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SEDIMENTATION AND STRATIGRAPHY OF THE HUMBUG FORMATION IN CENTRAL UTAH

by

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SEDIMENTATION AND STRATIGRAPHY OF THE HUMBUG FORMATION IN CENTRAL UTAH

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Master of Science

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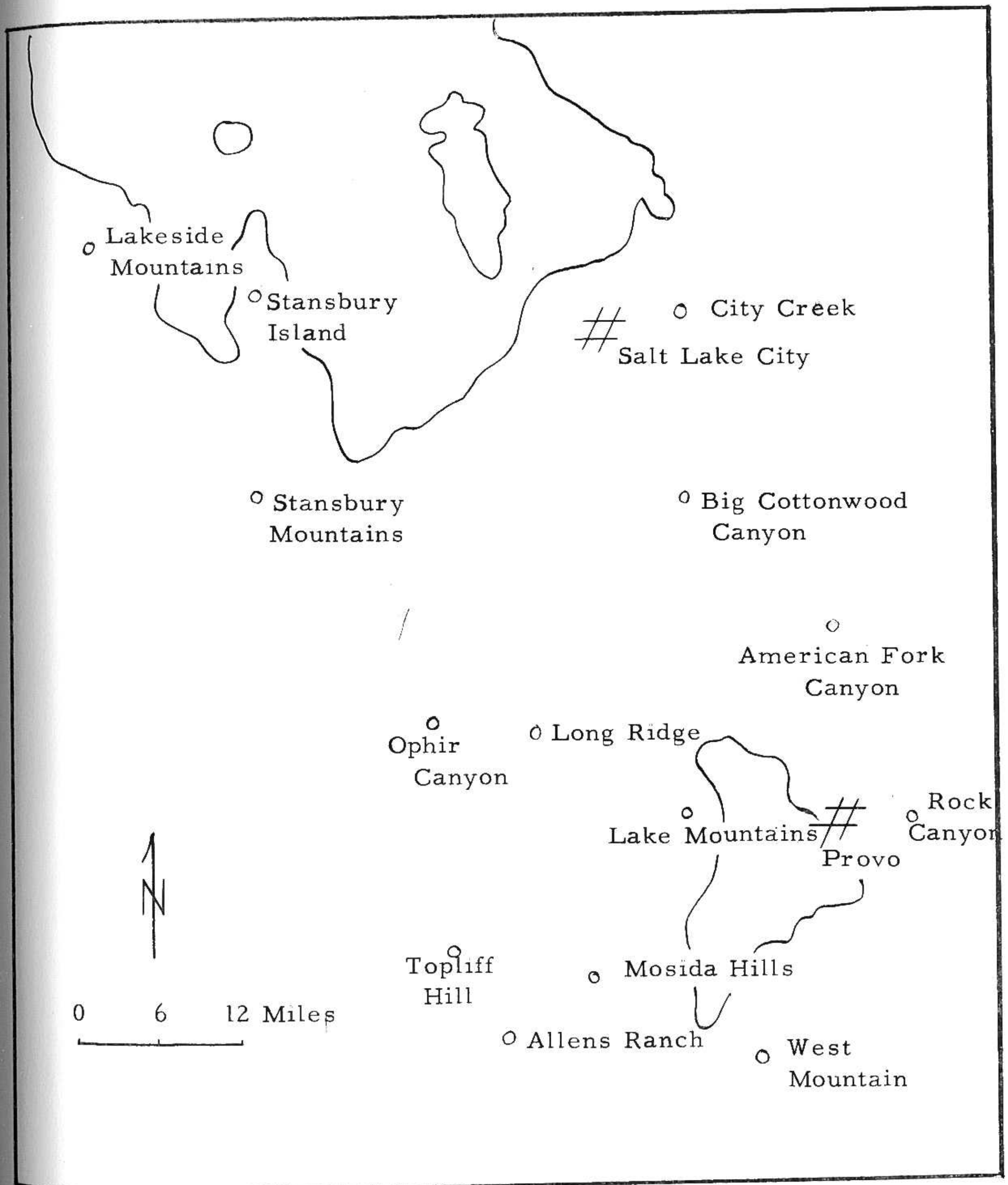
ABSTRACT

The Humbug formation outcrops in many localities throughout central Utah. It has been recognized as far east as Duchesne County, as far south as the Tintic mining district, and as far north and west as the Lakeside Mountains. It is over 2100 feet thick on Stansbury Island and thins rapidly to the south and east.

The Humbug formation consists of intercalated limestone, orthoquartzite, sandstone and dolomite. Many of the limestones and dolomites were deposited as clastics. Most of the carbonate clastic material was supplied by sessile benthonic organisms. Siliceous clastics probably originated west of the Brazer Basin. Several types of epigenetic and syngenetic sedimentary structures are present in the formation.

Faunal studies indicate that the formation is Upper Mississippian, probably Merimecian, in age. All of the fossils found in the formation are probably benthonic.



FRONTIS PIECE

INTRODUCTION

LOCATION

The Humbug formation outcrops at many places in central Utah. The formation was measured and studied at nine localities where complete stratigraphic sections are exposed (Plate 1). Six of these localities are in Utah County, the other three are in Tooele County.

The detailed sections are as follows:

1. Allens Ranch; one mile west of Allens Ranch in the Boulter Mountains, Sec. 12, T. 9 S., R. 4 W., Utah County.

2. Lake Mountain; one mile north of Rock Canyon on the west side of Lake Mountain, Sec. 20, T. 6 S., R. 1 W., Utah County.

3. West Mountain; one mile north of the Keigley Quarry, Sec. 22 & 23, T. 9 S., R. 1 E., Utah County.

4. Long Ridge; on the east side of the Oquirrh Mountains, Sec. 17 & 18, T. 5 S., R. 2 W., Utah County.

5. American Fork Canyon; on the south side of the canyon in Cattle Creek, Sec. 28, T. 4 S., R. 2 E., Utah County.

6. Rock Canyon; on the south wall of the canyon approximately one mile from its mouth, Sec. 26 & 27, T. 6 S., R. 3 W., Utah County.

7. Topliff Hill; on the northwest side of the hill opposite the old Columbia Iron Mining Company limestone quarry, Sec. 9, T. 8 S., R. 3 W., Tooele County.

8. Ophir Canyon; on the north wall of the canyon about two miles west of the town of Ophir, Sec. 19, T. 5 S., R. 4 W., Tooele County.

9. Stansbury Mountains; one hundred feet west of the first large limestone quarry just northwest of Grantsville on Highway 40, T. 2 S., R. 6 W., Tooele County.

PHYSICAL FEATURES

The Humbug sections which were studied are located in two major physiographic provinces. Seven of the stratigraphic sections are within the easternmost ranges of the Basin and Range Province; the remaining two sections are in the westernmost part of the Wasatch Range in the Central Rocky Mountain Province.

SCOPE OF REPORT

The Humbug formation has been mapped, measured and described by many geologists in central Utah, but not one of these workers has confined his investigation specifically to the Humbug formation. Therefore, the purpose of this report is to present a detailed study of the Humbug formation. It concerns the stratigraphy, conditions of sedimentation, and the fauna of the formation.

Outcrops of the Humbug formation are numerous in central Utah, but only a selected few were studied in detail. Some of the sections were measured in conjunction with studies being made by other graduate students at Brigham Young University. Other sections were measured at localities where work had been done previously by graduate students and professional geologists.

PREVIOUS WORK

The Humbug formation was named from exposures in the Humbug mine in the Tintic mining district by Tower and Smith (1897, p. 625). Previously Spurr (1894, p. 372), who mapped and measured it in the Mercur mining district, and Emmons (1877, p. 442), who mapped it in the Pelican Hills east of Lake Mountain, had called the formation the Lower Intercalated Series.

Lindgren and Loughlin (1919, p. 41) mapped the Humbug formation at its type locality. Dearden (1954, p. 34) mapped and measured a complete section of the Humbug in the Boulter Mountains. Rigby (1949, p. 65) mapped an incomplete section in the Selma Hills. Williams (1951, p. 40) and Hoffman (1951, p. 43) extended the mapping north into the Mosida Hills. Calderwood (1951, p. 41) and Bullock (1949, p. 16) mapped and measured the Humbug formation on Lake Mountain. Gilluly (1932, p. 26) mapped and measured a complete section of the Humbug formation in Ophir Canyon and McFarland (1955, p. 9) mapped and measured a complete section on Long Ridge in the Oquirrh Mountains.

Sirrine (1953, p. 47) mapped the Humbug formation in the Long Ridge area near Goshen, Utah. Elison (1952, p. 48) and Schindler (1952, p. 43) continued the mapping north past Keigley Quarry into the Genola Hills.

Baker (1947) measured the Humbug formation in American Fork Canyon. Mechan (1948, p. 33) mapped an incomplete section in Little Rock Canyon north of Provo. Brown (1950, p. 33) mapped an incomplete section in the Payson Canyon - Piccayune Canyon area.

PRESENT WORK

Field work.--Field work for this study was begun in September, 1953 and completed in December, 1954. The work consisted of detailed measuring with a steel tape and sampling each rock unit in the selected stratigraphic sections.

Laboratory work.--Laboratory work included preparation and study of thin sections and insoluble residues. Thin sections were prepared and analyzed using standard procedure. Insoluble residues were prepared by dissolving ten grams of dried pea-size sample at room temperature in dilute hydrochloric acid. The acid was prepared by diluting one part concentrated acid with ten parts distilled water. The residues were washed, filtered, dried, and weighed to determine the per cent of insoluble matter in the sample.

The petrographic microscope was used to make mineral identifications.

Grain size analyses of the orthoquartzites and sandstones were made by linear intercepts on thin sections. The data were grouped and plotted on histograms.

A cumulative lithofacies panel diagram was prepared.

STRATIGRAPHY

INTRODUCTION

Tower and Smith (1898, p. 625) described the Humbug formation at its type locality as:

> ...a number of beds of fossiliferous limestones and sandy limestones, the individual beds of which do not persist along the strike.

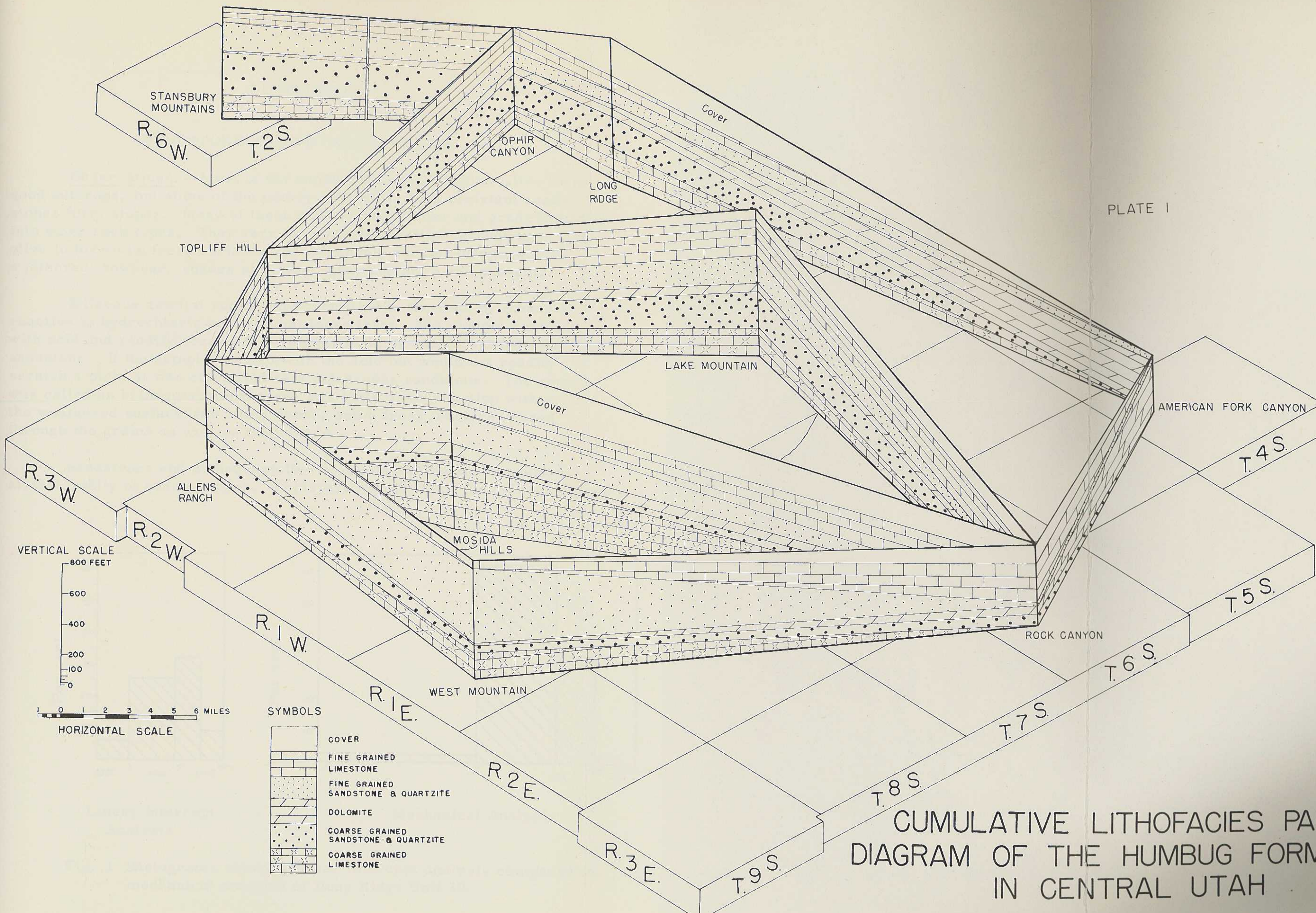
At all of the localities studied, the formation consists of interbedded limestone, dolomite, sandstone, and orthoquartzite except at American Fork Canyon. Here interbedded orthoquartzite and dolomite are characteristic.

Viewed from a distance the Humbug formation appears light brown, and forms ledges and slopes. The slopes are commonly found where easily eroded, poorly cemented sandstone or shaly limestone occur.

Individual units cannot be traced for great distances along the strike. Some of them pinch out while others grade by lateral facies change into other rock types. Spurr (1895, p. 372) notes the following about the Humbug formation (Lower Intercalated Series) in the Mercur mining district:

> Two parallel detailed sections were made up the sides of Lewiston Canyon... These sections were about three-quarters of a mile apart...the beds lying between them are very nearly in a horizontal position...in the southwesterly section the thickness of this intercalated series seems markedly greater than the northeasterly one. The beds of sandstone are rather markedly thicker, more numerous, and separated by thicker beds of limestone. In the northeasterly section fourteen distinct beds of sandstone were counted; in the southwesterly one, nineteen...there is no possibility of finding a perfect agreement between these two localities... in the intervening distance some of the sandstone beds of the one section must thin out and be replaced by the limestone which occurs in the other section.

PLATE I



CUMULATIVE LITHOFACIES PANEL DIAGRAM OF THE HUMBUG FORMATION IN CENTRAL UTAH

V.E. Livingston Jr.

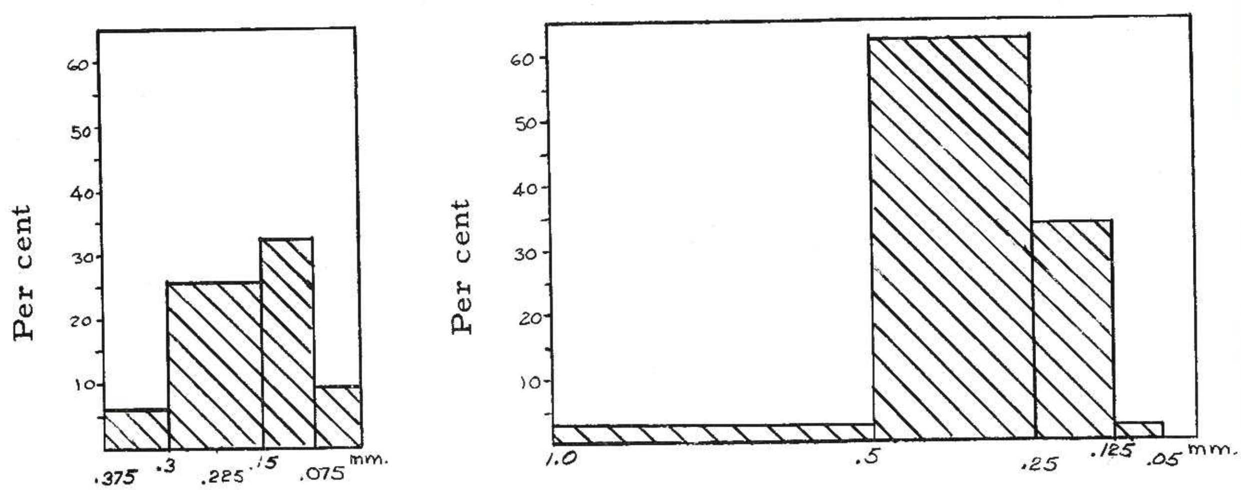
LITHOFACIES

SANDSTONE AND ORTHOQUARTZITE

Observations.--Most of the sandstones and orthoquartzites form good outcrops, but some of the poorly cemented, less resistant sandstones form slopes. Many of these beds are lenticular and grade laterally into other rock types. They vary in color from yellow through gray and olive to brown on fresh surfaces and commonly reddish-brown where weathered; however, shades of yellow, gray and olive are present.

Siliceous detrital rocks were identified in the field by means of reaction to hydrochloric acid and hardness tests. If a sample reacted with acid and readily scratched a geology pick, it was classified as a sandstone. If the sample reacted with the acid but would not readily scratch a pick, it was classified as a calcareous sandstone. The sample was called an orthoquartzite if there was little or no reaction with acid, the weathered surface was fairly dense, and a fresh fracture passed through the grains as well as the cement.

Sandstones and orthoquartzites of the formation are composed almost totally of quartz grains. Feldspars, which were the only accessory



Linear Intercept Analysis

Mechanical Analysis

Fig. 1 Histograms showing linear intercept analysis compared to mechanical analysis of Long Ridge Unit 20.

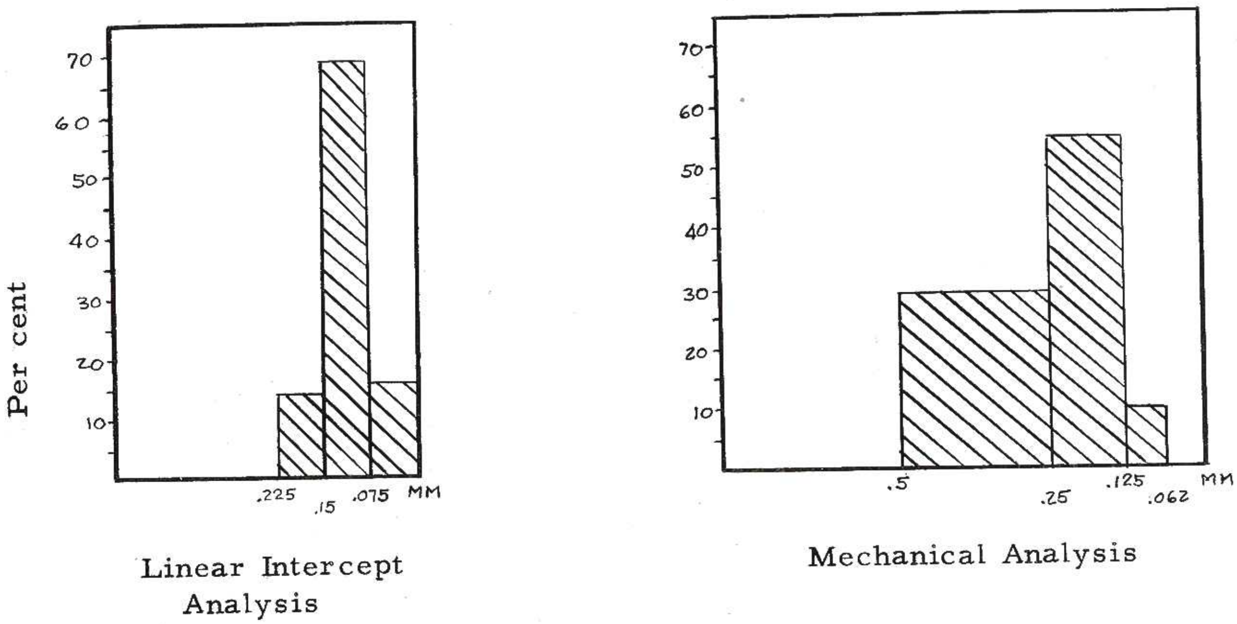


Fig. 2 Histograms showing linear intercept analysis compared to mechanical analysis of Long Ridge Unit 1.

