Circular 59

Glauconite in the Cambrian-Ordovician Bliss Formation Near Silver City, New Mexico

by Douglas W. Lewis

NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY
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CAMPUS STATION SOCORRO, NEW MEXICO

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Full fathom five my pellets lie,
Where periwinkles live and die;
Theyhave suffered a sea change,
Into something green and strange.

---R. G, and D. L. , with W. Shakespeare

Contents

FIGURES

Abstract

The Bliss Formation is composed principally of arenaceous dolomites and sandstones and has been divided into six members, from the base; lower quartzite, lower hematitic sandstone, thin-bedded glauconite, middle quartzite, middle calcareous sandstone, and upper glauconite. The thin-bedded glauconite and upper glauconite members are the most variable in thickness and lithology, both vertically and laterally, and contain most of the glauconite in the formation.

The glauconite is derived from fecal pellets of vagrant organisms in a shallow marine environment distant from the shore. Deposition took place under conditions of varying currents and turbulence. The term perigenic is proposed to describe material that originated near its position of final incorporation into the sediments. The glauconite is commonly replaced by carbonate minerals, hematite, and limonite, and more rarely by silica. Light- and dark-green varieties of glauconite are distinguished; the lighter variety probably represents incomplete glauconitization of clay minerals in the fecal pellets. No substantial difference was apparent between the glauconite of the different members .

Introduction

This study of the Bliss Formation in the Silver City area of New Mexico describes the genetic environment of glauconite, based on occurrences in closely associated beds of differing rock types but of similar post-depositional history. The Bliss Formation is a marine carbonate-rock series, about 190 feet thick, with interbedded quartzites and siltstones and with widely distributed hematite and glauconite.

Glauconite, in the original meaning of the word (Gr. glaukos—bluish green; -ite-.-resembling), was a globular, lobate, commonly shiny, blue-green mineral aggregate, usually less than 1 mm in size, and rich in iron and potassium. At the present, glauconite is a field term for small, subspherical, sometimes green, earthy pellets which often include chlorite and montmorillonite clay minerals, although true glauconite is similar to illite. In this usage, glauconite is the common green mineral in the Bliss Formation of the Silver City area.

PREVIOUS WORK

The type locality of the Bliss Sandstone (Richardson, 1909) is near Fort Bliss, Texas, on the eastern boundary of the Franklin Mountains. The Bliss consists of about 250 feet of gray sandstone in this area.

Paige (1916) described the Bliss Formation in the Silver City area; Kottlowski et al. (1956) studied the formation in the San Andres Mountains; Kelley (195l) published extensive work on the Bliss oolitic iron deposits of New Mexico and with Silver (1952) described the Bliss in the Caballo Mountains. W. P. Pratt and W. R. Jones of the U.S. Geological Survey have recently completed a study in the Silver City area, the results of which will be published.

The Bliss Formation in New Mexico lies unconformably on a peneplaned Precambrian surface and may be entirely lacking over occasional Precambrian monadnocks (Kelley, 1951; Kelley and Silver, 1952). The Bliss is truncated by pre Pennsylvanian erosion in central and northern New Mexico, in the northern Fra Cristobal Mountains, and in the southern Oscura Mountains. The depositional edge of the Bliss sediments may have been only tens of miles north of the area of truncation. From this area the formation thickens to 300 feet in the south-central part of the State and to a maximum of 400 feet in the southwest. This gradual thickening in southern New Mexico is toward the Sonoran trough, and recent studies suggest that the formation transgresses time and is relatively older in the west or southwest. Less clastic material is present to the west, indicating an easterly source of the sediments.

The Bliss Formation has numerous oolitic hematite beds; the association of hematite with glauconitic and calcareous facies suggests that the iron is syngenetic and was both mechanically and chemically deposited (for a further discussion of the postulated origin of the hematite, see Kelley, p, 22222225), Quartz, feldspar, mica, hematite, and glauconite are the common allogenic mine r al s of the arenaceous zones of the Bliss. The abundant glauconite is thought to indicate a very slow rate of deposition. Glauconite is especially common in the hematitic facies but occurs throughout the Bliss, mostly in a dark-green color. Some glauconite appears to be authigenic. Hematite commonly has replaced glauconite. Biotite is generally absent in the Bliss. Limited replacement of quartz, carbonates, and feldspar by glauconite has been noted by Kelley.

In the Silver City Range, the Bliss Formation rests unconformably upon a Precambrian complex which is primarily granite in the western part and mica schist and gneiss to the east, The Bliss Formation is overlain conformably by the Ordovician El Paso Limestone and is about 190 feet thick,

FIELD AND LABORATORY WORK

The field work was done in June and early July of 1960 concurrently with the University of Houston summer field geology session near Silver City, a town in Grant County in southwestern New Mexico (fig, 1) which lies in the southeast part of the Basin and Range physiographic province. Five complete sections of the Bliss Formation were measured, described, and sampled. They range a distance of 5 miles northwest to southeast along the Silver City Range (fig. 2), The most extensively sampled and described section was that of Ash Spring Canyon, This was used as the local "type" exposure of the Bliss, since it is in the middle of the area studied,

The Silver City Range trends northwestward from Silver City and is a fault-block tilted to the northeast, with the northeastern dip slopes less rugged than the southwestern backslopes. Formations that outcrop in the range are of. Precambrian to Recent ages, represent all the Systems except the Permian, Triassic, and Jurassic, and consist of both igneous and sedimentary rocks (Paige).

Zones in the various sections were correlated in the field. Then, six zones in the more variable rocks of the thin-bedded glauconite and upper glauconite members were examined more closely in all five sections and freshly broken samples were compared under a binocular microscope, using samples from Ash Spring Canyon as standards. These six zones correlated closely, allowing for slight depositional variations. Only the samples from the representative Ash Spring Canyon section, particularly those of the thin-bedded glauconite and upper glauconite members, were intensively studied in the laboratory. Laboratory work consisted of three parts: preparation of a sample of glauconite for X-ray diffraction study; binocular-microscope study

