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Marine Jurassic of Wyoming and South Dakota: Its Paleoenvironments and Paleobiogeography

By

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ABSTRACT -- During the Middle and Late Jurassic, the Twin Creek Limestone and Sundance Formation were laid down in open shelf, lagoonal, and littoral environments. Local thinning and pinching out of strata and abrupt vertical changes in lithology and biota within these formations are the result of deposition under variable shallow water conditions and, contrary to previous interpretations, do not represent regional unconformities.

In Bajocian times, three bivalve associations existed. The Camptonectes stygius fauna inhabited the outer shelf in westernmost Wyoming in an area of rapid lime-mud deposition (Sliderock and Rich Members of the Twin Creek Limestone). The Pleuromya subcompressa fauna lived nearer to shore and the Trigonia americana fauna fauna occupied lagoons along the eastern shoreline, sites of Gypsum Spring Formation deposition.

During Early and Middle Callovian, the Gryphaea nebrascensis fauna was restricted to an area of normal marine conditions (attested by the abundance and variety of foraminifera and ostracods) northwest of the Sheridan Arch, which acted as a marine barrier on the Wyoming shelf. The Meleagrinella curta fauna was restricted to brackish lagoons southeast of the arch (attested by the absence of foraminifera and abundance of ostracods). During this time, the Leeds Creek Member of the Twin Creek Limestone, the "Lower Sundance," and Stockade Beaver Shale were deposited northwest of the arch, and the Canyon Springs Sandstone, Stockade Beaver Shale, Hulett Sandstone, and Lak redbeds were deposited southeast of the arch.

In Late Callovian, the Camptonectes bellistriatus fauna, ostracods, and foraminifera ranged across the entire shelf. The water was deeper and the abundance of arenaceous formainifera suggests that the water was cooler than earlier in the Jurassic. During this time, the Pine Butte, Redwater Shale, and Windy Hill Sandstone Members of the Sundance Formation were deposited in central and eastern Wyoming; the "Upper Sundance" in northern Wyoming; and the Preuss and Stump Sandstones in western Wyoming.

Oxfordian regression ended Jurassic marine deposition in Wyoming and South Dakota.

INTRODUCTION

GEOLOGIC INVESTIGATIONS in the Western Interior since the middle of the 19th century have established that the Twin Creek Limestone in westernmost Wyoming and the Sundance Formation in Wyoming and the Black Hills of South Dakota include a wide range of lithologic types and faunal associations, reflecting a variety of depositional environments.

The Hayden Survey between 1868 and 1877 established the widespread distribution of marine Jurassic throughout South Dakota, Wyoming, and Idaho. In 1899 Darton applied the name Sundance Formation to the sequence of marine Jurassic sediments in the Black Hills. This was the first attempt to classify the sediments in the Black Hills. Veatch (1907) named the fossiliferous marine Jurassic sediments exposed on Twin Creek between Sage and Fossil, in southwestern Wyoming, as the Twin Creek Formation. During the years from 1945 until 1967, Imlay designated member names for the Twin Creek Limestone and Sundance Formation in Wyoming and South Dakota, described the distribution, lithology, thickness, faunal content, contact relationships, and age of each of the members. Taxonomic analyses of the marine Jurassic microfossils of Wyoming and South Dakota was done by many (Loeblich & Tappan, 1950; Loeblich, 1950; Peterson, 1954a; Swain & Peterson, 1951, 1952).

I was concerned with deriving a representative picture of the various depositional environments and their contained faunas in relation to their diversity and community structure during Middle and Late Jurassic time. The organisms studied include the marine Bivalvia, Foraminifera, and Ostracoda. The spatial distribution, relative abundance, and natural assemblages of the bivalves were determined. In addition, the habits and habitats of each bivalve taxon were studied by comparison of the fossils with closest living relatives (where possible), by functional considerations of hard parts and by noting burial positions. Diversity and abundance of the foraminifera and ostracods were used to establish possible fluctuations in salinity and water depth.

ACKNOWLEDGMENTS

During the course of field work, the author had continual assistance from various property owners in Wyoming and South Dakota. Special thanks are due to Mr. and Mrs. George Elley of Hot Springs, South Dakota, for the use of their summer cabin and their hospitality. John and Joan Green provided living accommodations for me and my field assistant, Mr. Brian Mann, in Lander, Wyoming, during the summer of 1969. Their home served as a base of operations for my work in the Big Horn Basin.

In the early stages of the project I had the benefit of many informal discussions with Dr. Robert Gernant concerning bivalve paleobiology and approaches to "outcrop" paleoecology. Also, Dr. Charles I. Smith and Dr. Robert V. Kesling guided the project to its completion with their expertise as field critics.

Dr. Ralph Imlay of the U.S. National Museum graciously made available descriptions of stratigraphic sections measured by him in the Big Horn Mountains.

The Department of Geology and Mineralogy provided a field vehicle during the summers of 1968 and 1969. The summer's work in 1969 was supported by a grant from the National Science Foundation, GB-8218, to N. G. Hairston, The University of Michigan, for research in Systematic and Evolutionary Biology.

The following people helped with drafting and typing: Mr. Karoly Kutasi, photographic plates; Miss Betty Salmon, drawings of bivalve life-modes; Mrs. Karen Freudenreich, text-figures; Mrs. Sherry Clay, stratigraphic diagrams; and Mrs. Helen Mysyk and Mrs. Patricia Kocsovsky, typing.

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Dr. Robert V. Kesling edited the manuscript.

GEOLOGIC SETTING

The area studied is set in the heart of the Rocky Mountains (text-fig. 1). A youthful and rugged topography includes numerous peaks reaching altitudes over 12,000 feet and standing 7,000 feet above basin floors. Grand Teton in the Teton Range and Ganett Peak in the Wind River Range are 13,747 and 13,785 feet in elevation respectively (Eardley, 1962).

The Snake River Mountains, Salt River Range, Wyoming Range, Teton Range, and Gros Ventre Mountains form the rugged topography in western Wyoming and thrust faults formed during the Laramide phase of the Cordilleran orogeny characterize this area. Some of the major thrusts include the Absaroka, St. John, Darby, Grizzly and Cabin, and Prospect-Cliff Creek. They were thrust eastward and now trend predominantly north-south.

EXPLANATION OF PLATE 1

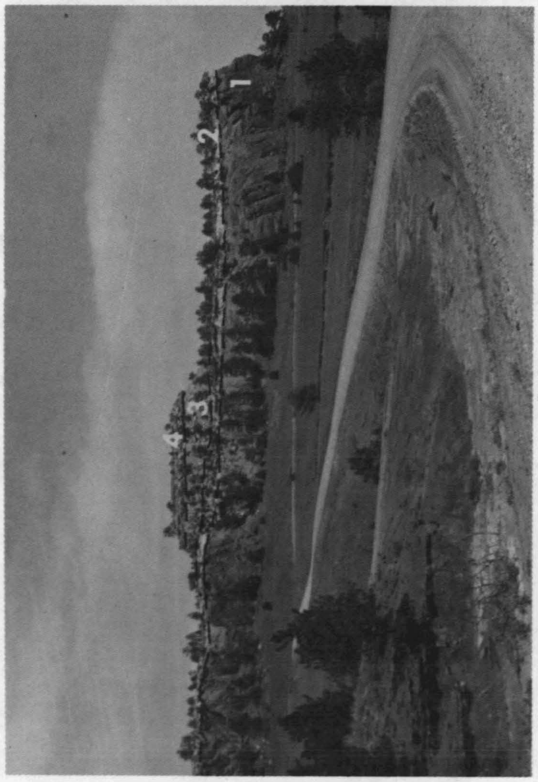
Fig. 1 -- Minnekahta. (1) Jelm Formation?, (2) Canyon Springs Sandstone, (3) Stockade Beaver Shale, and (4) Hulett Sandstone of the Sundance Formation.

Fig. 2 -- Freezeout Mountains. (1) Massive lower sandstone member of the Canyon Springs Sandstone, (2) Hulett Sandstone, and (3) Lak Member. No Stockade Beaver Shale was deposited between the Canyon Springs and Hulett Sandstones.

Fig. 3 -- Rapid City. (1) Thin sandstone beds of the upper part of the Stockade Beaver Shale grading into (2) the Hulett Sandstone.

Fig. 4 -- Douglas. Entire exposure of Sundance Formation. (1) Canyon Springs Sandstone, (2) Stockade Beaver Shale, (3) Hulett Sandstone, (4) Lak Member, (5) Pine Butte Member, and (6) Redwater Shale.

PLATE 1



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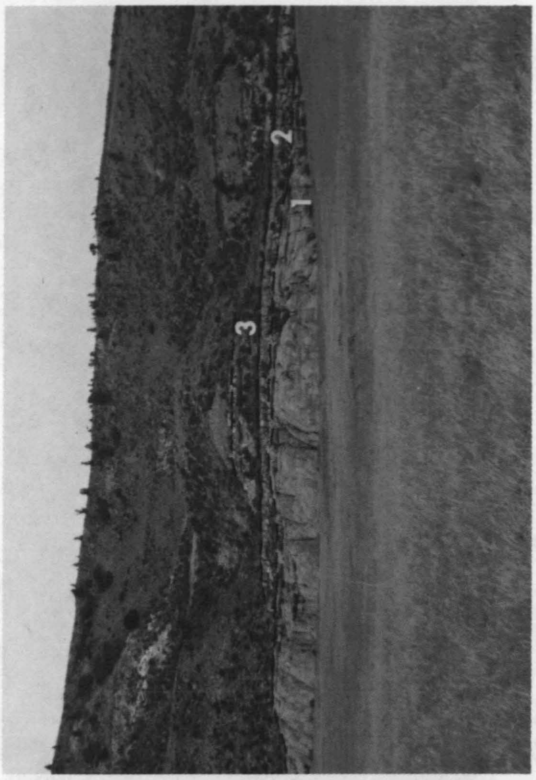

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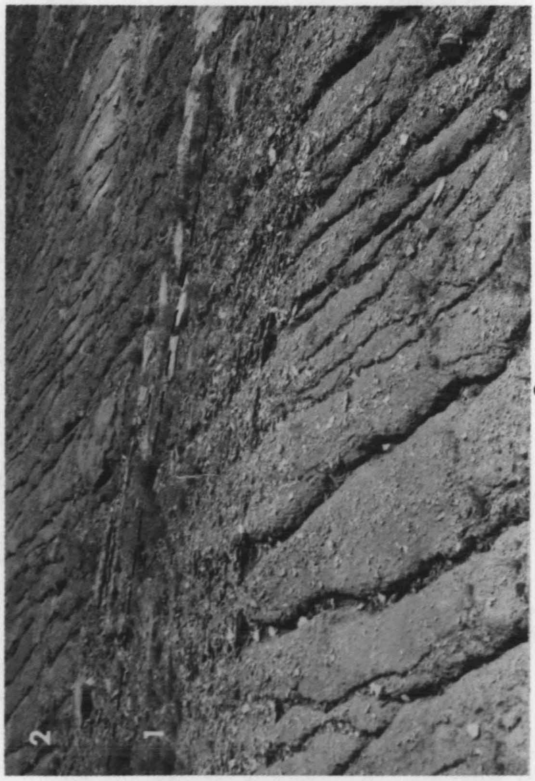

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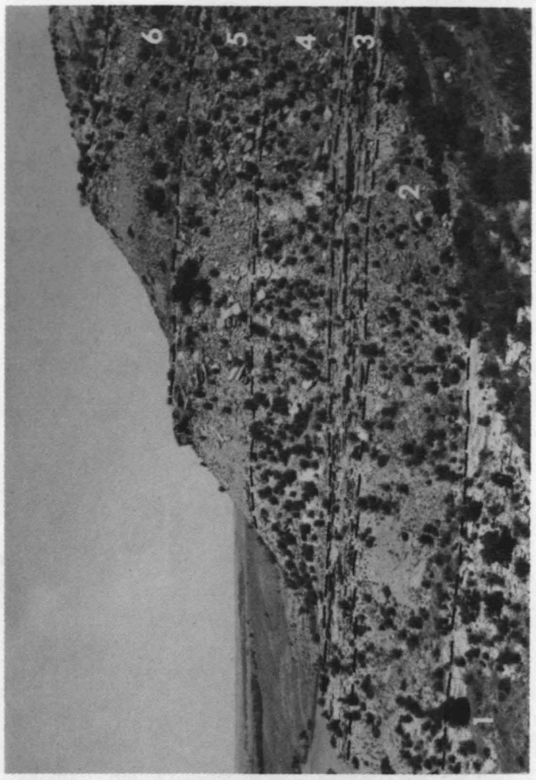

