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Petrology and Petrography of Ely Limestone in Part of Eastern Great Basin*

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ABSTRACT.—Ely Limestone of Early to Medial Pennsylvanian age was studied in terms of carbonate petrology and petrography in three areas in the eastern Great Basin. Results are as follows: (1) At Moorman Ranch area, White Pine County, Nevada, reference section for Ely Limestone (Steele, 1960), the formation is approximately 1700 feet thick and consists of limestones of these types: matrix, detrital-in-matrix, skeletal, and combinations. These are unstable-shelf to miogeosynclinal varieties of relatively shallow water origin. (2) In the central Pequop Mountains of Elko County, Nevada, the Ely Limestone is 1600 feet of argillaceous, silty, sandy matrix limestones and bioclastic limestones. Some chert-pebble conglomerates are present, and gypsiferous limestones are abundant. (3) The west side of Conger Mountain in the Confusion Range of western Utah contains a superb section of Ely Limestone, 2000 feet thick and consisting largely of bioclastic and sandy limestones. A new classification of carbonate rocks is proposed.

Carbonates of Ely in these localities are micritic, aphanitic to finely crystalline, silty and sandy, and fine to coarsely bioclastic. Calcarenites are common, and pelletoid grains are abundant in some matrix limestones. Material that was swept into the Ely Basin came from the Antler orogenic belt, western Utah Highland, and northern Nevada High. Numerous units within the Ely contain carbonates which have high interskeletal, intercrystalline, and interparticle porosity. Some rocks when broken emit hydrocarbon odors. Some sequences display repetitive intercalations of lithoclastic and bioclastic strata; many possibly accumulated on unstable shelves and within a miogeosyncline.

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*A thesis submitted to the Faculty of the Department of Geology, Brigham Young University in partial fulfillment of the requirements for the degree Master of Science.

INTRODUCTION

Purpose and Scope of the Investigation

Ely limestone of Early to Medial Pennsylvanian age was studied in two localities in eastern Nevada and at one locality in western Utah. Purpose of this paper is a field and laboratory investigation in petrology and petrography of the carbonates of this formation in areas representative of three different environments of sedimentation.

An additional facet of the study is proposal of a workable field and laboratory classification of limestones, particularly applicable to part of the Cordilleran area.

Location of the Sections

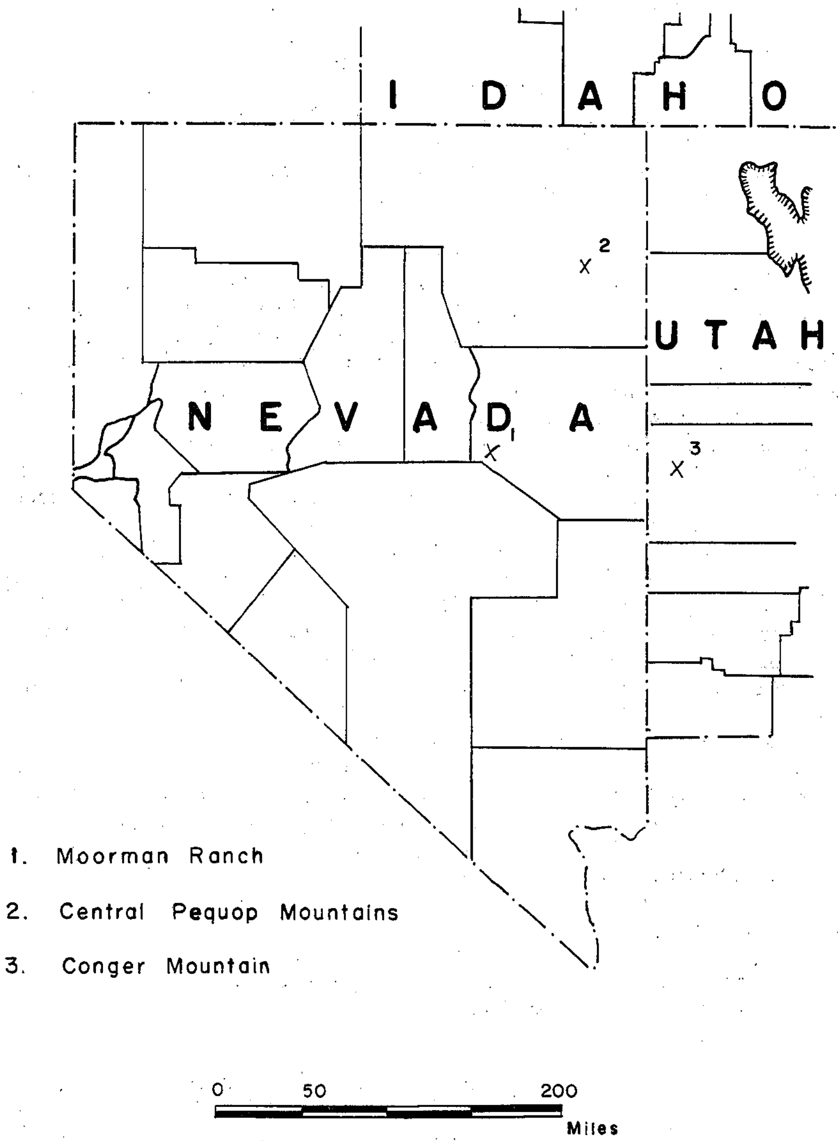
Three surface stratigraphic sections were studied in this investigation, two in eastern Nevada and one in western Utah. The Moorman Ranch section is the key locality, because it is reference section of the Ely Limestone, it is situated in the Butte Mountains of White Pine County, Nevada, on the north side of U.S. Highway 50, approximately 36 miles northwest of Ely. The section in Central Pequop Mountains of Elko County, Nevada, lies approximately 30 miles west of Wendover, Utah-Nevada. The one in western Utah is on the west side of Conger Mountain in the Confusion Range of Millard County, about one mile northwest of Conger Spring. Text-figure 1 is an index map showing location of the detailed sections.

Methods of Study

Both field and laboratory investigations comprise part of this study. The first field research was started June 1960 in connection with Brigham Young University Geology Department field camp in the Confusion Range, Millard County, western Utah. The writer mapped Mississippian, Pennsylvanian, and Permian marine strata, and measured and sampled the Ely Limestone in detail. Dr. Lehi F. Hintze extended counsel and advice during measurement and description of this section. During early July the writer measured and sampled in detail the Moorman Ranch stratigraphic section of Ely Limestone in southern extremity of the Butte Mountains, White Pine County, Nevada. In early August the Ely Limestone was similarly measured and sampled in the Central Pequop Mountains, Elko County, Nevada. Dr. Harold J. Bissell offered advice in the field for these two sections.

All stratigraphic sections were measured with aid of a 100-foot steel tape and Brunton Compass. Unit members of each section were conspicuously painted on the outcrops; samples of each five-foot increment were numbered and bagged. A systematic method of note-taking, modified after one proposed by Wengerd (1956, p. 42-48) was utilized throughout the field work.

Laboratory research was started in mid-July, resumed (after part of the field work was completed) in mid-August and then continued without major interruption until completion in April 1961. Samples and specimens of the carbonates of the Ely from the three measured sections were cut with diamond saw and separated into suites for study as follows: (1) thin-sections; (2) insoluble residues; (3) etched surfaces; (4) dye stains; (5) cellulose peels; and (6) peels from stained surfaces. A total of 700 thin sections was cut, 400 insoluble residues were prepared, and more than 1000 other surfaces were pre-



TEXT-FIGURE 1.—Index map and location of measured sections.

pared, from which 100 peels were made. All have been studied in detail with: (a) polarizing microscope; (b) stereoscopic binocular microscope; and (c) the latter equipped with polarizing adaptor.

Some sections were cut to standard thickness of 0.03 mm but it was discovered that in order to see certain features of the fabric of Ely carbonates, slightly thicker sections must be cut. Experience soon teaches the worker the thickness for each particular rock under study. Residues and etched surfaces were prepared by using 1:9 HCl and 1:6 CH_3COOH. Peels were obtained by using a mixture suggested by Bissell (1957, p. 417-420).

All materials collected and studied for this research are in the sedimentary petrography laboratory of Brigham Young University.

Previous Work

Ely Limestone was named by Lawson (1906, p. 295) for a thick carbonate sequence in the Robinson (Ruth) mining district a few miles west of Ely, Nevada; nearest suggestion for a type locality is in T. 16 N., R. 62 E., White Pine County where the formation consists of thick-bedded to massive, moderately cherty, medium gray matrix to bioclastic limestones. Lower and upper boundaries were more or less vaguely defined. Spencer (1917, p. 26-27) redefined the formation by placing the base of the Ely at the top of the Chainman Shale of Mississippian age; upper boundary was the same as that of Lawson, which was at the base of the Arcturus Formation as then understood. Pennebaker (1932) restricted the Ely and placed the upper contact at the base of a thick yellow to tan sandstone and siltstone sequence (formerly part of the Arcturus), but which he termed Rib Hill Formation; lower contact was maintained as perviously defined. Ehring (1957*ms.*) pointed out that the name Rib Hill is preoccupied and applies to a quartzite of Precambrian age in Wisconsin; he proposed the new name Murry Formation .

Recently Steele (1960, p. 96-103) has discussed stratigraphy of Ely Limestone and related formations. In harmony with policy of The American Commission on Stratigraphic Nomenclature Steele designated a reference section for Ely Limestone in the Moorman Ranch area, southern part of Butte Mountains. This was necessary because neither Lawson, Spencer, nor Pennebaker specifically designated a type locality for the formation. The sequence proposed as reference section by Steele (1960, p. 100) is adjacent to U.S. Highway, between Illipah Creek and Moorman Ranch, in sections 7 and 8, T. 17 N., R. 59 E., White Pine County; this locality is approximately 30 miles west of the so-called "type area."

Lane (1960, p. 114-116) presented a short but meaningful discussion of the Ely Limestone at the reference section proposed by Steele, and made brief mention of stratigraphy and paleontology.

Acknowledgments

The writer gratefully appreciates guidance and assistance of Dr. Harold J. Bissell, major professor, during field and laboratory investigations, and for critically reading the manuscript. Thanks are also extended to Dr. Lehi F. Hintze for aid and counsel during the writer's studies of the Conger Mountain area.

The writer deeply appreciates the opportunity to use facilities of the Geology Department of Brigham Young University for field, laboratory, and office studies.

STRATIGRAPHY

Mississippian and Pennsylvanian Systems

"Illipah Formation"

It is not the purpose of this paper to discuss problems of stratigraphy of the poorly-defined "Illipah Formation"; Bissell (1960, p. 1425-1928) notes that strata loosely referred to this formation underlie Ely Limestone in the Hamilton-Moorman Ranch area, and suggests the age as Late Mississippian and Early Pennsylvanian. The formation is exposed beneath the Ely and above Mississippian Chainman Shale west of outcrops of the reference section of Ely Limestone near Illipah Creek, and seemingly is present as a succession of interbedded bioclastic limestones, sandy limestones, shales, with a characteristic yellow-brown to red-brown, medium- to coarse-grained quartz sandstone at or near the base. Top of the formation is near U.S. Highway 50 where base of the Ely Limestone also can be studied (Text-fig. 1).

Pennsylvanian System

Ely Limestone

As noted previously, Steele (1960, p. 100) designated the section of Ely Limestone between Illipah Creek and Moorman Ranch as a reference, and Lane (1960, p. 114-116) provided a few details on stratigraphy and fossils. The present writer is in agreement with these two geologists that this section is one of the finest for the Ely in the eastern Great Basin. It was chosen for the present study of carbonate petrology and petrography because of superb outcrops, availability, and variation in carbonate facies.

Moorman Ranch.—This name identifies the locality of the reference section of Ely Limestone; reference to the U.S. Geological Survey Illipah topographic quadrangle sheet shows that it is in sections 12 and 13, T. 17 N., R. 58 E., and sections 7 and 18, T. 17 N., R. 59 E., White Pine County, Nevada. Seemingly Steele (1960, p. 100) made a slight error in only approximately locating this reference section, and that error is now rectified. Essentially full outcrop characterizes the Ely Limestone at this reference section (Pl. 1, fig. 1).

Lane (1960, p. 114-116) measured a total thickness of 1500-1600 feet of Ely Limestone at the Moorman Ranch reference section; a total thickness of 1660 feet was assigned to the Ely at this surface section in the present study. Thin- to thick-bedded and massive, medium brown-gray limestones, some rich in chert as layers, blebs and nodules, characterize this locality.

Central Pequop Mountains.—These mountains are located in Elko County, Nevada; the studied stratigraphic section crops out on a prominent spur on the west side of the range in sections 33 and 34, T. 34 N., R. 65 E. Mr. Gerald Robinson currently is studying a portion of the range in this area and measured a thickness of 1600 feet for the Ely Limestone. This is identical to the thickness obtained by the writer at the same spur. The formation consists of thick- to massively bedded matrix and bioclastic limestones, with some gypsiferous fine-textured limestones and a thick chert bed and chert-pebble conglomerate. In addition, brown-weathering chert in bands and discontinuous blebs and stringers comprises as much as 15% of some beds in the lower one-half of the formation.