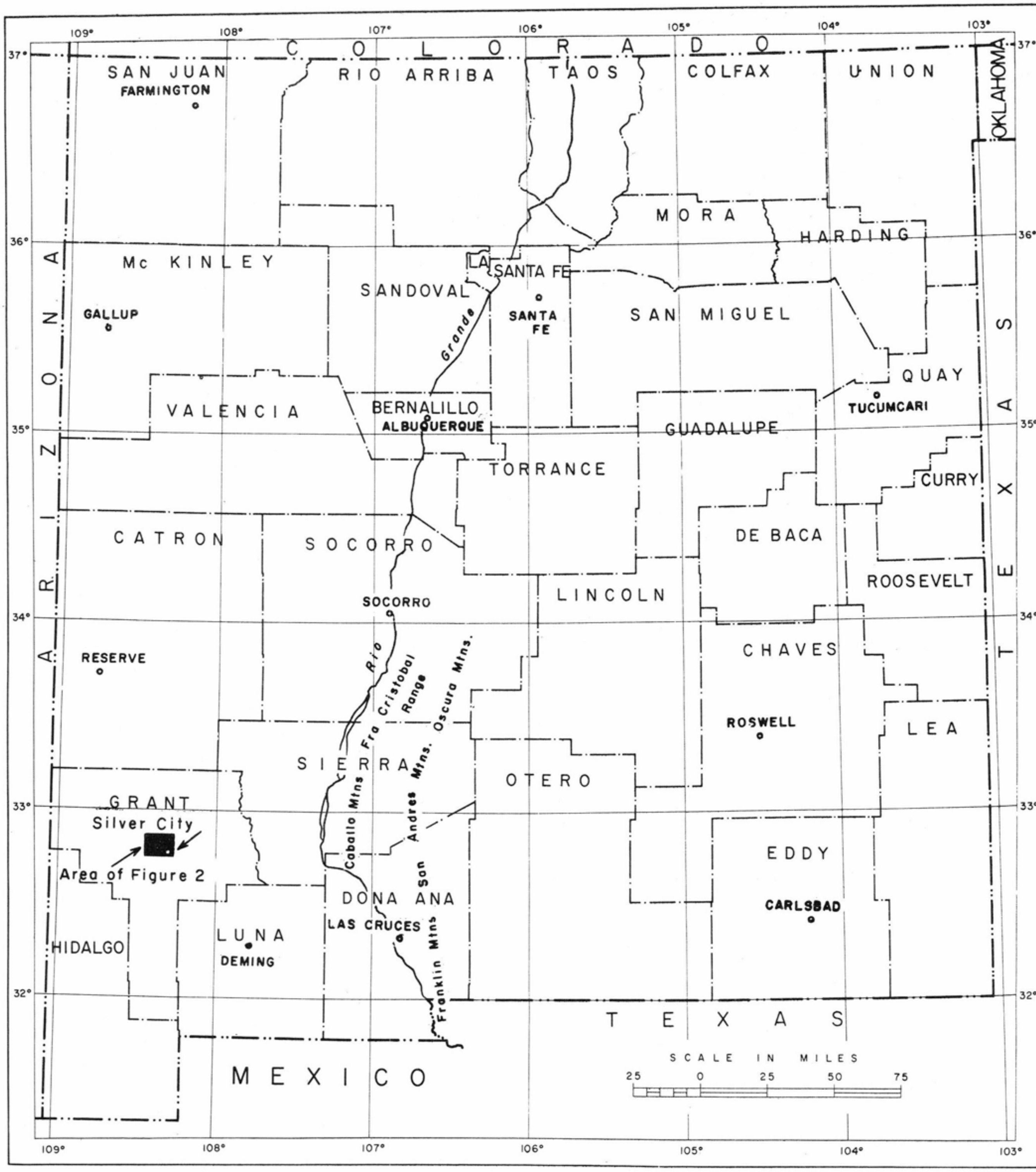

Figure I

Index Map of New Mexico

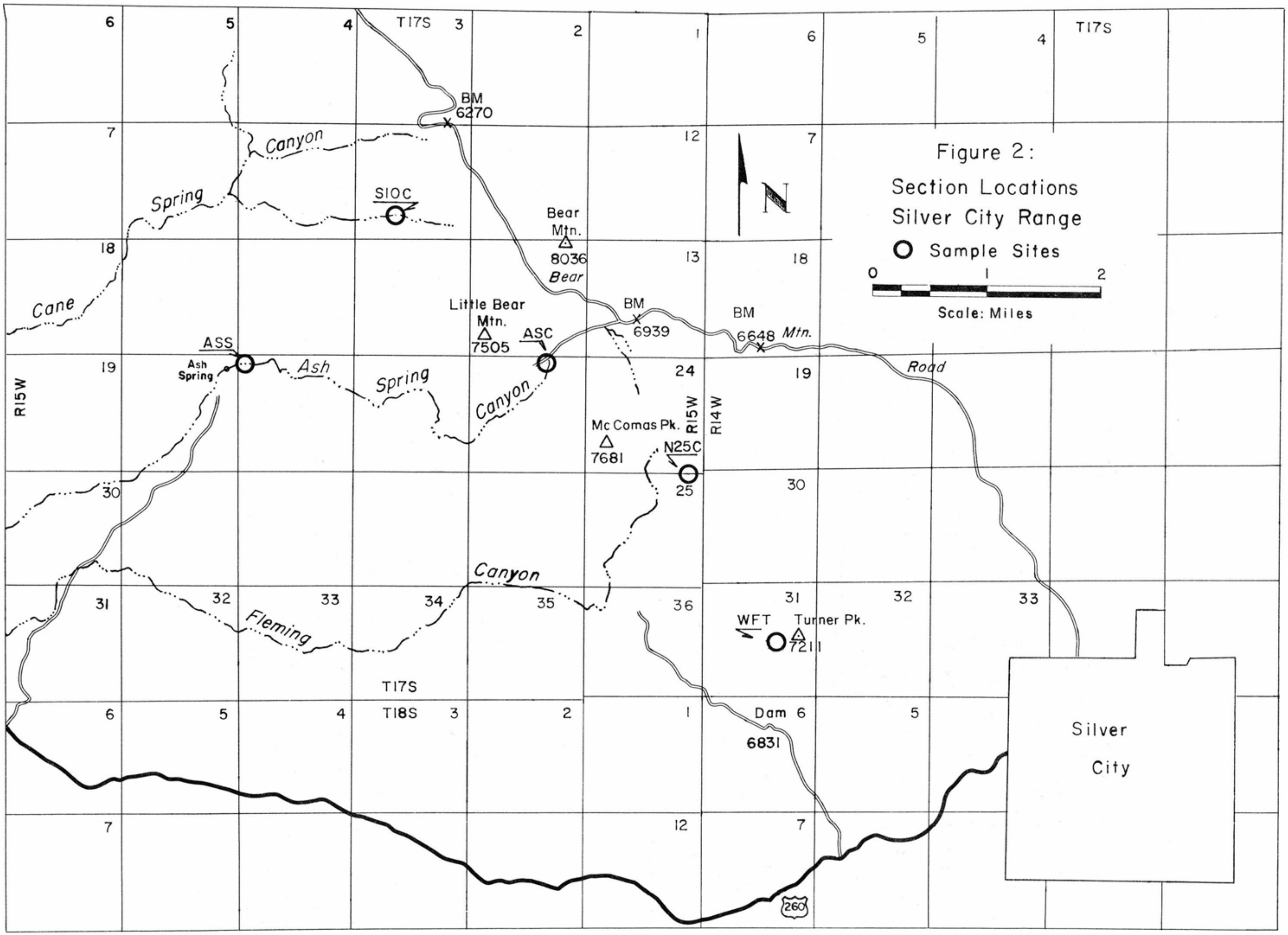
Figure 2:
Section Locations
Silver City Range
Sample Sites
0 1 2
Scale: Miles
N
T17S
T18S
R15W
R14W
BM 6270
BM 6939
BM 6648
Bear Mtn. 8036
Little Bear Mtn. 7505
Mc Comas Pk. 7681
Turner Pk. 7211
Dam 6831
SIOC
ASS
ASC
N25C
WFT
Ash Spring
Cane
Spring
Canyon
Ash
Spring
Canyon
Bear
Mtn.
Road
Fleming
Canyon
Silver City
260

of 39 sawed, polished, and etched sections; and petrographic study of 14 thin-sections from selected samples.

To confirm that the common green mineral in the Bliss Formation is glauconite rather than chamosite or greenalite, the representative, finely ground, pure mineral after separation from a sample was identified by Dr. J. F. Burst from its X-ray diffraction pattern. Seven representative samples from the thin-bedded glauconite and upper glauconite members were X-rayed by Dr. Robert Greenwood and showed a dominance of dolomite over calcite in each.

The index of refraction was determined for five glauconite samples; it lay between 1.602 and 1.613 in each instance, although an occasional grain seemed to show one index slightly higher than 1.613. Exact determinations were impossible since the glauconite occurs as microcrystalline aggregates, necessitating index determinations based on the overall movement of the Becke line.

The refractive indexes were determined for two of the carbonate-rock samples which were used in the qualitative X-ray determinations. The results supported the X-ray determinations in that most of the carbonate minerals showed one index greater than 1.658, indicating dolomite rather than calcite.

In one sample, light- and dark-green glauconite grains (more fully discussed later) were individually studied.

ACKNOWLEDGMENTS

This study was made possible by the assistance and suggestions of Dr. Robert Greenwood of the University of Houston. Dr. John F. Burst of Shell Development Company identified the glauconite and reviewed the thesis on which this report is based. Dr. Max F. Carman of the University of Houston helped with some of the sedimentary petrography studies. I am grateful to Wallace P. Pratt and William R. Jones of the United States Geological Survey, Denver, who told me of their recent work on the Bliss Formation in the Silver City area; to Dr. James L. Wilson of Shell Development Company for his critical review of the paper; to Dr. W. Charles Bell of The University of Texas who identified some brachiopods; and to Dr. Rousseau H. Flower of the New Mexico Bureau of Mines and Mineral Resources for his contribution concerning the age of the Bliss Formation.