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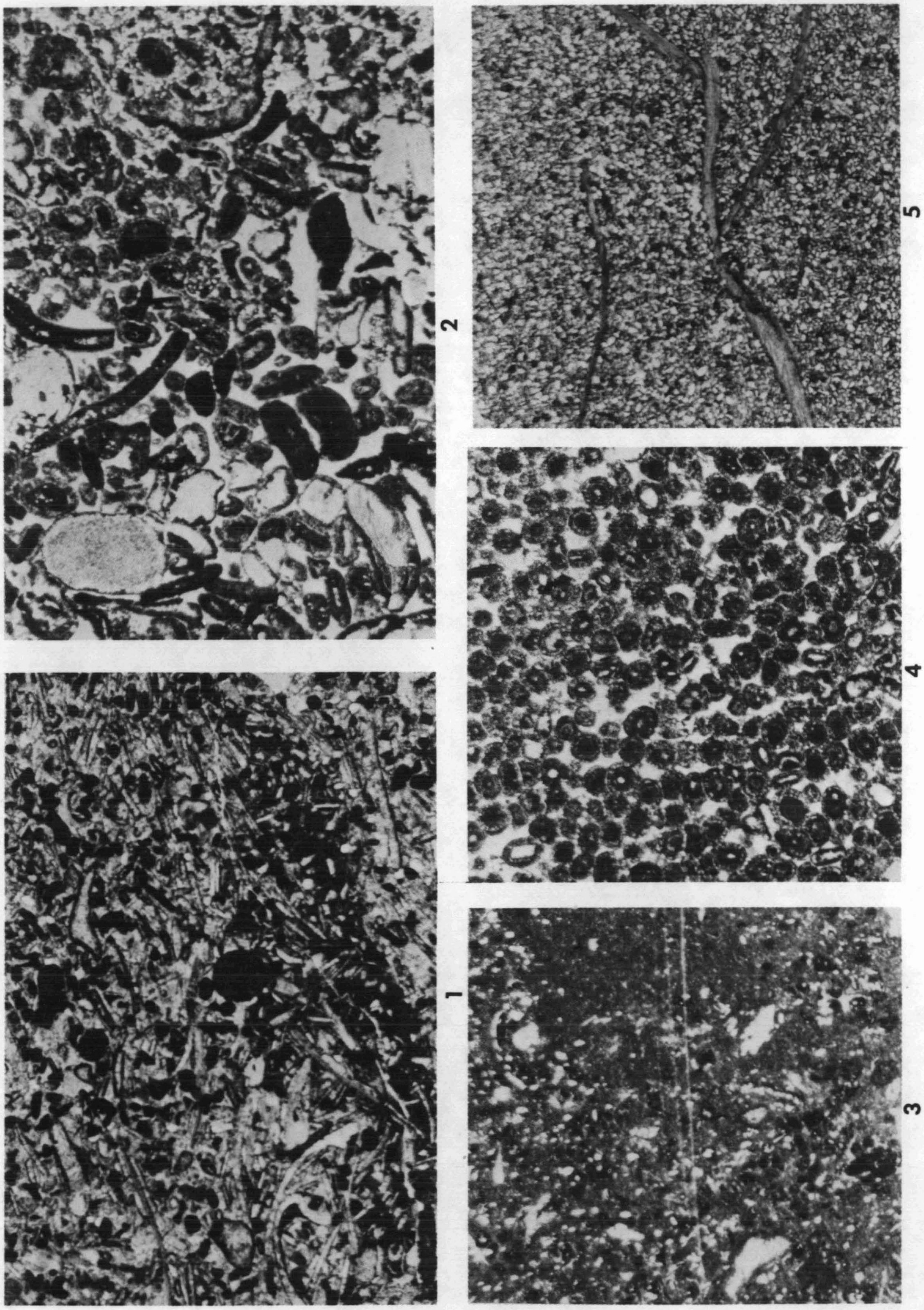
PLATE 2



Associated with the thrusts and other major faults are thick clastic deposits such as the Paleocene-Eocene Hoback Formation and the Eocene Pass Peak Formation representing the products of rapid erosion of the surrounding highlands produced during the Laramide phase.

East of the thrust zone are the Absaroka Range, Big Horn Mountains, Owl Creek Mountains, Wind River Mountains, Laramie Mountains, and Black Hills. Separating the mountains are basins filled with Tertiary sediments. The main basins are the Powder River, Big Horn, Green River, and Wind River. Paleozoic and Mesozoic sediments, covered by the Tertiary basin deposits, are exposed along the flanks of the mountains.

For the most part, the mountain ranges trend northwest-southeast, are asymmetrical, and have cores of exposed Precambrian rock. The Absaroka Mountains is an exception, being largely composed of volcanic flows, pyroclastics, and small plutons.

METHODS

The field work involved the detailed measuring of twenty-two stratigraphic sections during the summers of 1968 and 1969. The section locations are distributed over a wide geographic area, from the Black Hills of South Dakota to westernmost Wyoming (text-fig. 2). The first sections studied in the field were selected on the basis of their degree of completeness, accessibility, and geographic distribution. During the course of field work other sections were added to insure adequate coverage of the various depositional environments.

Bivalves were observed in situ prior to collection in order to distinguish transported from relatively undisturbed assemblages. Channel samples were collected at regular intervals and later were picked for foraminifera and ostracods.

From each selected channel sample 300 grams of sediment were washed and wet-sieved in the laboratory for foraminifera and ostracods. Foraminifera were counted directly. Direct counts of ostracods cannot be made because during growth they molt their shells. Potentially, valves from eight instar stages plus the adult may be from a single individual. The method used to count the number of ostracods was to total the number of whole shells with the greatest number of either right or left valves of the juveniles, males and females.

Quaternary-O was used to deflocculate the dry samples. It does an excellent job on calcareous shales or claystones. The following procedure was used: (1) Cover 300 gms of sample with diluted (directions with stock solution) Q-O solution and let stand overnight, (2) simmer on a hot plate for approximately one hour, (3) wet-sieve the entire sample through a 100-mesh screen, first with cold water, then with warm water in order to clean the surface of the shells, and (4) dry residue and dry-sieve to pick desired size fraction.

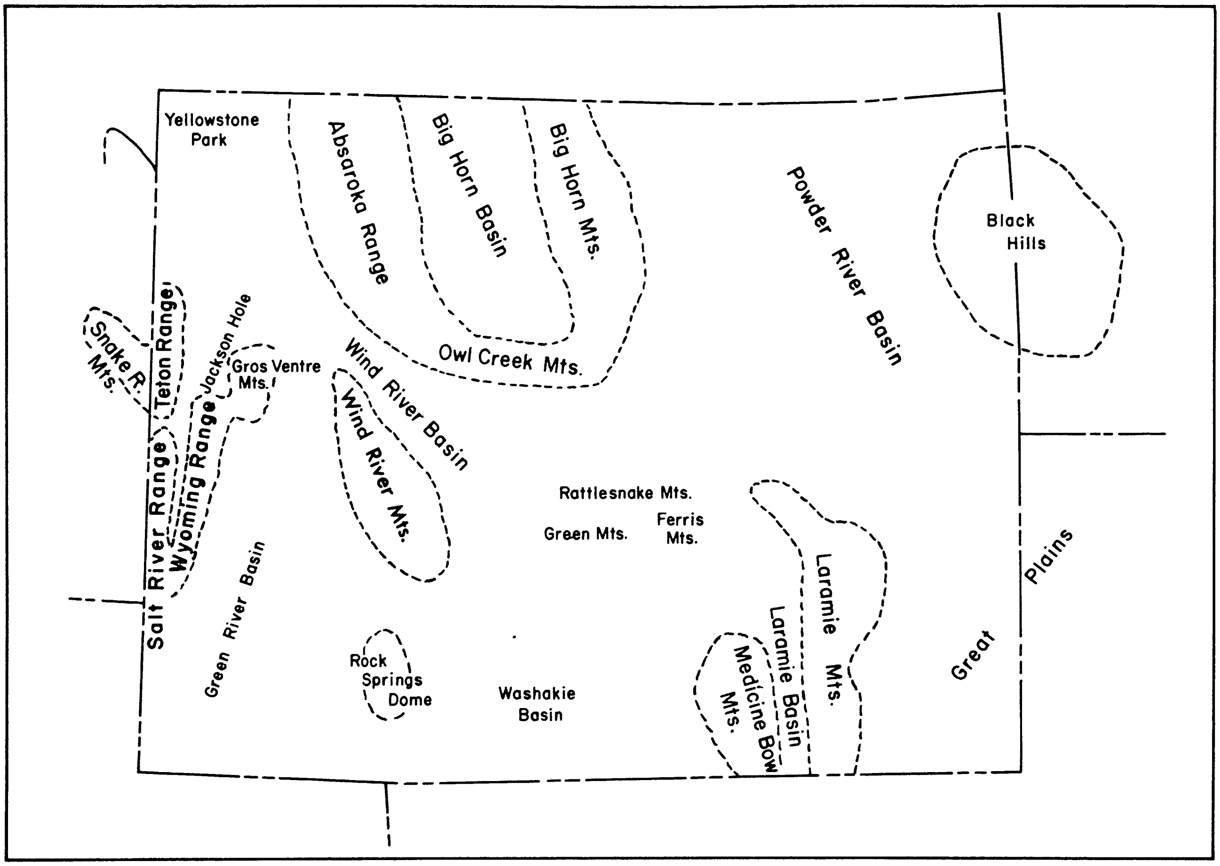
COLLECTING LOCALITIES

1. Buffalo Gap. Exposures on Beaver Creek, adjacent to Trout Haven Ranch, 2.9 miles west of State Highway 79. Improved light-duty road to Beaver Creek exists from highway 1.3 miles north of exit to the town of Buffalo Gap. Sec. 13, T6S, R6E, Custer County, South Dakota.
2. Minnekahta. Exposure on the south side of an improved light-duty road 3.2 miles west from its intersection with State Highway 89. Sec. 11, T7S, R3E, Fall River County, South Dakota.
3. Minnekahta. Outcrop on the north side of an improved light-duty road 7.3 miles west from its intersection with State Highway 89.

EXPLANATION OF PLATE 2

All photomicrographs x 5

Fig. 1 -- Packed poorly washed biosparite. Allochems include bivalve and echinoderm fragments, oolites, and pellets.
Fig. 2 -- Poorly washed sandy packed oobiosparite. Allochems include pellets, bivalve and echinoderm fragments. Stockade Beaver Shale, Sundance Formation, Maverick Spring.
Fig. 3 -- Biopelmicrite. Allochems include bivalve and echinoderm fragments, and ostracods. Stockade Beaver Shale, Sundance Formation, Maverick Spring.
Fig. 4 -- Poorly washed sandy oosparite. Stockade Beaver Shale, Sundance Formation, Bull Lake.
Fig. 5 -- Calcareous sandstone with oyster shell fragments. Stockade Beaver Shale, Sundance Formation, Rapid City.



TEXT-FIG. 1 -- Location of major mountain ranges and basins in Wyoming and adjacent areas.

Sec. 13, T7S, R3E, Fall River County, South Dakota.

4. Rapid City. Road cut on Federal Highway 16, 5 miles south of the southern limit of Rapid City. Sec. 34, T1N, R7E, Pennington County, South Dakota.

5. Spearfish. Cliff face at the eastern end of an improved light-duty road 2.0 miles east of its cutoff from Federal Highway 85. This cutoff is 1.9 miles north of Lookout Memorial Hospital on Highway 85 on the northern outskirts of Spearfish. Sec. 36, T7N, R2E, Lawrence County, South Dakota.

6. Newcastle. Exposure side of unimproved light-duty road #124 on east side of Elk Mountain. Road #124 exists west from improved light-duty road #769 (which connects with Federal Highway 16) 18 miles east of Newcastle. Secs. 18 & 19, T4S, R1E, Custer County, South Dakota.

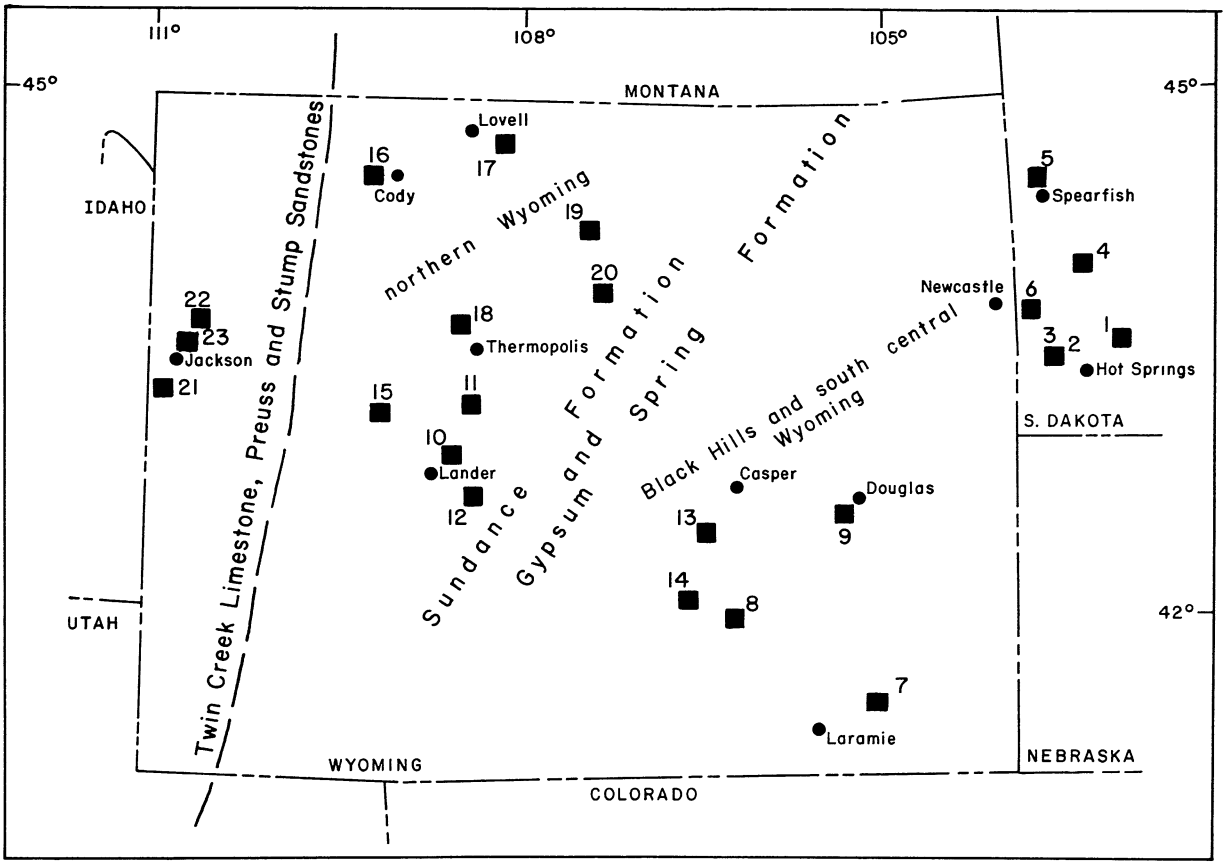
7. Farthing. Exposure on side of Middle Chugwater Creek, 1.9 miles west of railroad crossing at Farthing. Sec. 4, T18N, R70W, Laramie County, Wyoming.

