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CONTENTS

Paleoenvironments of the Colton Formation, Colton, Utah .... Allen R. Peterson 3

The Paleoenvironment of the Summerville Formation on the West Side of the San Rafael Swell, Emery County, Utah .... Robert Guy Stanton 37

Permian Reef Complex, Tunisia .... Norman D. Newell, J. Keith Rigby, Allan Driggs, Donald W. Boyd, Francis G. Stehli 75

Paleoenvironments of the Upper Entrada Sandstone and the Curtis Formation on the West Flank of the San Rafael Swell, Emery County, Utah .... Larry S. Smith 113

Paleoenvironment of the Carmel Formation at Sheep Creek Gap, Daggett County, Utah .... Ronald O. Lowrey 175

Geology of Billies Mountain Quadrangle, Utah County, Utah .... George E. Young 205

Publications and Maps of the Geology Department 281

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Daggett County, Utah .... Ronald O. Lowrey 175

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Paleoenvironment of the Carmel Formation at Sheep Creek Gap, Daggett County, Utah*

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ABSTRACT.—The Carmel Formation on the north slope of the Uinta Mountains at Sheep Creek Gap represents shallow marine and littoral deposition along the oscillating eastern margin of the Middle Jurassic Sundance Seaway.

A 100-meter-thick section in a roadcut at Sheep Creek Gap was studied in detail. The Carmel Formation, overlying the Navajo Sandstone and overlain by the Entrada Sandstone, can be divided into two lithologically distinct units of deposition.

The lower 20 meters consists of sandstone, gray shale, and fossiliferous micritic limestone which grades into ledge-forming oolitic limestone. Deposition occurred in a warm, shallow marine environment, judging from lithologies, fossils, and sedimentary structures present. Bivalves, gastropods, echinoderm fragments, foraminifera, bryozoans, and algae occur in the lowermost beds. Bedding is laminar with some minor cross-bedding. Deposits of storm surges and beds of oolites in the limestones suggest shallow deposition.

The upper 80 meters is a sequence of alternating reddish brown and light green siltstone and shale, with massive gypsum beds occurring in cycles associated with the reddish brown siltstone. Absence of fossils, presence of extensive disrupted bedding, evaporites, and small-scale cross-bedding suggest deposition along an arid, hypersaline, gently shelving, low energy coastline.

CONTENTS

Text .... page
Introduction and geologic setting 174
Location 174
Methods of study and nomenclature 176
Previous work 177
Acknowledgments 178
Lithologies 178
Clastic rocks 178
Siltstone 178
Light green siltstone 178
Reddish brown siltstone 179
Dolosiltstone 179
Shale 179
Medium to dark gray shale 179
Light grayish green shale 182
Sandstone 182
Buff to yellow sandstone 182
Glauconitic sandstone 182
Conglomerate 183
Carbonate rocks 183
Silty dolobiomicritic 183
Peloobiosparite 183
Peloosparite 183
Silty intradolobiosparite 183
Silty introdolooobiosparite 184
Evaporite deposition 184
Paleontology 184
Molluscan fauna 186
Echinoderm fragments 188
Foraminifera 188
Algae 188
Bryozoans 188
Ichnofossils 188
Paleoenvironment 190
Paleoclimate 190
Salinity 192
Wave and current energy 192
Lithologic associations 192
Sedimentary model 194
Subtidal environment 194
Low-energy subtidal environment 194
High-energy subtidal environment 194
Intertidal environment 195
Supratidal environment 195
Appendix (measured section) 197
References cited 202

Text-figures
1. Index map 176
2. Paleogeographic map 177
3. Stratigraphic column 180, 181

*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree of Master of Science, August 1975. J. Keith Rigby, thesis chairman.

4. Block diagram showing interpreted sedimentary environment 193

Plates
1. Outcrops in study area 175
2. Photomicrographs of carbonate lithologies 185
3. Photomicrographs of microfossils 187
4. Megafossils 189
5. Ichnofossils 191

INTRODUCTION AND GEOLOGIC SETTING

The Jurassic (Bajocian-Callovian) Carmel Formation is unusually well exposed at Sheep Creek Gap along Utah Highway 44 on the north flank of the Uinta Mountains. It offers a unique opportunity to observe lateral and vertical relationships of complexly interfingering shallow marine and continental deposits (Pl. 1, figs. 2-6). The Carmel Formation rests disconformably upon the eolian Navajo Sandstone and below the Entrada Sandstone. The entire thickness of the Carmel Formation is exposed in easily accessible roadcuts and eroded slopes.

Rapid changes of sedimentary facies (Text-fig. 3; Appendix) range from reworked eolain Navajo Sandstone at the base, through alternating medium gray marine shales and limestones, to repetitive marine-continental, light green shales, siltstones, and reddish brown siltstones associated with evaporitic deposition toward the top. Distinct lithologies occur in a rhythmic pattern and allow development of a three-dimensional depositonal model of sedimentation along a shallow, low energy, arid hypersaline coastline (Text-fig. 4).

Depositon of the Carmel Formation at Sheep Creek Gap documents a major transgressive and regressive phase of an epeiric sea (Text-figs. 2-4). Multiple oscilations of the shore position during the marine inundation are recorded as packages of reoccurring lithologies.

Location

The study area is located on the north slope of the Uinta Mountains, six miles south of Manila, at Sheep Creek Gap in Sec. 6, T. 2 N., R. 20 E., Daggett Co., Utah (Text-fig 1). The detailed section was measured in excellent ex-

EXPLANATION OF PLATE 1
OUTCROPS IN STUDY AREA

Fig. 1.—Alternating light green shale and siltstone of Unit 49 with nodular bedding and bimodal current directions.

Fig. 2.—Alternating light green shale and siltstone with reddish brown siltstone and gypsum (unit 66) in upper fourth of measured section.

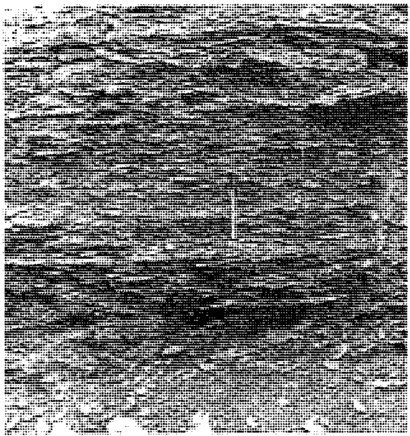
Fig. 3.—Light green siltstone (lower right) grading into reddish brown siltstone with indistinct bedding and massive gypsum (unit 53).

Fig. 4.—Reddish brown siltstone of unit 35 with bedding destroyed by gypsum heaving (lower right) grading up into resistant dolosiltstone. Upper left demonstrates cyclic nature of reddish brown and light green units in the middle of the measured section.

Fig. 5.—Lower third of Carmel Formation with medium gray shale grading into micritic in the lower part and oolitic limestone alternating with shale in the upper part.

Fig. 6.—Lowermost beds of the Carmel Formation above Navajo Sandstone which is exposed at lower right. Glauconitic sandstone in center of photograph grades vertically into alternating medium gray shale and micritic limestone.

PLATE 1



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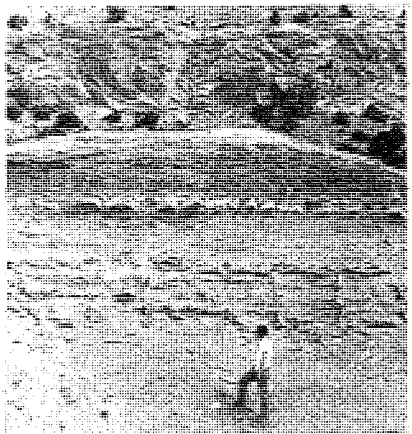

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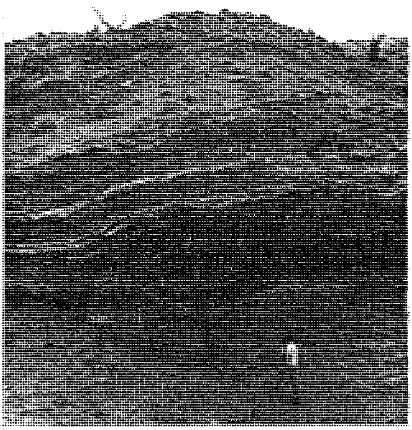

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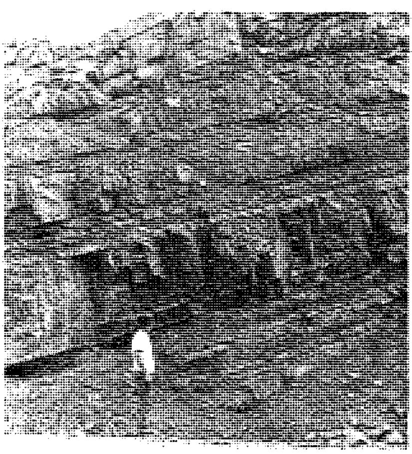

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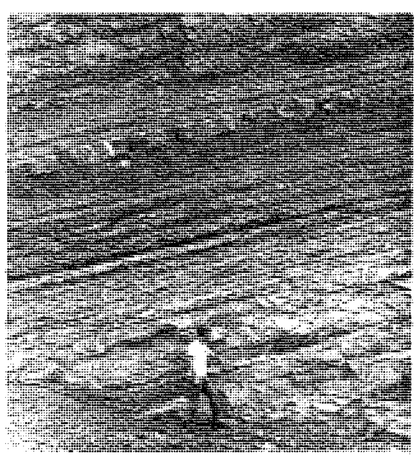

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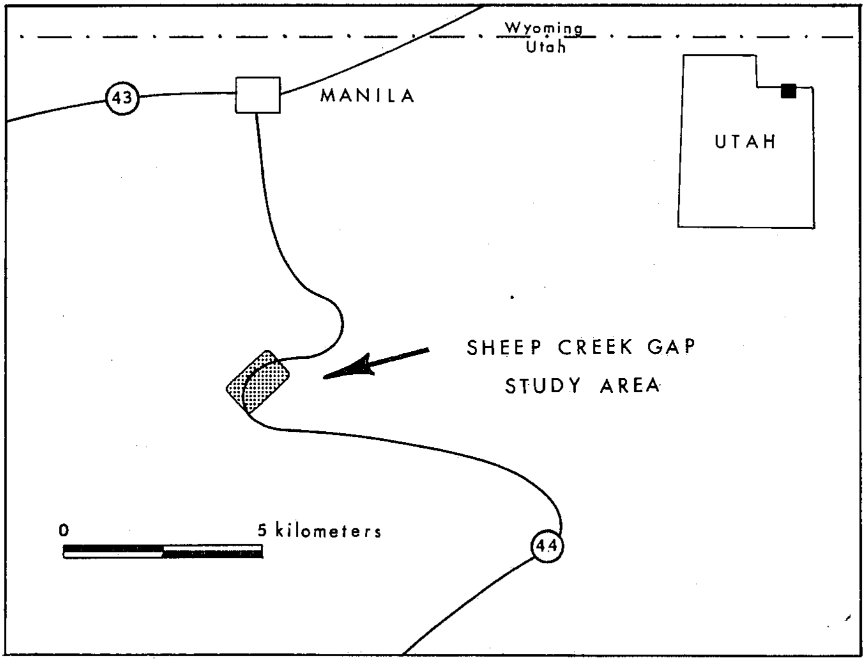


TEXT-FIGURE 1. —Index map.

posures in roadcuts along the east and west sides of Utah Highway 44. The entire Carmel Formation is exposed, from top to bottom, in Sheep Creek Gap (Text-fig. 3). The detailed section and the surrounding area are readily accessible by paved Utah State Highway 44 south from Manila or north from Vernal, Utah.