Conger Mountain.—Confusion Range is in western Utah, and Conger Mountain is a southwesterly trending spur in the southern part of the range. Hose & Repenning (1959, p. 2170-74) were first to correctly apply the name Ely Limestone here, noting that earlier geologists extended the name Bird Spring Formation into this part of Utah; they measured a total thickness of 1800-2000 feet for the Ely, and their graphic section (p. 2172) shows a total of 1850 + feet. In the present study, a total thickness of 2000-2010 feet was obtained for the Ely on the west side of Conger Mountain and on the north wall of what is locally known as "Wallet Canyon" in the SE 1/4 T. 18 S., R. 17 W. Here the carbonates of the Ely are mostly bioclastic to calcarenitic, and some beds contain from 20-25% nodular to irregular chert.

CARBONATE PETROLOGY AND PETROGRAPHY

Introduction

In this study the term limestone will be applied to those carbonate rocks, 50% or more of which is calcareous material. Appropriate descriptive adjectival modifiers are applied when accessory materials are present in amounts of at least 10% but not exceeding 50% of the total rock.

Classification Schemes

Much creditable work has been done concerning classification and nomenclature of carbonate rocks, particularly the limestones. Grabau (1904; 1913) early proposed a scheme of classification, parts of which still merit attention of petrologists and petrographers. He applied such terms as endogenetic (chemical and biochemical), and exogenetic (clastic), and subdivided the former into hydrogenic, pyrogenic, biogenic, and atmogenic, but subdivided the latter into bioclastic, anemoclastic, hydroclastic, atmoclastic, pyroclastic, and autoclastic.

Pettijohn (1957) divided the carbonate rocks into two major groups, as follows: allochthonous, or those that are transported and redeposited (clastic), and autochthonous, or those that are formed by direct extraction of $CaCO_3$ from sea water by either organic or inorganic means, and have not been subject to current transport and redeposition. Gilbert (*in* Williams, Turner, & Gilbert, 1953) used the terms autochthonous and allochthonous with somewhat the same concept as that of Pettijohn, but only for organic limestones.

Sloss (1947) divided the limestones on the basis of depositional environments, such as platform, basin, and geosyncline. His was an approach to depositional realm related to sedimentary tectonics.

The study of organic limestones by Johnson (1951) is comprehensive and although it does not necessarily embody a classification approach, it does present excellent concepts of origin of this particular and important group of carbonate rocks.

Krumbein & Sloss (1951) presented a brief discussion of limestones, and divided them into the following types: normal marine, fossiliferous-fragmental, chemical and biochemical, siliceous, ferruginous, and other types.

The study of Bahaman calcareous sands by Illing (1954) is an outstanding approach in the investigation of mechanically formed limestones; he did not of necessity classify these sediments but presented an unusually fine research into genesis of the materials.

Bramkamp & Powers (1958) developed a classification of carbonate rocks which in the present writer's estimation is an excellent utilitarian approach to the study; although their study concerned carbonate rocks of Arabia the principles involved are valid in any area. They divided carbonates into the following types: fine-grained limestone, calcarenitic limestone, calcarenite, and coarse carbonate clastics, on basis of original particle size. They also demonstrated that from a genetic standpoint some carbonates are definitely of quiet water realms, but others form in strongly agitated waters.

Chilingar (1956) demonstrated on a triangle diagram that limestones can simply be grouped as either organic, chemical, or mechanical, with appropriate modifiers such as chemico-organic, organo-chemical, etc. This proposal was followed by a classification of limestones and dolomites on basis of Ca/Mg ratio (Chilingar, 1957).

Two significant and utilitarian classifications of carbonate rocks by Russian geologists appeared in 1958, in which the structural (that is, textural) entity was stressed; the concept of genesis of the sediment was inherent in the proposals (Shvetsov, 1958; Teodorovich, 1958).

Folk (1959) proposed a "practical petrographic classification of limestones" and set up an elaborate scheme based on three constituents which include allochems, 1-4 micron microcrystalline calcite ooze matrix, and coarse and clear sparry calcite. Folk perpetrated some of the terms proposed by Grabau (1904; 1913), and also modified some of the earlier terms by adding prefixes and suffixes.

Carozzi (1960) divided the limestones, as did some of his predecessors, into two major types, namely, authochthonous and allochthonous. The former were subdivided into bioconstructed limestone, bioaccumulated limestone, and fine-grained limestone; the latter were subdivided into calcirudites, calcarenites, and calcilutites.

Wolf (1960, p. 1414-16) proposed an interesting simplified classification of limestones which in the writer's opinion has distinct advantages in both field and laboratory. His terminology of intraclasts, skeletal constituents, pellets, lumps, coated grains, and undisturbed organic structures has real utility over many prevailing terms some of which almost defy correct pronunciation.

Thomas (1960, p. 1833-34) vigorously objected to current usage of petrologists of the term "bioclastic limestone," but his proposals hardly can be termed an adequate substitute.

Nomenclature and Classification Used in This Study

It has commonly been considered by most sedimentary petrologists that limestone is polygenetic, and under such a concept the problem of a proper name for a limestone can become the subject of controversy. However, consideration of origin, process, texture, and composition of any rock under investigation can yield scientifically sound nomenclature; if sufficient numbers of samples and specimens are studied in the petrologic realm (field) in stratigraphic sections, and these are studied in required detail as petrographic (laboratory) entities, a classification of utility will result. This classification should prove practical in the field, with laboratory investigations an integral part but not a substitute for the study. In the discussion which follows, the nomenclature and classification that have been developed have value in study of limestones of the eastern Great Basin area and possibly have special emphasis for carbonates of Late Paleozoic age. However, the concepts and ideas are considered by the writer to have applicability in other realms where limestones form important units in stratigraphic sections.

As pertains origin, any given limestone may be lithoclastic, bioclastic, biogenic, biochemical, or they may result from a variety of combinations of two or more of these.

Nomenclature

I. *Lithoclastic.*—Allogenic materials that are mostly inorganic, are grains of different kinds of minerals and rocks or rock fragments that are transported and re-deposited as detrital grains and matrix; these are lithoclastic. Detritals may be derived from breaking up of different existing rocks having variable composition and texture, and may occur in source area(s) outside or within the depocenter (depositional basin).

II. *Bioclastic.*—As used in the original sense by Graubau (1904) these are the "life-broken" fragmented rocks; this category in his classification comprises rocks made up of fragments which originated through breaking action of organisms. This is not the usage of most geologists, and Thomas (1960, p. 1833-34) objects to the departure geologists have made from Grabau's original terminology. Thomas suggests such a term as "clastizoic" could be applied to many fossiliferous-fragmental limestones. The present writer uses the term bioclastic in the practical and classical sense as used by most geologists, as illustrated in the next sentence. Allogenic materials that are rather high in organic material, usually contain a variety or varieties of skeletal fragments that are transported and deposited as detrital material or as finely textured matrix material. The source of the clastic material is skeletal fragments, ranging in size from "tailings" of brachiopods and other broken, abraded and comminuted fossil detritus to calcarenitic limestone and rudaceous textured sediment. Fore-reef and back-reef talus areas seemingly comprise excellent source regions for the "hash" and "trash" substances.

III. *Biogenic.*—These are organic materials which result from physiological activities of organisms, such as corals, algae, foraminifers, etc., that are solidified in the place of their growth without any cycle of transportation and redeposition. Reef limestones, especially the wall reef or that part of reefs that develop in high energy environments as well as some that were protected from very vigorous wave action are examples of biogenic deposits.

IV. *Biochemical.*—The materials that are deposited directly or indirectly as a result of combined activities of biological and chemical agencies are termed biochemical carbonates. This is not the same as biogenic, because materials classified as biochemical commonly accumulate in lower energy environments; oölites and pisolites, particularly those formed where gentle agitation by waves and currents operate in shallow waters of intense algal activity seemingly are examples of biochemical deposits. Numerous examples of micritic limestones possibly fit this category. It is known for example, that bacterial precipitation of lime ooze in sea water is a reality; to what degree really extensive deposits of carbonates accumulated in the past by this mechanism is not known, of course, but certainly the possibility is strong that such biochemical deposits did form. Seemingly, many micrites and fine-textured matrix carbonates could be explained in this manner.

V. *Chemical.*—Inorganic materials that are directly precipitated as carbonate ooze or flocculents by chemical and physical-chemical means from sea water are grouped in this category. Many examples of micritic limestone and dolomite, travertine and tufa, and some micro-lumpy to lumpy limestones can be so grouped. Grapestone carbonates possibly should be included in this realm. Dolomites, whether of the evaporite suite or of strictly primary origin can be allocated to this origin; fine-texture (either crystalline or grained), particularly of pelitomorphic proportions, equigranular arrangement, thin-bedding (particularly micro-layering), and fairly uniform Ca/Mg ratio over large areas characterize these deposits.

Diagenesis and Nomenclature

During and after deposition of carbonate mud the sediment is subject to chemical, physical, and biological changes (or combinations); these modifications are part of the entire spectrum of post-depositional changes leading to induration and lithification of the sediment and ultimate formation of a carbonate rock. Diagenisis is but one of the processes which may operate, but does not necessarily do so, in the formation of limestones and dolomites. Diagenesis refers primarily to reactions which take place within a sediment between one mineral and another or between one or several minerals and the interstitial fluids (Pettijohn, 1957, p. 648). In reality, diagenesis is regarded by some geologists as incipient metamorphism, because it leads to modification of textures, structures, and mineral composition of a sediment.

The following include some of the diagenetic changes which can occur in a lime sediment or carbonate rock: replacement such as silicification, dolomitization, de-dolomitization (calcification), and pyritization; crystallization, or recrystallization; formation of concretions; Liesegang bands, etc.; hydration; dehydration; or a combination of these processes. The present classification of limestones studied for this paper includes a subdivision for those that are either in essentially unaltered condition (other than compacted, hardened and indurated), or for those that have had fabric altered due to diagenesis. This break-down is not however, as vigorous as that proposed by Bramkamp & Powers (1958, p. 1308-1317) in which an attempt was made to separate unaltered carbonates from those that were either: (a) moderately altered; (b) strongly altered; or (c) so strongly altered that original texture was obliterated. Short definitions are given below as they apply to the present study; in the writer's opinion they should have wide appeal to sedimentary petrographers:

1. *Diagenetically Unaltered.*—These are rocks which were not visibly altered except for compaction and cementation, and were not recrystallized or replaced after deposition; lime muds for example were indurated and became limestones without alteration of fabric beyond normal cementation, compaction, and induration. Less than 10% dolomite is present, assuming any was added in the post-depositional regimen. Texture and composition of the rock are essentially the same as they were at time of deposition, although admittedly less interstitial water is present and greater density due to packing and compaction has resulted.

Size and shape of fragments or grains of which a rock is composed certainly comprise an important basis for subdivision and modification during transportation under different energy factors. Deposits having coarse-texture are commonly attributed to high energy; possibly these materials have not been transported great distances (except by turbidity currents and other agencies). Finer textured deposits normally accumulate in environments of lower energy, but can be transported considerable distances. It should also be remembered that many reefs can form only in a realm of high energy, because they grow opposing strong waves and currents.

Several different terminologies have been used by geologists for description of grain size. The writer applies the grade-scales proposed by Wentworth (1922, p. 377-92) because apparently these have wide application among sedimentologists and petrographers. Mechanically formed carbonates should be regarded essentially as other clastic rocks (conglomerates, sandstones, siltstones, and shales), and thus wide application of the two terms lithoclastic and bioclastic is possible.

A. *Rudite.*—This textural term was suggested by Grabau (1904, p. 242) for fragmental sedimentary rocks in which discrete particles are coarser than sand-size. In the writer's present classification the term rudite is applied to rocks consisting of 50% or more fragmental material, of which discrete particles are larger than 2 mm in diameter. They are obviously the calcirudites when used to identify coarse textured detrital, mechanically formed limestones, or by comparison, dolorudites.

B. *Arenite.*—Grabau (1904, p. 242) used this term for consolidated rocks with a sand texture, and as applied in the present study refers to carbonate rocks, mechanically formed, that are composed of discrete fragments between 0.062 mm and 2 mm in diameter. The well known terms calcarenite and dolarenite aptly are used in this category. Also one can justify such a descriptive term as calcarenitic limestone, dolarenitic limestone, etc.

C. *Lutite.*—This term was proposed by Grabau (1904, p. 242) for rocks composed of particles of clay and silt-size; disaggregated material mixed with water forms mud. The term lutite is applied in the present study in reference to rocks that are composed of fragments, normally grains, that are between 0.0039 and 0.062 mm in diameter.