Dr. Colin W. Stearn of McGill University supervised the preparation of the manuscript. Technical editing of the report was by Dr. Frank E. Kottlowski and Miss Terry Ray of the New Mexico Bureau of Mines staff.

Stratigraphy

NOMENCLATURE

This study suggests that the designation Bliss Formation be employed for rocks in the Silver City area, rather than the classification Bliss Sandstone. Sandstone and quartzite are present in the Silver City area, but the dominant rocks are more dolomitic than arenaceous. The suggestion supports Kelley and Silver regarding the classification of the Bliss. At the type locality of the Bliss Sandstone in the Franklin Mountains, however, the unit is predominantly sandstone.

MEMBERS

In this study, the Bliss Formation is divided into six members which are distinct and continuous across the area. From oldest to youngest, these members are as follows:

(1) Lower quartzite: a generally pur e, slightly calcareous, cliff-forming quartzite that averages 11 feet thick and lies upon the peneplaned Precambrian complex. Worm tubes occur in the upper part of the member.

(2) Lower hematitic sandstone: A hematite-cemented sandstone, with massive to oolitic hematite in some localities. The member forms a recessional ledge, averaging 2 feet thick, immediately above the lower quartzite member. The lower hematitic sandstone corresponds to the continuous 2-foot-thick o oliti c hematite bed in.the northern part of the Silver City Range (Kelley).

(3) Thin-bedded glauconite: a diverse series with irregularly thin-bedded, arenaceous, carbonate rocks dominating. The member averages 85 feet thick.

(4) Middle quartzite: a clean, cliff-forming quartzite, averaging 20 feet thick. Minor calcareous cement, and some glauconite and hematite, is included at the base in some localities.

(5) Middle calcareous sandstone: a recessional, cliff-forming sandstone immediately above the middl e quartzite member. The member is highly calcareous and commonly cross-bedded. The lower two thirds of the member is stained by dark-reddish hematite. The

upper third shows a coarse-grained calcitic matrix without hematite. The middle calcareous sandstone averages 16 feet thick.

(6) Upper glauconite: another diverse series that is dolomitic and glauconitic but with less glauconite than the thin-bedded glauconite member. The upper glauconite averages about 63 feet thick.

In the lower half of the thin-bedded glauconite member, and the upper third of the upper glauconite member, siliceous zones occur in all the sections, These show highly variable rock types and thicknesses and therefore are not classified as members. The upper glauconite and thin-bedded glauconite show the greatest variations in thickness across the sections.

The upper contact of the Bliss Formation with the El Paso Limestone is arbitrarily chosen at the top of the uppermost glauconite-rich horizon. This may correspond to the upper surface of the siliceous zone in the upper glauconite member; it was never seen more than a few feet above that zone. The siliceous zone corresponds to the "upper quartzite" of Pratt and Jones (personal communication, 1960), which they used in the Lone Mountain section as the contact of the two formations. Probably little change in depositional environment occurred between the deposition of the uppermost Bliss and the lowermost El Paso, but most of the El Paso contains little quartz and no glauconite. The lamellar silica bands, considered characteristic of the El Paso Limestone, are in most places apparent slightly above the contact with the Bliss.

Many poorly preserved brachiopod shell fragments were seen in some zones of the thin-bedded glauconite member at several locations, but only one sample showed internal molds sufficiently well preserved to be identified. This was a float sample, taken in the Ash Spring Section location (fig. 2) , five feet from the base of the thin-bedded glauconite member. Highly limonitic shells in a typical coquina were identified by Bell as Eorthis remnicha (Winchell). A moderately well-preserved gastropod was collected from the SlOC section (fig. 2) and was identified as Schizopea typica (Ulrich and Bridge).

According to Dr. Rousseau H. Flower, the Bliss sandstone consists of discrete units of deposition. In the sections near Silver City and in the Cooks Range the Bliss consists of (1) a basal quartzite, (2) hematitic beds with Eorthis of basal Franconian age, and (3) dominantly glauconitic sands belonging to the late Franconian Prosaukia--Ptychaspis stage. The intervening Conaspis stage is wanting or is represented by thin and barren beds. Trempealeauan beds are coarser, somewhat cross-bedded, sands. Above, a coarse; more cross-bedded, sand marks the beginning of Canadian deposition. This sand, of 6 to 8 feet, is succeeded by 50 feet of thin-bedded dolomite with little sand and glauconite and with considerable chert in the upper half. There follows 16 feet of glauconitic sand with a 10-inch layer of green siltstone at the base. The section at White Signal is allied, except that the basal beds are lower, contain Camaraspis in abundance, and are of Ironton age.

Sections on the east side of the Black Range, the Caballo and Mud Springs Mountains, contain above a basal quartzite latest Franconian with Ptychaspis and Prosaukia. Trempealeauan beds are wanting, and the thick Canadian portion, which is largely dolomitic in the Silver City region, is dominantly sandy; near the top a 10-inch green siltstone yields Dictyonema flabelliforme var. anglicum. Sections in the San Andres, Franklin, and Sacramento mountains have yielded only Lower Canadian sands, It would appear proper to confine the term Bliss to the Canadian sediments and revive the term Shandon for sections containing both Cambrian and Lower Canadian.

Glauconite

CHEMISTRY AND CRYSTAL STRUCTURE

In this study, according to the classification of Burst (1958a), glauconite is defined by X-ray diffraction as monomineralic, iron-rich illite, characteristically with a lath-shaped micromorphology; it has a restricted chemical formula requiring a minimum of two thirds of all possible potassium positions to be filled.

The representative chemical form ul a for glauconite is given by Hendricks and Ross (1941) as:

$$(K, Ca_{1/2}, Na)_{.84}(Al_{.42}Fe^{+++}_{.97}Fe^{++}_{.19}Mg_{.40})(Si_{3.65}Al_{.35})O_{10}(OH)_2$$

Though variations are possible, they state that this composition is remarkably constant. The main variables are ferric oxide and aluminum oxide. Ferric iron varies from 16 to 30 weight percent of the mineral, and the aluminum oxide from 10 to less than 2 weight percent. Atom equivalents of potassium by lattice unit vary between 1.4 and 0.2, forming a transition to biotite with more potassium and to montmorillonite with less (Burst, 1958a, fig. 5, p. 493). The ferric iron is generally greater than the ferrous by multiples of from 9 to 3. The total iron constitutes from 20 to 25 molecular percent of the mineral and the K_20 content from 7 to 8 molecular percent (Burst, 1958a). The birefringence, refractive indexes, and pleochroism vary with the iron content. Recent glauconite cannot be distinguished from older glauconite because each has the same range of optical and chemical properties (Schneider, 1927).

Studies of the structural relationships between the micas and glauconite have been made by X-ray diffraction methods. Glauconite structure is similar to muscovite and illite; they are all dioctahedral (Burst, 1958a). It is difficult to reconcile biotite and glauconite, since biotite rarely has more than 40 percent SiO_2 while glauconite varies between 46 and 51 percent SiO2 (Gruner, 1935), and the structure of biotite is trioctahedral (Burst, 1958a). Yet biotite alters to glauconite (Galliher, 1937) which has never been seen replacing muscovite. Glauconite is monoclinic, is in the heptaphyllite group of micas (Hendricks and Ross), and has a higher silicon-to-aluminum ratio than the micas. It has unfilled potassium positions, compared to muscovite (Burst, 1958a). Glauconite is quite similar to illite and is therefore considered intermediate between muscovite and montmorillonite. It differs from illite primarily in having ferrous and ferric iron (Burst, 1958a).