Methods of Study and Nomenclature

A 100-meter-thick section of the entire Carmel Formation was measured with a meter stick, described in detail, and sampled along roadcuts and places of good exposure. The section was subdivided into 72 units.

Thickness, lithology, composition, grain size, color, bedding, contact relations, bioclasts, and characterizing sedimentary structures were determined for each unit. Lithologic hand samples and bag samples of weathered or unconsolidated material were collected from each unit. Several samples were collected from some units, as lithologies varied.

Thin sections were made of samples of each major lithology and were examined under a binocular dissecting microscope for microsedimentary structures and microfauna. Solutions of alizarine red S and potassium ferricyanide (Friedman, 1959) were used to detect calcite and dolomite, respectively. Lithified samples were disaggregated in a dilute solution of Quaternary "O," washed on a 200-mesh screen, and examined under a dissecting microscope for microfossils and clastic grain characteristics.

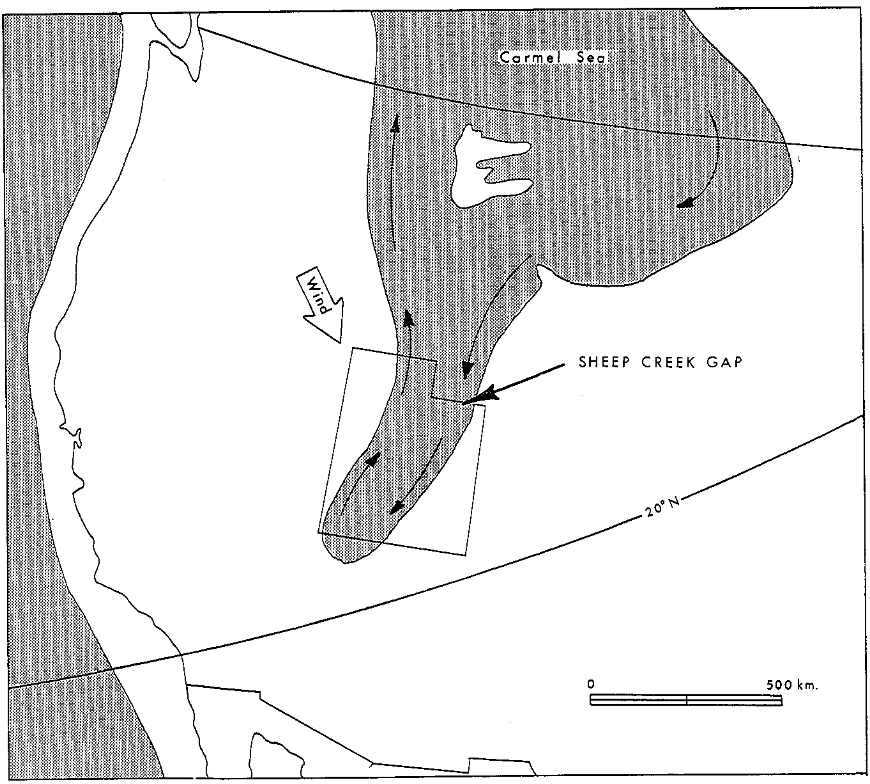
Paleocurrent directions were determined with a Brunton compass at each bed where definitive structures were observed. Trends were rotated back to original directions by removing present dip.

Descriptive grain-size terms are from the Modified Wentworth Grade Scale (Dunbar and Rodgers, 1957). Carbonate rocks were subdivided using the carbonate classification proposed by Folk (1959).

Previous Work

The Carmel Formation in the Flaming Gorge area has not been extensively studied. John Wesley Powell originally named the limestone member of the present-day Carmel Formation as the White Cliff Limestone of the Flaming Gorge Group. In 1926 the name Carmel Formation was first proposed at a joint conference of H. E. Gregory, R. C. Moore, James Gilluly, and J. B. Reeside, Jr. The name was first extended into the Uinta Mountains by Baker, Dane, and Reeside in 1936 according to Hansen (1965).

Ralph W. Imlay (1950) worked out a general time-stratigraphic subdivision of the Carmel and partially equivalent Twin Creek formations after studying many stratigraphic sections in the Uinta and Wasatch Mountains. Correlation of the Jurassic formations in the western interior of the United States, including the Carmel Formation, was done by Imlay (1952) on the basis of faunal distributions.



TEXT-FIGURE 2. —Paleogeographic map of the western United States during Middle Jurrassic showing regional wind direction and epeiric sea circulation pattern with postulated paleolatitude.

Hansen (1955) mapped the Flaming Gorge quadrangle and published it as part of the United States Geological Survey Geologic Quadrangle series. Ritzma (1958) compiled a geologic map of Daggett County.

Richards (1958) wrote an article dealing with cyclic deposition in the Carmel Formation and briefly discussed the section at Sheep Creek Gap.

Wallace R. Hansen (1965) published sections measured in the area and correlated various stratigraphic units along the north flank of the Uinta Mountains. His work is the most extensive study of the area to date.

Acknowledgments

The author wishes to acknowledge the assistance of Dr. J. K. Rigby who gave freely of his time, talents and encouragement while serving as thesis committee chairman. Dr. W. K. Hamblin offered helpful comments and served as a committee member. Thanks are also extended to Dr. J. L. Baer for his helpful advice. Dr. N. F. Sohl identified gastropods. Possible ostracodes and algae were examined by Dr. I. E. Sohn and Dr. John L. Wray, respectively.

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Financial assistance was provided by a Mountain Fuel Supply Company Graduate Fellowship.

LITHOLOGIES

Clastic Rocks

In the Carmel Formation at Sheep Creek Gap, clastic rocks represent 90 percent of all rocks deposited. Reddish brown and light green siltstone is dominant; light grayish green and medium gray shale is abundant with sandstone and conglomerate occurring at the base of the Carmel Formation.

Siltstone

Siltstone is the most common lithology in the Carmel Formation, making up nearly 45 percent of the total thickness at Sheep Creek Gap (Text-fig. 3; Appendix). Two distinct kinds of siltstone units are recognized; light green and reddish brown. A third variety, dolosiltstone, occurs where light green and reddish brown siltstones have been locally dolomitized by seepage refluxion.

Light Green Siltstone.—Light green siltstone is found in the middle and upper part of the formation (Text-fig. 3; Appendix). It is thin- to thin-laminar-bedded and in some units is globular weathering. The siltstone is poorly indurated to nonlithified and is a slope former. Light green siltstone is most often found alternating with the light grayish green shale and below the reddish brown siltstone in a rhythmic pattern (Pl. 1, figs. 2, 4).

Equant, angular to well-rounded quartz grains make up 60 to 70 percent of the total rock. Potassium feldspar and amphibole grains are present, but in negligible amounts. Clay minerals make up the matrix. Limonite pseudomorphs are found as yellow specks in the light green rock.

Units 47, 49, 50, and 51 are cross-bedded (Pl. 1, fig. 1), and most of these also show evidence of intensive burrowing. Both fodinichnid and domichnid trace fossils are found, but other fossils are absent.

Reddish Brown Siltstone.—Reddish brown siltstone is the most abundant lithology in the Carmel Formation at Sheep Creek Gap, making up 25 percent of the total thickness (Text-fig. 3; Appendix). Bedding is indistinct to absent in most units. The reddish brown siltstone is poorly indurated and often has a soil-like appearance. Many units show evidence of root impressions or intense bioturbation which has destroyed bedding (Pl. 5, fig. 4). Some units are globular weathering. Both calcareous and noncalcareous varieties occur.

Equant, angular to subrounded quartz grains are a major constituent, making up 30 to 40 percent of the total clasts. Oxidized clay constitutes 60 percent of the rock volume. Mica flakes are present but are rare.

Reddish brown siltstone is associated with the grayish green shale, light green siltstone, and gypsum in repetitive occurrences throughout the upper two-thirds of the measured section (Text-fig. 3; Pl. 1, figs. 2, 4). Abundance of reddish brown siltstone increases upward in the section, responding to a westward or northwestward shift in normal marine deposition as the Carmel Sea retreated (Text-fig. 4).

Fossils are totally absent; even ichnofossils were not observed.

Dolosiltstone.—Light gray to reddish brown, well-indurated, ledge forming dolosiltstone (Text-fig. 3; Pl. 1, fig. 4; Appendix) occurs in units 37, 38, 39, 40, and 43. Stratigraphically, these occur above the limestone and medium gray shale and below the lowest gypsum unit. Silt-sized quartz grains surrounded by dolomite cement dominate; dolomitization appears to have replaced calcite as the cementing agent. Limonite pseudomorphs after pyrite occur in unit 39, suggesting a reducing environment.

Fossils, other than ichnofossils, are absent in the dolosiltstone. Evidence of burrowing organisms is found in units 38 and 39.