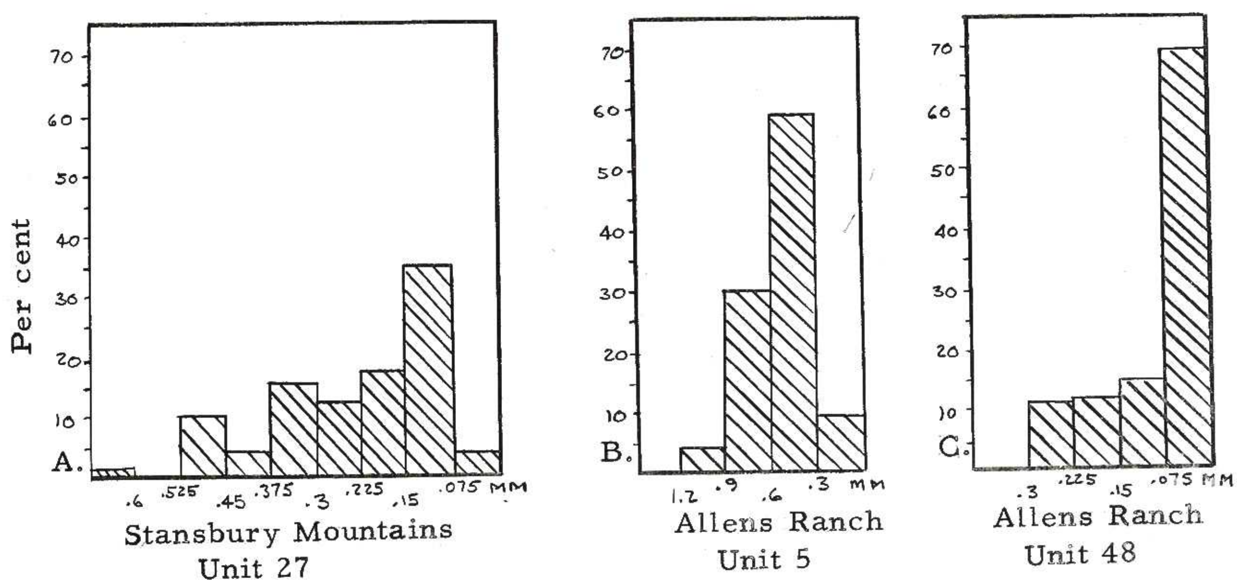


Fig. 3 Histogram showing grain size (linear intercepts on thin sections) of selected samples from the Humbug formation.

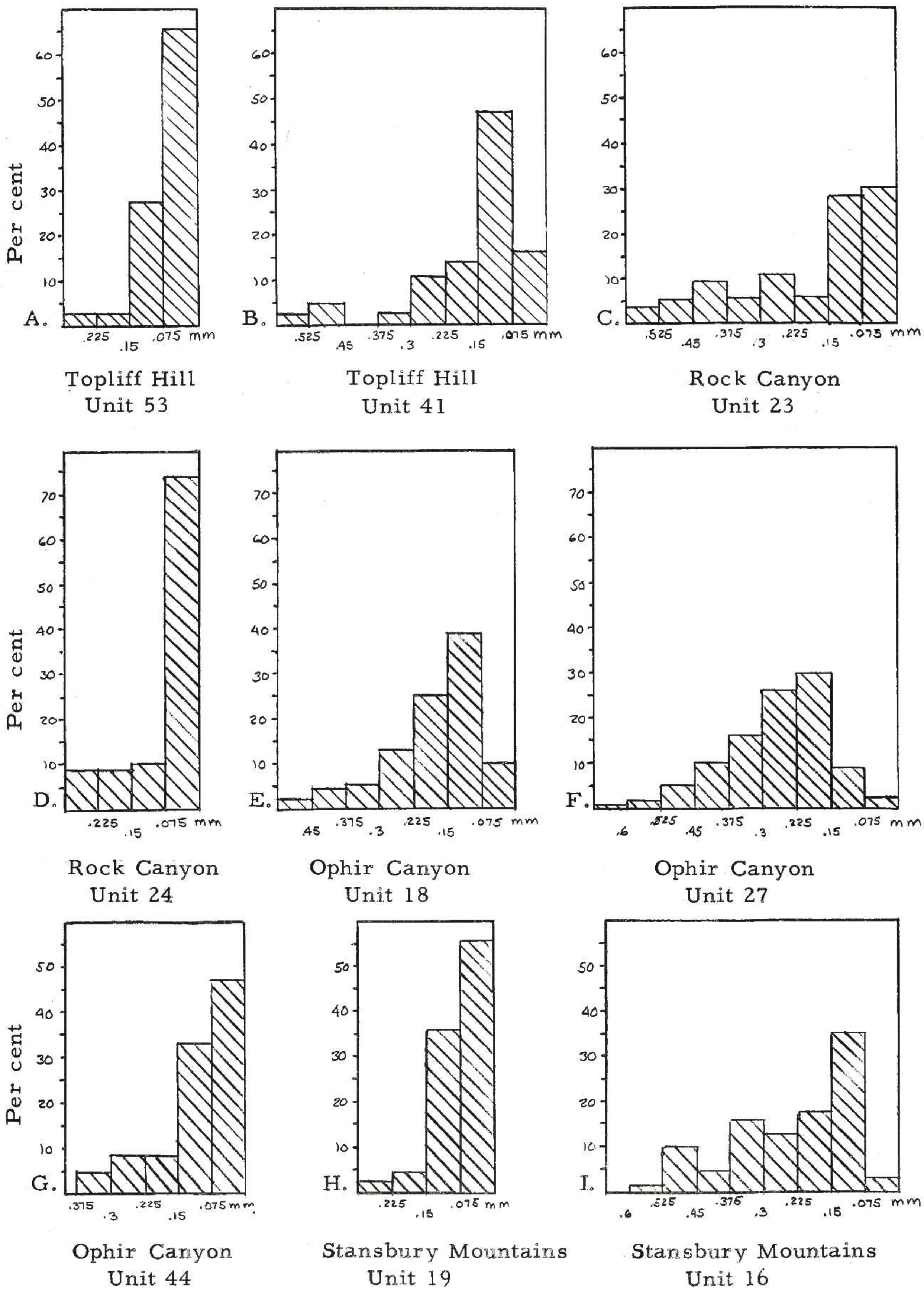


Fig. 4 Histograms showing grain size (linear intercepts on thin sections) of selected samples from the Humbug formation.

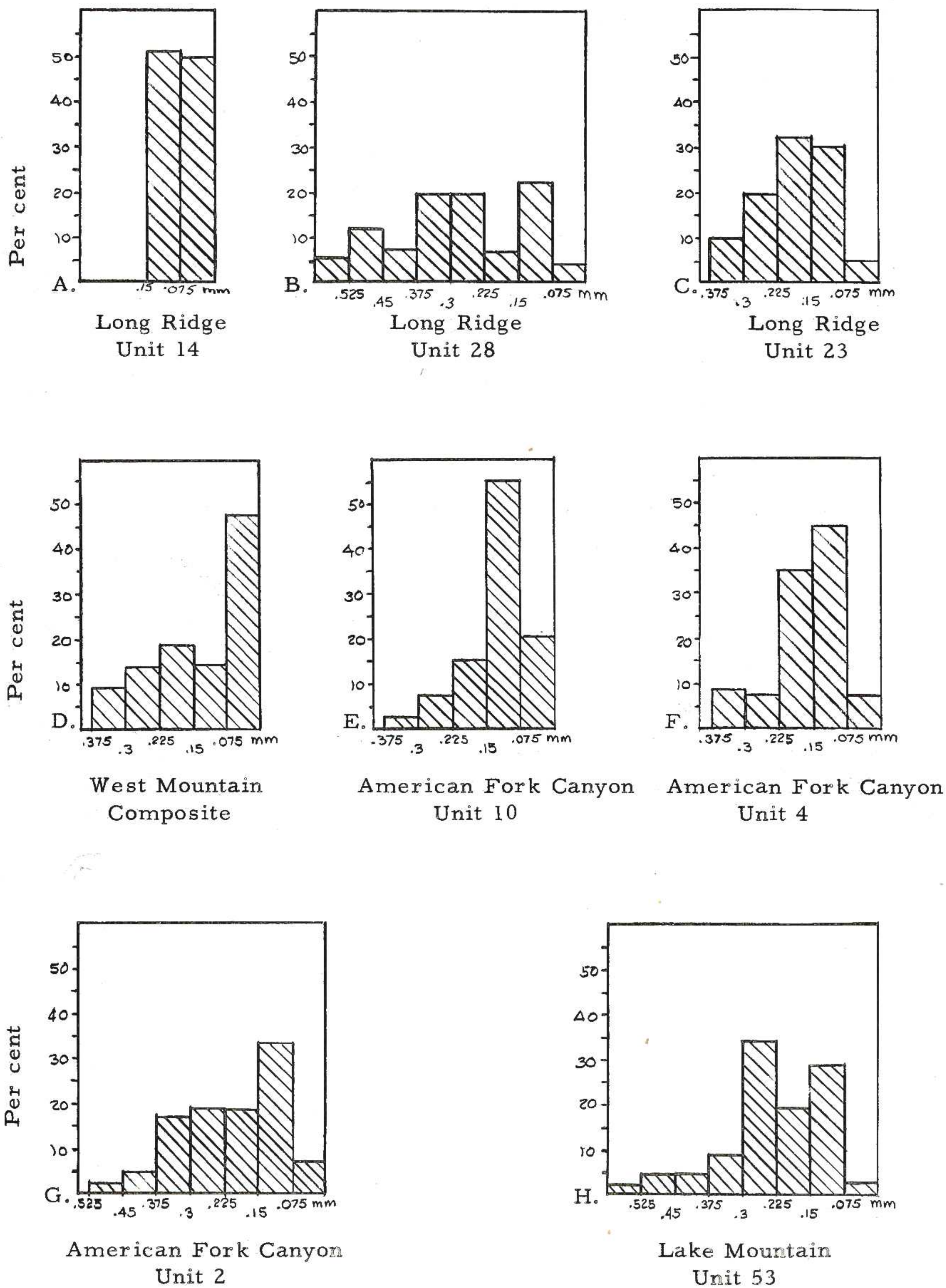


Fig. 5 Histograms showing grain size (linear intercepts on thin sections) of selected samples from the Humbug formation.

minerals found, comprise less than one per cent of the rock. The cement consists predominantly of silica with some calcite.

Characteristic sands in the Humbug formation are well sorted as seen in thin sections. The finer grained samples are all unimodal (Fig. 3 B & C; Fig. 4 A, D, G & H; Fig. 5 A, D, E & F) while the coarser grained samples are either bimodal (Fig. 4 B; Fig. 5 F & H) or trimodal (Fig. 3 A; Fig 4 C & I; Fig. 5 B) in their cumulative frequency graphs. These graphs (Fig. 3, 4 & 5) are skewed to the left because of the method used in measuring grain size. For comparison to mechanical analysis see Fig. 1 & 2.

Deviation from the mean grain size is a function of the grain size, i. e., deviation increases with grain size (Fig. 5 A & H). Deviation from the mean seems to be related also to the amount of cementing material. Deviation is least when the amount of cement is high (Fig. 5 B) and increases as the cement decreases (Fig. 3 H).

Very few of the sand units in the Humbug formation can be classified as coarse grained according to the particle size classification of Wentworth (1922, table 2). All of the coarse grained samples studied in thin sections and by mechanical analyses were found to contain a minority of conspicuous large grains surrounded by less conspicuous smaller grains.

Degree of rounding varies from angular to subrounded. It is distinctive in each unit and does not vary unless there are two or more distinct grain sizes present. If more than one grain size is present in a sample the larger grains are always better rounded. Pettijohn (1949, p. 53) suggests that if the grains are not derived from pre-existing sediments the roundness will be the same for all grain sizes, but if the sediments being studied have undergone a long abrasion history the larger grains will be the better rounded.

Conclusions.--Deviation from the mean grain size is related to average grain size and amount of cementing material. Roundness is related to grain size and probably to length of time the grain was subjected to abrasion.

The sands of the Humbug formation were probably derived from pre-existing sediment and have consequently undergone more than one cycle of erosion. This is suggested by the correlation between grain size and roundness.

LIMESTONE

Most of the limestone in the Humbug formation forms ledges. Bedding is usually distinct and varies from laminated to massive. The beds are sometimes lenticular and occasionally grade laterally into other rock types. Often coarse grained limestone grades vertically into sandstone and frequently fine grained limestone grades vertically into dolomite. The limestones vary from olive-brown to dark gray on both fresh and weathered surfaces. Grain size in the limestones vary from grains so small that they could not be definitely distinguished in thin sections, to grains large enough to be seen with the unaided eye.

The limestones have been divided into coarse and fine grain types. Samples were classified as coarse grained if discrete grains could be seen on a fresh surface with a hand lens, and fine grained if no grains could be seen.

Coarse Grained Limestone

Observations.--The coarse grained limestone (Plate 4 A) is composed almost totally of shell and supporting structure fragments. The largest number of fragments were derived from echinoderms, corals, and bryozoans. Endothyrids are abundant and in some samples make up almost 10 per cent of the rock. Whether these organisms lived together or their remains were brought together after death is not known. The former seems more probable as they are found associated in the same type of environment today. Detrital quartz, authigenic quartz, and some unidentifiable clay size material are also present (See appendix C).

The grains range from approximately 0.1 mm. to 1 cm. in diameter and are commonly well sorted. Grains larger than 3 mm. in diameter are uncommon and when present are frequently crinoid columnals.

Even though echinoderm fragments make up the greater part of the coarse grained limestones, these rocks are not true "crinoidal limestones" as described by Pettijohn (1949, p. 301). One unit (Stansbury Mountains Unit 18) is made completely of echinoderm fragments. This is unusual, however, as commonly fossil fragments other than echinoderms make up an estimated 15 per cent to 50 per cent of the coarse grained samples. "Encrinite" or "encrinal" limestone are perhaps more suitable descriptive terms for these units.

The coarse grained limestones are characterized by lateral and vertical gradation into siliceous clastics, and by the presence of two types of calcium carbonate, clastic and authigenic (cement), in the rock. In a few of the coarse grain samples the clastic material is totally fossil fragments. In most, however, quartz grains are present also. The coarse grained limestones show sorting, cross-bedding, and graded bedding.

Unit 1 of the Topliff Hill (See appendix C) stratigraphic section is a typical coarse grained unit. Common detrital constituents are echinoderm, coral, brachiopod, and bryozoan fragments, and endothyrids. The clastic material comprises 95 per cent of the rock. The remaining 5 per cent is clear crystalline calcite cement. The average grain size of the detrital material is 1.5 mm. Seventy per cent of the sample was soluble in dilute hydrochloric acid. Silicified fossil fragments comprise 95 per cent of the insoluble residue. The other 5 per cent of the insoluble material is authigenic quartz. Average grain size of insoluble material is 1.0 mm. in diameter.

Conclusions.--Coarse grained limestones of the Humbug formation are made of two types of calcium carbonate; (1) detrital and (2) precipitated cement. Most of the detrital material was formed from shells and skeletal material broken probably by wave and current action. Coarse grained limestone units of the Humbug formation are not "crinoidal limestone" and are best described as "encrinite" or "encrinal" limestones.

Fine Grained Limestone

Observations.--Fine grained limestones (Plate 4B) of the Humbug formation are composed of calcium carbonate, detrital quartz, authigenic quartz, and clay size material. Most samples are dense and have conchoidal fracture. They vary in color from olive-brown to light gray on both fresh and weathered surfaces.

Many of the fine grained limestones are made of grains smaller than 0.03 mm. in diameter. Thin sections of these extremely fine grained limestones appear dark and turbid. Texture and composition of these fine grained samples are uniform and varieties have not been differentiated. Possibly some of the fine grained limestones are clastic and probably composed of the same material as are the coare grained limestones. This is not positively known because individual grains are so small they cannot be readily indentified.

Laminae are present in some fine grained samples. In thin sections the laminae appear as light and dark bands resembling varves. Reasons for this laminated arrangement are not definitely known. Olsen (1955, p. 46) ran spectro-analyses on laminated argillaceous limestones of the Great Blue formation and found that there was no chemical relationship between the laminae. He concluded that the laminae were the result of difference in grain size. The writer of this report found this to be true of some laminated samples in the Humbug formation. However, in other samples in which discrete grains could not be seen this relationship could not be verified. Light and dark clay size material or organic remains may be important in forming laminae in extremely fine grained samples.

Unit 6 in Rock Canyon is one of the more unusual fine grained limestone units found in the Humbug formation. Approximately 50 per cent of the sample which was studied is comprised of small subspherical ooliths. Most of these ooliths, which average 0.07 mm. in diameter, have a quartz grain or fossil fragment as a core. Some show one laminae, others show two. A few appear dark and structureless. Dr. J. K. Rigby* suggests that the latter dark structureless bodies may be coprolites.

Clay size material is the commonest siliceous impurity in the fine grained limestone. Detrital sand grains, authigenic quartz and most of the chert which is found in the Humbug formation, are found in the fine grained limestones.

Complete fossils are not common or abundant in the fine grained limestones. However, where they do occur, they are invariably well preserved.

Conclusions.--Some of the fine grained limestones were probably precipitated as a calcium carbonate mud or drewite similar to that being precipitated on the Great Bahama Bank today (Drew, 1914, pp. 7-45). Shortly after precipitation this dominantly aragonite mud is altered to a fine grained calcite. Bacteria, according to Kellerman and Smith (1914, pp. 400-402) can be instrumental in precipitation of calcites, and may have caused calcite to be precipitated directly from sea water. Some of the fine grained limestones were probably formed by deposition of clastic clay size carbonate fragments. It is possible that some of the fine grained limestone units were formed by a combination of accumulation of clastic material and precipitated material.

The greater amount of authigenic quartz in the insoluble residues, plus the presence of chert rosettes (Plate 3 D & E) indicates that the fine grained limestones probably have more optimum conditions for secondary siliceous growth than do the coarse grained limestones.

DOLOMITE

Observations.--The dolomite (Plate 4C) beds in the Humbug formation form excellent outcrops and were never found grading laterally into other rock types. Their contacts are usually sharp but occasionally grade vertically into a fine grain limestone. The dolomites are medium

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*Personal communication, March 1955

gray to olive gray on fresh surfaces and commonly weather medium gray to gray-white. Most are fine grained and show conchoidal fracture. .

Siliceous impurities, such as sand and clay size material are common residues when dolomite samples are digested in dilute acid with clay size material being the most abundant. Authigenic quartz in dolomite is found only in the American Fork Canyon section, Units 1 and 11. These crystals are badly pitted as seen in insoluble residues, and in thin sections appear to be partly replaced by dolomite. In American Fork Canyon the dolomite also contains dolomitized fossils, replaced oolites, and an abundance of detrital quartz.

Conclusions.--Most of the dolomite in the Humbug formation has probably had a marine replacement origin. Cloud and Barnes (1948, pp. 89-95) believe that sea water is probably the only adequate source for the quantity of magnesium needed to form extensive beds of dolomite. This replacement could occur penecontemporaneously with deposition or shortly thereafter. Jenkins (1954, p. 229) believes that the upper contact of the dolomite can be used to determine the time of replacement. If the dolomite grades into the overlying limestone, replacement probably took place after the overlying limestone was deposited. If the upper contact is sharp and distinct, replacement took place before the deposition of the overlying beds. These contact relationships are found in the dolomites of the Humbug formation, but lower as well as upper contacts were found to be gradational.

Limestones of the Humbug formation in American Fork Canyon have become dolomitized by post depositional hydrothermal or ground water activity. Evidence of this is the localized character of the dolomitization in the formation, the presence of dolomitized fossils, replaced oolites, and an abundance of detrital quartz. At no other known locality has the formation been so extensively dolomitized, nor have replaced primary sedimentary structures been found elsewhere. The section may have been dolomitized during deformation as it is located in a fold belt of the Wasatch Mountains. The localized nature of the dolomitization indicates ground water or hydrothermal alteration. The altered fossils and oolites along with the abundance of detrital quartz seem to corroborate this theory.

SEDIMENTARY STRUCTURE

INTRODUCTION

The history of the Humbug formation can be divided into two phases; (1) syngenetic or primary phase, which includes the formation and accumulation of the sediments, and (2) epigenetic or secondary phase, which includes consolidation, reorganization, replacement, and all other post depositional changes.