8. Freezeout Mountains. Outcrop on east side of unimproved light-duty road 2 miles west of its intersection with State Highway 487. Dirt road exit is 14 miles north of Medicine Bow. Sec. 29, T25N, R78W, Carbon County, Wyoming.

9. Douglas. Section on the property of Robert Haefeler, whose ranch is 5.6 miles south of Center St. in Douglas. Sec. 8, T31N, R71W, Commerce County, Laramie.

10. Lander. Exposures 3 miles east of Lander, just north of State Highway 789. Sec. 19, T2S, R2E, Freemont County, Wyoming.

11. Maverick Spring. Outcrops in Maverick Spring Dome Oil Field, 19 miles north of



TEXT-FIG. 2 -- Index map showing distribution of stratigraphic sections and formations. Dashed line indicates geographic boundary between the Twin Creek Limestone, Preuss, and Stump Sandstones in the west and the Gypsum Spring and Sundance Formations in the east. Sections: 1 - Buffalo Gap; 2 - Minnekahta; 3 - Minnekahta; 4 - Rapid City; 5 - Spearfish; 6 - Newcastle; 7 - Farthing; 8 - Freezeout Mountains; 9 - Douglas; 10 - Lander; 11 - Maverick Spring Anticline; 12 - Vinceants Ranch; 13 - Alcova; 14 - Seminoe Dam; 15 - Bull Lake; 16 - Cody; 17 - Lovell; 18 - Thermopolis; 19 - Hyattville; 20 - Tensleep; 21 - Cabin Creek; 22 - Ditch Creek; 23 - Lower Slide Lake.

Pilot Butte Oil Field, just off of Federal Highway 26. Secs. 23 & 26, T6N, R2W, Freemont County, Wyoming.

12. Vinceant Ranch. Exposures on the east side of Twin Creek, 3 miles south of Federal Highway 287. Sec. 13, T31N, R97W, Freemont County, Wyoming.

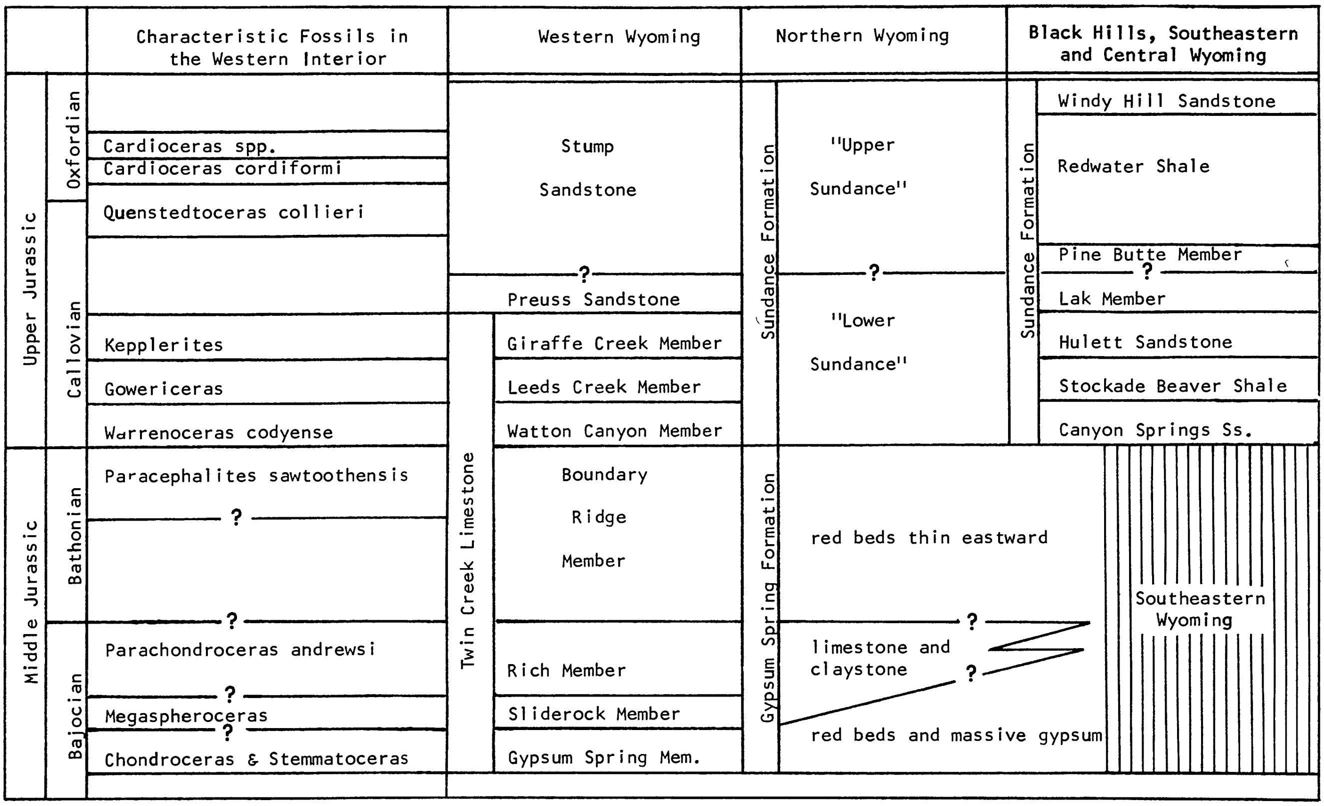
13. Alcova. Cut on the north side of an oiled road 1 mile east of Alcova Reservoir Dam or 2 miles east of Alcova on State Highway 220. Sec. 30, T30N, R82W, Natrona County, Wyoming.

14. Seminoe Dam. Outcrops on south side of improved light-duty road, 4.5 miles south of Seminoe Dam. Sec. 20, T25N, R85W, Carbon County, Wyoming.

15. Bull Lake. Exposure on the north shore of Bull Lake Reservoir at the south end of the reservoir. Sec. 31, T3N, R3W, Fremont County, Wyoming.

16. Cody. Exposure on the north side of Trail Creek 1 mile northwest of Newton Lakes on the northwestern outskirts of Cody. Sec. 22, T53N, R102W, Park County, Wyoming.

17. Lovell. Roadside exposures along an improved light-duty road leading to Georgia Pacific Bestwall Gypsum Plant. Road joins State Highway 789 7.1 miles south of Lovell. Section 2.4 miles west of Highway 789. Sec. 28, T56N, R95W, Bighorn County,



TEXT-FIG. 3 -- Correlation chart of marine Jurassic in Wyoming and South Dakota. Modified after Imlay (1948, 1953, 1967).

Wyoming.

18. Thermopolis. Outcrop on west side of State Highway 789, 2.0 miles north of Thermopolis. Sec. 25, T43N, R95W, Hot Springs County, Wyoming.

19. Hyattville. Exposure 3.5 miles southeast of Hyattville. Sec. 16, T49N, R89W, Bighorn County, Wyoming.

20. Tensleep. Exposure on east side of Upper Nowood Road, 18 miles south of Tensleep. Sec. 6, T44N, R87W, Washakie County, Wyoming.

21. Cabin Creek. Outcrop 7.5 miles south of junction of Federal Highways 89 & 26 with 189 & 187. Sec. 17, T38N, R116W, Teton County, Wyoming.

22. Ditch Creek. Exposure on north side of unimproved light-duty road, 7.3 miles east of Elbow Ranch. Sec. 11, T43N, R114W, Teton County, Wyoming.

23. Lower Slide Lake. Exposure at west end of Lower Slide Lake. Sec. 4 & 5, T42N, R114W, Teton County, Wyoming.

STRATIGRAPHY

The geographic distribution of Middle and Upper Jurassic marine sediments in Wyoming and South Dakota is shown in text-fig. 2. The correlation chart (text-fig. 3) presented here is adapted from Imlay (1948, 1953, 1967) with some modification. Correlation is on the basis of distinct ammonite zones and closely associated bivalves.

The Twin Creek Limestone (Middle and Upper Jurassic) occurs in western Wyoming. The first four members (Gypsum Spring, Sliderock, Rich, and Boundary Ridge) can be correlated with the Gypsum Spring Formation in south-central and northern Wyoming and the Black Hills of South Dakota. The upper three members (Watton Canyon, Leeds Creek, and

Giraffe Creek) can be correlated with part of the "Lower Sundance" in northern Wyoming, and with the first three members of the Sundance Formation in the Black Hills and south-central Wyoming.

The Gypsum Spring Formation (Middle Jurassic) in northern Wyoming contains a lower redbed and gypsum member, a middle claystone and limestone member, and an upper redbed member. In central and eastern Wyoming and the Black Hills, gypsum and redbeds persist but the middle claystone and limestone member thins greatly and is absent at some localities.

The Upper Jurassic rocks exposed throughout most of Wyoming are here referred to as the Sundance Formation. In south-central and western Wyoming the Sundance contains seven distinct members. They are from bottom to top: Canyon Springs Sandstone, Stockade Beaver Shale, Hulett Sandstone, Lak Member, Pine Butte Member, Redwater Shale, and Windy Hill Sandstone. Each member varies in thickness, composition, and color, and is easily recognizable.

In northern Wyoming distinct units typical of the Canyon Springs Sandstone, Hulett Sandstone, Lak Member, Pine Butte Member, and Windy Hill Sandstone are not recognizable. Because of this, Imlay (1956) used the names "Lower Sundance" and "Upper Sundance" formations for those deposits which in part resemble and are laterally equivalent to the seven members of the Sundance Formation in south-central and eastern Wyoming.

In the past most students of the Middle and Upper Jurassic in Wyoming have contended that major disconformities exist between the Gypsum Spring Formation and Sundance Formation, between the Preuss and Stump Sandstones, between the "Lower Sundance" and "Upper Sundance," and between the Lak or Pine Butte and the Redwater Shale Member of the Sundance Formation. Mary Hileman (1969) has now established that a disconformity does not separate the Preuss and Stump Sandstones. John Green (1970) has also shown that a major disconformity does not separate the Gypsum Spring Formation and Sundance Formation in the Wind River Basin as proposed by Pipiringos (1968).

It is my contention that disconformities representing substantial, lengthy periods of time do not exist between the "Upper Sundance" and "Lower Sundance," and between Lak or Pine Butte and Redwater Shale.

The following indirect evidence has been used (Imlay, 1948) to infer the presence of a disconformity between the "Lower Sundance" and "Upper Sundance." In Montana, Kepplerites mclearni occurs in the upper 10 or 15 feet of the Rierdon Formation (Imlay, 1948) of Montana, which is time equivalent of the "Lower Sundance" in northern Wyoming. Quenstedtoceras collieri is found to occur 25 to 30 feet above the base of the Swift Formation, which is the time equivalent of the "Upper Sundance" in northern Wyoming. Kepplerites mclearni and Quenstedtoceras collieri are early and late Callovian respectively (Imlay, 1948). On the basis os similar stratigraphic horizon between the Rierdon and "Lower Sundance" and Swift and "Upper Sundance," the conclusion is that middle and most of upper Callovian deposits are absent in the Wyoming area and represented by a major disconformity.

Concerning the Wyoming area, Imlay (1947, p. 257) states: "A disconformable relationship with the overlying Redwater Shale Member is indicated by abrupt change from unfossiliferous red beds [of the Lak] to highly fossiliferous sandstone and shale [Redwater Shale] and possibly by marked local variations in thickness of the Lak Member." In the Big Horn Basin of north-central Wyoming, the disconformity is supposedly indicated by passing from non-glauconitic shale or fine-grained sandstone or sandy limestone of the "Lower Sundance" to highly glauconitic coarse-grained impure sandstone and shale of the "Upper Sundance" (Imlay, 1947, p. 258).