Hyrocarbon traces in unit 39 are seen in thin section where dolomitization has enhanced permeability.

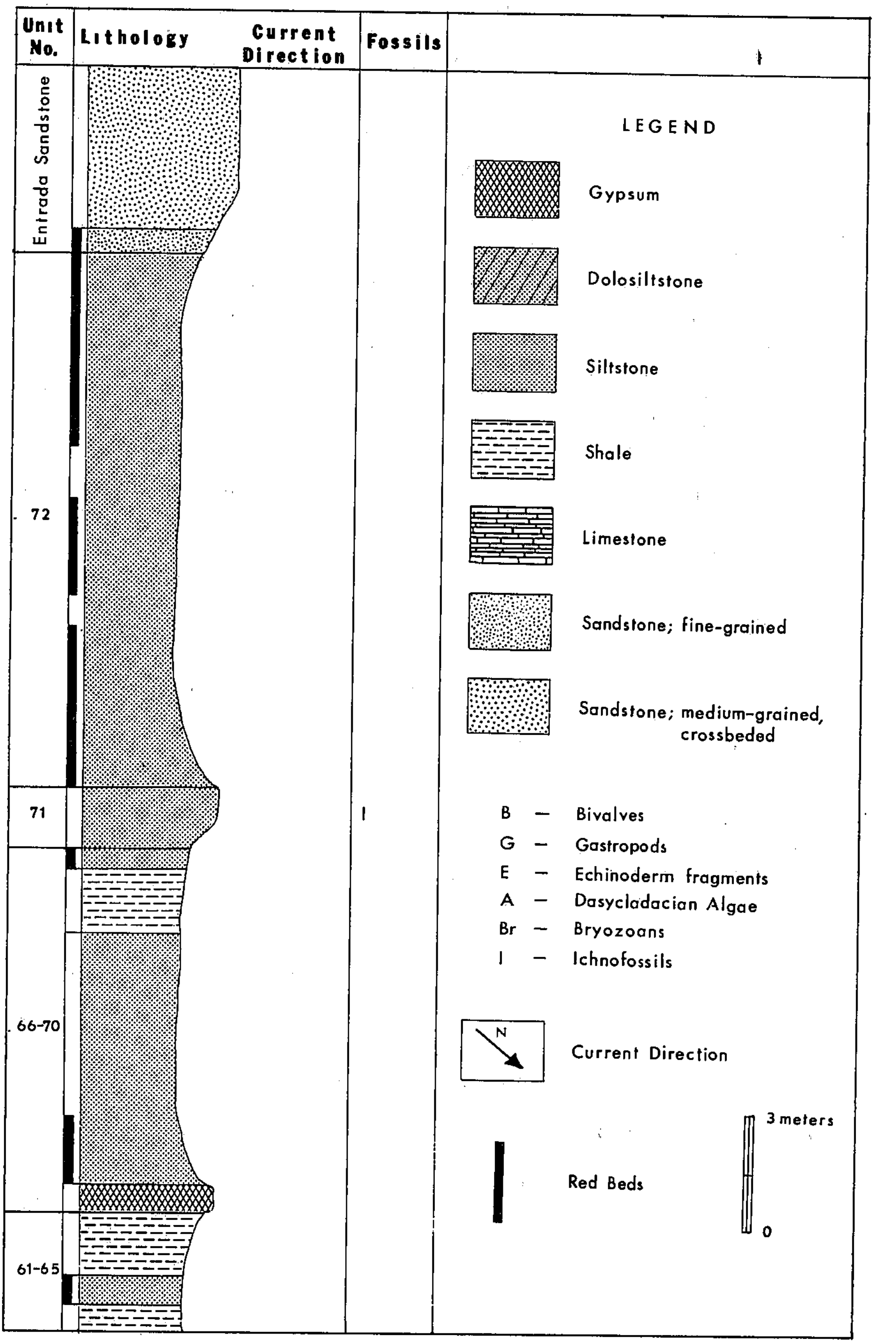
Shale

Shale is relatively abundant in the Carmel Formation, constituting approximately 25 percent of the measured section at Sheep Creek Gap. There are essentially two distinct lithologic and stratigraphic varieties.

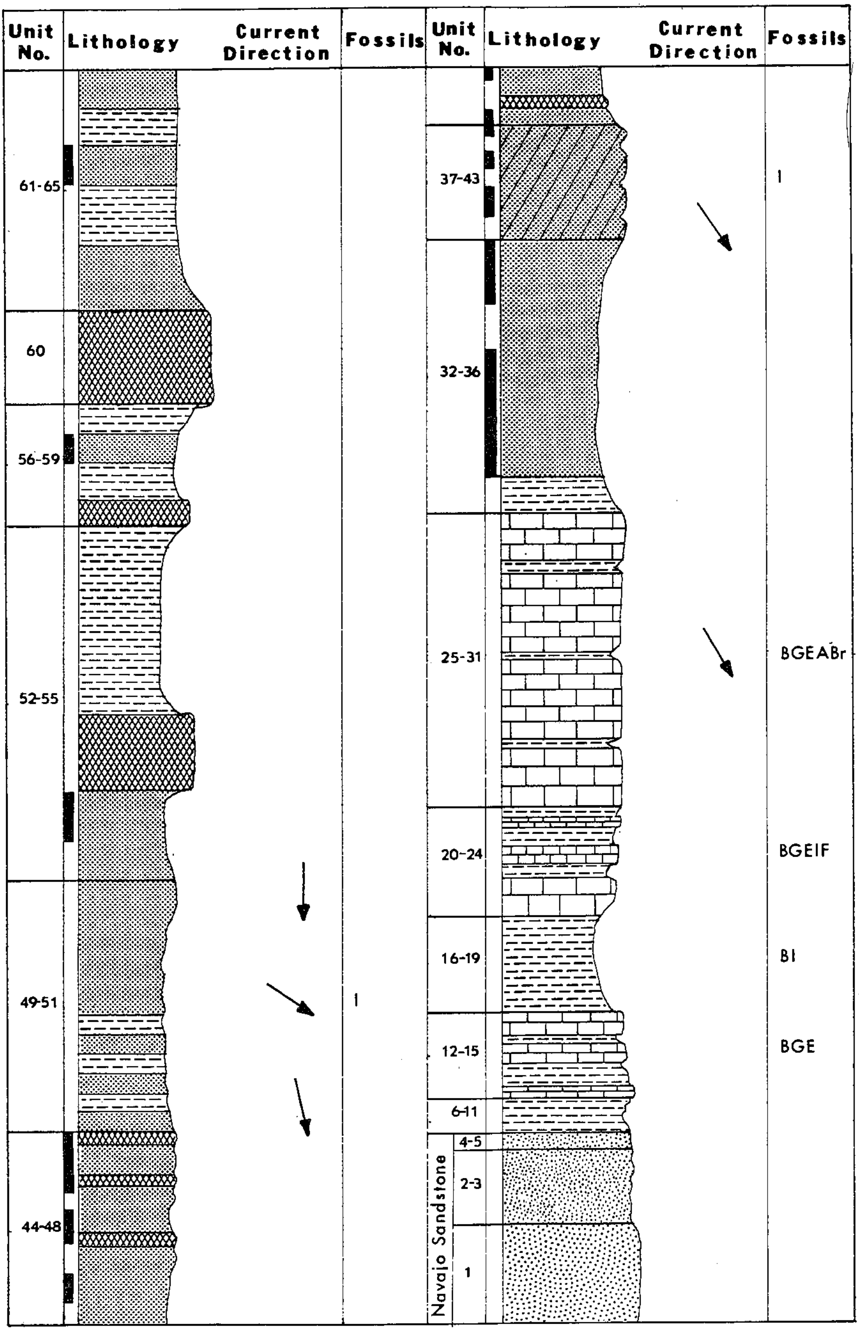
Medium to Dark Gray Shale.—Medium to dark gray shale occurs commonly in the lower third of the formation (Text-fig. 3; Appendix) as bedded units or as shale partings in limestone. Medium to dark gray shale occurs exclusively in the lower third of the section in a repetitive association with limestone units (Pl. 1, figs. 5, 6). The shale is a slope former, weathers to a light gray, and often exhibits a globular or spheroidal weathering character. Shale varies from calcareous to noncalcareous and shows laminar to thin laminar bedding and, in some instances, a varved-like laminated character suggesting variations in rate of deposition.

Microscopically, it consists almost completely of clay minerals with equant, subrounded quartz grains as a minor component. Biotite and muscovite flakes are present. Amphibole grains occur but are rare. Pyrite cubes and limonite pseudomorphs replacing pyrite are found in some units, suggesting a reducing environment.

Fossils are rare in medium to dark gray shale units. Trace fossils, i.e., burrows, are abundant in units 15, 16, and 17. In unit 18 the shale becomes



TEXT-FIGURE 3a.—Stratigraphic section.



3b.—Stratigraphic section (continued).

very calcareous and could possibly be called a marlstone. The bivalve *Camptonectes* is relatively abundant as shell fragments in unit 18.

Light Grayish Green Shale.—Light grayish green shale occurs in the middle and upper parts of the formation (Text-fig. 3; Appendix). It is a slope former throughout the section and is thin-laminar-bedded, although in some instances it is not lithified. Both calcareous and noncalcareous varieties are found. Yellow iron stains from weathering and secondary gypsum are often found along fractures.

Microscopically, the shale is dominantly clay minerals, but equant, angular to subangular quartz grains compose 10 to 15 percent of the total. Muscovite and biotite flakes occur but are rare. Limonite pseudomorphs after pyrite also occur and suggest a reducing environment.

Stratigraphically, grayish green shale is associated with light green siltstone, reddish brown siltstone, and gypsum in an alternating pattern. The shale generally occurs below the reddish brown siltstone and alternates with light green siltstone (Pl. 1, fig. 1).

Light grayish green shale units are devoid of fossils, including recognizable trace fossils, although nonlithified units may be bioturbated and structures obscured by weathering. Current-generated sedimentary structures were not found in the shale.

Sandstone

Sandstone occurs only at the base of the Carmel Formation and is a result of reworking of the uppermost underlying Navajo Sandstone (Pl. 1, fig. 6; Text-fig. 3). Sandstone is present only in units 1 to 5 and in unit 7. Buff to yellow quartz sandstone grades vertically into a glauconitic sandstone.