THEORIES OF ORIGIN

There are many questions as to the origin of glauconite, despite much study. There are points of general agreement about the physical conditions associated with its formation, but specific conditions and the genetic processes are controversial, Glauconite apparently forms from a variety of parental substances in a number of different ways. A brief summary of the theories of glauconite genesis is presented below.

(1) Takahashi and Yagi (1929) and others advocated the theory of fecal pellet conversion. "Peculiar mud grains,"ovoidal and pelletal and considered to be excretions of certain living mud-eating organisms, were investigated. All stages from patchy glauconitic pigmentation to entirely glauconitic grains were seen, and the authors stated that positive identification with fossil glauconite was made. At present, this theory is accepted as one of the most common methods of genesis.

(2) Glauconite has been thought to be associated necessarily with small shells or foraminiferal tests. Emery (1960) suggested that most of the glauconite forming today off the coast of southern California was originally internal casts of foraminifera that were presumably filled with clay. He noted the presence of glauconite (primarily a soft, light-green variety) in many foraminiferal tests. Swelling of the glauconite before it hardened would give irregular shapes to the final grains after they were freed from the restricting tests. Doubt exists as to whether much of the ancient glauconite was formed in this way, since foraminiferal tests often are found associated with glauconite but do not include any of the mineral (Prather, 1905). Twenhofel (1950) stated that the relation between foraminifera and glauconite may not be casual.

(3) Another theory is that the mineral results from the alteration of clay-pellet agglomerations present on the sea floor because of undulating currents. Carroll (1958) proposed that glauconite would alter from montmorillonite, hydrous micas, or degraded chlorite and vermiculite minerals with a rearrangement of the proportions resulting from exchange of cations with sea water. Ferric iron would be closely attached to the clays originally, and bacteriological reducing conditions would maintain ferrous iron in the depositional environment. Light (1952) noted the common intimate association of authigenic glauconite with illitic clays (not kaolinite).

(4) Galliher (1935, 1937) assumed that most glauconite is a result of the alteration of biotite, favored by alkaline solutions and an anaerobic marine environment with little agitation. He has provided excellent support for this theory with studies in Monterey Bay, California, where a continuous series from biotite to glauconite is present. Emery noted a few grains that seem to show this alteration. Burst (1958b) believed most glauconite to be of fecal origin; therefore, organisms with selective dietary habits, preferring biotite to muscovite,

would be necessary. Such organisms are improbable. As summarized by Twenhofel (p. 441), glauconite in many places occurs extensively in rocks which probably never contained much or any biotite, so it is difficult to explain the presence of enough biotite to form notable glauconite-rich formations, especially the thick New Jersey deposits.

(5) Other parental substances for glauconite, claimed by various authors, include volcanic glass, organic opaline silica, feldspars, and pyroxenes. An unusual occurrence of glauconite in the terrestrial beds of the Morrison Formation (Keller, 1956) is postulated as resulting from supergene alteration of montmorillonite.

PHYSICAL LIMITS OF FORMATION

Cloud (1955) reviewed the physical conditions that limit the formation of glauconite. These are summarized, with discussions of modifications proposed by other writers.

Glauconite ordinarily results from submarine processes acting on a variety of parental substances. The marine waters are of near-to-normal or normal salinity, and there must be an appropriate source of sediments. Slow sedimentation favors the formation of glauconite in terrigenous deposits close to continental masses. Glauconite is rarely found in pure clay, quartz, or chemical carbonate rocks. It is seldom present in pelagic deposits and is rarely found where there are abundant detrital sediments, such as those that accumulate off the mouths of rivers (Emery). It is doubtful whether glauconite occurs in the volcanic muds and sands around oceanic islands, but it is found in volcanic deposits nearer the continents (Hendricks and Ross).

Glauconite was found in the terrestrial deposits of the Morrison Formation (Upper Jurassic) in Colorado by Keller. Here the mineral is in micaceous form and probably constitutes an intermediate stage in the alteration of montmorillonite to glauconite, as it is associated with altered volcanic ash and bentonite. Apart from this unique occurrence, marine processes are considered to have the most widespread significance in glauconite genesis.

Specific Factor s

The presence of potassium in glauconite indicates marine conditions of genesis (Hendricks and Ross), organic acids probably motivating glauconite formation, Burst (1958a) suggested migration of potassium and iron into favorable concentration centers within defective three-layer clay lattices, under favorable marine oxidation potentials.

Glauconite genesis is favored by associated organic material, but the amount necessary is subject to much controversy. Glauconite has an affinity for siliceous sponge spicules, and accumulations are associated with abundant mollusk shell-fragments and foraminifera (Cloud; Lochman, 1957; and Emery). Shells of foraminifera, brachiopods, pelecypods, gastropods, and trilobites are often present; conversely, bryozoa, stromatoporoids, and sessil benthonic forms are usually absent. The only living organisms at the time of glauconite genesis apparently were worms and scavengers (Lochman). Worms would be expected continuously to stir the sea-bottom sediments, but generally anaerobic conditions would prevail. Oxygen-deficient muds might be in contact with bottom waters of normal oxygen content. Hadding (1932) noted that glauconite never forms in highly oxygenated waters, although agitation is present. Galliher (1935) proposed persistently alkaline waters. Carroll also concluded that reducing conditions are necessary for the retention of ferrous iron but suggested bacterial action as the reason for these conditions, within a generally oxidizing environment. Emery suggested a microreducing environment for glauconite, due to decomposition of associated protoplasm, but thought there may be up to 90 percent oxygen saturation in the overlying waters, as that off the California coast today.

Twenhofel pointed out the common occurrence of glauconite in the Upper Cambrian Franconia Formation in the upper Mississippi Valley, which was deposited under aerobic conditions. Glauconite off the coast of California, associated with turbulent flow, current and wave action, an abundance of bottom scavengers and worms, and a low organic content, indicates that accumulations occur in abundantly oxygenated areas (Emery). Castano and Garrels (1950) stated that hematite (which is common in the Bliss Formation) indicates an environment of open circulation with a rapid destruction of organic material. The hematite, however, is probably secondary where it is in close association with glauconite, Burst (1958a, 1958b) suggested that the overall environment is oxidizing to semioxidizing, local reducing conditions being associated with decaying organic material.

The rather uniform ratio of ferric to ferrous iron in glauconite (Burst, 1958a; Grim, 1951) suggests that a specific oxidation-reduction potential is required for glauconite genesis. Cloud concluded that a pH of 7 to 8 and an Eh of about -0.2 volt is necessary. Carroll supported this conclusion, while Emery agreed with the pH estimation but observed an Eh of approximately +0.3 volt off the California coast where glauconite is forming.

Depth

Traces of modern glauconite have been found offshore to depths of 2400 fathoms, but glauconite is usually r are above 5 and below 1000 fathoms. It occurs most commonly between 10 and 400 fathoms (Cloud; Galliher, 1935). Generally, this would be the neritic but not the shallowest environment.

Temperature

The temperature at which glauconite forms is quite variable. Today, genesis occurs in seas of warm-temperate to temperate climates, in waters ranging from 8° to 20°C (Cloud). Glauconite genesis is probably restricted by other considerations also, such as oxygen content.

Turbulence

Glauconite is associated with turbulent deposition, but no specific generic relation is apparent.

Source Rocks

Most researchers conclude that decomposition products of crystalline rocks were and are the best sources for the parent materials of glauconite. The proximity to plutonic and metamorphic terranes would favor illite- and biotite-rich sediments. The mineralogical associations of glauconite are quartz, carbonate minerals, orthoclase (often kaolinized), other feldspars, white mica, clay minerals, various shell and rock fragments, hornblende, magnetite, garnet, and epidote (Leith, 1903; Twenhofel).