SYNGENETIC STRUCTURE

Size and shape.--The Humbug formation is tabular according to Krynine's (Krumbein and Sloss, 1951, p. 95) shape classification using the ratio of formation thickness to width. If the ratio of width to thickness is 1000 to 1 or greater the formation is a blanket; between 1000 to 1 and 50 to 1, tabular; between 50 to 1 and 5 to 1, prism; less than 5 to 1, shoestring.

Krynine (Ibid.) has also suggested a classification of sedimentary body size related to total volume of the formation and not its shape. A formation with 500 cubic miles is large; 1 cubic mile to 500 cubic miles, medium; less than 1 cubic mile, small. The Humbug formation by these standards is medium sized.

Stratification.--Stratification varies from laminated to massive in the Humbug formation. The following classification is used in this report:

Massive bedded	6 or more feet.
Thick bedded	3 feet to 6 feet.
Medium bedded	6 inches to 3 feet.
Thin bedded	1/8 inch to 6 inches.
Laminated	1/8 inch or less.

Seven types of separation planes between beds were noted in the Humbug formation. They are: (1) gradual change in lithology

(Unit 1, Long Ridge), (2) abrupt change in lithology along an even separation plane, (3) similar lithologies separated by an even plane (Fig. 6 A), (4) abrupt change in lithology along an uneven separation plane (Fig. 6 B), (5) similar lithologies separated by an uneven plane (Units 15 & 16, Topliff Hill), (6) abrupt change in grain size (Units 2 & 3, Allens Ranch), and (7) abrupt change in cement (Units 1 & 2, Stansbury Mountains).

Graded bedding.--Graded bedding (Plate 3 D) is not common in the Humbug formation. It occurs in sandstone and coarse grained limestone and is often associated in the same bed with cross-bedding and ripple marks.

Bailey (1936, p. 1716) noted in rocks of the Caledonian geosyncline of Scotland, Ireland and Wales that cross-bedding and graded bedding are not commonly found together in one bed. He believes that the two structures represent different sandstone facies. He concluded:

> Current bedded sandstones are obviously the products of bottom currents. Graded bedded sandstones are products of settling through comparatively still bottom water, which allows sand and mud to accumulate in one and same locality, though with a lag on the part of the mud, determined by its finer texture.

Kuenen (1953, p. 1045) points out that small scale cross-bedding as well as ripple marks are common in beds showing graded bedding. He suggests turbidity flows as a cause of graded beds and he believes that turbidity flows are probably associated with relatively steep slopes and that they deposit their loads in deep water.

Graded bedding in the Humbug formation is restricted mostly to laminae and is best seen in sandstone thin sections (Plate 2). Graded bedding in the formation has probably not been formed by turbidity currents. The beds show none of the characteristics associated with turbidity flows as described by Kuenen (Ibid., p. 1045-47). There is some doubt whether graded bedding as described by Bailey (Op. cit., p. 1716) is similar to that found in the Humbug formation. He makes no statement concerning the circumstances which placed the clastic material in a position to settle out of the water. Currents probably played an important part in forming graded beds in the Humbug sea through changes in transporting power and direction of flow. Deep storm waves were probably of equal importance. Such large waves may have stirred up a large quantity of sediment which when deposited was graded through differential settling. Probably the greatest difference between these beds and turbidity deposits is the lack of extremely fine material and an association with ripple marks (Kuenen, 1952, p. 92).

Cross-bedding. --Cross-bedding has been found in all of the studied sections. Both concave upward (Fig. 6 C) and tangential (Fig. 6 D) cross-bedding were observed. Average direction of the cross-bedding suggests that the currents flowed toward the south in sections measured at Ophir Canyon, Lake Mountain, and Rock Canyon; and flowed toward the north at Allens Ranch.

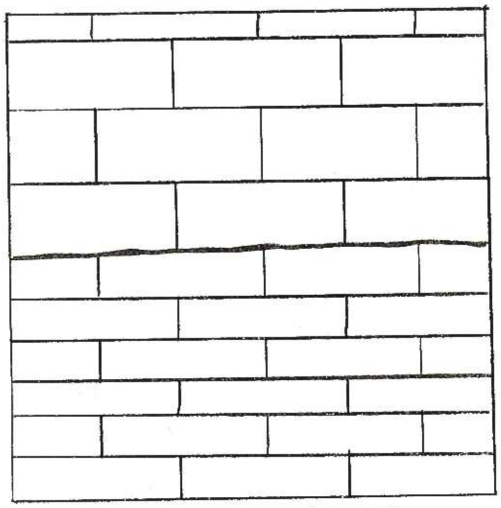
According to Thoulet (1887, p. 33-64) the angle of inclination of sand never exceeds 41°. In the present study, inclination of the forset beds did not exceed 21°30'. The average is estimated at 15°. The different inclinations may indicate the current velocities. If the currents were weak the forset beds would probably be steep, becoming less steep as the current increased. Cross-bedding probably indicates filling in of depressions in the sea bottom. In Unit 18 of Rock Canyon cross-bedding could be traced for about one hundred feet. At its southernmost exposure the forset beds were two inches long and inclined 18°. At the bed's northernmost exposure the forset beds were 18 inches long and inclined 20°. The cross-bedded unit was a fine grained sandstone overlain and underlain by dolomite. The bottom dolomite thinned in the direction in which the sandstone thickened, indicating that the sand filled in a minor depression.

Ripple marks. --Asymmetrical or current ripple marks, symmetrical or oscillation ripple marks, and interference ripple marks are found in the Humbug formation. The largest ripples observed were 5cm. from crest to crest and had an amplitude of 0.5 cm. (ratio of 1:10). The smallest were 2.5 cm. from crest to crest and had an amplitude of 0.4 cm. (ratio of 1:8).

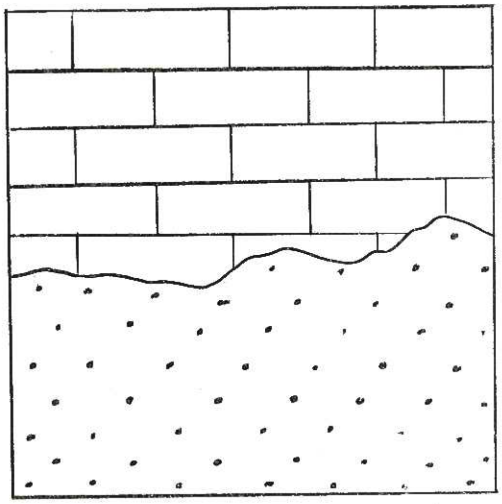
Current ripple marks were found in all of the studied sections except American Fork Canyon. They all indicated current flow toward the south or east. They can also be used to estimate current velocities. According to Gilbert (1914, p. 69) water velocities needed to initiate motion of sand grains and to start active formation of ripple marks are as shown in table 1.

Mean grain diameter (inches)	Water depth (feet)	Velocity (feet/sec)
0.015	0.425	0.85
0.020	0.391	0.93
0.031	0.659	1.12

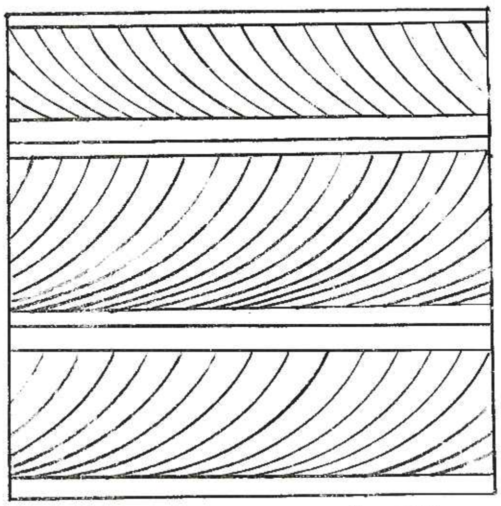
Table 1. Showing grain size and water velocity needed to start formation of ripple marks. (Modified from Gilbert, 1914, table 9, p. 69)



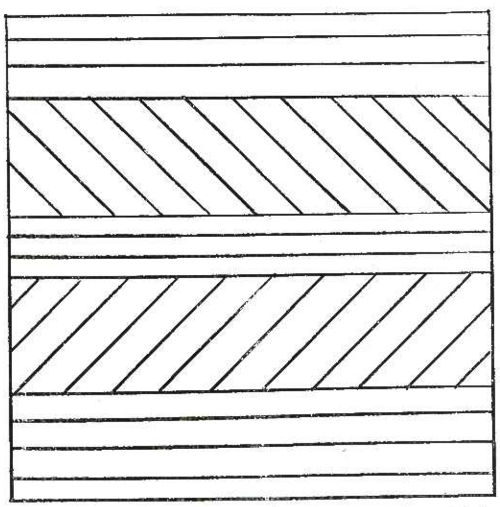
A. Even separation plane separating similar lithologies.



B. Uneven separation plane separating dissimilar lithologies.



C. Concave cross-bedding.



D. Tangential cross-bedding.

Figure 6

Current ripple marks are formed much the same as cross-bedding. Sand grains are moved up the stoss of the ripple mark by current action and deposited on the lee side. As this process continues the ripple mark moves in the same direction as the current.

Unlike current ripple marks, oscillation ripple marks are stationary. They are formed by vortices which develop alternately on each side of the ripple mark as the currents are reversed. In the Humbug formation oscillation ripple marks are found only in Rock Canyon.

Interference ripple marks are formed when one set of ripple marks intersects another set at an angle. These two sets can be of the same type or of different types. Interference ripple marks are found in Rock Canyon near the center of the formation. Small N. 20°E. trending current ripples are superimposed upon larger N. 41°W. trending oscillation ripple marks.

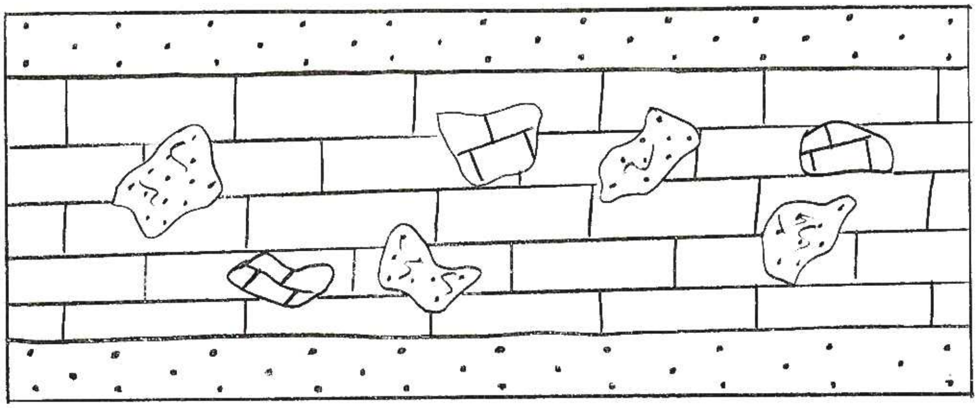
Penecontemporaneous deformation.--Several beds of limestone and orthoquartzite containing large limestone and orthoquartzite fragments (Fig. 7 A) occur in Rock Canyon, unit 12, and Ophir Canyon, units 22 and 24. It is not known whether these units were formed shortly after deposition by slumping or during subsequent Laramide folding.

Many tabular limestone fragments occur near the middle of a thick sandstone bed (Unit 28, Stansbury Mountains) along the same stratigraphic horizon (Fig. 7 B). These fragments are as large as six inches thick, eighteen inches long, and twelve inches wide. Kuenen (1953, p. 1054) has found similar isolated fragments in the sediments of the Ventura Basin and believes them to be evidence of post-depositional slumping.

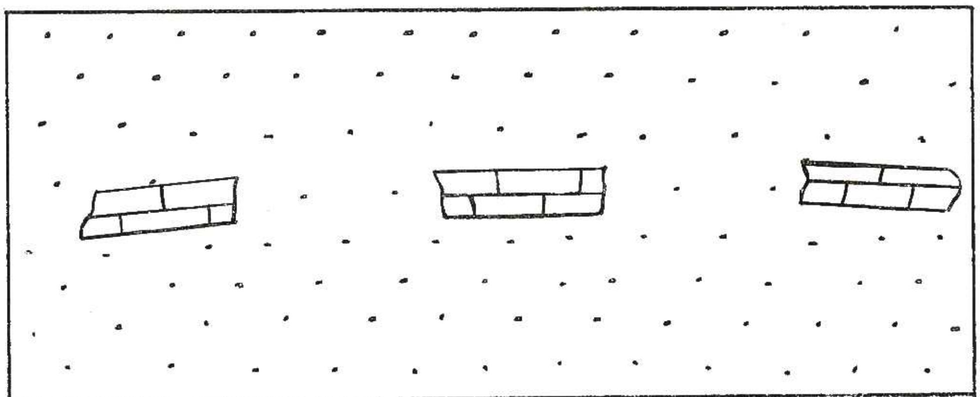
An intricately contorted one-foot argillaceous limestone bed occurs within unit 28 of the Rock Canyon section (Fig. 7 C). It is probably the result of post-depositional slumping also. It is contained within a large sandstone bed which is conformable with the overlying and underlying beds. The sandstone does not exhibit any of the drag features caused by the slumping limestone as they are shown by Kuenen (1953, p. 1054-55) but the general slump pattern is similar to those found by Kuenen (Ibid.) in the Ventura Basin. This unit is also similar to slump structures found by Newell, et. al. (1953, ll. 89-93) in the Guadalupe Mountains.

EPIGENETIC STRUCTURES

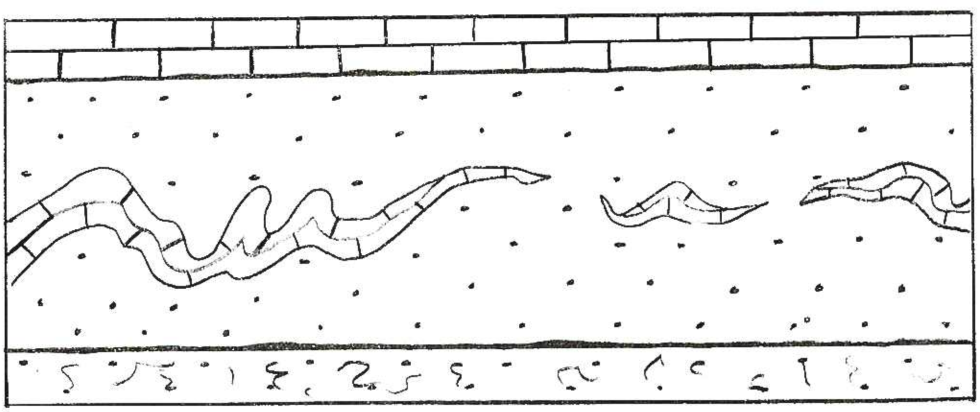
Authigenic quartz.--Authigenic quartz (Plate 4 F & Appendix C) is present in many of the limestones which were studied. It is found



A. Limestone unit containing large orthoquartzite and limestone fragments (Idealized from Unit 28, Rock Canyon.



B. Stansbury Mountains Unit 28 showing limestone fragments scattered along same stratigraphic horizon.



C. Rock Canyon Unit 28 showing contorted argillaceous limestone within sandstone.

Figure 7

in three distinct forms which appear to be related to the size of the crystal. The larger crystals (approximately 0.2 mm. long) are formed around a detrital core, most of which are quartz grains. The secondary growth of the quartz grain is not always in crystallographic continuity with the grain. In one thin section several authigenic quartz crystals were found growing around single crinoid ossicles. The insoluble residue prepared from this unit showed that much of the fossil hash, including the crinoid ossicles, was silicified.

Authigenic quartz crystals that are approximately 0.1 mm. long have minute calcite inclusions within them. Under crossed nicols these inclusions show a high birefrigence and some appear to have twinning striations. These inclusions are usually irregularly shaped and visible calcite rhombs are rarely seen.

The smallest crystals are approximately 0.05 mm. long. They are long, slender, and clear. According to Williams <u>et. al.</u> (1954, p. 359) this elongate crystal habit develops in quartz crystals formed at low temperatures and is typical of authigenesis in limestone.

In thin sections the authigenic quartz grains appear to have no preferred orientation. Some of the thin sections show the quartz crystals to be pitted and partially replaced by calcite. The replacement was probably caused by a change of minerals in solution in the interstratal solutions.

Evidence that these crystals are secondary is: (1) some crystals are found transgressing across primary sedimentary structures such as foraminifera and other fossil fragments, (2) some crystals form around fossil fragments, and (3) some of the silicified bryozoans are formed by doubly-terminated quartz crystals reproducing the lattice structure.

<u>Authigenic calcite</u>. --Authigenic calcite is very common in the coarse grained limestones of the Humbug formation. It appears as encrustations on fossil fragments and as cement. It was probably introduced by intrastratal solutions shortly after burial.

<u>Authigenic gypsum</u>. --Gypsum is an uncommon mineral in the Humbug formation. It was observed only in insoluble residues as irregular-shaped crystals, the largest of which are approximately 0.5 mm. in diameter.

<u>Limonite</u>. --Limonite cubes are common in the insolubles prepared from many of the limestones. Their presence probably indicates a sedimentary environment of low oxygen content and at

least partly stagnated conditions. They are much more common in the insoluble residues of the fine grained limestones than in the residues of the coarse grained limestones.

Chert & Quartz druzes. --Chert comprises a minor amount of the silica in the Humbug formation, appearing as irregular masses. None of the larger chert masses were studied in detail. Several small quartz druzes were examined. These are composed of euhedral quartz with associated white crystalline calcite. They are found in two orientations: (1) those that are filling cavities in the parent rock (Plate 4 E) and (2) those that are growing out into the parent rock (Plate 4 D). In both varieties the length of the individual quartz grains does not exceed 0.75 mm. It appears that quartz is replacing the calcite, for euhedral quartz is found where the two minerals are in contact.

Cementation. -- Petrographic examination of selected clastic samples from the Humbug formation revealed silica, calcite, and in one instance, dolomite (Unit 15, American Fork Canyon) to be the binding materials. Although silica is the most common cementing constituent of the sandstones and orthoquartzites, calcite is the most common cement in the formation. This is because the calcite is found in the calcarenites as well as in some of the quartz sand units. Very few of the sandstones and orthoquartzites are cemented exclusively by silica (Plate 3 A). Most are cemented by an admixture of silica and calcite (Plate 3B). Also, sandstones cemented solely by calcite are uncommon (Plate 3 C).

In samples which are cemented by both silica and calcite, the quartz was deposited first and the calcite last. The calcite in all of the samples has partially replaced the quartz (Plate 3 B).

In samples that are cemented by silica the grains are well packed due to secondary enlargement of the quartz grains. All of the pore space has been eliminated by the secondary enlargement and a quartz mosaic has resulted (Plate 3 A). The formation of this anhedral quartz mosaic may result from the following: (1) secondary growth of detrital quartz grains forming euhedral and subhedral quartz crystals, and (2) continued growth of these crystals until all of the pore space has been eliminated and an anhedral quartz mosaic resulted. The writer did not observe euhedral and subhedral crystals in any of the thin sections studied; however, subhedral crystals were noted in the insoluble residue of the Stansbury Mountain Unit 7.

The source of the siliceous cement is unknown to the writer of this report. However, after studying data gathered by other workers the writer found that it is generally believed that the source was not from within the sand units but was introduced by intrastratal solutions. According to Clarke (1924, p. 123) present-day sea water contains silica in the ratio of 1:200,000 to 1:460,000. If a sand unit was saturated with sea water at burial, and all of the silica precipitated from the water, the silica would be insufficient to fill the pore space of the sandstone.

Some writers have suggested that the silica is derived from solution of the sand grains where they are in contact with each other. This is possible if the volume of the sand unit is decreased by the volume occupied by the pore space. As the grains are dissolved at their points of contact with other grains they become smaller in one dimension and larger in another (where secondary growth is taking place). If there is no silica being introduced from other sources the filling of the pore space must be accompanied by a reduction in volume equal to the original volume of the pore space.

Some workers have postulated that the calcareous cement is formed from dissolved invertabrate shells which was then reprecipitated as cement. It seems improbable that this source could supply all of the calcite found as cement. Waldschmidt (1941, p. 1865) suggests the following as a source of calcite cement in a water saturated sand:

> ...the existing pressure and temperature in the buried sand could readily be responsible for the solution of any carbonate remains such as shell fragments, Foraminifera, limestone grains, et cetra, which were deposited originally within the sand. Furthermore, decomposition of included organic material and its accompanying formation of carbonic acid and ammonium carbonate, and other decomposition products, should further increase the solubility of any carbonate particles within the sandstone. Thus the amount of calcium and magnesium carbonates already present in the saturated waters is increased by that taken into solution from carbonate remains within the sandstone.

Waldschmidt (Ibid.) concluded that a slight change in temperature or pressure could cause precipitation of the calcium carbonate.

