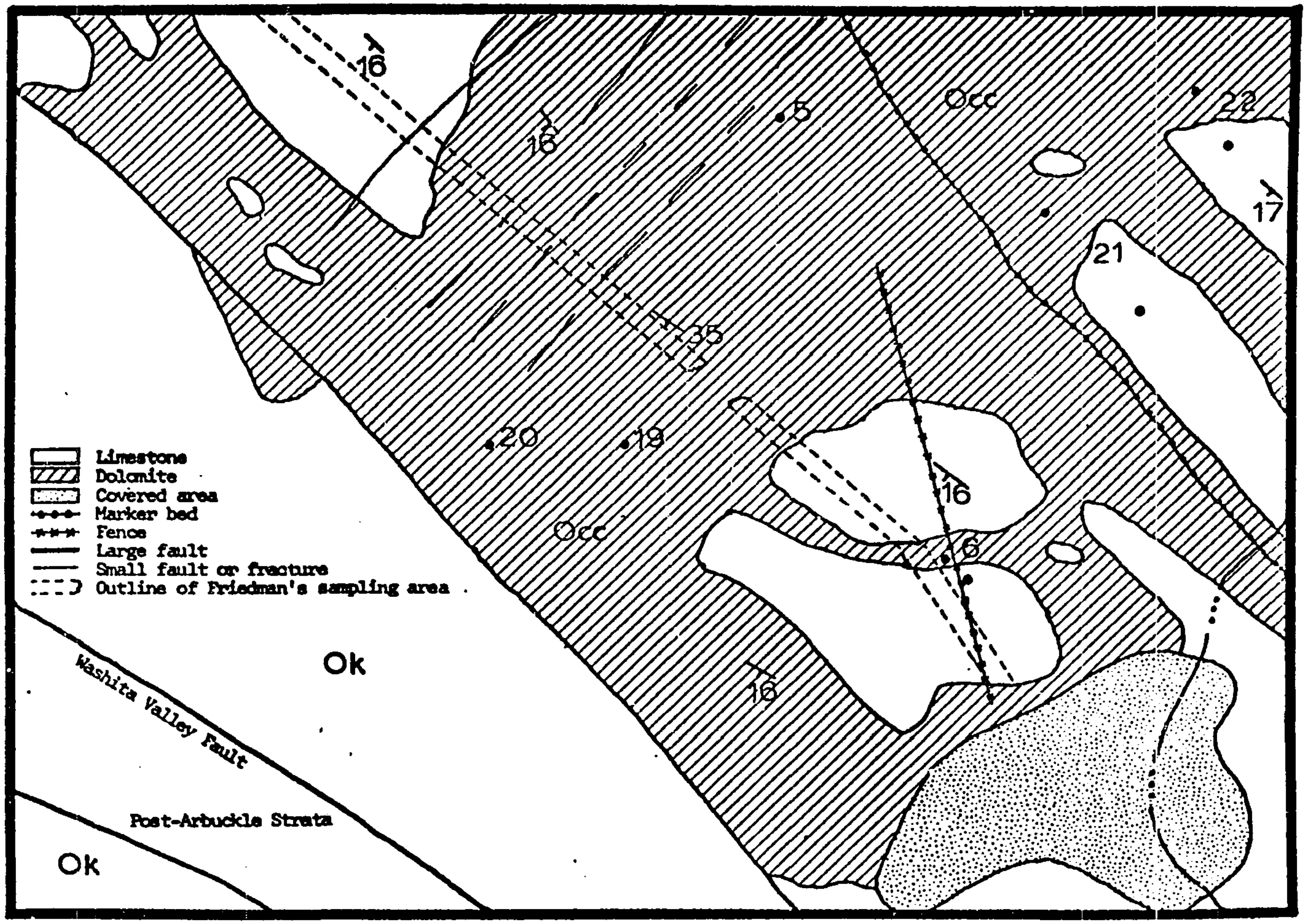


Figure 9. Locality TA-4 (map enlarged from Sargent, 1969) showing approximate location of Friedman's sampling area (dashed lines outline bed).

]

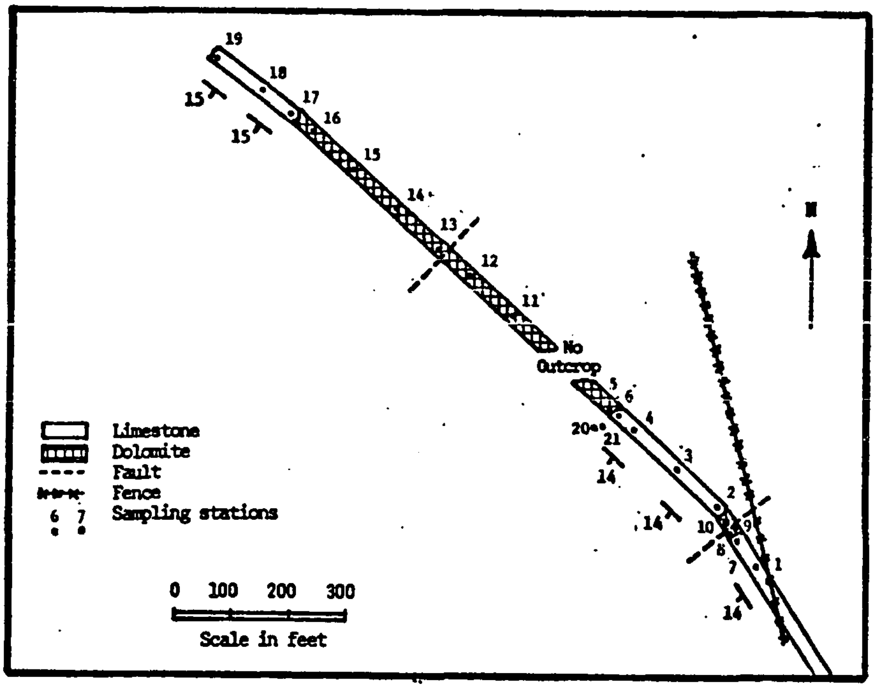


Figure 10. Sampling stations of Friedman in Cool Creek Formation, Locality TA-4 of Sargent (1969).

order to utilize the additional isotopic data for discriminant analysis, two groups were established, characterized by the five variables common to both analyses: Fe, Mn, Sr, δO^{18}, and δC^{13}. The means and standard deviations of these variables, the discriminant coefficients from computer run MDISC 13, and the results of the Kolmogorov-Smirnov tests on these variables appear in Table 18. All the samples were assigned to their own groups and the associated probabilities were all 100% when rounded. The coefficients of the discriminant function agree with the Kolmogorov-Smirnov test in selecting Mn as the least discriminating variable. The isotopic ratios, on the other hand, are important discriminators.

Table 18. Evaluation of variables for MDISC 13.

		Fe	Mn	Sr	$\delta\ O^{18}$	$\delta\ C^{13}$
Stratigraphic dolomites	$\bar{x}$ (5)	1,483.00	213.20	29.00	-6.80	0.18
	s	717.14	211.81	16.00	1.99	0.79
	k	0.01189	-0.00254	0.19591	-1.74922	3.06381
	k$\bar{x}$	17.6	-0.5	5.7	11.9	0.6
	% of DF	49.9	(-)1.4	16.1	33.7	1.7
Tectonic dolomites	$\bar{x}$ (18)	450.94	120.00	51.33	-4.20	-1.86
	s	215.88	64.44	14.50	1.55	0.43
	k	-0.00363	-0.00005	0.17672	-2.75237	-9.25724
	k$\bar{x}$	-1.6	-0.006	9.1	11.6	17.2
	% of DF	(-)4.4	(-)0.0002	25.1	32.0	47.4
Kolmogorov-Smirnov Test (N=3.9)	d_n	0.74	0.34	0.69	0.78	0.94
	P(%)	97	24	95	98	99.8

k = discriminant coefficient
P(%)= Probability

Evaluation of the Discriminant Function

The discriminant coefficient for each variable gives an indication of that variable's importance to the discriminant function. However, it must be remembered when evaluating variable importance that the means for each variable can differ greatly in value. For instance the mean for copper is 3 ppm in stratigraphic dolomites, while iron averages 1231 ppm. Furthermore, there can be an overlap of the standard deviations for a variable between groups as is the case for both manganese and iron. Clearly, one must consider both the means and standard deviations along with the discriminant coefficients when evaluating a variable's importance to discriminating between two groups.

Table 13 gathers together the information used to evaluate the variables from MDISC 6, 9, and 14, while Table 14 contains this information for MDISC 15 and 16. On the basis of means, overlap of standard deviations, and percent contribution to the discriminant function, lead, zinc, manganese, and iron were eliminated from runs MDISC 7, 8, and 9. However, a Kolmogorov-Smirnov test of each of the ten variables showed that while these four variables indeed were not good discriminators, two others, potassium and strontium, were also poor discriminators. Of the remaining four variables, three discriminate at a confidence level of better than 99% while the fourth is better than 90%. The six variables eliminated were all below the 45% confidence level. Subsequently, run MDISC 14 utilized the remaining four variables: sodium, lithium, nickel, and copper.

The results of all of the discriminant identification program runs (see Table 11) involving the group of 24 indeterminate dolomite samples appear in Table 15. A brief look at this table indicates that both the group assignments and their associated probabilities can change appreciably as the variables used for discrimination are changed. Examples of these changes can be seen in samples 2, 3, 7, 16, 19, and 21. Furthermore, as mentioned earlier, the probabilities and group assignments of the discriminant analyses can also change as group parameters change.

The problem as it now appears is to determine which discriminant function is the most reliable. One might intuitively choose the four variable discriminants (MDISC 14) since these four variables were selected on the basis of the Kolmogorov-Smirnov and other tests. However, statistical tests may often be manipulated by varying the grouping arrangement along one of the graphical parameters. The Kolmogorov-Smirnov test may be so manipulated by changing the class interval along the abscissa of the frequency histogram. This is illustrated in figures 7 and 8 of Appendix C where the separation of the cumulative frequency curves, d_n, is changed by shifting the grouping interval of the δO^{18} and δC^{13} data by 1/2 interval. Changes can also occur if the class interval is either increased or decreased. Thus the Kolmogorov-Smirnov statistic is to some degree variable.

However, the discriminant analysis statistic operates in a different manner. The graphical plot of two variables as in figure 11 results in the overlap of the group clusters. In the discrimination analysis these data points are plotted on a separating plane that is rotated in such a way as to minimize the dispersion of data points within the clusters while maximizing the separation between the two clusters as in figure 12. The discriminant coefficients are then calculated from the new vector coordinates and thus achieve a better discrimination than could be achieved by clustering on the original graph.

Figure 11. Two-dimensional, two-variable scatter diagram.

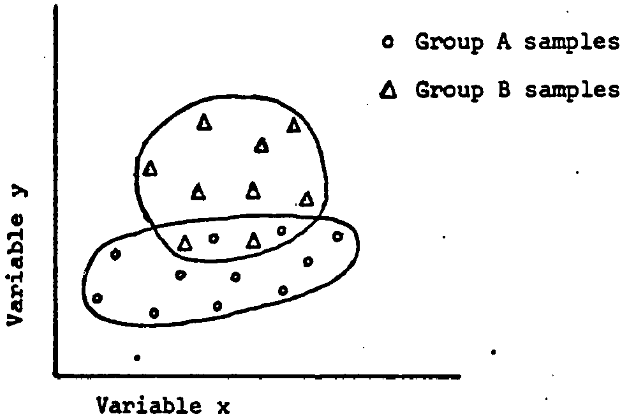
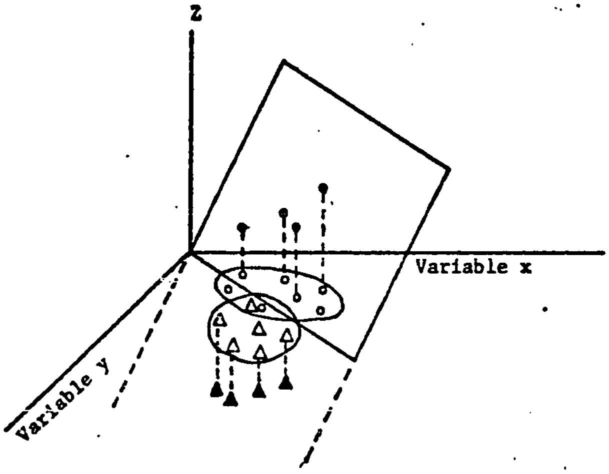


Figure 12. Projection of the scatter diagram points onto a separating plane.



A better method for testing the significance of additional variables is given by Rao (1952, p. 252-256) and involves the use of Mahalanobis' D^2 function to arrive at a variance ratio which may be tested with the standard F-test. Mahalanobis' D^2 is an estimate of the distance between two populations and is calculated by the discriminant analysis program used here. The D^2's of two functions cannot be compared directly since the distribution of this distance involves the population value of the distance based on the variables common to both discriminant functions. Instead the statistic used is $U_{q,p}$ which also compares the two D^2 values but has a simple distribution.

The statistic $U_{q,p}$ is

$$U_{q,p} = \frac{1 + \dfrac{N_1 N_2}{(N_1 + N_2)(N_1 + N_2 - 2)} D^2_{p+q}}{1 + \dfrac{N_1 N_2}{(N_1 + N_2)(N_1 + N_2 - 2)} D^2_p} - 1$$

where p is the number of basic variables to which are added q variables and N_1 and N_2 are the sizes of the two groups. The actual test statistic

$$\frac{N_1 + N_2 - p - q - 1}{q} U_{q,p}$$

is compared as a variance ratio with q and $(N_1+N_2 - p - q - 1)$ degrees of freedom.

When the q variables contribute little to the distance between groups, D^2_{p+q} and D^2_p will be approximately the same and U_{p+q} will approach unity. When there is a significant contribution by the q variables, U_{p+q} will be greater than unity and can be compared with the F-test.

This method was used to test whether the exclusion of variables in runs MDISC 9 and 14 significantly reduced the discrimination between the two groups. Table 19 contains the results of these tests.

Table 19. Results of F-test for MDISC 6, 9, and 14.

MDISC Runs	$D^2_{p+q}-D^2_p$	$^m/_n$	$^m/_n U_{q+p}$	F(m,n) dx=.90	F(m,n) dx=.75	F(m,n) dx=.50
6, 9	10	$^{34}/_4$	1.11	3.81	2.08	1.17
9, 14	11	$^{38}/_2$	3.04	9.47	3.45	1.42
6, 14	21	$^{34}/_6$	1.76	2.79	1.75	1.10

MDISC	N_1	N_2	Variables	D^2
6	17	28	10	84
9	17	28	6	74
14	17	28	4	63

In each case the test shows that the added distance provided by the additional variables is not significant at the 90% level. The distance provided by the four variables deleted from MDISC 9 is significant at slightly below the 50% level. The distance provided by the two additional variables deleted from MDISC 14 is significant at slightly below the 75% level. The distance added by all the six variables deleted from MDISC 6 for MDISC 14 is significant at slightly above the 75% level.

The first four variables eliminated, Pb, Zn, Fe, and Mn, were assigned low probabilities by the Kolmogorov-Smirnov test (0, 16, 27, and 30% respectively.) The F-test indicated a significance below the 50% level for these variables. The two additional variables deleted, K and Sr, discriminated with probabilities of 42 and 27% respectively according to the Kolmogorov-Smirnov test. The F-test indicated a significance for these two variables of slightly below the 75% level. On the basis of these results, the MDISC runs utilizing the four best discriminating variables should provide the best results with the greatest economy of effort.

Distinguishing Tectonic and Stratigraphic Dolomites

There is one problem remaining in connection with the dolomite samples which cannot be readily solved. Stratigraphic dolomites can be readily distinguished in the field area of this study when they occur alone without any tectonic dolomitization. Thus the control group of 17 stratigraphic dolomites was relatively easy to establish. This observation is borne out by the fact that these samples were assigned to their own group by all the MDISC runs with relatively high probabilities. Outcrops of tectonic dolomite can also be readily distinguished by their field relationships. However, the problem is in identifying each sample taken in a tectonically dolomitized area as a tectonic dolomite. Thin and discontinuous lenses of stratigraphic dolomite commonly occur interbedded with the limestone in the study area. Thus it can be difficult to establish that a particular sample is a tectonically dolomitized limestone or a sample of a stratigraphic dolomite within the tectonically dolomitized area. In addition, this stratigraphic dolomite may or may not have been affected by the tectonically dolomitizing solutions.

This sampling difficulty could account for the six samples of tectonic dolomite that were consistently either assigned to the stratigraphic dolomite group or assigned low probabilities in the tectonic dolomite group. It would be important to note here as has been discussed before that once these six samples were excluded, the probabilities in both groups were increased. Furthermore, the probabilities assigned by the identification runs DSCID 6 and 7 to the 24 indeterminate samples were also higher than those assigned by runs DSCID 3 and 4. When these six samples were tested in DSCID 8, they were all assigned to the stratigraphic dolomite group with probabilities ranging from 93 to 100%. These results are given in Table 15.

Although there appears to be considerable evidence to indicate that these samples might be stratigraphic lenses within the tectonically dolomitized area, the possibility must also be recognized that there could exist a range in composition for the tectonic dolomites from samples that are close in composition to the stratigraphic dolomites, to those that are herein characterized as "good" tectonic samples. The six dolomite samples were all sampled as "good" tectonic dolomites. The field relations indicated that the dolomite was tectonic and no stratigraphic dolomite lenses were observed. Furthermore, two of the samples were collected along with a limestone sample from the same bed. This was established by physically tracing the bed from the limestone into the tectonically dolomitized area. Two other samples were also sampled along with equivalent limestone samples although the certainty of the tracing was not as great as in the first case. The two remaining samples are dolomite breccias taken from a faulted zone. In none of these cases is there any indication of a stratigraphic origin, except for their trace element content. The answer then must be that the tectonic dolomites do range in composition. A more thorough investigation of the isotopic compositions might provide the final solution to this question.

INTERPRETATION OF THE ANALYTICAL RESULTS

Discussion of the Trace Element Compositions

The trace element impurities in the carbonate samples of this study could be present as structural impurities (either substitutional or interstitial), as intragranular growth inclusions, or as intergranular adsorbates on carbonate or noncarbonate grains.

Small ionic size is necessary for interstitial substitution. Lithium in tetrahedral coordination is the only one of the ten elements small enough in size for interstitial substitution. In octahedral coordination it becomes too large for such substitution.

The large ions, lead, strontium, sodium, and potassium, substitute more readily in the spaceous aragonite structure and are appreciably lost upon conversion to the less spaceous calcite structure.

The divalent ions of copper, nickel, zinc, iron, and manganese are within the correct ionic size range for substitution for magnesium in the dolomite structure. Iron and manganese can also occur as oxides. Copper, nickel, and zinc can commonly occur adsorbed in organic material.

The alkali elements, lithium, sodium, and potassium, due to their size and charge would be unsuitable for interstitial substitution or for extensive mutual substitution for either calcium or magnesium in the carbonate structure. They would most likely occur as adsorbates on carbonate and noncarbonate grains or as solid or liquid intragranular inclusions. No obvious inclusions were observed in thin-section. Thus much of the lithium, sodium, and potassium could occur as surface adsorbates.

For surface adsorption from solution, the empirical Freundlich isotherm equation is used in the form $a = kc^n$, where a is adsorption, c is concentration, while k and n are constants for the given adsorbent and adsorbate. Thus adsorption is directly related to concentration of the adsorbate in solution. (See Glasstone and Lewis, 1960, p. 567.)

The total amount of lithium, sodium, and potassium in the carbonate samples should then be related to the concentration of each in the diagenetic solutions, the amount of insoluble residue in each sample, and the proportion of clays (better adsorbents) to the other insoluble minerals. Complete evaluation of these complex interrelationships was not attempted in this study. However, an analysis of the insoluble residue data generated in this study and comparison to other published studies allows some interpretations to be made.

Weber (1964b) in analyzing 300 "primary" and "secondary" dolostones and 150 dolomites discovered several elemental variations. It is difficult to compare his results with those of the present study which is concerned with early diagenetic and late diagenetic dolomites. However, the "primary" dolostones were based on evidence which only suggest the possibility of direct chemical precipitation. As reported by Weber, the characteristics suggesting primary origin are "excellent stratification, very fine to cryptocrystalline grain size, uniform grain size, complete absence of faunal remains, absence of any relict textures or structures, lack of appreciable porosity, relatively light color, and subconcoidal to concoidal fracture." The stratigraphic dolomite samples of the present study exhibit many of these features. The secondary dolostones in Weber's report were those which exhibited replacement features with no breakdown as to early or late diagenesis. A further difficulty is that the analyses of the dolostones were made on the whole rock sample which includes contributions from the non-carbonate fraction. The 150 dolomites were obtained by acid dissolution of 150 dolostone samples and thus would provide data more compatible to the present study, although the aforementioned problem of the secondary dolomites remains.

Weber attributed the greater Li content of the primary dolostones to the greater abundance of clay minerals in these rocks. Horstman (1957) had noted that the Li content of carbonates was most likely incorporated in the clay fraction since Li does not occur as a carbonate in nature or enter into the calcite or dolomite structure. The present study found that the low-iron tectonic dolomites contained more Li than the stratigraphic dolomites. However, this higher Li content was mainly due to four samples with high Li contents beyond one standard deviation from the mean. These four samples were also high in insoluble residue content. When these samples are removed from the group, the mean Li content is only slightly higher than that of the stratigraphic and ferroan tectonic dolomites. When plotted against insoluble residue content in figure 13 the Li shows a highly variable but recognizably positive correlation for low-iron tectonic dolomites. However, as seen in figure 14, no correlation exists for the stratigraphic dolomites. In addition, no correlation was found between the Li content and insoluble residues of the limestones or ferroan tectonic dolomites.

Linear regression analysis of the data points in figure 13 results in a correlation coefficient of $r = 0.63$ where $r = 0$ indicates no covariance and $r = 1$ indicates perfect covariance. The value $100 \cdot r^2$ yields the % of variation of random variable Y that is accounted for by variation in X. For the tectonic dolomites, the insoluble residue variation accounts for 40% of the variation of the lithium content indicating significant positive correlation for these data. For the stratigraphic dolomites (figure 14), the correlation coefficient is $r = 0.24$ which yields a $100 \cdot r^2$ value of 6%. This would indicate no significant covariance between lithium and and the insoluble residue content of the stratigraphic dolomites. Furthermore, contrary to the findings of Weber, the

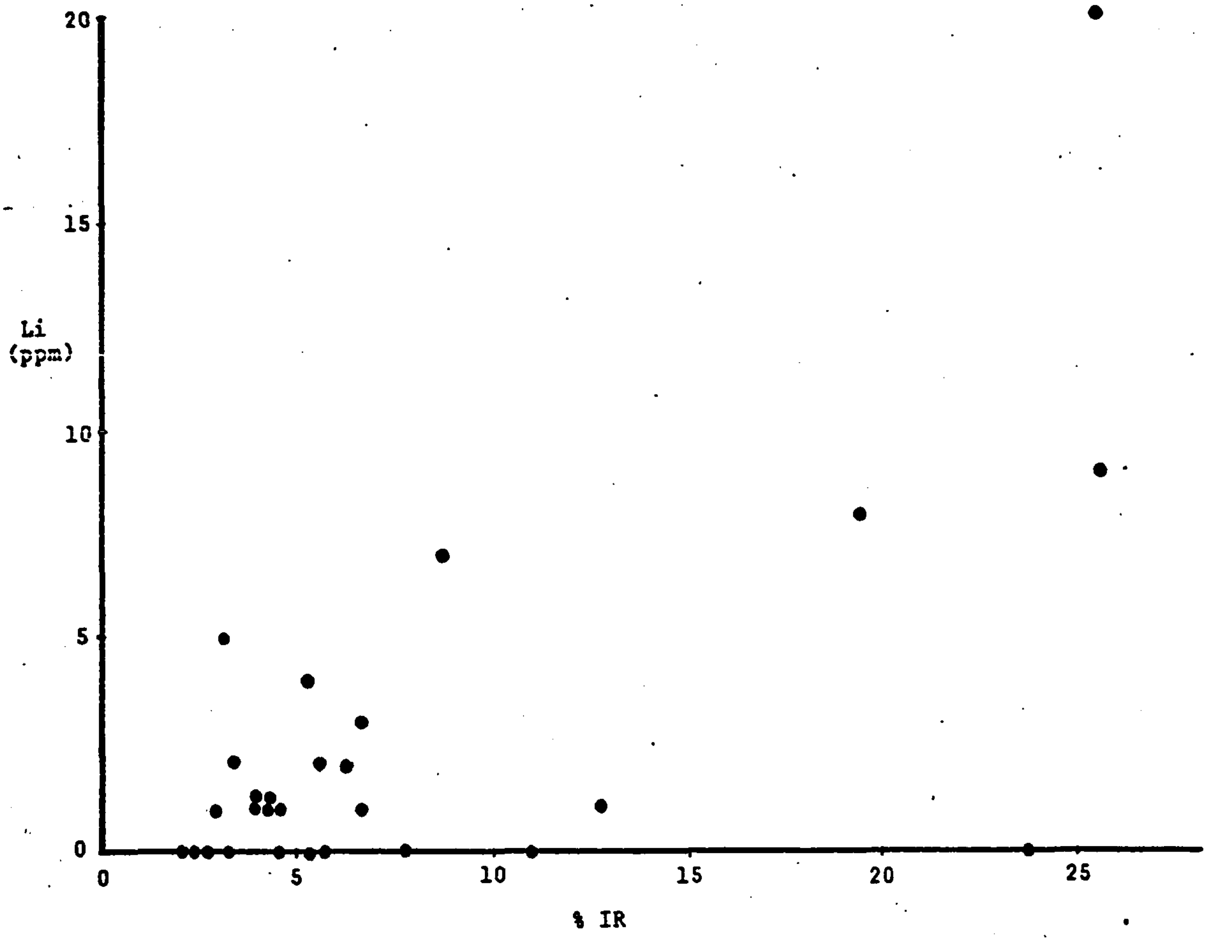


Figure 13. Lithium vs insoluble residue for low-iron tectonic dolomites.

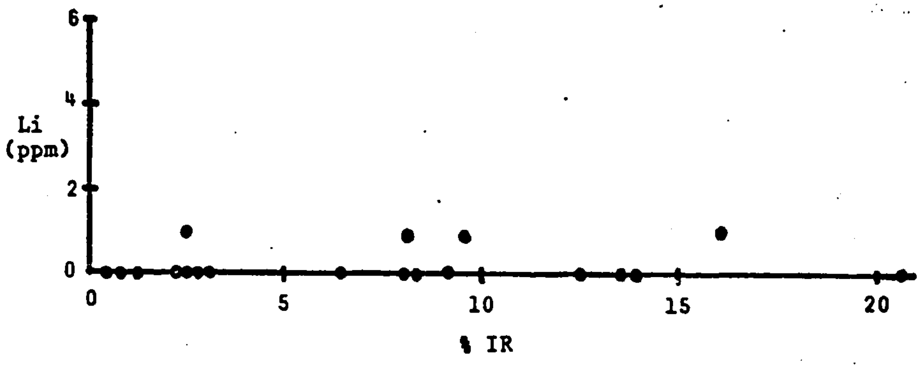


Figure 14. Lithium vs insoluble residue for stratigraphic dolomites.

lithium content of the low-iron tectonic dolomites was higher than that of the stratigraphic dolomites.

In examining the trace element analyses of all the samples, a regional trend becomes apparent in the Li distribution. The Arbuckle anticline dolomite samples contained no Li. The three Arbuckle anticline limestones contained only 1 ppm Li each, well below the average for all limestones in this study. On the other hand, of the Tishomingo limestones and tectonic dolomites, 80% contained some Li. Of the stratigraphic dolomites of the Tishomingo anticline, four contained 1 ppm Li and the remainder contained no Li. Clearly the relationship is complex. The only discernible patterns evident are that Tishomingo anticline rocks are in general richer in Li than the Arbuckle anticline rocks, and that the low-iron tectonic dolomites are enriched relative to the stratigraphic dolomites analyzed. This enrichment of the low-iron tectonic dolomites of the Tishomingo anticline relative to the stratigraphic dolomites may reflect an incomplete or ineffective leaching of the insoluble residue by the tectonic dolomitizing solutions and a more complete or effective leaching by those solutions causing stratigraphic dolomitization.

Weber also noted a higher K abundance in the primary dolostones and again attributed this to their higher clay mineral content. In the present study the stratigraphic dolomites were found to have a higher K abundance than any of the tectonic dolomite groups. However, the average insoluble residues of the dolomite groups are within 2% of each other, with the low-iron tectonic dolomites containing on the average 1% more than the stratigraphic dolomites. When the K abundance is plotted against the insoluble residue content for both stratigraphic dolomites and low-iron tectonic dolomites (figures 15 and 16), a variable but positive correlation results.

Linear regression analysis of the data for the stratigraphic dolomites (figure 15) yields a correlation coefficient of $r = 0.76$ which gives a $100 \cdot r^2$ value of 58%. This would indicate that the insoluble residue data account for 58% of the variability of the potassium content. For the low-iron tectonic dolomites (figure 16), the correlation coefficient is $r = 0.56$ which yields a $100 \cdot r^2$ value of 31%. This would indicate significant covariance between potassium and the insoluble residue content of both the stratigraphic and tectonic dolomites.

Most of the variability of the data points within dolomite groups is thought by the author to be due to variations in the clay mineral content of the insoluble residue. In figure 16, the four samples which have the highest insoluble residue content also tail off from the linear mean. All four samples were observed to contain abundant grains of quartz sand and iron oxides. The abundance of these non clay minerals in the insoluble residue would explain the tailing off of the data in figure 16. With these four samples removed, a correlation coefficient of $r = 0.60$ is obtained yielding a $100 \cdot r^2$ value of 36%.

It would thus appear that K may be concentrated in the clay mineral fractions and would be of only limited use in distinguishing between stratigraphic and tectonic dolomite. However, there are statistical differences between the K content of the stratigraphic dolomites, the low-iron tectonic dolomites, and the ferroan dolomites. The stratigraphic dolomites averaged 206 ppm K, the low-iron tectonic dolomites 164 ppm, the ferroan tectonic dolomites 117 ppm, and the limestones 108 ppm. Since there is very little difference between the average insoluble residue contents, these differences could reflect either a difference in the percentage of clay minerals in the insoluble residues or differences in the temperature and composition of the dolomitizing solutions. Both temperature and cation concentration can affect the cation exchange capacity of clay minerals.

No correlation between the K content and insoluble residue was evident for the limestones and the ferroan tectonic dolomites. The evidence suggests that differences in the temperature and composition of the dolomitizing solutions produced the differences in K content of the stratigraphic and low-iron tectonic dolomites. None of the other elements analyzed could be correlated with insoluble residue content.

Sodium was found to be concentrated in all dolomites relative to the limestones. This general enrichment of

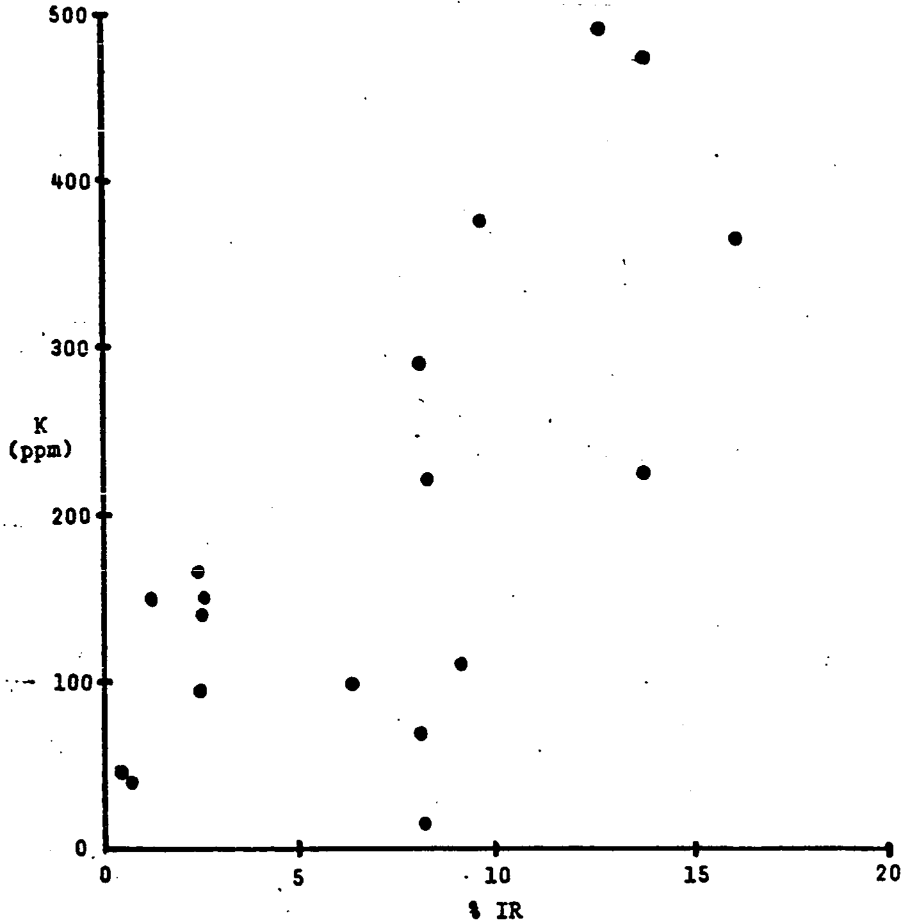


Figure 15. Potassium vs insoluble residue for stratigraphic dolomites.

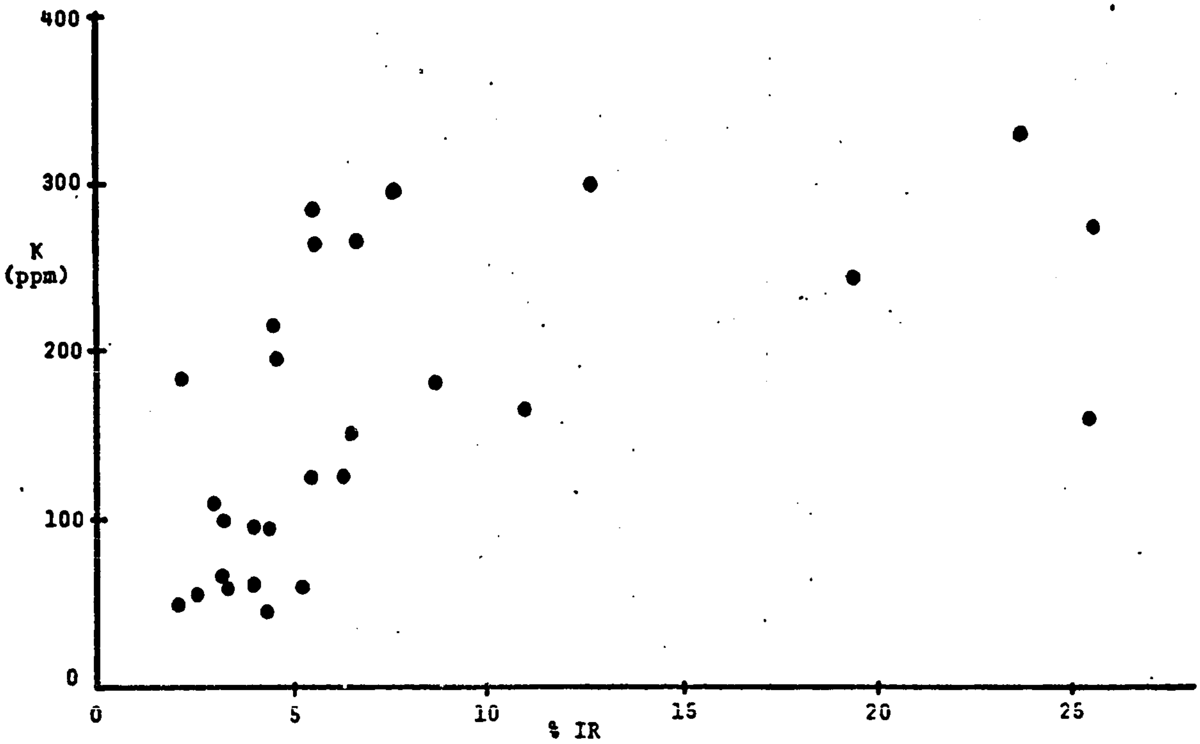


Figure 16. Potassium vs insoluble residue for low-iron tectonic dolomites.

sodium in the dolomites is probably due to a higher salinity of the dolomitizing solutions relative to normal sea water. No correlation of sodium with insoluble residue was evident. This agrees with Fritz and Katz (1972) who found no correlation between sodium and aluminum content. Furthermore, Fritz and Katz noted higher sodium and potassium content for supratidal dolomite with lower contents for later formed diagenetic dolomites. With the exception of the higher sodium content of the ferroan tectonic dolomites, the same relationship was noted in this study. The lack of correlation between sodium and insoluble residue content suggests that the sodium is mainly incorporated as solid or liquid intragranular inclusions, or substituted into the crystal structure which is less likely due to its charge and ionic size.

The ionic sizes of copper and nickel are close to that of magnesium and they could thus be accomodated in the dolomite structure by mutual substitution. Both elements have been reported to correlate to the organic content of rocks. (See LeRiche, 1959, or Krauskopf, 1956.)

The concentrations of Cu and Ni in the various dolomites provided the best discrimination. Weber suggested that Cu might also be concentrated in the clay mineral fractions and reported abundances of 5.72 ppm for primary dolostones and 6.74 ppm for secondary dolostones, both groups with large standard deviations. In contrast, the present study discovered a distinct difference between the Cu content of the stratigraphic dolomites ($\bar{x}$ = 3.12 ppm) and that of the tectonic dolomite groups ($\bar{x}$ = 5.93 ppm) with both groups having small standard deviations. In addition, the Kolmogorov-Smirnov test indicates that Cu discriminates between the tectonic groups and the stratigraphic group with a confidence of 100%. Cu also occurs in the limestones at only a slightly higher concentration ($\bar{x}$ = 7.16 ppm). Since Cu also occurs in the vein dolomites to the same extent as the other tectonic dolomites, the possibility exists that there was sufficient Cu in the tectonically dolomitizing solutions to prevent its removal from the limestone during diagenesis. However, the absence of relict structures of copper sulfide minerals in the limonite bodies within the tectonically dolomitized areas would suggest that copper, if present in the dolomitizing solutions, was in very low concentrations. The limonite samples with few exceptions exhibit the relict crystal or growth structures of their mineral precursors. These structures are, without exception in the specimens studied, characteristic of marcasite and pyrite. If Cu was present in the dolomitizing solutions in significant quantities, relict copper iron sulfide structures should also be present.

A similar condition exists for the Ni abundances. The stratigraphic dolomites have the least Ni with an average of 0.94 ppm followed by the ferroan tectonic dolomites with 1.88 ppm. The low-iron tectonic dolomites contain an average of 6.46 ppm Ni while the vein dolomites contain 9.60 ppm.

All dolomite groups have large standard deviations. The limestones contain 32.04 ppm. Again the vein dolomites with appreciable Ni content suggests sufficient Ni content in the tectonically dolomitizing solutions to prevent the complete removal of Ni from the limestones. Alternately, these two ions, Ni and Cu, may be complexed in the organic content of the rock and the difference in abundances between the stratigraphic and tectonic dolomites might only reflect the lack of organic structures in the stratigraphic dolomites. The Kolmogorov-Smirnov test indicates a confidence level of 100% for Ni in discriminating between the stratigraphic and low-iron tectonic dolomites.

The Sr content of the dolomites was of only limited use due to the large overlap of standard deviations between groups. The stratigraphic dolomites had the lowest average content at 26.65 ppm with the tectonic dolomite groups averaging just above 40 ppm. The vein dolomites averaged 46.20 ppm but this high average is probably due to the inevitable contamination when sampling these veins which range in width from one to five mm. and commonly contain Mn and Fe oxides in the center. When one sample very high in Sr is excluded the average becomes 28.25 ppm Sr. The sample believed to be the purest vein dolomite, TA 1-1-1v, contained 18 ppm. Thus there is some evidence to suggest that the vein dolomites might have a lower Sr concentration than the stratigraphic dolomites.