GENERAL STATEMENT

The parent materials of glauconite are some kinds of agglomerated argillaceous materials in a roughly pelletal form. Association with some decaying organic material and the syngenetic presence of iron are indicated. The clay pellets capture potassium from sea water to produce glauconite, Birdsall (1951) produced a poorly crystallized glauconite by coprecipitation of ferrous iron and silica gels, with an appropriate adjustment of pH and treatment in an autoclave. However glauconite forms, it first appears as a scattered pigmentation in the clay pellets, then gradually expands to homogeneous glauconite pellets. According to Burst (1958a), the conditions for the formation of glauconite are simply supplies of potassium and iron, a silicate lattice, and a favorable oxidation potential.

The grains of this mineral are classified as authigenic (autochthonous or primary) or detrital (allochthonous, allogenic, or secondary). Unfortunately, these terms are poorly defined and often mean different things to different people. In this report, authigenic implies genesis of glauconite on the spot, at the position where it is preserved in the rocks. Authigenic glauconite is immediately buried, without any transportation. Authigenic glauconite of replacement origin is a result of diagenetic replacement of other minerals after deposition. Use of the term detrital (or its synonyms) is avoided, inasmuch as most of the meanings implied by this term do not apply to the glauconite of the Bliss Formation in the Silver City area, Instead, the term perigenic is proposed to describe the glauconite of the Bliss. Perigenic (Gr, peri--near; genesis) is used to describe the origin of the material close to its point of ultimate deposition. Thus, perigenic implies short transportation of the material followed by incorporation into sediments of similar genetic environment.

If glauconite is transported a short distance, abrasion of the grains is minor, and perigenic and authigenic glauconite will be difficult to separate on the basis of physical criteria. Separation on a chemical basis probably would be impossible, as the environmental conditions would be similar before and after the slight transportation of the glauconite grains. A brief summary of significant physical features that may distinguish between authigenic and perigenic glauconite has been compiled from Cayeux (1931), Light (1952), and Carozzi (1960), These authors employed the classifications of authigenic and detrital (or their synonyms), but the features chosen would apply to authigenic and perigenic glauconite, as defined above.

Authigenic

Authigenic glauconite grains show less evidence of breaking, yet less regularity of shape, than perigenic ones. They are rough and pitted, dull to subvitreous, "Lobate" grains (Hadding; Carozzi) are the most common type of authigenic glauconite. These grains are irregular, larger than other associated glauconite grains, and cut by many radial, triangular cracks that are widest at the periphery. Such cracks attain up to 40 percent of the volume of the larger grains. Other occurrences suggesting the presence of authigenic glauconite are (a) glauconite crusts (megascopic) and coatings on shells and detrital minerals, (b) clay agglomerates only partially altered to glauconite, (c) foraminiferal test fillings, and (d) fracture fillings. Ovoidal or sub-spherical "globular" grains appear to be small concretions formed in place. These grains are well disseminated or concentrated in spots and clusters where they may join to give a "granular" aggregate that appears lobate. Fibrous glauconite showing cleavages in chalk (Cayeux) and pigmentary glauconite in silica also imply authigenic growth,

Perigenic

Perigenic glauconite grains should not show a genetic relationship to surrounding minerals. Tabular grains may have jagged ends and grooves perpendicular to the long axis, and they may show no preferred orientation along the bedding. Small glauconite grains are commonly broken, irregular, and "fragmental," without remnants of the former surface structure except for one, smooth, rounded side (they might represent transported pieces of desiccated, shattered lobate, or other grains). "Squeezed" grains, irregular aggregates compaction-molded onto other detrital particles and sometimes simulating a matrix, suggest glauconite that is embedded immediately after its formation. These accumulations are not necessarily authigenic. Generally, there is a close association of perigenic glauconite with detrital quartz in a similar range of grain sizes. Carozzi (p. 54) suggested that, in the cryptocrystalline aggregates of "detrital" (probably equivalent to perigenic in this instance) glauconite grains, "An incipient differentiation is shown by grains in which the elements of aggregate increase in size and simultaneously decrease in number. " As a result of this differentiation, perigenic glauconite may tend to form individual grains with a single optic orientation. Such grains show traces of cleavage and a higher birefringence than other associated glauconite grains. Rounded, spheroidal, discoidal, or ovoidal grains suggested as coprolites (Emery; Burst, 1958b) may be disturbed by agitation of the sediments, yet retain their general authigenic appearance with only minor modifications in shape due to agitation and short transportation by bottom currents. Subsequent compaction-squeezing and replacement by other minerals would constitute the major modifications of the appearance of the glauconite grains.

Authigenic Glauconite of Replacement Origin

Cayeux and Carozzi indicated that glauconite replaces silica or carbonate minerals which are present as shells or cement, feldspar (starting along the cleavages), and other minerals, or that it fills secondary fractures. Small inclusions of the original mineral may be present in the replacing glauconite, or replacement may not have continued to completion. Glauconite in the replacement occurrence may be generated just after sedimentation while the deposits are still impregnated with connate waters, or it may form during later diagene sis.

Glauconite in the Bliss formation

MINERALOGICAL ASSOCIATIONS

The following generalizations on the mineralogical associations of glauconite were made from study of 39 etched sections and 14 thinsections taken from the Ash Spring Canyon section. All the glauconite appears to be cryptocrystalline. It occasionally appears disseminated and homogeneous in hand specimen, but under the microscope most of this glauconite consists of deformed or fused aggregates of grains.

The rocks studied were divided into four groups on the basis of their quartz content. The orthoquartzites consist of 90 or more percent quartz; the sandstones of 50 to 89 percent; the arenaceous dolomites of 10 to 49 percent; and the dolomites of 9 or less percent. The nonquartz parts of the rocks consist essentially of dolomite, as determined by X-ray diffraction studies. Of the 40 specimens examined, 2 were from the lower quartzite, 1 from the lower hematitic sandstone, 21 from the thin-bedded glauconite, 1 from the middle quartzite, 2 from the middle calcareous sandstone, and 12 from the upper glauconite member. One sample from the base of the El Paso Limestone also was studied.

Orthoquartzite

The orthoquartzite of the Bliss is essentially restricted to the lower quartzite and middle quartzite members. Sparse carbonate-rock cement is present in the upper parts of these members. About 15 percent of hematite and limonite (after glauconite?) is present in the lowermost part of the middle quartzite member. The rock is a relatively pure, slightly limonitic orthoquartzite, with clasts ranging from pebbles, in the lowermost lower quartzite member, to less than 1 mm, The grains are subrounded, although subangular shapes dominate in local, poorly-sorted beds. In many places, the whole range of grain roundness is. seen. Graded bedding occurs in the basal part of the lower quartzite member. Bedding, emphasized by weathering, is primarily thin and irregular in the middle quartzite member, and some cross-bedding occurs. The lower quartzite member is massive, with occasional zones of less indurated, irregularly medium-bedded orthoquartzite. Exposed bedding surfaces always appear uneven, with small knobs and depressions. Worm tubes were seen in the upper portion of the lower quartzite member in most places.

Glauconite is absent from the orthoquartzite in most localities. None appears to be present in the lower quartzite member. Parts of the basal rocks of the middle quartzite member contain traces of glauconite associated with more abundant limonite and hematite.

Sandstone

Sandstone occurs throughout the Bliss Formation in the lower hematitic sandstone and middle calcareous sandstone members, as well as numerous beds in the thin-bedded glauconite and upper glauconite members. Eight samples of this group came from the thin-bedded glauconite member, primarily from the siliceous zone in the lower part. The four sandstone samples from the upper glauconite member were widely spaced and attest to the varying competence of currents in the environment of deposition.

The sandstone is roughly thin-bedded or highly disturbed, poorly sorted, and "chaotic. " The chaotic beds in many places include intraclasts (as defined by Folk, 1959). The term describes penecontemporaneous fragments, usually of poorly consolidated carbonate rocks, which were eroded from adjoining parts of the sea bottom and redeposited. The intraclasts consist of material similar to the rock in which they are found and reach a maximum size of 10 mm long, 5 mm wide. They lie roughly parallel to the bedding. The quartz grains in the sandstone are rounded to subrounded and sorted. The quartz grain sizes range from 1 to about 0.05 mm, with the average size for many beds being about 0.3 mm. The majority of the quartz grains show strain shadows. Fusion of associated grains or irregular extensions of isolated grains are common and indicate secondary, post-depositional growth of the grains. Occasional quartzite clasts, seen in some thinsections, are the same general size as the surrounding quartz grains.

