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STRATIGRAPHY AND SEDIMENTATION OF THE GARDNER FORMATION

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IN

CENTRAL UTAH

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ABSTRACT

The Gardner formation outcrops in many localities throughout central Utah. Faunal and lithologic studies indicate that the lower half of the formation is lower Kinderhookian and the upper half is upper Kinderhookian and lower Osagean in age.

The Gardner was deposited as a clastic limestone; petrographic investigations show that all of the dolomite present is secondary.

The Gardner is readily subdivided into five lithotopes. The lower two were deposited in the neritic zone on a stable shelf in the Madison Basin. Between the lower lithotopes and the upper ones an algal biostrome, locally called the "curley bed" occurs. It is overlain by strata deposited in the neritic zone upon a slightly unstable shelf.

Water conditions were favorable for abundant organic life in the upper lithotopes because of a rich fauna of over 30 genera which occur there.

The low silica content of the Gardner makes it economically valuable and data are presented indicating chemical composition.

INTRODUCTION

Location

The Gardner formation forms excellent outcrops in Central Utah, and at several localities complete sections have been studied in detail. Sections described in this report are for the most part limited to Utah County, although two sections just outside the County (in northern Juab County) are used for comparative purposes.

Sections studied include:

1. Rattlesnake Spur in section 1, Township 9 South, Range 3 West.
2. Lake Mountain area on the west side of the Cedar Valley Hills in section 32 of Township 6 South, and Range 1 West.
3. The north Selma Hills area on the south flank of Greeley Pass Hill, in sections 23 and 24 in Township 8 South, Range 2 West.
4. West Mountain region, particularly in the area where this mountain on the south joins the northern extremity of Long Ridge in sections 15 and 22, Township 9 South, Range l East.
5. The north Long Ridge area on "Chaffin Quarry Mountain" in section 8 of Township 10 South, Range 1 East.
6. Middle Long Ridge in section 20 of Township 10 South, Range 1 East.
7. South Long Ridge area particularly Government Ridge in sections 6 and 31 of Township 10 South and Range 1 East.
8. Piccayune Canyon, directly north of Dry Mountain, northeast of Santaquin, and in the southern Wasatch Mountains, in section 38 of Township 9 South, Range 2 East.
9. Rock Canyon in the south-central Wasatch Mountains, in the area northeast of the City of Provo, located in section 28, Township 6 South, Range 3 East.

Physical Features

Utah County is interesting in that within its borders is the junction of three major physiographic provinces. The western half of the county includes some of the easternmost ranges and valleys of the Basin and Range Province. Seven of the Gardner sections studied lie within this area.

The northern and eastern portions of the county include the rugged mountains of the Middle Rocky Mountain Province. Two of the Gardner sections are in this physiographic setting.

The south-eastern corner of Utah County includes a portion of the more uniform dipping beds of the highland Colorado Plateau. No Gardner is known in this locality.

Scope of Report

Although the Gardner formation has been mapped, measured, and discussed by various geologists who have done reconnaissance to detailed work in this part of Utah, no detailed petrologic and petrographic analysis of the sediments or correlation of its units have been reported. It is the purpose of this study to present details of the stratigraphy and conditions of sedimentation of the Gardner formation, to attempt a satisfactory regional correlation, and to point out not only the economic importance of this formation, but the various unsolved problems -- largely stratigraphic -- associated with such a study.

The Gardner formation was studied in the localities which, in the estimation of the writer, present complete and well exposed sections, as well as those having unusual features. Obviously, the problem of finding complete exposed sections was the principal limiting factor of the study. Some of the sections were measured and sampled in conjunction with studies of other graduate students of geology who were, at the time, mapping the areal geology in detail. Other sections were studied at localities where previous graduate students had completed geologic maps. However, none of these students devoted detailed work primarily to the Gardner. Every area where a good section of this formation is present in outcrop was visited, and to the writer's knowledge no outcrop of the Gardner containing additional data bearing upon this problem was left unstudied.

Previous Work

Lindgren and Loughlin (1919, p. 39) named the Gardner formation from the "spur west of Gardner Canyon" in the Tintic mining district. They also studied it in several other localities in the Tintic district. In their original report they wrote:

> "The top of the formation is mapped at the base of the lowest exposed black cherty beds of the Pine Canyon limestone . . . A black shale bed about 100 feet thick at about the same horizon would be a better boundary marker, were it not so poorly exposed. . . The greater part of the formation is fine-grained gray to dark bluish-gray dolomite containing an abundance of silicified fossils. . . Inter-stratified with the dolomites are a few beds of black dense carbonaceous limestone."

The thickness of the type Gardner evidently is on the magnitude of 800 feet.

Tower and Smith (1898, p. 1) measured 435 feet of lower Mississippian rocks between what they took to be Devonian strata and the lowest black cherty beds. Their section appears to be part of what they termed the Mammoth limestone. Ribgy (1952, p. 37) mapped and studied the Gardner in the Selma Hills, a northerly projection from the East Tintic Range. Hoffman (1951, p. 60) and Williams (1951, p. 101) extended this mapping northward to include the Mosida Hills. Johns (1950, p. 63) mapped the Gardner in the Twelve Mile Pass area. Calderwood (1951, p. 21) mapped a section on the west side of Lake Mountain in the Cedar Valley Hills.

Schindler (1952, p. 36), Elison (1952, p. 41), and Swanson (1952, p. 35), mapped the Gardner formation in the low hills between West Mountain and Warm Springs Mountain. Brown (1952, p. 331) recognized and mapped the Gardner in Piccayune Canyon.

Clark (1953, p. 41) mapped the Gardner from the Mona Resovoir in Juab Valley northward to Government Hill where Peacock (1953), Peterson (1953, p. 60), and Sirrine (1953, p. 32) extended it northward to and including Warm Springs Mountain. Petersen (1953, p. 27) mapped this formation west of Government Ridge on Goshen Hill.

Recent work by Lovering, et al (1951, p. 1505) has resulted in revised terminology. Lovering and associates working in the Tintic district and Allens Ranch area found that the Pinyon Peak formation measured years previously by Lindgrin and Loughlin in the Tintic district had been faulted below the Victoria quartzite and mapped as contiguous units by them. They had also included the Victoria quartzite as lower Mississippian. Present definitions assign the Victoria to the middle (?) Devonian, and indicates the Pinyon Peak which overlies the Victoria to have an upper Devonian age. Also, according to Proctor and Bissell* the Pinyon Peak consists of only the more or less "flakey" dark colored limestones which overlie the Victoria quartzite and are below the first dolomites of the Gardner, which are normally sucrose textured and light gray in color.

Using this definition, the Gardner sections of Williams, Hoffman, Calderwood, Johns, Elison, Swanson, and Schindler would be changed, as all of these writers included the lower light gray sucrose dolomites containing silicified Syringopora as part of the Pinyon Peak. Now that consensus exists among some geologists as to the definition of the Gardner, members of the U.S. Geological Survey working in the Wasatch Mountains and the Tintic District are at present attempting to re-define the Gardner and Pine Canyon formations.**

Present Work

Field Work. The field work for this problem was begun in October, 1952 and completed by December, 1953. Field work consisted of systematic

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* Field conference, March, 1953.

** Personal communication, Dr. Paul Dean Proctor, January 2, 1954.

measurement and sampling of stratigraphic sections of the Gardner formation in the mountains surrounding Utah Valley. Measurement was done with a steel tape. Samples were taken of each distinct lithotope in the section.

Laboratory Investigations. The laboratory work included preparation of thin sections, cellulose peels, insoluble residues, and spectographic analysis.

Thin sections are prepared by cutting oriented rock samples on a diamond saw, yielding slices approximately 5 mm. thick. These are then ground to desirable thickness for study.

Cellulose peels are made with less effort and cost and commonly yield much data for the time and energy expended. A rock sample or specimen is cut with a diamond saw--this rock ordinarily is so cut that half can be used for a thin section and the other half for a peel. Both parts of the slices are ground on abrasive plates or laps, finally finishing on 600 mesh. One half is cemented to a 2" x 2" glass slide, the other half etched in dilute Hydrochloric Acid for a few seconds. Length of the etching depends upon relative amount of calcareous material present. After the etch treatment the sample, or specimen, is washed, dried, and covered with a thick, syrupy cellulose solution * until it hardens--commonly 12 to 24 hours. This can easily be peeled off and mounted for binocular microscope examination and study.

Insoluble residues are made by crushing a small quantity of a rock sample, drying and weighing 10 grams of granule size fragments, and dissolving the soluble material in dilute HCl. HCl of approximately seven parts water to one part concentrated HCl is used. Gentle heating facilitates the action. The residue is filtered, washed, and dried, and then weighed to determine the insoluble portion.

Spectographic analysis of the samples was done in the Columbia-Geneva Steel Company chemistry laboratories.

Petrologic and petrographic examinations of the material prepared permitted identification of fossils and minerals and facilitated sedimentary analysis of the rocks.

An Isopach map and an Isometric Fence Diagram were compiled, using as a base the Utah County Planning Commission map of the scale 1 inch equals 1 mile.

Photomicrographs of certain sections were also made.

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*Solution is prepared as follows:

Parlodian	28 grams
Butyl Acetate	250 cc.
Amyl Alcohol	10 cc.
Ether	3 cc.
Castor Oil	3 cc.

THE GARDNER FORMATION

Stratigraphic Relations

Faunal Correlations. The Gardner formation was considered as lower Mississippian age by Lindgren and Loughlin. Four collections of fossils made by Lindgren and Loughlin from the Tintic District included:

Zaphrentis sp., Clisiophyllum sp.
Crinoid stems, Camarotoechia sp.
Spirifer centronatus, Syringopora surcularia
Composita humulis, Reticularia (?) sp.
Aulopora sp., Euomphalus luxus
Cystodictya sp., Chonetes illinoisensis
Cleiothyridina aff. C. hirsuta
Conocardium sp., Spirifer sp.

These fossils, identified by Dr. G. H. Girty of the United States Geological Survey, were "recognized with some certainity as indicating the horizon of the Madison limestone." (Lindgren and Loughlin, 1919).

The Madison limestone was considered as being Kinderhookian and Osagean and on this basis the Gardner was assigned a similar age. T. B. Nolan (1935, p. 27) considered the Madison limestone of the Oquirrh Range, the Gardner dolomite and the lower part of the Pine Canyon limestone in the Tintic district, as lower Mississippian age.

Gilluly (1932, p. 24) considered the Gardner to be correlatable with the Madison.

Lovering, et al (1951, p. 1505) in a revision of the Tintic stratigraphy based on new faunal discoveries, confirmed a Madison age for the Gardner.

H. J. Bissell collected a fauna from the Gardner on Long Ridge which James Steele Williams and Helen Duncan of the U. S. Geological Survey identified, as follows:

Euomphalus luxus, Caninia sp.
Triplophyllites sp., Multithecopora sp.
Spirifer centronatus, Schuchertella sp.

On the basis of these fossils, the Survey paleontologists assigned a lower Mississippian age to the Gardner in that area.

Thin sections from the Gardner show many endothyroids present with other fossil hash. Selected slides were sent to Dr. M. L. Thompson for identification. A letter from Dr. Thompson to H. J. Bissell * contains the following information:

> "The endothyroid slides . . . have been examined in detail by Ed and Doris Zeller, and they report as follows:
>
> Cl-7, Cl-8A, Cl-10B, Cl-12 all belong to the zone of Plectogyra tumula. This zone is present in the upper part of the Madison and its equivalents over most of the western area. The P. tumula zone may be Osagean in age, but no direct comparison can be made since P. tumula has not been found in Mississippi Valley rocks of Osagean age.
>
> Cl-19C is almost certainly Kinderhookian, and it belongs to the zone of Granuliferella. This zone is widespread in the lower Madison."

Cl-7, Cl-8A, Cl-10B, and Cl-12 are from strata above the "curley bed". Cl-19C is from below the "curley bed". This gives a good age assignment to the strata below and above the "curley bed". These same endothyroids are found from strata of similar stratigraphic position in other Gardner sections.

The occurrence of fossils identified from the Gardner are shown on Chart 1. The list, based on reported Gardner findings, has been supplemented in some areas by the writer's personal collections.

The widespread occurrence of zaphrentid type corals, Spirifer centronatus, Syringopora surcularia, and Eumophalus luxus would designate these forms as excellent guide fossils for the Gardner formation. In addition, the presence of Lithostrotionella sp., Triplophyllites sp., Caninia sp., Multithecopora sp., Loxonema sp., and the foraminifera Plectogyra sp., also unquestionably confirm a Gardner age.

As Table 1 shows by the occurrence of 31 genera, the Gardner formation contains an abundance of fossils. Much of the rock of the formation is good coquinoid limestone with some coquina present; some beds are criquinas. The fossils present seldom weather out completely, but many good fossils stand out in relief on the weathered surface and thus can be removed by various methods. Weathering is of such a nature as to permit identification of many fossils without removing the matrix.

None of the collections listed from the Gardner are detailed, nor are any of the faunal studies of the formation complete.

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* January 12, 1954

OCCURRENCE OF FOSSILS WITHIN THE GARDNER

	Tintic Area	Selma Hills	N. Selma Hills	Rattlesnake S.	Lake Mt	West Mt.	Piccayune Can.	N. Long Ridge	M. Long Ridge	S. Long Ridge	Goshen Can.	Rock Canyon
Zaphrentis sp.	X	X	X	X		X	X	X	X	X	X	
Clisiophyllum sp.	X									X		
Crinoid fragments	X	X	X	X	X	X	X	X	X	X	X	X
Camarotoechia sp.	X	X										
Spirifer centronatus	X	X	X	X		X	X	X	X	X	X	X
Syringopora spp.	X	X	X	X	X	X	X	X	X	X	X	X
Composita sp.	X	X	X	X			X			X		
Reticularia (?) sp.	X											
Aulopora sp.	X						X					
Euomphalus luxus	X	X	X	X	X	X	X	X	X	X	X	X
Cystodictya sp.	X											
Chonetes sp.	X	X	X				X					
Cleiothyridina sp.	X	X							X			
Concardium sp.	X											
Spirifer sp.	X		X	X	X						X	X
Marginifera (?) sp.		X										
Lithostrotionella sp.		X	X		X	X		X	X	X	X	
Productus spp.		X									X	
Triplophyllites sp.			X	X	X	X	X	X	X	X	X	
Caninia sp.			X	X	X	X	X	X	X	X	X	
Multithecopora sp.			X	X	X	X	X	X	X	X	X	
Martinia (?) sp.				X								
Loxonema sp.			X	X		X		X	X	X		
Plectogyra sp.				X		X		X	X	X		
Granuliferella sp.				X					X	X		
Dictyoclostus sp.										X		
Dielasma sp.											X	
Schuchertella spp.							X					
Brachythyris sp.							X					
Straparolus ophirensis							X					
Syringothyris sp.											X	

Table 1

Crinoidal fragments and plates are abundant throughout the Gardner. Many thick and massive beds of encrinite limestone are found in the formation.

According to Laudon (Weller, et al, 1948, p. 119):

> "In North America crinoids occur prolifically in Kinderhookian and Osagean rocks, and very complete evolutionary series can be traced. At the end of the Osagean, many genera and some whole families become extinct. Survivors in the Meramecian and Chesterian rocks are much less numerous, diverge widely from older forms, and show remarkable advances in evolution."

The general vertical distribution of the fragmentary crinoidal debris in the Mississippian system seems to bear out Laudon's views. However, because of the poor state of preservation of the crinoidal debris--largely ossicles--found in the Gardner rocks, no identification has been attempted.

It may be concluded that on the basis of the studied fauna of the Gardner, it is lower Mississippian in age; that is, Kinderhookian below the "curley bed" and upper Kinderhookian--lower Osagean above.