The large strontium ion is more easily accomodated in the calcium sites in the more spacious aragonite structure than in the calcite structure. Upon conversion of aragonite to calcite, much of the strontium is lost. During dolomitization much of the remaining strontium is removed as it does not readily fit into the smaller dolomite structure. The Sr content of the dolomites might then reflect the amount of excess calcite in the samples, the tectonic replacement dolomite having on the average more excess calcite than the stratigraphic dolomites, and the precipitated vein dolomites being the closest to the ideal dolomite composition. When the percentage of $CaCO_3$ for the 11 samples in Table 1 of Appendix A is plotted against the Sr content in figure 17, a variable but positive correlation results.

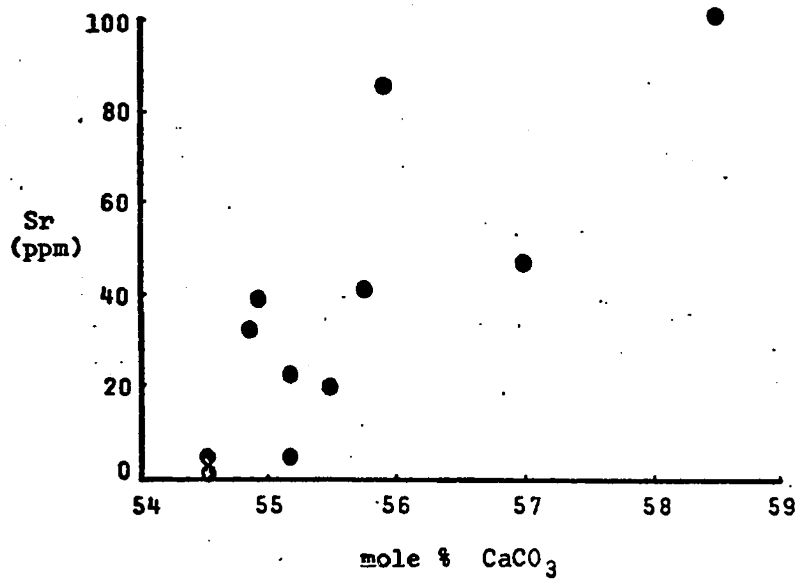


Figure 17. Strontium vs mole percent $CaCO_3$ in 11 carbonate samples including limestones, tectonic dolomites, and stratigraphic dolomites.

Atwood and Fry (1967), in analyzing 21 dolomitic limestones and secondary dolomites for Sr and Mn, reported a decrease in Sr and an increase in Mn in the dolomite samples. Correlation between the strontium content of the dolomite and the shift of the dolomite d_{112} diffraction peak suggested to them that the larger Sr ion in the parent calcite was progressively excluded from the smaller dolomite lattice during dolomitization (Atwood and Fry, p. 1533.) The increase in manganese was attributed to addition of this element to the system from the dolomitizing solutions. Similar trends were noted in the present study. Sr was depleted in the dolomites relative to the limestones while Mn and Fe were more abundant in the dolomites. The enrichment of the dolomites in Mn and Fe is due to the ease with which these ions can substitute for Mg in the dolomite lattice.

With the exception of the ferroan tectonic dolomites, lead and zinc were absent in all but a few samples. In the ferroan tectonic dolomites, the concentrations of these elements were higher than in the limestones, indicating the presence of these two elements in the epigenetic dolomitizing solutions responsible for the ferroan dolomites. The ionic size of zinc would allow substitution for magnesium but the large size of the lead ion would exclude it from extensive substitution for magnesium. However, lead could substitute in the calcium positions. Neither element was useful in the discriminations.

The ionic sizes of iron and manganese fall between calcium and magnesium and thus allow for substitution either in calcite for calcium or in dolomite for magnesium. The ease of substitution of iron and manganese for magnesium is seen in the ferroan tectonic dolomites. However, while much of this iron and manganese is substituted in the dolomite structure, some also occurs as noncarbonate minerals. Some dolomite crystals show good zoning under the microscope. This zoning is probably due to inclusions of iron oxides during growth. Disseminated iron and manganese oxide grains are also evident in some samples.

With the exception of the ferroan tectonic dolomites, the Pb, Zn, Mn, and Fe content of the dolomites was highly variable with no significant difference between the groups. These four elements must have been especially concentrated in the dolomitizing solutions in the Arbuckle anticline area, since all four elements are significantly concentrated in the tectonic dolomites from this area.

The results of the present study suggest that the solutions causing dolomitization in the Tishomingo anticline area were apparently barren in Pb and Zn, and low in Ni, Cu, Mn, and Fe content.

Stehli and Hower (1961) analyzed 41 samples of recent carbonate sediments and 20 Pleistocene carbonate rocks for Mg, Sr, Ba, and Mn. They discovered a marked decrease in abundance of all four elements in the rock samples and concluded that diagenesis of carbonate sediments results in loss of the trace constituents. A similar decrease in trace element abundance due to the diagenetic dolomitization was noted in the present study. The concentrations of Li, Ni, Cu, and Sr were lower for all dolomites relative to the limestones. In addition, the concentrations of Pb and Zn were lower for the stratigraphic and low-iron tectonic dolomites relative to the limestones.

Factors Affecting the Carbon and Oxygen Isotopic Compositions

This discussion is not intended to cover completely the isotopic geochemistry of carbonates, but instead to present the factors that most likely could have determined either singly or jointly the isotopic composition of the carbonates involved in this study. Detailed studies of the isotopic geochemistry of carbonates may be found in Degens and Epstein (1964) and Clayton, Jones, and Berner (1968).

The most obvious factors affecting the isotopic ratios would be the temperature and isotopic compositions of the dolomitizing fluids. The heavy isotope of oxygen is incorporated in the carbonate structure to a greater extent at low temperatures than at high temperatures. This of course is the basis of O^{18} paleothermometry.

The temperatures of the solutions causing the tectonic dolomitization of this study are not known and could conveivably have varied both spacially and temporally. If the solutions were entrapped at the maximum depths suggested for the Arbuckle formations (30,000 feet; see Ham et al, 1973, p. 15), their temperatures could have exceeded those generally assigned to stratigraphic dolomitization. (80-120°F; see Illing, Wells, and Taylor, 1965; Deffeyes, Lucia, and Weyl, 1965.) A depth of burial of 15,000 feet would give connate water temperatures in the range of 170 to 200° F according to Shelton (personal communication, 1974.) If entrapped at shallower depths, the tectonic solutions could have been at temperatures equal to those of the solutions producing the stratigraphic dolomitization.

Furthermore, the temperatures of the tectonic solutions could have varied between localities, especially between the Arbuckle and Tishomingo anticline areas which are separated by a distance of approximately 20 miles. Finally, solutions warmer than the ambient rock temperature would cool and thus there would be a variation from the beginning to the end of the dolomitization period.

The isotopic composition of the epigenetic solutions would be at least as important as temperature in determining the isotopic composition of the dolomites. If they were meteoric in origin the epigenetic solutions would have been enriched in the lighter isotope of oxygen. If the solutions were connate in origin and similar in composition to oilfield brines, they would have been enriched in the heavier isotope of oxygen. If hypersaline sea water produced the stratigraphic dolomites the resulting isotopic composition would most likely have been similar to that of normal sea water.

Since living organisms preferentially incorporate C^{12} into their structure, sediments rich in organic matter have more C^{12} available. Oxidation of this organic matter would supply carbon dioxide enriched in C^{12} to the diagenetic solutions within the sediments. Carbonates produced by precipitation from or equilibration with these solutions would also be enriched in the lighter isotope.

In summary, several factors would have an effect on the isotopic composition of dolomites. Since the two dolomites in this study - stratigraphic and tectonic - must have formed under different conditions, it is to be expected that their isotopic compositions would be different.

Discussion of the Isotopic Compositions

The range of isotopic values for samples in this study are given below in Table 20. The samples analyzed by Friedman as discussed previously are also included. The complete isotopic analyses appear in Table 7 of Appendix A, while Friedman's analyses appear in Table 8 of Appendix A.

Table 20. Range of isotopic values

	δC^{13}	δO^{18}
Limestone (Sargent) (3)	-2.9 to -1.6	-7.6 to -6.3
Limestone (Friedman) (10)	-3.9 to -1.4	-7.8 to -7.0
Stratigraphic dolomites (5)	-0.9 to +1.0	-9.4 to -5.2
Low-iron tect. dolo. (5)	-2.1 to -1.2	-6.2 to -2.9
Tect. dolo. (Friedman) (13)	-2.8 to -0.9	-7.6 to -2.7
Ferroan tect. dolo. (4)	-4.2 to -1.0	-5.6 to -2.9
Vein tect. dolo. (3)	-2.3 to -1.3	-3.8 to +2.4

Number in parentheses indicates
number of samples in group

Table 21 (page 79) gives a comparison of the means and standard deviations between Friedman's samples and those of this study, as well as the means and standard deviations of the two groups combined. The isotopic ratios of the 10 limestones and 13 tectonic dolomites analyzed by Friedman were similar to those of this study (see figures 18 and 19) and are included in their respective groups in the discussion that follows.

Table 21. Means and standard deviations of the isotopic concentrations.

	δ C^{13}		δ O^{18}	
	$\bar{x}$	s	$\bar{x}$	s
Limestones (Sargent) (3)	-2.4	0.7	-6.9	0.7
Limestones (Friedman) (10)	-2.6	1.0	-7.4	0.3
Combined (13)	-2.6	0.9	-7.3	0.4
Stratigraphic dolomites (5)	+0.2	0.8	-6.8	2.0
Low-iron tect. dolo. (5)	-1.8	0.4	-4.3	1.2
Ferroan tect. dolo. (4)	-2.3	1.4	-3.9	1.2
Combined (9)	-2.0	0.9	-4.1	1.2
Tect. dolo. (Friedman) (13)	-1.9	0.5	-4.2	1.7
Combined (22)	-1.9	0.7	-4.2	1.5
Tect. vein dolo. (3)	-1.7	0.5	-1.5	3.4

Number in parentheses indicates number of samples in group

Variation in C^{13} Content

Degens and Epstein (1964) have suggested that recrystallization and dolomitization do not significantly alter the carbon istopic ratio of the original carbonate precursor. On the other hand, Friedman and Sanders (1967), using Friedman's carbon isotopic analyses of 10 limestones and 13 tectonic dolomites from the present study area, concluded that there was a significant difference in the carbon isotopic ratios between the limestones and tectonic dolomites. They suggested that the dolomitizing solutions were hypersaline brines enriched in O^{18} and C^{13}. The isotopic data obtained in the present study agree with their conclusions. Friedman and Sanders (1967, p. 331) reported that while the δ C^{13} ranges of

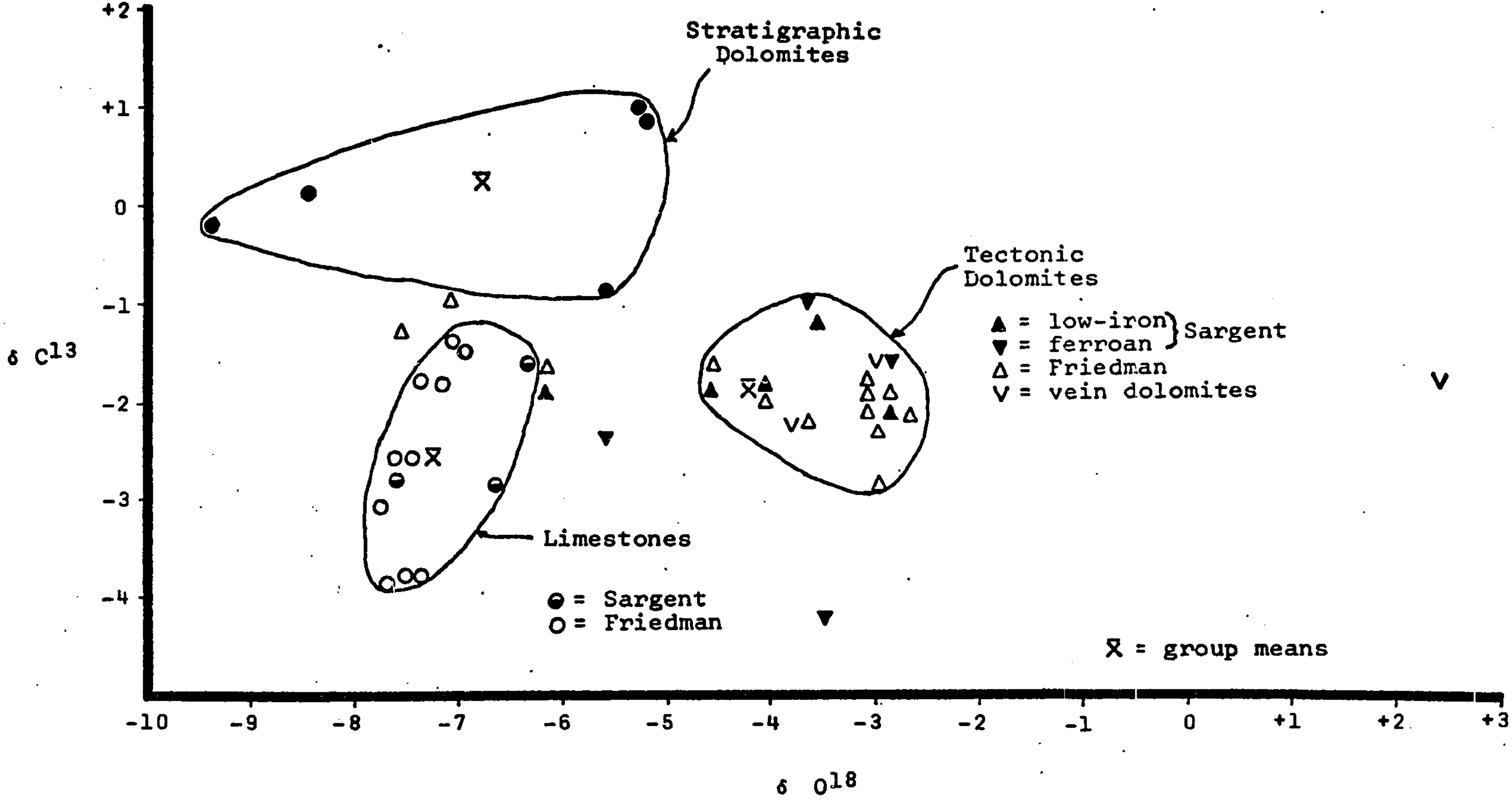


Figure 18. Plot of δC^{13} vs δO^{18} for all samples analyzed.

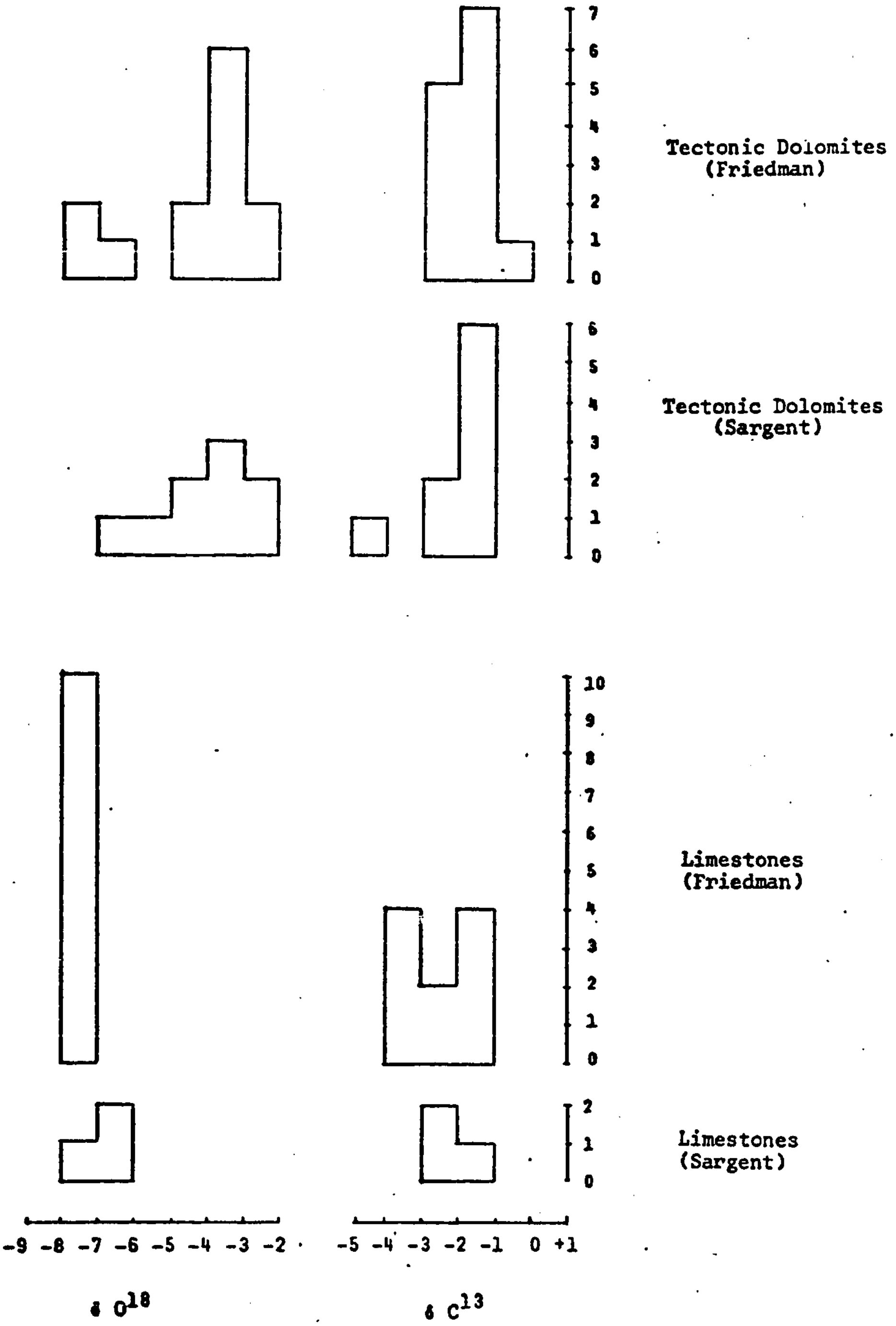


Figure 19. Comparison of the isotopic ratios of Friedman with those of Sargent.

the limestones and tectonic dolomites overlap (see Table 19), six of the ten limestones have values between -2.6 and -3.9, and eight of the thirteen dolomites have values between -0.9 and -1.9. From this they concluded that the dolomites were enriched in the heavier carbon isotope.

In the present study two of the three limestones were within the range -2.6 and -3.9, while six of the nine dolomites were within the range -0.9 and 1.9. With the data from both studies combined, eight of thirteen limestones and fourteen of twenty-two dolomites are within the ranges indicated above. Furthermore, the δ C^{13} range for the tectonic vein dolomites was -1.3 to -2.3 with two of the three samples within the tectonic dolomite range -0.9 to -1.9.

In figure 20 appear the frequency histograms for the combined isotopic data of Friedman and that of the present study. A Kolmogorov-Smirnov test of the carbon isotopic data indicates a probability of 98% that the distribution for the limestones is different from that of the tectonic dolomites. The Student's t-test indicates that there is a 99% probability that the means differ significantly. It would appear then that the carbon isotopes reequilibrate as do the oxygen isotopes, although not to as great an extent.

When the isotopic ratios of limestone-tectonic dolomite and stratigraphic dolomite-tectonic dolomite pairs are considered the reequilibration of the carbon isotopes becomes more complex. Table 23 compares the isotopic ratios of three

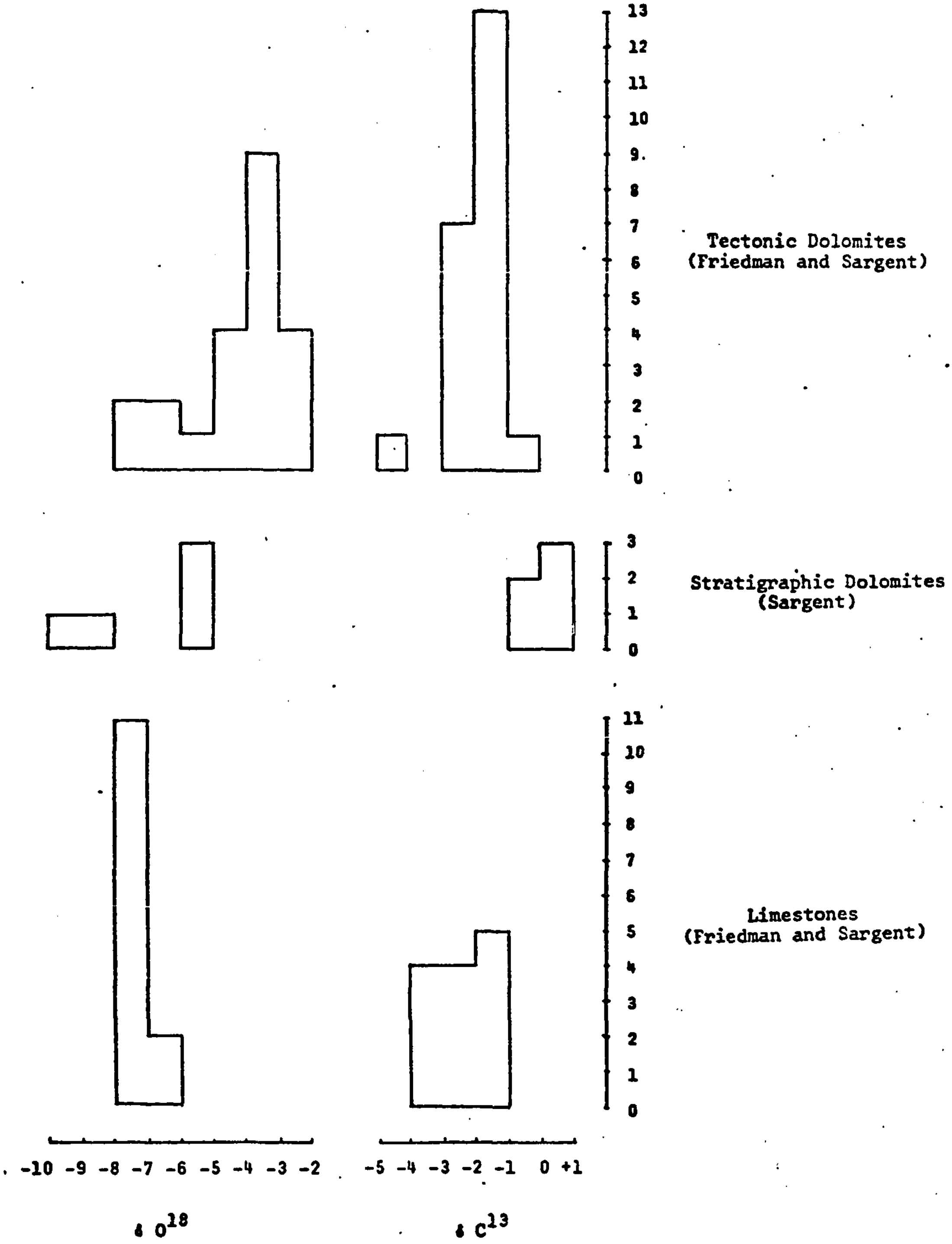


Figure 20. Comparison of the isotopic ratios of the tectonic dolomites, stratigraphic dolomites, and limestones.

Table 22. Group means of trace element and isotopic concentrations.

		Pb	Zn	Na	K	Li	Ni	Cu	Sr	Mn	Fe	δ O^{18}	δ C^{13}	
1	$\bar{x}$ (25)	4.36	5.80	139.36	108.56	3.64	32.04	7.16	251.80	39.32	535.84	-6.9	-2.4	(3)
	S.D.	3.72	11.80	38.63	62.07	4.29	7.82	2.54	130.95	19.70	228.36	0.7	0.7	
2	$\bar{x}$ (17)	1.00	0.12	222.24	206.18	0.24	0.94	3.12	26.65	176.24	1,231.24	-6.8	+0.2	(5)
	S.D.	4.12	0.49	51.15	143.35	0.44	1.43	0.93	17.02	191.61	1,000.58	2.0	0.8	
3	$\bar{x}$ (28)	0.21	1.46	169.61	162.68	2.50	6.46	6.57	40.25	94.57	858.11	-4.3	-1.8	(5)
	S.D.	0.96	3.67	68.83	90.76	4.26	4.82	2.36	24.32	72.70	760.13	1.2	0.4	
4	$\bar{x}$ (26)	14.54	15.46	269.62	117.31	0.27	1.88	5.04	41.42	2,300.08	10,857.73	-3.9	-2.3	(4)
	S.D.	43.47	29.26	128.48	55.93	0.60	2.89	1.89	19.69	933.83	3,292.62	1.2	1.4	
5	$\bar{x}$ (5)	0.6	0	192.20	63.00	0	9.60	7.00	46.20	210.00	1,612.20	-1.5	-1.7	(3)
	S.D.	1.3	0	66.73	26.60	0	7.80	2.55	40.60	113.11	1,144.50	3.4	0.5	

1 = Limestones
2 = Stratigraphic dolomites
3 = Low-Fe tectonic dolomites
4 = Ferroan tectonic dolomites
5 = Tectonic vein dolomites

Table 23. Analyses of limestone-tectonic dolomite and stratigraphic dolomite-tectonic dolomite pairs.

			Pb	Zn	Na	Li	Ni	K	Cu	Sr	Mn	Fe	δO^{18}	δC^{13}
All Ls from Ls-T-DOL Pairs (N = 16)			5	7	126	4	34	112	8	245	37	481	-6.7**	-2.4**
All T-DOL from Ls-T-DOL Pairs					187	2	7	161	6	43	54*	571*	-4.1**	-1.7**
Ls	TA	1-2-1	11	13	100	5	27	150	10	138	35	773	-6.7	-2.9
T-DOL	TA	1-2-2		8	157	7	7	180	10	66	54	606	-4.1	-1.9
Ls	TA	1-4-1		1	168	6	36	60	7	256	26	457	-6.3	-1.6
T-DOL	TA	1-4-2	1	6	107	4	8	60	6	27	49	418	-4.6	-1.9
Ls	TA	2-2-1	1		74	1	36	190	11	193	40	502	-7.6	-2.8
T-DOL	TA	2-2-2			109	1	10	95	10	20	49	481	-3.6	-1.2
S-DOL	AA	2-20-1			207			100	3	4	569	2527	-9.4	-0.2
T-DOL	AA	2-21-1		5	205		4	125	6	14	2751	14,092	-5.6	-2.4
S-DOL	AA	2-2-1			252			110	2	3	677	3988		
T-DOL	AA	2-1-1		5	338		5	175	6	33	3333	14,092		

* Anomalously high value from one sample omitted.
** Three pairs.

limestone-tectonic dolomite pairs and one stratigraphic dolomite-tectonic dolomite pair. In two of the three limestone-tectonic dolomite pairs, dolomitization resulted in C^{13} enrichment. In addition, part of the variability of the isotopic ratios of the tectonic dolomites must be a result of the variability of their carbonate precursors. The carbon isotope values of the carbonate precursors were variable with one limestone, TA 1-4-1, and the stratigraphic dolomite, AA 2-20-1, having ratios that were higher than the average for tectonic dolomites and the remaining two limestones, TA 1-2-1 and TA 2-2-1, having ratios that were lower. In each case the carbon isotopes appear to have reequilibrated to values that are within one standard deviation of the mean for all tectonic dolomites in this study. This suggests that isotopic equilibrium was approached. Variations in the ratio are still possible locally due to temperature differences and to restrictions on the reservoir size of the diagenetic solutions.

The stratigraphic dolomites were significantly lower in C^{12} than any of the other groups. The δ C^{13} range for the five stratigraphic dolomites was -0.9 to -1.0 with four samples within the range +1.0 to -0.2. Clearly the stratigraphic dolomites are enriched in the heavier carbon isotope relative to all other sample groups. This may be due to a lower content of organic material with respect to the other samples. The stratigraphic dolomites were in general nonfossiliferous, laminated, light colored rocks. The limestones and tectonic dolomites in general contained fossil debris or exhibited organic structures. Since C^{12} is preferentially incorporated by living organisms into their structures, this might account for the enrichment in C^{12} of the latter rock and the depletion in C^{12} of the stratigraphic dolomites. In any case this distinct difference between the dolomite types made the carbon isotopic ratio a good discriminator.

Variation in O^{18} Content

Friedman and Sanders reported an O^{18} enrichment in the tectonic dolomites relative to limestones. The present study likewise found an O^{18} enrichment of the tectonic dolomites relative to the limestones. Furthermore, the tectonic dolomites were enriched in O^{18} relative to the stratigraphic dolomites which were similar in O^{18} content to the limestones. This enrichment was statistically significant as was discussed earlier.

The O^{18} variability of the stratigraphic dolomite samples is of interest. The three samples from the Tishomingo anticline area were similar in their O^{18} values and averaged -5.4 compared to the limestones from the same area which averaged -6.9. Of the remaining two stratigraphic dolomites, one came from the Arbuckle anticline area and the other from along Highway 77. Their O^{18} values were -9.4 and -8.5 respectively, the lowest values of either Friedman's samples or those of this study. None of the limestones of the Arbuckle anticline area were analyzed isotopically, so that important evidence is missing. However, there remains the possibility that the stratigraphic dolomites have somewhat higher $\delta\ O^{18}$ values than limestones from the same area. Of course the Tishomingo limestones and stratigraphic dolomites were not equivalent samples, the limestones being located stratigraphically higher than the dolomites.

The non-ferroan tectonic and ferroan tectonic dolomites can be considered together as both groups have similar oxygen isotope ratios averaging -4.3 and -3.9 respectively. The tectonic vein dolomites on the other hand were quite variable. Of the three vein dolomites, two have oxygen isotope ratios falling within the range of the other tectonic dolomites, indeed within one standard deviation of the mean. The third, the sample believed to be the purest vein dolomite, had the only positive oxygen isotope ratio and fell considerably outside the range of all other samples. This high O^{18}/O^{16} ratio might reflect the precipitation of this dolomite near the end of the diagenetic period from solutions that cooled considerably from their initial temperatures. Alternately, the precipitating solutions might be anomalously high in O^{18} content representing a final pulse of solutions that were different in composition from the initial solutions.

If the three vein dolomites analyzed are grouped according to their "purity" as judged subjectively during their sampling, both the δO^{18} and δC^{13} values increase as the samples become more pure. The vein sample with the least vein wall contamination is the heaviest isotopically while that sample judged to be the most contaminated is the lightest isotopically. This would indicate that the solutions from which they precipitated were isotopically heavy or that these solutions were cooler than those producing the replacement dolomites.

Source, Nature, and Timing of the Dolomitizing Solutions

Essentially there are three main dolomite types: the early diagenetic stratigraphic dolomites, the late diagenetic replacement dolomites, and the vein dolomites. The source, nature, and timing of each type will be discussed.

For reasons stated earlier (see p. 12), the stratigraphic dolomites of this study are thought to have formed from calcite sediments shortly after deposition and prior to deep burial or lithification. The dolomitizing solutions were most likely magnesium-rich waters formed from normal sea water by selective removal of calcium or addition of magnesium. The higher sodium content of the dolomites relative to the limestones would indicate that these solutions were higher in salinity than normal sea water. This higher salinity could have been produced either by evaporation in a restricted lagoon or by selective filtration, diagenesis, and chemisorption of interstitial water. However, the salinity attained was not sufficiently high to deposit evaporite minerals within the stratigraphic dolomites.

The late diagenetic dolomite bodies are closely associated with vertical throughgoing faults and fractures. These dolomite bodies are restricted to a relative few stratigraphic units although other susceptible limestone units were available for replacement. They are not widespread and show no strong horizontal component as would be expected with descending meteoric water. These arguments, considered along with the higher Na and $\delta\ O^{18}$ content of the late diagenetic dolomites, suggest that dolomitization occurred at depth due to ascending magnesium-rich solutions of marine connate origin.

The fact that the tectonic dolomites, that are replacements of the limestones and stratigraphic dolomites, are isotopically heavier than their precursors is of interest. This difference would indicate, if the two dolomitizing solutions are assumed to have had similar carbon and oxygen isotopic ratios, that the epigenetic solutions were cooler. As checked experimentally by McCrea (1950) and verified by Clayton and Epstein (1958), O^{18} is incorporated into minerals to a greater extent at low temperatures than at high temperatures. However, if the two dolomitizing solutions are assumed to have had similar temperatures, then the solution causing the tectonic dolomitization would have to have been isotopically heavier than the solutions causing the stratigraphic dolomitization.

The epigenetic solutions causing the tectonic dolomitization were most likely marine connate in origin since warm solutions of meteoric origin would have produced dolomites exceptionally low in O^{18}. These connate waters were probably entrapped in adjacent basins and released in Late Pennsylvanian or Early Permian time when deformation of the Late Cambrian and Early Ordovician carbonates produced fractures along which these solutions could move. The temperatures of these late diagenetic solutions were then at least the same as if not greater than those of the solutions that deposited the limestones and produced the stratigraphic dolomites in Cambrian and Ordovician time.

This must mean then, that the epigenetic solutions were isotopically heavier than both the sea water in which the limestones were deposited and the early diagenetic solutions that produced the stratigraphic dolomites. The epigenetic solutions, although warmer, were sufficiently enriched in the heavy oxygen isotope with respect to normal sea water to produce dolomites enriched in O^{18} with respect to their limestone and stratigraphic dolomite precursors.

The solutions were most likely connate marine waters concentrated by evaporation or ion-filtration on charged-net clay membranes. Alteration of the connate water could also occur due to diagenetic reactions with enclosing rocks. Degens, et al., (1964) have suggested that ion-filtration does not affect the isotopic ratio of the solutions, and that isotopic deviations from normal sea water are the results of mixing with magmatic or fresh waters, or of evaporation. In contrast, Clayton, et al., (1966) suggests that simple concentration cannot entirely explain the isotopic composition of saline formational waters. The isotopic exchange between solutions and enclosing rocks must be considered as well. Thus the high salinity proposed for the dolomitizing solutions could be produced by evaporation, diagenetic exchange of coordinated or absorbed ions with enclosing rocks, and selective passage of ions and water molecules through semipermeable membranes (salt-sieving of DeSitter, 1947; membrane-filtration of White, 1965; ion-filtration on charged-net clay-membranes of Degens, et al., 1964).

The oxygen isotopic ratios of both the limestones and stratigraphic dolomites of this study fall within the range of values for Paleozoic limestones reported by Keith and Weber (1964). These ratios also fall near the average for Cambrian and Ordovician limestones reported by Degens and Epstein (1962). The tectonic dolomites, which are of Late Pennsylvanian or Early Permian age, have oxygen isotopic ratios only slightly higher than the average for Carboniferous and Permian limestones reported by these authors.

The progressive increase in O^{16} content with age as reported by Degens and Epstein (1962) reflects the isotopic equilibration of these rocks with O^{16} enriched interstitial connate or meteoric waters. The tectonic dolomites with O^{18}/O^{16} ratios higher than their carbonate precursors must have been formed by solutions enriched in O^{18} relative to the waters with which these precursors were equilbrated.

Clayton, et al., (1966) reported for 95 oil field brines computed temperatures that ranged from 8.7° to 142.8°C with a mean value of 42° C. The authors also reported a positive correlation between temperature, salinity, and O^{18}

content. Friedman and Sanders (1967, p. 331) suggested that all dolomites are formed by hypersaline brines. These observations along with the O^{18} enrichment previously mentioned allow the conclusion that the epigenetic dolomitizing solutions were most likely warmer and more saline than normal ocean water.

The compositional differences between the low-iron tectonic dolomites from the Tishomingo anticline area and the ferroan tectonic dolomites from the Arbuckle anticline area indicate compositional differences in the dolomitizing solutions and possibly different source areas. The solutions invading the rocks of the Tishomingo anticline were low in Fe, Mn, Cu, and Ni and barren in Pb and Zn. Those invading the Arbuckle anticline rocks were lower in Cu and Ni but enriched in Pb, Zn, Mn, and Fe.

The enrichment in Fe of the Arbuckle anticline solutions offers additional information as to the nature of these solutions. The solubility of iron sulfide is so low in saline sulfide or bi-sulfide solutions that appreciable quantities cannot be transported. It has been suggested (Barnes, 1966; Helgeson, 1964; and White, 1965a, as reported in Jackson and Beales, 1967) that appreciable iron could be transported as ammonia or chloride complexes. However, there still remains the problem of a source for the sulfide. Jackson and Beales suggest local H_2S-bearing carbonate rocks as the source of sulfide. The mixing of iron-bearing chloride solutions with sulfide-rich waters in the carbonates of this report could have caused the deposition of the marcasite and pyrite that are indicated by the brown-iron ore deposits.

Sour oil and water has been recovered from the Arbuckle formations in areas adjacent to the study area. Sulfur was produced at one time from associated brines recovered in the Madill field (John Roberts, personal communication, 1974).

The mutual occurrence of both ferroan dolomite and iron sulfides indicates that either the sulfide-rich solutions were of limited extent or that these solutions invaded the rocks only after the dolomite had formed. Due to the lower solubility of the sulfide of iron relative to the carbonate, pyrite rather than the carbonate would have formed as long as sulfide ions were present.

The late diagenetic dolomites everywhere conform with the local and regional structure produced in Late Pennsylvanian and Early Permian time. These dolomite bodies are not offset by the faults indicating that all movement had ceased by the time of their formation.

By Cretaceous time, the Arbuckle Mountains had been deeply eroded and the present surface would have been covered by only a few hundred feet or less. Thus these dolomite bodies must have formed after the cessation of the Late Pennsylvanian - Early Permian deformation of the Arbuckle Mountains and prior to the surface exposure in Cretaceous time of the stratigraphic units in which they occur.

The tectonic vein dolomites occur only in the low-iron tectonic replacement dolomites. No vein dolomites were observed in limestones, stratigraphic dolomites, or ferroan tectonic dolomites. The veins occur in fractured and brecciated tectonic replacement dolomite. The vein-wall contacts are sharp with no evidence of solution of the sharp breccia fragments or of deposition prior to the precipitation of the vein dolomite.

On the basis of the preceeding evidence, the author concludes that the emplacement of the vein dolomites occurred immediately or shortly after the formation of the replacement dolomite. The solutions depositing the vein dolomites could have been either the same solutions causing the late diagenetic dolomitization or a final pulse of magnesium-rich solutions. However, the tectonic vein dolomites had higher δO^{18} values than the tectonic replacement dolomites. This would indicate for the vein solutions either a lower temperature or a higher O^{18} content.

SUMMARY AND GENERAL CONCLUSIONS

In summary, there were found to exist between the stratigraphic and tectonic dolomites of this study chemical differences that must be the result of differences in the compositions and/or temperatures of the early and late diagenetic solutions causing the dolomitization. Furthermore, the various tectonic dolomite types of this study also exhibited chemical differences which must reflect variations in composition and/or temperature for the late diagenetic solutions causing the tectonic dolomitization. These chemical differences, both isotopic and elemental, make possible the statistical characterization of stratigraphic and tectonic dolomites as well as the various tectonic dolomite types.

The linear discriminant function proved to be a valuable multivariate method for characterizing the tectonic and stratigraphic dolomite groups. Additionally, when the standard IBM program for the linear discriminant function is used, the Mahalanobis D^2 function is also generated. The D^2 function provides a quantitative check on the contribution of discarded variables and, when used along with the Kolmogorov-Smirnov test, can evaluate the contribution of individual variables. Based on these tests the best discriminating variables were found to be δO^{18}, δC^{13}, Na, Li, Ni and Cu.

A discriminant identification program was written to utilize the calculated group discriminant functions to classify previously unassigned dolomite samples to one of the various dolomite groups. Along with the group classification, a probability is also calculated for each assigned sample.