The above terms apply to the generalized scheme of classification developed in the present study; there are in addition, certain terms which need clarification in a research program such as the one dealing with the carbonates of the Ely Formation. For example, the term *micrite* is used widely today, and the term *matrix* has some acceptance, but unfortunately some petrographers mistake one for another. *Micrite* refers to lime ooze, particulate fragments of which are visible only under high power magnification such as binocular microscope or better instruments. Folk (1959, p. 9) used this term in reference to microcrystalline calcite ooze. In the present study the term is applied to those carbonates in which grains (or crystals) are less than 0.0039 mm in average diameter; the textural term *aphanic* (DeFord, 1946, p. 1921-27) is most useful in the field to refer to fine-textured carbonate rocks which are micrograined (or micro-cystalline), or cryptograined (or cryptocrystalline). The term *pelitomorphic* could apply equally well, for indurated pelitic materials. Obviously, a rock termed aphanic, or pelitomorphic in the field would need careful checking in the laboratory to ascertain grain (crystal) size. In both petrologic (field) and petrographic (laboratory) realms the term *matrix* has real utility. This should not be considered synonymous with micrite, because matrix is not microcrystalline or cryptocrystalline. In hand specimen as examined under no magnification, a matrix carbonate appears textureless. However, with 10x hand lens and obviously with binocular microscope the fabric of such a rock is seen to consist of particulate material having variation in grain size and/or crystal size. Texture of the rock is either bioclastic, lithoclastic, non-clastic or a combination of these. Normally more than one size-grade can be readily seen, thus the appropriate name *matrix,* because this matrix has other materials "embedded" in it. Coarse-grained (or coarse-crystalline) matrix would have discrete particles larger than 2.0 mm diameter, medium-grained matrix would range from 0.25 to 2.0 mm diameter, fine-grained matrix would be 0.01 to 0.25 mm in size. Aphanic material would be smaller than 0.01 mm in diameter, a size not directly visible in the field with hand lens, but strongly suspected because of the dull luster of freshly fractured rock. It is apparent to the field and laboratory sedimentologist that all carbonate rocks are not distinct end-member varieties but normally consist of intergradations and intermixtures, some of which are subtle and difficult to assess. For example, one commonly encounters in limestones of the Ely, varieties that are definitely matrix types but which have less than 50% total material consisting of lithoclastic (i.e., rudaceous and/or arenaceous) material, and possibly bioclastic material surrounded by the matrix substance. Appropriate terms such as medium-textured calcirudite in matrix, fine-grained calcarenite in matrix, etc., can be used even in the field. More precise determinations of percentages and size-grades can be made in the laboratory with thin-sections, cellulose peels, etched surfaces, insoluble residues, etc.

Terminology of geometrical forms has been used in various ways by geologists to describe shape of sedimentary fragments; this shape is a valuable clue to maturity and composition of sediments. Angular fragments have not been transported far in normal sedimentary regimens, and therefore have not been well washed and reworked by time of deposition; these do not signify the same degree of maturity as do rounded fragments. In other words, shape of the grains provides data concerning at least part of the abrasion history of the sediment. Also, field and laboratory studies show that the shape of fragments is influenced by composition, that is, grains of quartz or tourmaline experience relatively less attrition than grains of calcite if they are consanguineous. In the classification developed in this research, shape of previously mentioned sizes of fragments is discussed as follows:

A. *Angular.*—This term applies to the shape of those grains that have maximum sharpness around their edges and show minimum amount of abrasion on corners.

B. *Subangular.*—This term indicates that the edges and corners of grains have definitely been abraded, but they still have their original form, and their original surfaces are relatively little worn.

C. *Subrounded.*—Grains fitting this category have shapes denoting considerable attrition and abrasion, so that the entire surface has been worn from faces and crystal boundaries to relatively smooth texture. Few if any crystal faces and sharp edges or corners remain.

D. *Rounded.*—This term refers to the shape of grains approximating roundness and sphericity combined; edges, corners and original surfaces have been so abraded that the entire remaining surface of the grain forms a smooth and broad curve, particularly if projected.

2. *Diagenetically Altered Rocks.*—Carbonate rocks commonly change chemically, physically, and even geometrically during and after deposition of the sediment of which they are composed. These changes may appear as first-cycle crystallization, later recrystallization and replacement, and reorganization

in different ways. Texture of these rocks may differ greatly from the original type according to amount and manner of alteration. Grains may change in size, shape, and also composition during early, medial or late diagenesis. For example, they may become crystalline, resulting in an entirely different fabric; size and shape of resultant crystallinity depends on amount of authigenesis and/or variation in composition induced in grains. This alteration also includes diagenetic (and in some instances epigenetic) dolomitization, and may be slight, moderate or strong, or even proceed to point of essential obliteration of original fabric. Positive and negative relics may provide a clue to original fabric and composition however. The following terms have been used in this paper to describe size grades of crystals resulting from diagenetic alteration of a previously grained and/or semi-crystalline carbonate:

A. *Macrocrystalline.*—This term was used by Howell (1922, p. 416-418) in following usage of the German investigator Hirschwald (1912, p. 511-516) to describe texture of recrystallized sedimentary rocks composed of crystals or grains greater than 0.75 mm in diameter. In the current study this term is applied to diagenetically altered, coarse crystalline rocks the fabric of which is 2.0 mm or greater in diameter.

B. *Mesocrystalline.*—Hirschwald (1912, p. 611-615) and later Howell (1922, p. 416-418) used this term to describe texture of recrystallized sedimentary rocks, the crystals of which range in size from 0.75 mm to 2.0 mm. The term is considered a useful one by the present investigator, but he would assign crystals between 0.062 mm and 2.0 mm to this category.

C. *Microcrystalline.*—This term was also applied by Hirschwald (1912) and by Howell (1922) to categorize grains and crystals which range in size from 0.01 mm and 0.1 mm in diameter; crystalline texture according to this size-grade would be recognizable only under the microscope. In the present study however, the writer refers this texture to fine crystalline rocks that have been diagenetically altered, and in which crystals range in size from 0.0039 to 0.062 mm in diameter.

D. *Cryptocrystalline.*—As used by Howell (1922) in following suggestion of Hirschwald (1912), this term describes rocks with a crystalline texture visible only under very high magnification of a microscope. In the current research, this term is used but applies to crystals or altered grains that are smaller than 0.0039 mm in diameter. Obviously, only high magnification at superb illumination would provide evidence of diagenetic changes, and nature of the recrystallization. In reality, many unaltered micrites would have textures in this size-grade range and it would prove difficult if not impossible to ascertain if diagenesis had occurred with ordinary stereoscopic binocular microscope. High magnifications achieved with oil-immersion lenses and polarizing microscope, or superior instruments, are necessary in this phase of the study.

A term which has had but limited usage in the past but which in the writer's estimation should be widely accepted is *aphanic.* The term aphanic has been used rather widely by some sedimentary petrologists, and DeFord (1946, p. 1921-27) adequately defined the term. Osmond (1956, p. 32-41) applied the term in connection with studies of Middle Devonian carbonate rocks in eastern Nevada, essentially as defined by DeFord. Therefore, the term aphanic is properly defined, correctly applied, and belongs in the glossary of terms relating to texture of carbonate rocks. It is a particularly useful term in the field when the rock cannot be termed matrix type or other type; thin-section in the laboratory subsequently will reveal if the texture is microcrystalline (or grained) or cryptocrystalline (or grained).

Some of the terms applied in this study have been further subdivided, such as coarse-macrocrystalline, medium-macrocrystalline, etc.

Crystalline boundary, or amount of crystallinity in a diagenetically altered rock is a significant feature in the determination of amount of alteration in terms of composition and geometry of previously existing grains and/or crystals. Highly diagenetically altered (not obliterated) carbonate rocks commonly have sharp boundaries between crystals of calcite or dolomite, and in some cases it is possible to distinguish grains of calcite from dolomite in a thin-section with use of polarizing attachment on a stereoscopic binocular microscope. With sparry carbonates that are so altered, polished and etched surfaces can be preferentially stained using one of many standard methods to selectively color calcite but not dolomite. In some rocks it is desirable to stain the dolorhombs to ascertain if zoning, mottling, "arrested" dolomitization, or other evidence of diagenesis is present. A micritic limestone may be reorganized by recrystallization and replacement to a coarse-grained or coarse-crystalline (macrocrystalline) rock; the amount and degree of alteration in this case can be shown by the proportion of microcrystalline to aphanic matrix material. In replacement by silica and sparry calcite the crystalline nature of chalcedony and calcite are distinguished from the original carbonates quite readily under the microscope. Some geologists regard the change of aragonite to calcite an important diagenetic change; this recrystallization from orthorhombic to hexagonal form is rapid and may cause loss of original textural detail. In some instances aragonitic rocks change their original texture and are converted to coarse-grained or coarse-crystalline calcite rocks with only faint relics or "ghosts" of their original fabric. The writer has found the following terms applicable in describing crystallinity in diagenetically altered rocks:

A. *Euhedral.*—This term is applied to those crystals that are bounded by their own crystal faces, resulting in relatively high degree of crystalline geometry.

B. *Subhedral.*—This term refers to those crystals whose crystal faces are of a definitely recognizable lower degree of perfection than euhedral forms.

C. *Anhedral.*—This term is used for crystals that are not bounded by their own crystal faces, but which have their outlines impressed on them by adjacent crystals. A degree of geometry lower than subhedral forms is evidenced.

In some rocks one of the above three types, or a combination, may form a mosiac fabric; if so, this should be mentioned as perfect, sutured, etc.

Composition of Limestone

In this classification, those rocks are considered limestone that contain 50% or more carbonates that consist of calcite and possibly aragonite. If dolomite is present in amounts of more than 50% the rock is a dolomite. Obviously this separation is purely arbitrary but has utility. In addition, of the various carbonate minerals present, any specific limestone may contain up to but not in excess of 50% "adulterant" materials that are composed singularly or in combination of silica (commonly quartz silt and sand), silicates, clay, or gypsum, plus others. Minor amounts of bituminous, humic, or coaly material, pyrite, hematite, glauconite, and other materials may occur in carbonate rocks. These last few rarely form more than four or five percent of the total rock, and may be authigenic, although occasionally one or more have been observed in the fabric suggesting syngenetic origin.

A triangular face with three end members is used to demonstrate the composition of the spectrum of carbonates of Ely Limestone studied for this project; it is believed that much wider application of the principles set forth here can be demonstrated. The end members consist of calcite as a major constituent at the top of the triangle, dolomite is placed at the lower right, and silica and clay on lower left (commonly the latter two are minor constituents, although in the Ely, rocks consisting mostly of dolomite are not common). The sides of the triangle are divided into a five-fold horizontal arrangement, with each subdivision representing 20% of the corresponding constituents or end members (Text-fig. 2).

The surface of the triangle is divided into 21 trapezoids by extending lines downward from the top horizontal bar to intersect equally-spaced points along the base of the triangle. The trapezoids are numbered from upper left to lower right in numerical sequence,and each number shows percentage of the end-members that are representative of composition of the rock. Closest number to each member is approximately 100% of that end-number, for example, 1 means essentially pure calcite, 21 is dolomite, and 5 approximates 75% (60-80%) calcite, 18% (16-24%) dolomite, and 7% (4-16%) silica and clay. With this simplification, it is possible to demonstrate composition of a rock by one number only.

In this study, it is possible to statistically demonstrate description of a carbonate rock by using appropriate symbols that are located on the left side of the terms which refer to origin, process, texture (both size and shape), and composition. Futhermore, as noted previously, because limestones commonly

Explanation of Plate 1

FIG. 1. View north of Ely Limestone north of Illpah Creek in the Moorman Ranch area, Butte Mountains, White Pine County, Nevada. U.S. Highway 50 in center of photograph is near base of Ely; skyline on upper right defines top of the formation. Sandstones of "Illipah" Formation crop out in lower portions of picture. Strata strike north, dip east.

FIG. 2. View north along west side of central Pequop Mountains, Elko County, Nevada; strata strike north and dip east. Ely Limestone forms most of outcrops in central foreground; dark-colored band near lower left is chert-pebble conglomerate.

FIG. 3. View northwest across most of Ely Limestone on west side of Conger Mountain, southern part of Confusion Range, Millard County, Utah. Strata strike north, dip west. Alternation of ledge-forming units and slope-forming units shown to advantage. Arcturus Formation forms low outcrops at extreme left.

Explanation of Plate 2
MOORMAN RANCH AREA CARBONATES

FIG. 1. Litho-bioclastic limestone; matrix detrital $I<II;\ 1.b_{m3,4}>d.1)$. Detrital consists of skeletal fragments and well rounded grains of quartz arenite. Midway of unit # 9, x15.

FIG. 2. Bioclastic limestone; matrix, detrital. $(II;1.b_{m1}>d.1)$. Detrital is skeletal fragments in micritic calcite as matrix. Upper part of unit # 12, x25.