Buff to Yellow Sandstone.—Buff to yellow sandstone is found in the Carmel Formation in units 2 and 3 (Text-fig. 3; Appendix). The sandstone is composed of over 95 percent equant, fine- to medium-grained, subangular to rounded, frosted quartz grains which are loosely cemented with chalcedony. The remaining 5 percent is a clay matrix between the quartz grains. The sandstone is moderately well sorted. The reworked sediments in units 2 and 3 are friable and less indurated than the underlying Navajo Sandstone of unit 1. Pyrite is found as small particles between grains. Medium gray patches are found throughout the sandstone and appear to be areas of unoxidized pyrite surrounded by yellow buff areas where pyrite has been oxidized to limonite. Glauconite occurs in unit 3 and becomes more abundant in successively higher units, as do other clay minerals.

Cross-bedding is absent to minor in the reworked sandstone of units 2 and 3. Evidence of organic activity is lacking in all these sandstone beds.

Glauconitic Sandstone.—Glauconitic sandstone occurs in units 4, 5, and 7. The medium green, extremely friable sandstone contains fine- to medium-grained, equant, subangular to rounded quartz grains which make up 70 percent of all particles. The remaining 30 percent of the volume is glauconite and clay minerals. Glauconite in the Carmel Formation appears to be authogenic, as initial deposits of a transgressive sea.

Pyrite and limonite are abundant in the glauconitic sandstone. Limonite staining accentuates the stratification in the thinly bedded units.

Cross-bedding is minor, except in unit 7 where the sandstone occurs as small lenticular channel-shaped bodies 20 cm in length. Fossils are absent.

Conglomerate

Conglomerate is rare in the Carmel Formation, occurring only in unit 6, which is a 2 to 4 cm thick, unlithified bed of chert, quartzite, and clay pebbles. Fragments are up to 4 cm long and are surrounded by very fine, equant, angular to subrounded quartz grains in a calcareous, glauconitic clay matrix. Intraclast pebbles of clay are present, indicating a local source for some fragments. The pebbles are subangular to subrounded and poorly sorted. Some pebbles are flattened but show no preferred orientation.

Carbonate Rocks

Although carbonate rocks are not a major part of the Carmel Formation at Sheep Creek Gap, they are important from a paleoenvironmental standpoint. They occur as thin beds, exclusively in the lower third of the measured section, in a repetitive association with medium gray shale (Text-fig. 3; Pl. 1, figs. 5, 6; Appendix). Five different carbonate lithologies occur: (1) silty dolobiomicrite, (2) peloobiosparite, (3) peloosparite, (4) silty intradolobiosparite, and (5) silty intradolooobiosparite.

Silty Dolobiomicrite.—Light gray to brown, well-indurated silty dolobiomicrite (Pl. 2, figs. 1, 2) occurs as thin beds up to 40 cm thick in units 12, 14, 15, 23, and 24. Bivalve fragments, high trochospiral gastropods, and echinoderm plates and spines are found in moderate abundance in the microcrystalline matrix. Quartz grains up to 0.3 mm in diameter are locally concentrated and represent possible storm surges in the micrite environment.

Dolomitization occurs in areas of high porosity and permeability associated with layers of high silt content (Pl. 2, figs. 1, 2). Areas dominated by microcrystalline calcite are not dolomitized. Some allochemical constituents demonstrate partial to complete replacement by dolomite.

Peloobiosparite.—Light to medium brown, well-indurated peloobiosparite (Pl. 2, fig. 3) occurs as beds ranging from 10 to 170 cm thick in units 25, 26, 27, 29, and 30. Oolites (Pl. 3, figs. 2, 3) averaging 0.5 mm across are the most abundant allochemical constituents. Dasycladacian algal fragments (Pl. 3, fig. 3), 0.1 to 0.5 mm in diameter, are also abundant. Fragments of bivalves, high trochospiral gastropods, echinoderm plates and spines, and crinoid segments are found in the sparry calcite matrix. Single fragments of cyclostome (?) bryozoan colonies were found in units 25 and 30 (Pl. 3, fig. 1). Silt-sized quartz grains are present but not as a major constituent. Hydrocarbon traces are seen in outcrop along fractures in unit 26.

Peloosparite.—Light gray to medium brown, well-indurated peloosparite (Pl. 2, fig. 4) occurs in units 28 and 31. Unit 31 is 250 cm thick and represents the thickest carbonate unit in the measured section. Oolites are the most abundant of the allochemical constituents and average 0.3 mm in diameter. Pellets, originating either as coated grains or fecal material, are abundant in the sparry calcite matrix. Dasycladacian algal fragments (Pl. 3, fig. 3) are abundant in this lithology. Other identifiable fossils are rare, although occasional bivalve fragments are found. Silt-sized quartz grains occur sporadically. Hydrocarbon traces are seen along fractures in outcrops.

Silty Intradolobiosparite.—Medium gray to reddish brown silty intradolobiosparite (Pl. 2, fig. 5) occurs as 5 to 10 cm thick beds in the medium gray shale of unit 20. This lithology is very fossiliferous and has a sparry calcite matrix. Intraclasts of microcrystalline calcite, up to 2.5 mm across, are found but lack any preferred orientation. Bivalve fragments are the most abundant allochemical constituent. High trochospiral gastropods, echinoderm spines (Pl. 3, fig. 5) and plates (Pl. 3, fig. 4), *Pentacrinus* segments (Pl. 3, fig. 6), and abundant low trochospiral to pseudoplanispiral foraminifera are seen in thin section (Pl. 3, fig. 2). Silt-sized quartz grains are abundant throughout the sparry matrix. Hydrocarbon traces surround allochemical constituents in thin section.

This carbonate lithology is predominantly dolomitized. Areas dominated by sparry calcite are subject to dolomitization. Allochemical constituents, with the exception of some partially replaced bivalve fragments, are not dolomitized.

Silty Intradolooobiosparite.—Light gray silty intradolooobiosparite (Pl. 2, fig. 6) is found in unit 22. Oolites and fossils are abundant in a sparry calcite matrix. Fossil constituents include bivalves, high trochospiral gastropods, echinoderm spines and plates, and low trochospiral to pseudoplanispiral foraminifera (Pl. 3, fig. 2). Intraclasts of microcrystalline calcite up to 0.5 mm across are found in the unit but have no preferred orientation. Silt-sized quartz grains occur abundantly throughout the lithology. Hydrocarbon traces occur along fractures in outcrop.

Dolomitization in this lithology assumes the same character as in the silty intradolobiosparite, in that areas of sparry calcite have been replaced by dolomite, leaving most allochemical constituents not dolomitized.

Evaporite Deposition

Evaporite deposits in the Carmel Formation occur as discontinuous beds of massive gypsum in the upper two-thirds of the measured section (Text-figs. 3, 4; Pl. 1, fig. 3). Primary gypsum dominates in units 48, 53, 56, 60, and 66. Massive, light green, orange to white gypsum beds range from 10 to 90 cm thick and occur in a repetitive association with light grayish green shale, siltstone, and reddish brown siltstone (Text-fig. 3). Each gypsum-dominated unit consists of several gypsum beds, each separated by shale and siltstone. Gypsum heaving has produced local variations of unit thickness throughout the continental portion of the Carmel Formation.

PALEONTOLOGY

The lower third of the Carmel Formation at Sheep Creek Gap contains relatively abundant, but poorly preserved, marine fossils, primarily in the

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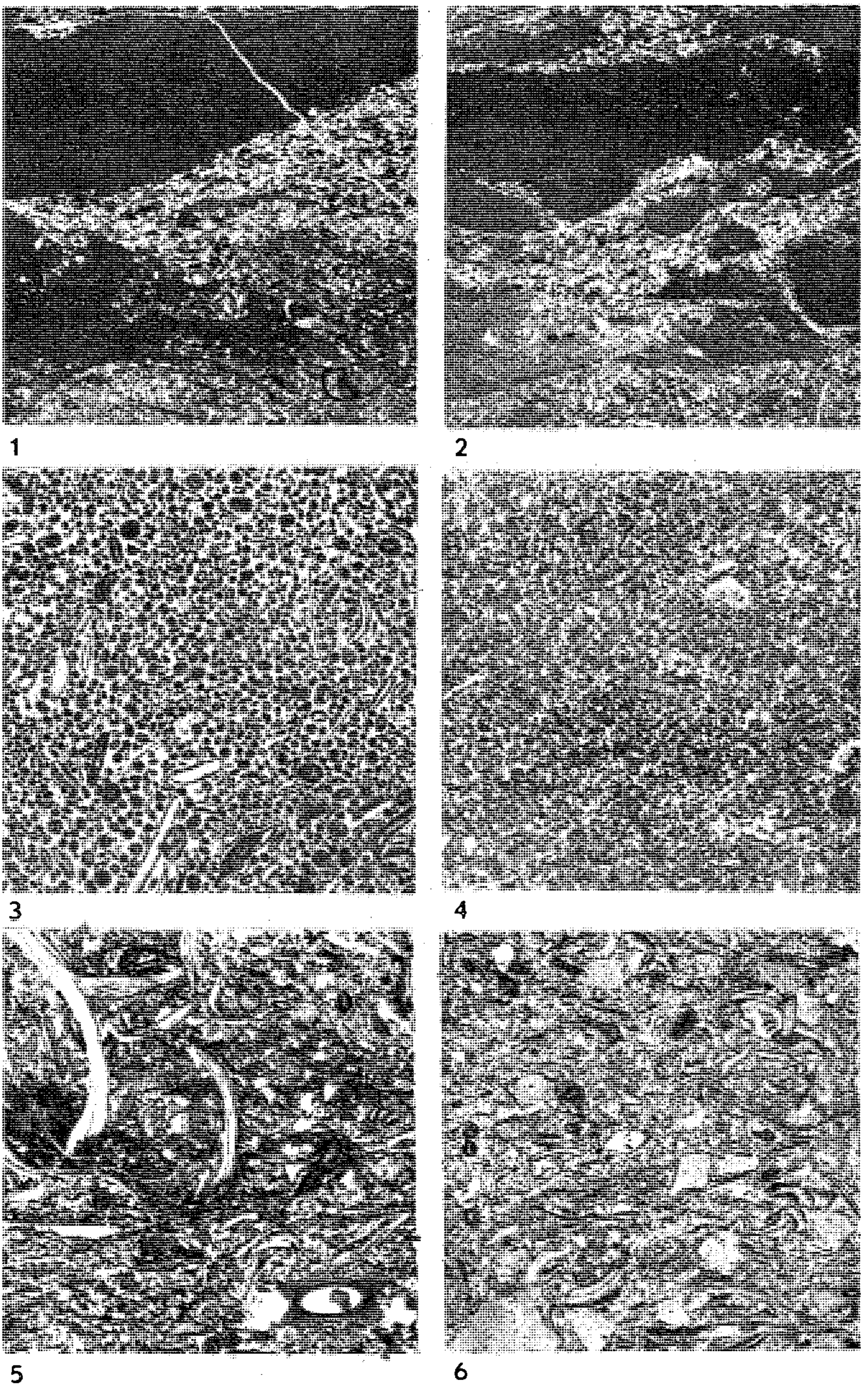
EXPLANATION OF PLATE 2
PHOTOMICROGRAPHS OF CARBONATE LITHOLOGIES
(All photographs X5)

Fig. 1.—Silty dolobiomicrite of unit 14 with silt surge.
Fig. 2.—Silty dolobiomicrite of unit 15, silt surge disrupted by burrowing organisms.
Fig. 3.—Peloobiosparite of unit 25.
Fig. 4.—Peloosparite of unit 28.
Fig. 5.—Silty intradolobiosparite of unit 20.
Fig. 6.—Silty intradolooobiosparite of unit 22.