Of the ten trace elements studied, four proved to be especially good for discriminating between tectonic and stratigraphic dolomite in the area of study. The four elements were Na, Li, Ni and Cu and, based on the Kolmogorov-Smirnov test, were shown to discriminate at the 99, 93, 100 and 100% confidence levels respectively.

Two of the remaining six elements, Pb and Zn, discriminated at below the 0 and 16% confidence levels respectively and were thus judged to be of little value to the total discrimination. The remaining four, K, Sr, Mn and Fe discriminated at the 42, 27, 27 and 30% confidence levels respectively and were of limited use in the discriminations.

The C and O isotopic ratios provided excellent discrimination between tectonic and stratigraphic dolomite with δC^{13} discriminating at the 99.8% confidence level and δO^{18} at the 98% confidence level. However, the samples selected for isotopic analysis were those that best fit their respective groups based on the trace element data. This was necessary due to the limited number of isotopic analyses available to the author. Thus no isotopic data are available on samples that either poorly fit their respective groups or were actually misclassified by the computer program. Certain known tectonic dolomite samples were statistically classified with the stratigraphic dolomites on the basis of their trace element content. Isotopic analyses of these misclassified samples and other samples that poorly fit their respective groups should prove useful in understanding the parameters of early and late diagenetic dolomitization.

The δC^{13} variation between the tectonic dolomites, stratigraphic dolomites, and the limestones provides insight into the dolomitization process. In agreement with Friedman and Sanders (1967) this author concludes that the carbon isotopically equilibrated with the late diagenetic dolomitizing solutions as did the oxygen isotopes.

Field evidence suggests that the late diagenetic dolomites were formed at depth by ascending magnesium-rich solutions of marine connate origin. The time of formation postdated the Late Pennsylvanian - Early Permian deformation producing the Arbuckle structures and predated the Cretaceous near exposure of the present surface.

Petrologic and field evidence suggests that the vein dolomites were emplaced shortly following the late diagenetic replacement dolomitization. The solutions from which they precipitated were either cooler or isotopically heavier than the preceeding solutions.

The compositional variability of the tectonic dolomites might be a result of compositional variability in the dolomitizing solutions, temperature variability in these solutions, restrictions in the reservoir size of the solutions, and/or limitations on the circulation of the solutions.

The epigenetic solutions producing the tectonic dolomites were found to vary in composition spatially and perhaps temporally. Spatial variations are evidenced in the trace element compositional differences between the low-iron and ferroan tectonic dolomites. In this latter case the differences were both elemental and isotopic, indicating compositional and possibly temperature variation.

A depth of burial of 15,000 feet using present temperature gradients would indicate a rock temperature of around 170-200° F. If as suggested by the author the solutions were entrapped at greater depths, and migrated upwards, the solution temperature would have been greater than the ambient rock temperature. While it is impossible to assign current thermal gradients to past periods, there is no evidence of a high heat flow in the regional rocks. Thus it would be valid to use present thermal gradients as a first approximation.

In addition, the following general conclusions can be stated:

1. The dolomitization of limestone results in a large loss of the trace constituents. In this study the loss was greater for stratigraphic dolomitization than for tectonic dolomitization.

2. The Sr content is directly related to the Ca excess of the dolomite suggesting that Sr is progressively expelled from the carbonate structure along with Ca as dolomitization proceeds.

3. All dolomites in this study were enriched in Na relative to the limestones indicating that the dolomitization may have been produced by Na-rich solutions.

4. The C^{13} enrichment of the stratigraphic dolomites relative to all other dolomites in this study may simply reflect a smaller amount of organic material in the stratigraphic dolomites and thus less C^{12}.

5. Potassium and to some extent lithium appear to be concentrated in the clay fraction of the insoluble residues of the low-iron tectonic and stratigraphic dolomites.

6. The epigenetic solutions causing dolomitization were enriched in C^{13} and O^{18} and contained enough CO_2 to exchange with the host carbonates.

7. The epigenetic solutions were probably chloride brines, some of which were enriched in iron. The sulfide needed to produce the pyrite and marcasite deposits could have been in solutions already in the host carbonates. The coexistence of iron sulfides and iron carbonates indicates either that the sulfide-rich waters were of limited extent or that they arrived after dolomitization was complete.

SELECTED BIBLIOGRAPHY

Artemov, Yu. M., Strizhov, V. P., Ustinov, V. I., and Yaroshevskiy, A. A., 1967, Possible isotope fractionation during dolomitization: Geochemistry International, v. 4, p. 443-451.

Atwood, D. K. and Fry, H. M., 1967, Strontium and manganese content of some coexisting calcites and dolomites: American Mineralogist, v. 52, p. 1530-1535.

Barnes, H. L., 1966, Sphalerite solubility in ore solutions of the Illinois-Wisconsin District: Symposium on the genesis of stratiform lead-zinc-barite-fluorite deposits, Paper presented orally at Soc. Econ. Geologists, New York, March 1966.

____________, and Czamanske, G. K., 1967, Solubilities and transport of ore minerals, p. 334-381 in Barnes, H. L., ed., Geochemistry of Hydrothermal Ore Deposits: Holt, Rinehart, and Winston, Inc., N. Y., 670 p.

Barton, P. B. and Skinner, B. J., 1967, Sulfide mineral stabilities, p. 236-333 in Barnes, H. L., ed., Geochemistry of Hydrothermal Ore Deposits: Holt, Rinehart, and Winston, Inc., N. Y., 670 p.

Beyer, Wm. H., ed., 1966, Handbook of Tables for Probability and Statistics: The Chemical Rubber Company, Cleveland, Ohio, p. 179-181.

Birnbaum, Z. W., 1952, Numerical tabulation of the distribution of Kolmogorov's Statistic for finite sample size: Jour. Amer. Stats. Assoc., v. 47, p. 425-441.

Brokaw, A. L., 1950, Geology and Mineralogy of the East Tennessee Zinc District: Inter. Geol. Congress, 18th Session, Part VII, p. 70-76.

Burma, Benjamin H., 1949, Studies in quantitative paleontology: II. Multivariate analysis - a new analytical tool for paleontology and geology: Jour. Paleontology, v. 23, p. 95-103.

Chayes, Felix, 1965, Classification in a ternary diagram by means of discriminant functions: American Mineralogist, v. 50, p. 1618-1633.

____________, and Velde, D., 1965, On distinguishing basaltic lavas of circumoceanic and oceanic-island type by means of discriminant functions: Amer. Jour. Sci., v. 263, p. 206-222.

Cheney, E. S. and Jensen, M. L., 1965, Stable carbon isotopic composition of biogenic carbonates: Geochim. et Cosmochim. Acta, v. 29, p. 1331-1346.

Clayton, R. N. and Epstein, S., 1958, The relationship between O^{18}/O^{16} ratios in coexisting quartz, carbonate, and iron oxides from various geological deposits: Jour. Geol., v. 66, p. 352-373.

____________, Friedman, I., Graf, D. L., Mayeda, T. K., Meents, W. F., and Shimp, N. F., 1966, The origin of saline formation waters, 1. Isotopic composition: Jour. of Geophy. Res., v. 71, p. 3869-3882.

____________, Jones, B. F., and Berner, R. A., 1968, Isotope studies of dolomite formation under sedimentary conditions: Geochim. et Cosmochim. Acta, v. 32, p. 415-432.

Daughtry, A. C., Perry, D., and Williams, M., 1962, Magnesium isotopic distribution in dolomite: Geochim. et Cosmochim. Acta, v. 26, p. 857-866.

Degens, E. T., 1967, Stable isotope distribution in carbonates, p. 151-167 in Chilingar, G. V., Bissell, H. J., and Fairbridge, R. W., eds., Carbonate Rocks; Pt. B: Elsevier Pub. Co., N. Y., 413 p.

____________, and Epstein, S., 1962, Relationship between O^{18}/O^{16} ratios in coexisting carbonates, cherts and diatomites: Bull. Amer. Assoc. Petrol. Geologists, v. 46, p. 534-542.

____________, and Epstein, S., 1964, Oxygen and carbon isotope ratios in coexisting calcite and dolomites from recent and ancient sediments: Geochim. et Cosmochim. Acta, v. 28, p. 23-44.

____________, Hunt, J. M., Reuter, J. H., and Reed, W. E., 1964, Data on the distribution of amino acids and oxygen isotopes in petroleum brine waters of various geologic ages: Sedimentology, v. 3, p. 199-225.

Deffeyes, K. S., Lucia, F. J., and Weyl, P. K., 1965, Dolomitization of recent and Plio-Pleistocene sediments by marine evaporite waters on Bonaire, Netherlands Antilles, p. 71-88 in Pray, L. C. and Murrey, R. C., eds., Dolomitization and Limestone Diagenesis: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 13, Tulsa, Oklahoma, 180 p.

DeSitter, L. V., 1947, Diagenesis of oil-field brines: Amer. Assoc. Petrol. Geologists Bull., v. 31, p. 2030-2040.

Dixon, W. J. and Massey, F. J., Jr., 1951, Introduction to Statistical Analysis: McGraw-Hill, N. Y., 370 p.

Engel, A. E. J., Clayton, R. N., and Epstein, S., 1958, Variations in isotopic composition of oxygen and carbon in Leadville limestone (Mississippian, Colorado) and in its hydrothermal and metamorphic phases: Jour. Geol., v. 66, p. 374-393.

_______________, and Engel, Celeste, 1957, Distribution of copper, lead, and zinc in hydrothermal dolomites associated with sulfide ore in the Leadville limestone (Mississippian, Colorado): Geol. Soc. Amer. Bull., v. 67, p. 1692.

Epstein, S., 1959, The variations of the O^{18}/O^{16} ratio in nature and some geologic implications, p. 217-240 in Abelson, P. H., ed., Researches in Geochemistry, Vol. I: John Wiley and Sons, Inc., N. Y., 511 p.

___________, Buchsbaum, R., Lowenstam, H. A., and Urey, H. C., 1953, Revised carbonate-water isotopic temperature scale: Geol. Soc. Amer. Bull., v. 64, p. 1315-1326.

___________, Degens, E., and Graf, D. L., 1962, The oxygen isotopic compositions of coexisting calcite and dolomite, Abs.: Jour. Geophy. Res., v. 67, p. 1636.

Friedman, G. M. and Sanders, J. E., 1967, Origin and occurrence of dolostones, p. 267-348 in Chilingar, G. V., Bissell, H. J., and Fairbridge, R. W., eds., Carbonate Rocks, Pt. A: Elsevier Pub. Co., N. Y., 471 p.

Friedman, I. and Hall, W. E., 1963, Fractionation of O^{18}/O^{16} between coexisting calcite and dolomite: Jour. Geol., v. 71, p. 238-243.

Fritz, P., and Katz, A., 1972, The Sodium Distribution of Dolomite Crystals: Chem. Geol., Vol. 10, p. 237-244.

Fritz, P. and Smith, D. G. W., 1970, The isotopic composition of secondary dolomites: Geochim. et Cosmochim. Acta, v. 34, p. 1161-1174.

Furman, N. Howell, Ed., 1962, Standard Methods of Chemical Analysis, 6th ed., Vol. 1: D. Van Nostrand Co., Inc., Princton, N. J., 1402 p.

Glasstone, S., and Lewis, D., 1961, Elements of Physical Chemistry: Van Nostrand Co., Inc., Princeton, N. J., 758 p.

Goldsmith, J. R., Graf, D. L., Witters, J., and Northrop, D. A., 1962, Studies in the system $CaCO_3$-$MgCO_3$-$FeCO_3$: 1. Phase relations; 2. A method for major element spectrochemical analysis; 3. Compositions of some ferroan dolomites: Jour. Geol., v. 70, p. 659-688.

Graf, Donald L., 1960a, Geochemistry of Carbonate Sediments and Sedimentary Carbonate Rocks: Part III, Minor Element Distribution; Illinois State Geol. Sur. Circular 301, 71 p.

______________, 1960b, Geochemistry of Carbonate Sediments and Sedimentary Carbonate Rocks: Part IV-A, Isotopic Composition Chemical Analyses; Illinois State Geol. Sur. Circular 308, 42 p.

Green, L. H., 1954, Wall-rock alteration at certain lead-zinc replacement deposits in limestone, Salma map-area, British Columbia: Geol. Survey of Canada, Bull. 29, 37 p.

Griffiths, John C., 1967, Scientific Method in Analysis of Sediments: McGraw-Hill Book Co., N. Y., 508 p.

Ham, W. E., 1951, Geology and petrology of the Arbuckle limestone in the Southern Arbuckle Mountains, Oklahoma: Yale University, Doctor of Philosophy dissertation, 162 p.

__________, 1955, Geology of the Arbuckle Mountain region: Okla. Geol. Survey, Guide Book III, 61 p.

__________, et al., 1968, Regional geology of the Arbuckle Mountains: Amer. Assoc. of Pet. Geologists - Soc. Econ. Paleontologists and Mineralogists, 1968, Annual Meeting, Field Trip Guidebook, 61 p.

__________, et al., 1969, Regional geology of the Arbuckle Mountains, Oklahoma: Okla. Geol. Survey, Guide Book XVII, 52 p.

Ham, W. E., et al., 1973, Regional geology of the Arbuckle Mountains: Geol. Soc. of Amer., 1973, Annual Meeting, Guide Book for Field Trips No. 5, 56 p.

__________, McKinley, M. E., et al., 1954, Geologic map and sections of the Arbuckle Mountains, Oklahoma: Okla. Geol. Survey, Guide Book III.

Helgeson, H. C., 1964, Complexing and hydrothermal ore deposition: New York, Macmillan Co., 128 p.

Hewett, D. F., 1928, Dolomitization and ore deposition: Econ. Geol., v. 23, p. 821-863.

____________, 1931, Geology and ore deposits of the Goodsprings Quadrangle, Nevada: U. S. Geol. Survey, Prof. Paper 162, 172 p.

Hill, W. E., Jr., Waugh, Wanda N., Galle, O. Karmie, and Runnells, R. T., 1961, Methods of Chemical Analysis for Carbonate and Silicate Rocks: State Geol. Surv. of Kansas Bull. 152, Reports of Studies, Pt. 1, p. 1-30.

Holland, Heinrich D., 1967, Gangue minerals in hydrothermal deposits, p. 382-436 in Barnes, H. L., ed., Geochemistry of Hydrothermal Ore Deposits: Holt, Rinehart, and Winston, N. Y., 670 p.

Horstman, E. L., 1957, The distribution of Li, Rb, and Cs in igneous and sedimentary rocks: Geochim. et Cosmochim. Acta, v. 7, p. 1-28.

IBM, Scientific Subroutine Package (1130-CM-02X) Programmers Manual: IBM Corp., Data Processing Division, White Plains, N. Y., 191 p.

Illing, L. V., Wells, A. J., and Taylor, J. C. M., 1965, Penecontemporary dolomite in the Persian Gulf, p. 89-111 in Pray, L. C. and Murrey, R. C., eds., Dolomitization and Limestone Diagenesis: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 13, Tulsa, Oklahoma, 180 p.

Jackson, S. A., and Beales, F. W., 1967, An aspect of sedimentary basin evolution: The concentration of Mississippi Valley-Type ores during late stages of diagenesis: Bull. Can. Pet. Geol., v. 15, p. 383-433.

Keith, M. L. and Weber, J. N., 1964, Carbon and oxygen isotopic composition of selected limestones and fossils: Geochim. et Cosmochim. Acta, v. 28, p. 1787-1816.

Koch, G. S., Jr., and Link, R. F., 1970, Statistical Analysis of Geological Data: John Wiley and Sons, Inc., N. Y., 375 p.

Kraft, C. H. and van Eeden, C., 1968, A nonparametric Introduction to Statistics: Macmillan, N. Y., p. 315-322.

Krauskopf, K. B., 1956, Factors controlling the concentrations of thirteen rare metals in sea water: Geochim. et Cosmochim. Acta, v. 9, p. 1-32.

Krumbein, W. C. and Graybill, Franklin A., 1965, An Introduction to Statistical Models in Geology: McGraw-Hill Book Co., N. Y., 475 p.

Le Riche, H. H., 1959, The distribution of certain trace elements in the lower Lias of southern England: Geochim. et Cosmochim. Acta, v. 16, p. 101-122.

Mellon, G. B., 1964, Discriminatory analysis of calcite- and silicate-cemented phases of the Mountain Park sandstone: Jour. Geol., v. 72, p. 786-809.

Miller, R. L. and Kahn, J. S., 1962, Statistical Analysis in the Geological Sciences: John Wiley and Sons, Inc., N. Y., 483 p.

Morrison, D. F., 1967, Multivariate Statistical Methods: McGraw-Hill Book Co., N. Y., 338 p.

Moses, P. L., 1961, Geothermal gradients now known in greater detail: World Oil, v. 152, p. 79-82.

Murata, K. J., Friedman, I., and Madsen, Beth M., 1969, Isotopic composition of diagenetic carbonates in marine Miocene formations of California and Oregon: V. S. G. S. Prof. Paper 614-B, 24 p.

McCrea, J. M., 1950, On the isotopic chemistry of carbonates and a paleotemperature scale: Jour. of Chem. Phy., v. 18, p. 849-857.

O'Neil, J. R. and Epstein, S., 1960, Oxygen isotope fractionation in the system dolomite-calcite-carbon dioxide: Science, v. 152, p. 198-201.

Ostrom, Meredith E., 1957, Trace Elements in Illinois Pennsylvanian Limestones; Ill. State Geol. Sur., Circular 243, 34 p.

Pandey, G. C. and Sharma, T., 1970, Oxygen and carbon isotope fractionation between dolomite and calcite in lesser Himalayan and Vindhyan limestones: Geochim. et Cosmochim. Acta, v. 34, p. 625-628.

Perry, W. T., Reeves, C. C., Jr., and Leach, J. W., 1970, Oxygen and carbon isotopic composition of West Texas lake carbonates: Geochim. et Cosmochim. Acta, v. 34, p. 825-830.

Potter, P. E., Shimp, N. F., and Witters, J. elements in marine and fresh-water orgillaceous sediments: Geochim. et Cosmochim. Acta, v. 27, p. 669-694.

Rao, C. R., 1952, Advanced Statistical Methods in Biometric Research: John Wiley and Sons, Inc., N. Y., p. 246-256.

Roberts, John, 1974, Personal communication: Oklahoma Geological Survey, Norman, Oklahoma.

Rosenberg, P. E., 1967, Subsolidus relations in the system $CaCO_3$-$MgCO_3$-$FeCO_3$ between 350° and 550° C: Amer. Mineralogist, v. 52, p. 787-796.

Sargent, K. A., 1969, Geology and Petrology of Selected Tectonic Dolomite Areas in the Arbuckle Group, Arbuckle Mountains, South-Central Oklahoma: University of Oklahoma, Master of Science thesis, 85 p.

Shelton, John, 1974, Personal communication: Dept. of Geology, Oklahoma State University, Stillwater, Oklahoma.

Siegel, S., 1956, Nonparametric Statistics: McGraw-Hill Book Co., N. Y., 312 p.

Stehli, F. G. and Hower, John, 1961, Mineralogy and early diagenesis of carbonate sediments: Jour. Sed. Pet., v. 31, p. 358-371.

Taft, W. H., 1967, Physical chemistry of formation of carbonates, p. 151-167 in Chilingar, G. V., Bissell, H. J., and Fairbridge, R. W., eds., Carbonate Rocks, Pt. B: Elsevier Pub. Co., N. Y., 413 p.

Tan, F. C. and Hudson, J. D., 1971, Carbon and oxygen isotopic relationships of dolomites and co-existing calcites - Great Estuarine Series (Jurassic), Scotland: Geochim. et Cosmochim. Acta, v. 35, p. 755-767.

Taylor, H. P., Jr., 1967, Oxygen isotope studies of hydrothermal mineral deposits, p. 109-142 in Barnes, H. L., ed., Geochemistry of Hydrothermal Ore Deposits: Holt, Rinehart, and Winston, N. Y., 670 p.

Tomlinson, C. W., and McBee, William, Jr., 1959, Pennsylvanian sediments and orogenies of Ardmore District, Oklahoma: Petroleum Geology of Southern Oklahoma, Amer. Assoc. Pet. Geologists, p. 3-52.

Toulmin, Priestley, III and Clark, Sydney P., Jr., 1967, Thermal aspects of ore formation, p. 437-464 in Barnes, H. L., ed., Geochemistry of Hydrothermal Ore Deposits: Holt, Rinehart, and Winston, N. Y., 670 p.

Usdowski, H. E., 1970, Einbau von Strontium in Dolomit: Naturwissenschaften, v. 57, p. 543.

Veizer, Jan and Demovic, Rudolf, 1974, Strontium as a tool in facies analysis: Journal of Sed. Pet., v. 44, p. 93-115.

Weber, J. N., 1964a, Carbon isotope ratios in dolostones: some implications concerning the genesis of secondary and "primary" dolostones: Geochim. et Cosmochim. Acta, v. 28, p. 1257-1265.

___________, 1964b, Trace element composition of dolostones and dolomites and its bearing on the dolomite problem: Geochim. et Cosmochim. Acta, v. 28, p. 1817-1868.

White, D. E., 1965a, Metal content of some geothermal fluids, in Symposium, Problems of post magmatic ore deposition, Prague, 1965, v. 2, p. 432-443: Geol. Survey Czechoslovakia.

___________, 1965b, Saline waters of sedimentary rocks, p. 342-366 in Fluids in Subsurface Environments - A Symposium: Amer. Assoc. Petroleum Geologists, Memoir 4.

___________, 1967, Outline of thermal and mineral waters as related to origin of Mississippi Valley ore deposits, p. 379-382 in Brown, J. S., ed., Genesis of Stratiform Lead-Zinc-Barite-Fluorite Deposits - A Symposium: Econ. Geol., Monograph 3.

___________, 1968, Environments of generation of some base-metal ore deposits: Econ. Geol., v. 63, p. 301-335.

Whittaker, E. J. W. and Muntus, R., 1970, Ionic radii for use in geochemistry: Geochim. et Cosmochim. Acta, v. 34, p. 945-956.

Yanat'eva, O. K., 1955, Effect of aqueous solutions of gypsum on dolomite in the presence of carbon dioxide: Akad. Nauk. SSSR, Doklady, v. 101, p. 911-912.

APPENDIX A

Table Page

TABLE 1

Major and Minor Element Analyses of Selected Dolomite Samples.

Sample Number	$CaCO_3$	$MgCO_3$	$FeCO_3$	
	Recalcd. to 100%			
Cb H-77-1	54.77	44.53	0.70	Stratigraphic Dolomite
Cb H-77-2	54.55	44.84	0.61	
AA 2-10-1	54.60	44.90	0.50	
AA 2-20-1	55.19	44.12	0.69	
TA 2-2-2	55.52	44.24	0.24	Tectonic Replacement Dolomite
TA 6-1-1	55.78	43.66	0.56	
TA 4-3-1	56.98	42.78	0.24	
TA 4-7-1	55.21	42.53	2.26	Ferroan Tectonic Replacement Dolomite
AA 1-1-3	58.47	28.80	12.73	
AA 1-2-1	54.87	41.83	3.30	
AA 2-3-1	55.65	42.00	2.35	

TABLE 2. Trace Element Analyses of Limestones (25).

		Pb	Zn	Na	K	Li	Ni	Cu	Sr	Mn	Fe
TA	1-1-2	12	57	143	200	19	25	13	123	35	816
	1-1-3		9	157	80	2	36	10	642	31	543
	1-2-1	11	13	100	150	5	27	10	138	35	773
	1-4-1		1	168	60	6	36	7	256	26	457
	1-4-3	1	4	132	45	6	32	9	234	26	481
	2-1-1	8	4	121	75	1	36	10	267	26	521
	2-2-1	1		74	190	1	36	11	193	40	502
	3-2-2			121	85	3	32	8	151	40	501
	3-7-1	6		230	125	5	41	8	177	31	522
	4-4-2	3	2	97	80	1	36	9	232	26	502
	4-6-2	4		93	100	2	41	7	248	31	669
	4-8-2	10		128	140	3	32	7	206	40	356
	4-21-1	3		166	75	1	36	8	187	26	251
	4-22-1	6		143	105	1	36	4	216	40	356
	4-23-1	2		103	75	1	41	6	195	45	251
	4-24-1	2	1	181	195	2	41	6	134	40	606
	5-1-3	12		103	44	3	36	6	318	22	168
	5-2-2	4	18	221	110	4	32	6	283	31	356
	5-6-1	4	5	93	250	1	36	8	180	109	836
	6-1-3	3	2	135	85	2	32	6	284	45	773
	6-1-5	1	5	150	30	5	32	4	675	22	168
	7-2-2	1		143	90	14	23	3	251	26	606
AA	1-1-1	5	10	177	75	1	18	6	229	45	543
	2-4-1	5	13	155	220	1	14	3	213	82	1,149
	2-4-2	5	1	150	110	1	14	4	213	63	690
	$\overline{x}$	4.36	5.80	139.36	108.56	3.64	32.04	7.16	251.80	39.32	535.84
	s.	3.72	11.80	38.63	62.07	4.29	7.82	2.54	130.95	19.70	228.36

TABLE 3. Trace Element Analyses of Stratigraphic Dolomites (17).

		Pb	Zn	Na	K	Li	Ni	Cu	Sr	Mn	Fe
TA	5-3-1		2	313	365	1	3	6	23	86	1,212
€b	1			188	45		3	2	16	54	105
€b	2			173	165		1	3	22	63	439
€b	3			238	490			3	27	54	794
€b	4			298	150		1	3	23	49	397
€b	5			196	140		1	3	32	45	376
€b	6			284	375	1	1	3	34	63	836
€b	H-77-1			169	475			2	32	146	1,754
€b	H-77-2			177	95		1	3	1	146	1,253
WSC	S-1			221	150	1		3	49	100	857
WSC	S-2			270	70	1		3	55	45	356
Occ	1			201	225			3	39	114	878
Occ	2			274	290			3	48	234	1,504
Occ	3			160	220			4	41	146	1,128
AA	2-2-1			252	110		5	2	3	677	3,988
AA	2-10-1	17		157	40			4	4	405	2,527
AA	2-20-1			207	100			3	4	569	2,527
	$\bar{x}$	1.00	0.12	222.24	206.18	0.24	0.94	3.12	26.65	176.24	1,231.24
	s.	4.12	0.49	51.15	143.95	0.44	1.43	0.93	17.02	191.61	1,000.58

TABLE 4. Trace Element Analyses of Low-iron Tectonic Replacement Dolomites (28).

		Pb	Zn	Na	K	Li	Ni	Cu	Sr	Mn	Fe
TA	1-2-2		8	157	180	7	7	10	66	54	606
	1-3-1			117	100	5	5	8	86	63	606
	1-4-2	1	6	107	60	4	8	6	27	49	418
	1-8-1			74	160	20	1	9	14	45	2,694
	2-1-2			143	60	2	5	8	30	54	251
	2-2-2			109	95	1	10	10	20	49	481
	2-4-1			157	60	1	10	6	52	49	251
	2-5-2			143	285	2	7	9	39	63	606
	3-4-1			173	50		3	6	39	211	2,464
	3-5-1			100	165		1	8	27	211	2,694
	4-1-3			217	265	1	5	12	75	54	752
	4-2-2			143	65		5	6	6	54	356
	4-3-1		1	209	95	1	10	6	47	75	418
	4-5-1			121	125		5	8	47	183	752
	4-6-1			165	125	2	10	6	47	40	439
	4-8-1			221	215	1	12	7	33	299	1,817
	4-9-1			343	265		10	8	28	225	1,942
	4-18-1			128	330		23	8	22	183	648
	5-1-1			213	185		10	3	91	68	1,337
	5-2-1	5		354	55		7	4	14	49	168
	5-5-1			110	295		5	4	19	45	439
	6-1-1			188	245	8	1	3	86	54	460
	6-1-2		1	146	195		5	6	43	49	335
	6-1-4		4	157	45	1	1	4	20	45	251
	6-2-1		4	221	150	3	10	3	77	151	1,170
	6-3-1		17	135	275	9		7	20	49	857
	7-1-1			284	110	1	5	6	32	132	564
	7-2-1			114	300	1		3	20	45	251
	$\bar{x}$	0.21	1.46	169.61	163.68	2.50	6.46	6.57	40.25	94.57	858.11
	s.	0.96	3.67	68.83	90.76	4.26	4.82	2.36	24.32	72.70	760.13

TABLE 5. Trace Element Analyses of Ferroan Tectonic Replacement Dolomites (26).

		Pb	Zn	Na	K	Li	Ni	Cu	Sr	Mn	Fe
TA	1-5-1			146	55	1	1	7	20	664	14,614
	4-7-1		4	128	65	2	5	8	22	326	7,414
	4-21-2			103	70	1	12	6	30	1,536	11,482
	4-23-2			161	110	1	5	4	36	497	7,411
	5-4-1	10	1	187	185	2	5	6	33	165	3,675
AA	1-1-2	35	13	513	125			2	59	3,019	11,294
	1-1-3	210	153	173	70		1	6	101	3,019	17,327
	1-2-1		37	313	120			7	39	2,751	11,775
	1-3-1	8	10	333	45			3	70	2,751	8,706
	2-1-1		5	338	175			6	33	3,333	14,092
	2-3-1		6	343	260			4	41	2,150	7,871
	2-3-1A	10	11	396	245			2	51	2,524	10,860
	2-5-1		11	333	105			3	34	2,524	9,687
	2-5-2		13	333	160			9	34	3,019	13,445
	2-6-1		17	359	85			3	41	2,150	7,620
	2-8-1	33	12	274	130			4	35	3,019	9,332
	2-9-1		8	308	85			6	23	3,019	14,801
	2-11-1		8	173	80		4	4	25	3,019	12,296
	2-12-1		11	613	200		4	7	44	2,326	7,620
	2-13-1		14	343	105			3	39	3,019	11,294
	2-14-1		5	323	85			3	41	1,444	7,871
	2-19-1		15	243	70			6	39	2,751	10,856
	2-21-1		5	205	125		4	6	14	2,751	14,092
	2-22-2			93	85		4	6	78	2,751	14,092
	2-23-1		23	80	100			6	68	2,751	15,553
	2-24-1	43	20	196	110		4	4	27	2,524	7,161
	$\bar{x}$	14.54	15.46	269.62	117.31	0.27	1.88	5.04	41.42	2,300.08	10,857.73
	s.	43.47	29.26	128.48	55.99	0.60	2.89	1.89	19.69	933.83	3,292.62

TABLE 6. Trace Element Analyses of Tectonic Vein Dolomites (5).

	Pb	Zn	Na	K	Li	Ni	Cu	Sr	Mn	Fe
TA 1-1-1v			303	50		5	11	18	82	230
3-4-1v			165	55		5	7	30	234	2,109
4-1-1v	3		188	85		23	7	118	156	1,608
4-9-1v			181	95		10	4	34	386	3,216
4-18-1v			124	30		5	6	31	192	898
$\bar{x}$	-	0	192.20	63.00	0	9.6	7	46.20	210.00	1,612.20
s.	-	0	66.73	26.60	0	7.80	2.55	40.60	113.11	1,144.50

TABLE 7. Isotopic Analyses.

Limestones

		δO^{18}	δC^{13}
TA	1-2-1	-6.7	-2.9
	1-4-1	-6.3	-1.6
	2-2-1	-7.6	-2.8
	$\bar{x}$	-6.9	-2.4
	s.	0.7	0.7

Stratigraphic Dolomites

		δO^{18}	δC^{13}
Cb	3	-5.3	+1.0
Cb	6	-5.2	+0.9
Cb	H-77-1	-8.5	+0.1
Occ	2	-5.6	-0.9
AA	2-20-1	-9.4	-0.2
	$\bar{x}$	-6.8	+0.2
	s.	2	0.8

Tectonic Replacement Dolomites

		δO^{18}	δC^{13}
TA	1-2-2	-4.1	-1.9
	1-3-1	-6.2	-1.9
	1-4-2	-4.6	-1.9
	2-2-2	-3.6	-1.2
	4-1-3	-2.9	-2.1
	$\bar{x}$	-4.3	-1.8
	s.	1.2	0.4

Ferroan Tectonic Replacement Dolomites

		δO^{18}	δC^{13}
TA	1-5-1	-2.9	-1.6
AA	1-1-3	-3.7	-1.0
	2-1-1	-3.5	-4.2
	2-21-1	-5.6	-2.4
	$\bar{x}$	-3.9	-2.3
	s.	1.2	1.4

Tectonic Vein Dolomites

		δO^{18}	δC^{13}
TA	1-1-1v	+2.4	-1.3
	3-4-1v	-3.8	-2.3
	4-18-1v	-3.0	-1.6
	$\bar{x}$	-1.5	-1.7
	s.	3.4	0.5

TABLE 8. Trace Element and Isotopic Analyses of Friedman's Samples.

Limestones	Sr	Mn	Fe	$\delta\ O^{18}$	$\delta\ C^{13}$
1	1100	31	390	-7.4	-1.8
7	480	27	330	-7.5	-2.6
2	730	31	380	-7.0	-1.5
3	980	30	290	-7.1	-1.4
4	620	28	360	-7.2	-1.8
6	440	29	380	-7.6	-2.6
21	480	78	66	-7.4	-3.8
17	370	52	380	-7.7	-3.9
18	500	54	450	-7.5	-3.8
19	480	43	400	-7.8	-3.1
$\bar{x}$	618	40	343	-7.4	-2.6
s.	245	17	106	0.3	1.0
Dolomites					
8	40-60	120	184	-7.6	-1.3
10w	"	105	220	-6.2	-1.6
10b	"	104	390	-7.1	-0.9
9	"	105	310	-3.1	-1.9
5	"	100	460	-3.0	-2.3
20	"	102	200	-3.7	-2.2
11	"	190	560	-2.7	-2.1
12	"	200	820	-2.9	-1.9
12w	"	160	310	-4.6	-1.6
13b	"	143	380	-4.1	-1.9
14	"	154	800	-3.1	-1.8
15	"	300	540	-3.1	-2.1
16	"	108	80	-3.0	-2.8
$\bar{x}$	40-60	145	404	-4.2	-1.9
s.		58	228	1.7	0.5

TABLE 9. Trace Element Analyses of Dolomite Samples of Undetermined Origin (24).

		Pb	Zn	Na	K	Li	Ni	Cu	Sr	Mn	Fe
TA	1-5-3	1	9	217	45	1	14	6	33	913	11,086
	1-5-5		5	298	675	5	1	10	21	100	1,316
	3-1-1			143	465	2		6	39	109	1,942
	3-2-1			196	165	2	10	7	23	165	606
	3-6-1			146	175		7	8	20	183	2,276
	4-1-1			284	1,325	9	1	4	45	100	2,047
	4-2-1	4		284	320	2	5	6	20	96	710
	4-7-2		2	318	210	2	14	6	52	216	1,817
	4-7-3			157	525	4	10	6	104	54	794
	4-10-1			247	180	2	14	8	39	174	836
	4-10-1A			117	200	3	18	6	55	63	314
	4-11-1	1		217	215		10	6	23	142	585
	4-12-1			230	60		10	7	44	183	1,065
	4-13-1		1	205	450	3	5	8	94	49	710
	4-14-1	1		192	400	4	5	6	68	54	669
	4-15-1			139	430		5	4	47	100	1,358
	4-16-1			134	165	1	14	8	61	49	209
	4-17-1	1		137	270	3	14	7	91	45	272
	4-19-1			308	90		1	6	41	109	460
	4-20-1	3		333	45		10	6	39	151	230
	4-22-2	6		387	250	1	3	6	27	68	606
	4-24-2			188	220	2	7	4	65	45	356
	4-24-3		6	256	385	2	7	5	120	68	1,170
AA	2-17-1		4	261	175			3	22	1,444	4,719

TABLE 10. GROUPINGS FOR MDICS 1 THROUGH 6 AND 15.

GROUP 1. (17) STRATIGRAPHIC DOLOMITES

PB	ZN	NA	LI	NI	K	CU	SR	MN	FE	SAMPLE
0	2	313	1	3	365	6	23	86	1212	T5-3-1
0	0	188	0	3	45	2	16	54	105	CB-1
0	0	173	0	1	165	3	22	63	439	CB-2
0	0	238	0	0	490	3	27	54	794	CB-3
0	0	298	0	1	150	3	23	49	397	CB-4
0	0	196	0	1	140	3	32	45	376	CB-5
0	0	284	1	1	375	3	34	63	836	CB-6
0	0	169	0	0	475	2	32	146	1754	CBH-77-1
0	0	177	0	1	95	3	1	146	1253	CBH-77-2
0	0	221	1	0	150	3	49	100	857	WSC-S-1
0	0	270	1	0	70	3	55	45	356	WSC-S-2
0	0	201	0	0	225	3	39	114	878	OCC-1
0	0	274	0	0	290	3	48	234	1504	OCC-2
0	0	160	0	0	220	4	41	146	1128	OCC-3
0	0	252	0	5	110	2	3	677	3988	A2-2-1
17	0	157	0	0	40	4	4	405	2527	A2-10-1
0	0	207	0	0	100	3	4	569	2527	A2-20-1

GROUP 2. (33) LOW-FE TECTONIC DOLOMITES

PB	ZN	NA	LI	NI	K	CU	SR	MN	FE	SAMPLE
0	0	303	0	5	50	11	18	82	230	T1-1-1V
0	8	157	7	7	180	10	66	54	606	T1-2-2
0	0	117	5	5	100	8	86	63	606	T1-3-1
1	6	107	4	8	60	6	27	49	418	T1-4-2
0	0	74	20	1	160	9	14	45	2694	T1-8-1
0	0	143	2	5	60	8	30	54	251	T2-1-2
0	0	109	1	10	95	10	20	49	481	T2-2-2
0	0	157	1	10	60	6	52	49	251	T2-4-1
0	0	143	2	7	285	9	39	63	606	T2-5-2
0	0	173	0	3	50	6	39	211	2464	T3-4-1
0	0	165	0	5	55	7	30	234	2109	T3-4-1V
0	0	100	0	1	165	8	27	211	2694	T3-5-1
3	0	188	0	23	85	7	118	156	1608	T4-1-1V
0	0	217	1	5	265	12	75	54	752	T4-1-3
0	0	143	0	5	65	6	6	54	356	T4-2-2
0	1	209	1	10	95	6	47	75	418	T4-3-1
0	0	121	0	5	125	8	47	183	752	T4-5-1
0	0	165	2	10	125	6	47	40	439	T4-6-1
0	0	221	1	12	215	7	33	299	1817	T4-8-1
0	0	343	0	10	265	8	28	225	1942	T4-9-1
0	0	181	0	10	95	4	34	386	3216	T4-9-1V
0	0	128	0	23	330	8	22	183	648	T4-18-1
0	0	124	0	5	30	6	31	192	898	T4-18-1V
0	0	213	0	10	185	3	91	68	1337	T5-1-1
5	0	354	0	7	55	4	14	49	168	T5-2-1
0	0	110	0	5	295	4	19	45	439	T5-5-1
0	0	188	8	1	245	3	86	54	460	T6-1-1
0	1	146	0	5	195	6	43	49	335	T6-1-2
0	4	157	1	1	45	4	20	45	251	T6-1-4
0	4	221	3	10	150	3	77	151	1170	T6-2-1
0	17	135	9	0	275	7	20	49	857	T6-3-1
0	0	284	1	5	110	6	32	132	564	T7-1-1
0	0	114	1	0	300	3	20	45	251	T7-2-1

TABLE 10 CONT'D.