Lithologic Correlation. The upper black shale as mentioned by Lindgren and Loughlin (1919, p. 39) for the Tintic district was not seen by the writer outside this dsitrict. The Tintic shale section probably is an expression of local lithofacies change extending west from Tintic but not eastward.

The dolomite of the Tintic Gardner is probably secondary, as the only extensive dolomite found in other Gardner sections is where intense alteration can be noted. The same alteration and replacement which is responsible for the extensive mining activity of the Tintic area is probably responsible for alteration of the original Gardner lithology there. Sirrine (1953, p. 32), Peterson (1953, p. 62), and Petersen (1953, p. 28) describe much dolomite in their measured Gardner sections. Again, the areas where this dolomite occurs has experienced much alteration.

Other than these local facies variants, the Gardner lithotopes appear to be rather uniform throughout the outcrop belt. Correlation of this limestone and dolomite lithology to the Madison of the Wasatch Range and the Joana of western Utah-Nevada can be effected with a fair degree of accuracy. It can be concluded that lithologically the Gardner is equivalent to other lower Mississippian sections of the Cordilleran region.

Devonian-Mississippian Contact. The Gardner formation lies conformably upon the upper Devonian Pinyon Peak formation and is conformably overlain by the Osagean Pine Canyon limestone. The lower contact of the Gardner is taken at the occurrence of the first sucrose dolomites above the limestones of the Pinyon Peak. In altered areas where the Pinyon Peak occurs as a dolomite, the Gardner contact can be placed with safety about 20 feet below the first occurrence of Syringopora. The upper contact of the Gardner is placed at the base of the first bedded cherts of the Pine Canyon limestone. In all of the Gardner sections studied, the upper contact is the most prominent and consistent. The bedded cherts occur with minimum deviation from place to place and clearly define the upper contact.

As discussed previously, the lower contact of the Gardner formation has been the subject of controversial discussion in recent years. Lovering, et al (1951, p. 1505) redefined the upper Devonian and lower Mississippian formations, thus aiding the stratigrapher to interpret the east-central Mississippian Cordilleran section in the most logical way. It is interesting to note, however, that this definition varies from the "standard" recognized throughout much of North America.

According to Weller, et al (1948, p. 102):

> "Black shales of questionable age separate undoubted Devonian and Mississippian rocks throughout much of the interior of North America. They extend almost continuously from Michigan on the north to Alabama on the south, and from Virginia on the east to Alberta and New Mexico on the west. . . Originally, most of the black shales were classed with the Devonian, but, since Ulrich stated his contention that the Chattanooga shale is Mississippian (1912), his view has been adopted by others."

Holland (1952, pp. 1702-1710), recognized shales along the Devonian-Mississippian contact of the northeast Utah-southwest Montana area. The Pilot shale, in western Utah-eastern Nevada, of questionable Kinderhookian age also substantiates the widespread occurrence of upper Devonian-lower Mississippian shale. The occurrence of shale with limestone, as is the case in the lower Mississippian of eastern Nevada and western Utah, would definitely separate these unstable shelf lithotopes from the more stable shelf association of the Gardner-Madison basin, and account for, in part, the non-occurrence of shale in most of the Gardner.

Lower Mississippian Paleogeography. On the basis of lithologic composition, stratigraphic succession and faunal content, Weller, et al (1948, p. 110) divided the North American Mississippian system into four principal stratigraphic provinces. The division includes:

1. The eastern or Atlantic province
2. The central or Interior province
3. The western or Cordilleran province
4. The far west or Pacific province

Discussing the Cordilleran province, Weller points out:

> "The Cordilleran province occupies an enormous area extending from Mexico to western Canada and includes most

of the western third of the United States. Many details of stratigraphy in this region are inadequately known, and some of the correlations of formations recognized in different parts are more or less uncertain. Lithologic development is quite variable, and if it were better known, several subprovinces undoubtedly could be distinguished."

Weller further points out that few satisfactory correlations have been made between the type Mississippian strata of the Mississippian Valley area and those of the Cordilleran. He mentions the possibility of a land barrier which could have extended from "Minnesota to Colorado throughout a more or less broad zone in which Pennsylvanian strata now overlie pre-Mississippian formations in the subsurface."

Faunal collections from New Mexico seem closer related to those of the Mississippi Valley than to other regions which are closer geographically and would indicate that marine connections existed during Mississippian time possibly through Kansas and Oklahoma to Texas and New Mexico.

The lower Mississippian of the Cordilleran consists essentially of a very widespread limestone, the Madison, Gardner, and their equivalents. Weller points out (1948, p. 110) that deposition of the lower Mississippian limestones was probably interrupted by a positive axis which extended from Colorado, southeast to Arizona. This axis was actually one of the early movements of the Ancestral Rocky Mountains, and contributed some clastic material to the adjacent basins. Bissell (1953, p. 27) discusses the more severe tectonism of the upper Palezoic as accounting for many of the lithofacies changes of the Mississippian. This "progressively shifted the axis of thickest sedimentation in the miogeosyncline eastward."

Bissell notes that:

> "The Madison basin became the dominant negative portion of the geosyncline during lower Mississippian time, but was profoundly modified by epeirogenic uplift and faulting of the Uncompaghre and Colorado Rockies to the east. However, continued clastic sedimentation accounted for thousands of feet of Mississippian rocks--largely carbonates and arenites."

The Gardner formation not only reflects these regional tectonic developments of the Madison basin, but also the local shelf conditions on which it was deposited.

SEDIMENTARY ANALYSIS

Introduction

For purposes of discussion and illustration (Plate 3), the Gardner lithofacies is divided into five lithotopes. This division, while not primarily used in measurement of the sections, seems to be lithologically feasible when the segmented Gardner sections are compared. The lithotopes are probably approximate time correlative but represent different lithologic units in each section which can be compared with some degree of correlation. As Chenoweth (1952, p. 537) points out:

> "One may draw lines of supposed synchornuity connecting the top and bottoms of formations, but individual beds lend themselves less readily to exact correlation."

The facies of the lithotopes vary from section to section, but the whole unit is quite uniform.

LOWER DOLOMITE LITHOTOPE

Petrology

The basal beds of the Gardner fromation are predominantly dolomite. Only the Rattlesnake Spur section has a limestone facies within the lower dolomite lithotope. The thickness varies from a maximum of 278 feet in the south Long Ridge section to a minimum of 77 feet in the Piccayune Canyon area. The lower dolomite averages about 110 feet in thickness in eight detailed sections. If the Jefferson (?) dolomite of Rock Canyon is considered as equivalent to part of the lower Gardner, the average thickness is approximately 130 feet.

The color of the rock varies from dark gray to light somber gray, locally becoming medium gray-blue. In areas where alteration by dolomitization is prominent, the dolomite is a darker color. Perhaps the degree of alteration (epigenetic activity) controls the color. Other than this the color, when studied over a wide area, seems to have little diagnostic value.

The lower dolomite is predominantly thick to massive bedded. Chert is present in some of the sections, but the majority of the outcrops have none. The texture, varying from medium crystalline to fine grained, seems to vary with the intensity and type of replacement to which the rock was subjected.

A guide fossil for the lower dolomite lithotope is the coral genus Syringopora. Well preserved silicified Syringopora is present within the first ten feet above the base of the Gardner. Caninia sp. and Triplophyllites sp. also occur in the basal beds.

Petrologic determinations of dolomite in the field were based on the ability of the rocks to effervesce in cold dilute (1:7) HCl, and other characteristic dolomite features.

Occurrence of Dolomite

Thin sections show that all of the dolomite of the lower lithotope likely is secondary. There are also indications that not only is most of the dolomite secondary, but there occurred at least two stages of secondary dolomitization in some of the sections studied. Although a complete discussion and review of the theories concerning the origin of dolomite is not the prime purpose of this report, certainly definite conclusions can be drawn from the writer's work and the more detailed work of others.

McKinley (1951, p. 170) has pointed out that:

"The theories of alteration have their foundation on the apparent fact that magnesium-bearing solutions prefer to release their magnesium for metasomatic reation with calcium carbonate, rather than to directly precipitate dolomite."

The direct precipitation theory has had many advocates in the past (Van Tuyl, p. 265); obviously, a certain set of special conditions must be obtained for primary dolomite to form.

Van Tuyl classified the theories of the origin of dolomite in three general headings with their sub-divisions:

I. Primary deposition theories:
   A. The chemical theory
   B. The organic theory
   C. The clastic theory

II. Alteration theories
   A. The marine alteration theory
   B. The groundwater alteration theory
   C. The pneumatolytic theory

III. Leaching theories:
   A. The marine leaching theory
   B. The surface leaching theory

His old, but nontheless excellent paper discusses at some length the history and evidences for each theory which was developed up until 1914. More recently, McKinley (1951 pp. 169-183) has reviewed the replacement origin of dolomite. His classification includes:

I. Marine Replacement
   A. Penecontemporaneous replacement
   B. Syndiagenetic replacement
   C. Post-diagenetic replacement

II. Ground Water Replacement

III. Hydrothermal and Pneumatolytic Replacement

Evidence, as will be discussed, seems to indicate that much of the dolomite in the Gardner formation is of the marine replacement type. Groundwater dolomitization facilitated by faulting is also important.

Marine Replacement. The majority of the extensive, very thick dolomite sections had a marine replacement origin. Cloud and Barnes (1948 pp. 89-95) have pointed out that the sea is the only adequate source for the magnesium needed in such cases. It could occur penecontemporaneous with deposition of the original limestone sediment, at the same time as diagenesis of the limestone, or, after complete lithification of the rock, but under conditions of "metharmosis".

Van Tuyl has shown that 15% of the salts in average sea water are salts of magnesium. It seems likely that dolomitization must be attributed to this factor. Whether or not the double carbonate is formed directly, or if the hydrous $MgCO_3$ is formed first and then combines with the $CaCO_3$ with the subsequent loss of water of crystallization to form dolomite, is not clearly known. Van Tuyl has shown that the former is the most likely. Mineral composition, original $MgCO_3$ content, fineness of grain, porosity, CO_2 content, temperature, pressure, concentration, and time are all conditions which influence replacement. Garrels and Dreyer (1952) have shown through volume for volume limestone replacement experiments that the replacement mechanism involves a continued solution of the host rock and deposition of the guest. They found that the key to the replacement process included the factors controlling calcium carbonate solubility, and that solubility is a function of several variables, among which the ph is the most important. They also showed that a ph decrease of one unit causes approximately a hundred-fold increase in solubility.

Fineness of grain and porosity have always been considered important factors in replacement. Van Tuyl believed that if all other factors remained constant, that the fine grained porous limestone is most susceptible to dolomitization. Garrels and Dreyer (1952, p. 377) found that the finer the grain, the more rapid was the replacement reaction. They also point out that primary permeability ordinarily is too low to permit extensive replacement. The ideal conditions for replacement occur where there are numerous small, closely spaced secondary openings creating a somewhat higher secondary permeability. Garrels and Dreyers' study was primarily for sulfide replacement of limestone, but their results can be used as guide in the study of dolomite replacement.

Experiment has also shown that dolomitization proceeds most favorably at elevated temperatures (Van Tuyl, p. 402). The sea maintains a constant temperature, and perhaps dolomitization is not facilitated as much in the marine environment by temperature as it is in other types of replacement.

Sander's work (1951, p. 123) furnishes proof for original chemically deposited, as well as mechanically deposited dolomite. Although many of Sander's samples showed dolomite-calcite boundaries cutting across the older fabric and thus proving secondary metasomatic dolomite, he concluded that "primary origin predominates and is widely distributed."

Sander (1951, p. 124) also points out that in his samples "there is no evidence that magnesium has been substituted for calcium during free chemical precipitation". His work shows that magnesium can be derived from a primary magnesium carbonate in the sediments, or from sea-water. Sander's conclusions are based on fabric analysis of Triassic limestones and dolomites.

Ground Water Replacement. The occurrence of dolomite around faulted zones has been noted by Van Tuyl (1914), McKinley (1951), Ham (1950), and others. The dolomite is often associated with ore deposits, but many large bodies of dolomite occur independently of ore bodies. The mechanism of replacement, while greatly unknown, probably is similar to processes occurring under marine conditions.

Hydrothermal Replacement. The hydrothermal and pneumatolytic replacements of dolomite are associated with large ore bodies. The Tintic district consists of Paleozoic dolomites and limestones intruded by monzonite bodies which formed the ore and altered the limestone. Other districts have been discussed by McKinley (1951, p. 175) and Van Tuyl (1914, p. 285.)

The dolomites of the Gardner seem to be of at least two types:

A. Marine Replacement
B. Ground Water Replacement around fault zones.

Basal dolomite beds are present in sections which contain only minor amounts of other dolomite. In most of these areas there are no obvious explanations for any origin other than marine. The basal dolomites are underlain and overlain by unaltered limestone and grade laterally in at least one direction into limestones. This suggests that dolomitization after lithification would have to have been very selective.

No evidence for a "selectiveness" of these basal beds is found from field relations, chemical analysis, petrologic, or petrographic studies. If a "selectiveness" existed, it was not borne out by the writer's investigations. It can, therefore, be concluded that evidence from the lower dolomites suggests a marine origin either penecontemporaneous with sedimentation or during and shortly after lithification of the rock.

The second type of alteration noted is the ground water type found associated with faulted areas. As cited by Van Tuyl (1914, p. 285) and McKinley (1951, p. 175), many areas have been described where dolomitization is associated with faults. Evidently the faults provided channel-ways through which ground water moved. These waters transported magnesium-bearing solutions which were probably leached from dolomites or other magnesium-rich rocks below. These solutions seemed to alter the previously marine replaced dolomites as well as much fresh limestone. This type of alteration is especially prominent in the Long Ridge area.

Petrography

Insoluble residue studies show that authigenic activity which was probably facilitated by intrastratal solutions, was quite prominent in the basal beds. Many good doubly-terminating quartz crystals, averaging 0.2 mm., are found in the majority of the insoluble residues prepared from samples of the basal beds.

TYPICAL RESIDUES AND SPECTOGRAPHIC ANALYSIS FROM THE LOWER DOLOMITE LITHOTOPE

Section and	Sample No.	Wt. Gms	Soluble Gms	Soluble %	Insoluble Gms	Insoluble %	Clay Size Matter	Quartz in % Authigenic An.	Authigenic Sub.	Authigenic Eu.	Detrital R SR R A	Fossils	Limite	Gyp.	Fe-Mg	Mica	Chert	Mag.
Rattle-	24C	10.20	9.85	96.6	.35	3.4	100											
Snake	24B	10.16	10.15	99.9	.01	.09			75		20		X		X	X	X	
Spur	24A	10.61	10.48	98.8	.13	1.2			15		80		X			X	X	
	24	9.56	9.56	99.9	.01	.10			85		10	Bryozn	X				X	
	23	10.14	2.26	22.5	7.88	77.5		Quartzitic mat										
	22	10.16	9.29	91.5	.87	8.5	100											
West Mt.	*N14	22.82	21.98	96.4	.84	3.6	95	5										
N. L. Ridge	Cg-1	8.02	7.48	93.3	.54	6.7	99						X					
M. L. Ridge	O-1	14.98	14.67	97.9	.31	2.0			90			Crinoid						
S. L. Ridge	H1A	11.87	11.21	94.5	.66	5.5	15	80					X		X			
	H1B	11.74	11.60	98.8	.14	1.2	100											
	H1C	10.63	10.41	97.9	.22	2.0	50	37		10			X					
	H1D	12.16	12.14	99.8	.02	.16		100										
	H1E	11.88	10.96	99.0	.11	.92				98					X			
	H1F	10.91	10.74	98.5	.17	1.5	40			50			X	X	X			

	SiO_2	Al_2O_3	CaO	MgO	Fe	S	P	Mn	Na
24C	2.92	.34	47.86	5.13	.20	.008	.016	.10	.27
24B	.54	.12	54.92	.32	.08	.006	.003	.05	.17
24A	1.72	.12	54.22	.34	.08	.008	.010	.06	.15
24	.96	.12	54.90	.33	.09	.012	.012	.12	.17
23	43.30	1.25	27.82	2.14	.80	.014	.024	.09	.27
22	9.52	1.20	45.10	3.64	.40	.007	.052	.08	.26
O1	1.16	.07	32.00	19.70	.4	.005	.060	.11	.15

*Composite sample

Table 2

It is interesting to note an abundance of authigenic quartz in the non-dolomitic Rattlesnake Spur section. In the dolomite beds of the lower lithotope at other localities, the authigenic quartz is present, but in some instances etched. In the north Long Ridge section which has experienced marine alteration followed by ground water dolomitization associated with faulting, the authigenic quartz is entirely missing. Authigenic quartz is present in the limestone and marine replaced dolomite sections at every locality studied, except the north Long Ridge section. This section experiences postlithification ground water dolomitization, as well as the marine dolomitization. This leads to three conclusions:

1. Authigenic quartz in the basal lithotope formed before marine dolomitization took place.
2. The average size of the euhedral doubly terminating quartz crystals is 0.2 mm. with the largest crystal 0.675 mm. suggesting that the original marine dolomitization was post diagenesis.
3. Marine alkali dolomitization solutions removed some authigenic quartz and etched other.
4. Ground water dolomitization associated with faults in the north Long Ridge area removed almost all authigenic quartz that was present.