PLATE 2



carbonate rocks (Pl. 4, figs. 1-4). Fossils found include mollusks, echinoderm fragments, foraminifera, algae, and bryozoans.

Ralph W. Imlay (Hansen, 1964, p. 78) identified the following fossils from the lowermost oolitic limestone beds at Sheep Creek Gap (Mesozoic loc. 21626).

Placunopsis sp.
Camptonectes platessiformis White
Trigonia conradi Meek and Hayden
Trigonia sp.
Ostrea strigilecula White
Lyosoma cf. *L. phaseolaris* (White)

The following fossils are those collected during the present study from carbonate units in the lower third of the Carmel Formation. Gastropods were identified by Norman F. Sohl.

Rhabdocolpus viriosus Sohl
Cylindrobullina (?) sp.
Procerithium (?) sp.
Neritina (?) sp.
Camptonectes stygius White
Camptonectes platessiformes White
Ostera Liostrea strigilecula White
Myophorella (*Promyophorella*) *montanaensis* (Meek)
Echinoderm spines, spine bases, and plates
Pentacrinus columnals
Dasycladacian algae (?)
Arenaceous, pseudoplanispiral foraminifera
Cyclostome bryozoans (?)

Molluscan Fauna

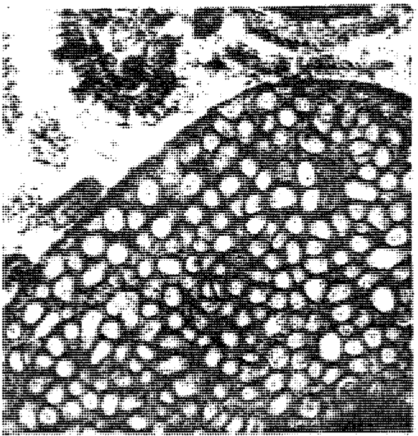
Mollusks, including bivalves and gastropods, constitute the majority of all fossils found in the studied section (Pl. 4, figs. 1-4), and most show poor preservation. Whole valves are not abundant. Valve fragments and small high trochospiral gastropods shells (Pl. 4, fig. 4) occur abundantly in all carbonate lithologies, except peloosparite units. In some instances, mollusks and molluscan fragments have served as nuclei for oolite formation (Pl. 3, fig. 2).

EXPLANATION OF PLATE 3
PHOTOMICROGRAPHS OF MICROFOSSILS

(All photographs X50)

Fig. 1.—Cyclostome (?) bryozoan fragment.
Fig. 2.—Low trochospiral to pseudoplanispiral foraminifera associated with oolites.
Fig. 3.—Dasycladacian algae (upper left) with oolites in lower right.
Fig. 4.—Echinoderm plate.
Fig. 5.—Transverse section of echinoid spine (?).
Fig. 6.—*Pentacrinus* fragment.

PLATE 3



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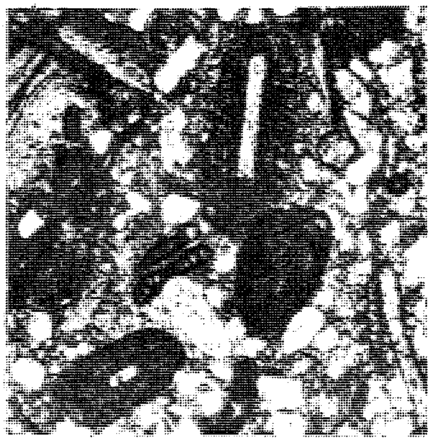

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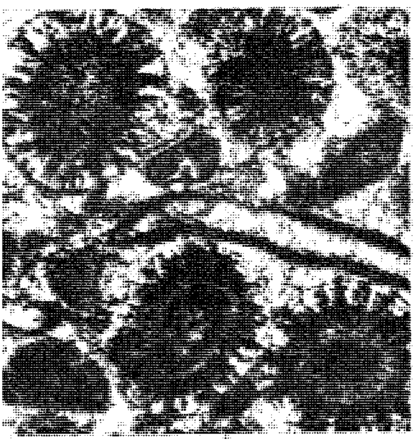

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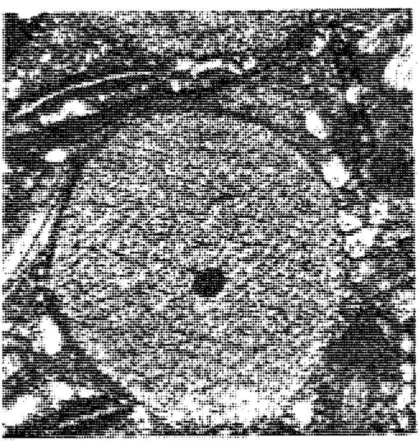

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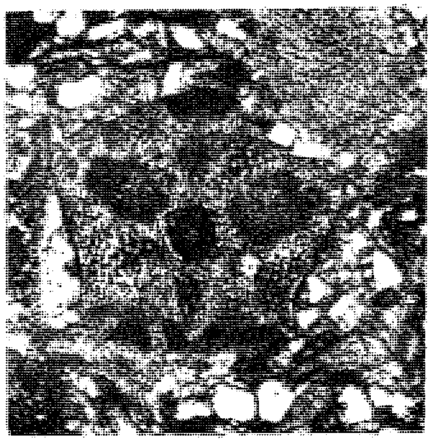

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Echinoderm Fragments

Echinoid spines, spine bases, and plates are found in most carbonate lithologies (Pl. 3, figs. 4, 5). *Pentacrinus* columnals are found in unit 20 (Pl. 3, fig. 6). Even small fragments of echinoderms (Pl. 3, fig. 4) were easily identified in thin sections because of distinctive texture.

Foraminifera

Arenaceous, low trochospiral to pseudoplanispiral foraminifera, 0.4 mm long, occur in the silty intradolobiosparite of unit 20 and the silty intradolooobiosparite of unit 22. Foraminiferal tests are well preserved and chambers are easily recognized in thin section (Pl. 3, fig. 2) but generic identification was not made.

Algae

Dasycladacian algal material (?) (Pl. 3, fig. 3) forms hollow, disarticulated spherical structures, 0.1 to 0.5 mm in diameter, with radiating, fibrous fringing edges when seen in cross section. These differ structurally, as well as genetically, from oolites which demonstrate concentric carbonate layers around a nucleus. The dasycladacian fragments lack concentric layering and have hollow centers. These algae are minor constituents, less than 2 percent by volume of the peloobiosparite and peloosparite units (Pl. 2, figs. 3, 4).

Bryozoans

Isolated cyclostome (?) bryozoan fragments, up to 2 mm across, occur in peloobiosparite units (Pl. 3, fig. 1). Neither complete colonies nor encrusting forms were found.

Ichnofossils

Ichnofossils (Pl. 5, figs. 1-6) occur only in light grayish green siltstone, dolosiltstone, and medium gray shale units and represent the only evidence of organism activity during deposition of clastic units. Ichnofossils are classified according to Seilacher's (1964) terminology as fodinichnia (feeding burrows by hemisessile deposit feeders), pascichnia (winding feeding trails), and repichnia (evidence of direct locomotion).

Fodinichnid burrows (Pl. 5, fig. 5) occur in the light grayish green siltstone of units 49 to 51. The burrows are 1 to 2 mm across and perpendicular to bedding planes. Other authors (Perkins and Stewart, 1971, p. 78) classified similar burrows as *Chondrites.*

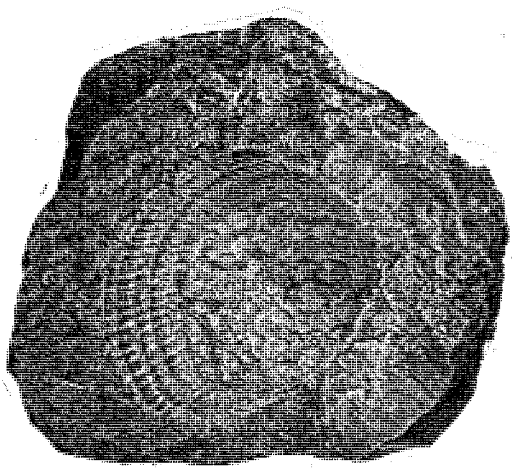
EXPLANATION OF PLATE 4
MEGAFOSSILS

(All natural size except where noted)

Fig. 1.—*Ostrea strigilecula* White, unit 22.
Fig. 2.—*Camptonectes platessiformes* White, unit 22.
Fig. 3.—*Myophorella* (*Promyophorella*) *montanaensis* (Meek), float from approximately unit 12 to 14.
Fig. 4.—High trochospiral gastropods, bivalve fragments, echinoid spines and plates; *Pentacrinus* columnal; unit 22, X2.5.