After a study of numerous calcareous sandstones in the Humbug formation the writer concludes that some of the calcareous cement was derived by solution of closely associated limestones and recrystallization of the calcite in the sandstone. Complete and comparatively unabraided fossils (Corals, Stansbury Mountains Unit 10) found in a calcareous cemented sandstone indicate also that at least part of the cement is not derived from fossils. In the latter case the cement is probably precipitated directly out of the connate water or was introduced later by intrastratal solutions.

Cement in the clastic limestone is primarily calcite. Williams et. al. (1954, p. 347) points out that the calcite cement is precipitated in crystallographic continuity with the fossil fragments. In this investigation the preceding condition was found to be untrue in most cases.

Some samples of fine grained limestone which were studied appeared to be cemented by argillaceous material. Dr. J. K. Rigby* suggested, however, that the actual cement may be finely crystalline calcite and what appears to be detrital argillaceous material may be impurities derived from fossil fragments through their solution.

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*Personal communication, March 1955

PALEONTOLOGY

INTRODUCTION

Five phyla were found represented in the Humbug formation. As compared to other Upper Mississippian formations in central Utah fossils are not abundant. The main fossil concentration coincides with a long arcuate basin that extends from Lake Mountain northward to the Stansbury Mountains (See plate 2).

DISTRIBUTION AND PALEOECOLOGY

Corals. --Corals are the most abundant macro fossils in the Humbug formation and occur intermittently in every stratigraphic section except American Fork Canyon. They are particularly abundant in the Humbug rocks of the Stansbury Mountains and Long Ridge (table 2). They are also abundant in the basal Humbug of Stansbury Island according to Carl R. McFarland.*

No other fossils were found associated with corals. Their lithologic occurrence varies from fine grained limestone (Unit 19, Stansbury Mountains) through coarse grained limestone (Unit 13, Long Ridge) to sandstone (Unit 10, Stansbury Mountains).

Brachiopods. --Complete brachiopods were found in only five units, each of which was in a different stratigraphic section. In three of these units spiriferid type brachiopods were found associated with bryozoans in argillaceous limestone. In the remaining two units, which were siliceous limestone, productid type brachiopods were found alone. Spiriferids were probably restricted to an environment similar to that of bryozoans and crinoids, i.e., they all required a solid substratum. Productids were probably suited to muddy bottoms.

Brachiopods were much more abundant than these few complete specimens indicate for fragments of their shells are commonly found in the coarse grained limestones.

Bryozoans. --Bryozoan fragments are found in most of the coarse grained limestones which indicates that they lived in large colonies associated with brachiopods, echinoderms, and foraminifera. Complete zooaria were found in argillaceous and siliceous limestone. The bryozoans may have been partially responsible for the accumulation of the argillaceous sediments because their large fronds functioned as efficient

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*Personal communication, September 1954

sediment traps by reducing the velocity of transporting bottom currents.

When bryozoans were found in an argillaceous limestone, they were usually attached to large dark gray crystalline limestone blocks which may be of algal origin.

Bryozoans thrive in clear agitated water. Areas with moving sand are not favorable for them as they need a solid substratum for attachment.

Endothyrids.--The foraminifera found in the Humbug formation were benthonic. Their distribution was probably controlled mostly by temperature and salinity much as are modern foraminifera. They are commonly found associated with brachiopod, echinoderm, and bryozoan fragments. Their presence only in coarse clastic limestone may indicate that they liked clear agitated water, although they may have been introduced after the death of the organism. They are the most abundant unbroken fossil in the Humbug formation, making up as high as 10 per cent of the rock volume in a few samples.

Echinoderms.--No complete echinoderms were found in the Humbug formation during this study. They must have been abundant, however, for some of the coarse grained limestones are made up almost entirely of echinoderm fragments. They probably lived in extensive marine colonies, associated with brachiopods, bryozoans, and foraminifera.

Summary.--Bryozoans, echinoderms, brachiopods, and foraminifera may have lived together in vast subaqueous colonies or their shell fragments may have been brought together after their death. Most writers agree that these animals lived in about the same environment. Bryozoans, (non-encrusting types), stemmed echinoderms, and attached brachiopods must have a firm substratum on which to anchor themselves. Skeletons of these animals can be easily transported (Menard & Boucot, 1951, pp. 131-51) and concentrated by currents after death. Fragmentation was probably caused by abrasion during transportation rather than by predators as suggested by some writers. It seems probable that these animals lived together and consequently fragments of their shells are now found together.

CONCLUSIONS

CORRELATION

Faunal correlation.--Tower and Smith (1897, p. 628) made fossil collections from the Humbug formation in the Tintic area. Dr. G. H. Girty recognized the following:

Syringopora sp.
Productus punctatus
zaphrentid type corals

Dr. Girty (Tower and Smith, Ibid.) noted:

> While the type represented by Productus punctatus begins well down in the Mississippian. . . and while Syringopora sp. a and sp. b are quite similar to certain species of the Mississippian ages. . . nevertheless stratigraphic considerations seem to indicate that these several localities, at least, belong to the coal measures, for even if the locality funishing Productus costatus can be properly referred to the Mississippian series, it is improbable that this series can attain a thickness of 2000 or 3000 feet or more so as to include the higher beds as well.

Lindgren and Loughlin (1919, p. 42) assigned the Humbug formation in the Tintic area to the Upper Mississippian but correlated it incorrectly with the bottom part of Spurr's (1894, p. 376) Upper Intercalated Series (Oquirrh) which is Pennsylvanian.

Dr. Girty (Gilluly 1932, p. 28) identified the following fossils collected from the Humbug formation by Gilluly in the Stockton and Fairfield quadrangles:

Fenestella sp.
Pinnatopora sp.
Polypora sp.
Rhombopora sp.
Syringopora sp.
Cyathophyllum sp.
Pentremites sp.
crinoid indet.
Echinocrinus sp.
Productus brazerianus
Orthotetes sp.
Girtyella ? sp.
Spirifer aff. centronatus
Productus ovatus
Productus sp.
Pugnoides aff.
P. ottumwa
Spirifer n. sp. aff.
S. brachythyris

Dr. Girty reported that the closest affinities of this fauna are with the faunas of the older Brazer limestone.

Dr. Girty (Calkins and Butler 1943, pp. 27-28) identified the following fossils from the Humbug formation in the Cottonwood quadrangle:

Stenopora aff. S. rudis	Cleiothyridina crassicardinalis
Fenestella aff. tenax	Platyceras sp.
Campophyllum nevadanse	Griffithides sp.
Spirifer aff. striatus	Diaphragmus elegans
Dielasma sp.	Martinia sp.
Chonetes aff. loganensis	Composita sp.
	Cleiothyridina hirsuta

Nolan (1935, p. 28) concluded that the upper part of the Woodman formation and lower part of the Ochre Mountain formation in the Gold Hill mining district may correlate with the Humbug formation of the Oquirrh Mountains and of the Tintic area.

Dr. M. L. Thompson and Ed Zeller identified Meramecian Endothyra s.s., which were collected by Calderwood (1951, p. 48) from the Humbug formation on Lake Mountain. Similar foraminifera were found in all of the studied sections except American Fork Canyon.

Weller et. al. (1948, p. 146) points out that Diaphragmus elegans has been found in the Humbug formation in the Cottonwood area. He concluded that the formation is probably younger in the Wasatch Mountains than it is to the west (Fig. 8).

The fossils which were collected by the writer during this study are listed on table 2.

Lithologic correlation. --Individual units of the Humbug formation cannot be correlated from one area to another (See appendix B). The formation can be correlated as a unit, however, on the basis of its characteristic lithology and stratigraphic position.

Both the upper and lower contacts are gradational. The lower contact was chosen at the base of the first continuous sandstone encountered above the cherty facies of the Deseret and Pine Canyon formations. The upper contact was placed at the top of the uppermost mappable sandstone bed and beneath the argillaceous limestones of the Great Blue formation.

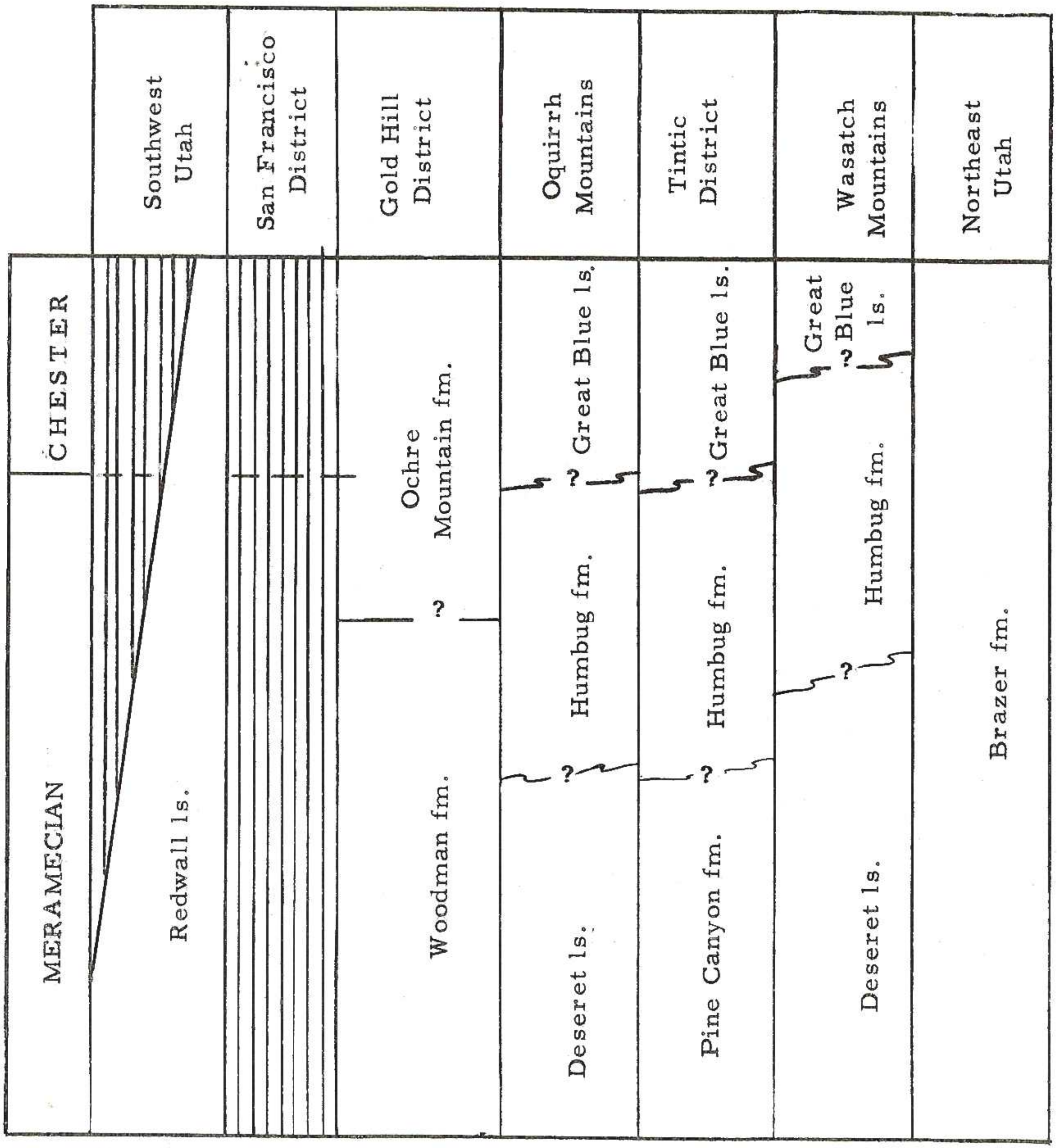


Fig. 8. Correlation of the Humbug formation with other formations in Utah (Modified from Weller and others, 1948, Chart 5).

Table 2

Fossils found in the Humbug formation during this study.

	Lake Mountain	Stansbury Mountains	Ophir Canyon	American Fork Canyon	Topliff Hill	Allens Ranch	West Mountain	Rock Canyon	Long Ridge
Lithostrotionella		C							
Zaphrentid Corals	C	A	C		R	C	A	C	A
Syringopora		C					R		
Ekvasophyllum sp.					R				
Faberophyllum sp.					R				
Endothyrids	A	A	A		A	A	A	A	A
Productus sp.	R		R						
Spirifer		R					R	R	
Pinnatopora	C						R	R	R
Fennestella	A	R	R				C	C	C
Algal structures ?	R			R		R			

A - Abundant C - Common R - Rare

TECTONICS

Regional tectonics.--During, or possibly shortly before the Devonian period a large geanticline was formed in western Nevada. This uplift divided the Cordillerian geosyncline into a western and eastern trough. Nolan (1943, pp. 141-96) named this positive area the Manhattan geanticline.

The trough along the eastern margin of the geanticline has been divided into two basins by Eardley(1951 , p. 47). The Lower Mississippian or Madison Basin is represented by the Gardner and Madison formations in central Utah. They are characteristically dolomite and fossiliferous limestone. Williams (1943, pp. 607-13) noted that the Madison formation gives way to sandstones in Wyoming and Colorado. The Upper Mississippian or Brazer Basin occupies approximately the same region as did the Madison Basin. It is represented by the Pine Canyon, Deseret, Humbug, and Great Blue formations in central Utah and by the Brazer formation in Northern Utah. These sediments are characterized by massive limestone and intercalated sandstones and limestones. Williams (1943, p. 611) noted that at no locality known to him was there any angular discordance between the sediments of the two basins. In central Utah the contact between them is gradational.

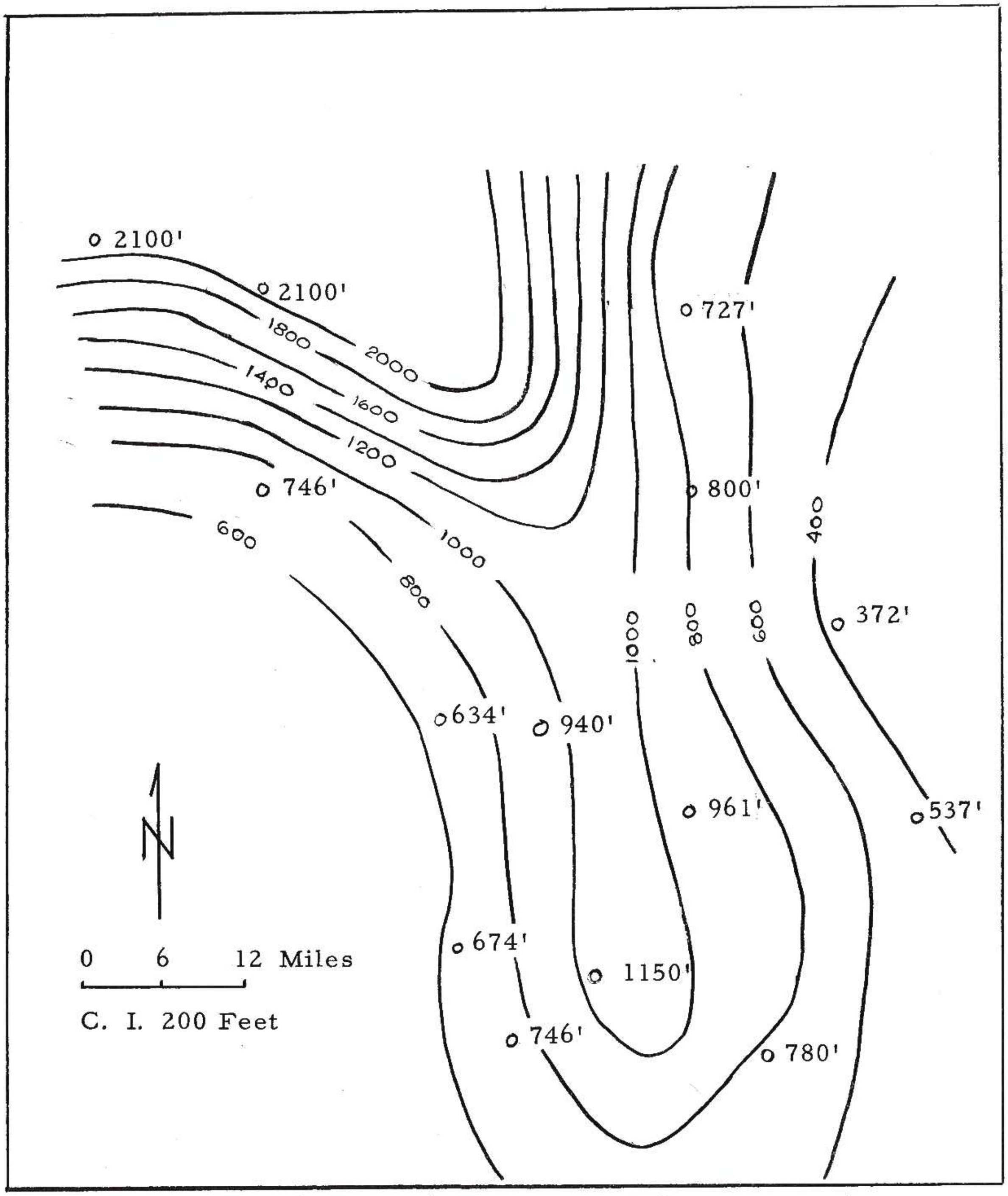
The Brazer Basin was the larger and deeper of the two basins according to Eardley (1951, plate 5). It connected to the Big Snowy Basin of Montana and to the California Basin of California and western Nevada. According to McKee (1951, plate 1) and Thomas (1949, p. 16) the Brazer sea shored on a land mass through central Colorado and Wyoming.

Local Tectonics.--The rocks of the Humbug formation reflect the rapid changes which were taking place in the Brazer Basin during their deposition. In American Fork Canyon the thickness of the Humbug formation points to a less negative area. The formation received 200 to 600 feet less sediments as compared to adjacent areas (See plates 1 & 2).

West of Utah Lake a long arcuate basin extended from the Mosida Hills northward through Lake Mountain and Long Ridge. This local basin received approximately 200 to 300 feet more sediments than did immediately adjacent areas (See plates 1 & 2).

A highly negative area existed in the vicinity of the Lakeside Mountains-Stansbury Island. This area received over 2000 feet of Humbug sediments. It was also likely near the depocenter of the Brazer Basin during Humbug time.

Plate 2



Isopachous Map of the Humbug formation in central Utah (See Frontis Piece for location names).

SOURCE OF SEDIMENTS

The following observations may have bearing on the possible source of the sediments: (1) the Humbug formation thins toward the east, (2) coarse clastics give way to finer clastics toward the east, (3) if Weller et. al. (1948, p. 146) are correct, the Humbug sediments become younger to the east indicating a greater distance from the source, and (4) scattered cross-bedding and ripple marks indicate that average current flow was to the south and east.

Probably most of the siliceous clastics came from the Manhattan geanticline and from a local uplift* just east of the geanticline. The land mass described by Thomas (1949, p. 16) and McKee (1951, plate 1) may have supplied additional material, but was probably not the chief source.

Some of the calcareous clastics were possibly swept into the basin from the surrounding shelf area. However, most of the material was probably derived from animals that lived within the basin. Fragments of brachiopods, echinoderms, bryozoans, and complete foramifera are common constituents of the calcareous clastics.

ENVIRONMENT OF DEPOSITION

Lenticular units in the Humbug formation together with cross-bedding and ripple marks suggest that the currents which traversed the basin were strong and varied in direction. Irregularities in the basin floor were probably important in controlling these currents. There were areas in which the water was quiet as is shown by laminae found in some of the argillaceous units. If there had been strong currents in these areas during deposition the laminae would have been destroyed.

Abundant corals indicate that the sediments of the Humbug formation were deposited in water probably not more than 100 feet deep. The presence of corals further indicates that the water temperature was near 68° F. although they have been found living in water as cold as 40° F. (Twenhofel 1932, p. 171). Salinity was probably near normal (3.5 per cent by weight) except for possible mildly stagnated areas as suggested by numerous limonite euhedra in some of the argillaceous limestone units.

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*Personal communication from Dr. H. J. Bissell, November 1954

ECONOMIC PROSPECTS

Petroleum appears to offer the best economic potential of the formation. Although petroliferous material was absent in the sections studied, Huddle and McCann (1947) found sweet smelling petroliferous limestone in the Humbug formation in Duchesne County.

The pronounced vertical and lateral lensing that characterizes the Humbug formation, as well as a variation in thickness, should be considered in exploration for oil. Very little is known concerning relations of the Humbug formation in central Utah with time equivalent units in western Utah and Nevada. The arenaceous and calcarenaceous units of central Utah are probably replaced by shale and limestone, such as the Chainman shale to the west. The sandstone, orthoquartzites and especially the calcarenites of the Humbug formation should afford excellent reservoir rocks.