Though etching of the quartz seems to be prominent in the dolomitized sections, it must be pointed out that the solutions causing etching are not limited to the dolomitizing solutions. In the limestone facies of the lower dolomite lithotope, a few good euhedral crystals show etching. Since there is no dolomite present, other solutions evidently contributed to the etching.

Only the unaltered Rattlesnake Spur section contains detrital quartz. This indicates:

A. Rattlesnake Spur section was closer to source area, or
B. Dolomitization removed all detrital quartz, as well as much of the authigenic variety.

Cubic pseudomorphs of limonite after pyrite occur throughout the basal dolomite lithotope seemingly unaffected by dolomitization. Neither did dolomitization seem to affect the occurrence of igneous fragments.

Silicified fossil material (brachiopods, bryozoans, corals, and crinoids) are rare in the basal lithotope but present in the limestone and the dolomite facies of some sections.

Spectographic analysis of samples from this lithotope in the Rattlesnake Spur section show some degree of correlation with the insoluble residues. The silica content and the amount of quartz material present is quite consistent. No correlation between the presence of limonite pseudomorphs and the Fe-content of the rock is shown. The pseudomorphs are too small and few in number to expect any rise in Fe-content from a few analyses. It is interesting to note the similarity between the residues and chemical analyses of 24, 24A, and 24B.

Chemical conditions of the water, during and shortly after deposition of this strata (over 80 feet), must have been very uniform in the early Madison basin. A sudden influx of siliceous material, as is shown by 23, greatly altered the chemical conditions from what they had been.

The average grain size, as determined from thin sections of the lower limestone lithotope is shown plotted against the MgO content on Table 4. The decrease in grain size from the unaltered limestone facies of the Rattlesnake section through the "doubly dolomitized" sections, and increase again in the only slightly altered south Long Ridge section presents two possibilities:

A. As noted previously, fine grained limestones are most susceptible to dolomitization, or
B. The inadequately known process of dolomitization decreases the grain size.

Van Tuyl (1914, p. 402) discussed the susceptibility that fine grained limestone has to being dolomitized. He also discusses obliteration of original structure by dolomitization as evidence of shrinkage which resulted from the molecule-by-molecule replacement of limestones by dolomite.

If the Rattlesnake Spur section can be considered as an average of the lower Gardner as it was before dolomitization, it is likely that subsequent replacement by dolomite has reduced the original grain size.

Lithologic studies from residues, as well as fossil occurrence from unaltered through altered sections, would indicate that all of the Gardner sediments were similar at the time of deposition. From this evidence it seems necessary to conclude that in the lower dolomite lithotope, dolomitization has decreased grain size.

The grain relations vary through the most dolomitized to the unaltered section. The doubly dolomitized north Long Ridge section is composed of little other than uniform interlocking dolomite rhombs. The dolomitized middle Long Ridge section shows uniform interlocking dolomite rhombs interrupted by at least 5% (/) calcite grains, showing quite well the paragenesis. The slightly dolomitized southern Long Ridge section shows many dolomitized crinoidal fragments, but some unaltered crinoids as well as etched bordered calcite grains are present.

The undolomitized Rattlesnake Spur section has matrix which varies from 10% of the rock in the base, to 75% of the rock at the top of the lower lithotope. The grains in this section are sub-angular to sub-rounded and vary from equant to elongate. Many of the grains show evidence of solution--perhaps intrastratal solution activity. The largest grains are characteristically crinoid fragments.

Crinoid, coral, brachiopod, and bryozoan hash is abundant throughout the unit. Some of the crinoid fragments show secondary growth. A few poorly preserved foraminiferas, probably Endothyroids, are also present.

Environment and Summary of Post-Depostional Activity

The lower dolomite biotope of corals, bryozoans, crinoids, brachiopods, and foraminifera indicate that the lower Gardner was deposited in shallow, temperate, clear water. For example, the sessile benthos brachiopods prefer clear, warm water and a close to shore habitat. Although many brachiopods live as deep as 600 feet, the ecology of the whole biotope clearly shows a neritic environment.

Normal marine and fossiliferous-fragmental limestones suggest that the lower lithotope was deposited on a stable shelf.

The detrital material, consisting of rounded to subrounded quartz, some igneous material, and a few large flakes of biotite, indicate a source area at some distance from the deposition site. The degree of rounding of the few grains of quartz and igneous material suggests long transportation, with much elimination of material. The few flakes of mica have buoyance that also supports the idea of a long transportation history.

During deposition of the carbonate material authigenesis facilitated by intrastratal solutions was active. Good, doubly terminating quartz crystals and gypsum rhombs bear evidence to this.

Either synonymous with the diagenesis of the sediments, or likely after lithification, conditions became favorable for dolomitization of the the lower Gardner limestones. It seems likely that the magnesium content of the Gardner sea, coupled with factors not discovered in this study, reached a point where extensive replacement could take place. The etching on authigenic quartz crystals seems to indicate a post-authigenic age for the replacement. The marine replacement governed by as yet unknown factors altered the majority of the clastic Gardner limestone to dolomite.

Much later, geologically, complex faulting of the formation provided channel-ways for magnesium solutions, possibly leached from the thick dolomites below. This ground water activity passed through the marine altered dolomite, etching and removing much material susceptible to alkali solutions, and dolomitized any material previously unaffected.

LOWER LIMESTONE LITHOTOPE

Petrology

Conformably overlying the lower dolomite lithotope is a section of lithologically similar limestones, dolomitic limestones, cherty limestones, and dolomites. This unit will collectively be termed the lower limestone lithotope. The sections on Rattlesnake Spur, Lake Mountain, West Mountain, and Piccayune Canyon consist essentially of limestone. The middle and southern Long Ridge sections are dolomitic limestone, and the north Long Ridge and north Selma Hills sections are predominently dolomite, with some cherty limestones.

In the Rattlesnake Spur and north Selma Hills sections, the great thickness of the strata below the "curley" and above the lower dolomite lithotope permit a division of the lower limestone lithotope into two units. These two field units are not recognizable as discrete units eastward, for they thin and become one unit in the Lake Mountain, West Mountain, Long Ridge, and Piccayune Canyon areas. This is shown on plate 3.

For purposes of discussion the two lithotopes in the Rattlesnake Spur will be considered as equivalent, in part at least, to the one unit of the Long Ridge area sections. The writer recognizes the possibility that all of one of the units may be completely missing eastward; or, thinning eastward accompanied by lithofacies change may have occurred.

The thickness varies from 60 feet to about 400 feet but seems to average approximately 180 feet.

The limestone varies from dark blue-gray, through gray, becoming almost black in some places. The lithographic limestones in the top of the sections vary through pink-brown-gray and purple. The limestones commonly weather somewhat lighter and grayer and characteristically show a "meringue" surface. The dolomites and dolomitic limestones vary from dark blue-gray, through gray-blue, to dark gray-black. They are slightly dolomitized in some sections, more or less completely in others. The grain size varies from fine to medium grained. Much of the rock is crystalline. No uniformity of bedding is seen in the sections. It varies from thinly laminated to massive bedded, and most of the sections show these variations.

The majority of the sections are moderately hashy near the top of the lithotope.

Chert is present locally in a few of the sections. Examination shows that much of this chert is the "case hardened" variety, which seems to indicate a residual accumulation of silica, concentrated by subsequent removal of carbonates and other unstable minerals. Some of the rock which only superficially resembles chert actually is true chert.

Near the top of most of the measured sections, just below the "curley bed", a lithographic to sub-lithographic limestone characteristically can be recognized. It serves to locate the stratigraphic position of the "curley bed" where this latter may locally be hard to locate. An interesting feature seen only in the Rattlesnake Spur section is a two inch bed of intraformational conglomerate and a pseudo-"curley bed" of about the same thickness. They occur about seven feet below the base of the "curley bed".

Fossils identified in field study include:

Caninia sp., Syringopora spp., other coral material and various brachiopod remains. This is charateristically one of the most unfossiliferous parts of the Gardner formation. The chief organic material appears to be crinoids.

Petrography

Insoluble residues show that the lower limestone lithotope has a larger percentage of authigenic and detrital quartz than the lower dolomite lithotope. As mentioned previously, this can be attributed to less dolomitization. The detrital quartz, as is the case with the lower dolomite lithotope, is limited to the unaltered section on Rattlesnake Spur.

This quartz varies from 0.025 mm. to 0.15 mm. and is sub-angular to sub-rounded. The grains are predominantly equant.

The absence of detrital quartz in the other undolomitized sections indicates that perhaps the Rattlesnake Spur section was closer to a source area, although its removal in other localities by intrastratal solution may possibly have occurred.

Authigenic quartz is present in the lower limestone lithotope of all sections studied. In the north Long Ridge area, it does not form a high percentage of the insoluble material; in fact it is very limited in total amount. The slightly altered south Long Ridge section and the Rattlesnake Spur section contain etched quartz. As pointed out before however, etching is not necessarily limited to dolomitizing solutions.

Pseudomorphic limonite after pyrite is found in all of the sections. In the north Long Ridge area it comprises 75 % of the residues. This suggests that the solutions responsible for dolomitization also facilitated pseudomorphic growth. In many of the residues the iron did not have a crystal shape and apparently had been disaggregated by crushing.

TYPICAL RESIDUES FROM THE LOWER LIMESTONE LITHOTOPE

Section and	Sample No.	Wt. Gms	Soluble		Insoluble		Clay Size Matter	Quartz in %							Fossils	Limite	Gyp.	Fe-Mg	Mica	Chert	Mag.
								Authigenic			Detrital										
			Gms	%	Gms	%		An.	Sub.	Eu.	R	SR	SA	A							
Rattle-	21D	10.86	9.94	91.6	.92	8.4	90			7					Corals	X		X			
snake	21C	10.57	8.14	97.7	2.43	22.9			15			80			Bryozn	X		X			
Spur	21B	10.15	8.98	88.5	1.17	11.5				15		80			Crinoid	X		X			
	21A	10.00	9.73	97.3	.27	2.7	80		5			15				X					
	20B	10.53	10.43	99.0	.10	.94	40	45							Bryozn	X	X	X			
	20A	10.03	9.71	96.8	.32	3.19	65	20							Corals	X		X			
	19C	9.90	9.45	95.5	.45	4.5	20			70					Corals	X		X			
	19B	10.26	10.10	98.7	.16	1.4		75			20					X		X			
	19A	11.06	10.97	99.19	.09	.81			85			10									
	18A	10.17	9.47	93.1	.70	6.9	80	15							Bryozn	X					
	18	10.00	9.27	92.7	.73	7.3	75			5		15			Corals	X					
	17A	10.18	10.08	99.02	.10	.98	35			60					Corals	X		X			
	17	10.29	10.12	98.4	.17	1.6	80		15							X	X	X			
West Mt. *	N5	18.54	17.62	99.51	.92	.49	90								Bryozn	X					
*	N6-8	20.4	18.57	90.98	1.84	9.02				95					Brachs						
N. L. Ridge	Cg-2A	10.15	9.54	93.9	.61	6.0	85		10							X		X			
	Cg-2B	12.18	11.9	97.7	.28	2.3	10		10							X		X	X		
	Cg-2C	10.45	10.33	98.85	.12	1.15	60	30								X			X		
M. L. Ridge	O2 *	15.65	15.19	97.06	.46	2.94			90							X					
S. L. Ridge	H2A	11.0	10.63	96.63	.37	3.37	65			30						X		X			
	H2B	10.83	10.66	98.43	.17	1.57				95								X			

*Composite samples

Table 3

Basaltic material is present in many of the residues. The material averages 0. 03 mm. in greatest dimension and is sub-angular to sub-rounded. Biotite flakes are noted in only the north Long Ridge strata. In the lower dolomite lithotope mica is present in only the unaltered Rattlesnake Spur section. Its occurrence in dolomitized areas as well, suggests that it has no relation to dolomitization.

Many small, well silicified corals are present in the residues of the Rattle snake Spur rocks. They likely can be referred to the genus Triplophyllites. Other silicified corals, crinoids, brachiopods, bryozoans, and ostracods are present. Most of the silicified remains are too fragmental for precise identification. The coral fragments can however, be identified with some certainty as being Triplophyllites. sp. and Multihecopora sp.

The average grain size from thin section study varies from 0. 332 mm. in the Rattlesnake Spur section to 0. 123 mm. in the Long Ridge area, for an over-all average of 0. 227 mm. This slight decrease, as discussed previously, could be attributed to dolomitization.

The CaO content and the grain size are directly proportional. An inverse relation exists between the MgO content and the grain size. This definitely points out that dolomitization tends to decrease the grain size.

No correlation between the presence of limonite, gypsum, igneous Fe-Mags in residues and the chemical content from spectographic analysis is shown. The size and number of insoluble particles is too small in a few grams of material to affect a spectogr aphic analysis. The use of slightly over 10 grams of material for the insoluble residue tests greatly increases the chance of quantity and variety of insolubles o ccurring.

The matrix of the rock varies from 10-15% in the limestones. The dolomite sections have less than 10% matrix. In a few of the limestone sections some of the grains show solution borders. Evidently, the solutions responsible for the "hacksaw", or sutured edges on some of the grains were quite irregular. That is, beds not showing any evidence of solution activity are overlain and underlain by beds which have many solution bordered grains. This would suggest that intrastral solution activity was penecontemporaneous, or at the most syndiagenetic.

Many of the grains not affected by solutions are in contact with each other, and form a dense uniform texture. Most of the grains are equant.

The dolomite sections from the Long Ridge area show a good interlocking dolomite mosaic. One thin section of interlocking dolomite rhombs shows "hacksawed" calcite grains in such a relation to suggest that the paragenesis of calcite to dolomite had not been completed. It substantiates the idea that the dolomite is a secondary feature.

Many of the rocks in the lower limestone lithotope are encrinites.