GROUP 2. (28) LOW-FE TECTONIC DOLOMITES

PB	ZN	NA	LI	NI	K	CU	SR	MN	FE	SAMPLE
0	8	157	7	7	180	10	66	54	606	T1-2-2
0	0	117	5	5	100	8	86	63	606	T1-3-1
1	6	107	4	8	60	6	27	49	418	T1-4-2
0	0	74	20	1	160	9	14	45	2694	T1-8-1
0	0	143	2	5	60	8	30	54	251	T2-1-2
0	0	109	1	10	95	10	20	49	481	T2-2-2
0	0	157	1	10	60	6	52	49	251	T2-4-1
0	0	143	2	7	285	9	39	63	606	T2-5-2
0	0	173	0	3	50	6	39	211	2464	T3-4-1
0	0	100	0	1	165	8	27	211	2694	T3-5-1
0	0	217	1	5	265	12	75	54	752	T4-1-3
0	0	143	0	5	65	6	6	54	356	T4-2-2
0	1	209	1	10	95	6	47	75	418	T4-3-1
0	0	121	0	5	125	8	47	183	752	T4-5-1
0	0	165	2	10	125	6	47	40	439	T4-6-1
0	0	221	1	12	215	7	33	299	1817	T4-8-1
0	0	343	0	10	265	8	28	225	1942	T4-9-1
0	0	128	0	23	330	8	22	183	648	T4-18-1
0	0	213	0	10	185	3	91	68	1337	T5-1-1
5	0	354	0	7	55	4	14	49	168	T5-2-1
0	0	110	0	5	295	4	19	45	439	T5-5-1
0	0	188	8	1	245	3	86	54	460	T6-1-1
0	1	146	0	5	195	6	43	49	335	T6-1-2
0	4	157	1	1	45	4	20	45	251	T6-1-4
0	4	221	3	10	150	3	77	151	1170	T6-2-1
0	17	135	9	0	275	7	20	49	857	T6-3-1
0	0	284	1	5	110	6	32	132	564	T7-1-1
0	0	114	1	0	300	3	20	45	251	T7-2-1

GROUP 2. (22) LOW-FE TECTONIC DOLOMITES

PB	ZN	NA	LI	NI	K	CU	SR	MN	FE	SAMPLE
0	8	157	7	7	180	10	66	54	606	T1-2-2
0	0	117	5	5	100	8	86	63	606	T1-3-1
1	6	107	4	8	60	6	27	49	418	T1-4-2
0	0	74	20	1	160	9	14	45	2694	T1-8-1
0	0	143	2	5	60	8	30	54	251	T2-1-2
0	0	109	1	10	95	10	20	49	481	T2-2-2
0	0	157	1	10	60	6	52	49	251	T2-4-2
0	0	143	2	7	285	9	39	63	606	T2-5-2
0	0	173	0	3	50	6	39	211	2464	T3-4-1
0	0	100	0	1	165	8	27	211	2694	T3-5-1
0	0	217	1	5	265	12	75	54	752	T4-1-3
0	0	143	0	5	65	6	6	54	356	T4-2-2
0	1	209	1	10	95	6	47	75	418	T4-3-2
0	0	121	0	5	125	8	47	183	752	T4-5-1
0	0	165	2	10	125	6	47	40	439	T4-6-1
0	0	221	1	12	215	7	33	299	1817	T4-8-1
0	0	343	0	10	265	8	28	225	1942	T4-9-1
0	0	128	0	23	330	8	22	183	648	T4-18-1
0	0	213	0	10	185	3	91	68	1337	T5-1-1
0	1	146	0	5	195	6	43	49	335	T6-1-2
0	4	221	3	10	150	3	77	151	1170	T6-2-1
0	17	135	9	0	275	7	20	49	857	T6-3-1

TABLE 10 CONT'D.

GROUP 3. (24) INEDETERMINATE DOLOMITES

PB	ZN	NA	LI	NI	K	CU	SR	MN	FE	SAMPLE
1	9	217	1	14	45	6	33	913	11086	T1-5-3
0	5	298	5	1	675	10	21	100	1316	T1-5-5
0	0	143	2	0	465	6	39	109	1942	T3-1-1
0	0	196	2	10	165	7	23	165	606	T3-2-1
0	0	146	0	7	175	8	20	183	2276	T3-6-1
0	0	284	9	1	1325	4	45	100	2047	T4-1-1
4	0	284	2	5	320	6	20	96	710	T4-2-1
0	2	318	2	14	210	6	52	216	1817	T4-7-2
0	0	157	4	10	525	6	104	54	794	T4-7-3
0	0	247	2	14	180	8	39	174	836	T4-10-1
0	0	117	3	18	200	6	55	63	314	T4-10-1A
1	0	217	0	10	215	6	23	142	585	T4-11-1
0	0	230	0	10	60	7	44	183	1065	T4-12-1
0	1	205	3	5	450	8	94	49	710	T4-13-1
1	0	192	4	5	400	6	68	54	669	T4-14-1
0	0	139	0	5	430	4	47	100	1358	T4-15-1
0	0	134	1	14	165	8	61	49	209	T4-16-1
1	0	137	3	14	270	7	91	45	272	T4-17-1
0	0	308	0	1	90	6	41	109	460	T4-19-1
3	0	333	0	10	45	6	39	151	230	T4-20-1
6	0	387	1	3	250	6	27	68	606	T4-22-2
0	0	188	2	7	220	4	65	45	356	T4-24-2
0	6	256	2	7	385	5	120	68	1170	T4-24-3
0	4	261	0	0	175	3	22	1444	4719	A2-17-1

GROUP 4. (26) FERROAN TECTONIC DOLOMITES

PB	ZN	NA	LI	NI	K	CU	SR	MN	FE	SAMPLE
0	0	146	1	1	55	7	20	664	14614	T1-5-1
0	4	128	2	5	65	8	22	326	7474	T4-7-1
0	0	103	1	12	70	6	30	1536	11482	T4-21-2
0	0	161	1	5	110	4	36	497	7411	T4-23-2
10	1	187	2	5	185	6	33	165	3675	T5-4-1
35	13	513	0	0	125	2	59	3019	11294	A1-1-2
210	153	173	0	1	70	6	101	3019	17327	A1-1-3
0	37	313	0	0	120	7	39	2751	11775	A1-2-1
8	10	333	0	0	45	3	70	2751	8706	A1-3-1
0	5	338	0	0	175	6	33	3333	14092	A2-1-1
0	6	343	0	0	260	4	41	2150	7871	A2-3-1
10	11	396	0	0	245	2	51	2524	10860	A2-3-1A
0	11	333	0	0	105	3	34	2524	9687	A2-5-1
0	13	333	0	0	160	9	34	3019	13445	A2-5-2
0	17	359	0	0	85	3	41	2150	7620	A2-6-1
33	12	274	0	0	130	4	35	3019	9332	A2-8-1
0	8	308	0	0	85	6	23	3019	14801	A2-9-1
0	8	173	0	4	80	4	25	3019	12296	A2-11-1
0	11	613	0	4	200	7	44	2326	7620	A2-12-1
0	14	343	0	0	105	3	39	3019	11294	A2-13-1
0	5	323	0	0	85	3	41	1444	7871	A2-14-1
0	15	243	0	0	70	6	39	2751	10856	A2-19-1
0	5	205	0	4	125	6	14	2751	14092	A2-21-1
0	0	93	0	4	85	6	78	2751	14092	A2-22-2
0	23	80	0	0	100	6	68	2751	15553	A2-23-1
43	20	196	0	4	110	4	27	2524	7161	A2-24-1

GROUP 5. (4) TECTONIC VEIN DOLOMITES

PB	ZN	NA	LI	NI	K	CU	SR	MN	FE	SAMPLE
0	0	303	0	5	50	11	18	82	230	T1-1-1V
0	0	165	0	5	55	7	30	234	2109	T3-4-1V
3	0	188	0	23	85	7	118	156	1608	T4-1-1V
0	0	181	0	10	95	4	34	386	3216	T4-9-1V
0	0	124	0	5	30	6	31	192	898	T4-18-1V

TABLE 11. GROUPINGS FOR MDISC 7, 8, AND 9.

GROUP 1. (17) STRATIGRAPHIC DOLOMITES

SAMPLE	NA	K	LI	NI	CU	SR
TA 5 3 1	313	365	1	3	6	23
CB 1	188	45	0	3	2	16
CB 2	173	165	0	1	3	22
CB 3	238	490	0	0	3	27
CB 4	298	150	0	1	3	23
CB 5	196	140	0	1	3	32
CB 6	284	375	1	1	3	34
CB H 77 1	169	475	0	0	2	32
CB H 77 2	177	95	0	1	3	1
WSC S 1	221	150	1	0	3	49
WSC S 2	270	70	1	0	3	55
OCC 1	201	225	0	0	3	39
OCC 2	274	290	0	0	3	48
OCC 3	160	220	0	0	4	41
AA 2 2 1	252	110	0	5	2	3
AA 2 10 1	157	40	0	0	4	4
AA 2 20 1	207	100	0	0	3	4

GROUP 2. (28) LOW-FE TECTONIC DOLOMITES

SAMPLE	NA	K	LI	NI	CU	SR
TA 1 2 2	157	180	7	7	10	66
TA 1 3 1	117	100	5	5	8	86
TA 1 4 2	107	60	4	8	6	27
TA 1 8 1	74	160	20	1	9	14
TA 2 1 2	143	60	2	5	8	30
TA 2 2 2	109	95	1	10	10	20
TA 2 4 1	157	60	1	10	6	52
TA 2 5 2	143	285	2	7	9	39
TA 3 4 1	173	50	0	3	6	39
TA 3 5 1	100	165	0	1	8	27
TA 4 1 3	217	265	1	5	12	75
TA 4 2 2	143	65	0	5	6	6
TA 4 3 1	209	95	1	10	6	47
TA 4 5 1	121	125	0	5	8	47
TA 4 6 1	165	125	2	10	6	47
TA 4 8 1	221	215	1	12	7	33
TA 4 9 1	343	265	0	10	8	28
TA 4 18 1	128	330	0	23	8	22
TA 5 1 1	213	185	0	10	3	91
TA 5 2 1	354	55	0	7	4	14
TA 5 5 1	110	295	0	5	4	19
TA 6 1 1	188	245	8	1	3	86
TA 6 1 2	146	195	0	5	6	43
TA 6 1 4	157	45	1	1	4	20
TA 6 2 1	221	150	3	10	3	77
TA 6 3 1	135	275	9	0	7	20
TA 7 1 1	284	110	1	5	6	32
TA 7 2 1	114	300	1	0	3	20

TABLE 11 CONT'D.

GROUP 3. (24) INDETERMINATE DOLOMITES

SAMPLE	NA	K	LI	NI	CU	SR
TA 1 5 3	217	45	1	14	6	33
TA 1 5 5	298	675	5	1	10	21
TA 3 1 1	143	465	2	0	6	39
TA 3 2 1	196	165	2	10	7	23
TA 3 6 1	146	175	0	7	8	20
TA 4 1 1	284	1325	9	1	4	45
TA 4 2 1	284	320	2	5	6	20
TA 4 7 2	318	210	2	14	6	52
TA 4 7 3	157	525	4	10	6	104
TA 4 10 1	247	180	2	14	8	39
TA 4 10 1A	117	200	3	18	6	55
TA 4 11 1	217	215	0	10	6	23
TA 4 12 1	230	60	0	10	7	44
TA 4 13 1	205	450	3	5	8	94
TA 4 14 1	192	400	4	5	6	68
TA 4 15 1	139	430	0	5	4	47
TA 4 16 1	134	165	1	14	8	61
TA 4 17 1	137	270	3	14	7	91
TA 4 19 1	308	90	0	1	6	41
TA 4 20 1	333	45	0	10	6	39
TA 4 22 2	387	250	1	3	6	27
TA 4 24 2	188	220	2	7	4	65
TA 4 24 3	256	385	2	7	5	120
AA 2 17 1	261	175	0	0	3	22

GROUP 4. (26) FERROAN TECTONIC DOLOMITES

SAMPLE	NA	K	LI	NI	CU	SR
TA 1 5 1	146	55	1	1	7	20
TA 4 7 1	128	65	2	5	8	22
TA 4 21 2	103	70	1	12	6	30
TA 4 23 2	161	110	1	5	4	36
TA 5 4 1	187	185	2	5	6	33
AA 1 1 2	513	125	0	0	2	59
AA 1 1 3	173	70	0	1	6	101
AA 1 2 1	313	120	0	0	7	39
AA 1 3 1	333	45	0	0	3	70
AA 2 1 1	338	175	0	0	6	33
AA 2 3 1	343	260	0	0	4	41
AA 2 3 1A	396	245	0	0	2	51
AA 2 5 1	333	105	0	0	3	34
AA 2 5 2	333	160	0	0	9	34
AA 2 6 1	359	85	0	0	3	41
AA 2 8 1	274	130	0	0	4	35
AA 2 9 1	308	85	0	0	6	23
AA 2 11 1	173	80	0	4	4	25
AA 2 12 1	613	200	0	4	7	44
AA 2 13 1	343	105	0	0	3	39
AA 2 14 1	323	85	0	0	3	41
AA 2 19 1	243	70	0	0	6	39
AA 2 21 1	205	125	0	4	6	14
AA 2 22 2	93	85	0	4	6	78
AA 2 23 1	80	100	0	0	6	68
AA 2 24 1	196	110	0	4	4	27

TABLE 12. GROUPINGS FOR MDISC 10, 11, AND 12.

GROUP 1. (5) STRATIGRAPHIC DOLOMITES

SAMPLE	NA	K	LI	NI	CU	SR	O	C
CB 3	238	490	0	0	3	27	-5.3	1.0
CB 6	284	375	1	1	3	34	-5.2	0.9
CB H 77 1	169	475	0	0	2	32	-8.5	0.1
DCC 2	274	290	0	0	3	48	-5.6	-0.9
AA 2 20 1	207	100	0	0	3	4	-9.4	-0.2

GROUP 2. (5) LOW-FE TECTONIC DOLOMITES

SAMPLE	NA	K	LI	NI	CU	SR	O	C
TA 1 2 2	157	180	7	7	10	66	-4.1	-1.9
TA 1 3 1	117	100	5	5	8	86	-6.2	-1.9
TA 1 4 2	107	60	4	8	6	27	-4.6	-1.9
TA 2 2 2	109	95	1	10	10	20	-3.6	-1.2
TA 4 1 3	217	265	1	5	12	75	-2.9	-2.1

GROUP 2. (9) TECTONIC DOLOMITES

SAMPLE	NA	K	LI	NI	CU	SR	O	C
TA 1 2 2	157	180	7	7	10	66	-4.1	-1.9
TA 1 3 1	117	100	5	5	8	86	-6.2	-1.9
TA 1 4 2	107	60	4	8	6	27	-4.6	-1.9
TA 2 2 2	109	95	1	10	10	20	-3.6	-1.2
TA 4 1 3	217	265	1	5	12	75	-2.9	-2.1
TA 1 5 1	146	55	1	1	7	20	-2.9	-1.6
AA 1 1 3	173	70	0	1	6	101	-3.7	-1.0
AA 2 1 1	338	175	0	0	6	33	-3.5	-4.2
AA 2 21 1	205	125	0	4	6	14	-5.6	-2.4

GROUP 3. (4) FERROAN TECTONIC DOLOMITES

SAMPLE	NA	K	LI	NI	CU	SR	O	C
TA 1 5 1	146	55	1	1	7	20	-2.9	-1.6
AA 1 1 3	173	70	0	1	6	101	-3.7	-1.0
AA 2 1 1	338	175	0	0	6	33	-3.5	-4.2
AA 2 21 1	205	125	0	4	6	14	-5.6	-2.4

TABLE 13. GROUPINGS FOR MDISC 13.

GROUP 1. (5) STRATIGRAPHIC DOLOMITES

SAMPLE	FE	MN	SR	O	C
CB 3	794	54	27	-5.3	1.0
CB 6	836	63	34	-5.2	0.9
CB H 77 1	1754	146	32	-8.5	0.1
OCC 2	1504	234	48	-5.6	-0.9
AA 2 20 1	2527	569	4	-9.4	-0.2

GROUP 2. (18) TECTONIC DOLOMITES

SAMPLE	FE	MN	SR	O	C
8	184	120	50	-7.6	-1.3
10 W	220	105	50	-6.2	-1.6
10 B	390	104	50	-7.1	-0.9
9	310	105	50	-3.1	-1.9
5	460	100	50	-3.0	-2.3
20	200	102	50	-3.7	-2.2
11	560	190	50	-2.7	-2.1
12	820	200	50	-2.9	-1.9
13 W	310	160	50	-4.6	-1.6
13 B	380	143	50	-4.1	-1.9
14	800	154	50	-3.1	-1.8
15	540	300	50	-3.1	-2.1
16	80	108	50	-3.0	-2.8
TA 1 2 2	606	54	66	-4.1	-1.9
TA 1 3 1	606	63	86	-6.2	-1.9
TA 1 4 2	418	49	27	-4.6	-1.9
TA 2 2 2	481	49	20	-3.6	-1.2
TA 4 1 3	752	54	75	-2.9	-2.1

TABLE 14. GROUPINGS FOR MDISC 14 AND 16.

GROUP 1. (17) STRATIGRAPHIC DOLOMITES

SAMPLE	NA	LI	NI	CU
TA 5 3 1	313	1	3	6
CB 1	188	0	3	2
CB 2	173	0	1	3
CB 3	238	0	0	3
CB 4	298	0	1	3
CB 5	196	0	1	3
CB 6	284	1	1	3
CB H 77 1	169	0	0	2
CB H 77 2	177	0	1	3
WSC S 1	221	1	0	3
WSC S 2	270	1	0	3
OCC 1	201	0	0	3
OCC 2	274	0	0	3
OCC 3	160	0	0	4
AA 2 2 1	252	0	5	2
AA 2 10 1	157	0	0	4
AA 2 20 1	207	0	0	3

GROUP 2. (28) LOW-FE TECTONIC DOLOMITES

SAMPLE	NA	LI	NI	CU
TA 1 2 2	157	7	7	10
TA 1 3 1	117	5	5	8
TA 1 4 2	107	4	8	6
TA 1 8 1	74	20	1	9
TA 2 1 2	143	2	5	8
TA 2 2 2	109	1	10	10
TA 2 4 1	157	1	10	6
TA 2 5 2	143	2	7	9
TA 3 4 1	173	0	3	6
TA 3 5 1	100	0	1	8
TA 4 1 3	217	1	5	12
TA 4 2 2	143	0	5	6
TA 4 3 1	209	1	10	6
TA 4 5 1	121	0	5	8
TA 4 6 1	165	2	10	6
TA 4 8 1	221	1	12	7
TA 4 9 1	343	0	10	8
TA 4 18 1	128	0	23	8
TA 5 1 1	213	0	10	3
TA 5 2 1	354	0	7	4
TA 5 5 1	110	0	5	4
TA 6 1 1	188	8	1	3
TA 6 1 2	146	0	5	6
TA 6 1 4	157	1	1	4
TA 6 2 1	221	3	10	3
TA 6 3 1	135	9	0	7
TA 7 1 1	284	1	5	6
TA 7 2 1	114	1	0	3

APPENDIX B

Table 1. Listing of Discriminant Analysis Program - MDISC.

```
C         SAMPLE MAIN PROGRAM FOR DISCRIMINANT ANALYSIS - MDISC
C         THE FOLLOWING DIMENSION MUST BE GREATER THAN OR EQUAL TO THE
C         NUMBER OF GROUPS, K..
      DIMENSION N(20)
C         THE FOLLOWING DIMENSION MUST BE GREATER THAN OR EQUAL TO THE
C         NUMBER OF VARIABLES, M..
      DIMENSION CMEAN(35)
C         THE FOLLOWING DIMENSION MUST BE GREATER THAN OR EQUAL TO THE
C         PRODUCT OF M*K..
      DIMENSION XBAR(700)
C         THE FOLLOWING DIMENSION MUST BE GREATER THAN OR EQUAL TO THE
C         PRODUCT OF  M&1 *K..
      DIMENSION C(800)
C         THE FOLLOWING DIMENSION MUST BE GREATER THAN OR EQUAL TO THE
C         PRODUCT OF M*M..
      DIMENSION D(1250)
C         THE FOLLOWING DIMENSIONS MUST BE GREATER THAN OR EQUAL TO THE
C         TOTAL OF SAMPLE SIZES OF K GROUPS COMBINED, T  T   N 1 &N 2 &..
C         &N K  ..
      DIMENSION P(200),LG(200)
C         THE FOLLOWING DIMENSION MUST BE GREATER THAN OR EQUAL TO THE
C         TOTAL DATA POINTS WHICH IS EQUAL TO THE PRODUCT OF T*M..
      DIMENSION X 1000
      COMMON MX,MY
C         ..............................................................
    1 FORMAT(A4,A2,2I2,12I5/(10I6))
    2 FORMAT(////27H DISCRIMINANT ANALYSIS.....A4,A2//19H   NUMBER OF GR
     1OUPS,7X,I3/22H   NUMBER OF VARIABLES,I7/17H   SAMPLE SIZES../12X,
     25HGROUP)
    3 FORMAT 12X,I3,8X,I4
    4 FORMAT(//2X)
    5 FORMAT(12F6.0)
    6 FORMAT(//6H GROUP,I3,7H  MEANS/(8F15.5))
    7 FORMAT(///25H POOLED DISPERSION MATRIX)
    8 FORMAT(//4H ROW,I3/(8F15.5))
    9 FORMAT(////13H COMMON MEANS/(8F15.5))
   10 FORMAT(////33H GENERALIZED MAHALANOBIS D-SQUARE,F15.5//)
   11 FORMAT(//22H DISCRIMINANT FUNCTION,I3//6X,27HCONSTANT   *   COEFFI
     1CIENTS//F14.5,7H    *    ,7F14.5/(22X,7F14.5))
   12 FORMAT(////60H EVALUATION OF CLASSIFICATION FUNCTIONS FOR EACH OBS
     1ERVATION)
   13 FORMAT(//6H GROUP,I3/19X,27HPROBABILITY ASSOCIATED WITH,11X,7HLARG
     1EST/13H  OBSERVATION,5X,29HLARGEST DISCRIMINANT FUNCTION,8X,12HFUN
     2CTION NO.)
   14 FORMAT(I7,20X,F8.5,20X,I6)
   15 FORMAT(2I2)
C         ..............................................................
      READ(2,15)MX,MY
C         READ PROBLEM PARAMETER CARD
  100 READ(MY,1)PR,PR1,K,M,(N(I),I=1,K)
C         PR.......PROBLEM NUMBER  MAY BE ALPHAMERIC
C         PR1......PROBLEM NUMBER  CONTINUED
C         K........NUMBER OF GROUPS
C         M........NUMBER OF VARIABLES
C         N........VECTOR OF LENGTH K CONTAINING SAMPLE SIZES
      IF (K) 103,101,103
101   CALL EXIT
103   WRITE (MX,2) PR,PR1,K,M
```

Table 1 cont'd.

```
      DO 110 I 1,K                                                      MDISC 56
  110 WRITE  MX,3  I,N I                                                MDISC 57
      WRITE  MX,4                                                       MDISC 58
C        READ DATA                                                      MDISC 59
      L 0                                                               MDISC 60
      DO 130 I 1,K                                                      MDISC 61
      N1 N I                                                            MDISC 62
      DO 120 J 1,N1                                                     MDISC 63
      READ (MY,5) (CMEAN(IJ),IJ=1,M)
      L L&1                                                             MDISC 65
      N2 L-N1                                                           MDISC 66
      DO 120 IJ 1,M                                                     MDISC 67
      N2 N2&N1                                                          MDISC 68
  120 X N2  CMEAN IJ                                                    MDISC 69
  130 L N2                                                              MDISC 70
      CALL DMATX  K,M,N,X,XBAR,D,CMEAN                                  MDISC 71
C        PRINT MEANS AND POOLED DISPERSION MATRIX                       MDISC 72
      L 0                                                               MDISC 73
      DO 150 I 1,K                                                      MDISC 74
      DO 140 J 1,M                                                      MDISC 75
      L L&1                                                             MDISC 76
  140 CMEAN J  XBAR L                                                   MDISC 77
  150 WRITE  MX,6  I, CMEAN J ,J 1,M                                    MDISC 78
      WRITE  MX,7                                                       MDISC 79
      DO 170 I 1,M                                                      MDISC 80
      L I-M                                                             MDISC 81
      DO 160 J 1,M                                                      MDISC 82
      L L&M                                                             MDISC 83
  160 CMEAN J  D L                                                      MDISC 84
  170 WRITE  MX,8  I, CMEAN J ,J 1,M                                    MDISC 85
      CALL MINV  D,M,DET,CMEAN,C                                        MDISC 86
      CALL DISCR  K,M,N,X,XBAR,D,CMEAN,V,C,P,LG                         MDISC 87
C        PRINT COMMON MEANS                                             MDISC 88
      WRITE MX,9   CMEAN I ,I 1,M                                       MDISC 89
C        PRINT GENERALIZED MAHALANOBIS D-SQUARE                         MDISC 90
      WRITE  MX,10  V                                                   MDISC 91
C        PRINT CONSTANTS AND COEFFICIENTS OF DISCRIMINANT FUNCTIONS     MDISC 92
      N1 1                                                              MDISC 93
      N2 M&1                                                            MDISC 94
      DO 180 I 1,K                                                      MDISC 95
      WRITE  MX,11  I, C J ,J N1,N2                                     MDISC 96
      N1 N1& M&1                                                        MDISC 97
  180 N2 N2& M&1                                                        MDISC 98
C        PRINT EVALUATION OF CLASSIFICATION FUNCTIONS FO EACH           MDISC 99
C        OBSERVATION                                                    MDISC100
      WRITE  MX,12                                                      MDISC101
      N1 1                                                              MDISC102
      N2 N 1                                                            MDISC103
      DO 210 I 1,K                                                      MDISC104
      WRITE  MX,13  I                                                   MDISC105
      L 0                                                               MDISC106
      DO 190 J N1,N2                                                    MDISC107
      L L&1                                                             MDISC108
  190 WRITE  MX,14  L,P J ,LG J                                         MDISC109
      IF I-K  200, 100, 100                                             MDISC110
  200 N1 N1&N I                                                         MDISC111
      N2 N2&N I&1                                                       MDISC112
  210 CONTINUE                                                          MDISC113
      STOP                                                              MDISC114
      END                                                               MDISC115
// XEQ          1
*LOCAL,DMATX,MINV,DISCR
```

TABLE 2. Results of MDISC 1.

10 Variables Generalized Mahalanobis $D^2 = 620.51123$

$$DF_1 = 0.08641(Pb) - 0.15483(Zn) + 0.03820(Na) - 0.05124(Li) + 0.02247(Ni) + 0.00699(K) + 1.12619(Cu) + 0.05950(Sr) - 0.00197(Mn) + 0.00090(Fe) - 7.93562$$

$$DF_2 = 0.06796(Pb) - 0.13321(Zn) + 0.03431(Na) + 0.32578(Li) + 0.31534(Ni) + 0.00452(K) + 2.05488(Cu) + 0.07934(Sr) - 0.00008(Mn) + 0.00049(Fe) - 13.35627$$

$$DF_3 = 0.08360(Pb) - 0.16093(Zn) + 0.04187(Na) + 0.22932(Li) + 0.41830(Ni) + 0.01211(K) + 1.95224(Cu) + 0.08724(Sr) - 0.00062(Mn) + 0.00082(Fe) - 17.15610$$

$$DF_4 = 0.12731(Pb) - 0.28554(Zn) + 0.04666(Na) + 0.23598(Li) + 0.11976(Ni) + 0.00473(K) + 1.74695(Cu) + 0.09523(Sr) + 0.00317(Mn) + 0.00258(Fe) - 29.40547$$

Group 1 Stratigraphic Dolomites 17 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 5-3-1	0.60265	3
CB 1	0.95249	1
CB 2	0.94118	1
CB 3	0.92065	1
CB 4	0.94984	1
CB 5	0.93072	1
CB 6	0.87185	1
CB-H-77-1	0.96717	1
CB-H-77-2	0.96427	1
WSC-S-1	0.90868	1
WSC-S-2	0.89695	1
OCC 1	0.94288	1
OCC 2	0.91533	1
OCC 3	0.86319	1
AA 2-2-1	0.94325	1
AA 2-10-1	0.94047	1
AA 2-20-1	0.96448	1

TABLE 2. (Cont'd)

Group 2 Tectonic Dolomites 33 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 1-1-1v	0.82430	2
TA 1-2-2	0.85243	2
TA 1-3-1	0.88910	2
TA 1-4-2	0.91138	2
TA 1-8-1	0.97788	2
TA 2-1-2	0.90840	2
TA 2-2-2	0.88567	2
TA 2-4-1	0.78249	2
TA 2-5-2	0.61438	2
TA 3-4-1	0.52245	2
TA 3-4-1v	0.73515	2
TA 3-5-1	0.67520	2
TA 4-1-1v	0.79352	3
TA 4-1-3	0.53638	2
TA 4-2-2	0.67144	2
TA 4-3-1	0.66067	2
TA 4-5-1	0.83015	2
TA 4-6-1	0.69605	2
TA 4-8-1	0.64786	3
TA 4-9-1	0.84780	3
TA 4-9-1v	0.38127	3
TA 4-18-1	0.81896	3
TA 4-18-1v	0.77600	2
TA 5-1-1	0.63419	3
TA 5-2-1	0.58691	1
TA 5-5-1	0.64161	1
TA 6-1-1	0.53065	2
TA 6-1-2	0.60747	2
TA 6-1-4	0.77180	1
TA 6-2-1	0.51661	3
TA 6-3-1	0.89289	2
TA 7-1-1	0.55387	2
TA 7-2-1	0.93735	1

Group 3 Indeterminate Dolomites 24 Samples

TA 1-5-3	0.99340	4
TA 1-5-5	0.92758	3
TA 3-1-1	0.46348	3
TA 3-2-1	0.65069	2
TA 3-6-1	0.63390	2

TABLE 2. (Cont'd)

Group 3 (Cont'd)

TA 4-1-1	0.99741	3
TA 4-2-1	0.61816	3
TA 4-7-2	0.83979	3
TA 4-7-3	0.92028	3
TA 4-10-1	0.58710	3
TA 4-10-1A	0.51370	3
TA 4-11-1	0.52357	3
TA 4-12-1	0.65589	2
TA 4-13-1	0.81504	3
TA 4-14-1	0.70532	3
TA 4-15-1	0.46667	3
TA 4-16-1	0.61848	2
TA 4-17-1	0.62693	3
TA 4-19-1	0.44982	1
TA 4-20-1	0.52231	2
TA 4-22-2	0.54369	3
TA 4-24-2	0.42990	3
TA 4-24-3	0.89157	3
AA 2-17-1	0.80398	1

Group 4 Ferroan Tectonic Dolomites 26 Samples

TA 1-5-1	0.99999	4
TA 4-7-1	0.49917	2
TA 4-21-2	0.99985	4
TA 4-23-2	0.55154	1
TA 5-4-1	0.44283	3
AA 1-1-2	1.00000	4
AA 1-1-3	1.00000	4
AA 1-2-1	0.99999	4
AA 1-3-1	0.99999	4
AA 2-1-1	1.00000	4
AA 2-3-1	0.99943	4
AA 2-3-1A	0.99999	4
AA 2-5-1	0.99999	4
AA 2-5-2	1.00000	4
AA 2-6-1	0.99767	4
AA 2-8-1	0.99999	4
AA 2-9-1	1.00000	4
AA 2-11-1	1.00000	4
AA 2-12-1	0.99955	4
AA 2-13-1	1.00000	4
AA 2-14-1	0.98659	4
AA 2-19-1	0.99999	4
AA 2-21-1	1.00000	4
AA 2-22-2	1.00000	4
AA 2-23-1	1.00000	4
AA 2-24-1	0.99857	4

TABLE 3. Results of MDISC 2.

10 Variables Generalized Mahalanobis $D^2 = 103.47732$

$$
\begin{aligned}
DF_1 = {} & 0.17372(Pb) - 0.17180(Zn) + 0.04985(Na) + 0.07446(Li) \\
& - 0.03298(Ni) + 0.00665(K) + 1.17691(Cu) + 0.06802(Sr) \\
& + 0.00698(Mn) + 0.00027(Fe) - 9.82284
\end{aligned}
$$

$$
\begin{aligned}
DF_2 = {} & 0.07494(Pb) - 0.01141(Zn) + 0.04179(Na) + 0.29954(Li) \\
& + 0.21299(Ni) + 0.00548(K) + 2.09447(Cu) + 0.08219(Sr) \\
& + 0.01004(Mn) - 0.00017(Fe) - 14.19727
\end{aligned}
$$

$$
\begin{aligned}
DF_3 = {} & 0.20992(Pb) - 0.05730(Zn) + 0.05161(Na) + 0.27060(Li) \\
& + 0.28433(Ni) + 0.01195(K) + 2.05869(Cu) + 0.09586(Sr) \\
& + 0.01309(Mn) - 0.00015(Fe) - 18.99542
\end{aligned}
$$

Group 1 Stratigraphic Dolomites 17 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 5-3-1	0.53723	3
CB 1	0.94843	1
CB 2	0.92188	1
CB 3	0.92393	1
CB 4	0.95965	1
CB 5	0.92288	1
CB 6	0.90458	1
CB-H-77-1	0.96060	1
CB-H-77-2	0.94770	1
WSC-S-1	0.91466	1
WSC-S-2	0.92870	1
OCC 1	0.92803	1
OCC 2	0.89049	1
OCC 3	0.80233	1
AA 2-2-1	0.87586	1
AA 2-10-1	0.92940	1
AA 2-20-1	0.90384	1

Group 2 Tectonic Dolomites 33 Samples

TA 1-1-1v	0.73384	2
TA 1-2-2	0.80805	2
TA 1-3-1	0.84154	2
TA 1-4-2	0.92667	2
TA 1-8-1	0.96891	2

TABLE 3. (Cont'd)

Group 2 (Cont'd)

TA	2-1-2	0.90105	2
TA	2-2-2	0.91207	2
TA	2-4-1	0.79708	2
TA	2-5-2	0.66301	2
TA	3-4-1	0.54687	2
TA	3-4-1v	0.74539	2
TA	3-5-1	0.77750	2
TA	4-1-1v	0.82056	3
TA	4-1-3	0.53821	3
TA	4-2-2	0.72933	2
TA	4-3-1	0.66965	2
TA	4-5-1	0.80668	2
TA	4-6-1	0.73623	2
TA	4-8-1	0.67353	3
TA	4-9-1	0.85232	3
TA	4-9-1v	0.38804	2
TA	4-18-1	0.69508	3
TA	4-18-1v	0.79835	2
TA	5-1-1	0.44472	3
TA	5-2-1	0.76885	1
TA	5-5-1	0.55794	1
TA	6-1-1	0.41100	1
TA	6-1-2	0.68409	2
TA	6-1-4	0.63298	1
TA	6-2-1	0.49009	3
TA	6-3-1	0.92311	2
TA	7-1-1	0.45855	2
TA	7-2-1	0.89564	1

Group 3 Indeterminate Dolomites 24 Samples

TA	1-5-3	0.82258	3
TA	1-5-5	0.91974	3
TA	3-1-1	0.37845	3
TA	3-2-1	0.62890	2
TA	3-6-1	0.73134	2
TA	4-1-1	0.99220	3
TA	4-2-1	0.64086	3
TA	4-7-2	0.84390	3
TA	4-7-3	0.89193	3
TA	4-10-1	0.62849	3
TA	4-10-1A	0.60261	2
TA	4-11-1	0.49765	3
TA	4-12-1	0.60907	2
TA	4-13-1	0.81745	3
TA	4-14-1	0.69375	3
TA	4-15-1	0.43630	1

TABLE 3. (Cont'd)

Group 3 (Cont'd)

TA 4-16-1	0.67674	2
TA 4-17-1	0.61686	3
TA 4-19-1	0.50102	1
TA 4-20-1	0.61231	3
TA 4-22-2	0.55259	3
TA 4-24-2	0.42104	2
TA 4-24-3	0.87726	3
AA 2-17-1	0.91001	3

TABLE 4. Results of MDISC 3.

10 Variables Generalized Mahalanobis D^2 = 568.36938

$$DF_1 = 0.08044(Pb) - 0.13891(Zn) + 0.03524(Na) + 0.04147(Li) - 0.04733(Ni) + 0.01756(K) + 0.92171(Cu) + 0.05049(Sr) - 0.00249(Mn) + 0.00099(Fe) - 8.24388$$

$$DF_2 = 0.05076(Pb) - 0.10056(Zn) + 0.03007(Na) + 0.40111(Li) + 0.34787(Ni) + 0.00890(K) + 1.81767(Cu) + 0.07947(Sr) - 0.00045(Mn) + 0.00040(Fe) - 12.67333$$

$$DF_3 = 0.07888(Pb) - 0.20509(Zn) + 0.04846(Na) + 0.33081(Li) + 0.15228(Ni) + 0.00915(K) + 1.19059(Cu) + 0.06388(Sr) + 0.00053(Mn) + 0.00306(Fe) - 27.77725$$

Group 1 Stratigraphic Dolomites 17 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 5-3-1	0.88944	1
CB 1	0.90902	1
CB 2	0.95941	1
CB 3	0.99887	1
CB 4	0.97477	1
CB 5	0.94131	1
CB 6	0.99383	1
CB-H-77-1	0.99941	1
CB-H-77-2	0.97063	1
WSC-S-1	0.93739	1
WSC-S-2	0.87091	1
OCC 1	0.97987	1
OCC 2	0.99089	1
OCC 3	0.94039	1
AA 2-2-1	0.97324	1
AA 2-10-1	0.95518	1
AA 2-20-1	0.97999	1

TABLE 4. (Cont'd)

Group 2 Tectonic Dolomites 33 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 1-1-1v	0.99741	2
TA 1-2-2	0.99991	2
TA 1-3-1	0.99932	2
TA 1-4-2	0.99507	2
TA 1-8-1	0.99976	2
TA 2-1-2	0.99334	2
TA 2-2-2	0.99961	2
TA 2-4-1	0.99543	2
TA 2-5-2	0.99194	2
TA 3-4-1	0.71249	2
TA 3-4-1v	0.93010	2
TA 3-5-1	0.69152	2
TA 4-1-1v	0.99999	2
TA 4-1-3	0.99915	2
TA 4-2-2	0.84471	2
TA 4-3-1	0.99063	2
TA 4-5-1	0.98657	2
TA 4-6-1	0.99235	2
TA 4-8-1	0.98825	2
TA 4-9-1	0.93958	2
TA 4-9-1v	0.77165	2
TA 4-18-1	0.99986	2
TA 4-18-1v	0.94162	2
TA 5-1-1	0.81640	2
TA 5-2-1	0.53191	1
TA 5-5-1	0.83333	1
TA 6-1-1	0.68304	2
TA 6-1-2	0.84097	2
TA 6-1-4	0.64927	1
TA 6-2-1	0.94526	2
TA 6-3-1	0.94399	2
TA 7-1-1	0.84869	2
TA 7-2-1	0.98280	1

Group 3 Ferroan Tectonic Dolomites 26 Samples

TA 1-5-1	1.00000	3
TA 4-7-1	0.57959	3
TA 4-21-2	0.99999	3
TA 4-23-2	0.78276	3
TA 5-4-1	0.51641	1
AA 1-1-2	1.00000	3
AA 1-1-3	1.00000	3

TABLE 4. (Cont'd)

Group 3 (Cont'd)

AA 1-2-1	1.00000	3
AA 1-3-1	0.99999	3
AA 2-1-1	1.00000	3
AA 2-3-1	0.99891	3
AA 2-3-1A	0.99999	3
AA 2-5-1	0.99999	3
AA 2-5-2	1.00000	3
AA 2-6-1	0.99903	3
AA 2-8-1	0.99999	3
AA 2-9-1	1.00000	3
AA 2-11-1	1.00000	3
AA 2-12-1	0.99998	3
AA 2-13-1	1.00000	3
AA 2-14-1	0.99666	3
AA 2-19-1	0.99999	3
AA 2-21-1	1.00000	3
AA 2-22-2	1.00000	3
AA 2-23-1	1.00000	3
AA 2-24-1	0.99166	3

TABLE 5. Results of MDISC 4.