An interlocking and recrystallized carbonate matrix is common in the sandstone. Hematite is often present and ranges up to 25 percent (rare). It is disseminated and coats quartz grains or replaces glauconite, but rare hematite oolites were noted in some of the hand specimens from the lower hematitic sandstone member in several localities. Hematitic laminations define the rough, irregular bedding in many beds. The hematite also rims shell fragments or intraclasts. The upper glauconite member shows less hematite than the thin-bedded glauconite member; hematite does not constitute more than 5 percent of any rock of this upper member, where it is associated with glauconite.

The lower hematitic sandstone member contains abundant hematite, essentially as quartz-grain coatings. In the WFT section, most of the member is massive hematite with minor oolites. In the middle calcareous sandstone member, the hematite again primarily coats the quartz grains and cements rare zones.

Hematite appears to be syngenetic, to judge from its ubiquitous occurrence in most of the Bliss Formation in New Mexico (Kelley), Ferric iron probably was brought into the depositional environment of the Bliss as ferric hydroxide in a colloidal form, or adsorbed on clay minerals. The hematite is assumed to have attained its present form as a result of early diagenetic processes.

The lower hematitic sandstone member shows a special feature. In one sample, about 10 percent of the rock consists of yellow-brown grains that are subvitreous, rounded, and fine- to very fine-grained. These show some deformation associated with quartz grains and are similar to the glauconite grains of other sandstones. The average index of refraction is about 1.625, and the mineral shows crystallites of a very low birefringence, masked by the color. Biaxial character and a small optic angle were established. It is believed that these grains represent a ferruginous clay mineral related to glauconite.

Glauconite is common in the sandstones from the thin-bedded glauconite and upper glauconite members but is absent in the lower hematitic sandstone and middle calcareous sandstone members. It constitutes from traces to 40 percent of the rock, with a modal value of about 20 percent. Its grains show a size range similar to that of associated quartz grains, implying deposition by the same currents. There may be a wide range of sizes for each type of grain in the chaotic zones. Extensive replacement of glauconite often destroys the original shapes of these grains, making the determination of the original sizes of the glauconite grains difficult. Many "squeezed" and irregular glauconite grains are present, accumulations of which may simulate a local glauconite matrix. Such grains probably represent compaction-deformation of glauconite by associated quartz grains. The irregular glauconite grains rarely show microfractures, and their shapes imply that the grains had not hardened at the time of their inclusion into the sediments. The presence of spheroidal to ovoidal glauconite grains in carbonate-rock zones not associated with quartz grains suggests that the original glauconite grains were round or ovoidal. Associated glauconite grains may be fused. Some homogeneous glauconite fills small interstices between detrital quartz and glauconite grains.

Silica locally replaced glauconite grains peripherally, or in small, irregular, internal patches. The silica replacement is not seen in the etched sections unless rare, subvitreous glauconite grains constitute partially silicified glauconite. Carbonate minerals have also replaced glauconite, as de scribed below.

Glauconite grains frequently show replacement by hematite in the quartzites, arenaceous dolomites, and dolomites. The hematite replaced glauconite as irregular internal patches or, commonly, rims the glauconite grains. Manyhematite concentrations outline the original shape of a glauconite grain that had been replaced by silica or by carbonate minerals. Hematite grains similar in size and shape to associated glauconite grains are common in some ho r i z o n s and probably represent completely replaced glauconite grains. When it occurs as irregular laminations, however, the hematite does not appear to be after glauconite, and in its granular and other habits it did not replace glauconite. The replacement of glauconite by hematite in the form of crystal flakes is of interest. In a few samples the flakes appear to have a preferred orientation so that the thinsections cut perpendicular to the bedding show numerous thin, wedging, edge-views of these flake crystals. They seem, to have worked radially inward from the rims of the glauconite grains. They also are seen wedging out in two directions and transgressing grain boundaries without deviation. No relation to microfractures is apparent, and they do not represent a filling of cracks in lobate grains.

Limonite is common in most of the rocks in the Bliss Formation near Silver City. Limonitic light-brown stain is seen on many outcrops, and in etched and thinsections much of the carbonate rock is stained light tan. Darker limonite stains are concentrated in the intraclasts. Limonite often replaces glauconite and hematite. The original dimensions of glauconite grains that have been replaced by carbonate minerals are outlined by a stain that is darker than the surrounding rocks. Surficial limonite is probably due to recent weathering. The weathering may be related to the primary porosity of zones and beds that have high concentrations of quartz grains and in which glauconite may be totally replaced. Such zones often show a ferruginous stain darker than the surrounding rock. Some limonite appears in thinsection between glauconite and hematite, suggesting that hematite is the final stage in the oxidation of the glauconite.

Alteration of glauconite to limonite was localized on the surface, along cracks, or at the center of grains. The final stage of complete alteration to limonite also is apparent. Peripheral limonitization associated with hematite is the most common. Some dark greenish-brown grains are probably nearly completely replaced by limonite. Cayeux stated that in the final stage of alteration of glauconite, silica and iron are liberated. The liberation of these elements may explain the regrowth of the quartz grains and the disseminated ferruginous stain in the carbonate rocks of the Bliss Formation; or, it may partially explain some of the hematite occurrences. Much of the limonite in the Bliss is thought to be the result of fairly early diagenetic change from glauconite. Some probably resulted from a slow hydration of hematite, as postulated by Carroll.

Clay minerals in the thinsections examined constitute less than one percent of the rocks from the Bliss Formation. Apart from the clay(?) grains previously mentioned in the lower hematitic sandstone member, the only clay recognized was in very thin, laminated flakes up to 0.14 mm thick and, rarely, 20 mm long. Sparse, rounded grains up to 0.3 mm in diameter are also thought to be composed of clay minerals. Both the flakes and the grains are brownish, have very low birefringence, and have a refractive index between 1.54 and 1.59, a small optic angle, and a positive sign. The laminated flakes are not oriented with respect to the bedding and occasionally appear to be partially replaced by silica or carbonate minerals (or glauconite?). Longitundinal laminations sometimes appear to be filled with very thin hematitic material; cross-laminations are very rare and show no hematitic fillings. The flakes occasionally cut glauconite or quartz grains and seem to fill microfractures in these grains. Often, the flakes are deformed or broken by associated quartz grains and appear to be similar in composition to the rounded clay grains; they were tentatively identified as dickite. Rare microcline and plagioclase, noted in some thinsections, might have originally been more widespread and might have provided the source for the dickite. The alteration to dickite would release silica, providing a partial source for the regrowth of quartz grains and for silica replacement of glauconite.

A few, longitudinally laminated, highly birefringent, clear flakes were identified as muscovite in thinsection. Small, roughly angular plagioclase grains were corroded and partially replaced by limonite and carbonate minerals in the more chaotic zones of the Bliss, both in the quartz-rich and quartz-dolomite types. Quadrille twinning of microcline was seen in a few grains. Feldspar grains probably were more abundant originally than at present. Untwinned individuals may not have been recognized in thinsection. Thin, curved shell fragments are common in the sandstones, often associated with intraclasts,

Arenaceous Dolomite

Arenaceous dolomite is nearly as abundant as sandstone in the thin-bedded glauconite and upper glauconite members. As shown by the five samples examined from the thin-bedded glauconite member, this lithology dominates the upper part of the member above the siliceous zone. Four samples were collected from the upper glauconite member in which the arenaceous dolomites are evenly distributed. The sample taken from the lowermost El Paso Formation also is an arenaceous dolomite and contains small (averaging about 0.1 mm), scattered glauconite grains.