CHART SHOWING AVERAGE GRAIN SIZE PLOTTED AGAINST MgO CONTENT

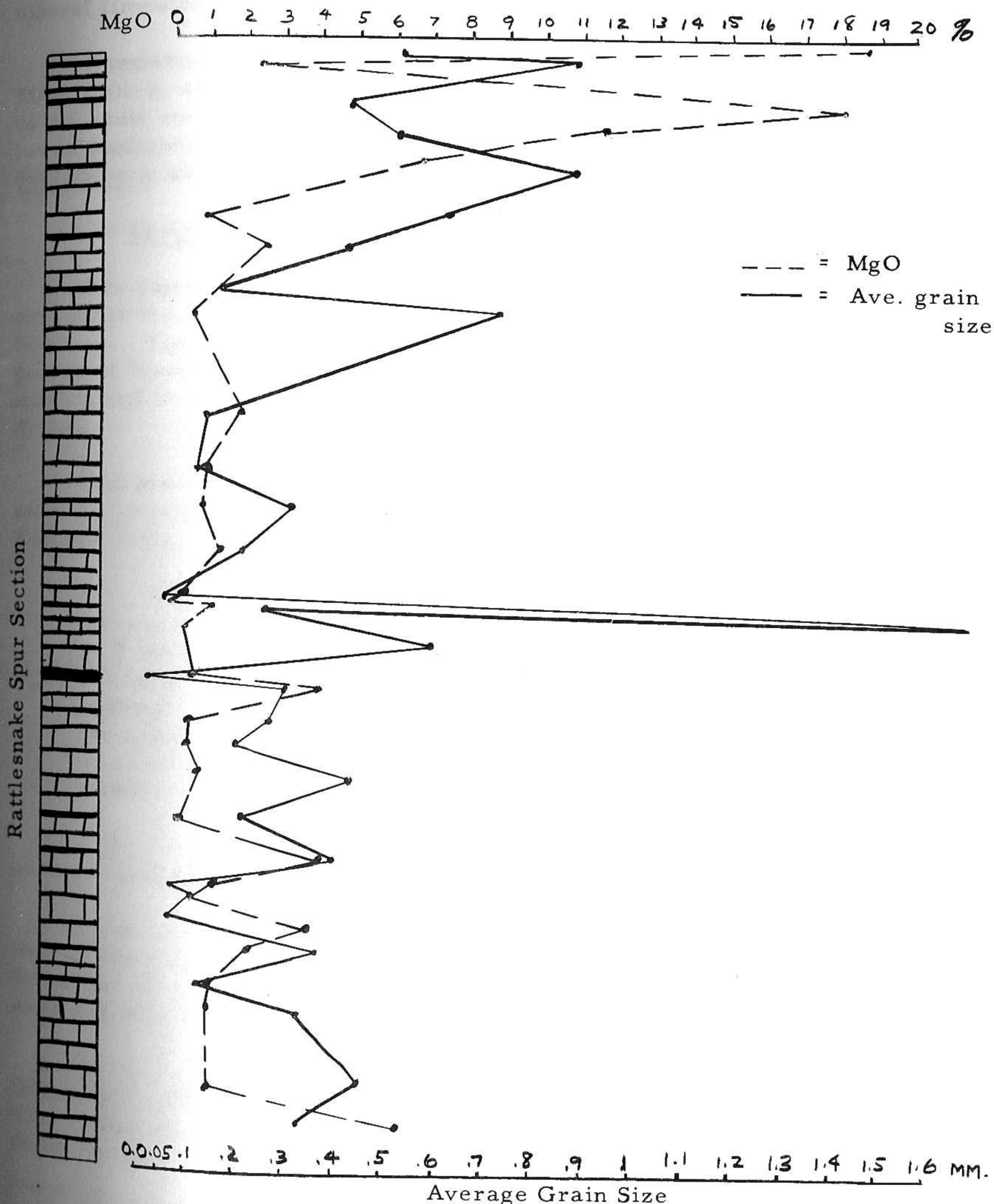

Table 4

Crinoidal debris is the most prominent organic material throughout this lithotope. Other fossils seen from thin section study are bryozoan debris and brachiopod hash. Numerous foraminifera are also present. In some rocks Granuliferella are so abundant as to give the name "foraminiferal limestone" to the strata containing them.

Comparison with foraminifera identified for the writer by Dr. and Mrs. Zeller, shows that most of the foraminifera of this lithotope belong to the same zone. Since the zone of Granuliferella is widespread in the lower Madison* and Gardner, it could be used as a guide fossil along with Syringopora as indicating rocks of Kinderhookian age.

Environment and Summary of Post-Depositional Activity

The same biotope of corals, brachiopods, bryozoans, and crinoids is present in the lower limestone lithotope as is present in the lower dolomite lithotope. This would indicate that the shallow, clear, temperate water persisted through deposition of the lower limestone lithotope. The normal marine and fossiliferous fragmental limestones show stable shelf conditions.

The presence of abundant foraminifera can also give much information as to the depositional environment. According to Moore, Lalicher, and Fischer (1952, p. 53):

> "The environment of sedimentation has a direct influence on the distribution of foraminifera, the type of material on the sea floor being one of the most important factors. Variations in the amount of light and the chemical and physical properties of sea water also influence the distribution of formainiferas . . . Although most of them occur in seas of normal salinity, some live in brackish waters, both along coasts and in some lakes . . ."

They further point out that foraminifera are absent in sandy strata and are most abundant in calcareous and argillaceous formations.

From fossil and lithologic evidence, it can be concluded that the lower limestone lithotope as well as the dolomite lithotope below, were deposited in clear, temperate, shallow water - - most likely the neritic zone of a stable shelf, in the Gardner Sea.

In the upper part of the lower limestone lithotope lithographic and sublithographic limestone becomes prominent. This is seen in all sections. The environment for depostion of this ex-solution limestone varied little from the shallow temperate water that had persisted before. However, the

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*Letter to Dr. H. J. Bissell from Dr. M. L. Thompson, January 12, 1954.

occurrence of a biostrome, as is discussed later, indicates that lagoonal or bank conditions likely existed in the Gardner Sea about this time. Such conditions would be ideal for precipitation of the ex-solution limestone and would readily account for the occurrence of an algae biostrome.

A small, two-inch intraformational conglomerate bed occurs near the top of the lithotope. The broken fragments show little rounding and are predominantly sub-angular and angular. Some minor diastrophic event such as an earthquake or other similar occurrence broke up newly consolidated rock and formed many discrete particles. Renewed sedimentation cemented these fragments into a new rock.

Pene contemporaneous with diagenesis of the sediment, or shortly after diagenesis was complete, intrastral solutions circulated through the sediments, etching and removing material. Authigenic action caused growth of much authigenic quartz, in many cases euhedral doubly terminating quartz crystals. Iron pseudomorphs were also prominent authigenic growths. Marine dolomitization controlled by as yet unknown factors and probably including many of the intrastral solutions, dolomitized the Gardner in various places. If a structural or topographic high existed around the Long Ridge area, as is indicated by the isopachous map, perhaps the depth of water was a control of dolomitization.

During post-lithification of the rock ground water and hydrothermal solution associated with faults, percolated through the rocks and subjected much of the section to another stage of dolomitization. This is especially noted in the north Long Ridge section.

PLATE
1

Explanation

A. Characteristic dolomite mosaic of the Long Ridge area, x 20.

B. Fine grained specimen from the Rattlesnake Spur section, x 20.

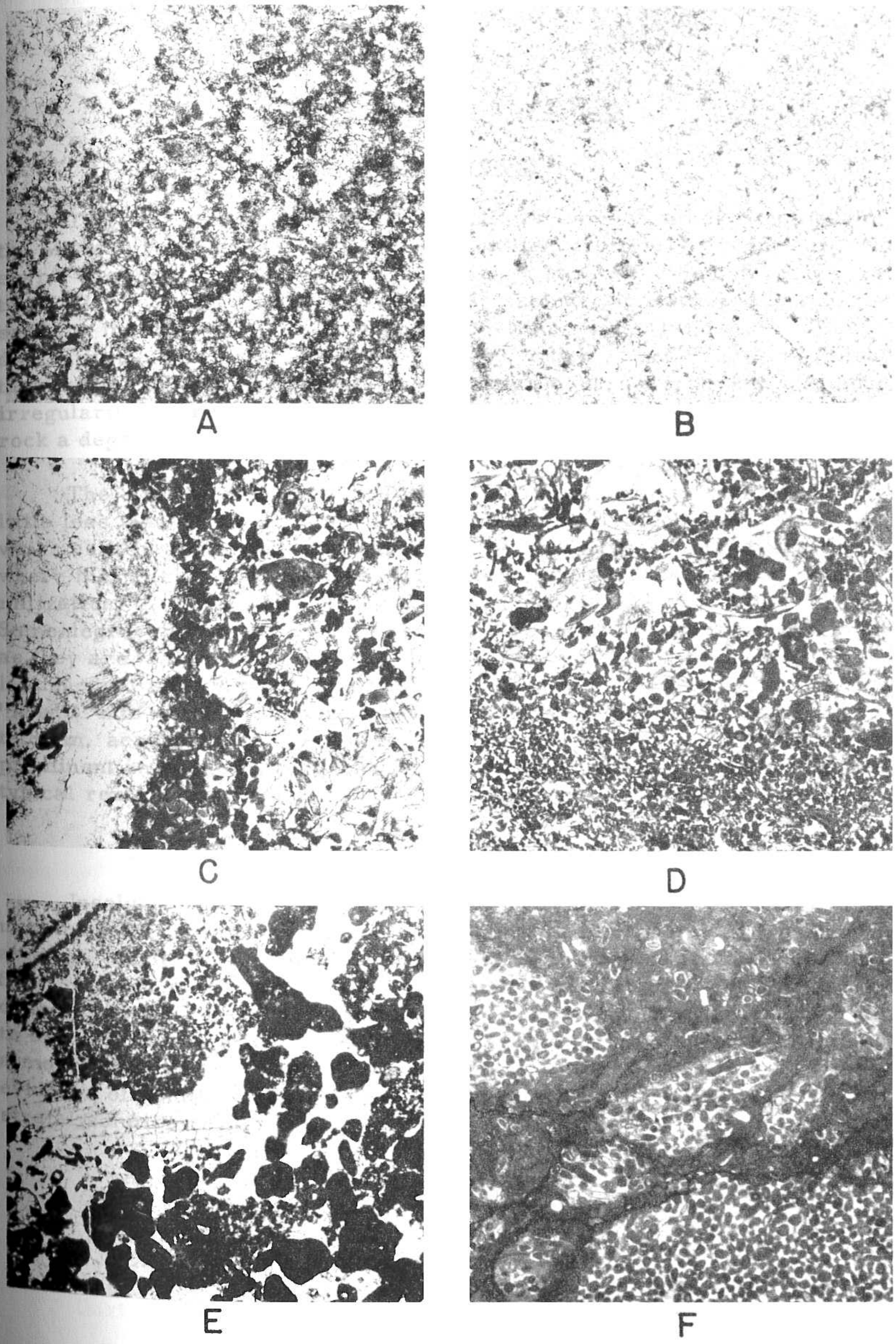
C. Detrital material and fossil hash from Rattlesnake Spur, x 20.

D. Graded bedding and fossil hash, Rattlesnake Spur, x 20.

E. Large angular particles from above the "curley bed" on Rattlesnake Spur, x 20.

F. Intraformational conglomerate occurring just below the "curley bed", Rattlesnake Spur, x 20.

Plate I



THE "CURLEY BED"

Petrology

The "curley bed" of the Gardner differs from all other lithotopes of the Mississippian strata. The outcrop or float from it has been found where-ever a complete section of Gardner has been studied. The bed varies from two to five feet thick. In unaltered areas, such as the Rattlesnake Spur section, it consists of lithographic to sub-lithographic limestone. The distinctive feature of this bed is the wavey, crinkly, and "curley" laminae that carry with some regular fashion throughout its outcrop belt. Although irregularity is present, many nearly symmetrical conical heads give the rock a degree of uniformity in places.

The laminae vary from 1/16 mm. to 5 mm. with an average of a little less than 1/4 mm. The color of the laminae varies from light gray which usually alternates with a medium or dark gray. In some sections where the "curley bed" has been subjected to different contitions (dolomitization) the colors vary through shades of brown-gray and blue-gray. Some degree of consistency is noted for the laminae in color and thickness as they are traced along strike. Inconsistency in color of the thickest laminae and alteration of light and dark bands is prominent. The individual "heads" into which the laminae at various intervals swell, vary from 4 cm. to 8 cm. across. The average seems to be about 6 cm., but variation is prominent in each locality. The laminae show differential weathering and a typical rough surface is usually present.

Petrography

Insoluble residues from the "curley bed" average 0.12 gms. of insoluble material from an average of 10.34 gms. of rock, or 1.10% of an average "curley bed" sample is insoluble. The residue from the Rattlesnake Spur section, which comprises a standard in this report, is 98% euhedral, doubly terminating quartz crystals. These crystals vary from 0.075 mm. to 0.4 mm. and average about 0.15 mm. Etching by solution activity has almost obscured the shape of many of the crystals, while others show no evidence of solution. This suggests several stages of authigenic and intrastratal solution activity:

A. Formation of quartz crystals
B. Etching and partial removal of many crystals by solution activity.
C. Second stage of authigenic growth

The repitition of this cycle is possible, but not proved from the writer's investigations. This cycle is further suggested by authigenic limonite growth. Six small irregular and cube-shaped crystals are present. Some of the quartz grains show iron staining not seen in other residues. The stained crystals are also etched and perhaps the solutions causing etching also carried enough iron material to stain them. The unaffected quartz crystals show no staining. A cycle of authigenic quartz and limonite growth followed by etching of quartz and staining by "solutionized" limonite and subsequent authigenic growth is suggested.

Spectographic analyses show that the MgO content is very low in unaltered sections. The only dolomitized "curley bed" is in the north Long Ridge area. The MgO average of the "curley bed" from the other sections is 0.70%. This is too low to attribute the dolomitization to anything but secondary replacement.

The iron content of the limonite is too low and the pseudomorphs too few to expect any noticeable increase in Fe. The silica average of 0.23% can be wholly attributed to authigenic quartz.

Thin section study does not contribute any significant information. The lithographic texture is not capable of measurement with the standard binocular microscope. Grains distinguisable with 40 power combination shows that they are smaller than 0.025 mm. No filaments or organic structure are present in thin sections of the unit. Probably the solution activity which facilitated authigenic growth removed most of the structure which was present.

Environment and Summary of Evidences

The "curley bed" has been considered by some geologists to be a result of sub-aqueous slump caused by a minor distrophic event while the sediments were only partially lithified. No "curley bed" was described by Lindgren and Loughlin (1914, p. 38) from the type locality, but a small intraformational conglomerate, at what appears to be approximately this horizon, may be its lateral correlative.

More recently work has suggested that the wide areal distribution (over 600 square miles) and its similarity to algal biostromes described elsewhere are indicative of an organic origin for this bed. Rigby (1949, p. 55) showed a sample of the "curley bed" to Dr. A. G. Fischer of the University of Kansas who commented on its similarity to cryptozoan limestone of the mid-continent. Clark (1953, p. 51), Peterson (1953, p. 67), and Sirrine (1953, p. 39) suggest that its similarity to the algae genus Codonophycus from the Mississippian Big Horn of Wyoming is evidence for its organic origin.

Darton (1906) and Fenton and Fenton (1939) mention the widespread occurrence of Codonophycus biostromes in the Mississippian Madison in Wyoming. Definite identification of the Gardner "curley bed" has been prevented by the lack of algal structure. As mentioned previously, extensive solution activity probably removed any structure that was present. The fact that algae are susceptible to replacement is borne out by the fact that much of the Codonophycus structure from the Madison was replaced by chert and amorphous silica.

Presently, much evidence for a biostrome nature of the "curley bed" has been found by Dr. P. D. Proctor. Dr. Harlan Johnson is now studying algal structure of the "curley bed" found by Proctor. Results of the independent work of Dr. Proctor and the writer will soon be published.