Two gray, pure limestone units occur near the center of the Humbug formation in Ophir Canyon. They may have economic possibilities in lithography. Kistler (1950, p. 1) states that the color of limestone is indicative of its lithographic quality. He points out:

> The light gray stones are best for most uses. They are of finer texture, stand the etch well, will take and hold a fine grain and are of good color to draw upon.

The limestone in these two units appear to be of fair quality according to Kistler's (Ibid.) description, but the quantity is probably not great enough to warrant exploitation.

None of the orthoquartzites appear pure enough for use as refractories or building sands.

PLATE
3

Explanation

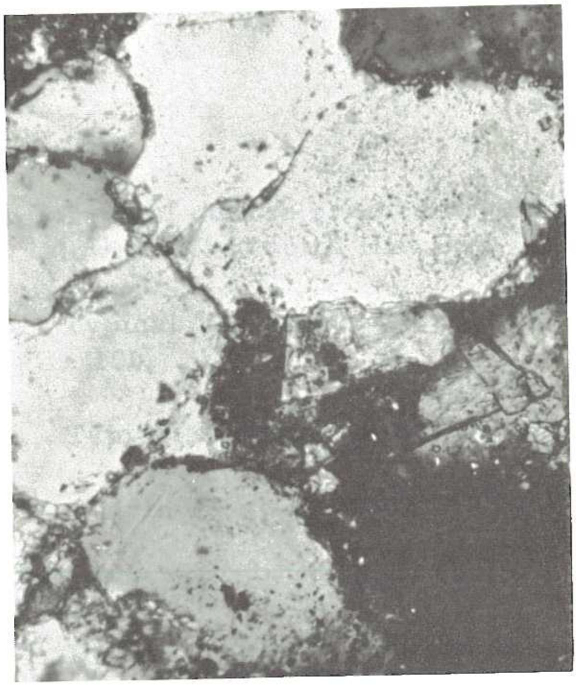
A. Orthoquartzite cemented by silica showing quartz mozaic (Lake Mountain Unit 69), x100.

B. Orthoquartzite cemented by silica and calcite (Allens Ranch Unit 1), x 100.

C. Sandstone cemented by calcite (Long Ridge Unit 4), x 100.

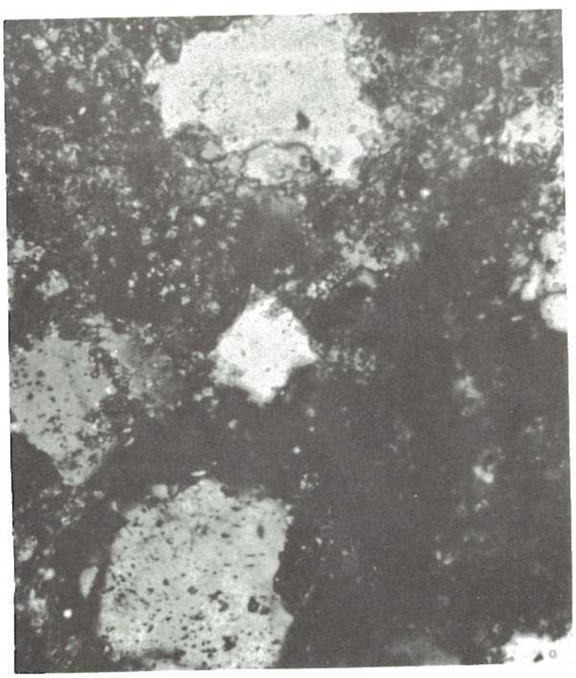
D. Graded sandstone (From near the center of the West Mountain section), x 50.

PLATE 3



A

B



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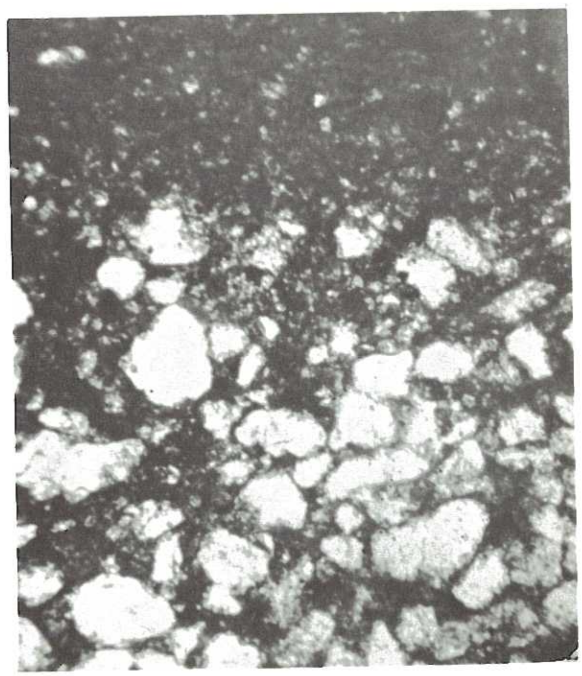


D

PLATE
4

Explanation

A. Typical coarse grained limestone, note the endothyrid at lower left (Topliff Hill Unit 1), x50.

B. Typical fine grained limestone (Ophir Canyon Unit 11), x 100.

C. Typical dolomite (American Fork Canyon Unit 14), x100.

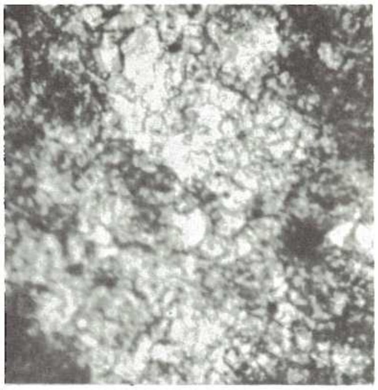
D. Quartz druze growing in country rock, x 25.

E. Quartz druze filling a cavity in the country rock, x50.

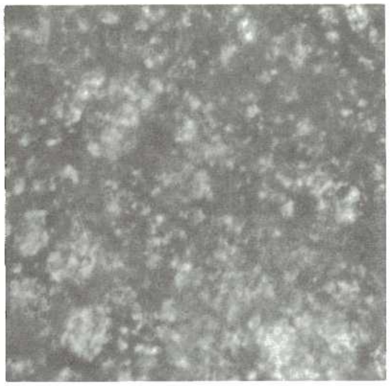
F. Doubly terminated quartz euhedra.

PLATE 4

A



B



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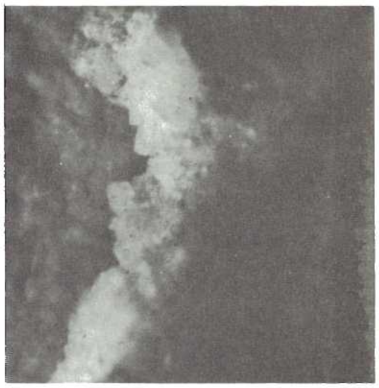
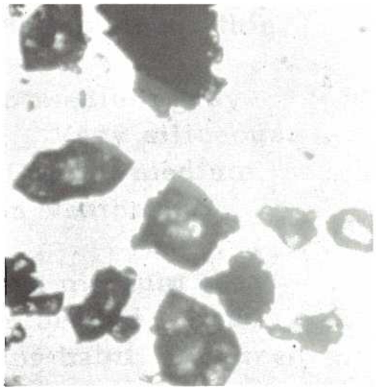


D

E



F

APPENDIX A

Typical section of the Humbug formation measured on the second spur south of Rattlesnake Spur in Section 1, Township 9 South, Range 3 West.

Great Blue limestone

Conformable contact

UNIT	DESCRIPTION	THICKN. IN FT.
Ia-52	Quartzite, yellow-brown, weathers red-brown. Coarse to medium grained, thin to medium bedded. Grains sub-angular. Cross-bedding indicates current flow was to south.	7.0
Ia-51	Limestone, dark gray, weathers light blue gray. Fine to medium grained, thin to thick bedded. Black weathering chert blebs and productid type brachiopods present. Two inch sandstone bed 19 feet from base.	37.0
Ia-50	Quartzite, red-gray, weathers same. Fine grained, thin bedded. Scintillating weathered surface, very dense . . .	3.0
Ia-49	Limestone, dark reddish-gray, weathers medium gray. Coarse grained to crystalline, medium bedded. Saccharoidal weathering habit, black weathering chert blebs. Scattered zaphrentid type corals.	11.0
Ia-48	Quartzite, yellow-brown, weathers red-brown. Fine grained, thin bedded. Half inch red bands present	11.0
Ia-47	Limestone, pink-gray, weathers same. Coarse grained to crystalline, thin bedded. Abundant crinoid hash, feted.	1.0
Ia-46	Limestone, dark gray, weathers same. Medium grained to crystalline, medium bedded. Very siliceous	4.0
Ia-45	Quartzite, buff-gray, weathers buff. Fine grained, thin bedded. Very dense	3.0
Ia-44	Limestone, dark gray, weathers dark to medium gray. Fine to coarse grained, medium bedded. Very siliceous. .	3.0
Ia-43	Quartzite, red-gray, weathers same. Fine to medium grained, thin bedded. Slightly friable on weathered surface.	3.0
Ia-42	Limestone, medium olive-gray, weathers medium gray. Fine to medium grained, thin to medium bedded. Gray Mottling at base, saccharoidal weathering habit. Scoured at top.	16.0

Ia-41	Quartzite, red-gray, weathers same. Fine grained, thin bedded. Very dense.	5.5
Ia-40	Limestone, olive to medium gray, weathers medium gray. Crystalline, thin bedded. Saccharoidal weathering habit.	4.0
Ia-39	Quartzite, red-gray, weathers same. Fine grained, thin bedded. Very dense.	19.0
Ia-38	Limestone, light olive-gray, weathers light gray. Sub-lithographic, medium bedded. Meringue weathering habit.	1.0
Ia-37	Quartzite, red-gray, weathers same. Fine grained, thin bedded. Very dense, some cross-bedding	14.0
Ia-36	Limestone, light olive-gray, weathers light gray. Sub-lithographic, medium beds.. Meringue weathering habit, scoured at top	19.0
Ia-35	Quartzite, very light brown, weathers light brown. Fine grained, thin bedded.	11.0
Ia-34	Limestone, light brown-gray, weathers light gray. Sub-lithographic, thick bedded. Laminations of fine grained sand show cross-bedding.	12.0
Ia-33	Cover, probably quartzite beneath. Float is about 90% quartzite	26.0
Ia-32	Limestone, pink-gray, weathers medium gray. Crystal-line, thick bedded. Fine saccharoidal weathering habit	16.0
Ia-31	Mostly cover, occasional quartzite outcrop. Float 100% quartzite.	59.0
Ia-30	Limestone, light brown, weathers same. Sublithographic, medium bedded. Many subsperhical algal ? bodies	5.0
Ia-29	Quartzite, red-gray, weathers same. Fine grained, thin bedded. Very dense, scintillating weathered surface	35.0
Ia-28	Dolomite, olive-gray, weathers magnesium white. Fine grained, medium bedded. Slightly calcareous	3.0
Ia-27	Limestone, dark to medium gray, weathers medium to light gray. Fine grained to crystalline, medium bedded. Meringue weathering habit	8.0
Ia-26	Dolomite, olive gray, weathers magnesium white. Fine grained, medium bedded. Siliceous.	3.0
Ia-25	Quartzite, red-gray, weathers same. Fine grained, thin bedded. Very dense, scintillating weathered surface	23.0
Ia-24	Dolomite, olive gray, weathers magnesium white. Fine grained, medium bedded. Slightly calcareous	4.0
Ia-23	Limestone, dark gray, weathers light to medium gray. Fine grained, medium bedded. 1/8" to 1/4" algal? structures present	4.0
Ia-22	Calcareous dolomite, medium gray, weathers magnesium white. Fine grained, medium bedded	3.0

Ia-21	Quartzite, red-brown, weathers same. Fine to medium grained, medium bedded. Very dense	2.0
Ia-20	Dolomite, light brownish green, weathers magnesium white. Crystalline, thin bedded. Meringue weathering habit, slightly calcareous.	1.0
Ia-19	Limestone, medium gray, weathers same. Fine grained to crystalline, thick bedded. Many white twiggy bodies near top, some algal? structures.	32.0
Ia-18	Dolomite, medium gray, weathers light gray. Fine grained, thin bedded. Saccharoidal weathering habit	1.5
Ia-17	Quartzite, purple-red, weathers brown. Fine grained, thin bedded. Very dense	9.0
Ia-16	Limestone, pink-brown, weathers darker pink-brown. Lithographic, medium bedded	2.0
Ia-15	Quartzite, medium gray to pink-gray, weathers red brown. Coarse grained, medium to thin bedded. Cross-bedding indicates current flow was due east near top of unit	35.0
Ia-14	Limestone, olive brown, weathers medium gray. Crystalline, medium bedded. Saccharoidal weathering habit, siliceous. Small white twiggy bodies present.	10.0
Ia-13	Quartzite, pink-gray, weathers reddish brown, Coarse grained, medium bedded	4.0
Ia-12	Limestone, olive-brown, weathers light gray. Lithographic, medium bedded	10.0
Ia-11	Quartzite, buff to pink-gray, weathers reddish-brown. Medium to coarse grained, thin to medium bedded. Saccharoidal weathering habit	23.0
Ia-10	Limestone, light gray, weathers medium gray. Fine grained, medium bedded. Siliceous, saccharoidal weathering habit	4.0
Ia- 9	Quartzite, same as No. 11	47.0
Ia- 8	Dolomite, olive-brown to gray, weathers light gray. Fine grained, thin bedded. Many vertical chert stringers (1/16" thick present.	10.0
Ia- 7	Quartzite, yellow brown, weathers light brown. Coarse grained, thin bedded. Cross-bedded near center of unit	20.0
Ia- 6	Limestone, medium gray, weathers same. Coarse grained, thick bedded. Cross-bedded.	9.0
Ia- 5	Quartzite, same as unit 11	9.0
Ia- 4	Dolomite, pink-gray to olive-gray, weathers light gray. Fine grained, thin bedded near base becoming medium bedded at top.	40.0
Ia- 3	Quartzite, same as unit 11	9.0
Ia- 2	Quartzite, pink-gray, weathers brown gray. Coarse grained, medium to thin bedded. Calcareous, friable on weathered surface	18.0

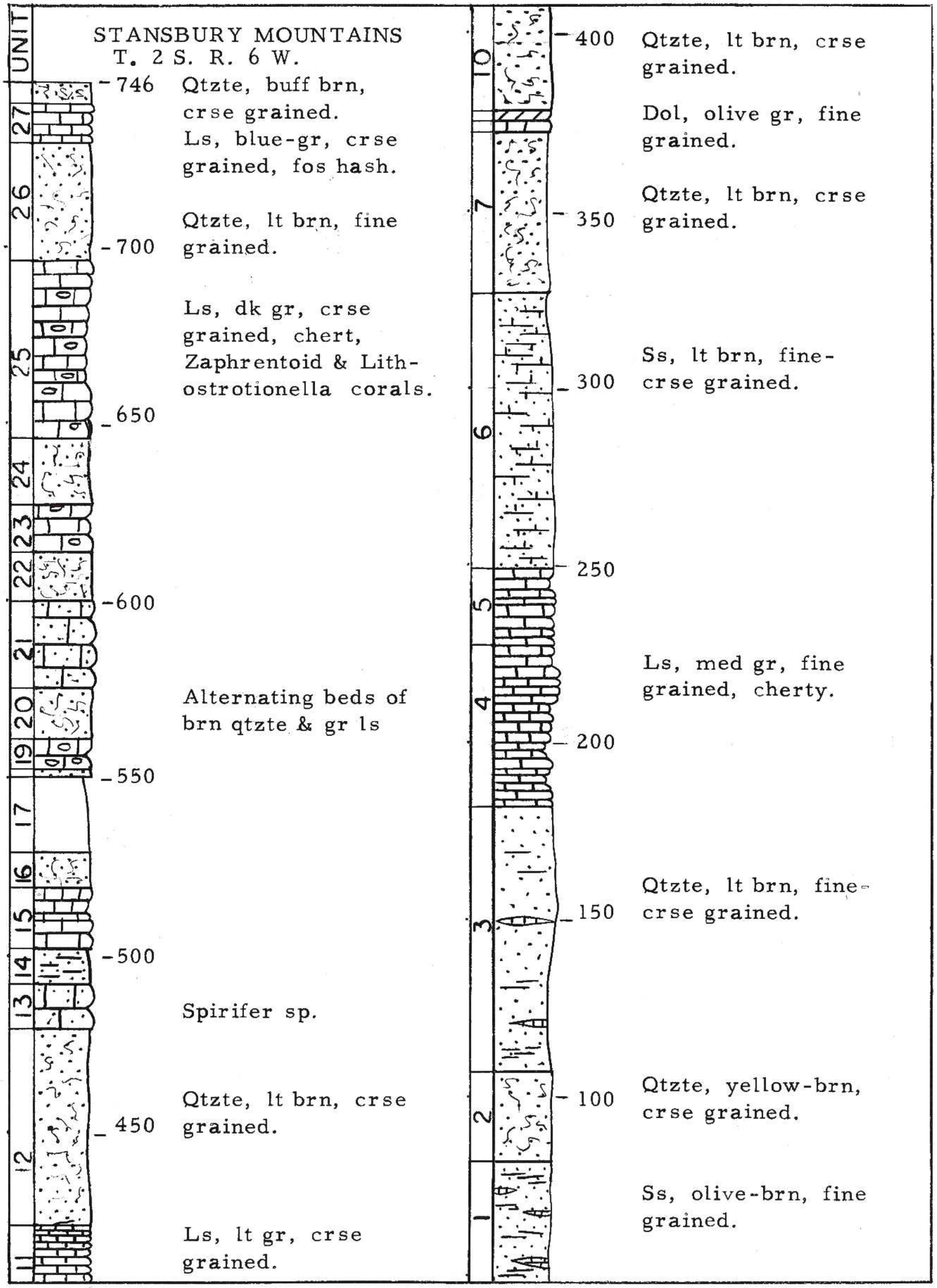
Ia- 1	Sandstone, light gray, weathers same. Coarse grained, laminated to thin bedded. Calcareous, friable on weathered surface	42.0
Conformable contact	Total Thickness	746.0