Peterson (1954b) states, "In other areas of occurrence [other than the Williston Basin], the Rierdon ["Lower Sundance"] is apparently overlain disconformably by the Swift Formation ["Upper Sundance"]. Where the 'Sundance red' or Lak beds are present, such a relationship is suggested by the consistently sharp change from redbeds to overlying clean, glauconitic marine sandstone or silty shale of the Swift. The widespread oolitic sandy to pebbly coquina at the top of the Rierdon in the Big Horn mountains is evidence for a submarine disconformity in that area."

Peterson also suggests (p. 487) that the faunal change (bivalves and ostracods) from the

Rierdon ("Lower Sundance") to the Swift ("Upper Sundance") Formation supports the existence of a disconformity.

Pipiringos (1968, p. 23) states that the "basal bed of Redwater Shale Member lies sharply on the underlying rocks on a surface of regional disconformity"; and "The Redwater Shale Member locally truncates the Pine Butte Member."

I believe that abrupt vertical change in lithology (e.g., Lak or Pine Butte to Redwater Shale), lateral pinching out of beds (e.g., Pine Butte Member), the occurrence of sedimentary particles like oolites and scattered fossil fragments (e.g., near top of "Lower Sundance," the Pine Butte Member), and a change in the fauna (e.g., "Lower Sundance" to "Upper Sundance") may represent response to temporal environmental changes rather than evidence for a major disconformity. Wyoming during Callovian time was an open shelf and lagoon area. The water was probably shallow, and the shelf floor relatively flat. Although minor changes in sea level no doubt resulted in diastems, major disconformities may be nonexistent. This interpretation does no injustice to previous workers whose excellent stratigraphic work makes environmental interpretation possible.

Gypsum Spring Formation

The Gypsum Spring Formation underlies the Sundance Formation in the Black Hills and throughout central and northern Wyoming (Pl. 13 and 14). In northern Wyoming it contains a lower gypsum and redbed member, a middle claystone and limestone member, and an upper redbed member. Throughout the rest of Wyoming the gypsum and redbeds persist but the middle claystone and limestone member thins greatly or is absent (Imlay, 1956).

The middle claystone and limestone member at Cody is about 50 feet thick. It is predominantly greenish gray shale interbedded with thin gypsum beds and poorly washed biosparites with pellets, oolites, and intraclasts (pl. 2, fig. 1). The absence of mud or silt matrix is indicative of the turbulent bottom conditions that existed at the time of deposition of these beds. The member is fossiliferous. The *Trigonia americana* biofacies of the Gypsum Spring Formation changes westward into the *Pleuromya subcompressa* biofacies of the Rich Member of the Twin Creek Limestone.

Along the eastern and south sides of the Big Horn Basin, the middle fossiliferous unit becomes dolomitic, laminated, crinkled, or vuggy and individual limestone beds thin greatly (Imlay, 1956). At Maverick Spring and throughout the Wind River Basin redbeds of siltstone, shale, and gypsum predominate.

The sediments of the Gypsum Spring Formation reflect a variety of depositional environments. In northern Wyoming (e.g., Cody area) semi-restricted hypersaline lagoons persisted in which deposition of the lower gypsum and redbed member and upper redbed member took place. The thick middle member of claystone and limestone was deposited when the lagoons were periodically flushed with normal marine water. Persistent hypersaline lagoons and infratidal and supratidal environments in the Wind River Basin (e.g., Maverick Spring) resulted in nondeposition or thin deposits of the middle member (Green, 1970).

Sundance Formation of the Black Hills and South-central Wyoming

Canyon Springs Sandstone Member. -- The Canyon Springs Sandstone Member was originally defined by Imlay (1947) and redefined by Pipiringos (1968). It is present in the southern part of the Black Hills and throughout south-central and eastern Wyoming (pl. 13). In the Black Hills it forms a resistant ledge of white sandstone (pl. 1, fig. 1; pl. 3, fig. 1) often containing current- or wave-deposited irregular stringers of broken oyster shells. At Buffalo Gap the member is more varied, containing maroon shale and salmon-colored sandstone. The sandstone is burrowed and cross bedded.

Throughout south-central Wyoming the member contains a lower unit of massive cliff-

EXPLANATION OF PLATE 3

Fig. 1 -- Minnekahta. Surface of the Canyon Spring Sandstone pitted with oyster fragments.
Fig. 2 -- Minnekahta. Oscillation ripples in the Hulett Sandstone.
Fig. 3 -- Rapid City. Ripple-mark sets in the Hulett Sandstone.
Fig. 4 -- Rapid City. Ripple marks and centrally furrowed trail marks in the Hulett Sandstone.

PLATE 3

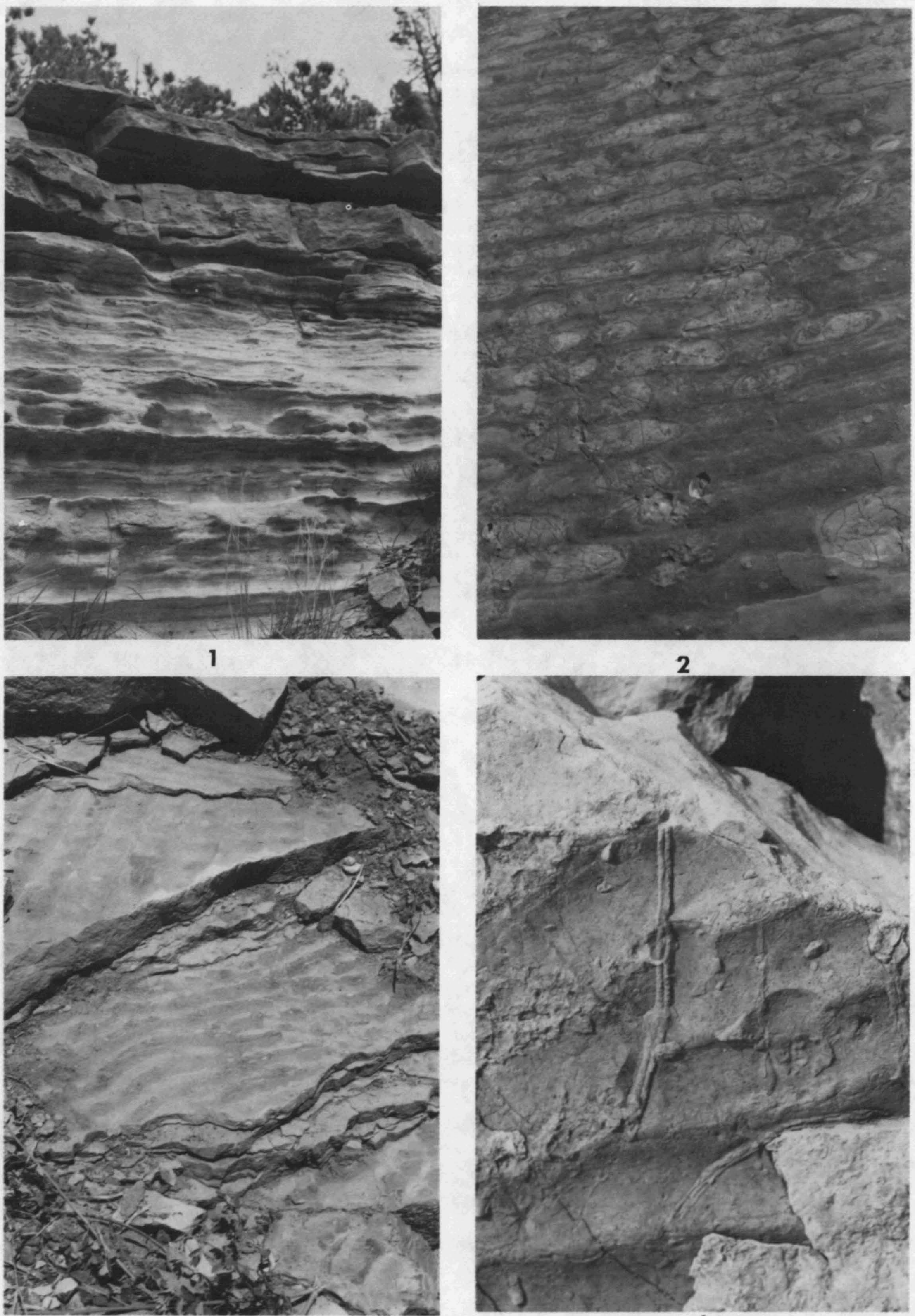


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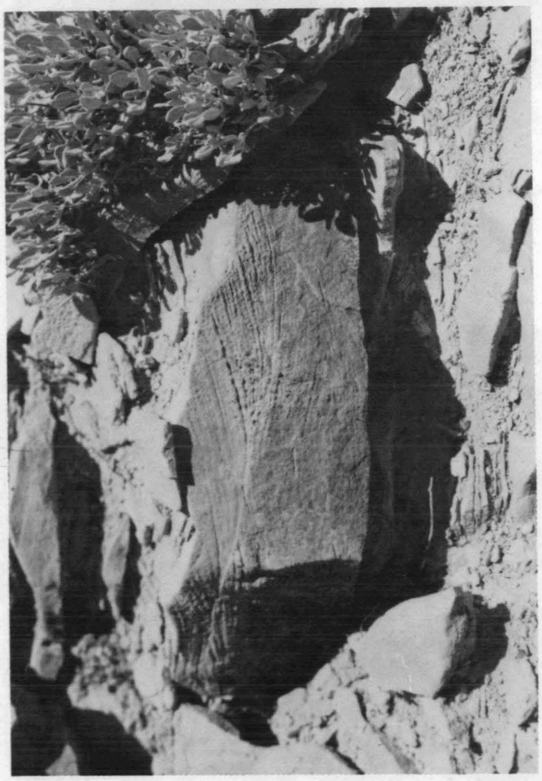
PLATE 4



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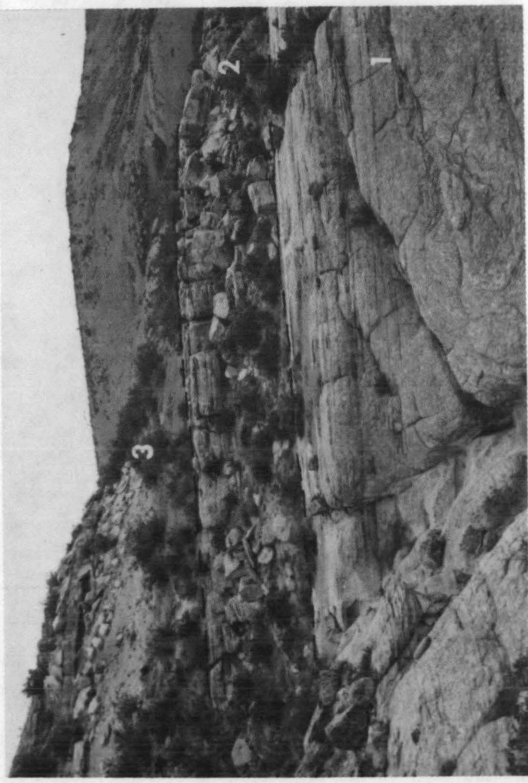

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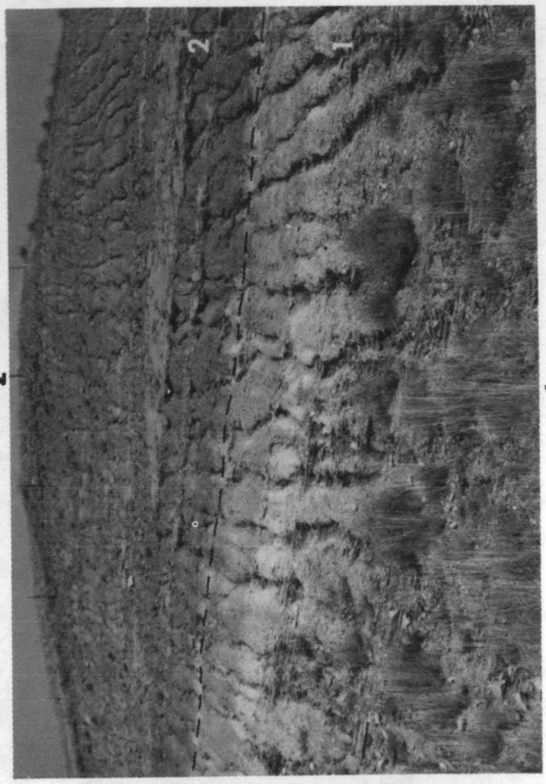

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forming cross bedded sandstone (pl. 1, fig. 2) and an upper unit of thin-bedded rippled oolitic sandstone. The member at Alcova is overlain by the Stockade Beaver Shale but further to the south, at Freezeout Mountains and Seminoe Dam, the Canyon Spring Sandstone is directly overlain by Hulett Sandstone, because the Stockade Beaver Shale is not present this far south.