From the wide distribution, similarity to other biostromes, and organic structure found in the "curley bed", it is quite evident that it is a biostrome. Biostromes are associated with clear, shallow warm water, and probably grow on a stable shelf in a lagoonal environment. Sediments above and below indicate that this occurrence is quite normal and few conditions would need to be changed to facilitate such growth. The biostrome grew by development of convex laminae over laminae covering limited areas, which were connected over long distances by laminae extending from "head to head". The size of the structure indicates that it was an important feature of the Madison sea of upper Kinderhookian time.

During diagenesis and after, cyclic solutions facilitated authigenic growth and removed much of the organic structure present.

It is interesting to note that fossils above and below the "curley bed" indicate that it grew during the transition from Kinderhookian to Osagean time. As mentioned previously, Granuliferella in the beds below and Plectogyra tumula above it are indicative of sedimentation changes from the Kinderhook to the Osage. Perhaps this lithologic break may prove to be a good formation time-unit break.

THE MEDIAL LIMESTONE LITHOTOPE

Petrology

The medial limestone lithotope derives its name from the fact that it includes the middle and parts of the upper strata of the Gardner formation. The lithotope is predominantly limestone in all sections, except those on Long Ridge where it varies from limestone to dolomitic limestone, and dolomite. The thickness of this lithotope varies from 102 feet to over 500 feet; it averages 274 feet. It is interesting to note that, because of lateral lithofacies changes, the thicknesses of the units vary greatly from east to west. The lithotopes below the "curley bed" are thickest in the western sections, and the lithotopes above the "curley bed" are thickest in the eastern sections.

The color of the limestone is light through medium and dark blue-gray. It weathers pales medium to dark blue-gray and gray-blue. The dolomites and dolomitic limestones of the Long Ridge area are gray to light and medium blue-gray. Many of the pure dolomites have a dirty, somber weathered surface, and some are almost black. The sub-lithographic and lithographic limestone occurring quite high in some sections are usually lighter shades of gray and blue. Some are pinkish. All gradations from lithographic to fine- and coarse-grained rocks are present in this lithotope. Chert is present especially in the Long Ridge-Piccayune Canyon area. Thin, medium, and massive beds are present throughout the lithotope. Thick bedding predominates.

The majority of the fossils found in the Gardner formation are found in this lithotope. Plate 1 lists the fauna of the Gardner. All except Granuliferella are found in the medial lithotope. Most common of the medial biotope are Euomphalus luxus, Multithecopora sp., Triplophyllites sp., Caninia sp., Zaphrentis sp., Spirifer centronatus, and Syringopora sp. The gastropods Euomphalus and Loxonema sp. are very abundant. This zone was mentioned by Rigby (1952, p. 43) and others as the Euomphalus zone of the Gardner. No occurrence of Euomphalus is noted below the "curley bed". Its occurrence, alone or with other Gardner fossils, would serve to identify upper Gardner age rocks.

Petrography

Authigenic quartz is an important part of the insoluble residues throughout the medial lithotope. 0-100% of many residues is subhedral to euhedral quartz. Most of the euhedral quartz crystals are doubly terminating. The crystals vary from 0.05mm. to 0.75 mm. and average about 0.217 mm. in length. The size attained during authigenesis by a few of the crystals, considered with the overall average, indicates that the authigenic process was either long continued or very fast. No etching is present on any of the authigenic quartz from the residues of this lithotope. Although etching is not attributed wholly to dolomitizing solutions, it is interesting that this lithotope is the least replaced by dolomite and contains a greater percentage of limestone than any other unit.

Detrital quartz is found not only in residues from the Rattlesnake Spur section--as is the case for the lower lithotopes--but in the north Long Ridge section as well. The quartz shows a degree of irregularity which suggests restricted reworking. The samples from this area display only slight dolomitization. The detrital quartz varies in length from 0.05 mm. to 0.325 mm. and averages 0.25 mm. It is sub-angular to sub-rounded and equant. The fine clay size quartz, which is predominantly cement material, increases in this lithotope. Much of it is stained by iron and carbonaceous material.

Pseudomorphic limonite after pyrite is present in various units in all of the sections. Its presence throughout the Gardner certainly seems to point out that much iron in solution was available for authigenesis. Whether the initial iron content of the sediments was sufficient for such concentration, or whether iron dissolved from other sources and carried in by intrastratal solutions was responsible, is not clearly shown. Perhaps the process was a combination of these two.

The presence of gypsum crystals in a few of the samples can be attributed to authigenic growth. Chemical tests on the purity of the HCl used in residue work show that growth of the gypsum crystals was not facilitated by impure acid.

A few detrital grains of igneous material are scattered throughout the sections. Mica is present only in the southern Long Ridge section.

Chert is a minor part of portions of the medial lithotope. Its absence in residues is because samples in cherty areas were purposely taken away from chert to allow a better sampling of the pure limestone. Although some of the chert is of the case-hardened variety, true chert (primary or secondary) is present. The writer's work contributed no pertinent information as to the origin of chert. It comprises a very minor portion of the Gardner lithology. Perhaps periodic influxes of volcanic silica around the north end of the Manhattan Geanticline within the Madison Basin during Lower Mississippian time contributed to some extent to formation of the chert. According to Pettijohn (1949, p. 315), a replacement origin for nodules seems to be the best founded theory. Perhaps the bedded chert present in some localities below the "curley bed" is primary and most of the nodules secondary. In the Rattlesnake Spur section, which is used as somewhat of a standard for this study, chert is

TYPICAL RESIDUES FROM THE MEDIAL LIMESTONE LITHOTOPE

Section and	Sample No.	Wt.	Soluble		Insoluble		Clay Size Matter	Quartz in %							Fossils	Lim'te	Gyp.	Fe-Mg.	Mica	Chert	Mag.
								Authigenic			Detrital										
		Gms	Gms.	%	Gms.	%		An.	Sub.	Eu	R	SR	SA	A							
Rattle-	15	10.37	9.87	95.2	.50	4.8	50		25							X					
snake	14A	10.11	10.11	99.12	.09	.88			50							X	X	X			
Spur	13	10.15	10.02	98.8	.13	1.2				100											
	12	9.76	9.29	95.2	.47	4.8	60			35					Corals	X					
	10B	10.32	9.92	96.2	.40	3.8	60		25						Brachs		X				
	10A	10.01	9.88	98.7	.13	1.3	75		15			10			Bryozn.						
	9E	10.15	9.70	95.6	.45	4.4			20	75						X					
	9D	10.02	9.45	94.3	.57	5.7	75		10					10				X			
	9C	11.22	10.85	96.7	.37	3.3	50			35						X	X				
	9B	10.00	9.59	95.9	.41	4.1	80			15			5		Bryozn.						
	9	10.93	10.42	95.4	.51	4.6	50		25							X		X			
	8B	10.32	10.11	98.0	.21	2.0	90						10								
	8	10.17	9.50	93.4	.67	6.6	80		15						Crinod.	X					
West	* N9-10	21.27	20.34	99.0	.93	.43	10			80					Bryozn	X		X			
Mt.	* N11-13	23.43	21.67	92.5	1.76	7.5			5						Brachs	X	X			X	
North	Cg5	12.39	11.87	95.8	.52	4.2	95								Bryozn.	X					
Long	Cg6	9.49	9.04	95.1	.45	4.9						90				X					
Ridge	Cg8A	10.42	10.22	98.1	.20	1.9	80		5				10		Corals	X					
	Cg8B	12.32	11.08	99.0	1.24	1.0	85						10		Bryozn.	X					
	Cg8C	11.66	11.1	95.2	.56	4.8	95								Corals						
Middle	O4	24.06	23.56	98.0	.50	2.0				98					Brach	X		X			
L. Ridge	O4A	16.59	16.23	97.9	.36	2.1	15			80					Corals	X		X	X		
South	H3A	11.2	10.67	95.2	.54	4.8	80			10					Corals					X	
Long	H3B	12.28	11.96	97.4	.32	2.6	80			5						X					X
Ridge	H3C	12.3	12.21	99.27	.09	.73				100											
	H3D	12.45	11.84	95.1	.61	4.9	98									X		X			

*Composite samples

Table 5

SPECTOGRAPHIC ANALYSES OF THE LOWER LIMESTONE AND MEDIAL LIMESTONE LITHOTOPE

	SiO_2	Al_2O_3	CaO	MgO	Fe	S	P	Mn	Na
21D	.84	.12	54.12	.98	.08	.016	.010	.05	.22
21C	4.50	.21	51.44	1.36	.08	.008	.013	.06	.20
21B	4.02	.73	48.14	3.97	.30	.018	.063	.08	.35
21A	1.80	.42	53.62	.54	.09	.029	.014	.06	.43
20B	.80	.13	54.94	.73	.12	.013	.018	.06	.33
20A	3.20	.05	31.30	19.34	.15	.008	.004	.06	.26
19C	.22	.14	54.62	.91	.08	.009	.007	.02	.17
19B	1.14	.12	54.76	.28	.08	.008	.004	.03	.12
19A	.54	.12	52.44	2.48	.08	.014	.018	.04	.35
18A	3.22	.28	53.10	.85	.08	.013	.005	.05	.24
18	1.78	.38	53.86	.57	.09	.012	.007	.03	.24
17A	.40	.09	54.96	.21	.08	.042	.005	.02	.37
17	.48	.36	51.20	3.53	.10	.017	.006	.03	.46

Lower Limestone Lithotope

	SiO_2	Al_2O_3	CaO	MgO	Fe	S	P	Mn	Na
15	1.46	.21	54.22	.37	.11	.017	.008	.02	.14
14A	.42	.12	54.95	.28	.10	.008	.006	.02	.27
13	.68	.12	54.98	.24	.09	.021	.003	.02	.07
12	2.96	.18	53.32	.55	.10	.004	.004	.02	.21
10B	3.04	.19	53.10	.86	.09	.012	.02	.02	.18
10A	1.62	.28	54.02	.41	.09	.016	.008	.02	.18
9E	1.46	.16	54.40	.48	.08	.006	.005	.02	.12
9D	1.82	.21	54.08	.40	.09	.013	.004	.03	.21
9C	1.50	.56	46.40	6.83	.10	.010	.006	.02	.48
9B	.84	.13	54.80	.33	.18	.008	.010	.04	.12
9	.92	.08	53.98	1.08	.09	.019	.012	.05	.10
8B	1.58	.13	54.10	.52	.08	.009	.024	.04	.48
8	2.85	.32	52.90	.84	.09	.016	.004	.03	.50

Medial Limestone Lithotope

Table 6

present in only a few scattered strata. When present it is restricted to several nodules. Its occurrence in different intensity elsewhere would indicate that local conditions control its presence.

Spectographic analyses from this lithotope show quite a low silica content for most of the strata. The high CaO ratio and larger grain size bear out earlier conclusions.

The average grain size of the sections stay quite uniform through the Rattlesnake Spur to Long Ridge sections. . Average grain size is 0. 343 mm. for all thin sections from the medial limestone lithotope. In some encrinite units of the Rattlesnake Spur lithotope, average grain size is 2. 6 mm. This is the largest grain size noted in the first four lithotopes of the Gardner. As is characteristic throughout, the largest grains are crinoid fragments and the coarsest rocks are encrinites. Thin section study shows that most of the grains are sub-angular to sub-rounded and equant.

The matrix of this lithotope comprises approximately 10 to 40% of the rock, averaging about 20%. Many of the grains show evidence of solution activity. Secondary calcite growth on some crinoid fragments is also characteristic.

Organic debris forms a larger percentage of this lithotope than in the units below. The fragments show evidence of being broken, worn, and shifted about by the wave and tidal currents which were part of the environment.

From this lithotope, the writer cut numerous thin sections; Dr. and Mrs. Ed. Zeller identified several slides containing Plectogyra tumula. This same species occurs abundantly in the Rattlesnake Spur section through southern Long Ridge area. It serves as a good index microfossil for upper Gardner age rocks. Bryozoan, brachiopod, coral, and crinoid hash is abundant in thin sections. Sponge (?) spicules are also present. These fragments with abundant Plectogyra tumula form a veritable coquina in many strata.

Environment and Summary of Post-Depositional Activity

Rigby (1952, P. 43) considered the upper fossiliferous limestones of the Gardner in the Selma Hills to have been deposited in stagnant waters. Because most fossil debris was broken and only Euomphalus was found whole and in all stages of its ontogeny, Rigby concluded "that Euomphalus was the only organism which inhabited the area."

Peterson (1953, p. 67) pointed out, however, that in Long Ridge many unborken shells besides those of Euomphalus are present, and "various stages of a species ontogeny can be represented by the normal process of living and dying". He concluded that different environmental contitions were typical of the Gardner and Rigby's thesis did not apply in the Long Ridge area.

Study of the Gardner throughout most of its outcrop area indicates that while stagnant water conditions may have been present locally, the over-all environment was probably clear, temperate, shallow water, much like conditions which existed previously. The presence of abundant bryozoans and corals which seem to thrive in clean, circulated water, as well as the occurrence of numerous crinoids which evidently devour much dead organic material, indicate that stagnant water was not widespread. Conditions for prolific growth of corals, brachiopods, crinoids, gastropods, bryozoans, and foraminifera suggest a neritic environment.

The presence of very little detrital quartz in the Rattlesnake Spur and Long Ridge areas indicates a source area at some distance from the depositional site. The increase in percent insoluble matter, greater percent matrix, and minor rise in average grain size coupled with the more clastic nature of the sediments, indicates a slightly more unstable shelf than existed previously. Greater angularity of soluble and insoluble material with the presence of magnetite indicate that reworking, sorting, and removal of various material was not as complete as in the lower lithotopes. Perhaps these conditions express a transition from the more stable shelf conditions below to the unstable conditions shown in many of the higher Mississippian rocks.

During diagenesis authigenic growth of quartz, limonitic pseudomorphs, and gypsum occurred. During intrastral activity some calcitic material was dissolved from crinoidal fragments and other clastic carbonate material. Evidently the solutions differed somewhat from those affecting the lower lithotopes, as no etching on the siliceous material is evident. Other solutions facilitated carbonate growth, as is evidenced from over growths on some crinoid debris.

Because the widespread occurrence of limestones above the "curley bed" and because these dolomites and dolomitic limestones occur only in areas where post-lithification alteration has taken place, it is the writer's conclusion that the dolomites of the medial limestone are due to ground water solutions. This alteration is correlated with the second stage of alteration mentioned for the lithotopes below.

PLATE
2

Explanation

A. Left, doubly terminating quartz crystals showing intense etching. Right, euhedral quartz crystals not affected by solution, both x 40.

B. "Foraminiferal limstone" containing abundant *Plectogyra tumula*, from above the "curley bed", Rattlesnake Spur. x 20.