10 Variables Generalized Mahalanobis $D^2 = 538.36963$

$$\begin{aligned} DF_1 = {} & 0.07772(Pb) - 0.13497(Zn) + 0.03516(Na) + 0.05147(Li) \\ & + 0.01030(Ni) + 0.01558(K) + 0.99957(Cu) + 0.05639(Sr) \\ & - 0.00233(Mn) + 0.00090(Fe) - 8.21777 \end{aligned}$$

$$\begin{aligned} DF_2 = {} & 0.04611(Pb) - 0.09848(Zn) + 0.03064(Na) + 0.44683(Li) \\ & + 0.49245(Ni) + 0.00765(K) + 1.87600(Cu) + 0.10296(Sr) \\ & - 0.00030(Mn) + 0.00030(Fe) - 13.65833 \end{aligned}$$

$$\begin{aligned} DF_3 = {} & 0.07335(Pb) - 0.20098(Zn) + 0.04878(Na) + 0.31577(Li) \\ & + 0.33161(Ni) + 0.00575(K) + 1.19593(Cu) + 0.08385(Sr) \\ & + 0.00041(Mn) + 0.00295(Fe) - 27.45286 \end{aligned}$$

Group 1 Stratigraphic Dolomites 17 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 5-3-1	0.88675	1
CB 1	0.93437	1
CB 2	0.97154	1
CB 3	0.99897	1
CB 4	0.98079	1
CB 5	0.95116	1
CB 6	0.99318	1
CB-H-77-1	0.99943	1
CB-H-77-2	0.98647	1
WSC-S-1	0.93292	1
WSC-S-2	0.85218	1
OCC 1	0.98170	1
OCC 2	0.98943	1
OCC 3	0.94646	1
AA 2-2-1	0.97657	1
AA 2-10-1	0.98199	1
AA 2-20-1	0.99101	1

TABLE 5. (Cont'd)

Group 2 Tectonic Dolomites 28 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 1-2-2	0.99997	2
TA 1-3-1	0.99977	2
Ta 1-4-2	0.99628	2
TA 1-8-1	0.99976	2
TA 2-1-2	0.99335	2
TA 2-2-2	0.99967	2
TA 2-4-1	0.99801	2
TA 2-5-2	0.99496	2
TA 3-4-1	0.70196	2
TA 3-5-1	0.59052	2
TA 4-1-3	0.99964	2
TA 4-2-2	0.77605	2
TA 4-3-1	0.99578	2
TA 4-5-1	0.98958	2
TA 4-6-1	0.99666	2
TA 4-8-1	0.99466	2
TA 4-9-1	0.96570	2
TA 4-18-1	0.99997	2
TA 5-1-1	0.95913	2
TA 5-2-1	0.52580	1
TA 5-5-1	0.83871	1
TA 6-1-1	0.86757	2
TA 6-1-2	0.87650	2
TA 6-1-4	0.75126	1
TA 6-2-1	0.98721	2
TA 6-3-1	0.93075	2
TA 7-1-1	0.86864	2
TA 7-2-1	0.98833	1

Group 3 Ferroan Tectonic Dolomites 26 Samples

TA 1-5-1	1.00000	3
TA 4-7-1	0.67937	3
TA 4-21-2	0.99999	3
TA 4-23-2	0.87647	3
TA 5-4-1	0.52442	2
AA 1-1-2	1.00000	3
AA 1-1-3	1.00000	3
AA 1-2-1	0.99999	3
AA 1-3-1	0.99999	3
AA 2-1-1	1.00000	3
AA 2-3-1	0.99831	3

TABLE 5. (Cont'd)

Group 3 (Cont'd)

AA 2-3-1A	0.99999	3
AA 2-5-1	0.99999	3
AA 2-5-2	1.00000	3
AA 2-6-1	0.99893	3
AA 2-8-1	0.99998	3
AA 2-9-1	1.00000	3
AA 2-11-1	1.00000	3
AA 2-12-1	0.99998	3
AA 2-13-1	1.00000	3
AA 2-14-1	0.99688	3
AA 2-19-1	0.99999	3
AA 2-21-1	1.00000	3
AA 2-22-2	1.00000	3
AA 2-23-1	1.00000	3
AA 2-24-1	0.99082	3

TABLE 6. Results of MDISC 5.

10 Variables Generalized Mahalanobis $D^2 = 83.40121$

$$\begin{aligned} DF_1 = {} & 0.31438(Pb) - 0.00503(Zn) + 0.05737(Na) + 0.20600(Li) \\ & - 0.29643(Ni) + 0.01896(K) + 0.86459(Cu) + 0.06099(Sr) \\ & + 0.02049(Mn) - 0.00059(Fe) - 11.97447 \end{aligned}$$

$$\begin{aligned} DF_2 = {} & 0.11264(Pb) + 0.18346(Zn) + 0.04331(Na) + 0.30432(Li) \\ & + 0.09603(Ni) + 0.00969(k) + 1.65504(Cu) + 0.07241(Sr) \\ & + 0.01321(Mn) - 0.00014(Fe) - 12.89740 \end{aligned}$$

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
Group 1	Stratigraphic Dolomites	17 Samples
TA 5-3-1	0.89485	1
CB 1	0.80041	1
CB 2	0.89427	1
CB 3	0.99792	1
CB 4	0.97487	1
CB 5	0.88176	1
CB 6	0.99469	1
CB-H-77-1	0.99763	1
CB-H-77-2	0.88348	1
WSC-S-1	0.93941	1
WSC-S-2	0.91986	1
OCC 1	0.96955	1
OCC 2	0.99625	1
OCC 3	0.89541	1
AA 2-2-1	0.99377	1
AA 2-10-1	0.99614	1
AA 2-20-1	0.99535	1
Group 2	Tectonic Dolomites	33 Samples
TA 1-1-1v	0.99117	2
TA 1-2-2	0.99982	2
TA 1-3-1	0.99770	2
TA 1-4-2	0.99826	2
TA 1-8-1	0.99913	2
TA 2-1-2	0.99365	2
TA 2-2-2	0.99982	2
TA 2-4-1	0.99562	2

TABLE 6. (Cont'd)

Group 2 (Cont'd)

TA 2-5-2	0.99129	2
TA 3-4-1	0.89094	2
TA 3-4-1v	0.96493	2
TA 3-5-1	0.94376	2
TA 4-1-1v	0.99997	2
TA 4-1-3	0.99729	2
TA 4-2-2	0.95265	2
TA 4-3-1	0.98772	2
TA 4-5-1	0.98269	2
TA 4-6-1	0.99261	2
TA 4-8-1	0.96513	2
TA 4-9-1	0.83002	2
TA 4-9-1v	0.85050	2
TA 4-18-1	0.99984	2
TA 4-18-1v	0.95747	2
TA 5-1-1	0.85786	2
TA 5-2-1	0.83640	1
TA 5-5-1	0.50037	2
TA 6-1-1	0.81702	1
TA 6-1-2	0.91617	2
TA 6-1-4	0.70492	2
TA 6-2-1	0.90212	2
TA 6-3-1	0.98902	2
TA 7-1-1	0.62749	2
TA 7-2-1	0.94413	1

TABLE 7. Results of MDISC 6.

10 Variables Generalized Mahalanobis D^2 = 83.48902

$$DF_1 = 0.28584(Pb) - 0.02778(Zn) + 0.06005(Na) + 0.19933(Li) - 0.30267(Ni) + 0.01620(K) + 1.04597(Cu) - 0.04771(Sr) + 0.01894(Mn) - 0.00089(Fe) - 11.74972$$

$$DF_2 = 0.21919(Pb) + 0.18268(Zn) + 0.04579(Na) + 0.30497(Li) + 0.19991(Ni) + 0.00763(K) + 1.75316(Cu) + 0.07999(Sr) + 0.00941(Mn) - 0.00025(Fe) - 13.39734$$

Group 1 Stratigraphic Dolomites 17 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 5-3-1	0.90504	1
CB 1	0.84837	1
CB 2	0.92486	1
CB 3	0.99806	1
CB 4	0.98246	1
CB 5	0.89757	1
CB 6	0.99419	1
CB-H-77-1	0.99736	1
CB-H-77-2	0.94842	1
WSC-S-1	0.93551	1
WSC-S-2	0.90835	1
OCC 1	0.97288	1
OCC 2	0.99641	1
OCC 3	0.91088	1
AA 2-2-1	0.99761	1
AA 2-10-1	0.99037	1
AA 2-20-1	0.99908	1

Group 2 Tectonic Dolomites 28 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 1-2-2	0.99993	2
TA 1-3-1	0.99916	2
TA 1-4-2	0.99896	2
TA 1-8-1	0.99872	2
TA 2-1-2	0.99181	2
TA 2-2-2	0.99982	2
TA 2-4-1	0.99825	2
TA 2-5-2	0.99341	2

TABLE 7. (Cont'd)

Group 2 (Cont'd)

TA 3-4-1	0.88549	2
TA 3-5-1	0.90651	2
TA 4-1-3	0.99847	2
TA 4-2-2	0.91844	2
TA 4-3-1	0.99459	2
TA 4-5-1	0.98175	2
TA 4-6-1	0.99706	2
TA 4-8-1	0.97885	2
TA 4-9-1	0.86849	2
TA 4-18-1	0.99996	2
TA 5-1-1	0.98253	2
TA 5-2-1	0.74260	1
TA 5-5-1	0.51673	2
TA 6-1-1	0.59843	1
TA 6-1-2	0.93728	2
TA 6-1-4	0.59529	2
TA 6-2-1	0.98243	2
TA 6-3-1	0.98638	2
TA 7-1-1	0.58938	2
TA 7-2-1	0.96217	1

TABLE 8. Results of MDISC 7.

6 Variables Generalized Mahalanobis $D^2 = 109.07231$

$$DF_1 = 0.02757(Na) + 0.01491(K) + 0.05998(Li) + 0.06289(Ni) + 1.09642(Cu) + 0.05190(Sr) - 7.03948$$

$$DF_2 = 0.02906(Na) + 0.00750(K) + 0.44143(Li) + 0.52142(Ni) + 1.86834(Cu) + 0.09491(Sr) - 13.36115$$

$$DF_3 = 0.03820(Na) + 0.00181(K) + 0.08725(Li) + 0.12436(Ni) + 1.76893(Cu) + 0.09295(Sr) - 11.76718$$

Group 1 Stratigraphic Dolomites 17 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 5-3-1	0.59646	1
CB 1	0.72215	1
CB 2	0.86613	1
CB 3	0.99372	1
CB 4	0.60814	1
CB 5	0.71866	1
CB 6	0.94219	1
CB-H-77-1	0.99723	1
CB-H-77-2	0.86310	1
WSC-S-1	0.54059	1
WSC-S-2	0.78612	3
OCC 1	0.85379	1
OCC 2	0.81862	1
OCC 3	0.78605	1
AA 2-2-1	0.80588	1
AA 2-10-1	0.65520	1
AA 2-20-1	0.82998	1

Group 2 Tectonic Dolomites 28 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 1-2-2	0.98747	2
TA 1-3-1	0.93181	2
TA 1-4-2	0.94185	2
TA 1-8-1	0.99886	2
TA 2-1-2	0.71877	2
TA 2-2-2	0.96354	2
TA 2-4-1	0.90764	2

TABLE 8. (Cont'd)

Group 2 (Cont'd)

TA 2-5-2	0.94856	2
TA 3-4-1	0.68452	3
TA 3-5-1	0.45284	3
TA 4-1-3	0.83277	2
TA 4-2-2	0.40107	2
TA 4-3-1	0.88010	2
TA 4-5-1	0.69159	2
TA 4-6-1	0.94542	2
TA 4-8-1	0.96475	2
TA 4-9-1	0.82151	2
TA 4-18-1	0.99977	2
TA 5-1-1	0.85237	2
TA 5-2-1	0.71252	3
TA 5-5-1	0.87499	1
TA 6-1-1	0.73641	2
TA 6-1-2	0.58034	2
TA 6-1-4	0.46572	1
TA 6-2-1	0.92590	2
TA 6-3-1	0.77818	2
TA 7-1-1	0.60694	3
TA 7-2-1	0.98200	1

Group 3 Ferroan Tectonic Dolomites 26 Samples

TA 1-5-1	0.66567	3
TA 4-7-1	0.74137	2
TA 4-21-2	0.96868	2
TA 4-23-2	0.42472	2
TA 5-4-1	0.65967	2
AA 1-1-2	0.94083	3
AA 1-1-3	0.82193	3
AA 1-2-1	0.92130	3
AA 1-3-1	0.94000	3
AA 2-1-1	0.84091	3
AA 2-3-1	0.51383	1
AA 2-3-1A	0.56505	1
AA 2-5-1	0.68803	3
AA 2-5-2	0.92724	3
AA 2-6-1	0.82949	3
AA 2-8-1	0.62495	3
AA 2-9-1	0.88713	3
AA 2-11-1	0.40330	3
AA 2-12-1	0.97307	3
AA 2-13-1	0.74802	3
AA 2-14-1	0.76925	3
AA 2-19-1	0.87673	3
AA 2-21-1	0.47790	3
AA 2-22-2	0.57622	2
AA 2-23-1	0.64416	3
AA 2-24-1	0.41229	1

TABLE 9. Results of MDISC 8.

6 Variables Generalized Mahalanobis $D^2 = 90.94477$

$$DF_1 = 0.05345(Na) + 0.00436(K) - 0.00354(Li) + 0.02056(Ni) + 1.17574(Cu) + 0.05164(Sr) - 8.92025$$

$$DF_2 = 0.04731(Na) + 0.00313(K) + 0.24639(Li) + 0.26010(Ni) + 2.04112(Cu) + 0.07041(Sr) - 13.54054$$

$$DF_3 = 0.05862(Na) + 0.00819(K) + 0.17234(Li) + 0.37189(Ni) + 1.96751(Cu) + 0.08044(Sr) - 17.57042$$

Group 1 Stratigraphic Dolomites 17 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 5-3-1	0.62069	3
CB 1	0.94504	1
CB 2	0.91337	1
CB 3	0.89341	1
CB 4	0.92806	1
CB 5	0.90166	1
CB 6	0.83344	1
CB-H-77-1	0.95086	1
CB-H-77-2	0.94227	1
WSC-S-1	0.87533	1
WSC-S-2	0.87634	1
OCC 1	0.90958	1
OCC 2	0.88012	1
OCC 3	0.79013	1
AA 2-2-1	0.93769	1
AA 2-10-1	0.88094	1
AA 2-20-1	0.95749	1

Group 2 Tectonic Dolomites 28 Samples

TA 1-2-2	0.76012	2
TA 1-3-1	0.84768	2
TA 1-4-2	0.86062	2
TA 1-8-1	0.98597	2
TA 2-1-2	0.85902	2
TA 2-2-2	0.85785	2
TA 2-4-1	0.67583	2
TA 2-5-2	0.64466	2
TA 3-4-1	0.61653	2

TABLE 9. (Cont'd)

Group 2 (Cont'd)

TA 3-5-1	0.82621	2
TA 4-1-3	0.52886	3
TA 4-2-2	0.64721	2
TA 4-3-1	0.51014	2
TA 4-5-1	0.80984	2
TA 4-6-1	0.61416	2
TA 4-8-1	0.64800	3
TA 4-9-1	0.87408	3
TA 4-18-1	0.78357	3
TA 5-1-1	0.66058	3
TA 5-2-1	0.55803	1
TA 5-5-1	0.57021	1
TA 6-1-1	0.43651	2
TA 6-1-2	0.60023	2
TA 6-1-4	0.76769	1
TA 6-2-1	0.59093	3
TA 6-3-1	0.84871	2
TA 7-1-1	0.42844	3
TA 7-2-1	0.90287	1

Group 3 Indeterminate Dolomites 24 Samples

TA 1-5-3	0.49971	3
TA 1-5-5	0.87302	3
TA 3-1-1	0.40490	2
TA 3-2-1	0.56200	2
TA 3-6-1	0.72905	2
TA 4-1-1	0.98235	3
TA 4-2-1	0.62177	3
TA 4-7-2	0.88926	3
TA 4-7-3	0.85909	3
TA 4-10-1	0.70802	3
TA 4-10-1A	0.54991	3
TA 4-11-1	0.56569	3
TA 4-12-1	0.50942	2
TA 4-13-1	0.77515	3
TA 4-14-1	0.64022	3
TA 4-15-1	0.38131	1
TA 4-16-1	0.54094	2
TA 4-17-1	0.65058	3
TA 4-19-1	0.43344	1
TA 4-20-1	0.69977	3
TA 4-22-2	0.65459	3
TA 4-24-2	0.45826	3
TA 4-24-3	0.89694	3
AA 2-17-1	0.94413	1

TABLE 10. Results of MDISC 9.

6 Variables   Generalized Mahalanobis $D^2 = 73.85130$

$$DF_1 = 0.06171(Na) + 0.01130(K) + 0.09531(Li) - 0.20131(Ni) + 1.03697(Cu) + 0.02160(Sr) - 9.84435$$

$$DF_2 = 0.04701(Na) + 0.00518(K) + 0.31673(Li) + 0.23570(Ni) + 1.75606(Cu) + 0.06152(Sr) - 12.57472$$

Group 1   Stratigraphic Dolomites   17 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 5-3-1	0.94275	1
CB 1	0.91542	1
CB 2	0.94329	1
CB 3	0.99751	1
CB 4	0.98919	1
CB 5	0.93068	1
CB 6	0.99349	1
CB-H-77-1	0.99553	1
CB-H-77-2	0.96373	1
WSC-S-1	0.92844	1
WSC-S-2	0.92784	1
OCC 1	0.96606	1
OCC 2	0.98857	1
OCC 3	0.87175	1
AA 2-2-1	0.96660	1
AA 2-10-1	0.90441	1
AA 2-20-1	0.98318	1

Group 2   Tectonic Dolomites   28 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 1-2-2	0.99975	2
TA 1-3-1	0.99939	2
TA 1-4-2	0.99396	2
TA 1-8-1	0.99917	2
TA 2-1-2	0.98760	2
TA 2-2-2	0.99953	2
TA 2-4-1	0.99622	2
TA 2-5-2	0.99298	2
TA 3-4-1	0.83238	2
TA 3-5-1	0.88663	2

TABLE 10. (Cont'd)

Group 2 (Cont'd)

TA 4-1-3	0.99847	2
TA 4-2-2	0.81885	2
TA 4-3-1	0.98784	2
TA 4-5-1	0.98943	2
TA 4-6-1	0.99383	2
TA 4-8-1	0.98923	2
TA 4-9-1	0.86356	2
TA 4-18-1	0.99995	2
TA 5-1-1	0.95951	2
TA 5-2-1	0.85531	1
TA 5-5-1	0.58269	1
TA 6-1-1	0.69087	2
TA 6-1-2	0.89523	2
TA 6-1-4	0.72726	1
TA 6-2-1	0.96667	2
TA 6-3-1	0.80627	2
TA 7-1-1	0.60335	2
TA 7-2-1	0.95547	1

TABLE 11. Results of MDISC 10.

8 Variables Generalized Mahalanobis $D^2 = 882.42151$

$$DF_1 = 3.66486(Na) + 0.65013(K) - 12.73588(Li) + 66.32724(Ni) - 29.49274(Cu) + 0.10836(Sr) - 107.84199(\delta O^{18}) - 1.31633(\delta C^{13}) - 874.17688$$

$$DF_2 = 2.38278(Na) + 0.44613(K) - 7.12272(Li) + 59.55704(Ni) - 13.40285(Cu) + 0.74709(Sr) - 76.58708(\delta O^{18}) - 11.64408(\delta C^{13}) - 528.51306$$

Group 1 Stratigraphic Dolomites 5 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
CB 3	1.00000	1
CB 6	1.00000	1
CB-H-77-1	1.00000	1
OCC 2	1.00000	1
AA 2-20-1	1.00000	1

Group 2 Tectonic Dolomites 5 Samples

TA 1-2-2	1.00000	2
TA 1-3-1	1.00000	2
TA 1-4-2	1.00000	2
TA 2-2-2	1.00000	2
TA 4-1-3	1.00000	2

TABLE 12. Results of MDISC 11.

8 Variables Generalized Mahalanobis $D^2 = 237.66961$

$$DF_1 = 0.36286(Na) + 0.03528(K) + 0.60395(Li) + 1.06064(Ni) + 1.45624(Cu) - 0.06473(Sr) - 12.64708(\delta O^{18}) + 18.80735(\delta C^{13}) - 94.59144$$

$$DF_2 = 0.17756(Na) + 0.00168(K) - 0.20940(Li) + 1.25890(Ni) + 2.66595(Cu) + 0.04728(Sr) - 6.48513(\delta O^{18}) + 4.65487(\delta C^{13}) - 38.56648$$

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
Group 1	Stratigraphic Dolomites	5 Samples
CB 3	1.00000	1
CB 6	1.00000	1
CB-H-77-1	1.00000	1
OCC 2	1.00000	1
AA 2-20-1	1.00000	1
Group 2	Tectonic Dolomites	9 Samples
TA 1-2-1	1.00000	2
TA 1-3-1	1.00000	2
TA 1-4-2	1.00000	2
TA 2-2-2	1.00000	2
TA 4-1-3	1.00000	2
TA 1-5-1	1.00000	2
AA 1-1-3	1.00000	2
AA 2-1-1	1.00000	2
AA 2-21-1	1.00000	2

TABLE 13. Results of MDISC 12.

8 Variables Generalized Mahalanobis $D^2 = 680.42810$

$$DF_1 = 0.34559(Na) + 0.02205(K) + 0.28067(Li) + 0.25328(Ni) + 0.90701(Cu) - 0.07564(Sr) - 11.37445(\delta O^{18}) + 18.19091(\delta C^{13}) - 84.85502 .$$

$$DF_2 = - 0.00022(Na) + 0.00937(K) + 4.01269(Li) + 10.63918(Ni) + 9.45664(Cu) + 0.38346(Sr) - 4.82974(\delta O^{18}) - 9.36825(\delta C^{13}) - 117.87438$$

$$DF_3 = 0.10273(Na) + 0.00314(K) + 1.37520(Li) + 4.69243(Ni) + 5.06481(Cu) + 0.17090(Sr) - 5.50938(\delta O^{18}) - 0.79576(\delta C^{13}) - 46.09136$$

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
Group 1	Stratigraphic Dolomites	5 Samples
CB 3	1.00000	1
CB 6	1.00000	1
CB-H-77-1	1.00000	1
OCC 2	1.00000	1
AA 2-20-1	1.00000	1
Group 2	Tectonic Dolomites	5 Samples
TA 1-2-2	1.00000	2
TA 1-3-1	1.00000	2
TA 1-4-2	1.00000	2
TA 2-2-2	1.00000	2
TA 4-1-3	1.00000	2
Group 3	Ferroan Tectonic Dolomites	4 Samples
TA 1-5-1	1.00000	3
AA 1-1-3	1.00000	3
AA 2-1-1	1.00000	3
AA 2-21-1	1.00000	3

TABLE 14. Results of MDISC 13.

5 Variables Generalized Mahalanobis $D^2 = 148.05157$

$$DF_1 = 0.01189(Fe) - 0.00254(Mn) + 0.19591(Sr) - 1.74922(\delta O^{18}) + 3.06381(\delta C^{13}) - 17.61298$$

$$DF_2 = - 0.00363(Fe) - 0.00005(Mn) + 0.17672(Sr) - 2.75237(\delta O^{18}) - 9.25724(\delta C^{13}) - 18.08232$$

Group 1 Stratigraphic Dolomites 5 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
CB 3	1.00000	1
CB 6	1.00000	1
CB-H-77-1	1.00000	1
OCC 2	0.99942	1
AA 2-20-1	1.00000	1

Group 2 Tectonic Dolomites 18 Samples

8	1.00000	2
10 W	1.00000	2
10 B	0.99998	2
9	1.00000	2
5	1.00000	2
20	1.00000	2
11	1.00000	2
12	0.99999	2
13 W	1.00000	2
13 B	1.00000	2
14	0.99999	2
15	1.00000	2
16	1.00000	2
TA 1-2-2	1.00000	2
TA 1-3-1	1.00000	2
TA 1-4-2	1.00000	2
TA 2-2-2	0.99996	2
TA 4-1-3	1.00000	2

TABLE 15. Results of MDISC 14.

4 Variables Generalized Mahalanobis $D^2 = 62.78983$

$$DF_1 = 0.06507(Na) + 0.14054(Li) - 0.18624(Ni) + 1.08373(Cu) - 8.84934$$

$$DF_2 = 0.05181(Na) + 0.37257(Li) + 0.24735(Ni) + 1.75482(Cu) - 11.42511$$

Group 1 Stratigraphic Dolomites 17 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 5-3-1	0.76264	1
CB 1	0.91878	1
CB 2	0.91857	1
CB 3	0.97630	1
CB 4	0.98338	1
CB 5	0.93866	1
CB 6	0.97498	1
CB-H-77-1	0.96996	1
CB-H-77-2	0.92245	1
WSC-S-1	0.96307	1
WSC-S-2	0.98037	1
OCC 1	0.96187	1
OCC 2	0.98516	1
OCC 3	0.88217	1
AA 2-2-1	0.91739	1
AA 2-10-1	0.87798	1
AA 2-20-1	0.96468	1

Group 2 Tectonic Dolomites 28 Samples

TA 1-2-2	0.99878	2
TA 1-3-1	0.98974	2
TA 1-4-2	0.98821	2
TA 1-8-1	0.99947	2
TA 2-1-2	0.97149	2
TA 2-2-2	0.99929	2
TA 2-4-1	0.98086	2
TA 2-5-2	0.99373	2
TA 3-4-1	0.61238	2
TA 3-5-1	0.86993	2

TABLE 15. (Cont'd)

Group 2 (Cont'd)

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 4-1-3	0.99330	2
TA 4-2-2	0.84843	2
TA 4-3-1	0.96257	2
TA 4-5-1	0.96631	2
TA 4-6-1	0.98308	2
TA 4-8-1	0.99030	2
TA 4-9-1	0.92958	2
TA 4-18-1	0.99998	2
TA 5-1-1	0.72088	2
TA 5-2-1	0.82501	1
TA 5-5-1	0.69377	2
TA 6-1-1	0.68261	1
TA 6-1-2	0.84324	2
TA 6-1-4	0.78714	1
TA 6-2-1	0.82329	2
TA 6-3-1	0.91832	2
TA 7-1-1	0.52113	2
TA 7-2-1	0.86321	1

TABLE 16. Results of MDISC 15.

10 Variables Generalized Mahalanobis $D^2 = 262.92083$

$$\begin{aligned} DF_1 = {} & 0.41136(Pb) - 0.11160(Zn) + 0.07808(Na) + 0.41261(Li) \\ & - 0.21821(Ni) + 0.00867(K) + 1.08108(Cu) + 0.04722(Sr) \\ & + 0.01824(Mn) - 0.00125(Fe) - 12.86262 \end{aligned}$$

$$\begin{aligned} DF_2 = {} & - 0.13432(Pb) + 0.93134(Zn) + 0.03398(Na) - 0.14419(Li) \\ & + 1.18386(Ni) - 0.02097(K) + 3.58503(Cu) + 0.16548(Sr) \\ & - 0.02496(Mn) + 0.00675(Fe) - 24.63765 \end{aligned}$$

Group 1	Stratigraphic Dolomites	17 Samples
Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 5-3-1	0.99901	1
CB 1	0.99999	1
CB 2	0.99999	1
CB 3	1.00000	1
CB 4	1.00000	1
CB 5	0.99997	1
CB 6	1.00000	1
CB-H-77-1	1.00000	1
CB-H-77-2	0.99993	1
WSC-S-1	0.99997	1
WSC-S-2	0.99998	1
OCC 1	0.99999	1
OCC 2	1.00000	1
OCC 3	0.99957	1
AA 2-2-1	0.99998	1
AA 2-10-1	1.00000	1
AA 2-20-1	1.00000	1
Group 2	Tectonic Dolomites	22 Samples
TA 1-2-2	1.00000	2
TA 1-3-1	1.00000	2
TA 1-4-2	1.00000	2
TA 1-8-1	0.99999	2
TA 2-1-2	0.99990	2
TA 2-2-2	1.00000	2
TA 2-4-1	0.99999	2
TA 2-5-2	0.99998	2

TABLE 16. (Cont'd)

Group 2 (Cont'd)

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 3-4-1	0.99999	2
TA 3-5-1	1.00000	2
TA 4-1-3	1.00000	2
TA 4-2-2	0.96290	2
TA 4-3-1	0.99998	2
TA 4-5-1	0.99995	2
TA 4-6-1	0.99999	2
TA 4-8-1	0.99998	2
TA 4-9-1	0.99978	2
TA 4-18-1	1.00000	2
TA 5-1-1	0.99999	2
TA 6-1-2	0.99130	2
TA 6-2-1	0.99995	2
TA 6-3-1	0.99998	2

TABLE 17. Results of MDISC 16.

4 Variables Generalized Mahalanobis $D^2 = 123.40965$

$$DF_1 = 0.08139(Na) + 0.22444(Li) - 0.09836(Ni) + 1.18730(Cu) - 10.97576$$

$$DF_2 = 0.05677(Na) + 0.46757(Li) + 0.62303(Ni) + 2.66338(Cu) - 17.17649$$

Group 1 Stratigraphic Dolomites 17 Samples

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 5-3-1	0.93954	1
CB 1	0.99702	1
CB 2	0.99555	1
CB 3	0.99956	1
CB 4	0.99979	1
CB 5	0.99746	1
CB 6	0.99962	1
CB-H-77-1	0.99945	1
CB-H-77-2	0.99596	1
WSC-S-1	0.99915	1
WSC-S-2	0.99974	1
OCC 1	0.99891	1
OCC 2	0.99981	1
OCC 3	0.98707	1
AA 2-2-1	0.99739	1
AA 2-10-1	0.98610	1
AA 2-20-1	0.99906	1
Group 2	Tectonic Dolomites	22 Samples
TA 1-2-2	0.99998	2
TA 1-3-1	0.99941	2
TA 1-4-2	0.99872	2
TA 1-8-1	0.99997	2
TA 2-1-2	0.99771	2
TA 2-2-2	0.99999	2
TA 2-4-1	0.99786	2
TA 2-5-2	0.99987	2
TA 3-4-1	0.61310	2
TA 3-5-1	0.97740	2
TA 4-1-3	0.99995	2

TABLE 17. (Cont'd)

Group 2 (Cont'd)

Sample	Probability Associated with Largest Discriminant Function	Largest Function No.
TA 4-2-2	0.93350	2
TA 4-3-1	0.99236	2
TA 4-5-1	0.99784	2
TA 4-6-1	0.99796	2
TA 4-8-1	0.99944	2
TA 4-9-1	0.98630	2
TA 4-18-1	1.00000	2
TA 5-1-1	0.52424	2
TA 6-1-2	0.92877	2
TA 6-2-1	0.65237	2
TA 6-3-1	0.94765	2

Table 18. Listing of Discriminant Identification Program - DSCID.

```
*NAME DSCID

C                       *****************************************
C                       *  PROGRAM TO CALCULATE DISCRIMINANT    *
C                       *  FUNCTIONS USING DISCRIMINANT COEF-   *
C                       *  FICIENTS, SELECT THE LARGEST         *
C                       *  FUNCTION, AND COMPUTE ASSOCIATED     *
C                       *  PROBABILITIES FOR ALL FUNCTIONS.     *
C                       *  USES AS INPUT THE DATA AND OUTUT     *
C                       *  FROM IBM DISCRIMINANT ANALYSIS       *
C                       *****************************************


C    -DIMENSIONED FOR 100 OBSERVATIONS, 20 GROUPS, 25 VARIABLES
      DIMENSION DC(20,25),C(20),OBSVN(100,25),DF(20,100),NRP(100),DFUNC(
     1100),PL(100),NPRG(6)
C     -READ THE PROGRAM I.D., NO. OF OBSERVATIONS, NO. VARIABLES, AND NO. OF
C     -GROUPS.
      READ (2,101)  (NPRG(L),L=1,6),M,N,K
C     -READ THE GROUP DISCRIMINANT COEFFICIENTS, ONE SET FOR EACH GROUP
C     -THE CORRECTION CONSTANT IS READ FIRST, ONE FOR EACH GROUP
      DO 1  I=1,K
      READ (2,102)  C(I),(DC(I,J),J=1,N)
1     CONTINUE
C     -READ THE INPUT DATA
      DO 5  J=1,M
      READ (2,103)  (OBSVN(J,I),I=1,N)
5     CONTINUE
C     -CALCULATE THE DISCRIMINANT FUNCTION, ONE FOR EACH GROUP PER OBSERVATION
      DO 15  L=1,K
      DO 2  I=1,M
2     DF(L,I)=0
15    CONTINUE
      DO 17  I=1,M
      DO 4  L=1,K
      DO 3  J=1,N
3     DF(L,I)=DC(L,J)*OBSVN(I,J)+DF(L,I)
4     DF(L,I)=DF(L,I)+C(L)
17    CONTINUE
C     -CALCULATE THE LARGEST DISCRIMINANT FUNCTION FOR EACH OBSERVATION
      DO 30  I=1,M
      L=K-1
      SUM=DF(1,I)
      NRP(I)=1
      DO 20  J=1,L
      IF (SUM-DF(J+1,I))  10,20,20
10    SUM=DF(J+1,I)
      NRP(I)=J+1
20    CONTINUE
30    DFUNC(I)=SUM
C     -CALCULATE THE PROBABILITY ASSOCIATED WITH THE LARGEST DISCRIMINANT
C     -FUCTION FOR EACH OBSERVATION
      DO 60  I=1,M
      PG=0.0
      DO 50  J=1,K
50    PG=PG+EXP(DF(J,I)-DFUNC(I))
60    PL(I)=1/PG
      WRITE (5,104) NPRG
      DO 70  I=1,M
70    WRITE (5,105) I,NRP(I),DFUNC(I),PL(I)
      CALL EXIT
101   FORMAT (6A1,I3,2I2)
102   FORMAT (8F10.5/3F10.5)
103   FORMAT (10F6.0)
104   FORMAT  (1H116X,14HPROGRAM I.D. -4X,6A1/////19X,20HGROUP NO. OF LA
     .RGEST8X,20HLARGEST DISCRIMINANT9X,27HPROBABILITY ASSOCIATED WITH/1
     .2H OBSERVATION6X,21HDISCRIMINANT FUNCTION6X,24HFUNCTION FOR OBSERV
     .ATION6X,29HLARGEST DISCRIMINANT FUNCTION/12H -----------6X,21H----
     .-----------------6X,24H------------------------6X,29H-------------
     .----------------/)
105   FORMAT (5X,I3,20X,I1,23X,F10.5,24X,F7.5)
      END
```

TABLE 19. Results of DSCID 1.

Sample		Group No. of Largest Discriminant Function	Largest Discriminant Function for Observation	Probability Associated with Largest Discriminant Function
TA	1-5-3	3	29.63464	0.99999
	1-5-5	1	24.50050	0.58496
	3-1-1	1	13.84820	0.94546
	3-2-1	2	15.05999	0.99426
	3-6-1	2	13.29618	0.94456
	4-1-1	1	31.02982	0.99981
	4-2-1	1	14.75912	0.55672
	4-7-2	2	22.37304	0.99774
	4-7-3	2	24.06616	0.99705
	4-10-1	2	22.29688	0.99973
	4-10-1A	2	18.65541	0.99995
	4-11-1	2	13.36298	0.94933
	4-12-1	2	16.69931	0.99692
	4-13-1	2	24.65422	0.99150
	4-14-1	2	18.02206	0.93174
	4-15-1	1	11.05817	0.87923
	4-16-1	2	20.38750	0.99993
	4-17-1	2	23.45535	0.99995
	4-19-1	2	12.54241	0.51223
	4-20-1	2	17.24710	0.99069
	4-22-2	1	17.73974	0.77376
	4-24-2	2	12.41556	0.92699
	4-24-3	2	22.94655	0.98433
AA	2-17-1	1	8.26748	0.93039

TABLE 20. Results of DSCID 2.

Sample		Group No. of Largest Discriminant Function	Largest Discriminant Function for Observation	Probability Associated with Largest Discriminant Function
TA	1-5-3	2	15.36573	0.96141
	1-5-5	2	23.76629	0.50958
	3-1-1	1	12.55875	0.90039
	3-2-1	2	14.93047	0.94129
	3-6-1	2	12.68896	0.80365
	4-1-1	1	27.87002	0.99888
	4-2-1	2	13.89008	0.46720
	4-7-2	2	21.78302	0.97368
	4-7-3	2	23.19935	0.99260
	4-10-1	2	21.99761	0.98634
	4-10-1A	2	18.67880	0.99922
	4-11-1	2	13.16452	0.84908
	4-12-1	2	16.24126	0.79912
	4-13-1	2	23.77079	0.94548
	4-14-1	2	17.25510	0.87723
	4-15-1	1	10.34347	0.85554
	4-16-1	2	20.24792	0.99269
	4-17-1	2	22.98442	0.99779
	4-19-1	3	14.71020	0.90710
	4-20-1	2	16.77905	0.56232
	4-22-2	3	17.05227	0.68925
	4-24-2	2	11.92743	0.79712
	4-24-3	2	22.22940	0.90992
AA	2-17-1	1	7.19659	0.77840

TABLE 21. Results of DSCID 3.

Sample		Group No. of Largest Discriminant Function	Largest Discriminant Function for Observation	Probability Associated with Largest Discriminant Function
TA	1-5-3	2	20.82790	0.99947
	1-5-5	1	29.81961	0.87650
	3-1-1	1	13.24166	0.85250
	3-2-1	2	14.95852	0.97993
	3-6-1	2	12.80072	0.98667
	4-1-1	1	34.66374	0.99998
	4-2-1	1	18.93349	0.82549
	4-7-2	2	22.79695	0.99109
	4-7-3	2	20.16396	0.99058
	4-10-1	2	21.26808	0.99821
	4-10-1A	2	13.43210	0.99995
	4-11-1	2	13.94652	0.91538
	4-12-1	2	16.83871	0.99255
	4-13-1	2	23.34816	0.96415
	4-14-1	2	17.18412	0.80329
	4-15-1	1	9.16149	0.63179
	4-16-1	2	16.41468	0.99992
	4-17-1	2	18.77547	0.99987
	4-19-1	1	17.78798	0.81550
	4-20-1	2	19.85272	0.90501
	4-22-2	1	24.85853	0.96233
	4-24-2	2	11.44552	0.90390
	4-24-3	2	23.07980	0.98025
AA	2-17-1	1	33.98417	0.99999

TABLE 22. Results of DSCID 4.

Sample		Group No. of Largest Discriminant Function	Largest Discriminant Function for Observation	Probability Associated with Largest Discriminant Function
TA	1-5-3	2	14.04259	0.99690
	1-5-5	1	27.27125	0.84139
	3-1-1	1	11.48951	0.79641
	3-2-1	2	14.19177	0.98437
	3-6-1	2	12.12401	0.97497
	4-1-1	1	28.43012	0.99963
	4-2-1	1	17.13516	0.75449
	4-7-2	2	21.13091	0.98609
	4-7-3	2	18.08370	0.99580
	4-10-1	2	20.35016	0.99835
	4-10-1A	2	13.07419	0.99991
	4-11-1	2	13.04846	0.91425
	4-12-1	2	15.90467	0.99082
	4-13-1	2	21.35337	0.97929
	4-14-1	2	15.68833	0.89081
	4-15-1	1	7.74886	0.61482
	4-16-1	2	15.99704	0.99985
	4-17-1	2	17.40497	0.99988
	4-19-1	1	17.08543	0.80541
	4-20-1	2	18.60534	0.91218
	4-22-2	1	23.15880	0.95366
	4-24-2	2	10.70915	0.89404
	4-24-3	2	19.90019	0.95426
AA	2-17-1	1	11.82556	0.99007

TABLE 23. Results of DSCID 5.