PLATE 4

1



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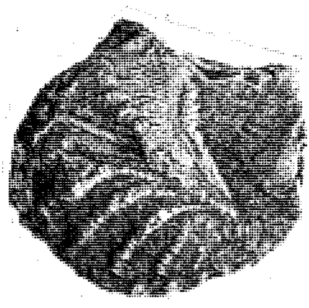

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Pascichnid burrows (Pl. 5, figs. 1-3), oriented parallel and oblique to bedding planes, are represented in the medium gray shale of units 16, 17, 19, and 20, as well as in the light grayish green siltstone of units 49 to 51. Those occurring in the medium gray shale show positive and negative epirelief, range from 1 to 3 mm in diameter, and are recognized by their having a lighter gray to yellow color in the medium gray shale. The pascichnid trace fossils found in siltstone units (Pl. 5, figs. 1-3) exhibit positive epirelief and are gently meandering features, 1 to 2 mm across and 1 cm long. These are similar to the ichnogenus *Heliminthopsis* (Haentzschel, 1962. p. W200).

Repichnid trace fossils (Pl. 5, figs. 3-6) occur in light grayish green siltstone of units 49 to 51. These fossils represent the largest ichnofossils found in the measured section and are 0.2 to 1.0 cm in diameter. These straight, cylindrical, positive-epirelief to full-relief structures are parallel to bedding planes and are abundant. Burrows up to 3 cm long were found.

PALEOENVIRONMENT

Rocks of the Bajocian-Callovian Carmel Formation represent sedimentation along the shallow, low-energy, fluctuating margin of an epeiric sea. Factors involved in interpreting the paleodepositional environment for the Carmel Formation include climate, salinity, current and wave direction and intensity, as well as repetitive vertical and lateral lithologic association of marine and continental deposits.

Paleoclimate

Climate throughout deposition of the Carmel Formation was probably of uniform, warm temperatures year-round, extremely low precipitation, with wind currents coming from present north and northwest. Certain lithologies are climatic indicators. Red beds associated with evaporites may be indicative of a warm arid climate (Walker, 1967, p. 353). Calcium carbonate precipitation in the lower third of the measured section also required fairly warm temperatures. Presence of gypsum indicates that temperatures were fairly high and rainfall low, since evaporation exceeded precipitation. Evidence of through-flowing streams is lacking in the Carmel Formation.

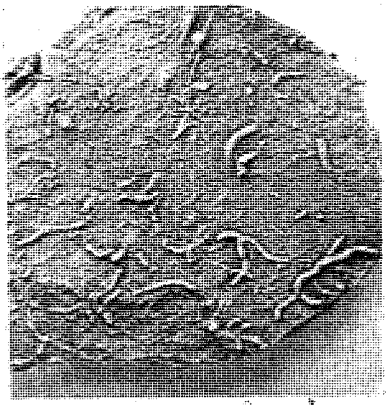
Interpretation of paleolatitude position of the studied Carmel Formation in Utah during the Middle Jurassic varies among authors, but the area was probably between 20 and 30 degrees north latitude (Text-fig. 2; Stanley, Jordan, and Dott, 1971, p. 13). Paleowind directions according to Dott and Batten (1971, p. 360-67) were toward the south and southeast (Text-fig. 2). At this latitude, temperatures would have been uniform year-round. In

EXPLANATION OF PLATE 5
ICHNOFOSSILS

(All figures are X1.5 and from units 49 to 51)

Figs. 1-2.—Pascichnid, *Heliminthopsis*-like burrows.
Fig. 3.—Pascichnid and repichnid burrows.
Fig. 4.—Repichnid burrow.
Fig. 5.—Fodinichnid, *Chondrites-like* burrows and large repichnid burrow.
Fig. 6.—Repichnid burrows.

PLATE 5



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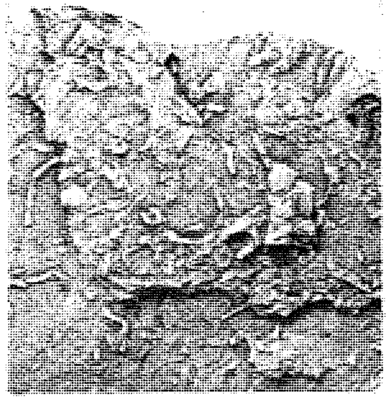

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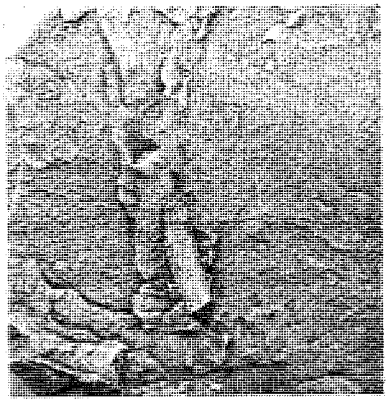

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many respects the paleoclimate of the Carmel Formation is similar to that of the present-day Persian Gulf (Iling et al., 1965, p. 90), which lies at the same latitude.

Salinity

Lithologies and fossil distribution indicate that normal marine through hypersaline conditions existed during deposition of the Carmel Formation. Limestone beds in the lower third of the section at Sheep Creek Gap contain bivalves, gastropods, bryozoans, and echinoderms many of which are stenohaline organisms (Heckel, 1972, p. 234). Only trace fossils are found in gray shale and light green siltstone, which are interpreted to represent environments which were beyond salinity tolerances for most organisms. Gypsum and dolosiltstone associated with reddish brown siltstone represent obvious hypersaline conditions.

Hypersalinity may have been related to restricted circulation near the periphery of the seaway and interaction with the warm arid climate.

Wave and Current Energy

Rocks deposited in the study area during the presence of the Carmel Sea demonstrate low current and wave energy. Channels were not observed cutting across presumably mudflat sediments. Small-scale cross-bedding occurs in light green siltstone and dolosiltstone units (Pl. 1, fig. 1) but is not common. Ripple marks and cross-beds occur in oolitic limestone units 25 and 31, respectively. Many indications of current influence may have been lost in chaotic bedding produced by gypsum heaving in units where interstratal gypsum was present (Pl. 1, fig. 4).

Structures produced by currents show paleocurrents to have been from north-northwest to south-southeast (Text-fig. 2). These directions correspond to prevailing wind directions at time of deposition, as well as the rotational effect of the earth or Coriolis phenomenon (Petersen, 1957, p. 425). Some evidence of current direction bimodality is seen in units 49 to 51 (Pl. 1, fig. 1).

Lithologic Associations

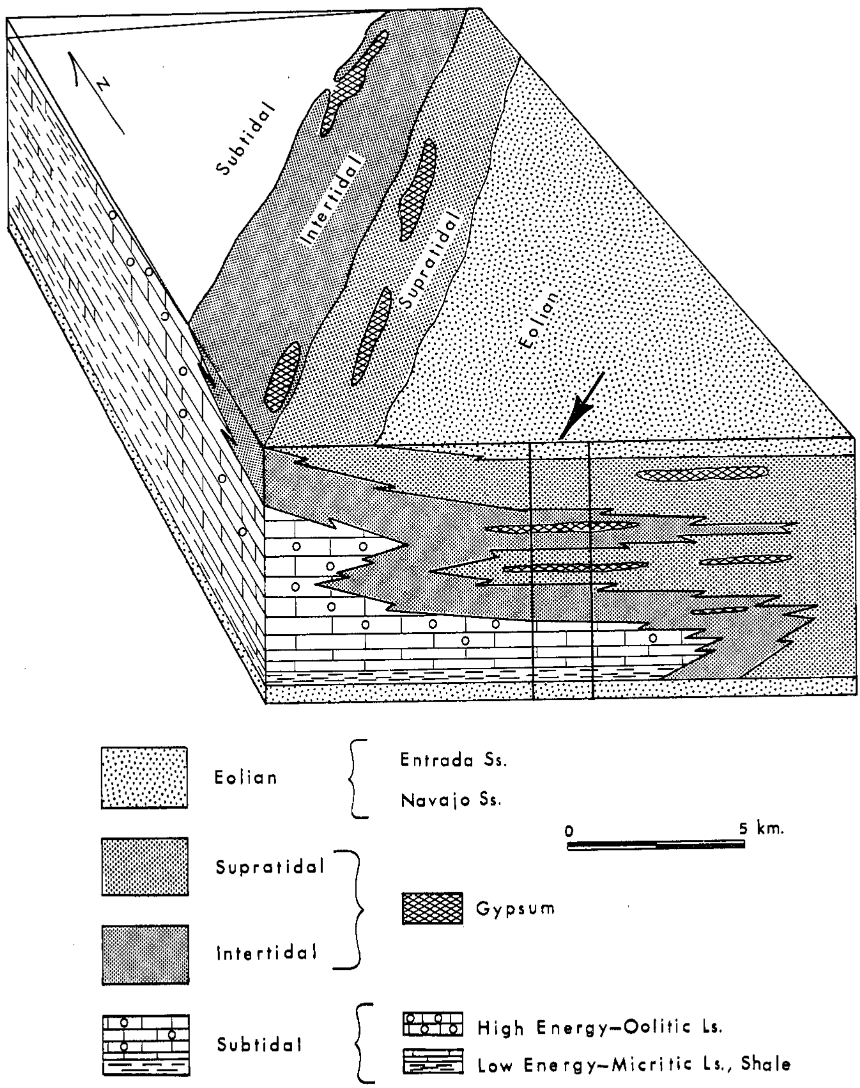
Environmentally, rocks of the Carmel Formation represent repetitive vertical and lateral sequences, ranging from open marine and oolitic shoal sedimentation to subaerially exposed mudflat and associated evaporite deposits (Text-fig. 4).

Open marine, gray shale grades laterally into micritic limestones which in turn grade into clean, oolitic limestones nearer shore. Oolitic limestones grade laterally through marine-continental light green siltstone and shale to reddish brown siltstone, dolosiltstone, and gypsum. Each lithology occurs laterally and vertically in a predictable sequence representing variable contemporaneous environments of deposition (Text-fig. 4).

Intermittently subaerially exposed mudflat sediments were probably submerged by occasional high tides. Wind may also have played a major role in driving water onto the mudflat. Segerstrale (1957, p. 767) observed that irregular oscillations of water level for a duration of hours to weeks and months in the Baltic Sea have varied by wind-driven surges by as much as 1.3 meters. This phenomena would have considerable influence on an extremely low gradiant coastline such as that of the Carmel Seaway.