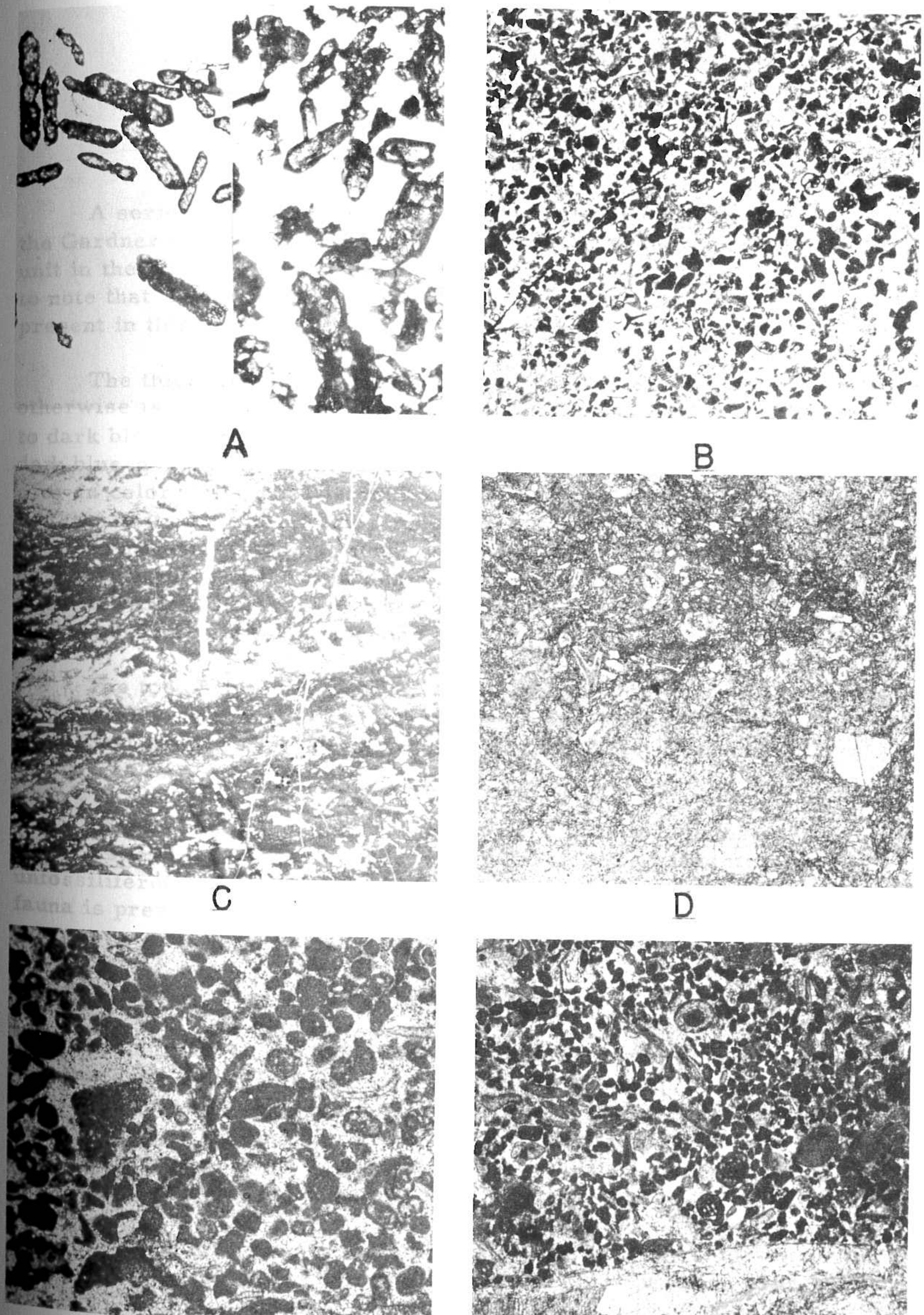
C. The "curley bed" , Rattlesnake Spur, x 40.

D. Fossil hash, showing bryozoan and much crinoid debris, x 20.

E. *Granuliferella* , from below the "curley bed", Rattlesnake Spur, x 20.

F. *Plectogyra tumula* and other organic debris from above the "curley bed" on Rattlesnake Spur. x 20.

Plate 2



THE UPPER LIMESTONE LITHOTOPE

Petrology

A series of rather uniformly bedded limestones occurs at the top of the Gardner formation. Dolomite and dolomitic limestones represent this unit in the altered middle and north Long Ridge area. It is interesting to note that the only dolomite present in the Rattlesnake Spur section is present in this unit. It occurs as two thin beds in the top of the formation.

The thickness varies from 56 to 160 feet at the extremes, but otherwise is quite uniform. Its average is 120 feet. The limestone is light to dark blue-gray and weathers pale light through shades of medium and dark blue-gray. The dolomites and dolomitic limestones are lighter gray in color. The rock is characteristically fine to coarse grained. A few thin units of lithographic limestone are present locally. The bedding is predominantly thick, although individual units of thin to massive beds do occur in most of the sections. A few scattered chert nodules are found at various horizons. In the southern Long Ridge area some of the limestone is slightly argillaceous.

The top of this unit is taken at the base of the first bedded cherts in the overlying Pine Canyon formation. This is an excellent contact for all of the Gardner sections the writer investigated. The contact is conformable.

Fossils in the uppermost lithotope are Triplophyllites sp., Euomphalus luxus, and a few brachiopods. This lithotope is characteristically unfossiliferous when compared to the rich fossil zone below, but a small fauna is present.

Petrography

Residues from the lithotope contain a high percentage of subhedral and euhedral authigenic quartz. Only in the dolomitic middle Long Ridge section is there no authigenic quartz present. The largest crystals are doubly terminating quartz. In length they vary from 0.025 mm. to 0.375 mm. and average about 0.125 mm. A few crystals near the top of the lithotope show evidence of having been slightly etched.

Sub-angular to sub-rounded detrital quartz is of minor importance in a few of the residues from the Rattlesnake Spur section. The grains are predominantly equant.

TYPICAL RESIDUES AND SPECTRO. ANALYSIS FROM THE UPPER LIMESTONE LITHOTOPE

Section and Sample No.		Wt. Gms	Soluble Gms	Soluble %	Insoluble Gms	Insoluble %	Clay Size Matter	Quartz in % Authigenic An.	Sub.	Eu.	Detrital R	SR	SA	A	Fossils	Limite	Gyp.	Fe-Mgs	Mica	Chert	Mag.
Rattle-	7	10.00	9.57	95.7	.43	4.3	25			50		20						X			
snake	6	10.33	10.24	99.13	.09	.87	90		5						Bryozn		X				
Spur	5B	10.18	9.95	97.8	.23	2.2	75		10				10		Crinoid	X					
	5A	8.61	8.20	95.3	.41	4.7	50			40			10					X			
	4A	10.07	9.81	97.5	.26	2.5	80		10				5		Bryozn						
	4	10.45	10.20	97.6	.25	2.4	75			20						X		X			
	3	10.07	9.43	93.7	.64	6.3	95								Bryozn			X		X	
	2	10.13	9.98	98.6	.15	1.4			45		40					X		X			X
	1	10.06	9.72	96.7	.34	3.3	95									X					X
West Mt.*	N14-15	19.12	18.81	98.4	.31	1.6	20			70					Corals	X			X		
M.L. Rdge.*	O4A	23.69	23.37	98.7	.32	1.3	100														
S.L. Rdge.*	H4A	11.55	11.50	99.57	.05	.43			100												

Sample	SiO_2	Al_2O_3	CaO	MgO	Fe	S	P	Mn	Na
7	4.56	.14	50.84	1.97	.09	.021	.005	.02	.19
6	.65	.09	55.04	.50	.08	.008	.008	.02	.20
5B	1.85	.18	53.16	1.22	.08	.011	.005	.05	.28
5A	.92	.09	52.50	2.25	.08	.008	.008	.02	.12
5	8.42	.18	50.20	.56	.20	.005	.044	.02	.30
4A	2.52	.12	46.78	6.56	.10	.016	.012	.04	.11
4	2.24	.28	40.46	11.82	.10	.015	.004	.04	.17
3	3.78	.16	32.30	18.05	.05	.024	.003	.03	.20
2	.48	.15	52.70	2.26	.08	.020	.003	.04	.10
1	.56	.18	33.44	18.80	.10	.012	.006	.05	.18
O4A	.88	.05	32.00	19.80	.3	.011	.012	.10	.20

*Composite samples

Table 7

Authigenic limonite pseudomorphs are present in the Rattlesnake Spur and West Mountain sections. Magnetite grains, sub-rounded to rounded are present in the top beds of the lithotope. The first occurrence of magnetite was noted in the medial lithotope. This suggests that incomplete sorting, borne out by other evidence, is characteristic of the upper lithotopes. Detrital basaltic material and mica are present in the residues.

High MgO content of a few thin strata in the upper lithotope must be attributed to marine alteration. A consequent decrease in grain size for these strata is also present.

The average grain size is 0 . 293 mm., a slight decrease from the lithotope below. The average grain size from the Rattlesnake Spur section is 0. 225 mm. compared to 0. 312 mm. in the Long Ridge area.

The grains studied in thin sections show a high degree of angularity not encountered in the lithotopes below. All of the sections show grains which are angular to subangular with only a minor portion which are subrounded. Heterogeneous assortment of grains is present in most of the sections. This is also evidence of incomplete sorting.

The matrix comprises as much as 75% of the rock in some sections. 15-20 % appears to be the lower limit of matrix for any of the sections. Matrix averages 30-40% of the thin sections studied. Some grains show evidence of solution activity, but no consistency in stratigraphic position or amount of etching is present. An interesting paragenetical sequence is shown by a thin section from the middle Long Ridge area. In this section, the matrix (which is 30% of the rock) has been altered to dolomite. The larger crinoidal gragments are seemingly the most resistant to dolomitization or at any rate the last affected. Many of the larger fragments have not been altered, while others show stages from partial recrystallization to a complete stage. Evidently the solutions responsible for the alteration were not strong enough to effect complete replacement, or they were not replenished sufficiently to cause complete alteration.

The rocks are characteristically hashy. Crinoid, brachiopod, sponge, bryozoan, and coral fragments are abundant. Brachiopod spines and fragments of impunctate brachiopod shells are present in a few of the thin sections.

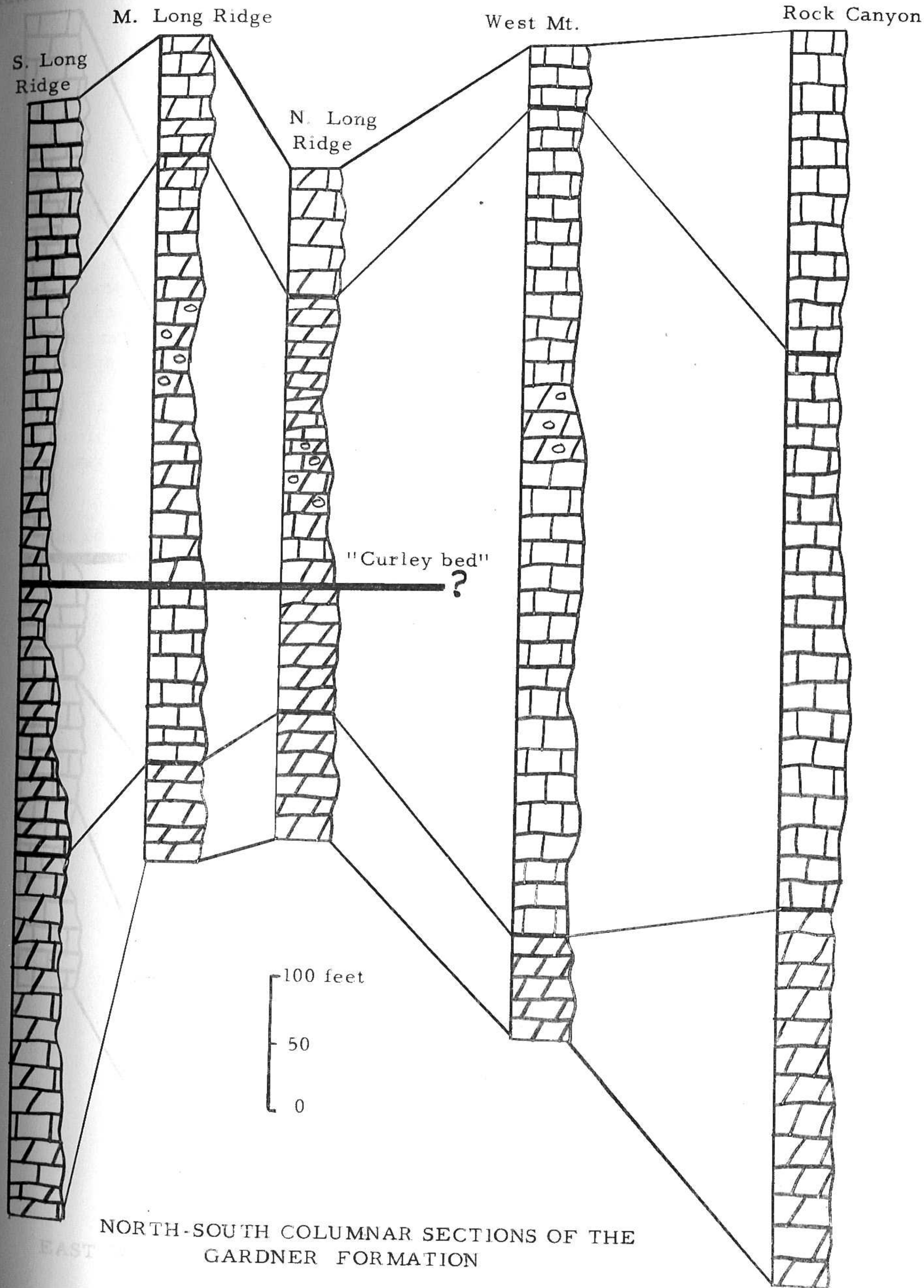
Thin sections from all of the areas show the presence of <u>Plectogyra tumula</u>. Some of these endothyroid foraminifera attain a length of 0. 5mm. Slides from this lithotope are among those identified by Dr. and Mrs. Ed Zeller.

Environment and Summary of Post-Depositional Activity

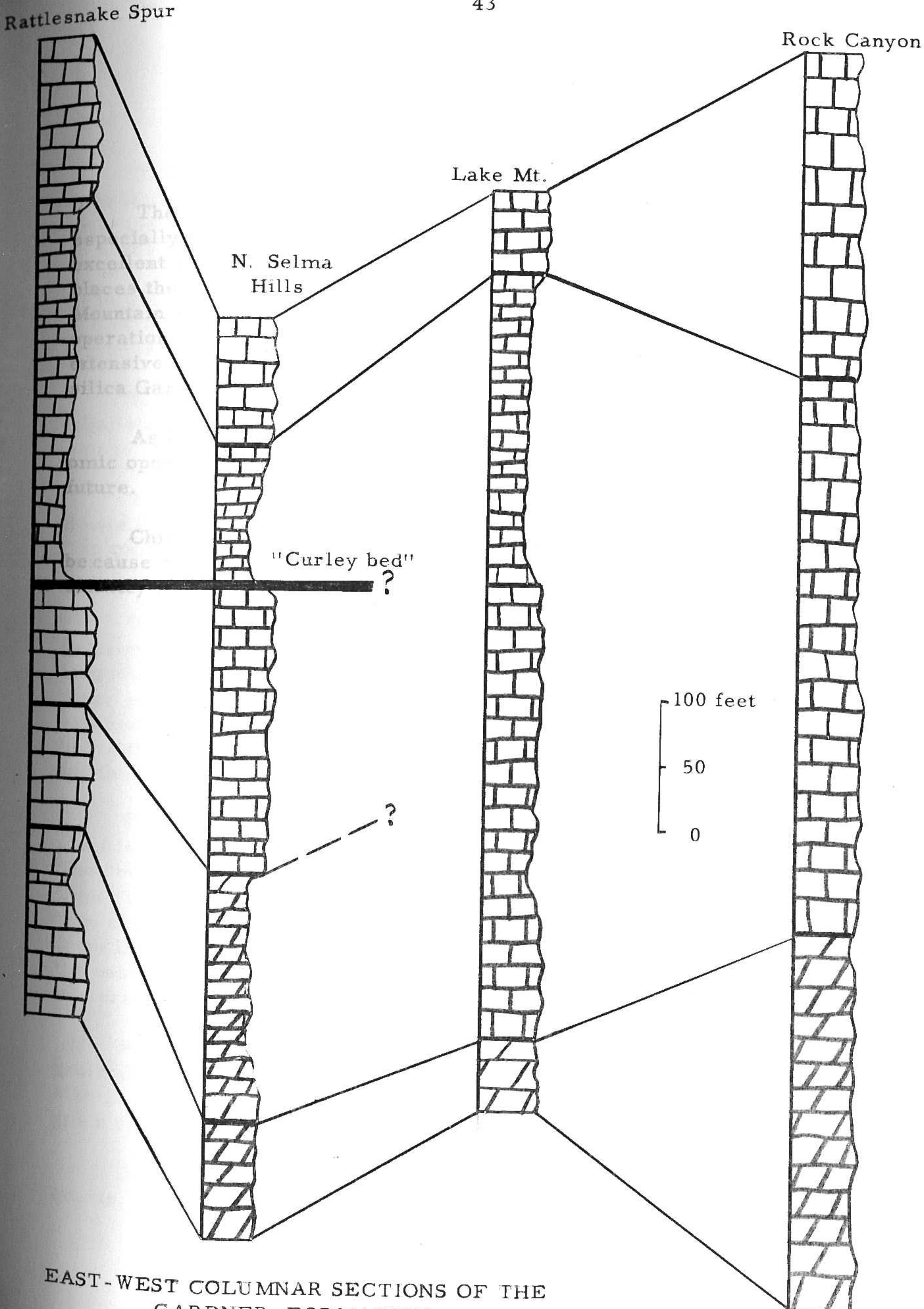
The upper limestone biotope suggests a neritic environment similar to the conditions which prevailed during deposition of the lithotope below. Incomplete sorting, high angularity of the discrete fragments comprising the sediments, and increase in clay size matrix material indicate that a slightly unstable shelf condition, as likely prevailed during sedimentation of the lithotope below, persisted through deposition of the upper Gardner beds. The water, while high in organic content, was probably not stagnant. Bryozoans and corals characteristically live in clear, temperate, shallow water which has some circulation.