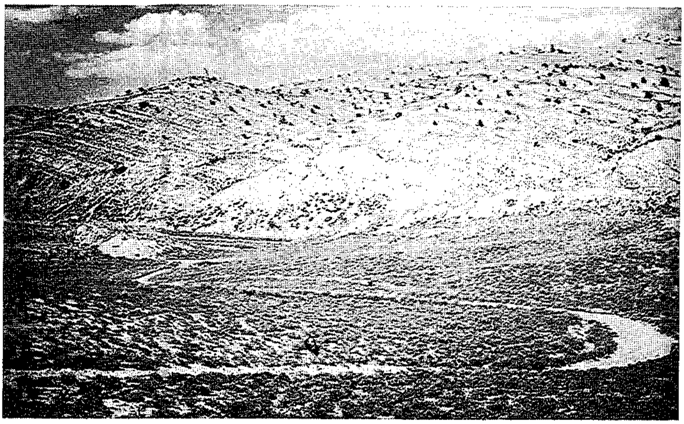
FIG. 3. Bioclastic limestone;; matrix, detrital. $(II;1.b_{m2}>d.1)$. Skeletal fragments in micritic calcite. Right side is replaced by calcite. Lower part of unit # 21, x15.

FIG. 4. Litho-bioclastic limestone; matrix, detrital. $(I<II;1.b_{m2}>d.1)$. Detrital is skeletal fragment and calcarenite in micritic calcite. Midway of unit # 22, x25.

FIG. 5. Litho-chemical limestone; detrital, matrix. $(I<V;1.C_{m2}<d.2)$. Detrital is quartz and calcilutite in micritic calcite. Lower part of unit # 22, x25.

FIG. 6. Bioclastic limestone; matrix skeletal. $(II;1.b_{f1}>d.1)$. Skeletal material in micritic calcite and dolomite. Upper part of unit #22, x15.

PLATE 1



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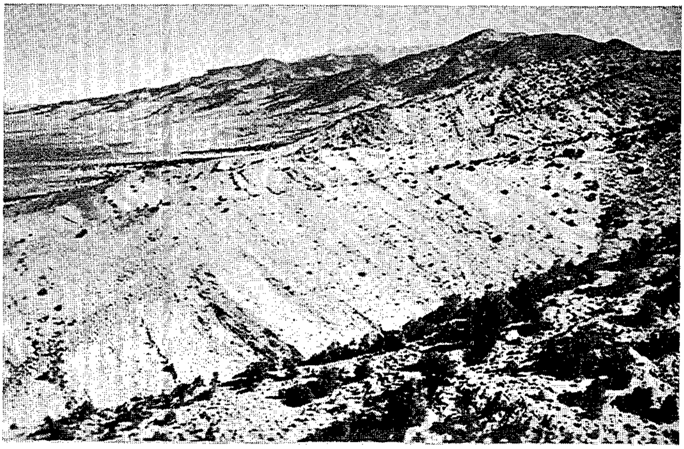

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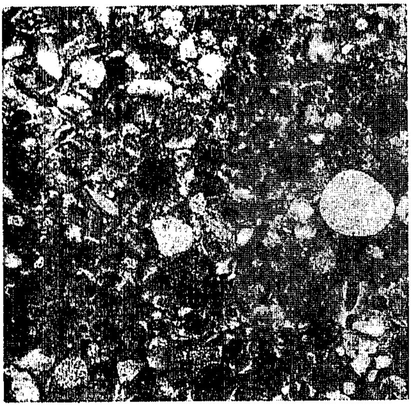
PLATE 2



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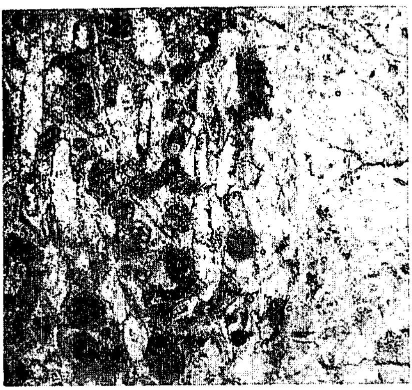

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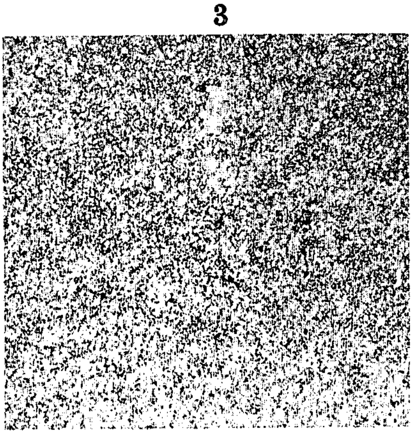

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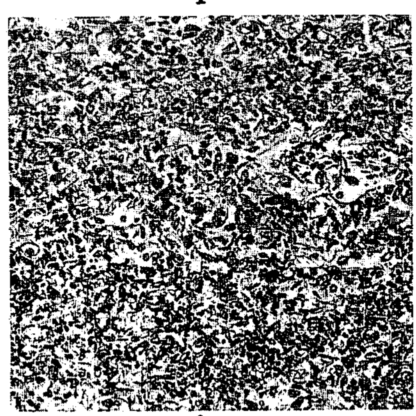

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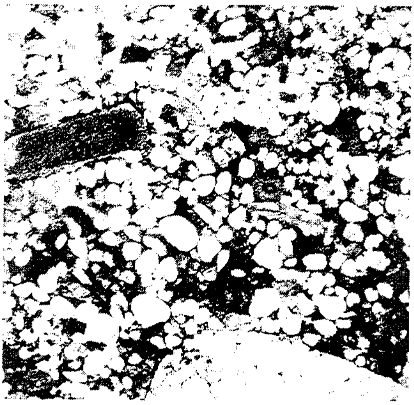
PLATE 3



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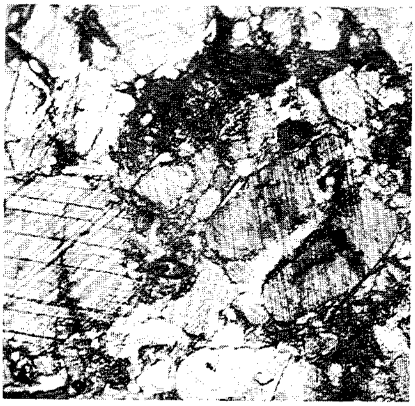

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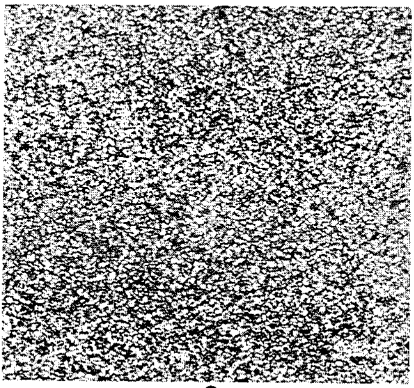

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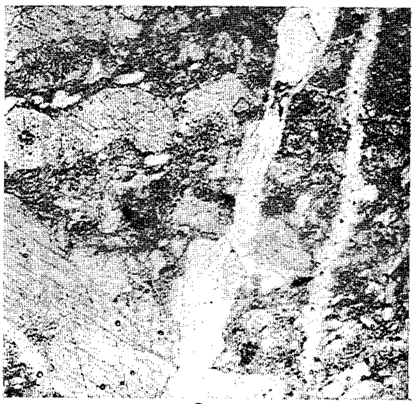

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PLATE 4

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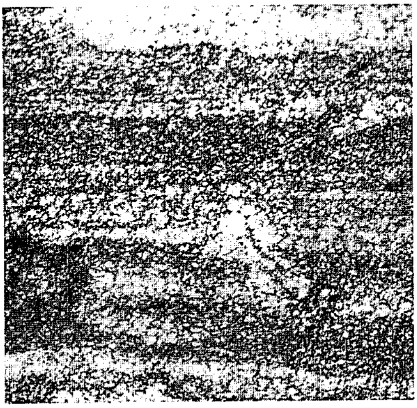

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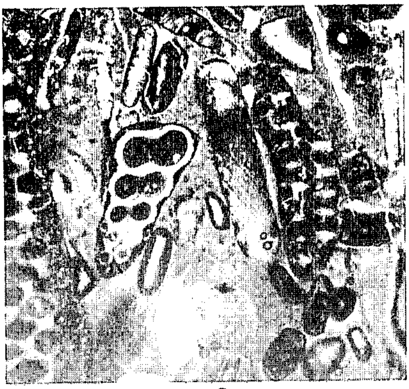

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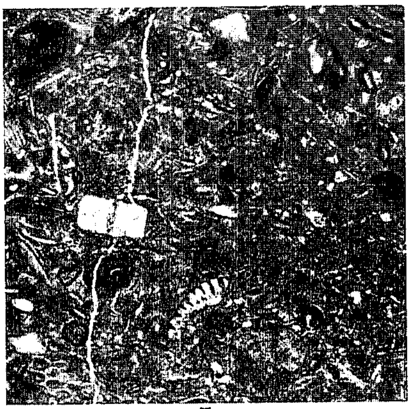

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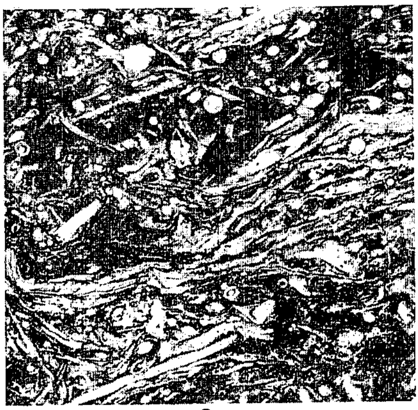

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are polygenetic, combinations of the various terms can be used. For example, the symbol $I>II$ indicates that the first is dominant over the second; $I<II$ shows that the second dominates over the first, and $I>II$, or $I<II$ indicates approximately equal amounts of each. In this illustration, I refers to lithoclastic carbonate and II denotes bioclastic carbonate, and so relative amounts of one can be shown in respect to the other.

For better understanding of the system evolved in this study and particular for carbonates (mostly limestones) of the Ely formation, the following singular example is given to illustrate the system:

Mathematical expression of the carbonate is: $I>II$; $1.b_{c2}>d_{m3}.1$.

The description of this limestone is as follows: the rock is lithoclastic, but is also slightly bioclastic ($I>II$), and fabric has not been altered by diagenesis, (1). The grains are coarse-textured, subangular arenite (b_{c2}), greater than medium-textured micrite that forms the matrix (d_{m3}). Composition of this particular carbonate is more than 80% calcium carbonate and less than 20% dolomite, silica and clay (1). Illustrations of the usefulness of this classification are shown on plates 1-4.

Explanation of Plate 3

CENTRAL PEQUOP MOUNTAIN CARBONATES

FIG. 1. Bio-lithoclastic limestone; matrix, detrital. ($II<I;1.a_{f3}<b_{m3}>d.7$). Detrital material consists of skeletal fragments and grains of rounded quartz arenite in micritic calcite. Upper part of unit # 8, x15.

FIG. 2. Litho-bioclastic limestone; matrix, detrital. ($I<II;2.B_{m1}>D.1$). Euhedral mesocrystalline in microcrystalline of calcite. Lower part of # 8, x25.

FIG. 3. Litho-chemical limestone; detrital, matrix. ($I<V;1.C_{3}<d.2$). Detrital is quartz lutite in micritic calcite as matrix. Upper part of unit # 10, x25.

FIG. 4. Bioclastic limestone; matrix, detrital. ($II;1.b_{m2}>d.1$). Detrital is skeletal fragments in micritic calcite. Upper part of unit # 10, x25.

FIG. 5. Bioclastic limestone; matrix, detrital. ($II;1.b_{c1}>d.1$). Skeletal material in micritic calcite. Midway in unit # 19, x25.

FIG. 6. Chemical, litho, bioclastic limestone; matrix, detrital. ($V<I<II;2.B_{m1}>C_{m2}>D.1$). Mesocrystalline microcrystalline calcite. Midway in unit #26 x25.

Explanation of Plate 4

CONGER MOUNTAIN CARBONATES

FIG. 1. Litho-bioclastic limestone; matrix, detrital. ($I<II;1.b_{m2}>d.6$). Detrital material is skeletal fragments and grains of subangular calcarenite. Midway in unit #2, x15.

FIG. 2. Bioclastic limestone; matrix, detrital. ($II:1.b_{c2}>d.1$). Skeletal and detrital material in micrite. Upper part of unit #2, x15.

FIG. 3. Litho-bioclastic limestone; matrix, detrital. ($I<II;1.5_{c3}>d.1$). Detrital material is skeletal fragments and grains of subrounded calcarenite. Midway in unit #4, x25.

FIG. 4. Bioclastic limestone; matrix, skeletal. ($II;1.b_{c1}>d.1$). Skeletal in micritic calcite. Uppermost of unit #16, x 15.