Sample	Group No. of Largest Discriminant Function	Largest Discriminant Function for Observation	Probability Associated with Largest Discriminant Function
TA 1-5-3	2	14.18204	0.99242
1-5-5	2	23.67266	0.85537
3-1-1	2	7.25777	0.50466
3-2-1	2	14.23202	0.98691
3-6-1	2	11.90915	0.98000
4-1-1	1	15.04407	0.75683
4-2-1	2	15.79973	0.57858
4-7-2	2	19.78742	0.97743
4-7-3	2	11.20175	0.99036
4-10-1	2	19.61855	0.99765
4-10-1A	2	10.73558	0.99977
4-11-1	2	12.82007	0.94830
4-12-1	2	15.24842	0.96795
4-13-1	2	15.58895	0.94972
4-14-1	2	11.77835	0.88089
4-15-1	2	4.03250	0.60668
4-16-1	2	13.39145	0.99933
4-17-1	2	12.53720	0.99915
4-19-1	1	17.50835	0.90022
4-20-1	2	18.83004	0.79755
4-22-2	1	22.41693	0.89548
4-24-2	2	7.81103	0.75304
4-24-3	2	13.08893	0.70771
AA 2-17-1	1	11.38511	0.98242

TABLE 24. Results of DSCID 6.

Sample	Group No. of Largest Discriminant Function	Largest Discriminant Function for Observation	Probability Associated with Largest Discriminant Function
TA 1-5-3	2	85.48297	1.00000
1-5-5	1	29.52571	0.99936
3-1-1	1	11.04830	0.92515
3-2-1	2	18.98593	0.99618
3-6-1	2	27.72584	1.00000
4-1-1	1	30.00957	1.00000
4-2-1	1	21.76050	0.99998
4-7-2	2	36.90114	0.99999
4-7-3	2	23.68153	0.99986
4-10-1	2	32.70037	0.99999
4-10-1A	2	27.17950	1.00000
4-11-1	2	15.65236	0.88564
4-12-1	2	28.75552	0.99999
4-13-1	2	27.11462	0.99903
4-14-1	1	16.41362	0.85522
4-15-1	1	7.29769	0.82079
4-16-1	2	31.84767	1.00000
4-17-1	2	31.22953	1.00000
4-19-1	1	21.58375	0.99958
4-20-1	1	23.37493	0.61250
4-22-2	1	29.99217	1.00000
4-24-2	2	11.51193	0.67281
4-24-3	2	33.55741	0.99999
AA 2-17-1	1	33.30898	1.00000

TABLE 25. Results of DSCID 7.

Sample	Group No. of Largest Discriminant Function	Largest Discriminant Function for Observation	Probability Associated with Largest Discriminant Function
TA 1-5-3	2	20.31286	0.99947
1-5-5	2	29.33564	0.95522
3-1-1	1	8.33568	0.61742
3-2-1	2	19.75952	0.99899
3-6-1	2	16.78017	0.99905
4-1-1	1	18.90979	0.98878
4-2-1	1	19.31987	0.58494
4-7-2	2	26.51420	0.99509
4-7-3	2	15.81725	0.99896
4-10-1	2	27.81029	0.99995
4-10-1A	2	18.06312	0.99999
4-11-1	2	17.35317	0.98819
4-12-1	2	20.75457	0.99625
4-13-1	2	20.28625	0.99181
4-14-1	2	14.68905	0.91744
4-15-1	1	4.69484	0.55271
4-16-1	2	20.92771	0.99999
4-17-1	2	19.36978	0.99998
4-19-1	1	21.21779	0.98668
4-20-1	2	23.93849	0.82795
4-22-2	1	27.67532	0.98969
4-24-2	2	9.44613	0.62504
4-24-3	2	15.96987	0.57760
AA 2-17-1	1	13.92892	0.99975

TABLE 26. Results of DSCID 8.

Sample	Group No. of Largest Discriminant Function	Largest Discriminant Function for Observation	Probability Associated with Largest Discriminant Function
TA 5-2-1	1	21.45301	0.99998
5-5-1	1	2.68632	0.98932
6-1-1	1	14.73734	0.99998
6-1-4	1	5.30984	0.92893
7-1-1	1	19.28754	0.97036
7-2-1	1	3.74679	1.00000
1-1-1v	2	32.44882	0.99976
3-4-1v	2	24.18970	0.99999
4-1-1v	2	58.37601	1.00000
4-9-1v	2	23.39904	0.99999
4-18-1v	2	12.77529	0.99843

APPENDIX C

Table Page

Figure

TABLE 1. Values of d_n for Pb, Zn, Mn, and Fe of the 10 Variable Groupings and for All Variables of the 8 Variable Groupings.

	d_n [between Stratigraphic Dolomites (17) and Tectonic Dolomites (28)]
Pb	0.06
Zn	0.19
Mn	0.21
Fe	0.22

	d_n [between Stratigraphic Dolomites (5) and All Tectonic Dolomites(9)]
Na	0.47
K	0.69
Li	0.47
Ni	0.78
Cu	1.00
Sr	0.44
$\delta\ O^{18}$	0.78
$\delta\ C^{13}$	1.00

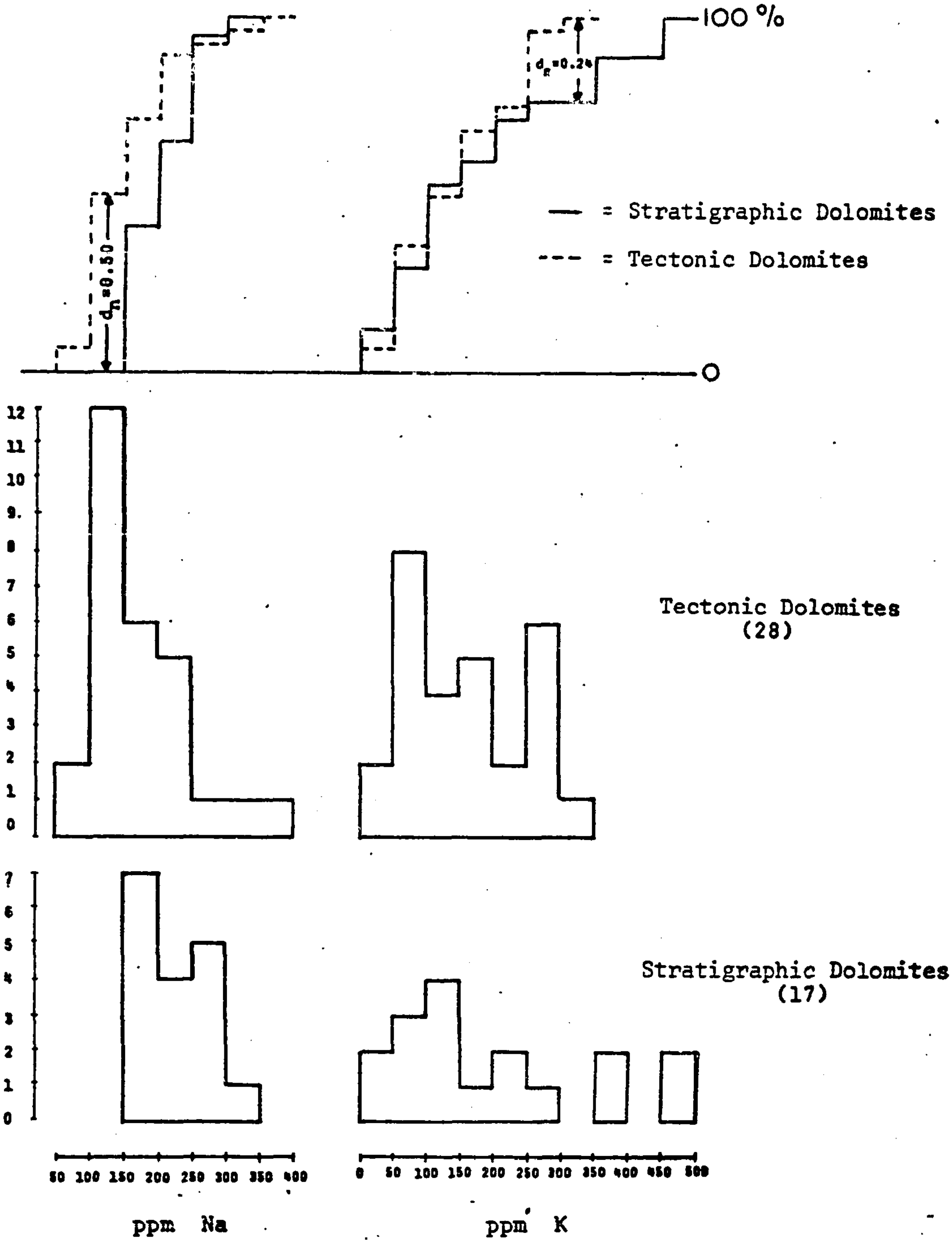


Figure 1. Frequency histograms and culmulative percentage histograms for Na and K.

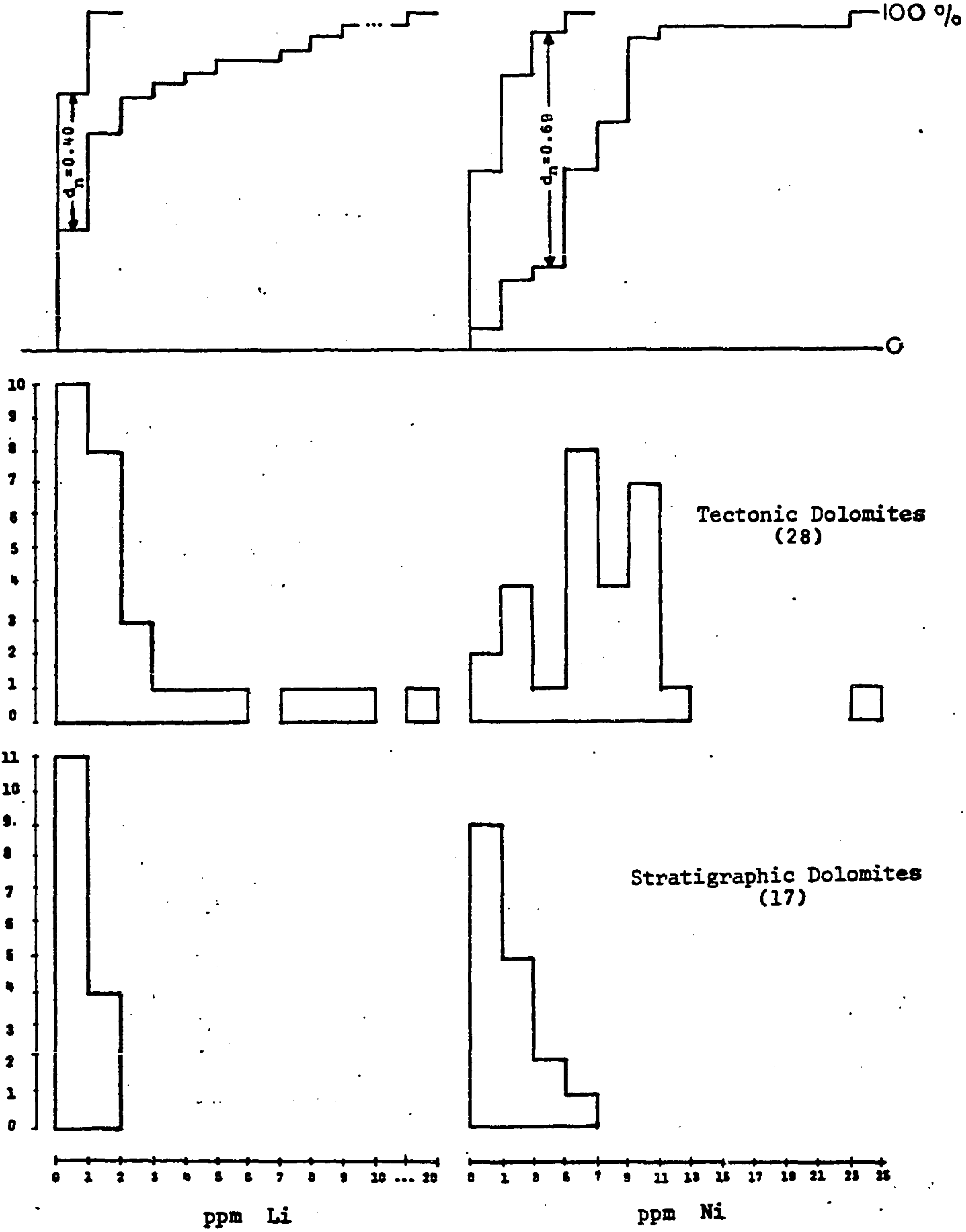


Figure 2. Frequency histograms and cumulative percentage histograms for Li and Ni.

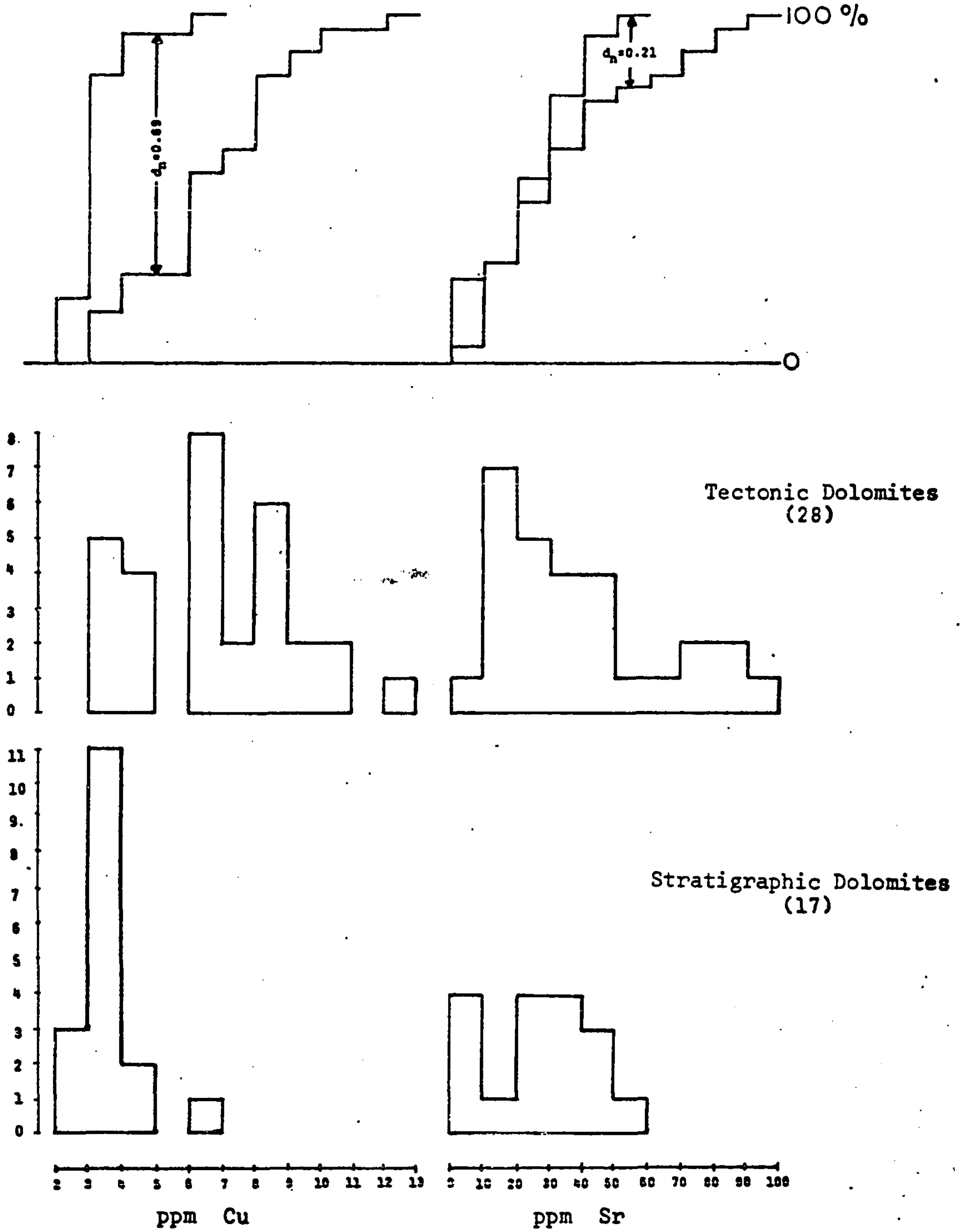


Figure 3. Frequency histograms and cumulative percentage histograms for Cu and Sr.

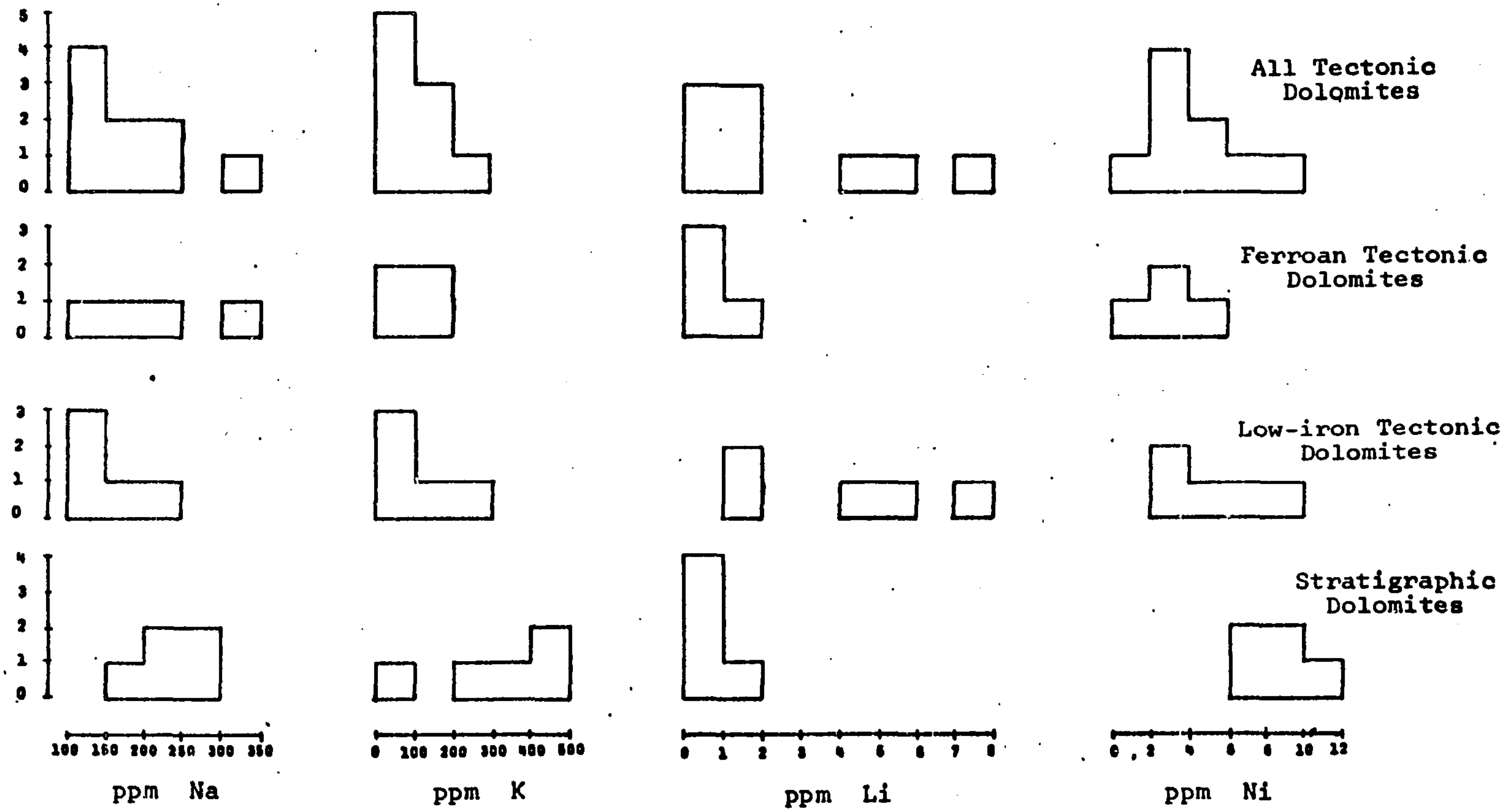


Figure 4. Frequency histograms for Na, K, Li, and Ni (8 variable groupings).

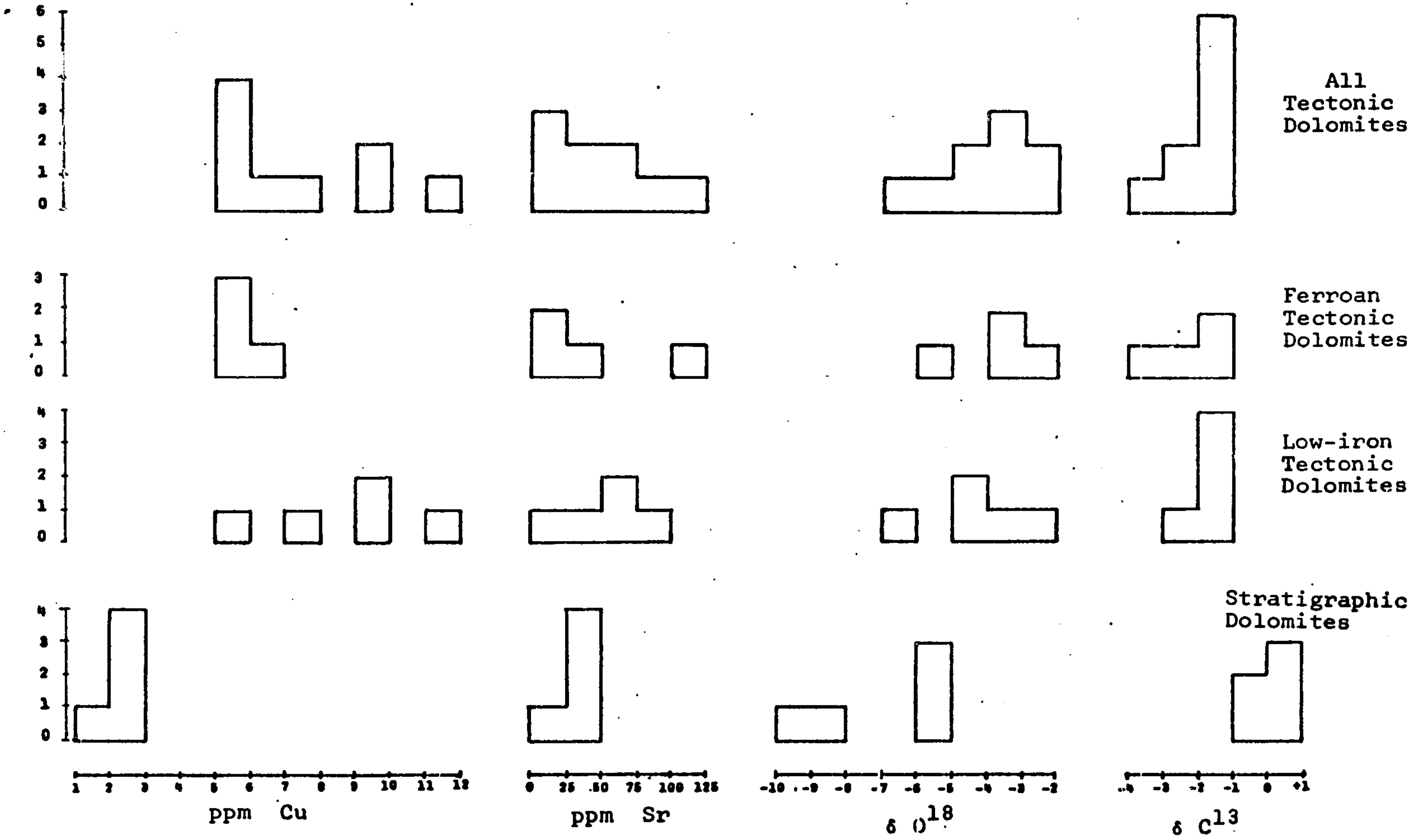


Figure 5. Frequency histograms for Cu, Sr, δ O^{18}, and δ C^{13} (8 variable groupings).

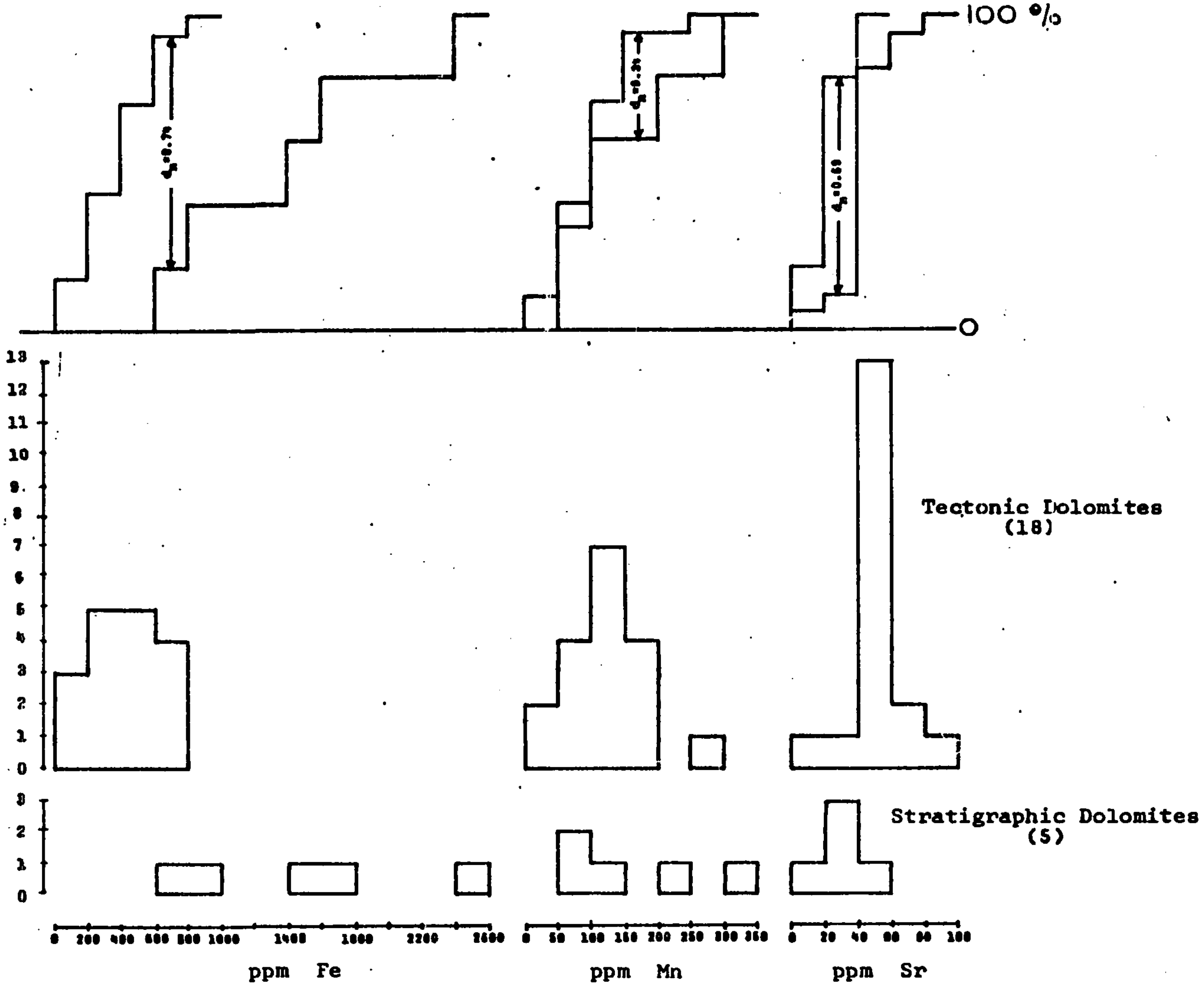


Figure 6. Frequency histograms and cumulative percentage histograms for Fe, Mn, and Sr used in MDISC 13 (5 variable groupings).

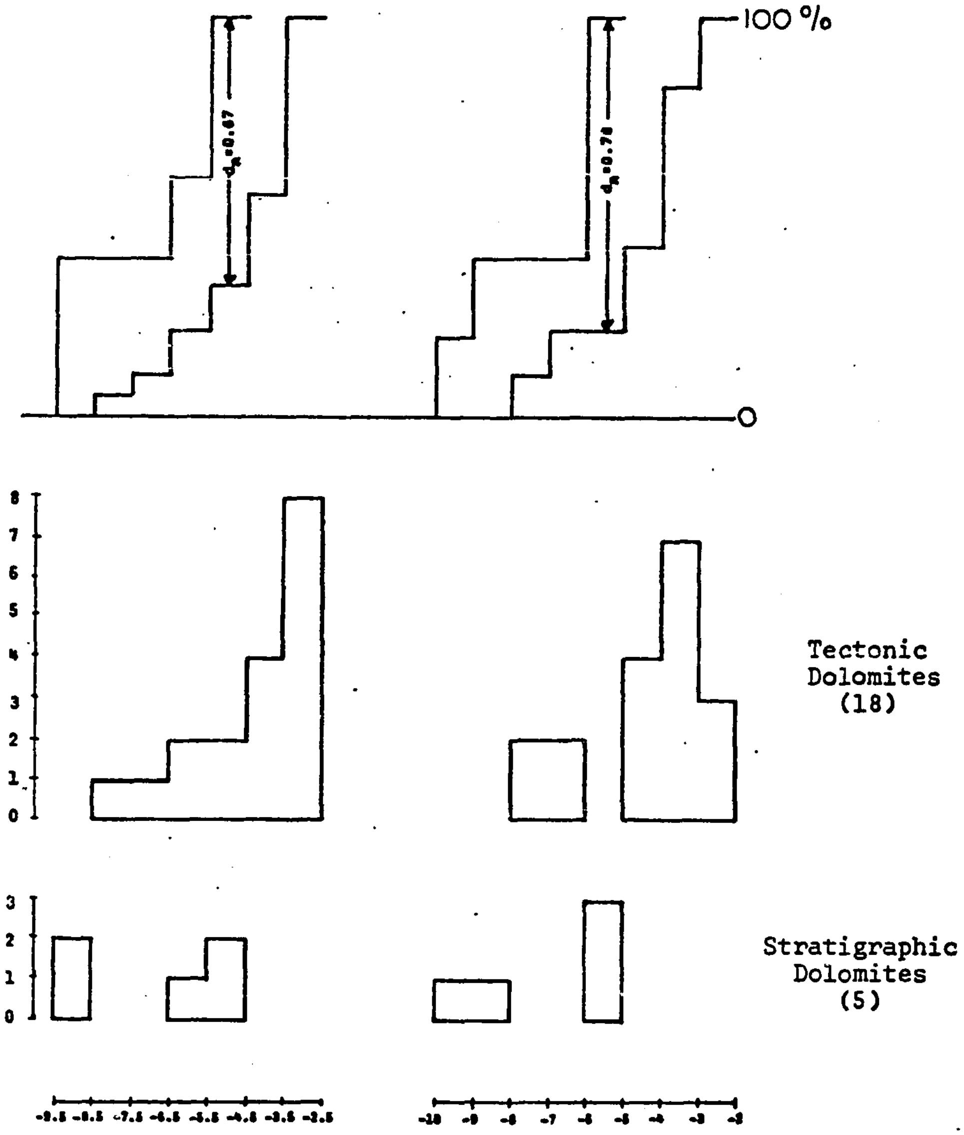


Figure 7. Variation of the value d_n due to changes in the interval along the abscissa of the frequency histogram for δO^{18} (5 variable groupings).

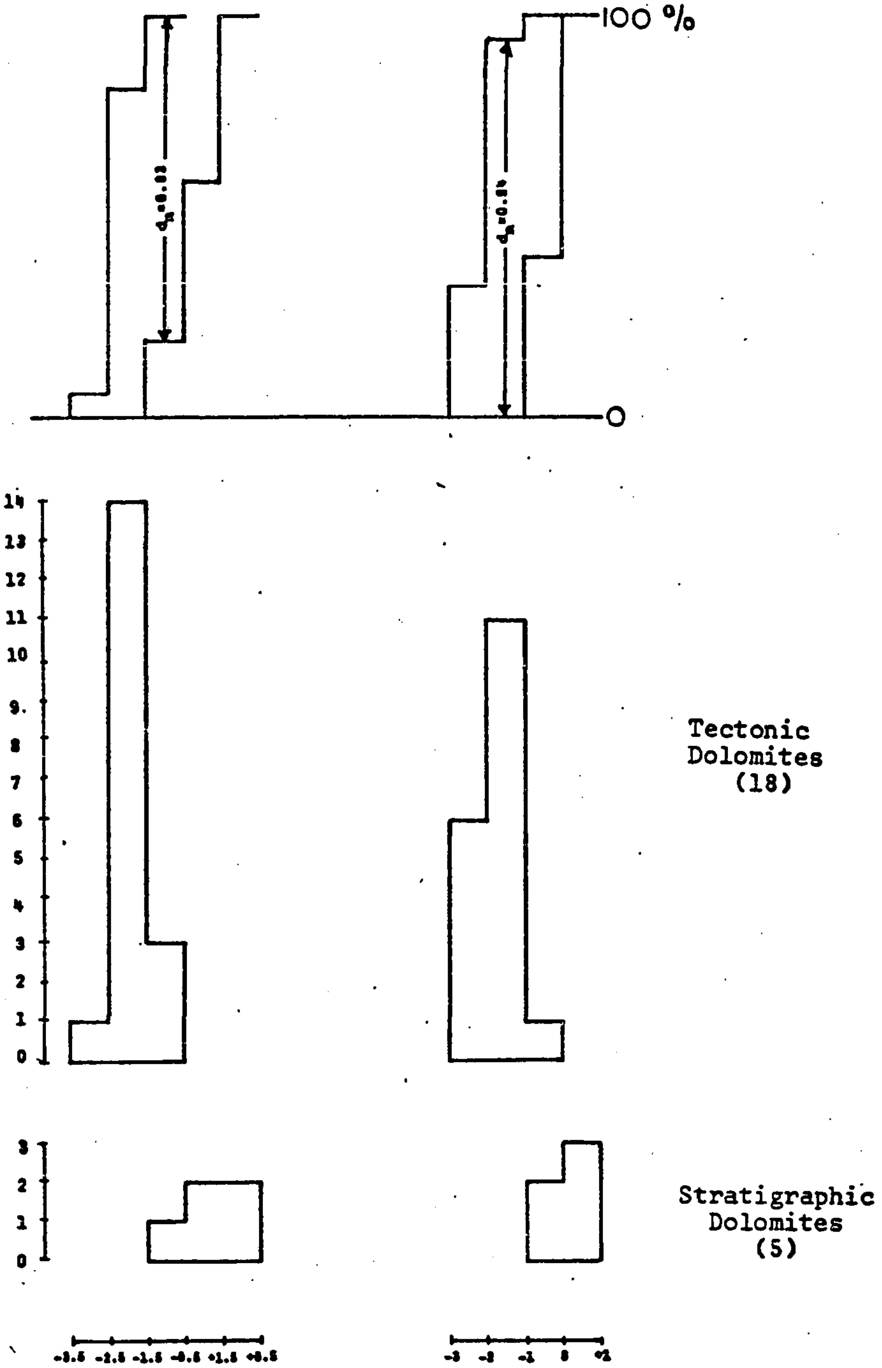
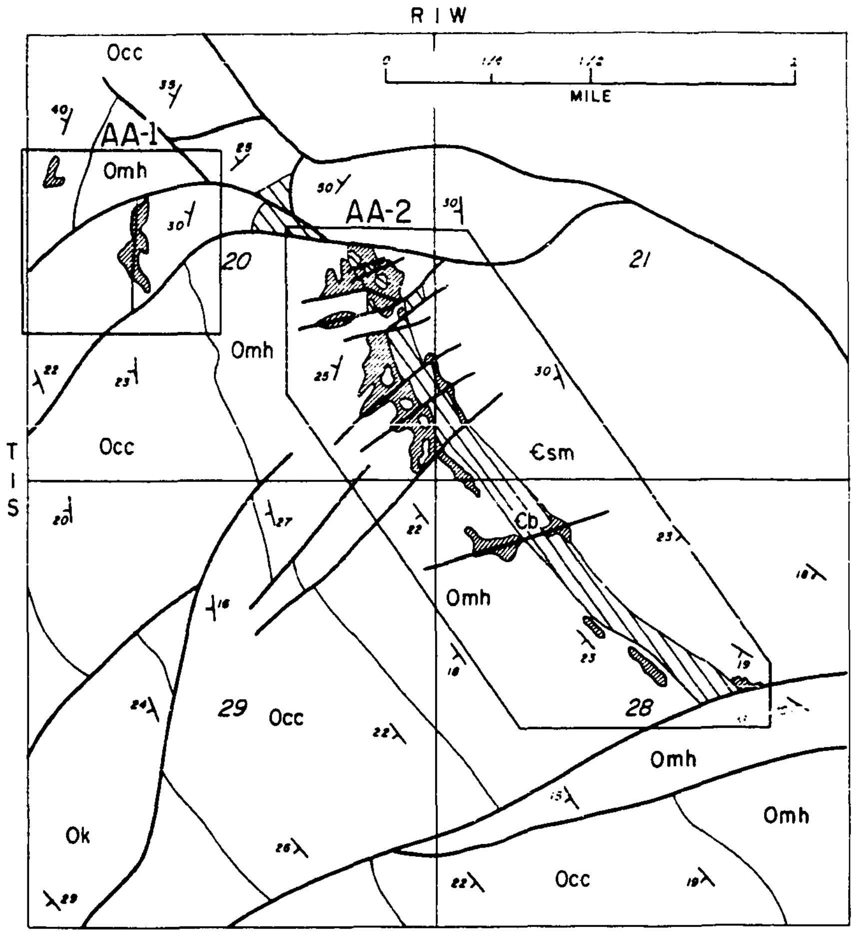
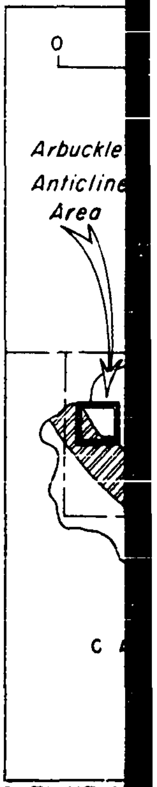


Figure 8 Variation in the value d_n due to changes in the interval along the abscissa of the frequency histogram for δC^{13} (5 variable groupings).