Minor marine dolomitization affected local strata not replaced previously, but by and large most of the upper Gardner was not altered. Authigenic growth produced quartz, limonite pseudomorphs, and a minor amount of gypsum crystals. Solution activity affected some of the authigenic material, as well as the carbonate debris.

The post-lithification ground water alteration of the Long Ridge area was not as intense as before and incomplete replacement prevails. Perhaps this activity was penecontemporaneous with the later tectonic activity which has affected the basin of deposition of the Gardner.



NORTH-SOUTH COLUMNAR SECTIONS OF THE GARDNER FORMATION



EAST-WEST COLUMNAR SECTIONS OF THE GARDNER FORMATION

ECONOMIC APPLICATIONS

The low silica and magnesium content of much of the Gardner, especially the Rattlesnake Spur section, indicate this formation as an excellent source of limestone for the steel industry. Also, in many places the Gardner is easily accessible. On the southern end of West Mountain in the Keigley Quarries, some Gardner is included in quarrying operations. In the north Selma Hills Columbia-Geneva Steel have extensive mining claims laid out for limestone and dolomite. The low silica Gardner is one of their main objectives.

As has been shown, at present much Gardner is utilized in economic operations. Probably the Gardner will be exploited more in the future.

Chicken feed and fertilizer are possible economic uses, but because of an abundance of better material in this same locality, it seems unlikely that the Gardner will be utilized as such.

SUMMARY

The Gardner formation consists of a series of thin to massive bedded limestones which have been affected by varying degrees of dolomitization. Only the lower lithotope is predominantly dolomite. This dolomite occurs in areas subsequently subjected to ground water and other alterations as well as unaltered areas and it is concluded that many of the lower beds were subject to marine dolomitization. Except in areas that were subjected to post-lithification dolomitization, the remaining beds of the Gardner are limestone.

In the middle portions of the formation an algal biostrome known locally as the "curley bed" occurs. Above this bed organic rich limestones and encrinites are abundant.

The base of the Gardner is taken at the first occurrence of sucrose dolomite (commonly light gray) above the Pinyon Peak "flakey" limestone. The top of the formation is drawn at the base of the first bedded cherts of the Pine Canyon Limestone.

Over 30 fossil genera including brachiopods, corals, bryozoans, gastropods, and foraminifera have been described from the Gardner. The largest and most prolific fauna occurs above the "curley bed", although many genera are distributed throughout the formation. Identification of much of the fauna has established a lower Kinderhookian age for the beds below the "curley bed" and an upper Kinderhookian to lower Osagean age for the beds above the biostrome.

The lower Gardner was deposited in the neritic zone of a stable shelf in the Cordilleran Miogeosyncline known also as the Madison Basin. The "curley bed" marks bank or lagoonal deposits in the geosyncline. Upper Gardner sediments reflect slightly more unstable shelf conditions than existed previously. No apparent break in sedimentation is noted from Devonian through Mississippian time in much of the basin, but to the east (now the site of the south-central Wasatch Mountains) a disconformity is present.

Petrographic examination shows that dolomitization decreases grain size. Consequently a direct proportion between CaO and grain size is usually present. An inverse relation exists between MgO and grain size.

Dolomitizing solutions are responsible for removal and etching of quartz, although other alkali solutions are in part responsible.

Mappability of Lithotopes. Although the lithotopic subdivisions and correlations are largely based on field relations, only a few of the lithotopes lend themselves readily to being mapped. The lower dolomite lithotope is quite widespread and could be mapped with little difficulty. The upper contact would be drawn at the first occurrence of limestone. Where limestone predominates throughout, this unit could only be mapped if a good field break occurs 100 ≠ feet above the base.

The lower limestone lithotope could readily be mapped where the lower dolomite lithotope is present. It would include the strata above the dolomite to the base of the "curley bed". In areas where the dolomite is not present, the entire strata below the "curley bed" and above the Pinyon Peak would be a good mappable unit.

Above the "curley bed" the lithotope cannot readily be sub-divided. The medial and upper limestones could be divided on the basis of the highest occurence of Euomphalus but this poses obvious difficulties. The upper Gardner above the "curley bed" if mapped as such would include two lithotopes as described in this report but would facilitate mapping locally if not throughout all the central Utah part of the Madison Basin.

Recommended Subdivisions. To students of the Gardner formation it is obvious that three prominent subdivisions occur and are readily recognized:

A. The strata above the Pinyon Peak formation and below the "curley bed".
B. The "curley bed"
C. The strata above the "curley bed" and below the Pine Canyon cherts.

On the basis of:

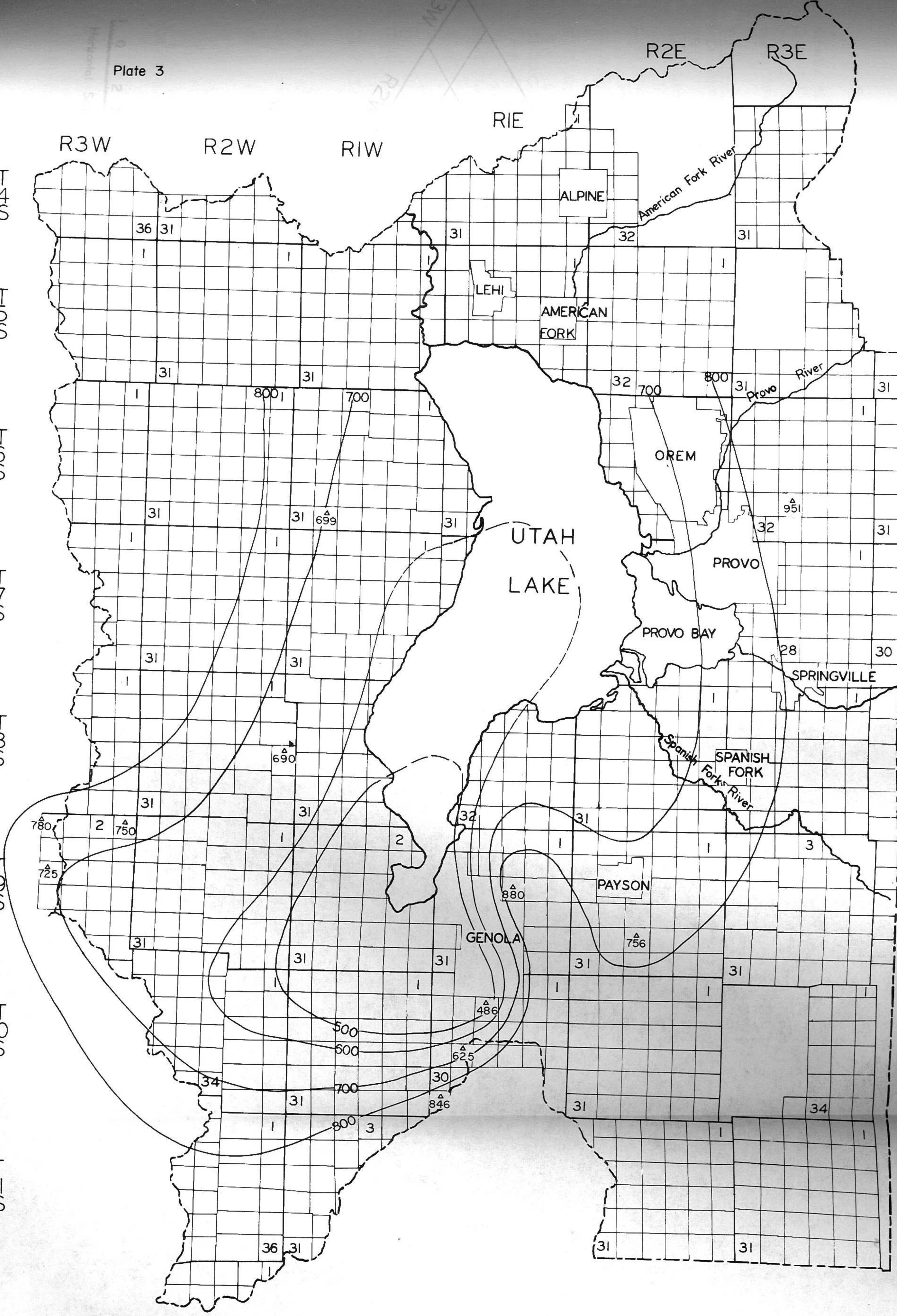
1. Mappability of units below and above the "curley bed"
2. Diagnostic fossils which indicate strata below "curley bed" are lower Madison (lower Kinderhookian) and strata above are upper Madison (upper Kinderhookian-lower Osagean).
3. Lateral similarity of lithofacies of strata above and below,

it is the writer's recommendation that the Gardner be divided into two members. These members would be the strata from the base of the "curley bed" to the base of the Pine Canyon formation.

This would greatly facilitate mapping and description of the Gardner as well as make the divisions time units. Perhaps this division is not ideal, but nonetheless it approaches nearest the stratigraphers concept of a good usable and mappable time-rock subdivision. The writer does not propose any new name for these two members at this time, because it is his understanding that members of the U. S.

Geological Survey, independent of this type of research, are currently drafting proposals of emended nomenclature of the Mississippian rocks in central Utah.

Plate 3



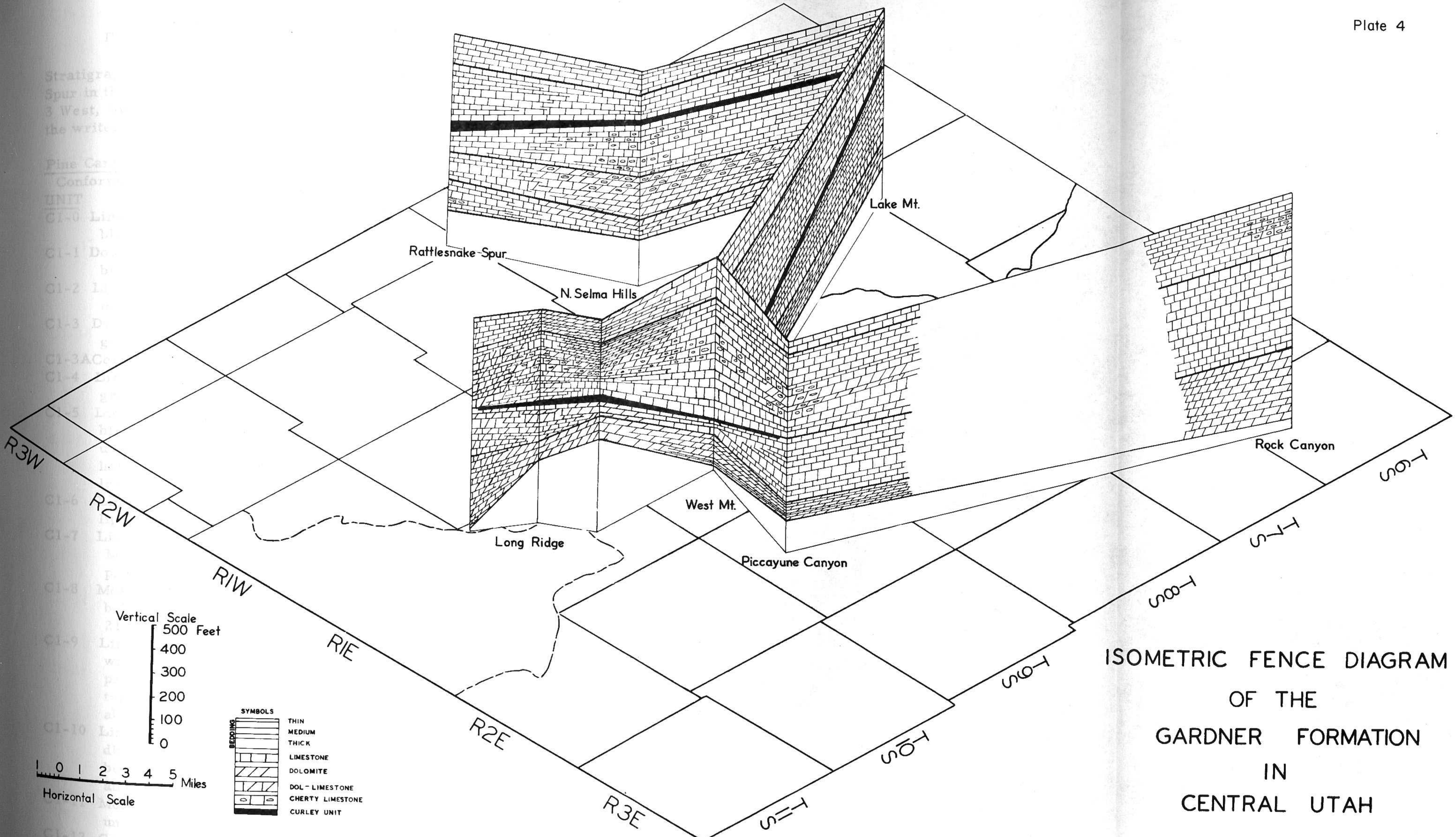
ISOPACHOUS MAP OF THE GARDNER FORMATION

2 1 0 1 2 3 4 5 6 7 8 9 10 Miles

CONTOUR INTERVAL 100 FEET

△- Measured Section

Plate 4



ISOMETRIC FENCE DIAGRAM
OF THE
GARDNER FORMATION
IN
CENTRAL UTAH

David Clark

APPENDIX

Detailed Stratigraphic Sections of the Gardner Formation

Stratigraphic section of the Gardner formation measured on Rattlesnake Spur in the northeast corner of section 1, Township 9 South, Range 3 West, by Dr. H. J. Bissell, Dr. J. K. Rigby, Jim McFarlane, and the writer.