The repetitive or rhythmic nature of the Carmel Formation is shown by recurrence of most lithologies in predictable sequence, especially alternating gray shale and limestone and alternating light green and reddish brown sediments with gypsum (Text-fig. 4; Pl. 1, figs. 1-6).

Cause of cyclic sedimentation is not known, although several possibilties exist. Richards (1958, p. 45) states that climatic changes related to the



TEXT-FIGURE 4.—Block diagram showing lateral and vertical relationships of rock units and interpreted environments of deposition. Arrow indicates Sheep Creek Gap study section.

periodicity of earth rotation and axis translation along with minor epirogenic movements accompanying basin filling are most likely causes for cyclicity in the Carmel Formation of eastern Utah.

SEDIMENTARY MODEL

Deposition for the Carmel Formation at Sheep Creek Gap can be divided into three general subenvironments using tidal flat terminology, even though wind-driven currents may be partially responsible for inundation of mudflat sediments. Basic subdivisions include subtidal, intertidal, and supratidal environments of deposition.

Subtidal Environment

The subtidal environment (Text-fig. 4) is that realm of marine sedimentation which is never subaerially exposed. Lithologies of the Carmel Formation which were deposited here include various carbonate units as well as medium gray shale. Low- and high-energy subdivisions of the subtidal environment are recognized on the basis of wave energy contemporaneous with deposition.

Low-Energy Subtidal Environment.—The low-energy subtidal environment occurs below effective wave base and therefore is affected little by wave agitation. Units of the Carmel Formation deposited in this evironment include medium gray shale and silty dolobiomicrite.

Medium gray shale is devoid of fossils, aside from ichnofossils (Pl. 5, figs. 1-3). Judging from biota found in the Carmel Formation in units above and below the gray shale (echinoderms, bryozoans, bivalves, and gastropods), areas where medium gray shale was deposited may have been unsuitable for habitation. Most forms like those found in the Carmel Formation of the study area require a firm substrate and nonturbid water (Heckel, 1972, p. 249-50). Hypersalinity may also have been a limiting factor, since less agitated areas could produce salinity stratification.

Pyrite and limonite pseudomorphs after pyrite are found throughout the medium gray shale, suggesting a reducing environment. Reducing conditions may be created when a significant amount of organic material accumulates in the sediment so that subsequent decay exhausts the free oxygen contained within the deposit (Dunbar and Rodgers, 1957, p. 212).

Silty dolobiomicrite also represents carbonate sedimentation in the low-energy subtidal environment. The microcrystalline carbonate rocks contain bivalve allochemical constituents and occasional surges of silt. Folk (1959, p. 12) indicates that microcrystalline, calcite-dominated limestones are indicative of environments where currents were not strong enough to winnow away the fine carbonate material. Some bivalves and gastropods were apparently tolerant of the more turbid and less agitated conditions and hence are found throughout the micritic material.

Spatially, medium gray shale probably grades laterally into the silty dolobiomicrite which was deposited in slightly shallower and more agitated water nearer shore and nearer the effective wave base. Micritic limestone and gray shale occur stratigraphically below the high-energy subtidal oolitic limestone in a repetitive sequence as sea-level oscillated.

High-Energy Subtidal Environment.—Sediments in the Carmel Formation deposited in more oxygenated and agitated areas at or above the effective wave base are characterized by bioclasts and/or oolites surrounded by a sparry calcite matrix. Only carbonate lithologies are represented. These include peloosparite, peloobiosparite, silty intradolobiosparite, and silty intradolooobiosparite.

Wave or current energy was sufficient to winnow away the microcrystalline calcite ooze, and interstitial pores have been filled with precipitation of sparry calcite cement in a manner like that described by Folk (1959, p. 12).

Most fossil organisms which occur in the high-energy subtidal deposits require a firm substrate and well-oxygenated, clear, agitated marine water of normal salinity. Pelmatozoans, bryozoans, oysters, and some echinoids require such conditions, as do most filter feeders (Heckel, 1972, p. 249-50).

The presence of oolites also gives an indication of position with respect to wave agitation. Formation of typical carbonate ooids requires water supersaturated with calcium carbonate and consistent agitation by waves and currents (Newell, Purdy, Imbrie, 1960, p. 481).

Intertidal Environment

The intertidal environment is defined as the depositional surface inundated at mean high tide and subsequently exposed at mean low tide (Lucia, 1972, p. 160). Sediments deposited may be gray to green and show evidence of a reducing environment. Thompson (1968, p. 1) described modern lower intertidal deposits in Baja California as gray silt and clay. Intertidal sediments may also show intense organism activity—burrowing, bioturbation, and rooting (Lucia, 1972, p. 188; Reineck, 1973, p. 356)—although such activities are not restricted to this environment.

Intertidal deposits of the Carmel Formation consist of light grayish green shale, light green siltstone, and dolosiltstone. Evidence of burrowing (Pl. 5, figs. 1-6), bioturbation, and rooting are recognized, although many units show well-developed bedding and lamination.

Fossils, other than ichnofossils, were not seen in these kinds of rocks in the Carmel Formation. In the intertidal environment, temperatures, salinity variation, and periodic desiccation are so extreme that few organisms, other than algae, can survive (Heckel, 1972, p. 253).

Pyrite and limonite pseudomorphs after pyrite are also found, suggesting reduction of iron silicates. A reducing environment could be a response to organic accumulation and decay related to the frequent submersion by sea water and to exhaustion of free oxygen.

The position of the intertidal sediments in the tidal flat sequence is important (Lucia, 1972, p. 61). Intertidal deposits in the Carmel Formation occur immediately above the near shore, subtidal environment deposits and immediately below the oxidized reddish brown, evaporite supratidal deposits (Text-fig. 4; Pl. 1, figs. 3-5).

Supratidal Environment

The supratidal environment (Text-fig. 4) is the area of tidal flat sedimentation not inundated by daily tides. Along modern shores sediments of this environment are covered only by spring or storm tides and may be subaerially exposed for weeks and months at a time (Lucia, 1972, p. 160).

Such circumstances in a warm, arid climate produce a variety of distinctive features. Diagnostic characteristics of the supratidal environment include disrupted bedding, gypsum and dolomite, scarcity of marine organisms, lithoclasts, mudcracks, burrows, association with marine sediments (Lucia, 1968, 1972, p. 188), and oxidized red sediments (Walker, 1967; Thompson, 1968). Not all characteristics are found in any one deposit (Lucia, Table 1, 1972, p. 162).

Those characteristics found in particular units in the Carmel Formation at Sheep Creek Gap indicating a supratidal environment include disrupted bedding, gypsum and dolomite, scarcity of marine organisms, presence of burrows, oxidized red sediments, and association with marine environment.

Many of the Carmel units considered to have been deposited in the supratidal environment demonstrate disrupted bedding and also often have a soillike character (Appendix). Penecontemporaneous evaporite formation within the sediment, hummocky surface features created by desiccation or organism activity may be responsible for the observed irregular, discontinuous bedding.

The harsh environment produced by hypersalinity and great salinity variations, temperature extremes, and long periods of exposure greatly reduce or eliminate virtually all organisms from the supratidal environment. Direct evidence of organisms in these kinds of rocks in the Carmel Formation is scarce, although some evidence of burrowing is found in the dolosiltstone. Those units demonstrating disrupted bedding possibly owe their breakage to rooting or bioturbation.

High evaporation rate as opposed to replenishment rate of less saline waters in a warm, arid climate results in a high concentration of salts and eventual precipitation of gypsum and halite. Evaporite deposition is accomplished in areas of restricted circulation, such as lagoons and estuaries or in hypersaline evaporating pans isolated from normal marine circulation by abandonment during periods of spring or storm tides (Lucia, 1972, p. 160).

Both restrictive mechanisms probably operated during deposition of the Carmel Formation. Gypsum units associated with intertidal sediments may represent evaporite deposition in restricted lagoons with associated reducing environments. Gypsum found in the supratidal environment is likely a result of evaporation of isolated hypersaline lakes left behind by lowered tidal range.

As sea water evaporates in restricted basins in modern tidal flats, gypsum precipitates, producing Mg-rich dolomitizing fluids. This brine has a high specific gravity and moves to lower areas within the evaporitic basin seeping down through permeable sediments dolomitizing underlying beds (Deffeyes et al., 1965, p. 71). This means of dolomitization is referred to as seepage refluxion.

During deposition of the Carmel Formation, Mg-rich brine seeped through supratidal and intertidal sediments and replaced calcite with dolomite in some siltstone units. Limestones forming in adjacent subtidal environments were especially susceptible to dolomitization. In rocks with varying permeabilities, the seeping brines migrated through the more porous zones, bypassing dense areas. Microcrystalline calcite-dominated portions of limestones were not dolomitized. A modern analogue to the Carmel Formation occurs on Bonaire Island in the Netherlands Antilles. On this island, evaporation of sea water in a supratidal environment produces a dense Mg-rich brine which seeps downward, replacing calcium in underlying sediments (Deffeyes et al., 1965, p. 87).

A visually diagnostic feature of the supratidal environment at Sheep Creek Gap is the red-pigmented siltstone. Walker (1967) indicates that the presence of red beds in association with bedded evaporites is indicative of postdeposition, interstratal oxidation of iron-bearing grains to hematite in a warm, arid environment.

Modern Baja California sediments grade laterally from reduced gray silt in the intertidal zone to oxidized brown silt of the supratidal environment (Thompson, 1968). The Carmel Formation exhibits a similar lateral variation. Reduced gray-green shales and siltstones of the intertidal environment grade laterally into oxidized reddish brown siltstones in the supratidal environment in units 66 to 68.