FIG. 5. Lithoclastic; detrital, matrix. ($I;C_{m3}<d.2$). Detrital consist of subrounded quartz lutite in micrite calcite. Upper part of unit 43.

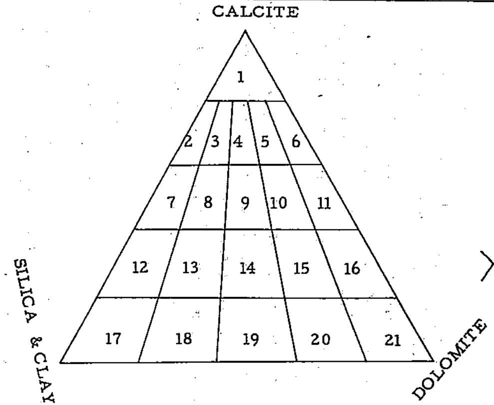
FIG. 6. Litho-bioclastic; matrix, detrital. ($I<II;a_{f2}<b_{m2}>d.3$). Detrital is skeletal material and subangular calcarenite. Midway in unit #50, x 15.

PROPOSED CLASSIFICATION OF CARBONATES

by Yazdan Mollazal

ORIGIN = I. Lithoclastic; II. Bioclastic; III. Biogenic (Organic); IV. Biochemical; V. Chemical.

		PROCESS = 1. Not Altered by Diagenesis		2. Diagenetically Altered	
TEXTURE	SIZE	a. Rudite: Coarse, Medium, Fine	> 2.0 mm	A. Macrocrystalline: Coarse, Medium, Fine	
		b. Arenite: Coarse, Medium, Fine	2.0 - 0.062 mm	B. Mesocrystalline: Coarse, Medium, Fine	
		c. Lutite: Coarse, Medium, Fine	0.062 - 0.004 mm	C. Finely Crystalline	
		d. Micrite	< 0.004 mm	D. Microcrystalline E. Cryptocrystalline } Aphanic	Textural term for field use with 10x lens
	SHAPE	1. Angular 2. Subangular 3. Subround 4. Round		1. Euhedral 2. Subhedral 3. Anhedral	



An Example of the Classification Scheme is as follows -

Rock classified as: I ≪ II; 1.bm$_2$ > Df. 5

Explanation = The rock is Litho-Bioclastic, slightly more bioclastic, and has not been diagenetically altered; the grains are subangular medium arenite (calcarenite), and form majority of the rock, enclosed in a fine-textured matrix.

Composition = 70% Calcite; 21% Dolomite; 9% fine-textured silicates, siliceous material, and clay.

> = greater than; ≪ = about equal proportions of each; one may be in slight excess of the other

< = less than.

TEXT-FIGURE 2.—Proposed classification of carbonates.

PETROLOGY AND PETROGRAPHY OF ELY LIMESTONE

Ely Basin was one of the more pronounced depocenters of the miogeosyncline which occupied the eastern Great Basin area in Early Pennsylvanian time, and the carbonates of Ely Formation are a direct response to the tectonic setting. Bissell (1960, p. 1426) shows the Ely Basin as occupying much of eastern Nevada and part of western Utah, with the Gold Hill Accessway the connection between it and Oquirrh Basin of Utah. In the discussion which follows, the petrologic and petrographic entities of Ely Limestone will be discussed area by area, starting with the reference section at Moorman Ranch and vicinity.

Moorman Ranch

This stratigraphic section is located in sections 12 and 13, T. 17 N., R. 58 E., White Pine County, Nevada, north and east of U.S. Highway 50 and also north of Illipah Creek. The area is approximately 36 miles northwest of the city of Ely, and is located in southern terminus of Butte Mountains. Thickness of the measured section of Ely Limestone is 1660 feet; the formation is conformably underlain by what Bissell (1960, p. 1425-33) terms Illipah Formation of Late Chesteran and Early Springeran age. Conformably above Ely Limestone is a sequence of calcareous siltstones and silty cherty limestones which are thin-bedded and only fairly well exposed; seemingly these are of Desmoinesian age (personal communication from Dr. H. J. Bissell) because of presence of the fusulinid *Wedekindellina* sp.

Yellow-brown to lavender-gray argillaceous limestones and brown-weathering coarse-textured bioclastic limestones with interbedded brown silty shales of the Illipah Formation give way upward rather abruptly to thin-bedded tan colored to light yellow-gray argillaceous and cherty limestones of the basal Ely. Above this basal unit the Ely consists of a sequence of alternating units of thick-bedded, ridge-forming limestones separated by less resistant medium-bedded, slope-forming silty and sandy limestones. Prominent beds are medium gray-brown on fresh fracture and weather medium gray to light brownish-gray and yellow-gray. Some beds contain between ten and twenty percent of nodular, thin-bedded and irregularly bedded dark brownish to medium reddish-gray chert that commonly weathers in relief. Thickness of the thickly bedded carbonates ranges from five to thirty feet. Less resistant and slope-forming beds are light brownish-gray and on weathering form yellowish-gray to medium yellow-gray slopes strewn with blocks of limestone. These limestones have less chert than intervening thick and massive beds. Furthermore, they are fine- to medium-textured (both crystalline and granular) and usually contain silt and sand size quartz as well as fine-textured argillaceous material.

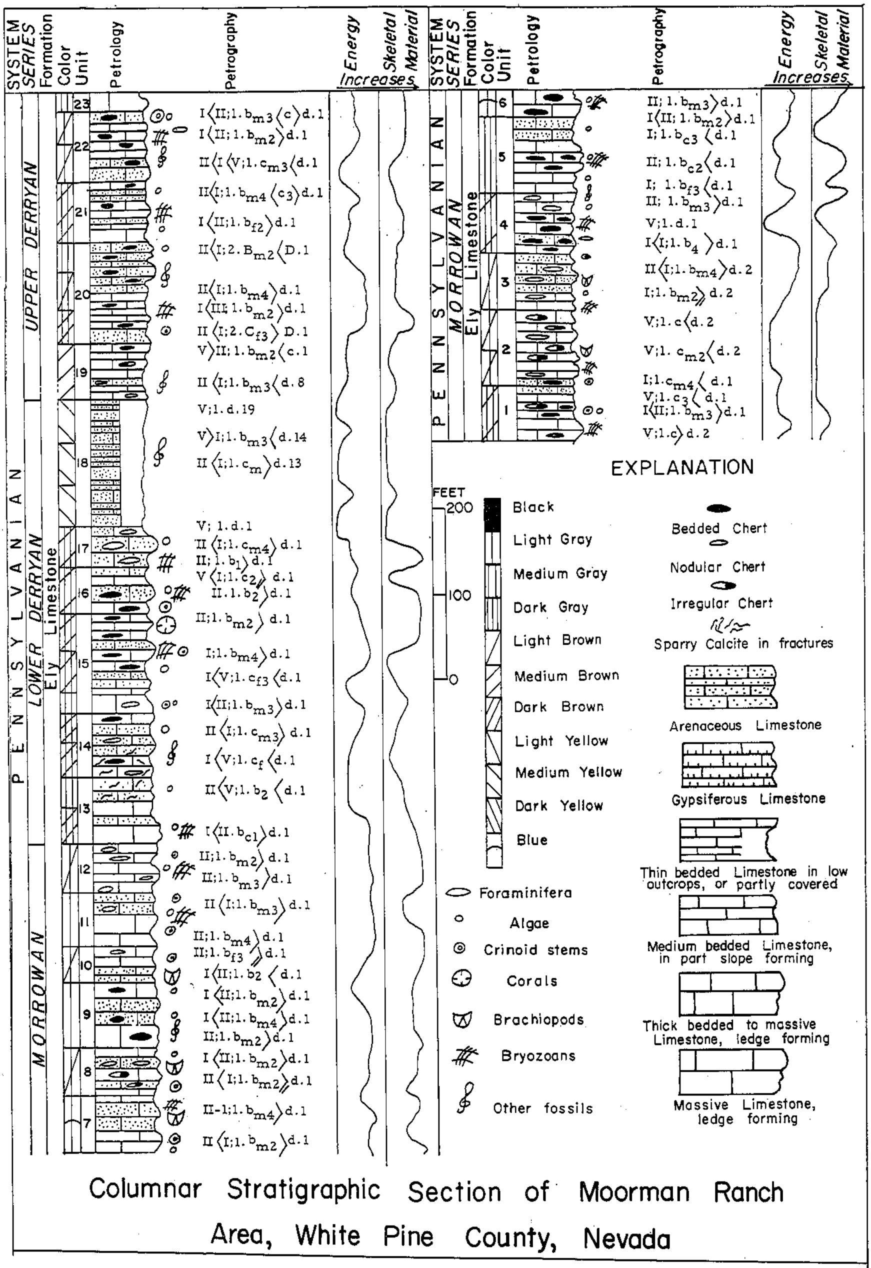
Slightly more than 200 thin-sections were cut of precise stratigraphically located carbonates of the measured Ely section; essentially all of these indicate that little if any important diagenetic changes have taken place in the sediments of the formation beyond usual compaction and cementation. Recrystallization, reorganization, authigenesis, and replacement (other than local chertification) are negligible. Rarely slight dolomitization has occured locally. Basal argillaceous limestones (units 1 and 2) of the Ely are matrix and fine-grained detrital-in-chemical carbonates. Small amounts of skeletal material, mostly endothyroid and plectogyroid foraminifers, crinoid ossicles, and brachiopod tailings are also present. Units 3, 4 and 5 aggregate more than 225 feet and consist of fine-grained bioclastic limestones interbedded with fine-grained lithoclastic and chemical limestones. Matrix of, rock in these units is mostly micrite, and ordinarily it dominates over detrital material. This sequence is overlain by about 150 feet (comprising units 6, 7 and 8) of bio-lithoclastic limestones interbedded with litho-chemical and bioclastic limestones; particles in a discrete bed normally are 0.06 to 0.3 mm diameter and are subround to subangular. Some rocks are matrix types and display fine- to medium-textured crystallinity.

Units 9, 10, 11, and 12 aggregate 245 feet in thickness, and consist largely of bioclastic material alternating with beds of chemical and fine-grained lithoclastic limestones. Near the base of this sequence is a distinctive six-foot bed of detrital bioclastic limestone that contains grains of well-rounded quartz, 0.5 to 0.2 mm in size interspersed in matrix material that contains algae, millerellid, plectogyroid, and paramillerellid foraminifers, bryozoans, sponge spicules, and brachiopod tailings. Comparable types of carbonates are seen to occur time and time again in the measured section. This 245 foot sequence is overlain by units 13 and 14, 160 feet total, and composed mostly of chemical, fine-textured matrix limestones that have some interbedded litho-bioclastic limestones some of which contain notable amounts of detrital coarse silt and fine quartz sand. Sparry calcite is present in some of the thin-sections, and characteristically fills openings, small veins, and some fossils. The overlying 170 feet consists of litho-bioclastic limestones with interbedded chemical and lithoclastic limestones; particular fossil debris and discrete grains and commonly subrounded to subangular, and are between 0.06 mm and 1.0 mm in size. Insoluble residues prepared of samples and some specifically selected specimens from this interbedded sequence shows numerous grains of quartz silt and fine quartz sand. Brown-weathering dark gray chert is present as gobs, blebs, irregular layers, nodules and stringers; locally this silica has replaced the "hair" coral *Chaetetes milleporaceous,* and the fusulinid *Profusulinella* sp. Other fossils include algae, crinoid ossicles, bryozoans, textularid foraminifers, and syringoporoid corals; some of these are replaced by gray to white silica, but many are unaffected.

In continuing order, there occur 56 feet of litho-bioclastic sandy limestones interbedded with fine-textured lithoclastic and chemical limestones (these are variations of matrix limestones). Nodular dark brownish-gray to red-brown chert is common to some beds. Above the 56 foot section is a sequence, 140 feet thick, of interbedded bio-lithoclastic to lithoclastic limestones that contain rounded to subangular particles 0.062 to 0.5 mm in size, and argillaceous siltstones that are covered in part but form low outcrops in part. Latter beds are thin-bedded and the rock consists of calcite micrite with clay material which fills interparticle space, particularly between fine-grained quartz sand and coarse silt in some beds. Microfossils consist of algae and fusulinids, with occasional bryozoans. This assemblage is overlain by 254 feet of bioclastic to lithoclastic limestones that contain rounded to subangular quartz and calcarenitic material, discrete or particulate fragments of which are 0.062 to 0.5 mm in size. Microfossils consist of algae, fusulinids, bryozoans, and "hash." The upper 98 feet of the measured section of Ely Limestone consists mostly of litho-bioclastic limestones that contain subrounded to subangular quartz silt and sand grains, ranging in size from 0.06 to 1.0 mm. Microfossils consist of algae, bryozoans, crinoid ossicles and fusulinids (Text-fig. 3)

Pequop Mountains

This stratigraphic section is situated in west side of the central Pequop Mountains in sections 33 and 34, T. 34 N., R. 65 E., Elko County, Nevada.