The geographic distribution of the Canyon Springs Sandstone throughout south-central and eastern Wyoming and the Black Hills and the fact that it is lateral gradational with the Stockade Beaver Shale in the Rattlesnake Hills (Pipiringos, 1968) suggests that it represents a near-shore to terrestrial facies of the Stockade Beaver Shale that developed along the southeastern shoreline during early Callovian time.

Chert pebbles are concentrated at the base of the lower massive sandstone unit (Freezeout Mountains) or the base of the upper platy sandstone unit wherever the lower sandstone unit is absent (Alcova). These chert pebbles are also found at the base of the Stockade Beaver Shale in Lander, Wyoming, and in the Black Hills.

Pipiringos (1968) has interpreted this chert horizon as marking a period of major regional uplift and erosion after the deposition of the Gypsum Spring Formation and prior to the deposition of Stockade Beaver Shale and Canyon Spring Sandstone. He interprets the chert as lag gravels from erosion of a large section of lower Jurassic and Triassic strata. On the contrary, the Gypsum Spring Formation onlaps the Nugget Sandstone and was not uplifted and truncated as proposed by Pipiringos (Green, 1970).

The chert pebbles represent the initial high-energy deposit formed during transgression of the sea across the Wyoming platform in early Callovian time after deposition of the Gypsum Spring Formation.

Stockade Beaver Shale Member. -- The Stockade Beaver Shale occurs stratigraphically above either the Canyon Spring Sandstone or Gypsum Spring Formation (wherever the Canyon Spring Sandstone is absent) and below the Hulett Sandstone.

In the Black Hills, the predominant lithology is gray shale. In the upper part of the member are beds of thin-bedded burrowed and ripple-marked sandstone containing bivalve shell fragments that were current deposited (pl. 2, fig. 5). The sandstone beds reflect the close proximity of the eastern shoreline in the Black Hills. Farther west at Douglas (pl. 1, fig. 4) and Alcova medium-gray shale predominates.

In the Black Hills and eastern Wyoming Meleagrinella curta dominated the bivalve fauna. It is replaced by the Gryphaea nebrascensis fauna in western and northern Wyoming.

To the south in the vicinity of Seminoe Dam and the Freezeout Mountains the member is not present (pl. 4, fig. 3). It is absent as far west as the Green Mountains (Pipiringos, 1968). The southern limit of Stockade Beaver Shale deposition apparently was just north of these southern outcrops and south of Alcova.

At Bull Lake, Maverick Spring, and Vinceant Ranch the member is varied. A bored surface is present at the top of a lower limestone unit at Vinceant Ranch (pl. 7, fig. 1). This bored surface indicates that the lime muds at Vinceant Ranch underwent subaerial lithification prior to being bored by clams. At Bull Lake the lower part of the member includes sandy oosparite (pl. 2, fig. 4), containing broken shell fragments and stringers of chert pebbles, biopelmicrite, poorly washed oopelsparite, and claystone. At Maverick Spring the lower oolitic sequence of the Stockade Beaver Shale consists of a variety of limestone (biopelmicrite, pl. 2, fig. 3; oobiosparite, pl. 2, fig. 2; and biosparite) and sandstone interbedded with claystone and shale. The limestone is burrowed, and contains bivalve, gastropod, bryozoan, and echinoderm fragments as well as bivalves in living position. The overlying shale is 60 feet thick and has the characteristic medium-gray to olive-gray color of the member as found in southeastern Wyoming and the Black Hills. Its contact with the overlying Hulett Sandstone is sharp but conformable.

EXPLANATION OF PLATE 4

Fig. 1 -- Douglas. Cross-bedding near the base of the Hulett Sandstone.
Fig. 2 -- Maverick Spring. Festoon cross-bedding at the top of the Hulett Sandstone.
Fig. 3 -- Freezeout Mountains. Upper thin-bedded sandstone of the (1) Canyon Springs Sandstone, (2) Hulett Sandstone, and (3) Lak Member.
Fig. 4 -- Rapid City. (1) Hulett Sandstone grading upward into (2) the Lak Member.

The lower oolitic sequence of the Stockade Beaver Shale at the Maverick Springs and Bull Lake area represents high energy deposits formed during early Callovian time when the water deepened over the Wyoming shelf during transgression.

Hulett Sandstone Member. -- The Hulett Sandstone forms relatively resistant sandstone ledges overlying the Stockade Beaver Shale or the Canyon Springs Sandstone (wherever the Stockade Beaver Shale is absent) and underlying the Lak Member or Redwater Shale (wherever the Lak is absent). Its lower and upper contacts with these members are conformable. The member has a wide geographic distribution from the Black Hills in the east, westward throughout south-central Wyoming.

In the Black Hills the thin- to medium-bedded sandstone of the Hulett Sandstone is oscillation and interference ripple-marked (which shows several sets of directions), cross-bedded, and centrally furrowed trail-marked (pl. 3, figs. 2-4; pl. 4, fig. 1). Shale inter-bedded with the sandstone (pl. 4, fig. 4) is commonly mottled maroon.

In southeastern Wyoming in the vicinity of Freezeout Mountains and Seminoe Dam, the Hulett Sandstone rests directly on Canyon Spring Sandstone. The Stockade Beaver Shale was not depostied this far south. The Hulett Sandstone at Freezeout Mountains forms relatively resistant beds of fine-grained, oscillation-rippled sandstone that is slightly cross bedded near the top.

At Maverick Spring the sandstone is locally burrowed, oolitic, and oscillation ripple-marked with the distance between crests being as much as 3 feet. The top of the Hulett here is strongly festoon cross-bedded in sets 1-2 feet thick with plan-view width of up to 4 feet (pl. 4, fig. 2; pl. 7, fig. 4). Current direction is predominantly north-south. Bedding planes are often covered with trail-marks.

The Hulett Sandstone characterized by oolites, oscillation and current ripples, cross-bedding (including festoon), trail-marks, and burrows, represents a shallow water deposit that formed throughout south-central and eastern Wyoming and the Black Hills. The water may have been only a few feet to several tens of feet deep as shallowing occurred across the Wyoming shelf following deposition of the Stockade Beaver Shale. The change in water depth may have been due to general uplift affecting the entire shelf. Similar sandstone within the "Lower Sundance" was deposited in northern Wyoming and sandstone, red siltstone, and oolitic sandy limestone of the Giraffe Creek Member of the Twin Creek Limestone was deposited in western Wyoming and southeastern Idaho at this time.

Lak Member. -- The Lak Member in the Black Hills is reddish-brown siltstone, sandy siltstone, and silty sandstone. Its contacts are conformable with the Hulett Sandstone below and the Pine Butte Member or Redwater Shale above.

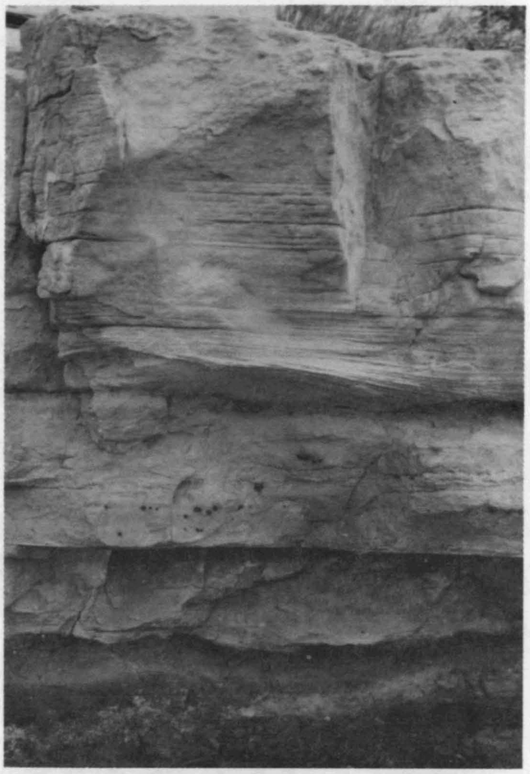
In south-central and eastern Wyoming the Lak may lose its reddish-brown to salmon color and be white to light tan in color and contain gypsum. At Freezeout Mountains the Lak Member is predominately light-gray sandstone, the lower portion of which is soft (pl. 5, fig. 2) and the top portion of which is ledge-forming (pl. 5, fig. 1), cross-bedded, and contains iron nodules. Gypsum is present at Alcova and gypsum stringers are common at Douglas. Farther west, in the Lander area, the Lak Member is typically red and maroon in color. It pinches out between Lander and Maverick Spring. It is not present in northern Wyoming.

Imlay (1947) suggested that the Lak's absence in northern Wyoming is due to either erosion of the red beds during post-Lak time or to deposition in that area of normal marine shale while the Lak redbeds were formed in the southern and eastern margin of the sea. The second interpretation seems more reasonable. There is no definite physical evidence (e.g., weathered surfaces, truncation, channeling) of a disconformity between the "Lower" and "Upper Sundance" in northern Wyoming, which would suggest that if the Lak were deposited in

EXPLANATION OF PLATE 5

Fig. 1 -- Freezeout Mountains. Cross-beds in the upper part of the Lak Member.
Fig. 2 -- Freezeout Mountains. White nonresistant sandstone of the Lak Member.
Fig. 3 -- Thermopolis. Entire exposure of the "Upper Sundance."
Fig. 4 -- Thermopolis. "Upper Sundance" sandstone covered with *Camptonectes bellistriatus*.

PLATE 5



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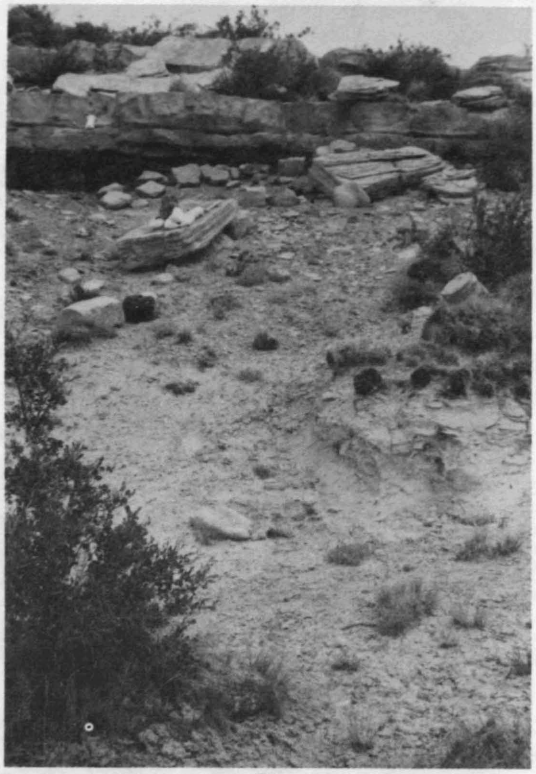

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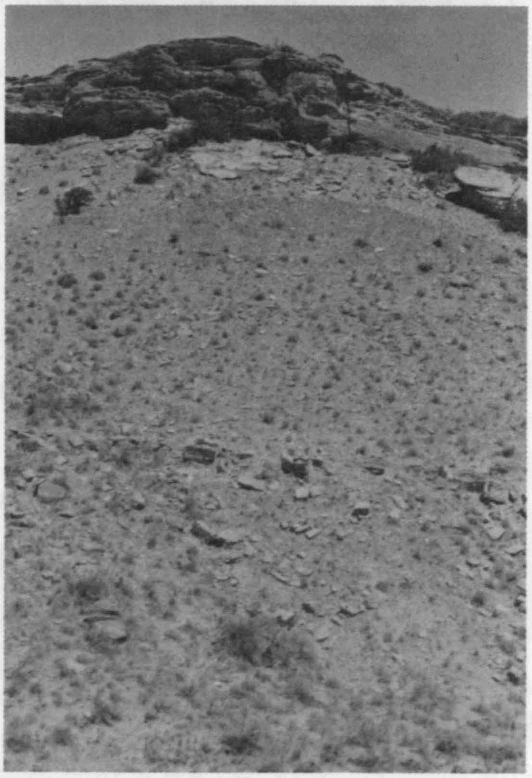