ARBUCKLE ANTICLINE AREA

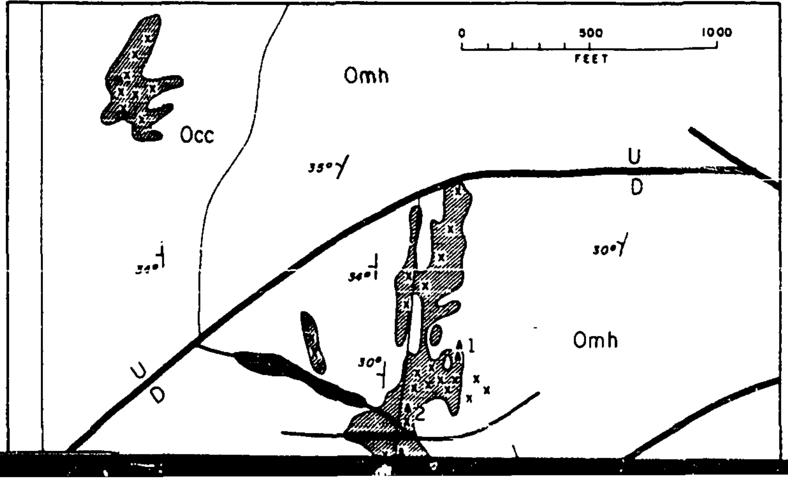


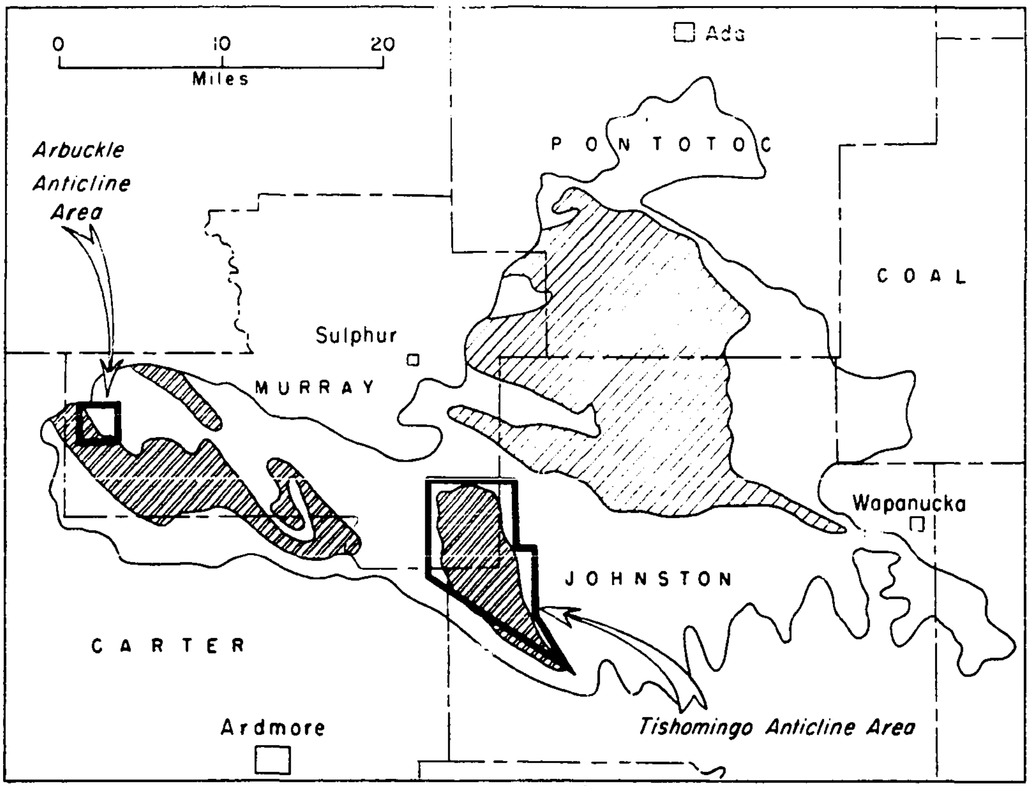


OUTLINE M

Invest
southern reg
ruling). In
dolomite (thi

AA-1

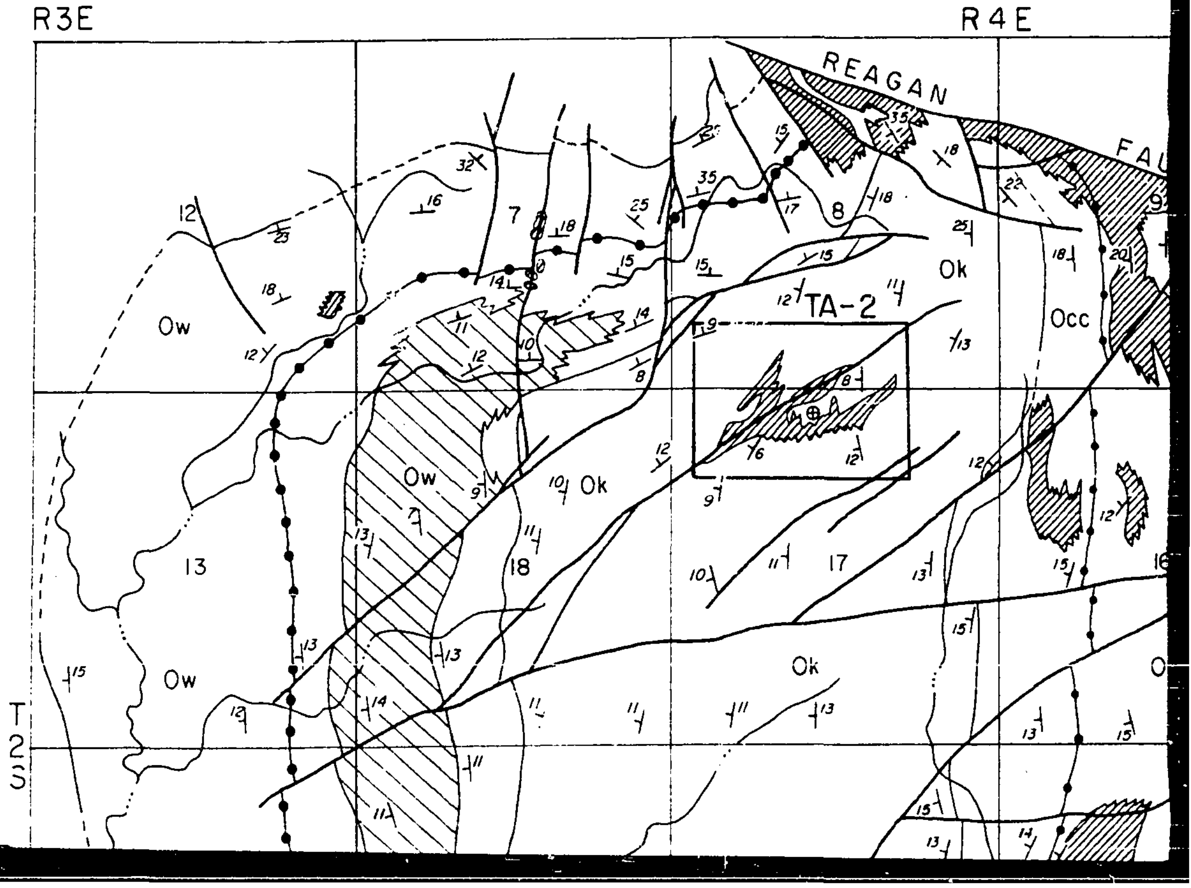


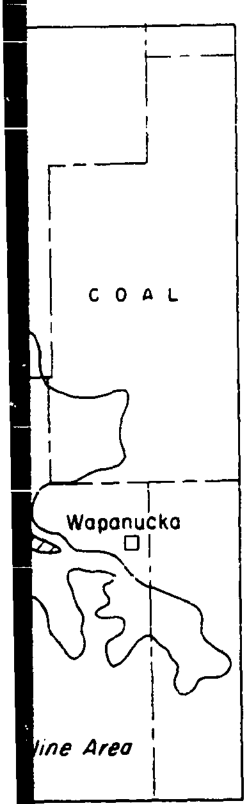


OUTLINE MAP OF ARBUCKLE MOUNTAINS SHOWING PRINCIPAL OUTCROPS OF ORDOVICIAN FORMATIONS OF ARBUCKLE GROUP

Investigated areas of tectonic dolomites are in Tishomingo anticline and Arbuckle anticline of southern region where the formations are thick and are composed chiefly of limestone (double-line ruling). In northern region the formations are thinner and are composed almost exclusively of dolomite (thin-line ruling).

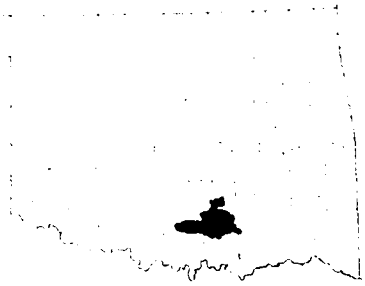
TISHOMINGO ANTICLINE AREA



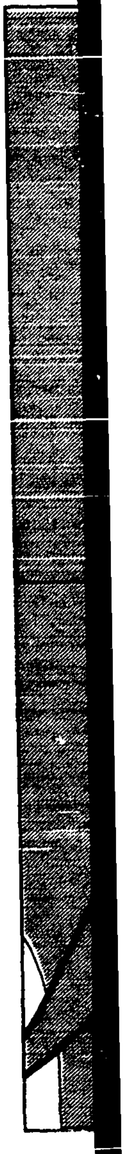


PS OF ORDOVICIAN

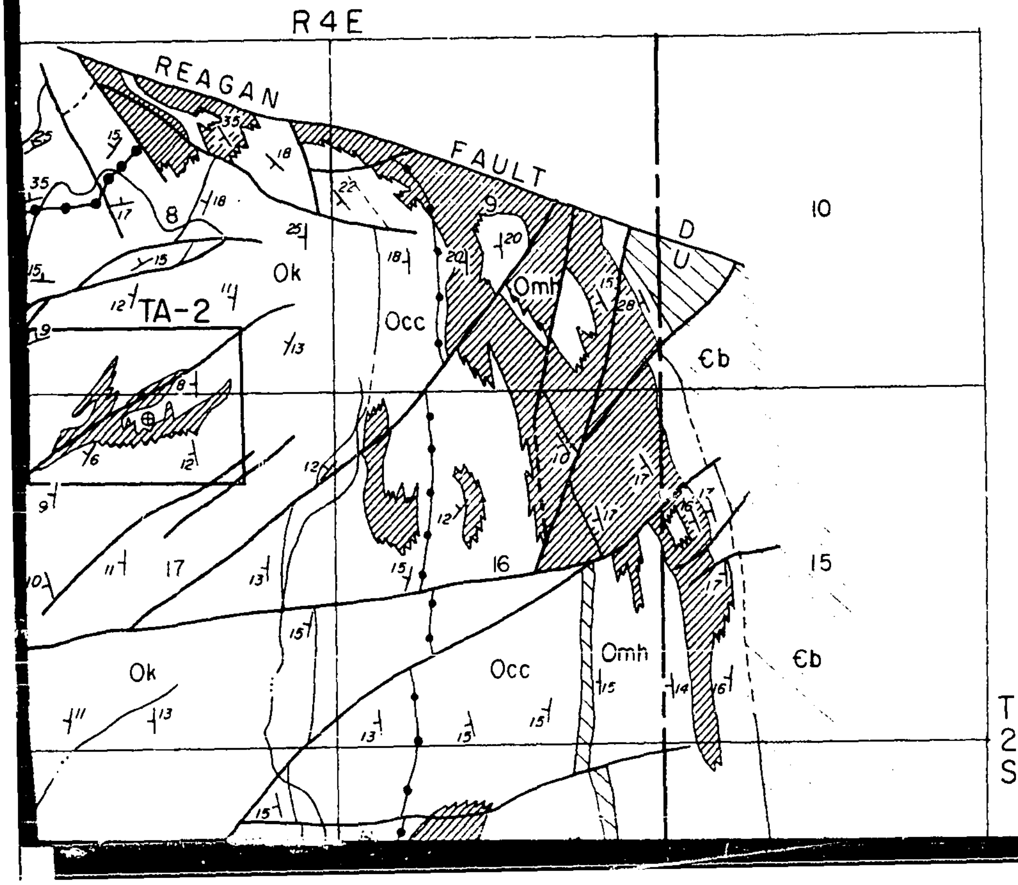
rbuckle anticline of
hestone (double-line
lmost exclusively of



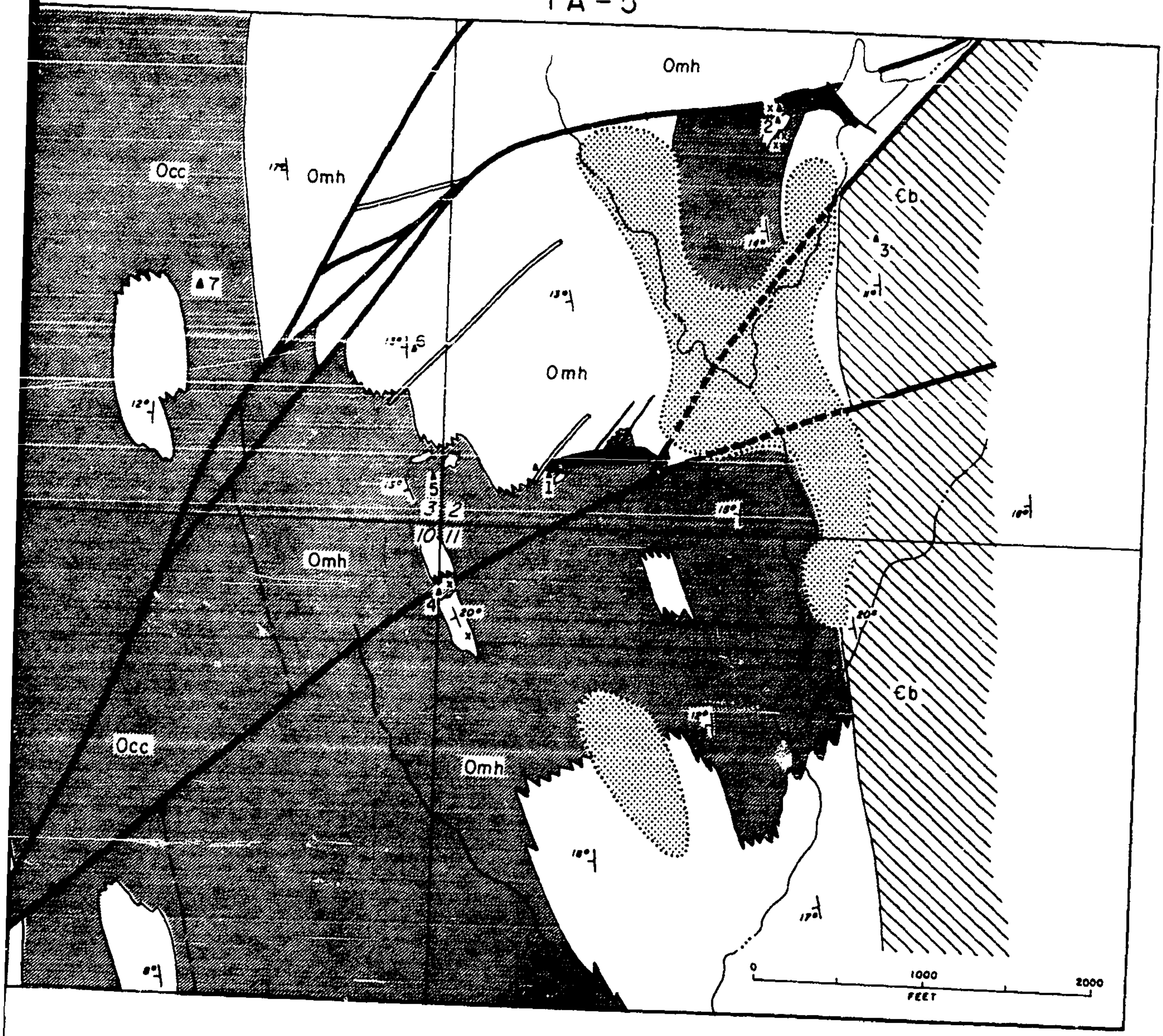
INDEX MAP OF OKLAHOMA SHOWING LOCATION
OF ARBUCKLE MOUNTAINS (SOLID)



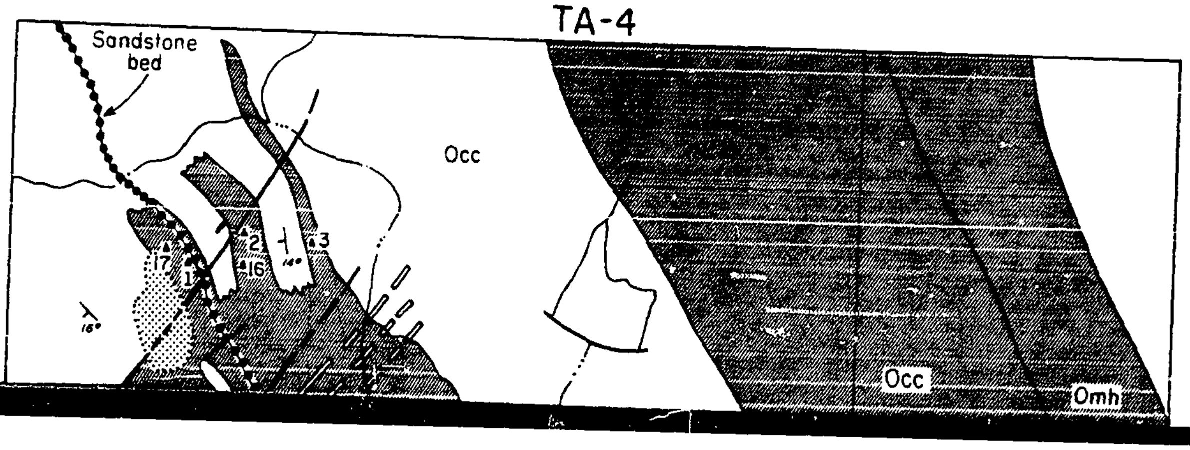
GO ANTICLINE AREA



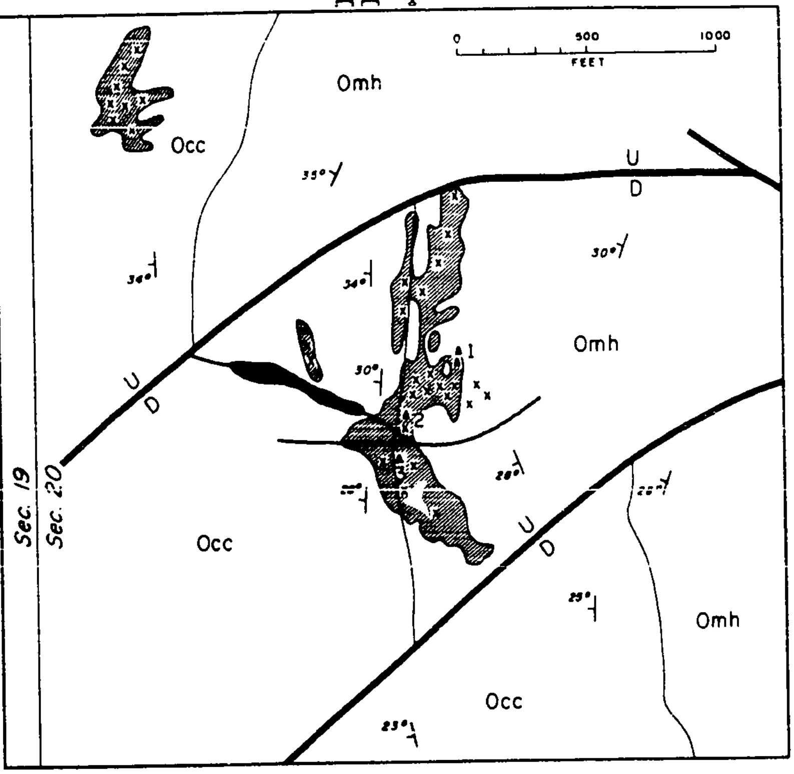
TA-5


Omh
Occ
Omh
▲7
Ꞓb
3
Omh
5
3
2
10
11
1
2
4
Omh
Ꞓb
Occ
Omh
12°
13°
15°
18°
20°
0
1000
2000
FEET

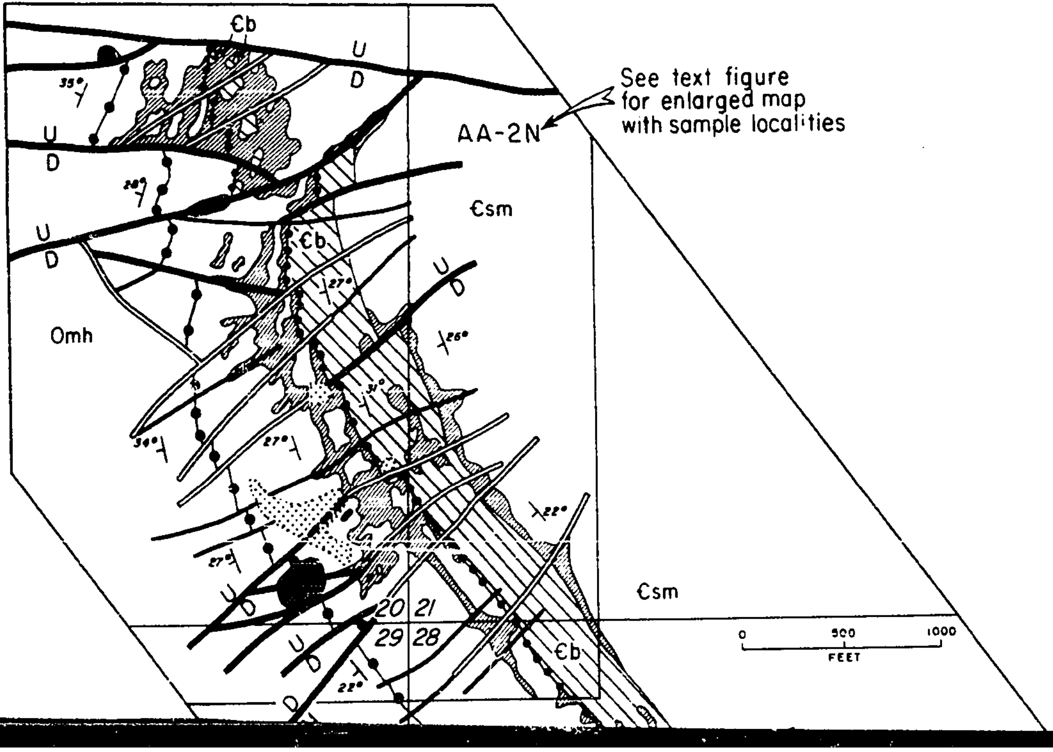
TA-4


Sandstone bed
Occ
2
3
17
1
16
14°
16°
Occ
Omh

AA-1

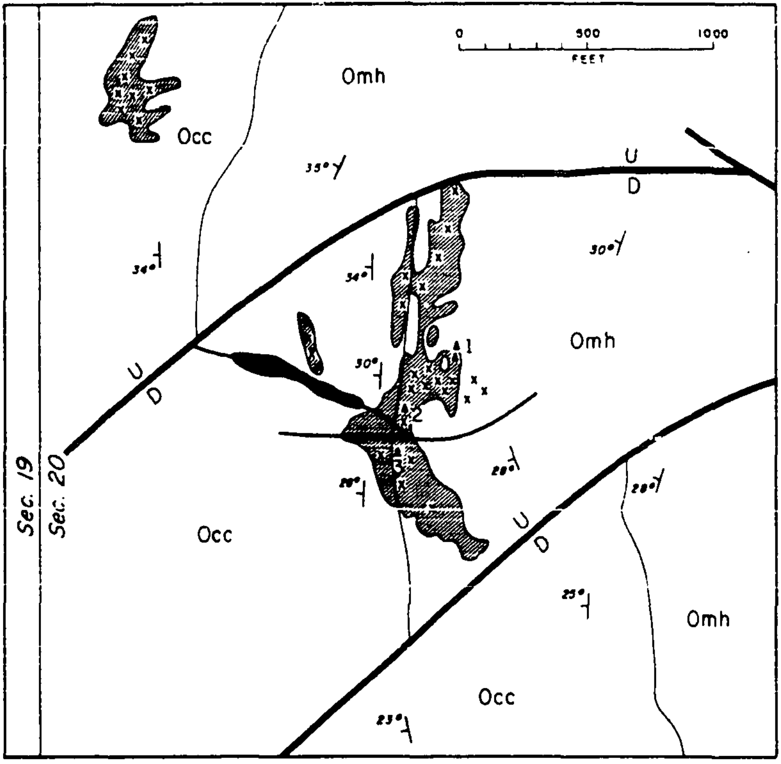


AA-2

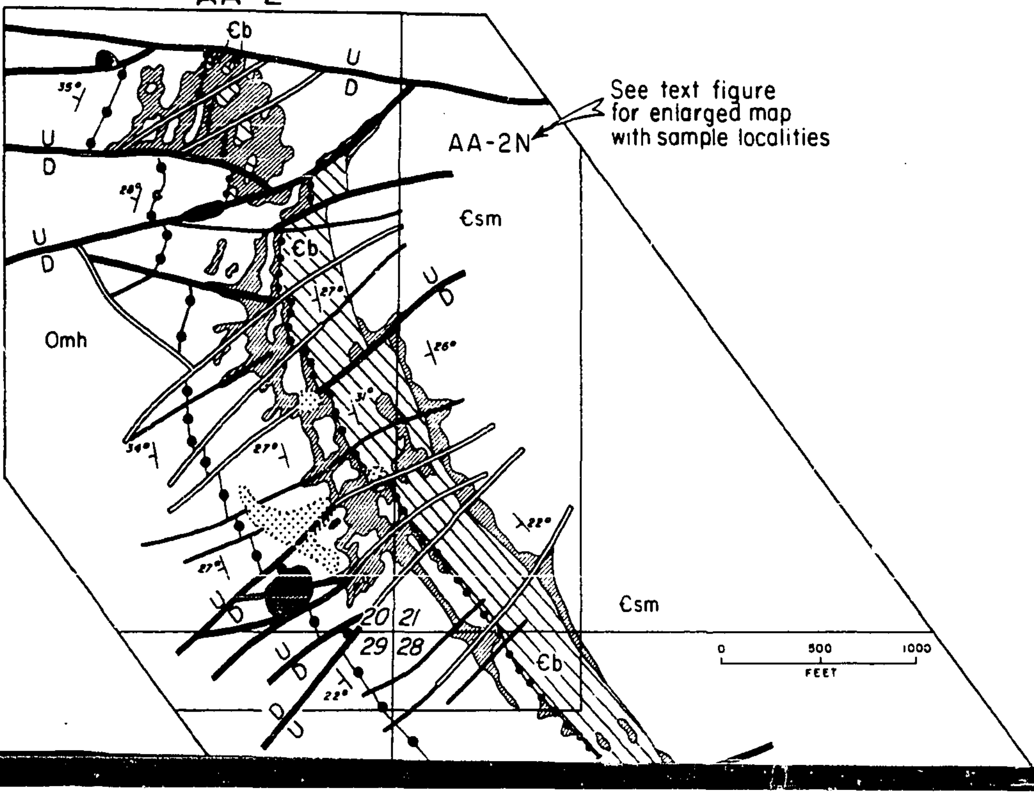


See text figure for enlarged map with sample localities AA-2N

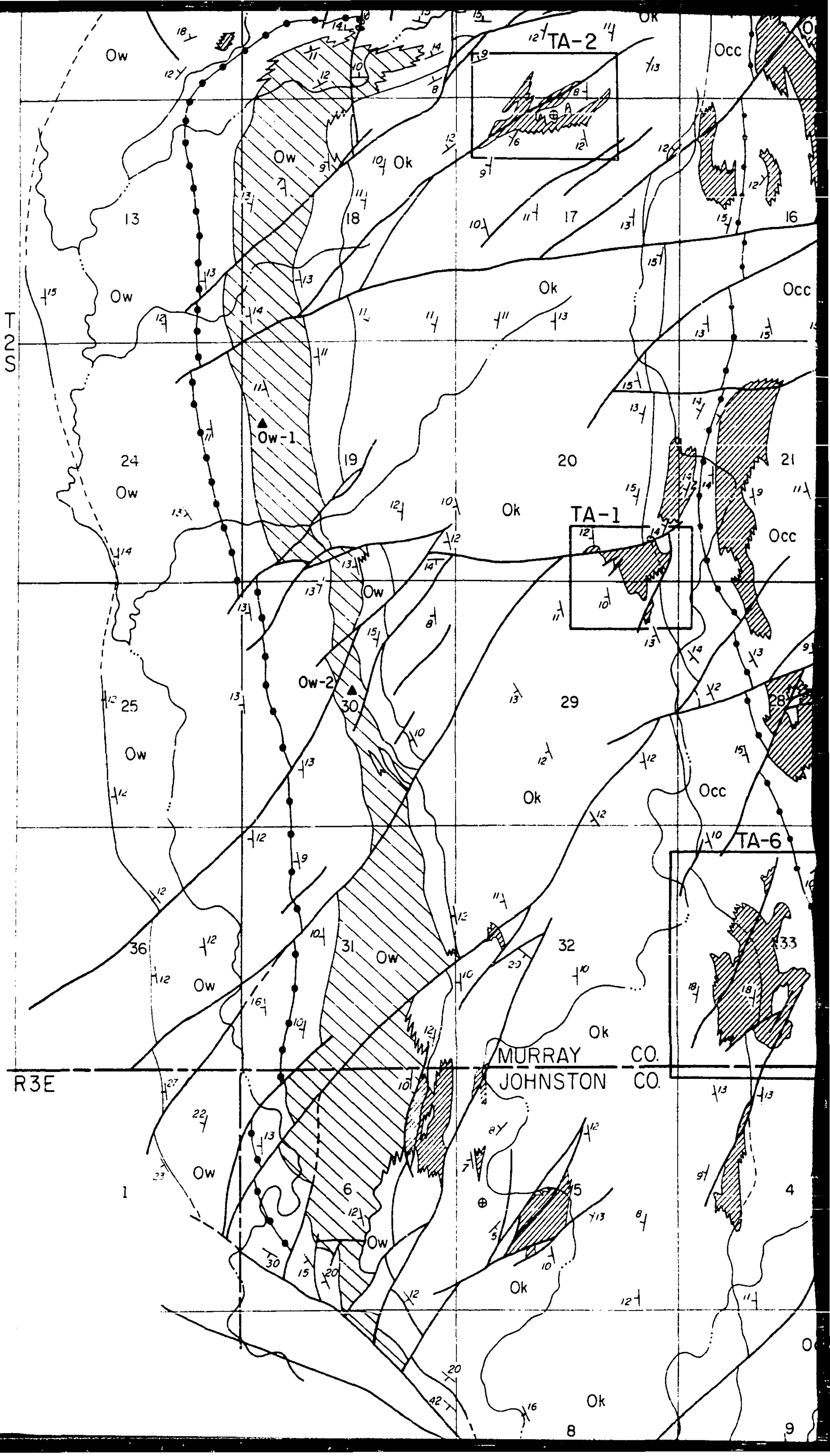
AA-1



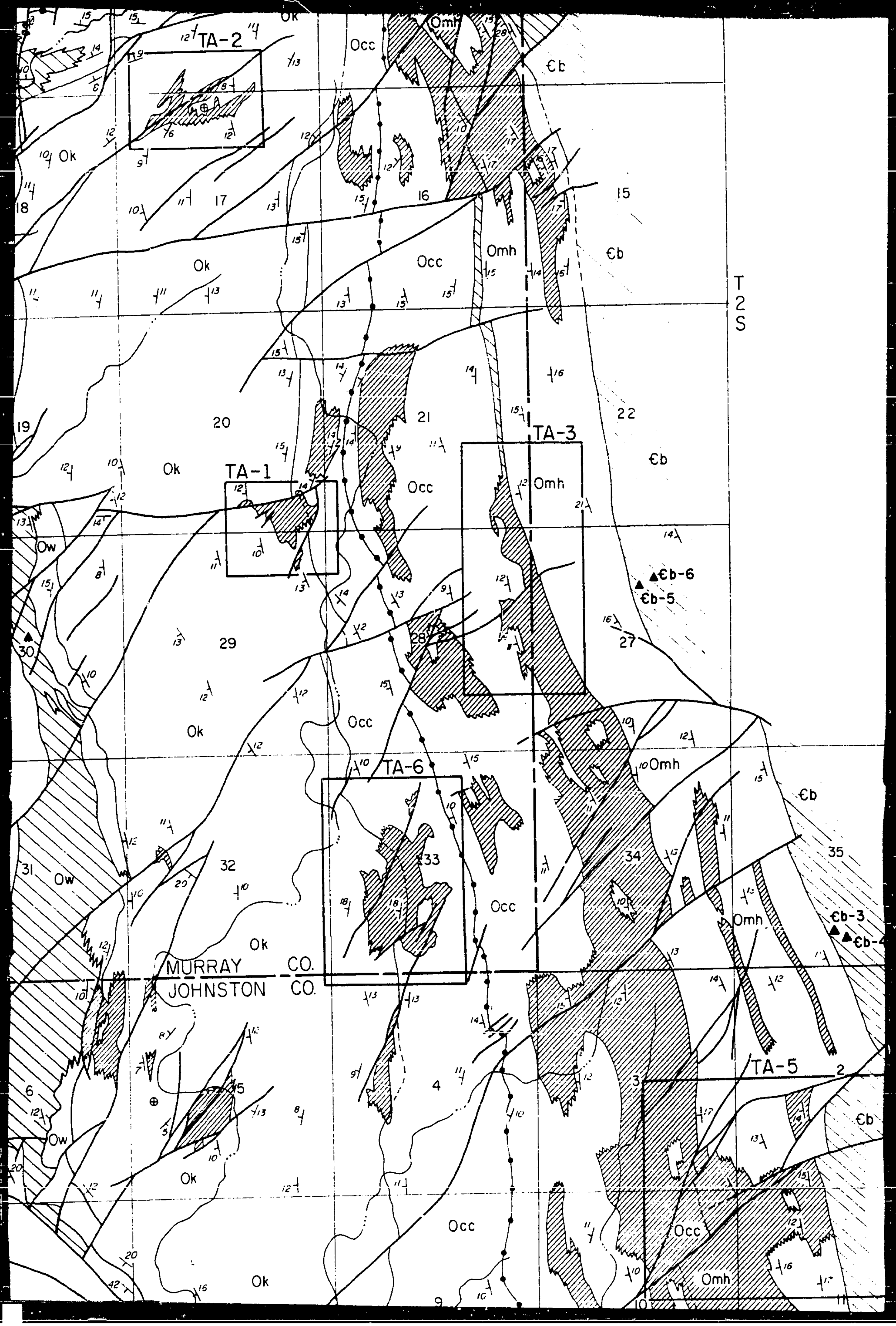
AA-2

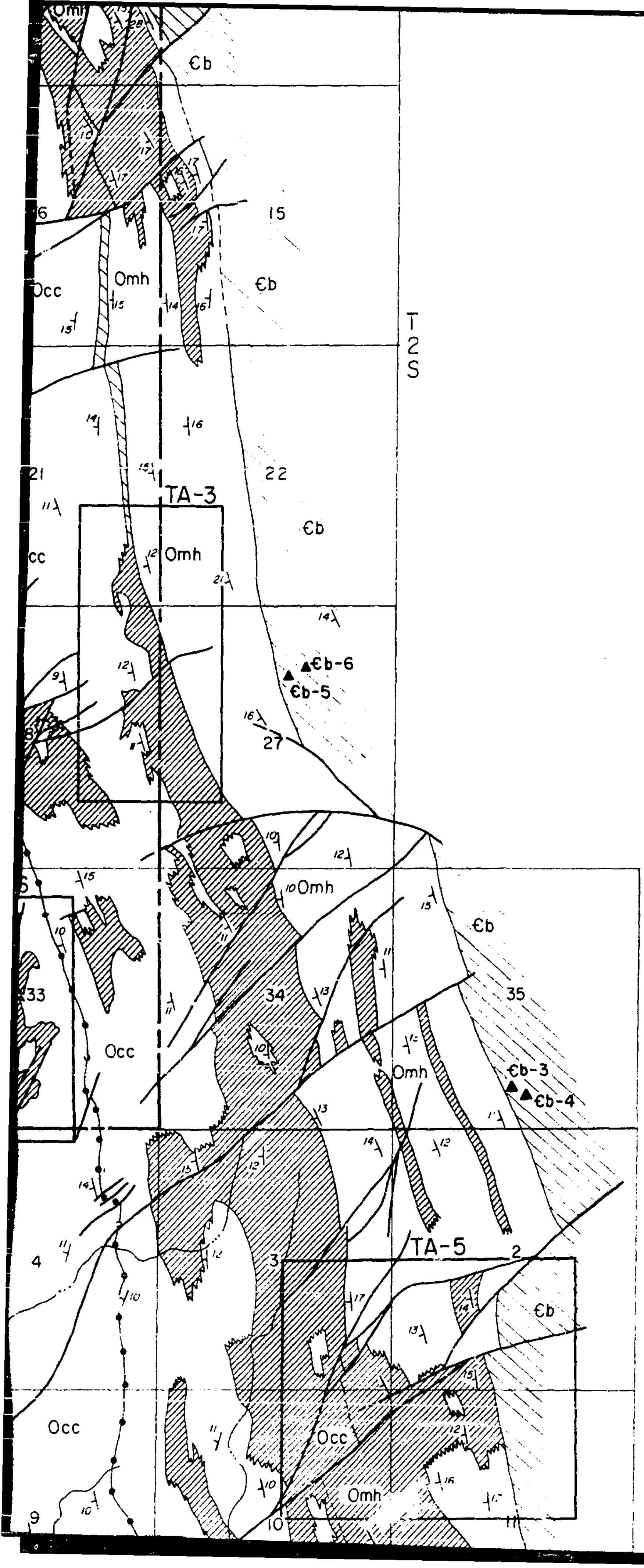


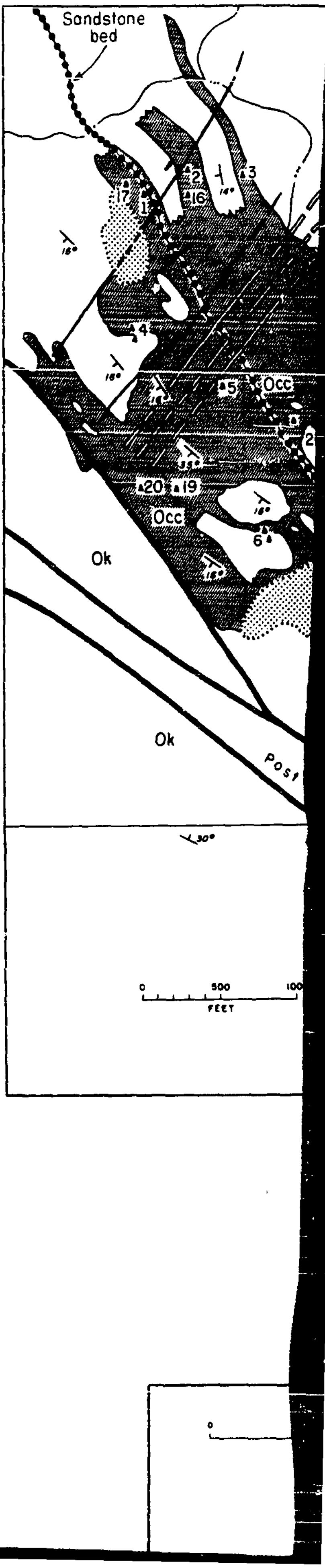
See text figure
for enlarged map
with sample localities



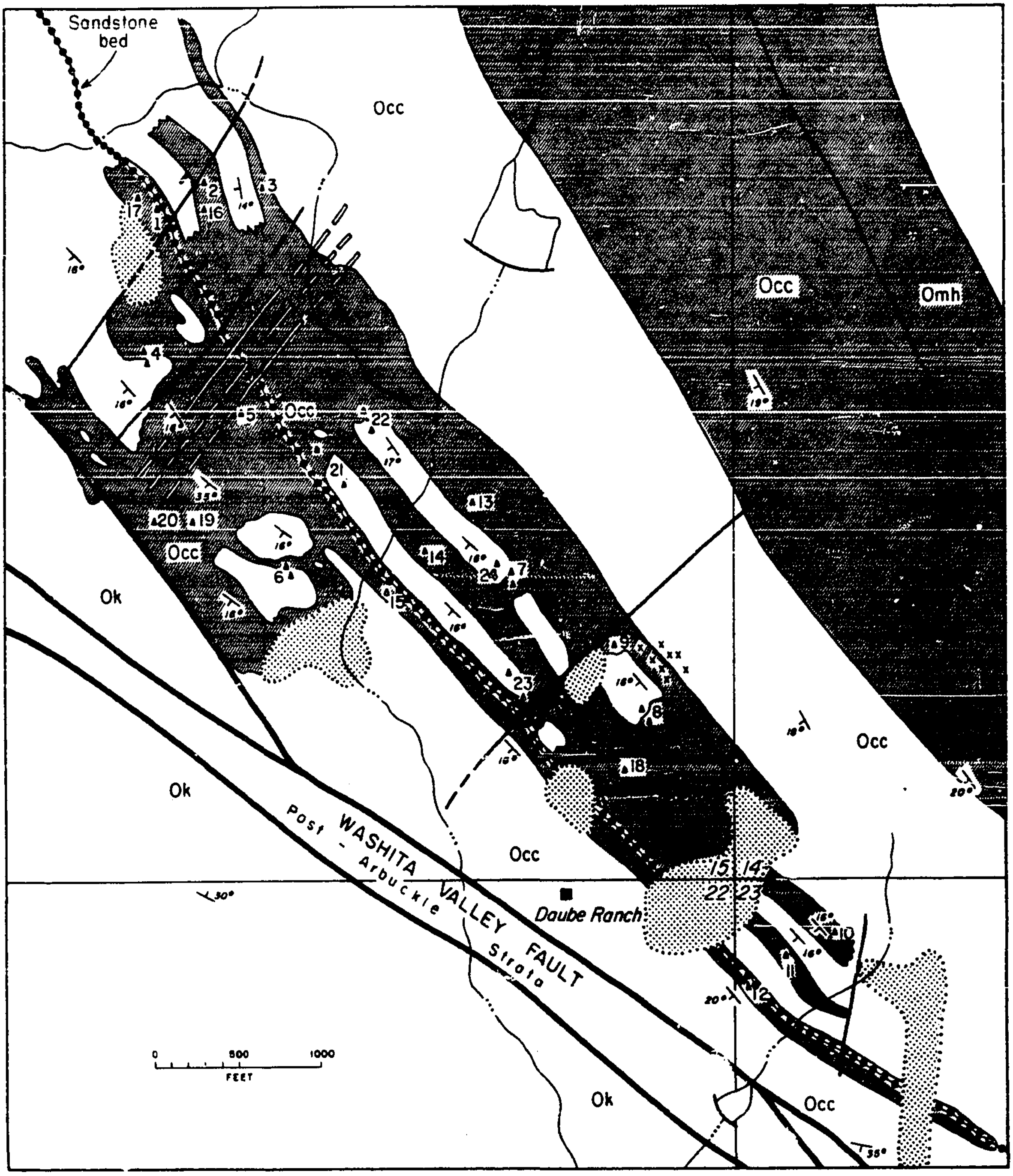
T
2
S
R3E
TA-2
TA-1
TA-6
Ow
Ok
Occ
Ow-1
Ow-2
13
16
17
18
19
20
21
24
25
28
29
30
31
32
33
36
1
4
5
6
8
9
MURRAY CO.
JOHNSTON CO.