Carbonate minerals dominate the arenaceous dolomites and constitute the bulk of the Bliss Formation in the Silver City area. The carbonate minerals have interlocking, recrystallized textures, and are mainly dolomite and calcic dolomite. They act as a firm matrix, and included quartz grains often break when the rock is fractured. The carbonate minerals are permeated with a light-brown, limonitic stain. Clear carbonate minerals occur sparsely as minute euhedral crystals, rims around glauconite grains, fracture fillings, shell fragments, and occasionally large crystals. Some fragmental ferruginous carbonate grains (up to mm long) are slightly elongated parallel to the bedding. These are rounded, probably detrital, and occur in the chaotic zones of the rocks. Carbonate minerals constitute the major portion of the intraclasts in the chaotic zones. The carbonate crystals range from 1 to 0.04 mm in size and often average 0.3 mm in the arenaceous dolomite. Lenses and irregular laminae of coarsely crystalline carbonate minerals up to 15 mm thick include more rounded but less numerous quartz and glauconite grains than are in the surrounding rocks. Occasional, unsorted, 1 to 2 mm thick laminae of especially fine-grained carbonate minerals, glauconite, and quartz parallel the irregular bedding in all the rocks.

In the arenaceous dolomite group, the quartz grains appear either in moderately well-sorted laminae and zones or as poorly sorted, scattered grains. They are sometimes concentrated as poorly sorted, angular, small grains in the irregular intraclasts. Quartz grains range from 0.5 to 0.07 mm in diameter with an average about 0.3 mm. Some of the quartz shows small-scale interlocking boundaries with the carbonate minerals of the matrix. Concentrations of grains may define irregular beds or zones that are truncated by the general bedding. Most of the quartz grains are rounded and secondary growth is common.

Hematite is relatively common in the thin-bedded glauconite member but makes up less than 5 percent of the upper glauconite member, appearing in the latter mainly as scattered grains. Its occurrence as quartz-grain coatings and as a replacement of glauconite and its association with limonite are similar to that in the sandstones. In many places the hematite preferentially replaced the glauconite concentrated in thin laminae but did not affect the scattered grains.

Glauconite grains average about 15 percent of the arenaceous dolomites. Occasional beds lack glauconite. Angularity of glauconite grains locally indicates compaction deformation, and a few grains developed a flat side parallel to the bedding. The glauconite grain sizes vary from about 0.3 to 0.07 mm, with a mode at about 0.25 mm. The glauconite grains are the same size as associated quartz grains in the irregular laminar concentrations of both minerals and in the intraclasts. In the chaotic zones, some glauconite is "fragmental," and grains are smaller than in the less disturbed zones. Glauconite is essentially the only mineral of some irregular, lensing laminae up to 0.5 mm thick in which the glauconite grains are elongated and fused by compaction. In the quartzose zones, the glauconite appears similar to that in the sandstones. As a rule, the grains are less replaced by limonite and hematite and are more frequently spheroidal and ovoidal than glauconite grains in the sandstones. Circular grains seen in thinsection may be cross sections of the ovoidal grains seen in etched sections. The ovoidal grains dominate in some rocks, while definite spheroidal ones dominate in others.

Carbonate minerals commonly replace or interlock with the glauconite grains in all the rock groups. The interlocking arrangement may be due to recrystallization of the carbonates, but carbonate minerals replaced glauconite along rims of the grains and in small, irregular, internal patches. Partial replacement of the glauconite gives the grains a "fragmental" appearance, but the original outline of the glauconite grain is shown by the dark, ferruginous stain of the replacing carbonate or by limonite and hematite concentrations. Occasional microfractures in the glauconite grains were filled with carbonate minerals.

Sparse glauconite grains were partially replaced by silica. Feldspars and laminated dickite flakes occur, as in the sandstones. A few rounded, equant, or elongated chalcedony grains show a radial structure. Thin, curved, shell fragments in the arenaceous dolomites are usually associated with intraclasts. Sparse, small grains of zircon and tourmaline were tentatively identified in some thinsections.

Dolomite

The dolomite group was represented by eight samples from the thin-bedded glauconite member and four sample s from the upper glauconite member. The repeated occurrence of the dolomites interbedded with more arenaceous rocks attests to the varying conditions of deposition of the Bliss Formation in the Silver City area.

Carbonate minerals constitute more than 50 percent of these rocks. They are mainly dolomite, similar in all respects to the carbonate minerals previously discussed. Quartz grains are often present but do not exceed 10 percent of the rock. They are rounded, poorly sorted, and concentrated in laminae and in the intraclasts. In the laminae, subequant quartz grains average from 0.5 to 0.1 mm in diameter. The smaller grains dominate, especially in the upper glauconite member. Quartz grains in the intraclasts are ordinarily about 0.1 mm in diameter.

Hematite is present in all the dolomite samples but does not make up more than 5 percent of the upper glauconite member. It occurs commonly in the thin-bedded glauconite member, though rarely more than 15 percent. In the dolomites, hematite replaces glauconite and coats quartz grains, but it is also present in the forms noted in other rocks. The hematite often appears to spread from laminae of glauconite grains and to coalesce and form irregular hematite laminae. The purple bedding surfaces of fissile, thin-bedded calcareous zones in the thin-bedded glauconite member, noted in many of the exposures of the Bliss Formation, reflect the presence of hematite.

Glauconite grains are scattered throughout the dolomites, in most places constituting more than 5 percent of the rocks and with a modal abundance of about 10 percent. Concentrations of glauconite grains are generally associated with concentrations of quartz grains that show an equivalent size range. The glauconite grains associated with quartz usually show compaction molding and deformation, but the typical grains are spheroidal to ovoidal. Replacement of the glauconite by carbonate minerals, silica, hematite, and limonite is similar to that previously discussed.

Laminated dickite flakes are absent in two highly fossiliferous samples but are present in two others. Feldspars are absent. Bedding is uneven and is defined by irregular laminae of quartz, glauconite, and hematite, or by subparallel intraclasts and fossil shells.

Thin fissures in etched section, and 1 mm deep and as much as 12 mm long, probably represent original fossil shell fragments. The fragments are seen in thinsection as curved carbonate-mineral laminae, a maximum of 2 mm thick. Abundant unoriented shells and numerous textures probably of organic origin mark two samples as fossil hashes. Some of the shell fragments are partially replaced by glauconite or silica and others interlock with the carbonate matrix because of recrystallization. Often the fragments are deformed and fractured about associated quartz grains. Some organic fragments are rimmed or partially replaced by limonite or hematite.

Reticulating patterns of short hematite laminae give a small-scale, honeycomb appearance to replaced rims of grains, or predominantly replaced grains, of carbonate minerals or occasionally glauconite. Such hematite textures may represent replacement along original organic structural lines of weakness,

Intraclasts and fossil shell fragments are common in the dolomites, occurring conspicuously in most of the samples in contrast to a more sporadic appearance in the other rock groups. Intraclasts are present in the more chaotic zones of the various rocks. They attain a maximum size of 4 by 2 cm and average 10 by 5 mm, Many of the intraclasts are roughly elongated parallel to the bedding and have a subrounded shape. They often show vague or mashed boundaries, suggesting that they were originally barely coherent and that they were reworked from surficial carbonate muds (Folk). The intraclasts generally consist of highly ferruginous carbonate minerals that are more finely crystalline and include finer-grained quartz and glauconite grains than the surrounding rock. The rims of some intraclasts show a concentration of limonite or hematite. The carbonate minerals of others interlock with the matrix because of recrystallization. Most of the original glauconite thought to have been present in the intraclasts seems to have been replaced by limonite and hematite, or by carbonate minerals, to a greater extent than the glauconite in the associated matrix. The intraclasts rarely constitute more than 15 percent of the rocks. The concentration of minute hematite grains and crystals in the intraclasts suggest that the intraclasts were reworked from beds that had undergone sufficient diagenesis to have formed hematitic accumulations.