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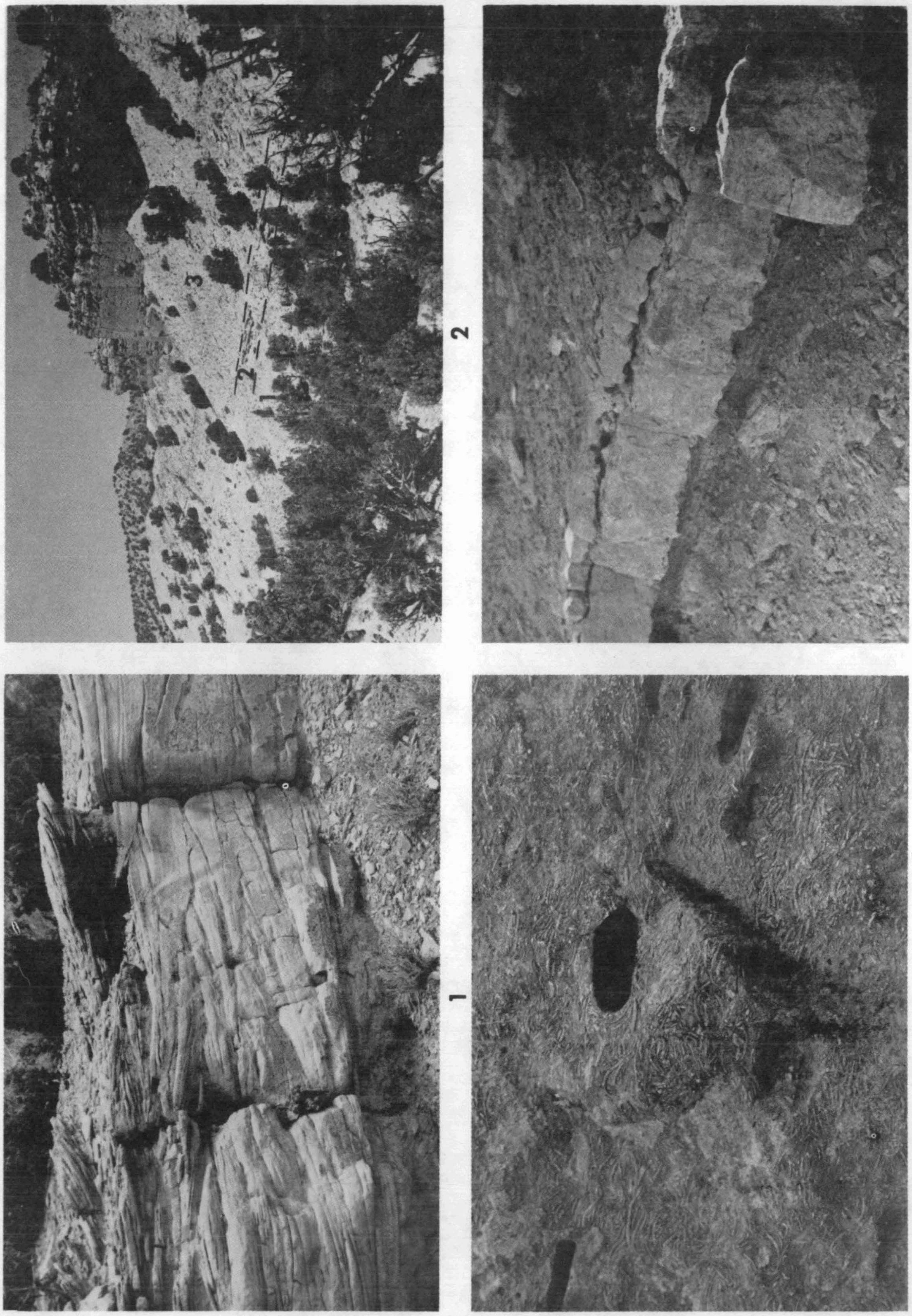
PLATE 6



northern Wyoming it was later removed by erosion. Also the Lak crops out only in south-central and eastern Wyoming and in the Black Hills. The water was shallow and the sea bottom flat on this part of the Wyoming shelf during early and middle Callovian. Minor fluctuations in sea level would have caused restricted circulation resulting in the gypsiferous Lak redbeds.

Pine Butte Member.-- The Pine Butte Member is used as defined by Pipiringos (1968) for light greenish-white ledge-forming sandstone, often interbedded with siltstone and olive-gray shale. It occurs stratigraphically between the Lak Member and Redwater Shale. Its geographic distribution includes the Black Hills and south-central and eastern Wyoming as far west as Sheep Mountain.

The Pine Butte Member contains a variety of sedimentary features. Some of the sandstone beds are extensively cross-bedded (Douglas and Freezeout Mountains, pl. 6, fig. 1), oolitic (Freezeout Mountains), burrowed (Douglas), and symmetrically ripple-marked, containing centrally furrowed trails (Freezeout Mountains and Alcova); some include broken oyster shells and crinoid columnals (Freezeout Mountains).

At these localities the Pine Butte Member is in sharp contact with the underlying Lak Member and the overlying Redwater Shale.

Pipiringos (1968) suggests that the Redwater Shale truncates the Pine Butte in south-central and eastern Wyoming and accordingly indicated a disconformity between the two. Plate 13 shows the Pine Butte's geographic restriction to southeastern Wyoming. The lateral thinning and pinching out at the Pine Butte may reflect its original areal extent of deposition rather than its extensive post-depositional erosion.

The sedimentary features and areal extent of the Pine Butte Member indicate that it is a marginal marine deposit which formed along the southern and eastern margin of the sea as the Wyoming shelf subsided in late Callovian time after deposition of the Lak beds. The Pine Butte may in part be a facies of the Redwater Shale.

Redwater Shale Member.-- The Redwater Shale Member is used as defined by Pipiringos (1968) for a sequence of clayey siltstone, clay shale, and beds of fossiliferous sandstone or limestone. It is widely distributed throughout the Black Hills and south-central Wyoming. In central and eastern Wyoming it varies very little in lithology and is predominantly shale and siltstone containing belemnites. Further west at Bull Lake and Maverick Springs the upper part of the member is glauconitic sandstone (pl. 6, fig. 2). The shale containing belemnites is still present at these localities (below the glauconitic sandstone) but it is much thinner than in central and eastern Wyoming and the Black Hills.

Fossiliferous beds are quite common in the Redwater Shale (pl. 6, fig. 3). Beds of oyster shells (pl. 8, fig. 1) and oyster-shell coquina occur at Newcastle and Freezeout Mountains. Camptonectes bellistriatus dominates the bivalve fauna throughout south-central Wyoming. Limestone (pl. 6, fig. 4; pl. 7, figs. 2 and 3; pl. 8, figs. 2-4) and sandstone beds are packed with their shells. The sandstone beds are often cross-bedded, ripple-marked, and burrowed. At both Alcova and Douglas there are clam-bored limestone cobbles covered with oyster spats near the top of the member. Such cobbles were not found at any other locality.

At Bull Lake and Maverick Springs, the member includes a proportionately greater amount of sandstone in its middle and upper parts. This sandstone is designated as the upper sandstone unit of the Redwater Shale. This sandstone is glauconitic throughout, contains belemnite shells in its lower part, contains Camptonectes bellistriatus beds, and is frequently cross-bedded and ripple-marked. The sandstone reflects a clastic source area to the west which also served as a source for the Preuss and Stump Sandstones. This upper cliff-forming sandstone is overlain by variegated shale of the Morrison Formation at Bull Lake

EXPLANATION OF PLATE 6

Fig. 1 -- Freezeout Mountains. Cross-bedded Pine Butte Member.
Fig. 2 -- Bull Lake. (1) Stockade Beaver Shale, (2) Hulett Sandstone, and (3) Redwater Shale.
Fig. 3 -- Douglas. Biosparite packed with bivalve shells occurring at the top of the Redwater Shale.
Fig. 4 -- Alcova. Camptonectes bellistriatus beds, Redwater Shale.

and by 40 feet of grayish-white sandstone that may be the Windy Hill Sandstone at Maverick Springs.

The Redwater Shale conformably overlies the Hulett, Lak, or Pine Butte Members and is overlain by either the Windy Hill Sandstone Member of the Sundance Formation or the Morrison Formation. Although the contact between the Redwater Shale and Windy Hill Sandstone is sharp, it appears to be conformable. The sequence of lithologic changes at Alcova -- from shale containing sandstone stringers and clam-bored limestone cobbles to silty sandstone to several limestone benches in the upper 20 feet of the Redwater Shale to oolitic rippled sandstone of the Windy Hill Sandstone -- suggests continued shallowing, as does the sequence at Seminoe Dam. There, cross-bedded sandstone and oolitic, ripple-marked limestone at the top of the Redwater Shale is overlain by oolitic, festoon cross-bedded sandstone of the Windy Hill Sandstone.

Windy Hill Sandstone Member. -- The Windy Hill Sandstone is used as defined by Pipiringos (1968). It consists of limy, oolitic, sparsely fossiliferous sandstone varying considerably in color, from gray-white to brownish-gray and shades of yellowish-brown. It is geographically distributed throughout south-central and eastern Wyoming, occurring between the underlying Redwater Shale and overlying Morrison Formation.

The type locality for the Windy Hill Sandstone is at the Freezeout Mountains (Pipiringos, 1968), where the member contains 12 feet of ledge-forming sandstone (pl. 12, fig. 3) that is symmetrically rippled and contains pebbles in its lower part. Elsewhere, the Windy Hill Sandstone is oolitic, cross bedded (pl. 9, fig. 1), and symmetrically ripple-marked (pl. 9, fig. 2). The Windy Hill Sandstone represents deposits formed during Oxfordian regression.

Sundance Formation of Northern Wyoming

"Lower Sundance". -- The "Lower Sundance" is used here as defined by Imlay (1956). The unit contains a lower sandstone member, a middle shale member, and an upper sandstone member. As shown on plate 14 the lower sandstone unit of the "Lower Sundance" is thickest at Lovell and Thermopolis (pl. 9, fig. 3). At these localities the member is not sandstone, but cross-bedded sandy oosparite (pl. 11, fig. 1) at Thermopolis and inter-bedded oolitic limestone and claystone at Lovell.

The middle shale member is well exposed throughout northern Wyoming. It is uniform in composition, predominantly soft calcareous olive-green shale. At Lovell, exposed bedding planes are covered with *Gryphaea nebrascensis* (pl. 10, fig. 1). The *G. nebrascensis* biofacies extends throughout western Wyoming. It does not occur at Thermopolis, Hyattville, or Tensleep. The middle shale member also thins at these localities. Imlay (1956) reports that it pinches out just northwest of Tensleep. The upper sandstone member thickens at Thermopolis, Hyattville, and Tensleep. Thickening of the upper sandstone member at the expense of the middle shale member, and the absence of *G. nebrascensis* at these localities reflects the presence of a topographic high in the Thermopolis-Tensleep-Hyattville area during early Callovian time (the Sheridan Arch of Peterson, 1957). The abrupt changes in macrofauna and microfauna to the north and south of the arch (text-figs. 9-11) also demonstrate the presence of a topographic high across the Wyoming shelf.

The upper sandstone member is well exposed at all localities except at Cody where a single sandstone ledge occurring near the top of the "Lower Sundance" may represent the westernmost extent of the member as it pinches out from the east. At Thermopolis the member is predominantly white or yellowish-tan calcareous fine-grained sandstone interbedded with medium-gray siltstone and gray shale (pl. 9, fig. 4). The sandstone is cross-bedded, interference and oscillation ripple-marked (pl. 10, figs. 2 & 3), and interbedded with sandy oosparite (pl. 11, fig. 2). At Tensleep the member is quite similar to that at Thermopolis and contains an oobiosparite bed packed with

EXPLANATION OF PLATE 7

Fig. 1 -- Vinceants. Bored surface in micrite near the bottom of the Stockade Beaver Shale.
Fig. 2 -- Alcova. *Camptonectes bellistriatus* beds in Redwater Shale. The vertically disposed valves represent a death position caused by current movement or opening of valves after death.
Fig. 3 -- Vinceants. *Camptonectes bellistriatus* beds in the Redwater Shale.
Fig. 4 -- Maverick Spring. Festoon cross-beds at the top of the Hulett Sandstone.