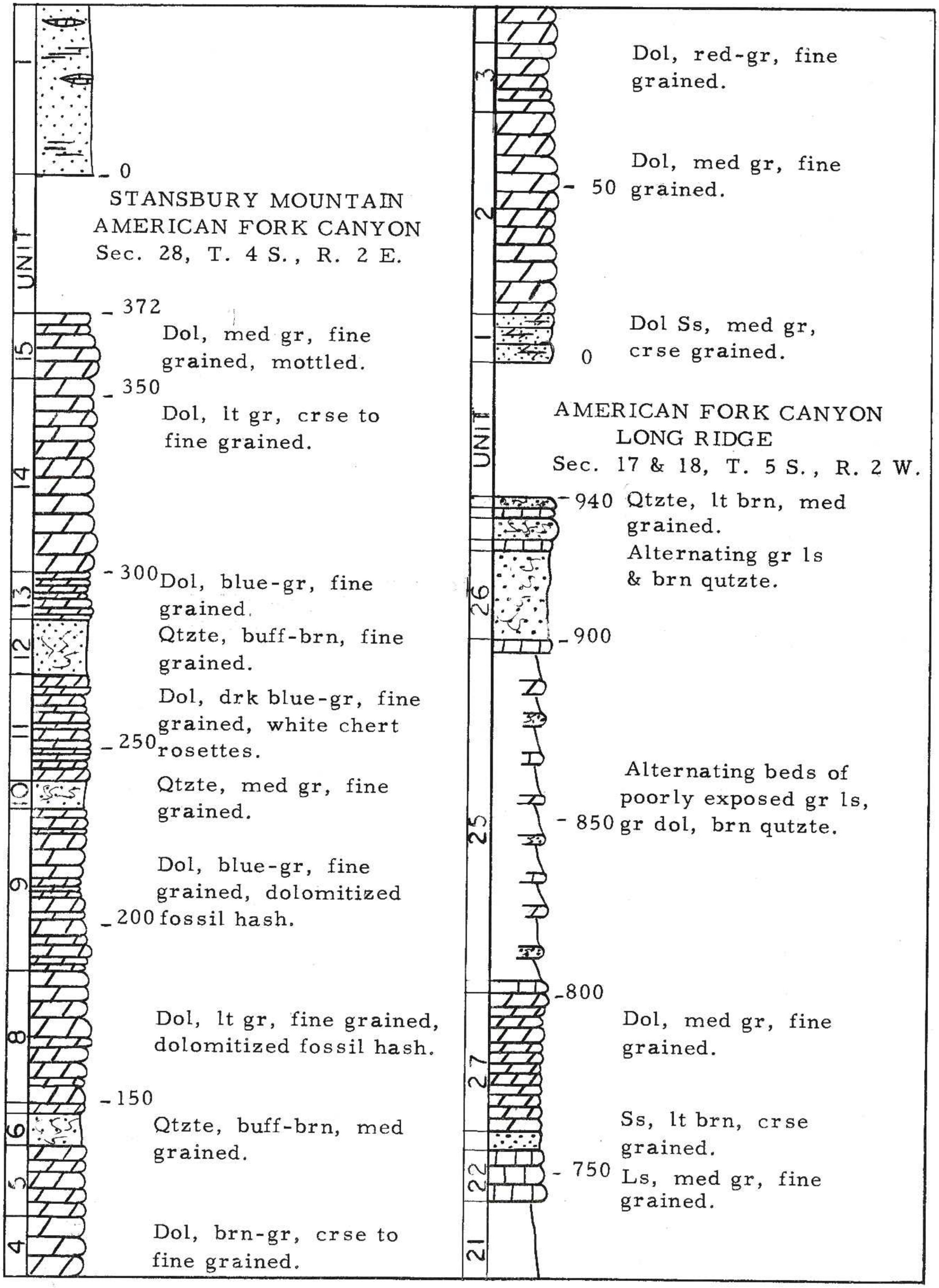
Pine Canyon formation

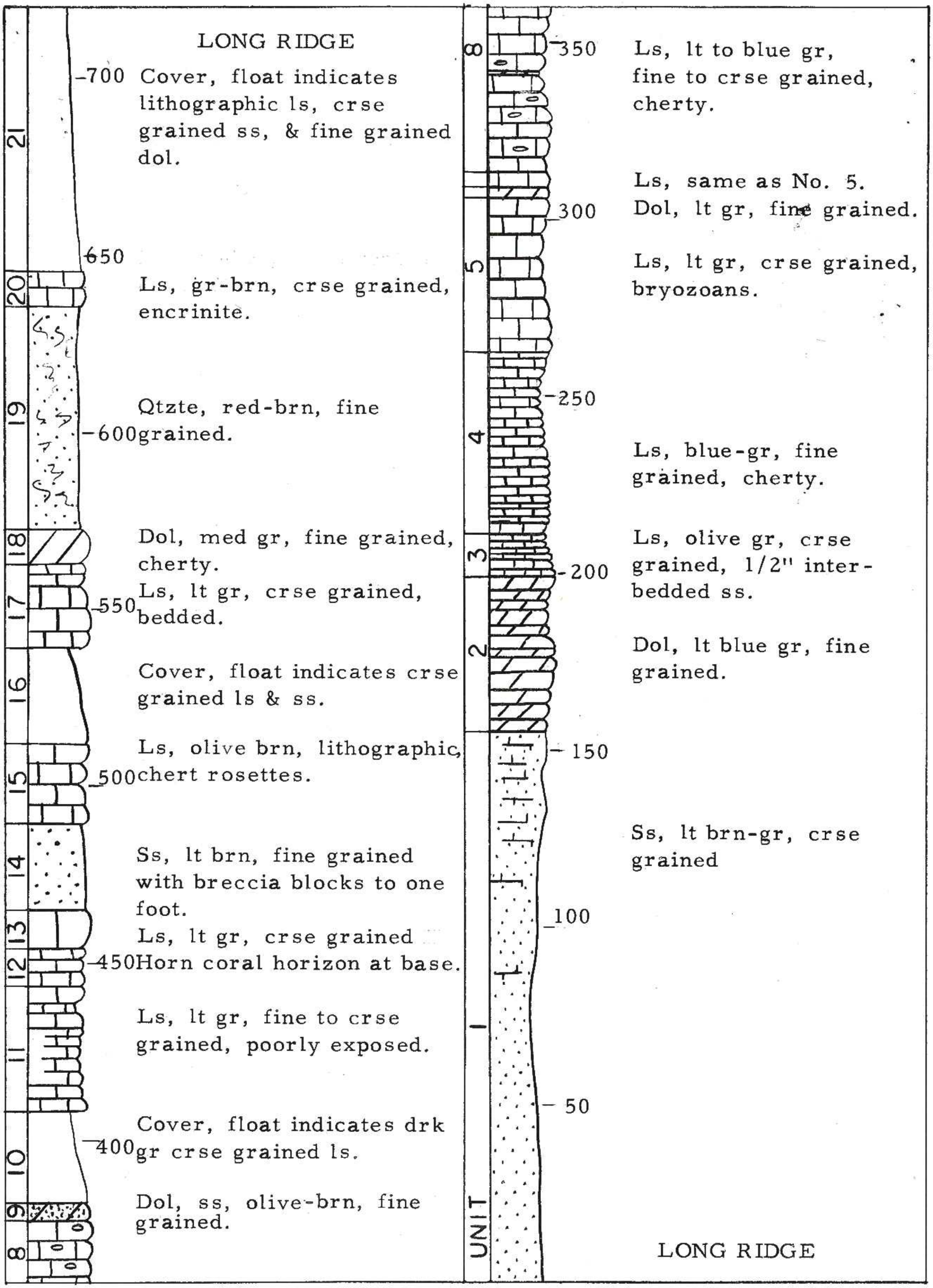
APPENDIX B

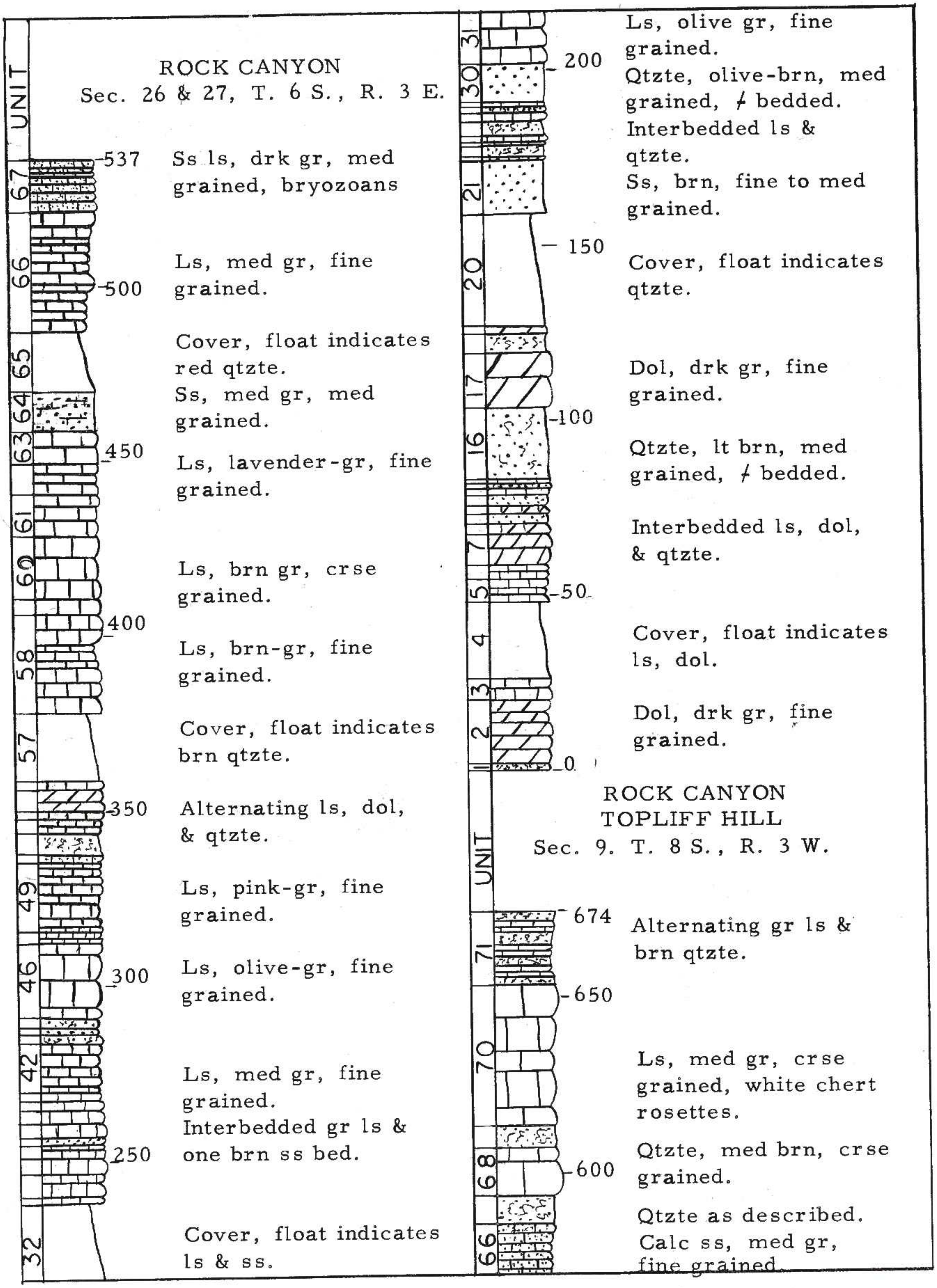
Stratigraphic columns of measured sections.*

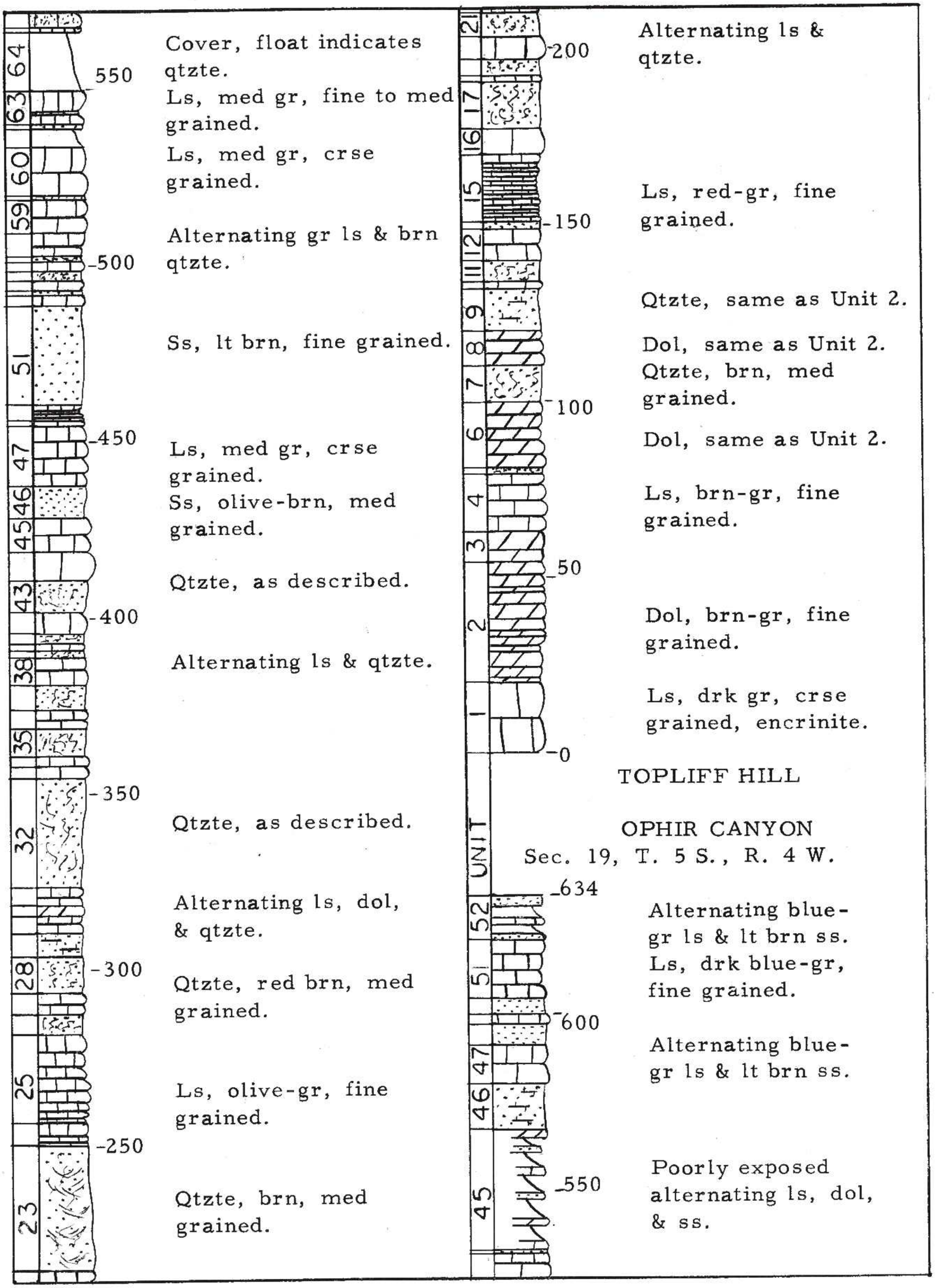
*Detailed descriptions of these sections are on file at the Brigham Young University Geology Department.

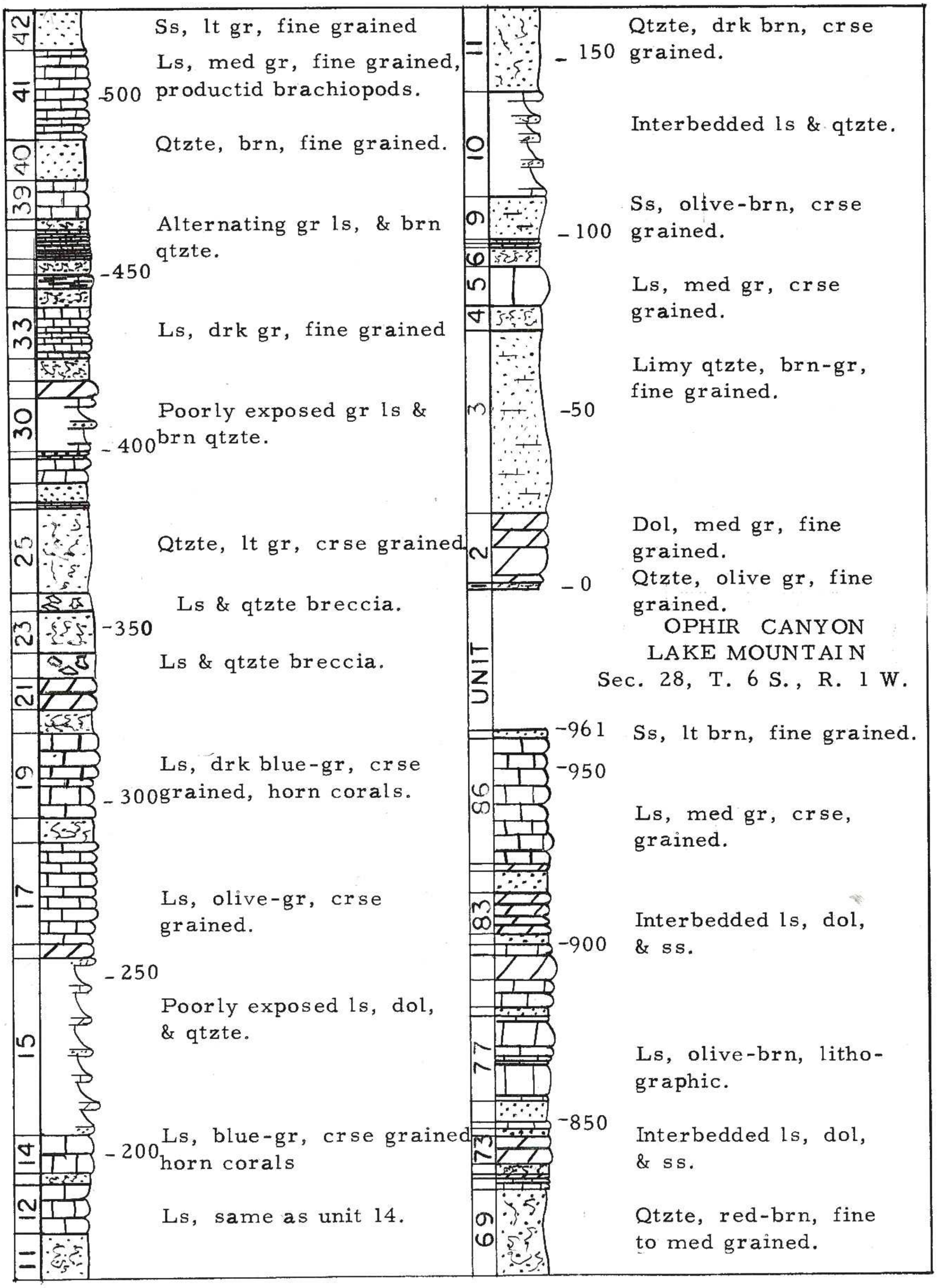

UNIT
STANSBURY MOUNTAINS
T. 2 S. R. 6 W.
746
Qtzte, buff brn, crse grained.
27
Ls, blue-gr, crse grained, fos hash.
26
Qtzte, lt brn, fine grained.
700
25
Ls, dk gr, crse grained, chert, Zaphrentoid & Lithostrotionella corals.
650
24
23
22
600
21
20
Alternating beds of brn qtzte & gr ls
19
550
17
16
15
500
14
13
Spirifer sp.
12
Qtzte, lt brn, crse grained.
450
11
Ls, lt gr, crse grained.
10
400
Qtzte, lt brn, crse grained.
Dol, olive gr, fine grained.
7
Qtzte, lt brn, crse grained.
350
6
Ss, lt brn, fine-crse grained.
300
250
5
4
Ls, med gr, fine grained, cherty.
200
3
Qtzte, lt brn, fine-crse grained.
150
2
Qtzte, yellow-brn, crse grained.
100
1
Ss, olive-brn, fine grained.