TA-2
TA-1
TA-3
TA-6
TA-5
Ok
Occ
Omh
Ow
Єb
Єb-3
Єb-4
Єb-5
Єb-6
T
2
S
MURRAY CO.
JOHNSTON CO.
16
15
17
18
19
20
21
22
27
28
29
30
31
32
33
34
35
2
3
4
5
6
9
10
11

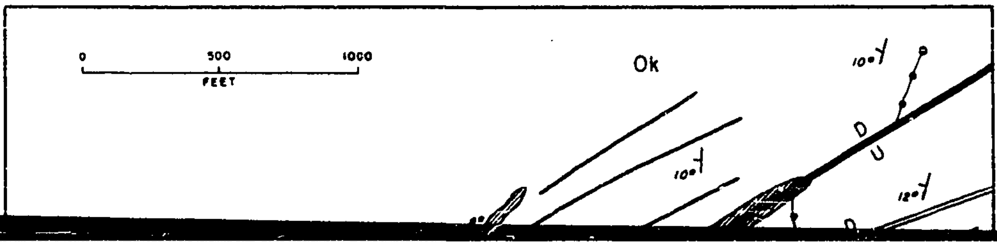

Omh
€b
16
15
Occ
Omh
€b
T 2 S
21
22
TA-3
Omh
cc
€b
€b-6
€b-5
27
S
33
Occ
34
Omh
35
€b
Omh
€b-3
€b-4
4
3
TA-5
2
€b
Occ
Occ
Omh
9
10
11

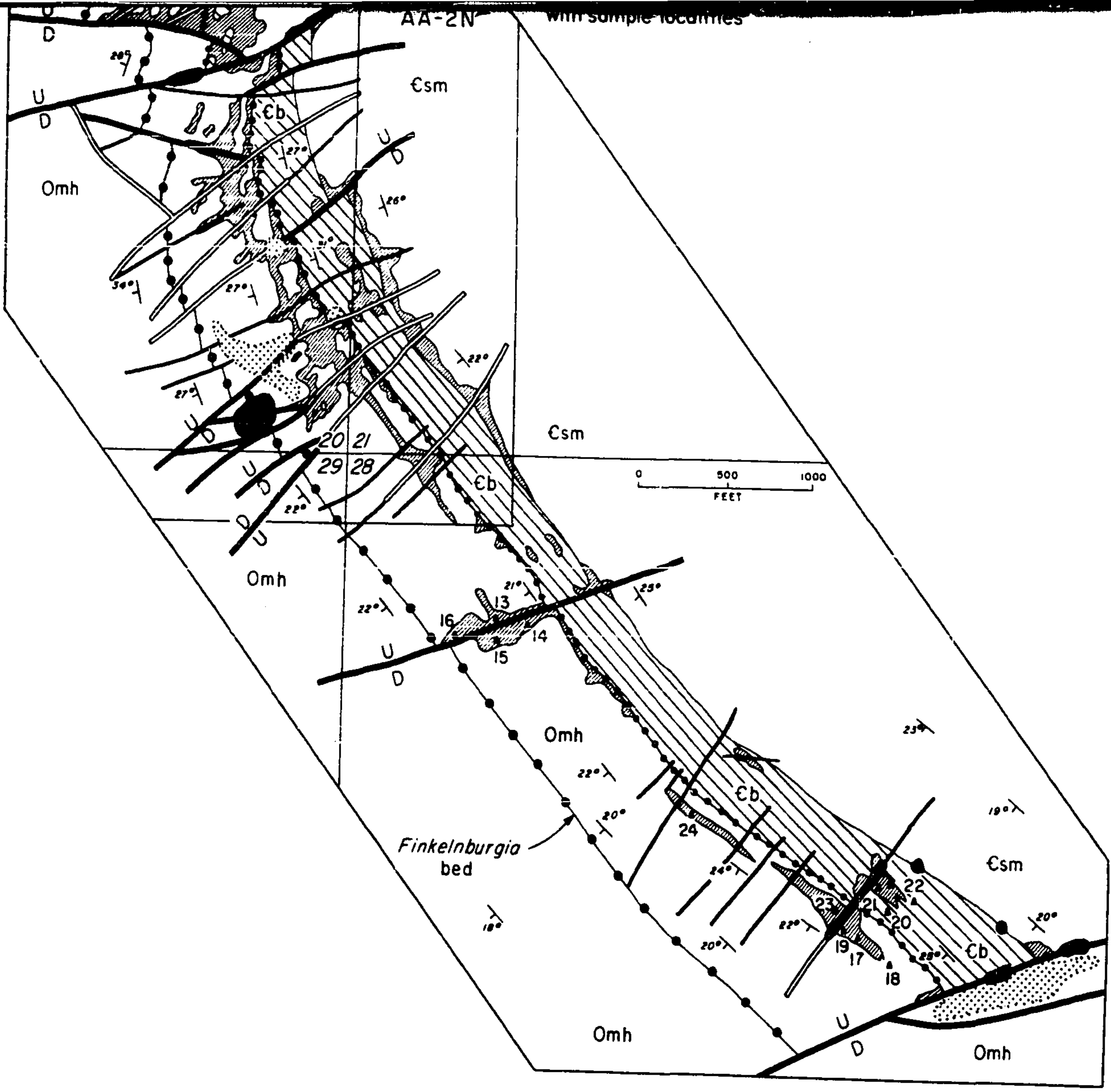

Sandstone bed
17
1
2
16
3
4
5
Occ
20
19
Occ
6
Ok
Ok
Post
0
500
100
FEET
0

TA-4


Sandstone bed
Occ
Omh
Ok
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
15 14
22 23
14°
16°
17°
18°
19°
20°
30°
35°
WASHITA VALLEY FAULT
Post - Arbuckle Strata
Daube Ranch
0
500
1000
FEET

TA-2


0
500
1000
FEET
Ok
10°
10°
12°
D
U
D



EXPLANATION

STRATIGRAPHIC

EARLY ORDOVICIAN

buckle Group

Ow	WEST SPRING CREEK FORMATION
Ok	KINDBLADE FORMATION
Occ	COOL CREEK FORMATION
Omh	

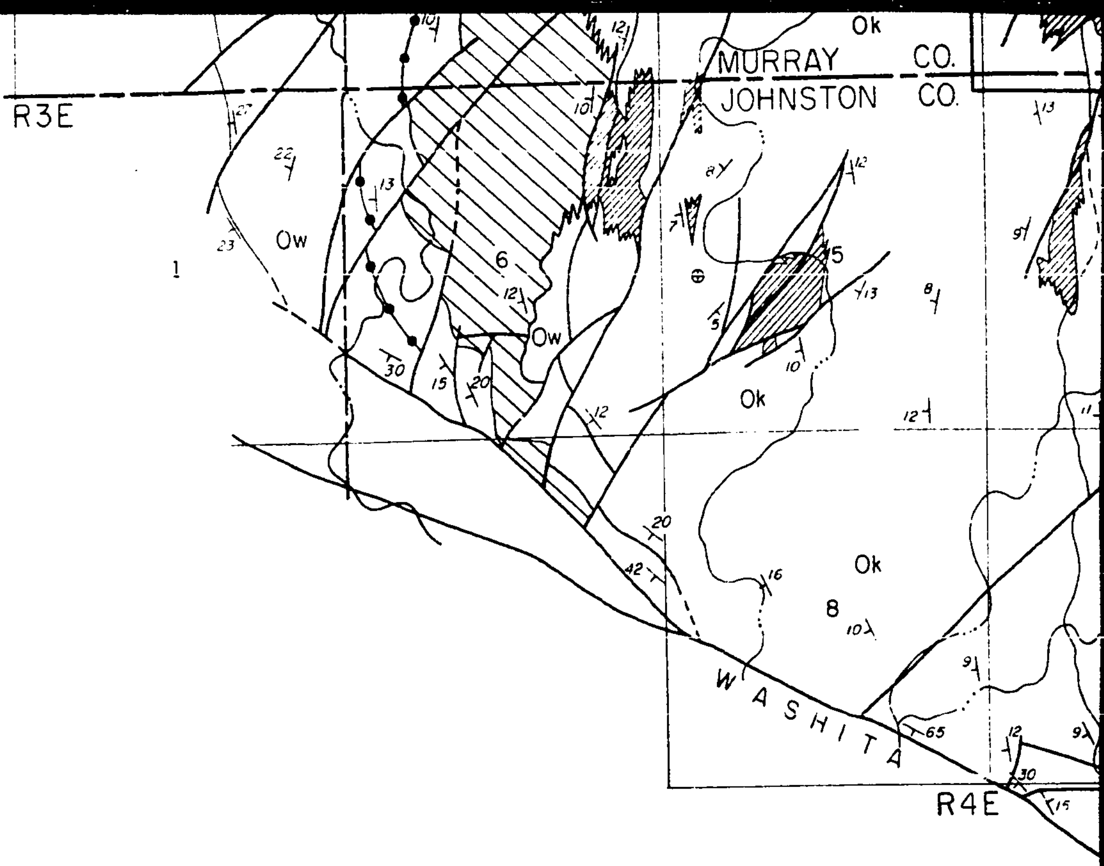
LITHOLOGIC

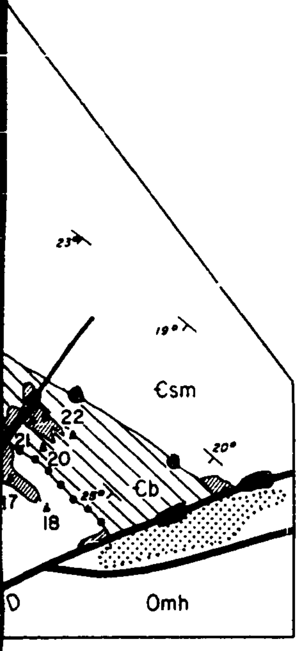
☐ LIMESTONE

▨ ■ TECTONIC DOLOMITE

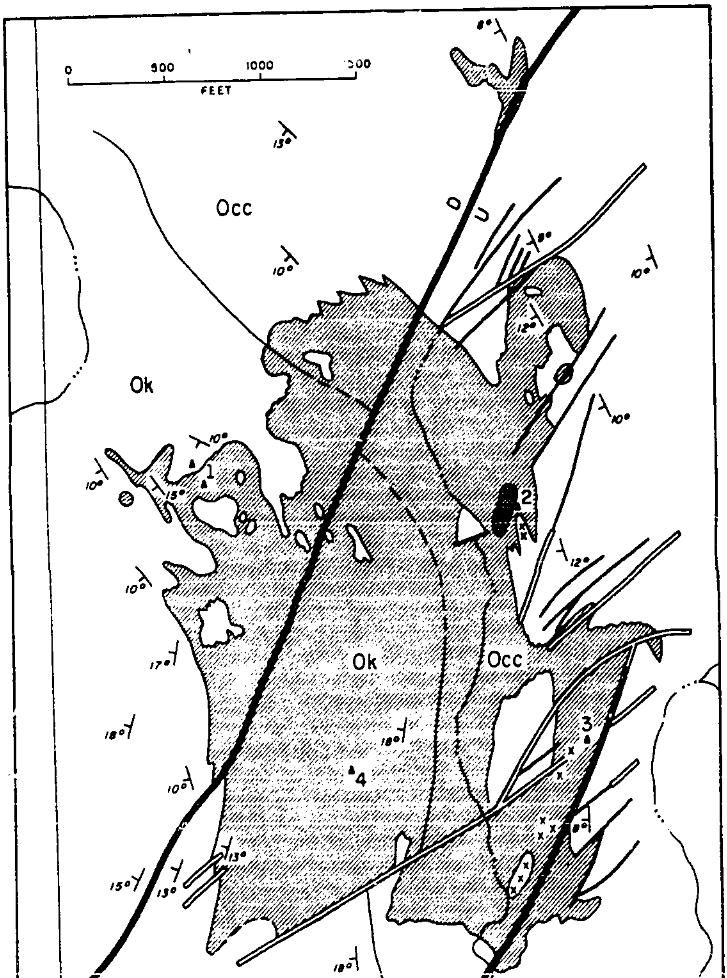
Introduced chiefly along faults and fractures. Generally high in Fe⁺⁺ in Arbuckle anticline and low in Fe⁺⁺ in Tishomingo anticline.

▨ PRE-TECTONIC DOLOMITE

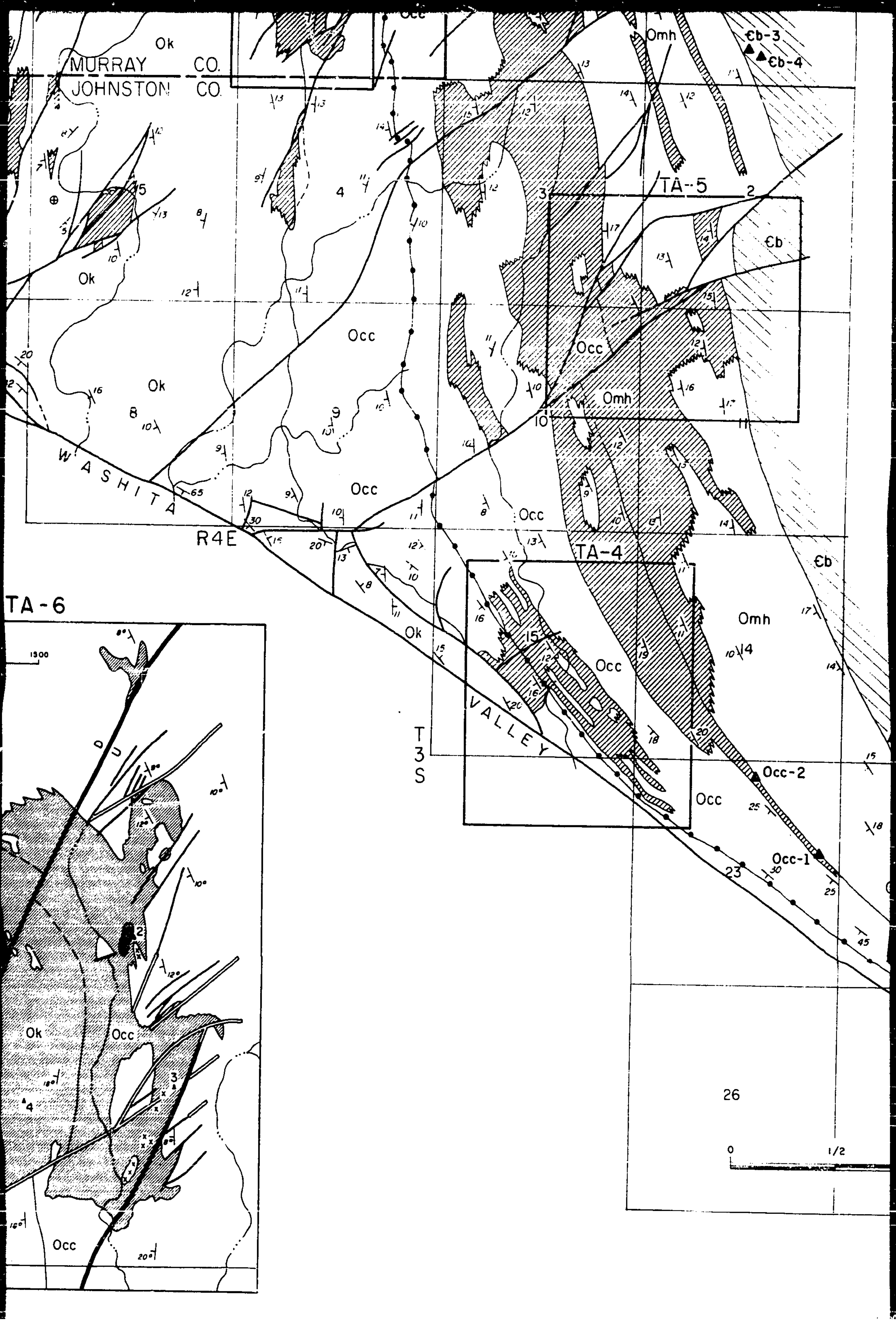


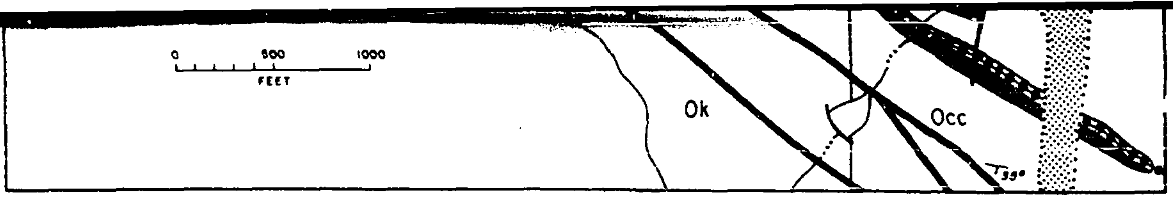


TA-6

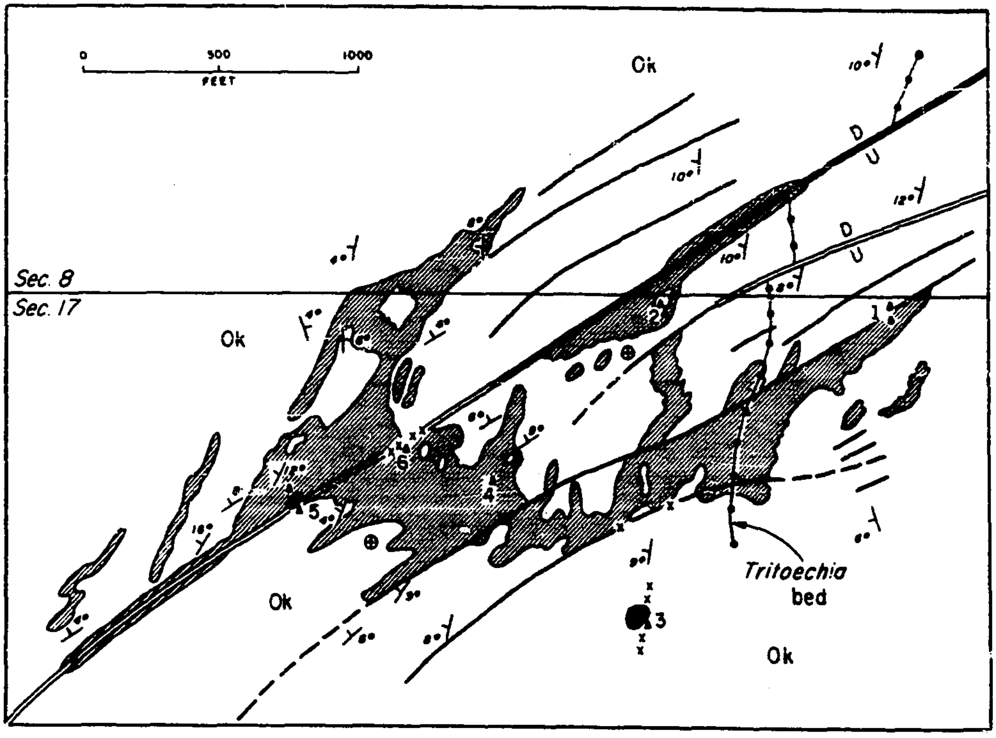


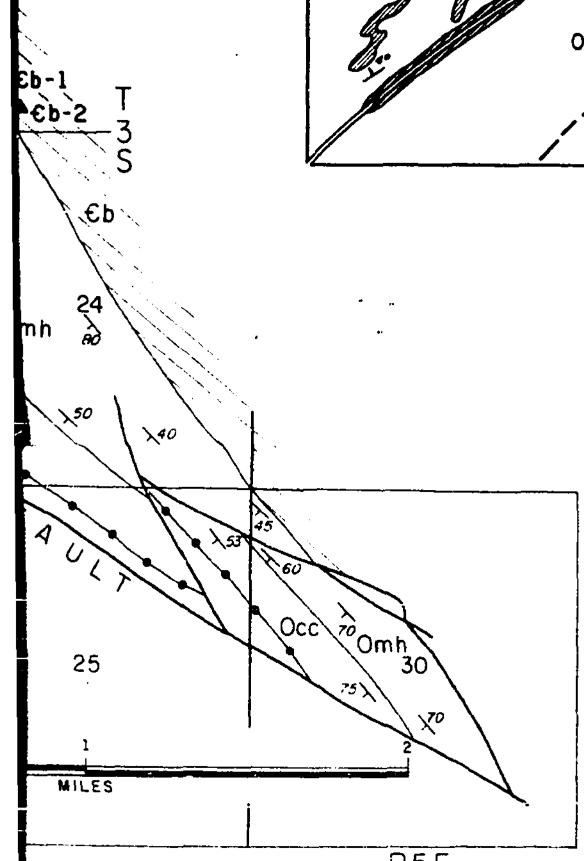
TE
is and
Fe^{++} in
Fe^{++} in


MURRAY CO.
JOHNSTON CO.
Ok
Occ
Omh
Єb
Єb-3
Єb-4
TA-5
TA-4
TA-6
Occ-1
Occ-2
WASHITA
VALLEY
R4E
T 3 S
2
3
4
5
8
9
10
11
15
23
26
1300
0
1/2
D
U

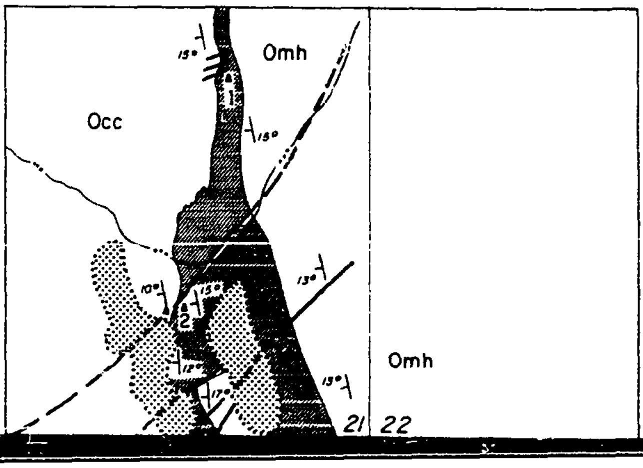

0
500
1000
FEET
Ok
Occ
35°

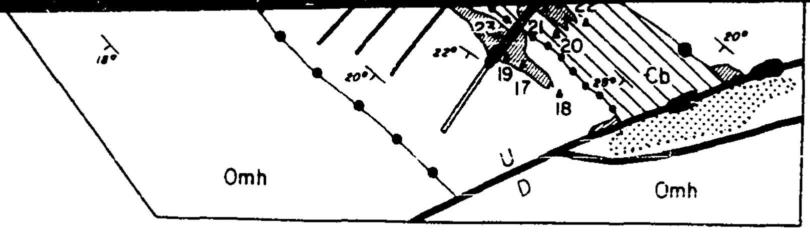
TA-2


0
500
1000
FEET
Ok
Sec. 8
Sec. 17
Ok
Ok
Ok
D
U
D
U
1
2
3
4
5
6
Tritoechia
bed


Єb-1
Єb-2
T
3
S
Єb
24
mh
80
50
40
45
53
60
A U L T
Occ
70
Omh
25
30
75
70
1
2
MILES
R5E

TA-3


Omh
Occ
1
15°
15°
10°
2
13°
13°
12°
17°
Omh
13°
21
22



EXPLANATION

STRATIGRAPHIC

EARLY ORDOVICIAN — Arbuckle Group

Ow
WEST SPRING CREEK FORMATION

Ok
KINDBLADE FORMATION

Occ
COOL CREEK FORMATION

Omh
McKENZIE HILL FORMATION

?

LATE CAMBRIAN

Ꞓb
BUTTERLY DOLOMITE

Ꞓsm
SIGNAL MOUNTAIN FORMATION

▒
ALLUVIUM OR SOIL

20°
Strike and dip of beds

LITHOLOGIC

☐
LIMESTONE

▨ ■
TECTONIC DOLOMITE
Introduced chiefly along faults and fractures. Generally high in Fe++ in Arbuckle anticline and low in Fe++ in Tishomingo anticline.

▨
PRE-TECTONIC DOLOMITE
Occurs in regional thick-bedded sequences that are offset by faults. Low in Fe++.

KEY BEDS

Fossil bed

Sandstone or other distinctive bed

● x x
Limonite, of tectonic origin

3 ▲ ▲ Ꞓb-2
Sample stations

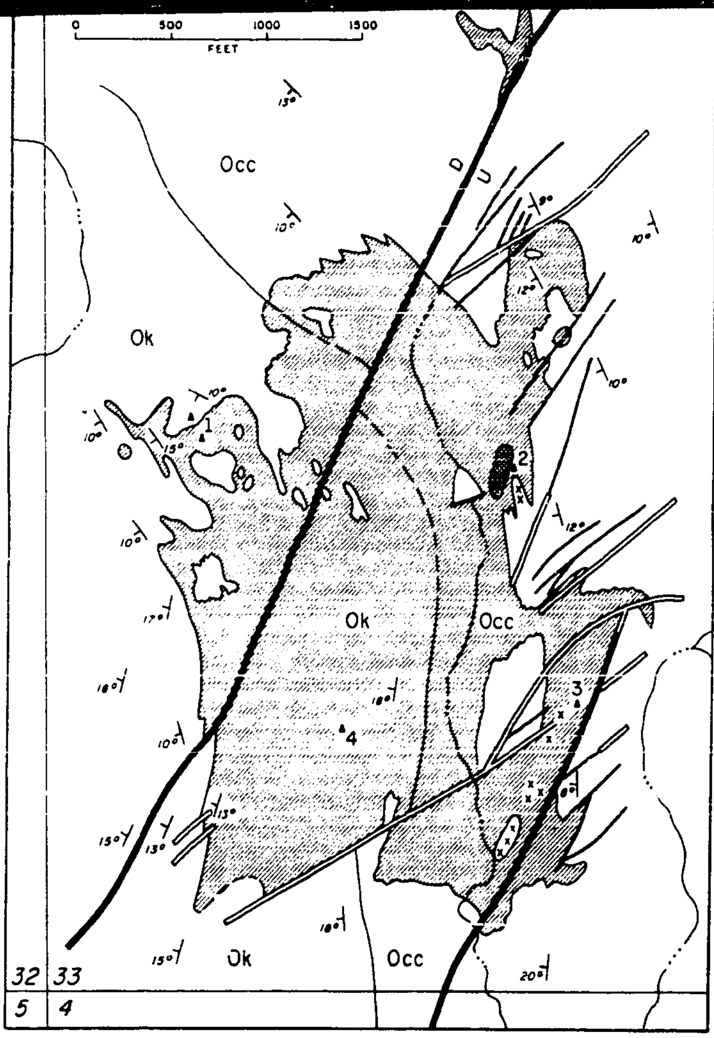
FAULTS
U, upthrown side; D, downthrown side
Dashed where inferred or concealed

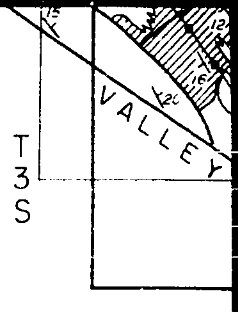
Throw indicated on detailed maps by following symbols

More than 25 feet

5 to 25 feet

Less than 5 feet



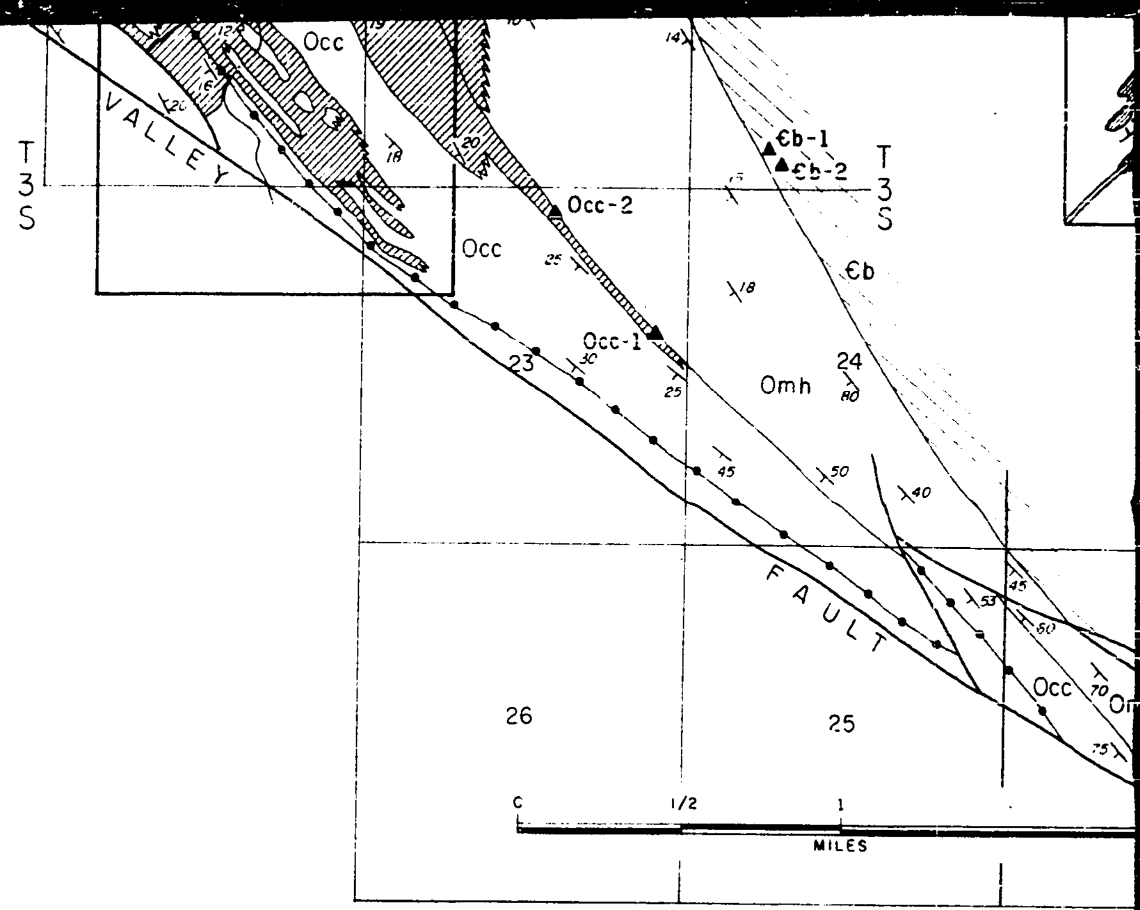


GEOLOGIC MAPS
OF
SELECTED TECTONIC DOLOMITE AREAS
IN THE
ARBUCKLE GROUP
ARBUCKLE MOUNTAINS, OKLAHOMA

by

Kenneth A. Sargent

M. S. Thesis, University of Oklahoma, 1966

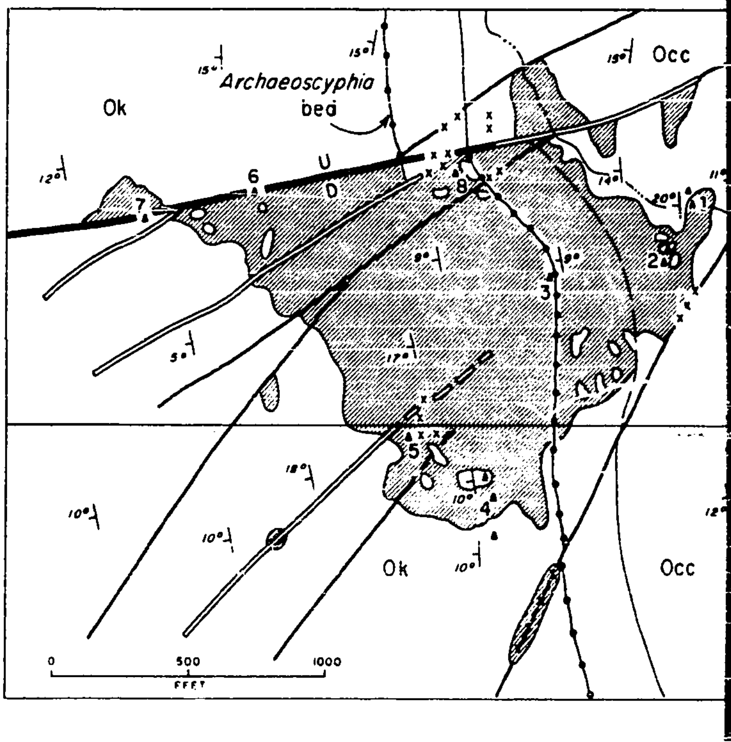


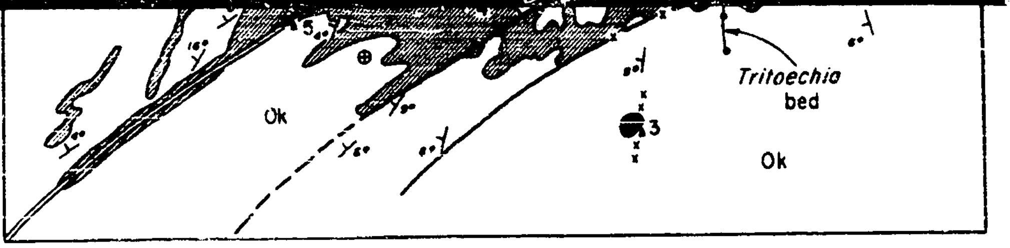
ITE AREAS

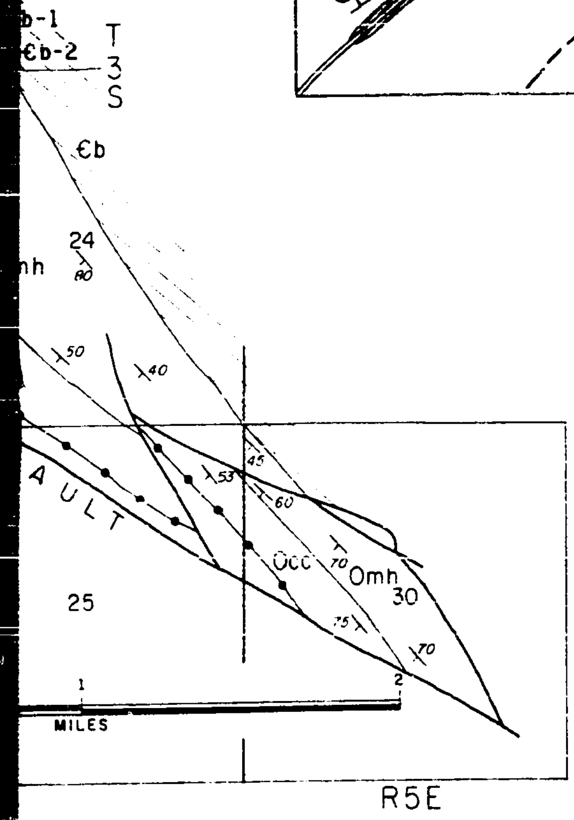
KLAHOMA

966

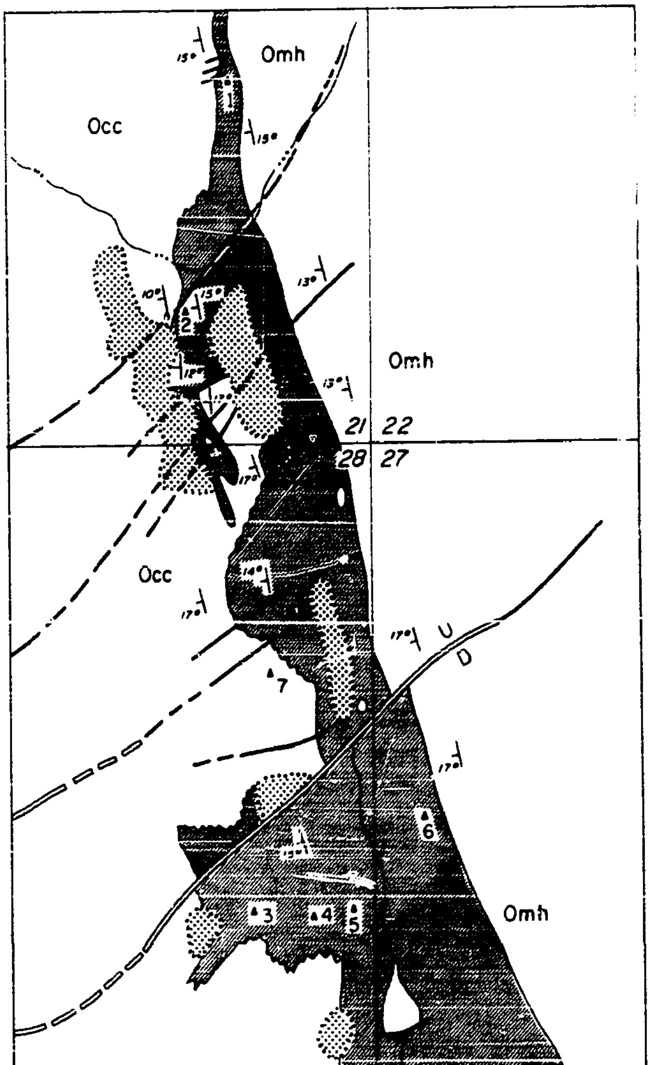
TA-1



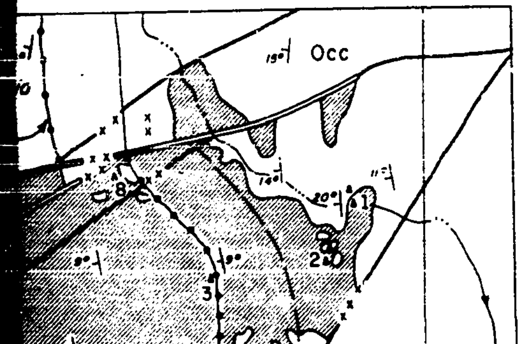

Tritoechia bed
Ok
Ok
5
3


Єb-1
Єb-2
T 3 S
Єb
24
80
Omh
50
40
45
53
60
AULT
Occ
70
Omh
30
25
75
70
1
2
MILES
R5E

TA-3


Omh
Occ
1
2
Omh
21 22
28 27
Occ
U
D
7
6
3
4
5
Omh
Occ
0 500 1000
FEET

TA-1


Occ
8
1
2
3
20 21
29 28
5
4
Ok
Occ