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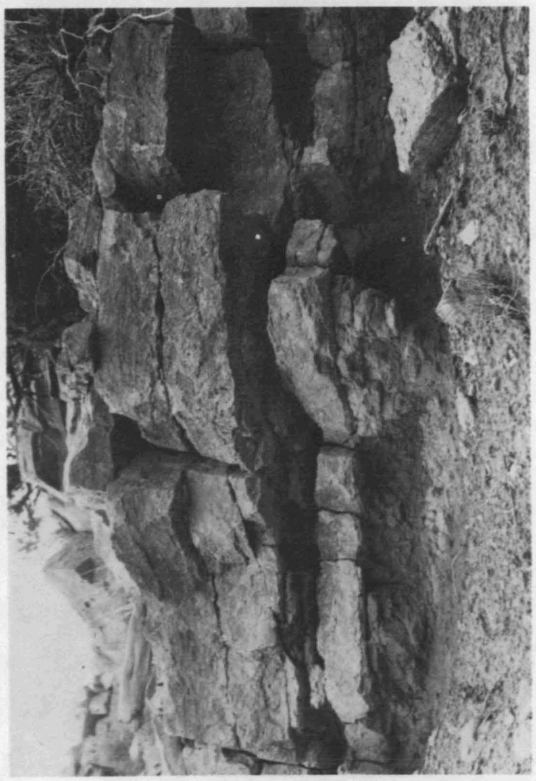

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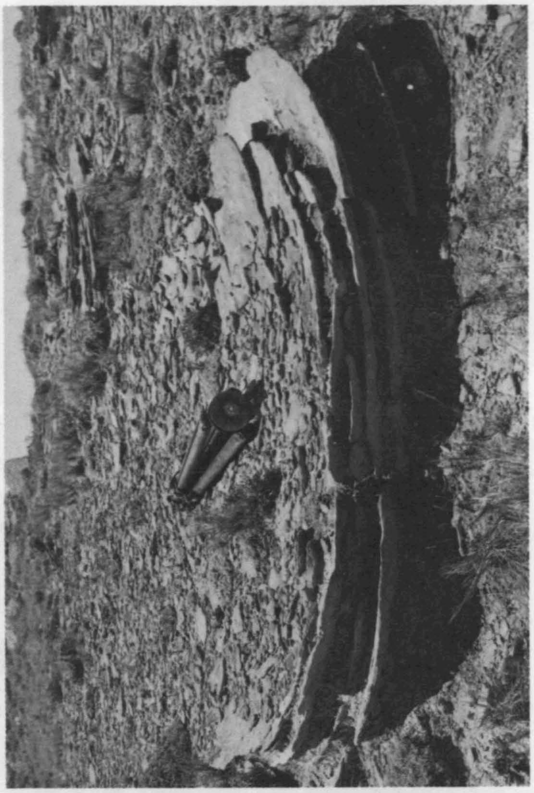

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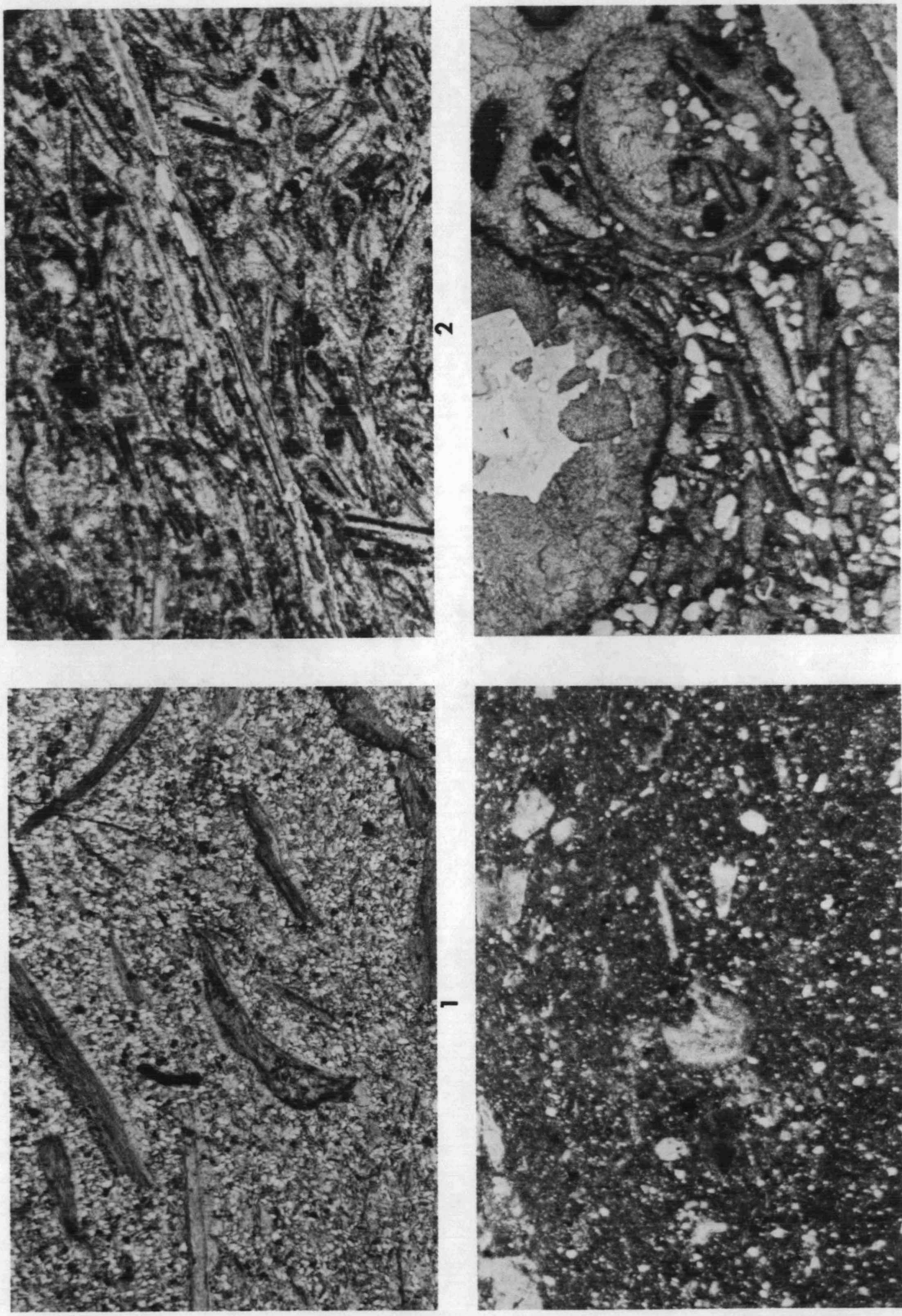
PLATE 8



bivalve fragments, pellets and intraclasts (pl. 11, fig. 3). At Lovell, oolites occur in stringers within the sandstone.

This upper sandstone member of the "Lower Sundance" is laterally continuous with the Hulett Sandstone Member as exposed in south-central Wyoming and like the Hulett Sandstone represents shallow water deposits formed during Callovian time.

"Upper Sundance."-- The "Upper Sundance" is used here as defined by Imlay (1956). It contains a lower shale member and an upper sandstone member along the east and south sides of the Big Horn Basin. At Cody, delineation of the lower shale member and upper sandstone member is not possible because sandstone is not restricted to the upper part of the "Upper Sundance."

The lower shale member is predominantly dark-green calcareous belemnite shale. The shale includes interbeds of limestone and sandstone, some of which contain Camptonectes bellistriatus (pl. 5, figs. 3 & 4), and other bivalves that are tightly packed together.

The upper sandstone member is predominantly glauconitic yellowish-brown sandstone that is often burrowed, cross-bedded, and symmetrically- and interference-rippled. Bivalve shell fragments and bivalve internal molds are quite common on bedding planes and within the sandstone (pl. 10, fig. 4). The upper sandstone member represents the last phase of marine sedimentation in Wyoming. The sedimentary features (cross-beds and ripple-marks) indicate shallowing of the water across the Wyoming shelf during early Oxfordian regression. The sands were derived from the west and were deposited along with the Stump Sandstone in western Wyoming.

Twin Creek Limestone

The Twin Creek Limestone was defined by Imlay (1967). He discussed the regional aspects of each member of the formation in terms of regional variations in lithology and paleontology. The two sections treated here are Cabin Creek and Ditch Creek.

In general, most members of the Twin Creek Limestone become thicker and more limy from Ditch Creek to Cabin Creek in the offshore direction.

Gypsum Spring Member. -- This is the lowest member of the Twin Creek Limestone. At both Ditch Creek and Cabin Creek it is predominantly light-pink vuggy brecciated limestone, but at Ditch Creek the top 10 feet of the member is red-brown calcareous shale that grades upwards into the overlying Sliderock Member.

Sliderock Member. -- At Ditch Creek the Sliderock Member contains 15 feet of brownish-gray calcareous silty shale overlain by 30 feet of blocky, medium-gray, oosparite (pl. 11, fig. 4) containing oyster fragments in its upper parts. At Cabin Creek the member is a very dark gray, platy splintery limestone.

Rich Member. -- At Ditch Creek it is a fairly homogeneous unit of calcareous shale with an occasional thin bed of black micrite. The bivalve fauna is dominated by Pleuromya subcompressa.

At Cabin Creek the member is thicker and the lithology is slightly more varied. The predominant lithology is a medium-gray splintery shaly limestone with several thin beds of dark-gray fossiliferous micrite (pl. 12, fig. 2) occurring in the lower 25 feet. The beds of fossiliferous micrite are frequently symmetrically rippled and covered with crinoid columnals indicating current action strong enough to transport skeletal debris. The bivalve fauna at Cabin Creek is dominated by Camptonectes stygius.

The Rich Member is correlative to the middle claystone and limestone unit of the Gypsum Spring Formation in northern Wyoming.

EXPLANATION OF PLATE 8

All photomicrographs x 5

Fig. 1 -- Calcareous fossiliferous glauconitic sandstone. Fossil fragments are oysters. Redwater Shale of the Sundance Formation. Newcastle.
Fig. 2 -- Poorly washed biosparite. Bivalve fragments are C. bellistriatus. Redwater Shale of the Sundance Formation. Alcova.
Fig. 3 -- Sandy biomicrite. Redwater Shale of the Sundance Formation. Alcova.
Fig. 4 -- Sandy biosparite. Redwater Shale of the Sundance Formation. Vinceants.

The transition of the P. subcompressa fauna to the Trigonia americana fauna of the Gypsum Spring Formation is discussed later in the text.

Boundary Ridge Member. -- This member of the Twin Creek Limestone is predominantly maroon calcareous silty shale at both Cabin Creek and Ditch Creek, but at Cabin Creek limestone occurs in the lower part of the member. The limestone beds commonly contain shell fragments, pellets, and intraclasts. Evidence of a soft-bodied bottom fauna is indicated by sand-filled burrows (p. 12, fig. 4).

Watton Canyon Member. -- This member at Ditch Creek is brownish-gray to gray calcareous siltstone overlain by medium-bedded oolitic limestone. The Watton Canyon Member is thicker at Cabin Creek, where the limestone includes oosparite and biomicrite and is occasionally symmetrically ripple-marked.

Leeds Creek Member. -- At Cabin Creek this member consists of about 340 feet of predominantly light-gray splintery shaly limestone. Occurring regularly throughout the member are thin beds of dark-gray micrite and sandy biosparite which is burrowed and packed with shell fragments (pl. 12, fig. 1). The most distinctive bed is an encrinal limestone, which occurs near the top of the member.

At Ditch Creek, 128 feet of Leeds Creek Member are exposed. This may not be the true thickness, since the slope is slumped. It may be of the same order of thickness as at Lower Slide Lake where it is 163 feet thick. The member is homogeneous throughout and consists of medium-gray calcareous shale. Gryphaea nebrascensis which is common to the Stockade Beaver shale and the "Lower Sundance" occurs in the Leeds Creek Member.

Giraffe Creek Member. -- The top member of the Twin Creek Limestone is the Giraffe Creek Member. It occurs at Cabin Creek but not at Ditch Creek. The lithology is silty slabby limestone which is overlain by light greenish-gray and salmon-colored, very platy, symmetrically rippled, calcareous siltstone of the Preuss Sandstone.

Preuss and Stump Sandstones

The overlying Preuss and Stump Sandstones are western deposits time equivalent to the upper part of the Sundance Formation. They represent a variety of prodelta or tidal flat deposits (Preuss Sandstone) and shallow marine sand banks and bars (Stump Sandstone) (Mary Hileman, 1969). Some of the beds are packed with shell fragments and are very calcareous.

BIVALVE PALEOAUTECOLOGY

Thirty-two genera and 38 species of bivalves were collected from the Twin Creek Limestone, Gypsum Spring Formation, and Sundance Formation. They represent five feeding groups: infaunal siphon feeders; labial-palp deposit feeders; infaunal nonsiphonate suspension feeders; infaunal mucus-tube feeders; and epifaunal suspension feeders. Text-figure 4 summarizes their abundance, life mode, and substrate reference. The bivalves are listed in their respective superfamilies inasmuch as bivalve workers generally agree that the superfamilies represent natural groupings of related taxa. The superfamilies recognized in this paper are those from the Treatise of Invertebrate Paleontology, Part N. Bivalve natural associations and paleobiogeography are discussed later in the text.

Labial palp deposit feeders. -- Recent species of Nucula are very shallow depth slow-burrowing nonsiphonate infaunal bivalves that remain relatively stationary once buried. Food is gathered directly from the sediment by labial palps since the animals do not have incurrent or excurrent siphons (Yonge, 1939; Drew, 1901). Jurassic Nucula (text-fig. 5) probably had a similar life mode and were vertically positioned in the substrate, as is common with protobranchs (Driscoll, 1964). They were collected from shale in the Stockade Beaver Shale and Redwater Shale suggesting that Nucula sp. preferred a mud substrate.

Epifaunal suspension feeders. -- Modiolus subimbricatus and Mytilus whitei represent the Mytilacea. These epifaunal suspension feeders (text-fig. 5) were closely attached to the substrate and held firm by a byssus. The predominant occurrence of M. subimbricatus and M. whitei in oolitic deposits indicates that they inhabited turbulent water. M. subimbricatus characteristically occur in small local populations made up of tightly packed individual shells. Although occurring in limestone of the Twin Creek Limestone and in shale of the Gypsum Spring Formation and Stockade Beaver Shale, they are more common to oolitic claystone in the lower sandstone member of the "Lower Sundance." M. whitei was also gregarious. At Thermopolis a small population occurs in an oolitic sandstone in the "Lower Sundance." At Cody their shells make up an entire thin bed within a matrix of calcareous sand of the Gypsum Spring Formation.