APPENDIX

Measured Section of the Entire Carmel Formation
at Sheep Creek Gap, Daggett County, Utah

Unit	*Description*	*Thickness* *Unit* (cm)	*Thickness* *Cumulative* (meters)
Top of Carmel Formation—Base of Entrada Sandstone			
72	Siltstone: reddish brown, fine grained, slope former; poor exposure; uppermost 100 cm indurated; gradational contact with Entrada Sandstone.	1400	91.55
71	Siltstone alternating with shale: light grayish green; fine to very fine grained; very thin bedded; extensively rippled, interference ripple marks; trace fossils; ledge former; desiccated appearance.	160	77.55
70	Siltstone: dark reddish brown; fine grained; not well bedded, possibly bioturbated; gypsum along fractures.	120	75.95
69	Calcareous shale with siltstone in middle 100 cm: grayish green; fine grained; thin to laminar bedding; gypsum along fractures.	320	74.75
68	Siltstone: light grayish green; fine grained; thin, well-developed bedding; gypsum along fractures.	240	71.55
67	Siltstone: reddish brown; fine grained; thin, well-developed bedding; gypsum along fractures.	200	69.15
66	Gypsum with interbedded calcareous shale in upper 30 cm: white to light green; discontinuous shale lenses; gypsum has podular nature; pinches out laterally.	70	67.15
65	Calcareous shale with interbedded siltstone in middle 50 cm: grayish to green; fine to very fine grained; very thin to laminar bedding; gypsum along fractures.	140	66.45
64	Calcareous shale with alternating silt stone: alternating light green and reddish brown; fine to very fine grained;	285	65.05

	siltstone has a nonlithified soillike appearance; very thin laminar to indistinct bedding; gypsum along fractures.		
63	Shale with 15 cm thick gypsiferous siltstone bed: light green shale, brown siltstone; very fine-grained; very thin to indistinct bedding.	270	62.20
62	Siltstone: medium gray with tan streaks; fine grained; very thin to laminar bedding; friable; gypsum along fractures.	130	59.50
61	Siltstone: medium gray to tan; fine-grained; nonlithified; bedding absent; gypsiferous.	110	58.20
60	Gypsum with 10-20 cm thick interbedded shale: green to grayish green; crystalline to very fine grained; thin laminar to massive bedding.	240	57.10
59	Shale: light gray to reddish brown; very fine grained; laminar bedding; secondary gypsum comprises 45 percent of unit.	60	54.70
58	Siltstone: reddish brown; fine grained. bedding absent; nonlithified, soillike appearance; gypsum occurs as an intricate network along small fractures.	150	54.10
57	Claystone: light green; very fine grained; thin laminar bedding; flakey; gypsum along fractures.	110	52.60
56	Gypsum with 0.5 cm thick alternating shale beds: grayish green; crystalline to fine grained; medium to thin laminar bedding; contorted.	40	51.50
55	Shale with 10 cm siltstone: medium gray with reddish streaks; fine grained; thin laminar bedding; siltstone has varved appearance.	30	51.10
54	Calcareous shale: grayish green; very fine grained; laminar to thin laminar bedding; secondary gypsum in lower 50 cm; upper 200 cm has mottled weathering character.	525	50.80
53	Gypsum with interbedded shale and siltstone: white to grayish green; crystalline to fine grained; thin laminar to medium bedded.	180	45.55
52	Siltstone: reddish brown to medium green; fine grained; very thin to laminar bedding; evidence of gypsum heaving; gypsum along fractures.	200	43.75
51	Siltstone: grayish green; fine grained;	180	41.75

	thin to laminar bedding; gypsiferous in upper 110 cm; southerly trend, trough-shaped cross-beds; burrowing in lower third.		
50	Calcareous siltstone: grayish green; fine grained; very thin to medium bedded; south-trending, troughlike cross-beds; burrowed; gypsum along fractures.	130	39.95
49	Calcareous shale with interbedded siltstone in upper third: grayish green; fine to very fine grained; very thin to thin laminar bedding; south-trending, troughlike cross-beds; extensively burrowed; gypsum along fractures.	345	38.65
48	Gypsum alternating with shale, mudstone, and siltstone: light green to reddish brown; fine to very fine-grained; very thin to medium bedded; siltstones are cross-bedded; evidence of gypsum heaving.	350	35.20
47	Siltstone with 15 cm thick shale: light gray to light green, has yellow streaks; fine to very fine grained; thin laminar to medium bedded; secondary gypsum abundant.	145	31.70
46	Siltstone: reddish brown; fine grained; thin bedded, not distinct; gypsum along fractures; poor exposure.	30	30.62
45	Siltstone with 30 cm thick gypsum bed in lower third: grayish green to reddish brown; fine grained; siltstone cross-bedded.	60	29.95
44	Siltstone: light gray to reddish brown; fine grained; thin laminar bedding; poor exposures.	70	29.35
43	Dolosiltstone: light gray; fine grained; thin to medium bedded; calcareous sandstone is slightly cross-bedded.	35	28.65
42	Calcareous siltstone: light gray to reddish brown; thin to laminar bedding.	90	28.30
41	Calcareous siltstone: reddish brown; fine grained; thin bedded; bioturbated; thickness varies.	60	27.40
40	Dolosiltstone with 16 cm thick calcareous siltstone at top: medium gray to light green; fine grained; thin laminar to medium bedded.	40	26.80
39	Dolosiltstone: light green to light gray; fine grained; thin to thin laminar bedding.	25	26.40

38	Dolosiltstone: light reddish brown; fine grained; medium bedded.	20	26.15
37	Dolosiltstone: light green to reddish brown; fine grained; thin to medium bedded; lower 10 cm is cross-bedded; southeast-trending, troughlike cross-beds; highly fractured.	32	29.95
36	Siltstone with calcareous shale lenses: reddish brown to yellow; fine to very fine grained; laminar bedding.	92	25.63
35	Siltstone: reddish brown; fine grained; medium bedded; cross-bedded; possible channel.	30	24.71
34	Siltstone: reddish brown; fine grained; bedding absent; intensely bioturbated; some cross-beds; gypsum along fractures.	100	21.21
33	Siltstone: reddish brown; fine grained; bedding absent; intensely bioturbated; cross-bedded near top.	320	24.41
32	Shale with calcareous siltstone in upper fourth: medium gray to reddish brown; fine to very fine grained; thin laminar to thin bedded; shale has varved nature; burrowed.	170	20.21
31	Limestone, oolitic: light gray; very thick bedded; cross-bedded in lower half; styolites; fossiliferous, bivalves.	250	18.51
30	Limestone, oolitic with alternating calcareous shale: medium gray to medium brown; very thin to medium bedded; fossiliferous, bivalves.	35	16.01
29	Limestone, oolitic with 1 cm thick shale in middle of unit: medium to light brown; thick bedded; very fossiliferous.	98	15.66
28	Limestone, oolitic with alternating calcareous shale and calcareous siltstone: light gray to medium brown; thin laminar to medium bedded; hydrocarbon bearing; fossiliferous.	40	14.68
27	Limestone, oolitic: medium brown; thick bedded; hydrocarbon bearing; fossiliferous.	96	14.28
26	Limestone, micritic with alternating calcareous shale: medium gray to yellow buff; hydrocarbon bearing in limestones; calcareous spheroids and bivalves.	85	13.32
25	Limestone, oolitic with shale at base: light gray to dark brown; very thick	170	12.47

	bedded; southeast-trending ripple marks at base; fossiliferous.		
24	Shale with alternating micritic limestone in upper half and siltstone in lower half: medium gray to medium brown; very fine grained; thin laminar to medium bedded; fossiliferous.	80	10.75
23	Shale with alternating micritic limestone: medium gray to medium brown; very fine grained; thin laminar to thin bedded; fossiliferous.	40	9.95
22	Limestone, micritic: medium gray to tan; thin to medium bedded; very fossiliferous.	80	9.55
21	Calcareous shale with alternating limestone: dark gray; thin laminar to thin bedded; varved character; limestone, very fossiliferous.	55	8.75
20	Calcareous shale with limestone in upper third: medium gray to medium brown; thin laminar to medium bedded; trace fossils; very fossiliferous.	30	8.20
19	Shale: medium to dark gray; very fine grained; thin laminar bedding; varved character; trace fossils.	30	7.90
18	Calcareous shale; marlstone with limestone lenses: buff; fine grained; thin bedded; hemitite along bedding planes; very fossiliferous; *Camptonectes*.	40	7.60
17	Shale with marlstone in upper third: medium gray to buff; very fine grained; thin laminar to thin bedded; shale has varved character; pyrite altered to limonite; trace fossils; fossiliferous.	75	7.20
16	Shale with marlstone in upper half; medium gray to buff; very fine grained; thin laminar to thin bedded; shale has varved character; pyrite altered to limonite; trace fossils; fossiliferous.	100	6.45
15	Shale with interbedded limestone, micritic: medium gray, buff to tan; very fine grained thin laminar to medium bedded; very fossiliferous, especially in limestone.	70	5.45
14	Limestone, micritic: medium gray to light brown; thin to thick bedded; fossiliferous; gypsum along fractures.	35	4.75
13	Calcareous shale: medium gray leached	65	4.40

	to tan; very fine grained; thin to thin laminar bedding; gypsum along fractures.		
12	Limestone with alternating calcareous shale: medium gray to light green; thin to thin laminar bedding; fossiliferous.	60	3.75
11	Siltstone and interbedded gypsiferous shale medium gray leached to tan; fine grained; thin laminar to thin bedded; iron stained along fractures.	45	3.15
10	Calcareous shale: light green to buff; fine to very fine grained; thin laminar bedding; glaucontic; gypsum along fractures.	7	2.70
9	Sandy shale: gray green to buff; fine grained; thin bedded; gypsum along bedding planes.	10	2.63
8	Siltstone, hemititic: dark red to buff; fine to coarse grained; poor sorting; medium bedded; soft sediment deformation.	10	2.53
7	Shale with sandstone lenses: grayish green to tan; fine to medium grained; thin laminar to thin bedded; sandstone is cross-bedded, poorly sorted; megarippled.	10	2.43
6	Conglomerate with shale matrix: gray green; very fine to coarse grained; thin laminar to thin bedded; poor sorting.	2	2.33
5	Sandstone: light gray to tan; fine grained; thin bedded; glauconitic.	15	2.31
4	Sandstone: green gray to yellow brown; fine grained; glauconitic; thin bedded.	24	2.16
3	Sandstone: yellow orange; medium grained; very thick bedded; cross-bedded.	81	1.90
2	Sandstone: yellow to tan; medium grained; very thick bedded; reworked.	110	1.10
Top of Navajo Sandstone—Base of Carmel Formation			
1	Sandstone: yellow to tan; medium grained; very thick bedded; well sorted; silica cement; cross-bedded.		

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