TEXT-FIGURE 3.—Columnar stratigraphic section of Moorman Ranch area.

Within this portion of Pequop Mountains, Ely Limestone (which is approximately 30 miles west of Wendover, Utah) varies in thickness from 1600 to 1700 feet, and this variation is attributed in part to the activity of the Antler Orogenic Belt to the west, accounting for more rapid sedimentation in parts of the depocenter, as well as cyclic deposition in the Ely Basin. Ely Limestone in this area is overlain by a thin sequence of brown-gray to yellow-gray calcareous siltstones to silty limestones which form a slope in which only low outcrops are found. There is some similarity between lithology of this slope-former and a like assemblage of cherty calcareous siltstones and platy siltstones in essentially identical stratigraphic position in the Moorman Ranch area, located about 100 miles to the southwest.

Diamond Peak Formation is subjacent to Ely Limestone in disconformable relation, in the central Pequop Mountains, and consists largely of protoquartzite and subgraywacke with some conglomerate, discrete clasts of which are composed of green and brown chert, limestone, and quartzite. This formation is reddish-gray, orange-gray, tan-gray, and dark reddish-brown. Contact with overlying Ely is marked in many places by a change from red-brown-weathering chert-pebble conglomerate upward to bioclastic limestones.

Petrology of Ely Limestone in some respects is similar to that of the reference section at Moorman Ranch area, inasmuch as alternating units consist of thick-bedded to massive, ridge- and cliff-forming limestones that are separated by less resistant, slope-forming thin-bedded aphanic to fine-textured silty limestones. Thick-bedded and massive units contain much more dark gray to red-brown chert bands, discontinuous layers, blebs and concetions than the thinner bedded units. That is, thick-bedded units contain from 10-15% chert, but others contain 5-10%. Freshly fractured limestones in this sequence (which is largely Morrowan in age) are dark gray, blue-gray, pink-gray and light brown-gray in color, and weather medium light gray to tan-gray. There are marked contrasts however, in lithology of Ely Limestone at Pequop Mountains when compared to others the writer has seen in eastern Great Basin. In many localities rocks of Derryan age normally consist of sandy limestones, silty and sandy bioclastic limestones, and some calcareous orthoquartzites. In part this is true of Derryan rocks at Pequop Mountains, but in addition a considerable thickness of gypsiferous limestone is present above a characteristic ledge-forming unit of bedded red-brown chert and chert-pebble conglomerate. Gypsiferous strata are light gray to ash-gray and locally white, but weather light blue-gray to light gray. This facies in Ely Limestone is of much interest because it reflects quiescence and local stabilization following a pulse of orogenic activity to the west, which accounts for the conglomerate. Gypsiferous limestone, aphanic in large measure, seemingly accumulated as a bank, lagoon, or other shallow water lithotope in an environment almost free of terrigenous clastic material. Some of these rocks, in addition to many others in Ely Limestone, emit hydrocarbon and fetid odors when the rock is broken under the hammer; units 15, 16 and 17 in particular have these distinguishing characteristics.

Slightly more than 200 thin sections were cut of stratigraphically located samples in the measured section of Ely Limestone. Some of these slices show diagenetic changes in the carbonates, noteworthy of which are crystallization of calcite and in some places dolomite of both cementing material and particulate fragments of skeletal (bioclastic) limestones and discrete detrital calcite grains. Silica replaced lithoclastic and bioclastic particles of some rocks, and units 20 and 21 typify this type of change. Irregular to rounded patches of hydrocarbon and what appears to be oil stains are noteworthy in several units of the section, especially in Morrowan rocks (such as units 8, 11, and 17).

Basal 85 feet of Ely Limestone of the mesaured section in Pequop Mountains has some features not shared by others of comparable stratigraphic position which the writer observed in eastern Great Basin. This basal unit, for example, contains litho-bioclastic limestone that has experienced slight diagenetic alteration and crystalline calcite 0.2 to 2.0 mm diameter is noteworthy, along with angular to subangular quartz grains, 0.1 to 2.0 mm diameter, that comprises 25% of the total rock. Within this unit there are interbeds of fine-grained limestone with small amounts of skeletal and detrital material, normally foraminifers and silt particles. Commonly the basal Ely Limestones in many localities consist only of thin- to medium-bedded argillaceous limestone, in part silty, with gray to pink-gray thin chert bands and blebs. This feature is lacking at Pequop Mountains. Furthermore, patches of hydrocarbon material ("dead oil") are abundant in this area in lower units of the Ely.

Overlying the 85-foot basal unit of the Ely is a sequence, 290 feet thick (units 9, 10, 11 and 12) consisting of lithoclastic carbonates with interbeds of aphanic and chemical to bioclastic limestones. There are at least five intercalations of conglomerate in this succession, the discrete clasts of which are green to red-brown chert, quartzite, and limestone; they are pebble- to cobble-size in part, but most are 2.0 to 16.0 mm in diameter, in a matrix and cement of quartz and calcite grains that are 0.062 to 2.0 mm in size, angular to subangular in shape. The next succession above is 170 feet thick and consists of interbedded lithoclastic, bioclastic, and chemical limestones, or a combination of these varieties; quartz grains occur in each type and are subangular to rounded in shape, and are up to 2.0 mm in diameter. Upper units of this assemblage contain chert conglomerate, clasts of which are 2.0 to 16.0 mm diameter, but are subangular to subround. In ascending stratigraphic order is a sequence 120 feet thick that consists of fine grained limestone with small amounts of subround to round quartz grains. Patches of petroliferous materials occur abundantly as dark brown to brownish-gray colorations and specks in the interstices of the rock; when the rock is freshly broken a strong odor emits from this material.

Units 18 to 22 inclusive comprise the next sequence above, is 3000 feet in thickness, and consists largely of bioclastic material in which interbeds of thin-bedded fine-textured sandy limestone occur. Units 19, 20 and 21 in this section contain microcrystalline to mesocrystalline calcite that occurs as euhedra, with patches of mesocrystalline dolomite sprinkled throughout. The writer considers this occurrence as evidence of early to medial diagenesis. Except for unit 21, in part at least, these three units contain but small amounts of quartz sand. Above unit 22 occurs 346 feet of gypsiferous limestone alternating with beds of chemical and fine-grained lithoclastic limestone. Within these chemically deposited limestone is a small amount of organic material comprising almost 20% of the total carbonate. A small amount of quartz sand occurs low in this evaporite sequence.

Upper 180 feet of measured Ely Limestone in this part of the Pequop Mountains consists largely of fine-grained limestone to silty detrital-in-matrix limestone with a slight amount of calcite grains and skeletal fragments; discrete grains are 0.004 to 0.2 mm in size and the shape is subangular to subrounded.

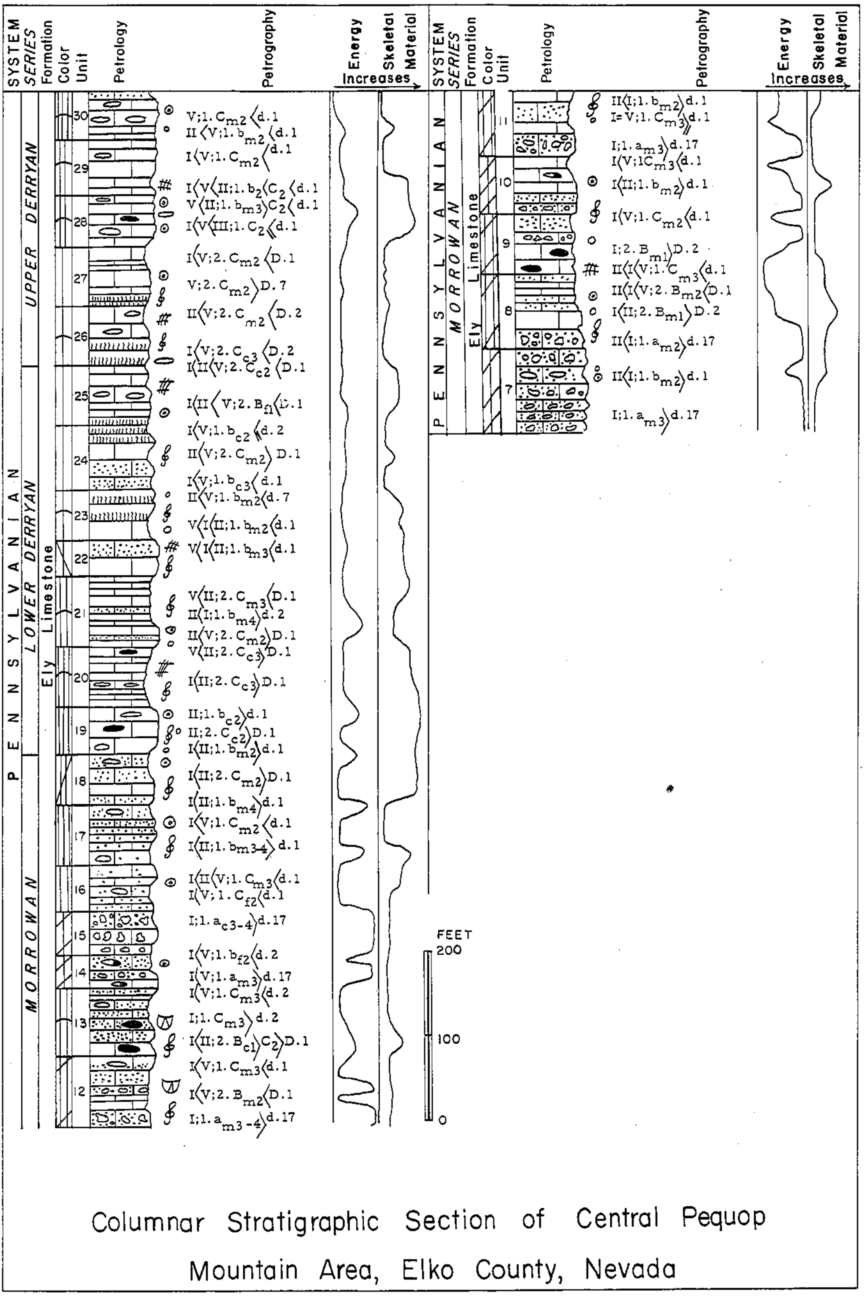
Text-fig. 4 is a columnar stratigraphic section summarizing details of petrologic and petrographic features of the measured section; noteworthy of this diagram is an attempt at interpretation of energy factors in the depositional realm of these carbonates and response of life-forms to the degree of energy.

Conger Mountain

This stratigraphic section was measured in SE½ T. 18 S., R. 17 W., southern part of the Confusion Range, Millard County, Utah, approximately one-half mile northwest of Conger Spring. Thickness of Ely Limestone in this area is 2000 feet at Conger Mountain, but thins eastward to 1800 feet southwest of Skunk Spring. Above the Ely is a sequence of yellowish-gray to light gray-brown beds of calcareous sandstone, sandy limestone, and calcareous and sandy siltstone. Sands in the lower part of this formation are mostly subrounded to subangular grains of quartz, feldspar, calcite, and minor tourmaline. Units commonly are thin-bedded, and many rocks are poorly indurated. Hose and Repenning (1959) referred this sequence to Arcturus Formation, a name which Lawson (1906) used in the area in and around Ely, Nevada. However, they suggested that lower beds in Ely Limestone are Mississippian in age, and uppermost beds are Permian. The writer cannot agree with this, because it was found during course of this research that foraminifers of Early Pennsylvanian age occur in beds directly beneath Ely Limestone (Illipah Formation of some geologists, Chainman Shale of other geologists). These were identified by Dr. Harold J. Bissell as *Paramillerella circuli* (Thompson) and *Paraplectogyra* spp. Furthermore, uppermost beds of Ely Limestone are of Late Derryan age, but are disconformably overlain by basal limestones of Arcturus Formation containing Medial Wolfcampian fusulinids which include *Dunbarinella wetherensis* Thompson, *Schwagerina elkoensis* Thompson & Hansen, and *Pseudofusulina robleda* Thompson.

Ely Limestone of the Conger Mountain area consists of medium-, thick-, to massive-bedded limestones interbedded with thin-bedded silty limestones. Lithology of discrete beds is such that ledge-and-bench topography is now displayed in outcrops. Part of this variation in lithic character results from cyclic or rhythmic sedimentary pattern, a fact demonstrated by Dott (1958, p. 3-14) for Ely Limestone in the Carlin Canyon area west of Elko, Nevada. Obviously, field examination of these units reveals that compositional differences in texture, cementation (or its degree), degree of diagenesis, and carbonate type. In the field a classification of the carbonates was effected, utilizing the now widely accepted terms of lithoclastic, bioclastic, micritic (or micrite), calcarenite, matrix, and detrital to approximately categorize or group them. In such examinations, it was noted that on fresh fracture these carbonates are light gray, dark gray, medium brown-gray to yellowish-dark gray, but weather light gray, yellow-gray, and gray-brown. Chert is present and is more common to Morrowan rocks in lower part of the formation; throughout the Ely this gray and red-brown chert to impure siliceous limestone is present in amounts up to 10% of total unit. It is disposed in small nodules, thin "lunch-meat" bands, discontinuous irregular lenses, "elbow-shaped" masses, large concretions, and replacement of fossils. Liesegang bands occur in some beds, and some siliceous lumpy limestone is present but in minor amount.