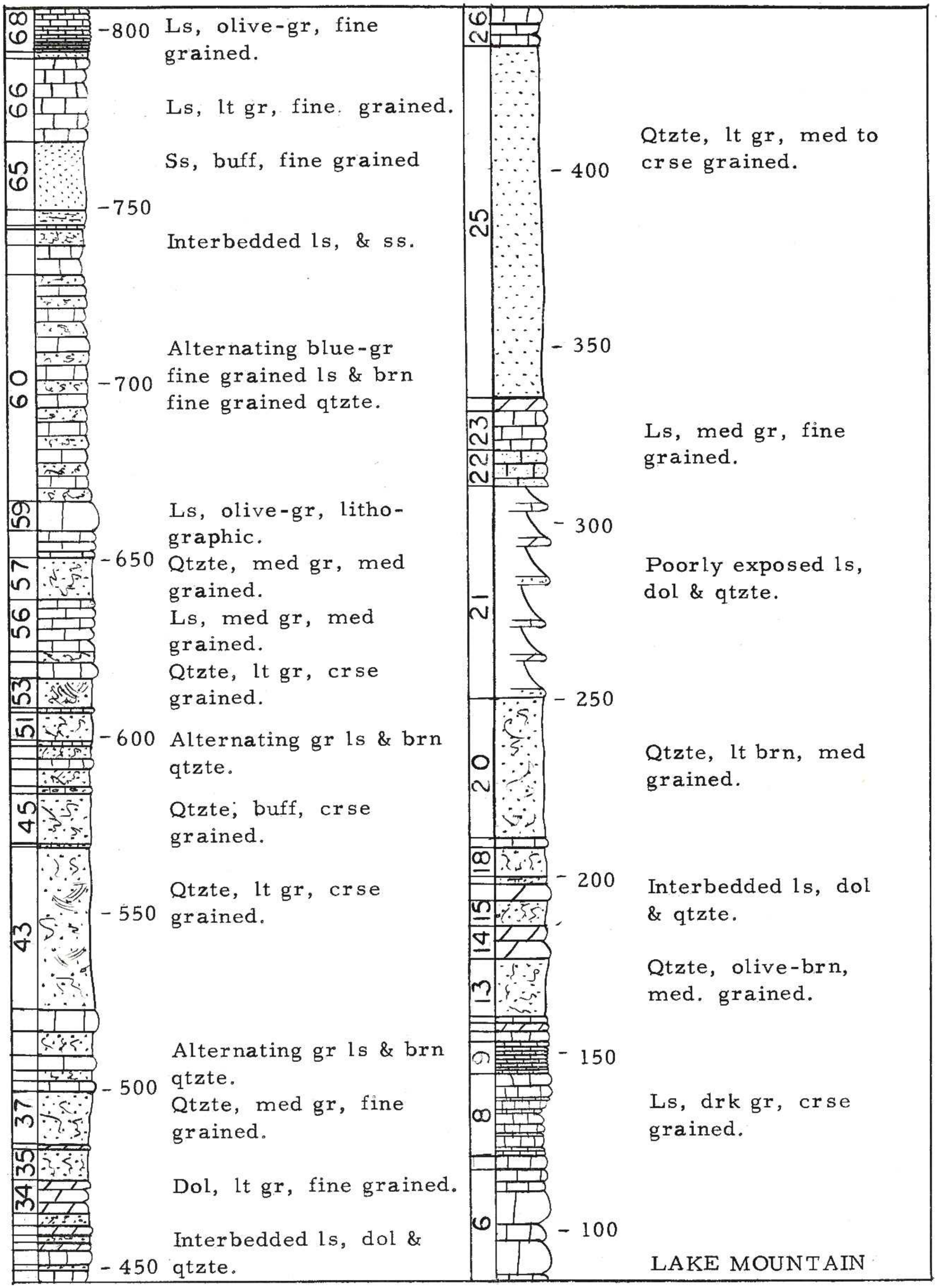

STANSBURY MOUNTAIN
AMERICAN FORK CANYON
Sec. 28, T. 4 S., R. 2 E.
UNIT
0
372
Dol, med gr, fine grained, mottled.
350
Dol, lt gr, crse to fine grained.
300
Dol, blue-gr, fine grained.
Qtzte, buff-brn, fine grained.
Dol, drk blue-gr, fine grained, white chert rosettes.
250
Qtzte, med gr, fine grained.
Dol, blue-gr, fine grained, dolomitized fossil hash.
200
Dol, lt gr, fine grained, dolomitized fossil hash.
150
Qtzte, buff-brn, med grained.
Dol, brn-gr, crse to fine grained.
1
15
14
13
12
11
10
9
8
6
5
4
Dol, red-gr, fine grained.
Dol, med gr, fine grained.
50
Dol Ss, med gr, crse grained.
0
3
2
1
AMERICAN FORK CANYON
LONG RIDGE
Sec. 17 & 18, T. 5 S., R. 2 W.
UNIT
940
Qtzte, lt brn, med grained.
Alternating gr ls & brn qutzte.
900
Alternating beds of poorly exposed gr ls, gr dol, brn qutzte.
850
800
Dol, med gr, fine grained.
Ss, lt brn, crse grained.
750
Ls, med gr, fine grained.
26
25
27
22
21

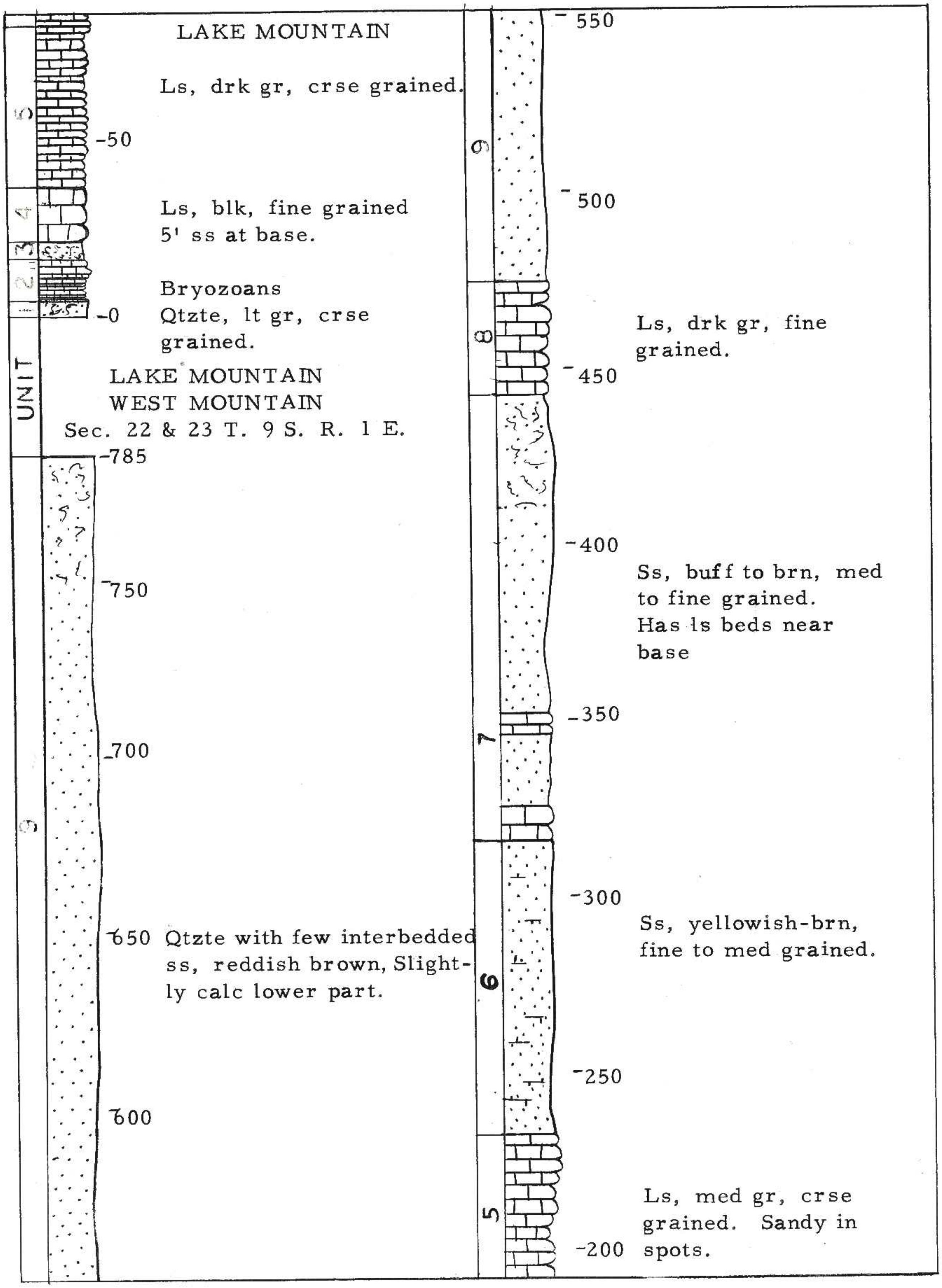

LONG RIDGE
-700 Cover, float indicates lithographic ls, crse grained ss, & fine grained dol.
21
650
20
Ls, gr-brn, crse grained, encrinite.
19
Qtzte, red-brn, fine
-600 grained.
18
Dol, med gr, fine grained, cherty.
17
Ls, lt gr, crse grained,
550 bedded.
16
Cover, float indicates crse grained ls & ss.
15
Ls, olive brn, lithographic,
500 chert rosettes.
14
Ss, lt brn, fine grained with breccia blocks to one foot.
13
Ls, lt gr, crse grained
12
-450 Horn coral horizon at base.
11
Ls, lt gr, fine to crse grained, poorly exposed.
10
Cover, float indicates drk
400 gr crse grained ls.
9
Dol, ss, olive-brn, fine grained.
8
8
350 Ls, lt to blue gr, fine to crse grained, cherty.
Ls, same as No. 5.
300 Dol, lt gr, fine grained.
5
Ls, lt gr, crse grained, bryozoans.
250
4
Ls, blue-gr, fine grained, cherty.
3
Ls, olive gr, crse
200 grained, 1/2" inter-bedded ss.
2
Dol, lt blue gr, fine grained.
150
Ss, lt brn-gr, crse grained
100
1
50
UNIT
LONG RIDGE

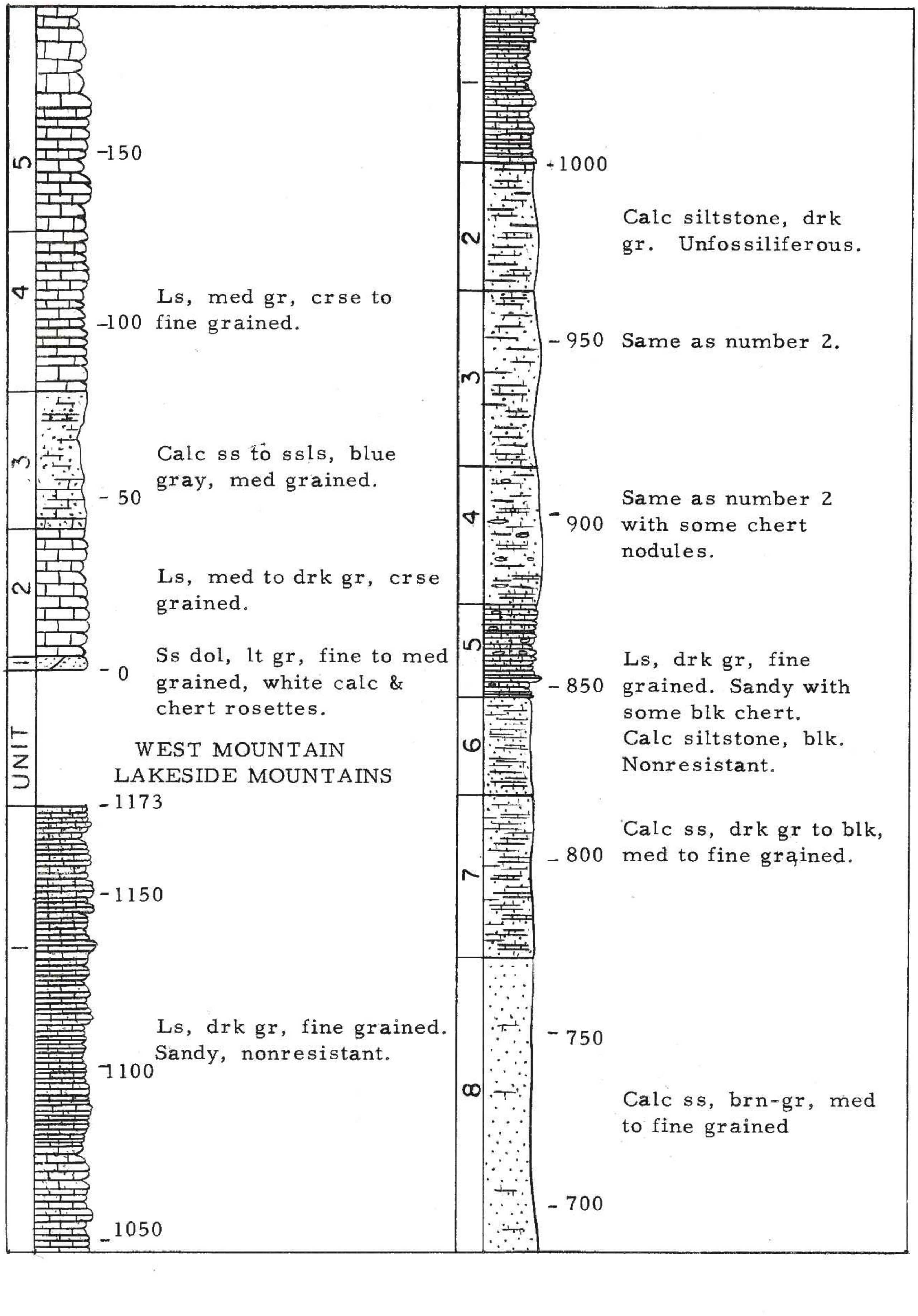

UNIT
ROCK CANYON
Sec. 26 & 27, T. 6 S., R. 3 E.
537
Ss ls, drk gr, med grained, bryozoans
67
66
500
Ls, med gr, fine grained.
65
Cover, float indicates red qtzte.
64
Ss, med gr, med grained.
63
450
Ls, lavender-gr, fine grained.
61
60
Ls, brn gr, crse grained.
400
58
Ls, brn-gr, fine grained.
57
Cover, float indicates brn qtzte.
350
Alternating ls, dol, & qtzte.
49
Ls, pink-gr, fine grained.
46
300
Ls, olive-gr, fine grained.
42
Ls, med gr, fine grained.
250
Interbedded gr ls & one brn ss bed.
32
Cover, float indicates ls & ss.
31
Ls, olive gr, fine grained.
200
30
Qtzte, olive-brn, med grained, ≠ bedded.
Interbedded ls & qtzte.
21
Ss, brn, fine to med grained.
150
20
Cover, float indicates qtzte.
17
Dol, drk gr, fine grained.
100
16
Qtzte, lt brn, med grained, ≠ bedded.
7
Interbedded ls, dol, & qtzte.
5
50
4
Cover, float indicates ls, dol.
3
2
Dol, drk gr, fine grained.
0
ROCK CANYON
TOPLIFF HILL
Sec. 9. T. 8 S., R. 3 W.
UNIT
674
71
Alternating gr ls & brn qtzte.
650
70
Ls, med gr, crse grained, white chert rosettes.
68
Qtzte, med brn, crse grained.
600
Qtzte as described.
66
Calc ss, med gr, fine grained.

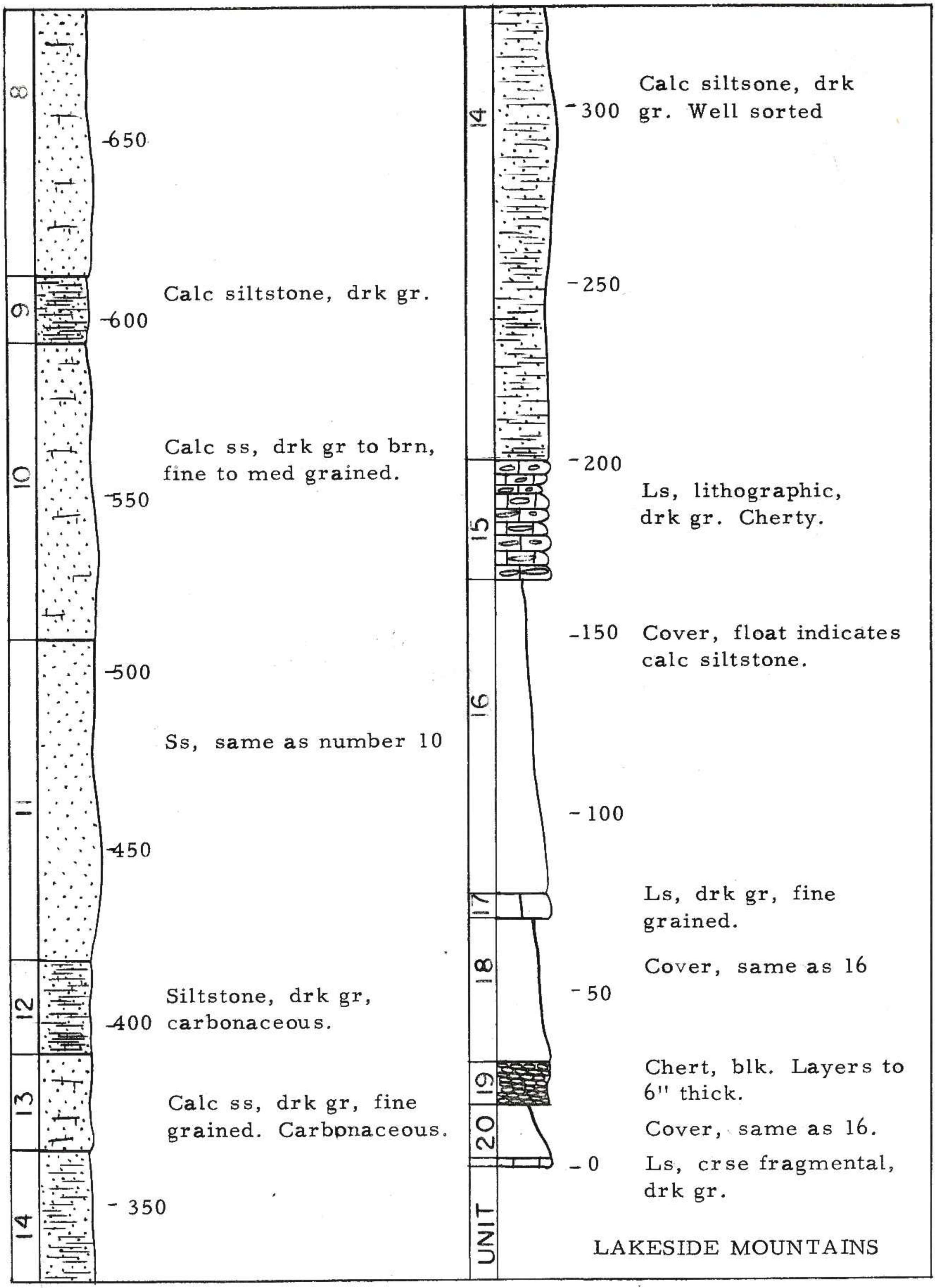

64
550
Cover, float indicates qtzte.
63
Ls, med gr, fine to med grained.
60
Ls, med gr, crse grained.
59
Alternating gr ls & brn qtzte.
500
51
Ss, lt brn, fine grained.
450
47
Ls, med gr, crse grained.
46
Ss, olive-brn, med grained.
45
Qtzte, as described.
43
400
Alternating ls & qtzte.
38
35
350
32
Qtzte, as described.
Alternating ls, dol, & qtzte.
28
300
Qtzte, red brn, med grained.
25
Ls, olive-gr, fine grained.
250
23
Qtzte, brn, med grained.
21
200
Alternating ls & qtzte.
17
16
15
Ls, red-gr, fine grained.
150
12
11
9
Qtzte, same as Unit 2.
8
Dol, same as Unit 2.
7
Qtzte, brn, med grained.
100
6
Dol, same as Unit 2.
4
Ls, brn-gr, fine grained.
3
50
2
Dol, brn-gr, fine grained.
1
Ls, drk gr, crse grained, encrinite.
0
TOPLIFF HILL
OPHIR CANYON
Sec. 19, T. 5 S., R. 4 W.
UNIT
634
52
Alternating blue-gr ls & lt brn ss.
51
Ls, drk blue-gr, fine grained.
600
47
Alternating blue-gr ls & lt brn ss.
46
550
45
Poorly exposed alternating ls, dol, & ss.


42
Ss, lt gr, fine grained
41
-500
Ls, med gr, fine grained, productid brachiopods.
40
Qtzte, brn, fine grained.
39
Alternating gr ls, & brn qtzte.
-450
33
Ls, drk gr, fine grained
30
Poorly exposed gr ls & brn qtzte.
-400
25
Qtzte, lt gr, crse grained
Ls & qtzte breccia.
23
-350
Ls & qtzte breccia.
21
19
Ls, drk blue-gr, crse grained, horn corals.
-300
17
Ls, olive-gr, crse grained.
-250
15
Poorly exposed ls, dol, & qtzte.
14
-200
Ls, blue-gr, crse grained horn corals
12
Ls, same as unit 14.
11
11
-150
Qtzte, drk brn, crse grained.
10
Interbedded ls & qtzte.
9
-100
Ss, olive-brn, crse grained.
6
5
Ls, med gr, crse grained.
4
3
-50
Limy qtzte, brn-gr, fine grained.
2
Dol, med gr, fine grained.
1
-0
Qtzte, olive gr, fine grained.
OPHIR CANYON
LAKE MOUNTAIN
Sec. 28, T. 6 S., R. 1 W.
UNIT
-961
Ss, lt brn, fine grained.
-950
86
Ls, med gr, crse, grained.
83
-900
Interbedded ls, dol, & ss.
77
Ls, olive-brn, lithographic.
-850
73
Interbedded ls, dol, & ss.
69
Qtzte, red-brn, fine to med grained.