Turbulence and Bedding

The majority of the units in the Bliss Formation near Silver City show various degrees of bedding. Quartz, glauconite, and hematite laminae up to 5 or more mm thick, the roughly elongate intraclasts and glauconite grains, and coarsely or finely crystallized carbonate rock laminae all define the bedding. Most of the bedding is highly irregular to chaotic. Irregular laminations up to 1 mm thick are common in all rock groups and show irregularities of about 2 to 3 mm, Other laminations are discontinuous and lensing or show angular relations to each other. They are more noticeable in the dolomite and arenaceous dolomite groups.

This observed association of glauconite with turbulent sedimentation indicates that the glauconite is not strictly authigenic, currents and waves having transported it to some extent; the preceding mineralogical descriptions also suggest that the glauconite is not strictly authigenic. It appears to have been incorporated into the sediments soon after its genesis; therefore, the classification of glauconite as "perigenic" is of value in that it implies local transportation of grains in their genetic environment,

VARIETIES OF GLAUCONITE

In this report, the glauconite of the Bliss Formation has been divided into two types, referred to as light- and dark-green varieties. The dark-green glauconite appears as microcrystalline to cryptocrystalline, subequant grains from 0. 8 to 0.02 mm in diameter. The large grains are often compaction elongated or deformed by associated quartz grains. The index of refraction lies between 1.602 and 1.613 in nearly all grains. Birefringence is obscured by the green color.

The light-green glauconite is similar to the dark-green variety except that it is softer. It is similar to that mentioned by Emery (p. 213) as composing the glauconite of internal casts of foraminifera. The light-green color is probably due to incomplete alteration of clay minerals that occur in small, internal, irregular, whitish patches which show either the same or a much lower birefringence than the glauconite. These patches may represent incipient alteration of glauconite to montmorillonite, which Carozzi (p. 143) suggested as being the only clay mineral to which glauconite usually alters. However, montmorillonite has a higher birefringence than the white, internal patches; thus, montmorillonite does not appear to be present.

Occasional, roughly tabular, light-green zones in the darker grains show a relatively high birefringence. An interpretation suggested by Carozzi (p. 54)is that this birefringence may be due to an incipient change of glauconite to homogeneous individuals with a single optic orientation. This interpretation explains the traces of cleavage noticed occasionally in the tabular zones, parallel to the long dimension.

Light-green glauconite grains appear alone in some quartzose rocks, but the darker variety dominates when both are present. Glauconite grains occurring in the more calcareous rocks are usually dark green, though many of them have subsidiary light-green patches in the dark grains. In a few samples the dominance of the light-green glauconite in the calcareous rocks may be related to the relatively small amount of glauconite that has not been replaced by carbonate minerals, limonite, and hematite. The light-green variety is distinctly more common in the highly arenaceous rocks than in the quartz-poor types. This occurrence may be related to the original porosity of the arenaceous rocks if the light-green variety of glauconite is a result of incomplete alteration from a clay mineral. A free circulation of connate waters in the porous zones might impede the glauconitization process.

Conclusions

The results of this study of the glauconite of the Bliss Formation in the Silver City area of New Mexico are briefly noted:

(1) The glauconite is generated predominatly by replacement of fecal pellets of vagrant organisms in a marine environment.

(2) Most of the glauconite consists of perigenic grains. (Material which was formed close to but not at its site of final deposition is referred to as perigenic.)

(3) The glauconite is commonly replaced by carbonate minerals, hematite, and limonite, and more rarely is replaced by silica.

(4) Light-green glauconite is less abundant than a harder dark-green variety. The light-green variety is probably due to incomplete glauconitization of the clay minerals of the fecal pellets.

The glauconite grains appear as cryptocrystalline aggregates which show smooth, subrounded surfaces, implying origin as fecal pellets and some rounding by transportation. No biotite was identified; Kelley stated that biotite is usually lacking in the Bliss Formation in New Mexico. No traces of foraminifera were seen. Moderate currents in the depositional environment are implied by the presence of (a) intraclasts, (b) irregularly laminated, cross-laminated, and poorly bedded sediments, and (c) abundant quartz grains of varying sizes. These moderate currents would tend to develop an overall aerobic depositional environment. The absence of chamosite, siderite, and pyrite and the occurrence of hematite suggest that organic matter was not present to any great extent (Castano and Garrels). However, the genesis of glauconite requires some association with organic matter and slightly reducing conditions; derivation of the glauconite from fecal pellets, with local reducing conditions maintained by bacteria, is suggested. The dominant elements of the macrofauna probably were worms, inasmuch as worm tubes occur in the uppermost lower quartzite member. The environment suggests excellent possibilities for the existence of mudeaters and scavengers (Lochman). Trilobites have been found in the Bliss Formation at other areas (Paige; Flower, 1953, 1955; Kottlowski et al.; Kelley and Silver). The majority of the fossils in the Bliss are perigenic shell fragments that very likely were brought in from nearby areas where life was more prolific. The glauconite probably originated from the excreta of vagrant organisms.

The ovoidal to spheroidal shapes of most glauconite grains in the Bliss Formation suggest transported fecal pellets. The moderate currents of the depositional environment, which deposited glauconite grains with quartz grains of equal sizes, suggest movement of the grains before their final incorporation into the sediments, Small "fragmental" glauconite grains in the more disturbed beds suggest local transportation of shattered authigenic grains. The glauconite appears to have been formed during the deposition of the Bliss, since there is no other feasible source. The compaction molding of glauconite around associated quartz grains often resulted in "squeezed" grains. The elongate, ovoidal pellets have not undergone sufficient transportation to attain spheroidal shapes. These features, compacted and elongated pellets, suggest that incorporation of the glauconite into the sediments was rapid and occurred before the glauconite had hardened.

Rare glauconite coatings of shell fragments and some small interstitial glauconite disseminations were noted and imply that some of this mineral was redistributed after deposition.

Diagenetic alteration of the Bliss Formation after burial is suggested by dickite, disseminated limonite, secondary quartz growth, and abundant recrystallized dolomite. No evidence was seen for replacement of the carbonate minerals, quartz, or feldspar grains by glauconite, although such replacements are mentioned by Kelley in other exposures of the Bliss Formation in New Mexico. In the Silver City area, carbonate minerals, limonite, silica, and hematite replaced glauconite.

The difference between the light- and dark-green varieties of glauconite seems to have no relationship to the conditions of deposition. The light-green grains are less abundant than the dark ones, and the light color appears to reflect incomplete alteration of the clay minerals in the fecal pellets. There are no essential differences among the glauconite grains in the different parts of the formation.

Judging from lithic similarities of the Bliss and parts of the Cambrian deposits in Montana and Wyoming (Lochman), the environments of deposition were similar. Sedimentation probably took place in a shallow area relatively far from shore, where arenaceous and carbonate sediments accumulated. The depth of water was usually less than 150 feet, and the carbonate minerals and fine-grained terrigenous sediments formed a soft sea floor. Variable currents agitated the sediments, and storms occasionally disturbed the bottom deposits to such an extent that intraclasts were formed; the beds were disturbed and mixed to remain as the chaotic beds of the Bliss Formation. Sedimentation was slow, as inferred from the relatively thin deposits of the Bliss Formation when compared to formations deposited during the Upper Cambrian and Lower Ordovician in other areas.

Time s of increased competence of bottom currents are indicated by the dominantly quartzose members and by the siliceous zones in the thin-bedded glauconite and upper glauconite members. The lower quartzite and middle quartzite members probably represent transgressive phases of the sea; the lower quartzite member was deposited over a clean Precambrian surface, and the middle quartzite member was very likely deposited after a regressive phase in latest Cambrian time. An increase in the power of the bottom currents probably produced the quartz-rich bands and laminations in the dominantly dolomitic rocks. The smaller average size of the quartz grains in the upper glauconite member suggests that the source of these sediments was farther away than it was during deposition of the thin-bedded glauconite member.

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