Hydrocarbon and fetid odors are characteristic of many units in the Ely Limestone. Dead oil and oil stained limestones are present, but not confined to any particular stratal unit. These occur througout the measured section.



TEXT-FIGURE 4.—Columnar stratigraphic section of central Pequop Mountain area.

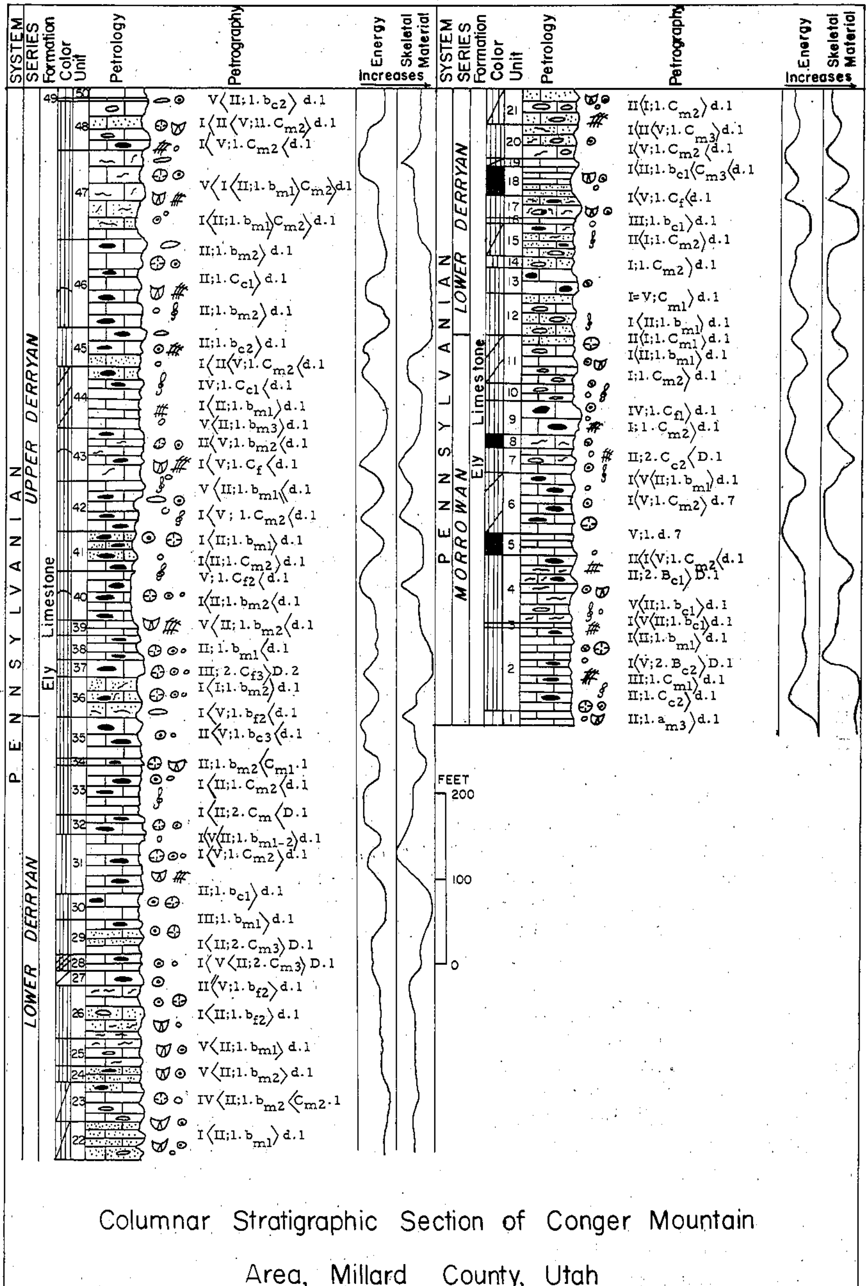
Approximately 200 thin sections were cut of stratigraphically located rocks in the measured section. Detailed study of these permits the following analysis of petrography of the Ely carbonates. The basal 18 feet consists of thin-bedded, light gray, poorly indurated, coarse-textured bioclastic limestone with an abundance of skeletal fragments consisting of brachiopod "tailings", bryozoan and coral fragments, sorted foraminifers (mostly paramillerellids and paraplectogyroids), and algae in form of öolite-like masses to crusts. A unit 35 feet thick on west side of Skunk Spring which forms basal unit of the Ely Limestone in that area is considered the correlative of the 18-foot unit at Conger Mountain, and is set off sharply from the underlying "Illipah" Formation or Chainman Shale.

Above unit no. 1 of the Ely occurs an assemblage of mostly litho-bioclastic limestones with interbedded chemical (micritic) and bioclastic limestones aggregating 440 feet in thickness, and comprising units 2 to 11 inclusive. Quartz is negligible; most calcite grains, largely detrital, are 0.004 to 0.07 mm in diameter, and are subangular to angular in shape. Bioclastic material consists of debris of earlier formed fossils, and has been abraded and comminuted to silt-size and sand-size grades as well. Lime mud, now micrite to micritic limestone, is present as is calcarenite to calcarenitic limestone. Some matrix as well as micritic limestones are typical, and have crystallinity of subhedral to euhedral quality in ranges from 0.004 to 0.05 mm.

Units 12 to 22 comprise the next sequence above which totals 340 feet in thickness, and consists dominantly of litho, clastic, bioclastic limestone of calcarenite limestone varieties; discrete particulate limestone fragments are from 0.004 to 0.062 mm in diameter and are subangular to subrounded. Interbedded with these sandy limestones and calcarenites are various units in which bioclastic limestone abounds; fine-grains and some crystals of calcite are present, and sand-size quartz is present as detrital material. In overlying sequence occurs 420 feet of bioclastic limestone alternating with fine-textured chemical limestones and fine- to medium-textured limestone in which beds the lower part contains abundant skeletal material. This sequence also contains interbedded sandy matrix to sandy micritic limestones in which discrete detrital particles range in size from 0.062 to 0.5 mm in diameter. These particles are mostly angular to subangular in shape.

In ascending order, the next 270 feet consist of bioclastic limestone with interbedded finely crystalline to fine-grained chemical limestones. Interbedded in this sequence, which is well documented by Derryan-age fusulinids, occur some colonies of the "hair coral" *Chaetetes* sp.; commonly the colonies are replaced by light gray silica which locally weathers red-brown. In the upper part of this sequence clusters of the algae *Komia* sp. can be discerned under the hand-lens by the characteristic "finger-print" pattern displayed on weathered surfaces. This algae was noted in other places in eastern Great Basin in Derryan to Desmoinesian limestones.

Uppermost 510 feet of the measured Ely Limestone in the Conger Mountain area consists mostly of bioclastic limestones interbedded with lithoclastic, bioclastic, litho-bioclastic, and chemico-bioclastic limestones. Fresh rock is medium gray to medium brown-gray, which weathers light gray to light gray-brown. Detrital material is angular to subangular silt and sand, both quartz and particulate limestone, ranging in size from 0.004 to 0.5 mm in diameter. Few interbedded micritic limestones were noted; seemingly the succession is moderate- to high-energy carbonate, much of it mechanically formed (Text-fig. 5).



TEXT-FIGURE 5.—Columnar stratigraphic section of Conger Mountain area.

Except for compaction, cementation, and slight replacement by silica in some beds of the Ely Limestone in this area, no pronounced diagenetic changes were noted either in the field or in the laboratory among the carbonates. Interestingly enough, criquinites, calcarenites, and other bioclastic carbonates experienced only negligible diagenesis except for local and minority examples.

Age of the Ely Limestone at the Conger Mountain section is Morrowan in lower beds, as shown by diagnostic millerellid foraminifers, including *Millerella inflecta* Thompson and *M. marblensis* Thompson, and species of *Nankinella*. Early Derryan age strata contain *Profusulinella apodacensis* Thompson, *P. regia* Thompson, and *P. spicata* Thompson. These forms were reported previously to be present in the Conger Mountains and other places in the Confusion Range by Thompson & Zeller (1956, p. 333-37). Late Derryan age rocks contain *Fusulinella acuminata* Thompson and *F. iowaensis* Thompson, with some forms referred with query to *Eoschubertella mexicana* Thompson. It was not established that rocks of Desmoinesian age are present; rather, it appears that a disconformity separates Ely Limestone from overlying Arcturus Formation, and basal beds of the latter contain Medial Wolfcampian schwagerinid fusulinids.

SEDIMENTARY AND TECTONIC ENVIRONMENT FOR DEPOSITION OF ELY CARBONATES

It has been pointed out that more than one depocenter characterized the eastern Great Basin area during Pennsylvanian time, and that during at least part of this period the Ely Basin was connected to the Oquirrh Basin to the east by the Gold Hill Accessway (Bissell, 1960, p. 1424-35). Furthermore, it is known (or inferred, at least) that the Western Utah Highland (Bissell, 1960, p. 1429) and Northeast Nevada High (Steele, 1959, p. 1105) were elevated areas within or adjacent to these basins and in all likelihood provided materials to the depocenters. Anter Orogenic Belt of central Nevada and adjacent part of Idaho and California was actively being elevated in Early Pennsylvanian time (Roberts, *et al.*, 1958, p. 2813-57) and certainly was one of the source areas for allochems contributed to sites of active sedimentation. Seemingly, the Emery Uplift of central to southeastern Utah may also in similar manner acted as one source area and provided sediment to the miogeosyncline (Herman & Barkell, 1957, p. 861-81; Wengerd & Matheny, 1958, p. 2048-2106). Steele (1960, p. 91-113) pointed out that an extensive unconformity separates Medial Pennsylvanian marine strata from marine Wolfcampian rocks in much of the eastern Great Basin, particularly within much of the Ely Basin. Such an interpretation suggests epeirogenic uplift with concomitant and subsequent stripping from some areas and synchronous deposition elsewhere. Possibly only conditions of non-deposition obtained in some places, but likely erosion with removal of sediment characterized other localities. Mild to moderate auto-cannibalism possibly occurred, and one portion of the depocenter provided sediment for another or for others. It would appear from what is known or can be deduced from available evidence that the Ely Basin was not a simple sag within the ancient miogeosyncline, but rather may have been typified by troughs, local welts and furrows, broad banks, shelf-like regions of variable instability, intrageosyncline positive areas, marginal uplifts, and an orogenically-active belt to the west. This in no respect detracts from the name miogeosyncline for this depocenter, but instead more clearly defines its integral mobile portions.

Moorman Ranch Area

Rudaceous and arenaceous materials are negligible to absent in carbonates of the Ely in the Moorman Ranch stratigraphic section. Silty sediment is present, but relatively abundant only in rocks of Derryan age. Morrowan rocks are, for the most part, matrix types and micritic limestones; when skeletal material is present it normally is within fine-textured carbonates and does not show evidence of strong abrasion. In fact, some of the rocks have articulated fossils, or at least those that were not broken, embedded in micritic to matrix limestones. In general, carbonates in most of the lower one-half of the Ely in this area accumulated in low-energy to only moderate-energy environments. The possibility is strong, therefore, that lime muds, biogenic oozes, chemical and biochemical precipitates, and but few lithoclastic and bioclastic sediments formed in shallow, gently agitated warm marine waters. Seemingly, broad and gently shelving banks and platforms of only mild instability typified this environment. Abundance of silica in the carbonates of Morrowan age in this region poses the problem of both source and environment or environments under which it accumulated. Chert is abundant in form of "lunch-meat" thin layers, discontinuous bands and lenses, nodules, blebs, irregularly shaped masses, and as replacement of fossils. Bissell (1959, p. 162-82) illustrates the Ely Limestone at the Moorman Ranch section, mentions abundance and varieties of chert, and concludes that not one single source should be postulated. He indicates that, in addition to normal increment added to sea waters as result of weathering of rocks on positive areas, silica may have been added by: (a) leaching of volcanic rocks on areas in or near the volcanic geosyncline (eugeosyncline of geologists); (b) extensive submarine volcanic activity west of the miogeosyncline; (c) halmyrolosis of submarine volcanic materials; (d) glowing avalanche materials; and (e) biologic agencies such as radiolarians and others. Assuming that siliceous materials were added to the ancient geosyncline by one or more of these methods (or others not mentioned), it is apparent that some mechanism of transportation in the ocean waters from the west would have been necessary in order to allow copious precipitation in the miogeosyncline, paticularly the area under discussion. Perhaps upwelling from relatively deeper waters carried silica in solution (and/or collodial or other suspension) onto the broad bank where psysicochemical conditions, and possibly biologic conditions, were condusive to silica sedimentation.