68
-800
Ls, olive-gr, fine grained.
66
Ls, lt gr, fine grained.
65
Ss, buff, fine grained
-750
Interbedded ls, & ss.
60
Alternating blue-gr fine grained ls & brn fine grained qtzte.
-700
59
Ls, olive-gr, lithographic.
-650
57
Qtzte, med gr, med grained.
56
Ls, med gr, med grained.
53
Qtzte, lt gr, crse grained.
51
-600
Alternating gr ls & brn qtzte.
45
Qtzte, buff, crse grained.
43
Qtzte, lt gr, crse grained.
-550
Alternating gr ls & brn qtzte.
-500
37
Qtzte, med gr, fine grained.
35
34
Dol, lt gr, fine grained.
Interbedded ls, dol & qtzte.
-450
26
25
Qtzte, lt gr, med to crse grained.
-400
-350
23
22
Ls, med gr, fine grained.
-300
21
Poorly exposed ls, dol & qtzte.
-250
20
Qtzte, lt brn, med grained.
18
-200
Interbedded ls, dol & qtzte.
15
14
13
Qtzte, olive-brn, med. grained.
9
-150
8
Ls, drk gr, crse grained.
6
-100
LAKE MOUNTAIN

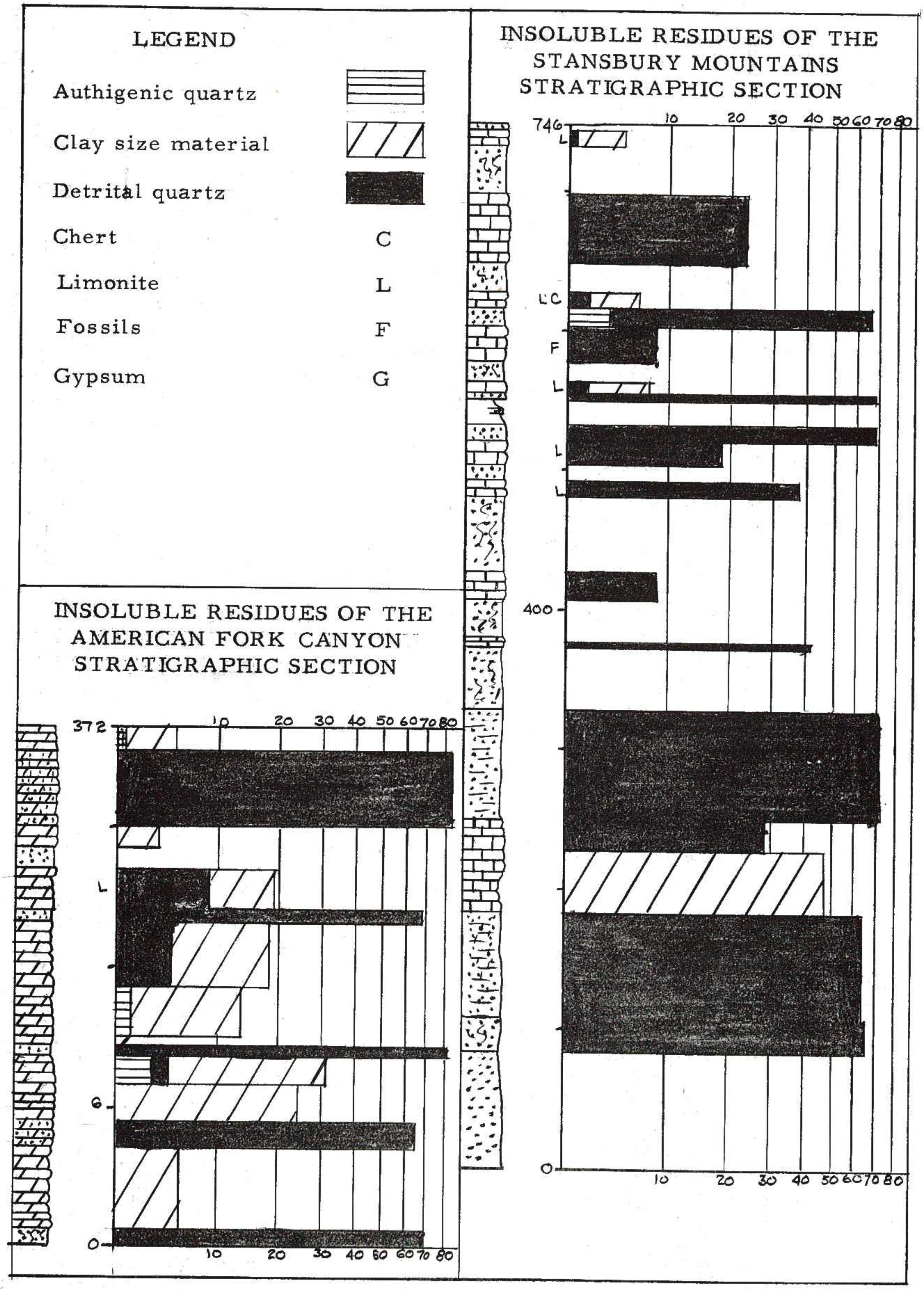

LAKE MOUNTAIN
Ls, drk gr, crse grained.
-50
Ls, blk, fine grained
5' ss at base.
Bryozoans
-0
Qtzte, lt gr, crse
grained.
LAKE MOUNTAIN
WEST MOUNTAIN
Sec. 22 & 23 T. 9 S. R. 1 E.
UNIT
5
4
3
2
1
6
-785
750
700
650
Qtzte with few interbedded
ss, reddish brown, Slight-
ly calc lower part.
600
550
9
500
8
Ls, drk gr, fine
grained.
450
400
Ss, buff to brn, med
to fine grained.
Has ls beds near
base
350
7
300
Ss, yellowish-brn,
fine to med grained.
6
250
5
Ls, med gr, crse
grained. Sandy in
spots.
-200


UNIT
5
4
3
2
1
-150
-100
- 50
- 0
Ls, med gr, crse to fine grained.
Calc ss to ssls, blue gray, med grained.
Ls, med to drk gr, crse grained.
Ss dol, lt gr, fine to med grained, white calc & chert rosettes.
WEST MOUNTAIN
LAKESIDE MOUNTAINS
1
-1173
-1150
-1100
-1050
Ls, drk gr, fine grained. Sandy, nonresistant.
1
2
3
4
5
6
7
8
-1000
- 950
- 900
- 850
- 800
- 750
- 700
Calc siltstone, drk gr. Unfossiliferous.
Same as number 2.
Same as number 2 with some chert nodules.
Ls, drk gr, fine grained. Sandy with some blk chert.
Calc siltstone, blk. Nonresistant.
Calc ss, drk gr to blk, med to fine grained.
Calc ss, brn-gr, med to fine grained

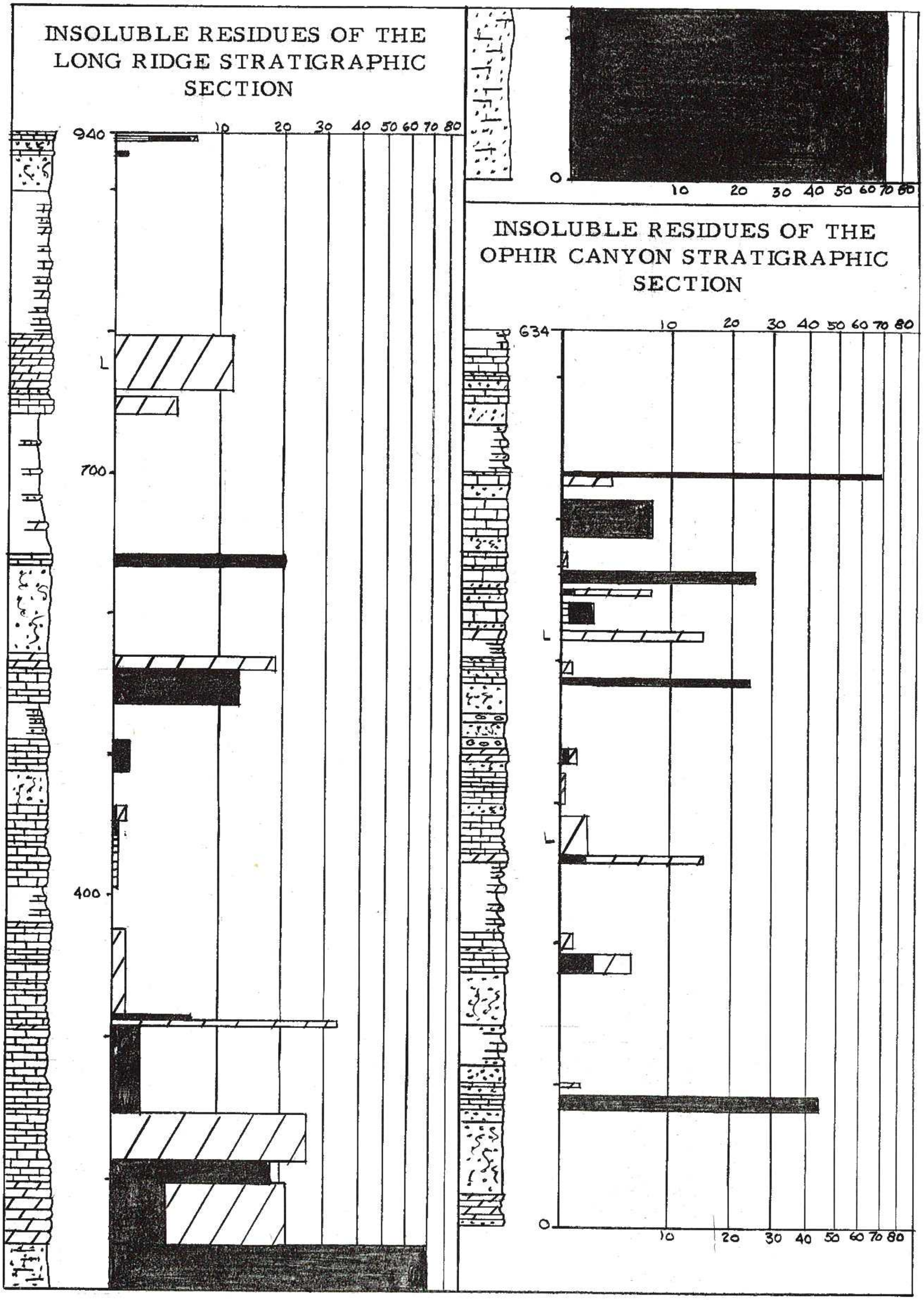

8
650
9
Calc siltstone, drk gr.
600
10
Calc ss, drk gr to brn, fine to med grained.
550
11
500
Ss, same as number 10
450
12
Siltstone, drk gr, carbonaceous.
400
13
Calc ss, drk gr, fine grained. Carbonaceous.
14
350
14
Calc siltsone, drk gr. Well sorted
300
250
200
15
Ls, lithographic, drk gr. Cherty.
150
Cover, float indicates calc siltstone.
16
100
17
Ls, drk gr, fine grained.
18
Cover, same as 16
50
19
Chert, blk. Layers to 6" thick.
20
Cover, same as 16.
0
Ls, crse fragmental, drk gr.
UNIT
LAKESIDE MOUNTAINS

APPENDIX C

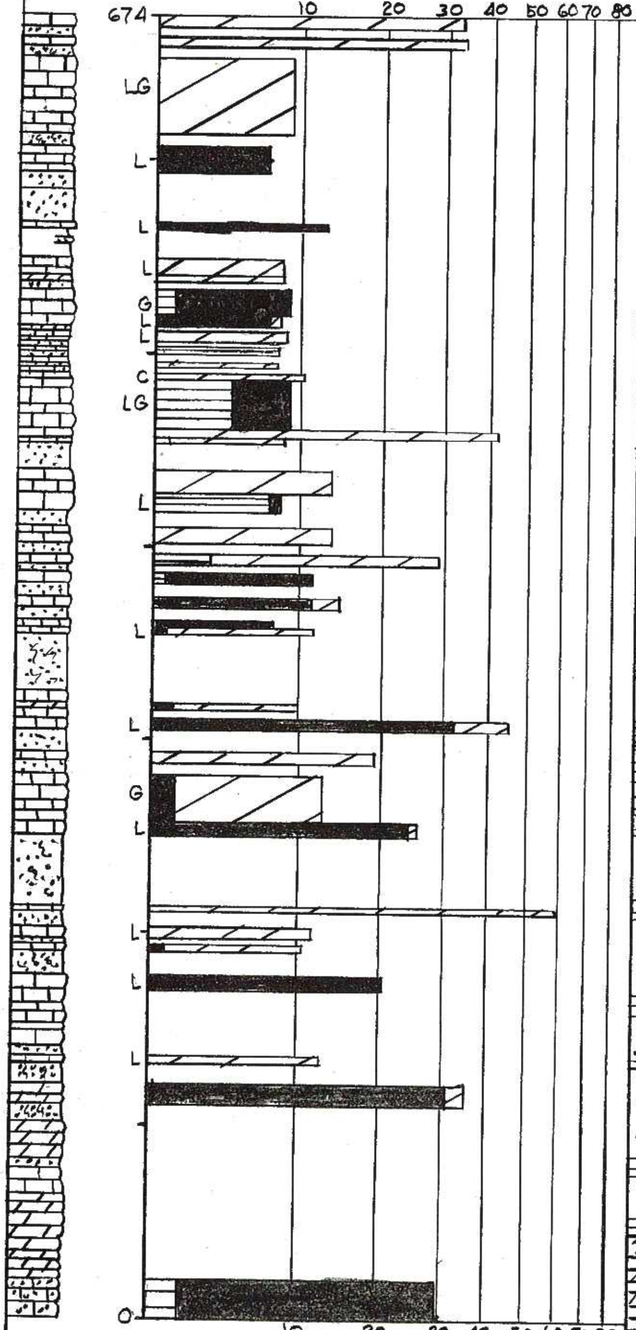
Insoluble residues of the Humbug formation.



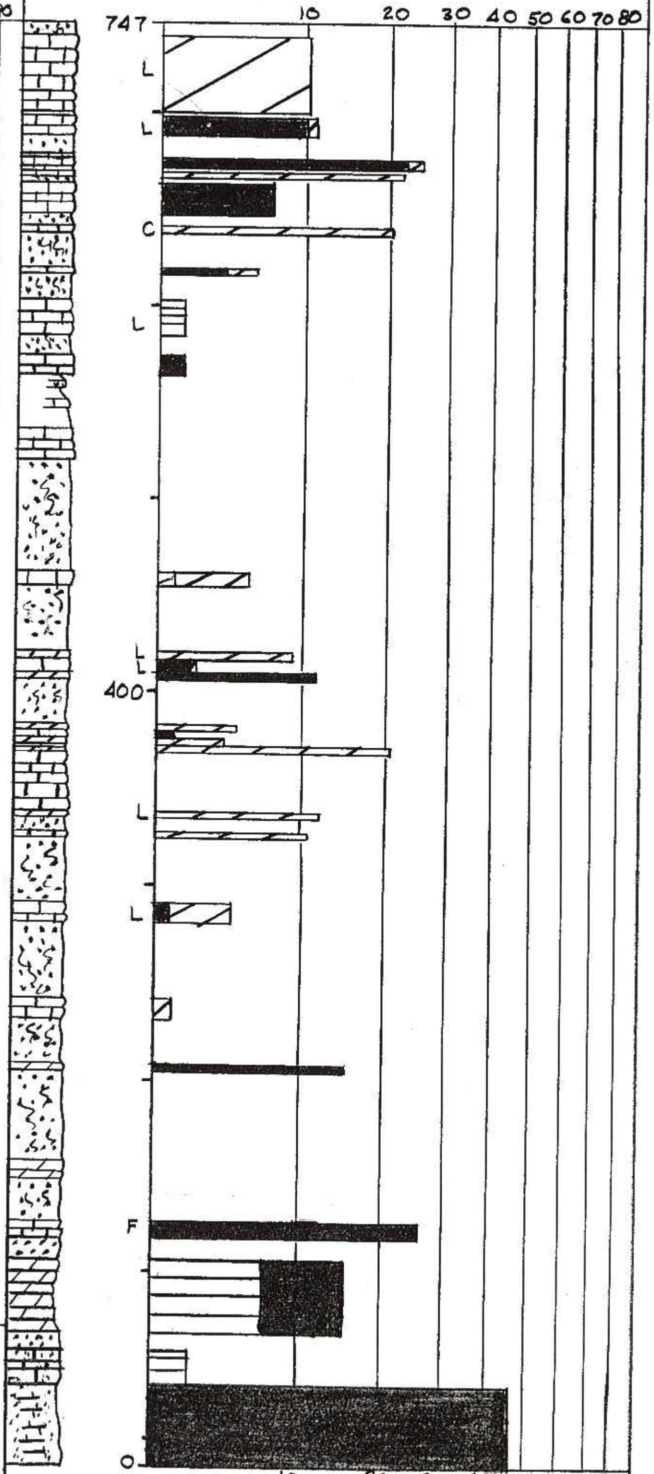
LEGEND
Authigenic quartz
Clay size material
Detrital quartz
Chert C
Limonite L
Fossils F
Gypsum G
INSOLUBLE RESIDUES OF THE STANSBURY MOUNTAINS STRATIGRAPHIC SECTION
746
400
0
10 20 30 40 50 60 70 80
L
LC
F
INSOLUBLE RESIDUES OF THE AMERICAN FORK CANYON STRATIGRAPHIC SECTION
372
6
0
10 20 30 40 50 60 70 80

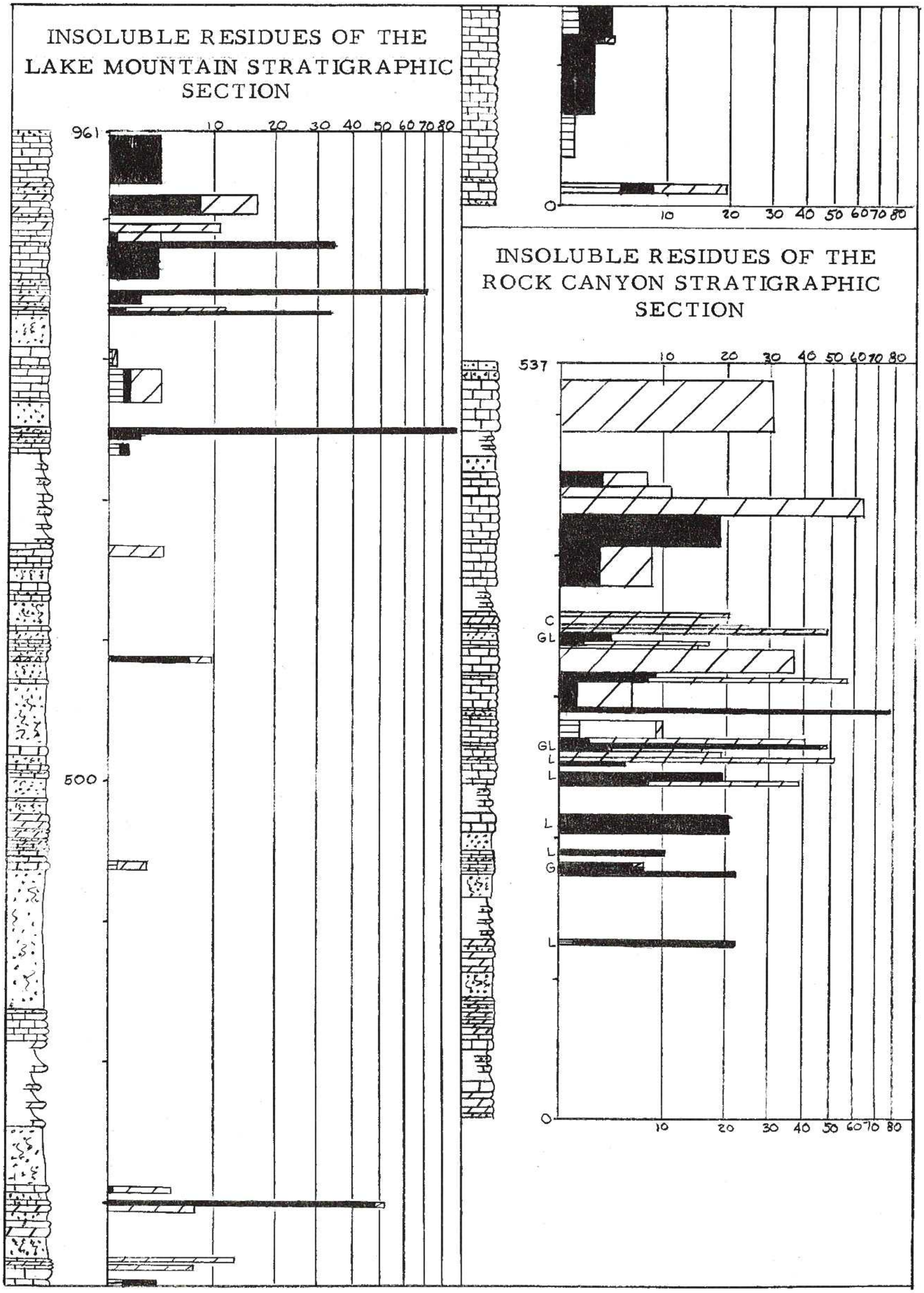

INSOLUBLE RESIDUES OF THE LONG RIDGE STRATIGRAPHIC SECTION
940
700
400
L
10 20 30 40 50 60 70 80
INSOLUBLE RESIDUES OF THE OPHIR CANYON STRATIGRAPHIC SECTION
634
0
L
10 20 30 40 50 60 70 80

INSOLUBLE RESIDUES OF THE TOPLIFF HILL STRATIGRAPHIC SECTION



INSOLUBLE RESIDUES OF THE ALLENS RANCH STRATIGRAPHIC SECTION





INSOLUBLE RESIDUES OF THE LAKE MOUNTAIN STRATIGRAPHIC SECTION

INSOLUBLE RESIDUES OF THE ROCK CANYON STRATIGRAPHIC SECTION

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