Pine Canyon limestone

Conformable contact

UNIT	DESCRIPTION	THCKN. IN FT.
C1-0	Limestone, med. blue-gray, weathers med. to dk. gray-blue, med. bedded, fine grained	4.0
C1-1	Dolomite, light to med. blue-gray, weathers med. gray-blue. Very crystalline, med. to thick bedded.	13.0
C1-2	Limestone, med. to dk. gray-blue, weathers pale light to med. blue-gray. Fine to med. grained, thick bedded. . .	9.6
C1-3	Dolomite, med. to dk. grayish-blue, weathers somber med. gray-blue. Fine grained, med. bedded.	2.0
C1-3A	Covered interval, probably thin bedded lms.	3.5
C1-4	Limestone, med. to dk. gray-blue, weathers med. blue-gray, meringue surface. Med. bedded, some fossil hash.	18.0
C1-5	Limestone, med. to dk. gray-blue, weathers somber med. blue-gray to gray-blue. Light brownish-black chert nodules present at random throughout unit. Fine grained to hashy. Much hash in base of unit. (C1-5 about 2 ft. below top, A from 1 ft. below top, B, from base).	27.0
C1-6	Limestone, blue-gray to med. gray-blue, weathers lighter, fine grained, some coarse. Med. to thick bedded.	48.0
C1-7	Limestone, med. to dk. blue-gray, weathers blue-gray. Med. grained, some siliceous material. _Euomphalus_ present, some corals.	1.0
C1-8	Mostly covered interval. First good bed occurs 21 ft. below top. Float is very hashy. (C1-8 from fossil bed 21 ft. below top, A from same fossil bed, B from base).	36.3
C1-9	Limestone, med. to dk. gray-blue, weathers darker and with a meringue surface. Fine to med. grained, some parts hashy. Massive bedded. (C-19 from 10 ft. below top, B from top bed, C, midway in unit, D from just above basal bed, E from base).	41.0
C1-10	Limestone, dk. blue to dk. gray-blue, weathers med. to dk. grayish-blue. Fine to coarse grained, thin to med. bedded, some laminae. Corals present. (A and B from about 7 ft. below top).	16.0
C1-11	Mostly covered slope, but scattered outcrops show that unit is very hashy and fossiliferous.	89.0
C1-12	Covered unit but outcrops present show that it is limestone, thin bedded containing corals and gastropods. . . .	72.0

C1-13	Limestone, dk. gray-blue weathering dk. somber gray-blue, fine grained, massive bedded. Fossil hash......	8.7
C1-14	Limestone, light to med. gray in base becoming gray-blue upwards. Fine grained to sub-lithographic. Some chert stringers present. Corals and brachs abundant. (C1-14 frp, top, A, 6 ft. from base).................	22.0
C1-15	Limestone, dk. gray-blue, weathering med. to dk. gray-blue. Thin bedded, weathers platey. Hashy....	7.0
C1-16	Limestone, lithographic to sub-lithographic, light to to med. gray-brown-blue. Bed occurs in waves and curley bedding, called the "curley bed"..............	4.0

Lower Gardner

C1-17	Limestone, lithographic, pink to light purple. Beds weather pale light blue-lavender with a meringue surface. Thick bedded. 2 inch intraformational conglomerate bed bed at base. (C1-17 from base, A from top)..	7.4
C1-18	Limestone, light to med. blue-brown, weathering pale light gray-blue. Thin to med. bedded. Some sub-lithographic beds(laminae)..........................	3.8
C1-19	Limestone, a sub-lithographic to med. grained clastic, med. to dk. gray-blue, some brown-blue, weathers light gray-blue. Med. to thick bedded, corals present..	73.7
C1-20	Limestone, forms a slope with only a few outcrops present, dk. gray-blue, fine grained, thin-bedded (A, about ten feet below top, B, top)......................	26.5
C1-21	Limestone, dk. gray-blue , some almost black, weathers medium to dk. blue-gray, with meringue surface. Dense, thin to medium at top to thick and massive farther down toward base of unit. Corals present, some chert nodules. (A, from base B, 2 feet above base C, near chert bed D, 20 feet from top.)	68.0
C1-22	Mostly covered unit of limestone, light gray-blue to light purple-blue.	23.3
C1-23	Calcarenite, sandy looking bed, light to med. gray-brown, weathering dirty looking brown-gray.................	1.0
C1-24	Limestone, med. to dark brownish-blue at top, weathering dull med. to dark blue-gray, massive bedded. Corals present. The rock then grades imperceptibly into a "chicken wire" limestone, which is the Pinyon Peak of other areas. Contact here is arbitrary................	123.5
	Total Thickness	749.3

Conformable contact

Pinyon Peak limestone

Stratigraphic section of the Gardner formation measured on the south end of Long Ridge, sections 6 and 31, Township 10 South, Range 1 East by Bob Clark and the writer.

Pine Canyon limestone

Conformable contact

UNIT	DESCRIPTION	THCKN. IN FT.
H-4	Limestone, sub-lithographic, argillaceous, and hashy, dark blue to med. blue-gray, weathers pale-light to med. blue-gray, fine to med. grain, med. to thick bedded.	130.0
H-3	Dolomite, limestone, and some chert. Limestone is med. to dk. blue-gray, weathering somber med. to dk. blue-gray, very fossiliferous, containing typical Gardner fauna. Some lithographic limestone in upper part. Float from "curley bed" found in this unit.	235.0
H-2	Limestone and dolomite, med. to dk. blue-gray, weathering pale light to med. blue-gray. Fine to med. grained some crystalline. Med. to thick bedded, corals present.	203.0
H-1	Limestone, med. to dk. blue-gray, weathering light to dark somber blue-gray, fine to med. grained, hashy and siliceous. Lower 74 feet is med. to thick bedded. In the upper 170 feet the outcrops are covered by talus. Many dolomites and dolomitic limestones present in basal parts of unit, few fossils.	278.0
	Total Thickness	846.0

Conformable contact

Pinyon Peak limestone

Stratigraphic section of the Gardner formation measured on a prominent spur in the Little Valley area of central Long Ridge, section 20 of Township 10 South, Range 1 East by Dallas Peterson and the writer.

Pine Canyon limestone

Conformable contact

UNIT	DESCRIPTION	THCKN. IN FT.
0-5	Dolomite, med to dk. gray-blue, weathering pale light to med. blue-gray with small white specks prominent on the weathered surface. Fine to med. grained thin to thick bedded.	93.0
0-4	Lithographic limestone in basal part. This is overlain by the "curley bed". Rock is light to med. brownish-blue fine grained. Some dolomite and dolomitic limestone, typical Gardner fauna occurs at this horizon. Upwards limestone is light to med. gray-blue, weathering dk. blue-gray, med. to thick bedded	329.0
0-3	Dolomite, light to med. gray-blue, fine grained, thin bedded. Some chert and cross-bedding noted	7.0

0-2	Dolomite, some calcareous, med. to dk. gray-blue, weathering light to med. blue-gray, medium grained. Unit forms a prominent slope with outcrops quite irregular, upper part of unit is hashy, thin bedded. Some massive bedding also present.	121.0
0-1	Dolomite, siliceous, med. to dk. blue-gray, weathering pale light blue-gray , very fine grained, thick to massive bedded.	75.0
	Total Thickness	625.0

Conformable contact
Pinyon Peak limestone

Stratigraphic section of the Gardner formation measured on "Chaffin Quarry Mountain" in section 8, Township 10 South, Range 1 East by Keith Sirrine and the writer.

Pine Canyon limestone
Conformable contact

UNIT	DESCRIPTION	THCKN. IN FT.
Cg-11	Limestone, dolomite and dolomitic limestone, med. blue-gray, weathers pale med. gray, med. grained. med. to massive bedded, some hash.	96.0
Cg-10	Dolomite, light blue-gray, weathers pale blue-gray fine grained, thin bedded. Chert present locally. Some talus covered outcrops.	80.0
Cg-9	Dolomite, dk. blue-gray , weathers pale gray, fine grained, med. bedded, some laminated. Higher in unit beds become massive. Chert present.	64.0
Cg-8	Limestone, dark dirty light to med. gray , weathering pale light to med. gray. Coarse grained, thick to massive bedded. Chert present.	68.0
Cg-7	Limestone, sub-lithographic to lithographic, and dolomite. This is the "curley bed". Light to dk. brown-gray, wavey laminae.	2.0
Cg-6	Limestone, dark to light gray, weathers pale light gray to dirty white. Thin bedded, forms a slope.	8.0
Cg-5	Dolomite, dark gray weathers paler, fine grained.	2.0
Cg-4	Dolomite, dark gray to black, weathers somber light gray to gray-white, friable surface.	4.0
Cg-3	Chert, brown-gray to orange-brown, some dark.	3.0
Cg-2	Dolomite, dark gray to black, weathers somber dark blue-gray. Crystalline, massive bedded.	60.0
Cg-1	Dolomite, dark gray to black, weathers pale dark gray. Fine grained, thin bedded. Much talus.	98.0
	Total Thickness	486.0

Conformable contact
Pinyon Peak limestone

0-2	Dolomite, some calcareous, med. to dk. gray-blue, weathering light to med. blue-gray, medium grained. Unit forms a prominent slope with outcrops quite irregular, upper part of unit is hashy, thin bedded. Some massive bedding also present.	121.0
0-1	Dolomite, siliceous, med. to dk. blue-gray, weathering pale light blue-gray, very fine grained, thick to massive bedded.	75.0
	Total Thickness	625.0

Conformable contact
Pinyon Peak limestone

Stratigraphic section of the Gardner formation measured on "Chaffin Quarry Mountain" in section 8, Township 10 South, Range 1 East by Keith Sirrine and the writer.

Pine Canyon limestone
Conformable contact

UNIT	DESCRIPTION	THCKN. IN FT.
Cg-11	Limestone, dolomite and dolomitic limestone, med. blue-gray, weathers pale med. gray, med. grained. med. to massive bedded, some hash.	96.0
Cg-10	Dolomite, light blue-gray, weathers pale blue-gray fine grained, thin bedded. Chert present locally. Some talus covered outcrops.	80.0
Cg-9	Dolomite, dk. blue-gray, weathers pale gray, fine grained, med. bedded, some laminated. Higher in unit beds become massive. Chert present.	64.0
Cg-8	Limestone, dark dirty light to med. gray, weathering pale light to med. gray. Coarse grained, thick to massive bedded. Chert present.	68.0
Cg-7	Limestone, sub-lithographic to lithographic, and dolomite. This is the "curley bed". Light to dk. brown-gray, wavey laminae.	2.0
Cg-6	Limestone, dark to light gray, weathers pale light gray to dirty white. Thin bedded, forms a slope.	8.0
Cg-5	Dolomite, dark gray weathers paler, fine grained.	2.0
Cg-4	Dolomite, dark gray to black, weathers somber light gray to gray-white, friable surface.	4.0
Cg-3	Chert, brown-gray to orange-brown, some dark.	3.0
Cg-2	Dolomite, dark gray to black, weathers somber dark blue-gray. Crystalline, massive bedded.	60.0
Cg-1	Dolomite, dark gray to black, weathers pale dark gray. Fine grained, thin bedded. Much talus.	98.0
	Total Thickness	486.0

Conformable contact
Pinyon Peak limestone

Stratigraphic section of the Gardner formation measured in sections 15 and 22 of Township 9 South, and Range 1 East on the south end of West Mountain. Adapted from Elison (1952, pp. 43-44).

Pine Canyon limestone

Conformable contact

UNIT	DESCRIPTION	THCKN. IN FT.
N-14-15	Limestone, med. to dk. gray, weathering light gray. Lower ten feet contains thin beds of siliceous limestone. Some chert.	166.0
N-11-13	Limestone, med. to dk. gray, texture grades upward from med. to coarse grained.	80.0
N-9-10	Limestone, blue-gray, weathers light gray, med. to coarse grained. Some fossil zones.	438.0
N-6-8	Limestone, med. gray, weathers light blue-gray, fine to coarse grained. Corals present.	63.0
N-5	Dolomite, med. gray, some parts calcareous, med. to thick bedded. Much of unit covered.	60.0
N-1-4	Dolomite, med. to dk. gray, weathering med. blue-gray, poorly bedded.	73.0
	Total Thickness	880.0

Conformable contact (?)

Pinyon Peak limestone (?)

Stratigraphic section of the Gardner formation measured on the south-east flank of "Mollies Nipple", section 28, Township 9 South, Range 2 East. Adapted from Brown (1950, p. 28).

Pine Canyon limestone

Conformable contact

UNIT	DESCRIPTION	THCKN. IN FT.
6B	Limestone, light-gray, well bedded.	56.0
6A	Limestone, medium light-gray, cross-bedded with fossil hash, clastic, medium grained with some quartz fragments present.	180.0
6	Limestone, medium light-gray, massive, resistant beds with nodular zones of black chert. Chert weathers a light reddish-brown. Limestone cut by thin veinlets of calcite.	175.0
5	Limestone, dense, crystalline, vuggy with black chert.	92.0
4	Limestone, medium light-gray, thin-bedded with chert.	56.0
3	Limestone, med. gray, thin bedded.	32.0
2	Limestone, medium light gray, well bedded with nodules of black chert.	88.0
1	Dolomite, med. gray, fine grained, crystalline	77.0
	Total thickness	756.0

Unconformity

Cambrian (?) Dolomites

Stratigraphic section of the Gardner formation measured in the northeast corner of section 23 and northwest corner of section 24, Township 8 South Range 2 West. Adapted from Williams (1951, pp. 26-27).

Pine Canyon limestone
Conformable contact

UNIT	DESCRIPTION	THCKN. IN FT.
10	Limestone, med. blue-gray, weathers light blue-gray, thick bedded.	97.0
9	Limestone, blue-gray, weathers lighter tone, massive bedded, very fossiliferous, especially the lower part, containing brachiopods and zaphrentid corals.	102.0
8	Limestone, med. gray, weathers smooth, thin laminated with light gray calcite, curley or crinkled laminae ("curley bed").	4.0
7	Limestone, pinkish-gray sublithographic, weathers smooth.	14.0
6	Limestone, blue, weathers blue-gray, massive, fossiliferous, contains a small amount of chert.	130.0
5	Limestone, med. to light bluish-gray, weathers lighter in color with a rough surface, massive bedded. Black chert occurs in nodules with an occasional band of chert.	40.0
4	Dolomite, blue to dark blue-black, weathers lighter blue with a rough surface, massive bedded, black chert in nodules with an occasional band of chert, upper 30 to 40 feet grades into limestone.	120.0
3	Dolomite, light gray, dense, crystalline, sugary texture on weathered surface, massive bedding.	99.0
2	Dolomite, med. blue, weathers lighter tone, sugary text..	45.0
1	Limestone, gray-bluish, weathers gray and to a semi-slope jagged surface, few silicified corals present.	36.0
0	Dolomite, light somber gray, quite siliceous.	3.0
	Total Thickness	690.0

Conformable contact
Pinyon Peak limestone

Stratigraphic section of the Gardner formation measured on the west side of the Cedar Valley Hills in section 32, of Township 6 South, Range 1 West. Adapted from Calderwood (1951, pp. 27-28).

Pine Canyon limestone
Conformable contact

UNIT	DESCRIPTION	THCKN. IN FT.
5	Limestone, med. gray-blue and fossiliferous, Euomphalus common. Beds are all one lithologic unit in well bedded 1 to 2 ft. layers except in upper 50 feet which is more massively bedded.	139.0
4	Limestone, med. gray-blue to dark gray-blue, well bedded Most of the beds are covered by talus.	285.5
3	Limestone, light blue-gray to med. blue-gray, well bedded	42.0

2	Dolomite, med. to coarse grained saccaroidal, med. gray to gray-brown, slightly darker colored on weathered surface. Becomes more brownish and more dense in upper portion.	50.5
1	Dolomite, dark gray-blue, well bedded to massive, becomes slightly sandy near top.	57.0
B	Dolomite, sugary, light gray to light med. gray. Rock is dense medium to fine-grained and crystalline, and is much lighter gray.	68.0
A	Dolomite, dark gray-blue to blue-gray and medium to medium light gray, also some calcareous dolomite. Massive bedded. Upward beds are med. to med. light gray, locally cherty and contain numerous white specks.	57.0
	Total Thickness	699.0

Conformable contact

Pinyon Peak limestone

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