The possibility is equally strong, and perhaps appealing, that the Antler Orogenic Belt, shown by Roberts, *et al.,* (1958, p. 2825) to have been an important positive area in Early Pennsylvanian time in central Nevada, provided great quantities of siliceous materials to adjacent marine waters. It is not known however, whether this orogenic area was characterized by volcanic activity, but this possibility certainly is considered.

Strata of Derryan age in the Moorman Ranch section contain notable amounts of silty sediment; silty limestones and siltstone are typical within the measured and sampled section. Arenaceous sediments are negligible. Influx of lutaceous and silty textured lithoclastic sediment during early-Medial Pennsylvanian time reflects higher energy in the depositional realm. Probably tectonism along eastern part of the Antler Oregenic Belt at this time accounted for the detrital material. Carbonates of Derryan age in the Carbon Ridge-Secret Canyon area south of Eureka, Nevada, for example, contain calcarenites and calcirudites in addition to limestones which contain chert pebbles. This area lies 31 miles west of the

Moorman Ranch section, and apparently was situated along the eastern border of the orogenic belt. Coarse- and medium-textured lithoclastic and bioclastic sediments evidently graded eastward over the 31 mile platform, and only lutaceous and silty textured materials were transported to the Butte Mountain region. Siliceous materials are present as gray chert nodules, discontinuous lenses, and irregular small blebs in Derryan-age rocks of the Moorman Ranch section. Perhaps the Antler Orogenic Belt served as at least one source area.

Central Pequop Mountains Area

Moderate- to high energy environments typified this portion of Nevada during Late Mississippian and Early Pennsylvanian times, as evidenced by abundance of coarse and medium textured clastic rocks in the section. Diamond Peak Formation (Late Mississippian) contains numerous conglomerate beds in which clasts of chert pebbles are dominant. Morrowan age carbonates in Ely Limestone also have interbeds and intercalations of conglomerates, protoquartzites, and orthoquartzites. Antler Orogenic Belt was situated more than 100 miles to the west, and probably was not as important a source area as nearer positives. Northeast Nevada High was a prominent positive area (or submarine welt in places) a few tens of miles to the north, however, and likely provided coarse- and medium-textured sediment to northern part of Ely Basin. Currents and waves washed out some materials, but rudaceous and arenaceous sediment (both lithoclastic and bioclastic types) accumulated in a trough-like sag that extended in a general north-south direction.

Energy of dynamic proportions waned, and during Derryan time micritic limestones, gypsiferous limestones, and fine-textured matrix limestones accumulated. Some bioclastic limestones continued to form as moderate-energy lithotopes. Silica continued to pour into the depocenter, and chert layers, bands, blebs and replacement of fossils comprise part of the sedimentary record. Sufficient detailed control is lacking to point up the cause of evaporites in the Ely of this area. There was sufficient stabilization within the depocenter to provide banks, pans, or lagoons and a moderate thickness of gypsiferous white to light gray micritic carbonate was deposited.

Gentle to moderate epeirogenic uplift within this and contiguous areas in the ancient epeiric sea or miogeosyncline late in Derryan time or Early Desmoinesian elevated broad areas. No evidence of marine advance again is shown until Medial to Late Wolfcampian; a blended disconformity characterizes the contact between Ely Limestone and Ferguson Mountain Formation, however.

Confusion Range

Hose & Repenning (1959, p. 2170-74) noted the thick and in part clastic nature of Ely Limestone in Confusion Range of western Utah. The writer studied primarily the sections of this formation near Conger Mountain in the southern part of this range, where the thickness of Ely Limestone is between 1800 and 2010 feet. Lithoclastic and bioclastic sediments (the latter locally consisting of coarse-textured organic detrital limestone) are characteristic and therefore evidence conditions of high energy within the area of sedimentation. Interbeds and intercalations of calcarenites, calcarenitic limestones, calcarenaceous orthoquartzites, bioclastic limestones, criquinites, and fossiliferous-fragmental, coarse-textured organic limestones alternate with beds of silty limestones, micritic and matrix limestones, micrites, and biogenic carbonates.

The sequence of Ely Limestone in this part of Utah bears evidence of periods of moderate- to high-energy (when mechanically formed limestones and other clastic sediments formed), interspersed with times of less vigorous wave and current action and even quiescence. The notable thickness of all these carbonates and other sediments suggests a tectonic setting of miogeosyncline to unstable shelf. Cyclic to rhythmic arrangement of the sedimentary succession possibly can be accounted for by alternation in dynamic energy in the depocenter. It is hardly necessary to consider eustatic changes in sea level as the only reason for this cyclic arrangement. True, such changes may have occurred, but the suggestion is advanced that fluctuations in stream courses, directions, and energy from adjacent source areas, coupled with comparable variations in marine currents acting within this eastern part of Ely Basin (that is, deltaic sedimentation in part) also were contributing factors to account for interbedding, intercalation, and rhythmic to cyclic sedimentation.

In commenting on origin of cyclic patterns in sediments of Ely Limestone of Nevada, Dott (1958, p. 13) states that ". . . Pennsylvanian limestones of northeast Nevada possess virtually all the necessary requirements for classification as stable shelf deposits by virtue of the quartzose sand, fragmental limestones, numerous coquinites, moderately abundant fossils, and evidence of widespread mechanical deposition with development of many diastems. . ." However, he added, "stable shelf" when his usage described a common depositional environment for the miogeosyncline and parts of the craton.

The writer cannot share the interpretation of Dott that Ely Basin was a stable shelf environment; possibly some portions (and at certain times) experienced unstable shelf conditions, but largely the sedimentary pattern was miogeosynclinal, with intra-positive areas, submarine welts and rises, platforms, banks, and sags. There are incremental parts of the miogeocyncline. Knill (1959, p. 317-25) points out the possibilities of both axial and marginal filling of geosynclinal basins. To what extent axial type filling of sedimentation typified all or parts of the Ely Basin can only be surmised; possibly that portion of the basin in which sediments now seen in central Pequop Mountains were formed was a north-south elongated trough or sag. Axial rather than strict marginal filling of this trough with at least a prominent source the Northeast Nevada High on the north, likely did occur. Probably the eastern part of Ely Basin, at least the Conger Mountain region, was irregular-ovate, in shape, and received sediment from the east marginal to Emery Uplift and from the prong of the Western Utah Highland.

Moorman Ranch area was bank-like, but it is doubtful if the area was a stable shelf; instability to the west typified Antler Peak Orogenic Belt.

This study has also pointed up certain features of the carbonates of Ely Limestone which permit interpretation of sedimentary conditions which persisted or alternated within the basin of deposition; some of these are enumerated below:

Marine

Occurrence of normal marine faunas such as corals, brachiopods, foraminifers, bryozoans, and algae throughout the sections studied evidences marine sedimentation.

Depth

Mechanically deposited carbonates, specifically limestones, exceed 80% of the total rock and these consist of approximately 60% bioclastic and 20% lithoclastic materials, indicating epineritic and shallow infraneritic water-depth conditions. Remaining 20% is mostly matrix to micritic limestones.

Texture

Presence of fine-grained, if not micritic, limestones that grade laterally into coarser textured limestones indicates variation in transporting power of waves and currents, in addition to possible relative nearness to or distance from source areas. Gradation vertically proves, or at least strongly suggests, comparable variation of these same factors. For example, in the Central Pequop Mountain section, Ely Limestone contains a mappable chert-pebble conglomerate but it is noted that this thins and disappears in a southerly direction. Such a fact suggests a northerly source, in all likelihood the Northeast Nevada High. This same coarse-clastic unit is overlain by micritic carbonates and evaporite sediments (gypsiferous limestone), indicating relative quiescence. Possibly a pulse in the Antler Orogenic Pulse some scores of miles to the west provided the setting such that erosianal debris was transported eastward into the Ely Basin. Quiet waters provided the environmental setting for deposition of gypsiferous limestones.

Washing

It is common in geologic literature to note that the term "winnowing" has been mis-applied to the subaqueous realm; winnowing is wind action, but washing is water action and should be properly used in connection with submarine sorting action as here applied. Presence of about 60% organic limestone in Ely Limestone in many areas, and abundance of bioclastic and lithoclastic limestones (and combinations) proves energetic movement of water. Little evidence of stagnancy within the basin was noted, so apparently waters were moved by currents and waves, washing and oxygenation resulted, and sediments provide an index to intensity and kind.

Quiescence

Rhythmic or cyclic succession of lithoclastic and bioclastic with matrix and micritic limestones in the Ely indicate low energy environments punctuated by times of vigorous wave and current activity. Less intense stirring of newly deposited sediment is shown by even textured, fine-grained or finely crystalline lime ooze.

Temperature

Appearance of evaporites in some parts of the Ely sections, particularly the one in central Pequop Mountains, is indicative of warm water, quiesence conditions, and most likely excessive evaporation in a lagoon or other restricted pan or basin.

Bottom Conditions

Presence of chemically deposited lime oozes in parts of the basin, and at different times, suggests shallow waters, warm waters, and gently-moving currents with possibly slight wave action. Particularly is this borne out by bank or platform deposits of the Moorman Ranch area.

Salinity

The abundance of microfossils, particularly foraminifers, algae, and some others, coupled with relative abundance of corals, brachiopods, and bryozoans indicates optimum conditions of salinity (also temperature) for the marine organisms.

Variation

Variation not only of sediment vertically, laterally, and vertico-laterally but also of fauna and microflora (or response of latter to former) is indicated in Ely Limestone. Variation in depth of water within the depocenter, and also temperature, pH, chemistry of sea water, and other factors seems to be a strong possibility.

Silicification

Different kinds and arrangements of chert in Ely limestones are noticeable features; possibly none of the chert is to be classed as eugeosynclinal (that is, volcanic) and therefore, is largely primary. Seemingly most is syngenetic, as metasomatic replacement of fossils, lime oozes, bioclastic material (calcarenites, criquinites, and fusulinid coquinites, etc.) and as irregular nodules, blebs, discontinuous lenses, "elbow-shaped" masses, and "lunch-meat" bands. The possibility is not to be overlooked that some thin layers (preferably the "lunch-meat" bands and thin stringers) may have been direct precipitates or flocculants. During diagenesis of some carbonates, possibly much silica migrated to form irregularly shaped masses. Amount of chert in Ely Limestone is not unusually great, but some units contain from 10-20% total bulk of siliceous materials, largely chert.

CONCLUSION

Ely Basin was an important repository of carbonates and related sediments during Early to Medial Pennsylvanian times in the ancient geosyncline. Miogeosynclinal conditions were usually present, but such a geosyncline was not a simple epeiric sea sag, but was composed of integral mobile portions. At times the depocenter acted as one simple segment, particularly during part of Morrowan time. Throughout most of its history however, Ely Basin within the ancient miogeosyncline consisted of sags, troughs, banks, unstable shelves, positive areas, submarine welts and furrows. At time an approach to biostromal conditions was obtained. Both axial and marginal filling of the geosyncline occurred, with sediment being poured into the subsiding areas from Antler Orogenic Belt, Western Utah Highland, Northeast Nevada High, and Emery Uplift. Possibly auto-cannibalism occurred in certain areas at times.

Epineritic to infraneritic conditions typified the basin, warm marine waters were at times gently agitated but at other times vigorously acted upon terrigenous, detrital, bioclastic, and precipitated sediment. Variation in direction, intensity, and arrangement of deltaic and other sediments carried to the depocenter is noteworthy. Carbonate sediments are dolomites, but many are mechanically formed. Silts, sands, and even conglomerates are present as intercalations, interbeds, or disseminated particulate material in carbonates, whether lime oozes (micrites), calcarenites, matrix varieties, bioclastic types, or in some biogenic rocks. Response to varied intensity of tectonism within and adjacent to Ely Basin is admirably shown by the carbonates studied for this research.

Evaluation of Ely Basin as source and reservoir of oil and gas was not one of the primary objectives of this study; however, it should be emphasized that within this vast area in eastern Great Basin carbonates of the Ely should not be overlooked by the petroleum geologist in his search for these products. Many bioclastic and lithoclastic carbonates have moderate to high porosity and permeability, a fact pointed up by the petrologic and petrographic investigations. These could serve as excellent reservoir rocks. Micrites, micritic limestones, and some matrix limestones possibly are source sediments; many of these rocks emit moderate to strong hydrocarbon odors when freshly fractured.

The classification of carbonates, and in particular limestones, which was developed during course of this investigation is new and in the writer's estimation has value in laboratory investigations, but has less utility in the field. However, during petrologic (field) studies, certain parts of the framework of the classifcation can provide guides to energy, origin, texture, and composition and these facts and impressions gained in the field facilitate proper classification when petrographic reaserch is completed.

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