Gervillia montanaensis and Isognoman perplana represent the Pteriacea. Recent Isognomon are firmly attached to the substrate by a byssus. The flat anterodorsal border of I. perplana (text-fig. 5) suggests that it was permanently attached by means of a byssus. G. montanaensis is common in limestone of the Rich Member at Lower Slide Lake, where it occurs in pods made up of several individuals. Generally, recent Gervillia are free-swinging bivalves, attached to hard substrates or vegetation by means of a strong byssus (Kauffman, 1969). G. montanaensis may have been attached to vegetation on the sea floor or it may have occurred in local pods made up of several individuals (text-fig. 5), as in the case of pearl oysters. Several shells together would have added support on a soft mud substrate.

The Pectinacea include Meleagrinella curta, Camptonectes stygius, C. bellistriatus, C. platessiformis, and Plicatula sp. Meleagrinella curta is the second most abundant bivalve collected. It can be found throughout the Sundance Formation but it is most abundant in the Stockade Beaver Shale in south-central and eastern Wyoming (text-fig. 9). It occurs flat-lying predominantly in shale deposits but is commonly found on siltstone or sandstone bedding planes. It was an epifaunal suspension feeder that may or may not have been weakly attached to the substrate by a byssus (text-fig. 7). Although a deep, auricular sulcus truncates the anterior dorsal margin of the right valve, the byssal opening remains small.

Camptonectes were also flat-lying epifaunal suspension feeders (text-fig. 5). They were byssally attached by the right valve, as indicated by the presence of a deep byssal notch in the right auricle. The dominant species in western Wyoming was C. stygius, which is abundant in limestone and limy shale of the Rich, Watton Canyon, and Leeds Creek Members at Cabin Creek. Its slightly convex, subcircular valves were well suited to lying on a soft mud bottom. This disk-shape prevented the animal from nestling too far down into the substrate and becoming passively buried. C. stygius or C. platessiformis, which lived on a mud substrate, might have solved the problem of silting-in by maintaining a strong byssal attachment which would elevate the posterior commissural border above the substrate, as in the case of some species of Pinctata (Herdman, 1903).

Plicatula sp., occurring with C. stygius and C. platessiformis, solved the problem of becoming passively buried by possessing radial corrugations and possibly spines (indicated by the presence of pits used for spine attachment), which raised the commissure slightly above the substrate (text-fig. 7).

C. bellistriatus occurs throughout northern, central, and eastern Wyoming and is the dominant bivalve in the Redwater Shale and "Upper Sundance." Unlike C. stygius and C. platessiformis, it was gregarious and apparently preferred a sand or shell substrate. A shell substrate provided a hard surface for byssal attachment and a settling place for spat. In addition, it served to elevate the entire shell above the underlying silt or mud bottom. If the depth of the byssal notch is an indication of the strength of shell attachment, then C. bellistriatus was strongly anchored by its byssus. The animal commonly makes up complete beds in which the valves are tightly packed one on top of another. Occasionally, one can find a few valves that are vertically oriented, but this probably was the result of the valves opening after the animal died.

Recent Lima species are both swimmers and byssally attached nestlers. Byssally attached forms have their valves vertically disposed to the substrate (Studnitz, 1931). Yonge (1953a) indicates that it is the only monomyarian to do so. The subovate to oblique outline of L. occidentalis, as well as the presence of a long lunule resulting in a flat anterodorsal border, suggests that it was permanently attached by means of a byssus (text-fig. 6) to the muds of the Stockade Beaver Shale.

Members of the superfamily Ostreacea comprise the greatest number of epifaunal suspension feeders in the marine Jurassic deposits of Wyoming.

Gryphaea nebrascensis was the dominant bivalve in western and northern Wyoming during the early Callovian.

Superfamily	Species	Substrate Preference	Abundance	Feeding Type
Nuculacea	Nucula sp.	mud	72	Labial palp deposit feeder
Arcacea	Grammatodon haguei	mud	4	Infaunal nonsiphonate suspension feeders
	Idonearca haguei	mud	1	
	Idonearca sp.	silty sand	1,m	
Pinnacea	Pinna kingi	mud	2	
Trigoniacea	Vaugonia conradi	silt or sand	29	
	V. sturgisensis	sand	7,m	
	Trigonia sp.	silt	1,m	
	T. americana	mud	2,Bp	
	Myopherella sp.	mud	4	
	M. montanaensis	mud	16	
Mytilacea	Modiolus formosus	sand	11	Byssiferous epifaunal suspension feeders
	M. subimbricatus	mud or silt	50,c	
	Modiolus sp.	mud to sand	1,m	
	Mytilus sp.	mud	3	
	M. whitei	sand or shell	20,f	
Pteriacea	Gervillia montanaensis	mud	19	
	Isognoman perplana	mud	1	
Limacea	Lima sp.	mud	2	
	L. occidentalis	mud	3,f	
Pectinacea	Meleagrinella curta	mud to sand	1,387;Bp	Byssiferous or cemented epifaunal suspension feeders
	Camptonectes stygius	mud	78,f	
	C. platessiformis	mud	51,f	
	C. bellistriatus	sand, silt, or shell	87,bf	
	Plicatula sp.	mud	12	
Ostreacea	Gryphaea nebrascensis	mud	3,382;f	Epifaunal suspension feeders
	G. planoconvexa	mud	68	
	Ostrea strigilecula	mud to sand	148,f	
	O. engelmanni	mud	2,f	
	Alectryonia procumbens	mud	400	

TEXT-FIG. 4 -- Bivalve feeding types and substrate preference. Numbers of specimens collected given in right column. f = shell fragments, Bp = molds on bedding planes, m = molds, bf = ledge forming, c = coquina beds. References for biology of superfamilies: Nuculacea (Drew, 1901; Yonge, 1939, Driscoll, 1964), Arcacea (Yonge, 1953a, 1955), Mytilacea (Field, 1922; Newell, 1942; Yonge, 1955), Pinnacea (Yonge, 1953b; Rosewater, 1961), Pteriacea (Yonge, 1953a & b), Pectinacea (Herdman, 1903; Dakin, 1928; Yonge, 1936, 1953a; Waller, 1969; Kauffman, 1969), Limacea (Studnitz, 1931; Lebour, 1937; Yonge, 1953a), Ostreacea (Yonge, 1960; Galtsoff, 1964; Rudwick, 1964; Kauffman, 1969), Trigoniacea (McAlester, 1965; Gould, 1968, 1969), Lucinacea (Allen, 1953, 1958; Kauffman, 1967), Crassatellacea (Saleuddin, 1965), Tellinacea (Yonge, 1949; Holme, 1961), Arcticacea (Forbes & Hanley, 1953; Saleuddin, 1964), Myacea (Yonge, 1946), Pholadomyacea (Runnegar, 1966), Pandoracea (Allen & Allen, 1955; Yonge, 1937, 1952).

Very young individuals of G. nebrascensis were cemented by the umbo of the left valve, as attested by the presence of a large flat attachment scar. The animal soon became free-living and during growth tilted toward the "ventral" margin so that the commissure was reoriented relative to the substrate. They lay sessile and embedded within the mud substrate (text-fig. 6). The deep convexity of the left valve, along with the upward growth of the ventral margin, insured that the commissure remained above the substrate. The posterior sulcus added stability to the shell on a mud substrate.

The life mode of G. planoconvexa was the same as G. nebrascensis. Although the shell is subcircular in outline and the left valve is only moderately convex, its flatness served the same purpose -- keeping the shell from passively settling too far down into the substrate -- as did the convexity of G. nebrascensis.

Alectryonia procumbens and Ostrea engelmanni are most restricted in their geographic distribution. Alectryonia procumbens was found only at Maverick Spring, where a local population occurs at the base of the Redwater Shale. Each animal was cemented by the umbo of the left valve to the shell of another individual (text-fig. 6). The most outstanding feature of the shell is the strong corrugations which may have served several purposes: to elevate the com-

Superfamily	Species	Substrate Preference	Abundance	Feeding Type
Lucinacea	Mactromya sp.	mud	2	Infaunal tube feeder
Crassatellacea	Astarte sp.	mud	2	Infaunal nonsiphonate suspension feeders
	A. packardi	mud or silt	13, Bp	
	A. meeki	mud	41	
	Prorokia fontenellensis	mud	3	
Tellinacea	Quenstedtia sp.	sand	11, Bp	Infaunal siphonate suspension or deposit feeders
	Q. sublevis	mud	5	
	Tancredia sp.	sand	36, Bp	
	T. transversa	sand	18, Bp	
	T. warrenana	sand	Bp	
Arcticacea	Pronoella sp.	mud	41	Infaunal siphonate suspension feeders
	P. cinnabarensis	mud or silt	40, bf	
Myacea	Corbula sp.	mud	4	
	C. munda	mud	Bp	
Pholadomyacea	Pholadomya sp.	sand	1	
	P. kingi	mud	14	
	Pleuromya sp.	mud to sand	16	
	P. subcompressa	mud	135	
	P. newtoni	silt or sand	21	
	Homomya gallatinensis	mud	2	
	Myopholas hardyi	mud	1	
Pandoracea	Platymyoidea sp.	sand	2	
	P. rockymontana	mud	2	
	Cercomya punctata	mud	1	
	Thracia weedi	mud	6	

missure above the substrate; to strengthen the shell; to stabilize the shell on the substrate; and possibly to increase the surface area of the mantle, thereby making respiration more efficient on a mud bottom. Ostrea engelmanni were flat-lying (text-fig. 6) and apparently required a hard substrate for attachment, because in the "Upper Sundance" at Thermopolis they were cemented by the left valve to valves of Camptonectes bellistriatus.

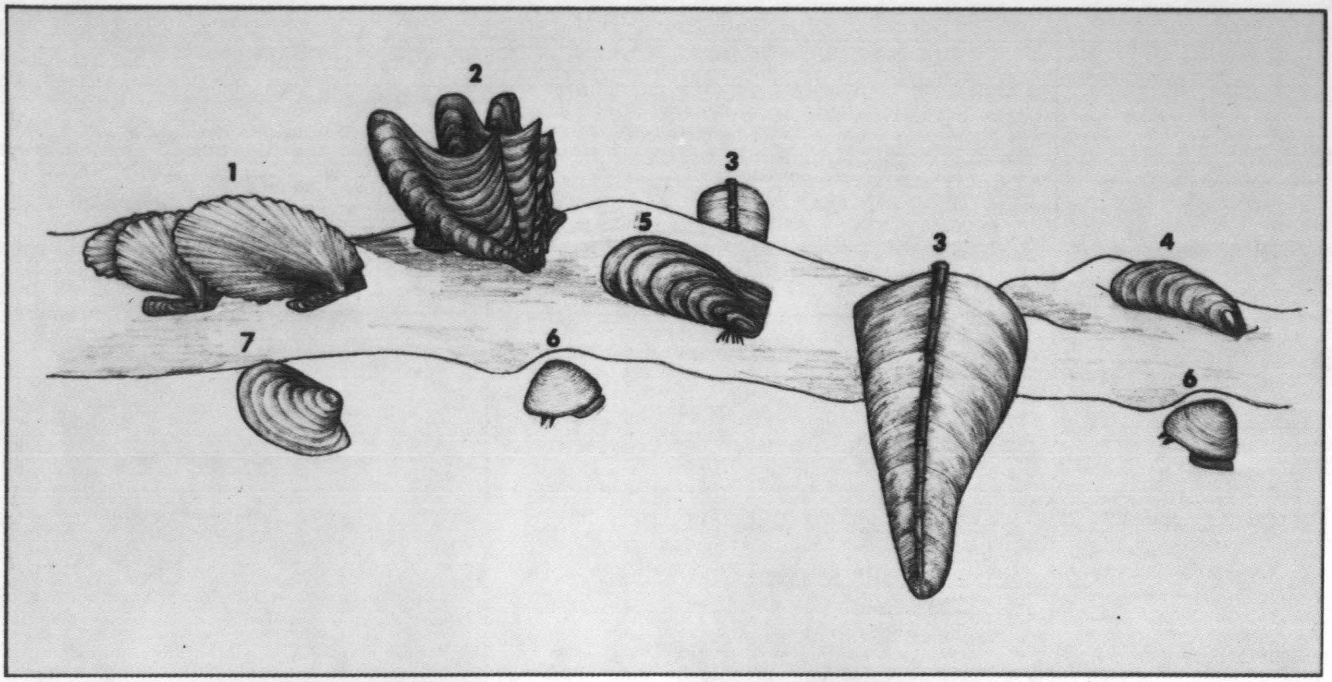
At Lovell and Tensleep fragments of O. engelmanni were found within a 10- to 15-foot interval in the "Upper Sundance." The producing bed was not located because of talus cover, but the concentration indicates that the shells must have weathered from locally developed oyster banks.

Infaunal nonsiphonate suspension feeders. -- This group is represented by the Pinnacea, Arcacea, Trigonacea, and Crassatellacea. Recent Pinna is more correctly called a semi-infaunal suspension feeder, because part of the posterior end of the shell projects above the substrate (text-fig. 5). The bivalve is sessile and may anchor itself to a shell fragment within the substrate by a byssus. Pinna kingi were found in living position in the Rich Member at Ditch Creek and Lower Slide Lake.

Many genera of the superfamily Arcacea (i.e., Arca) are epifaunal nestlers and byssally attached to the substrate (Yonge, 1953a, 1955). They characteristically possess a shallow mid-ventral concave reentrant marking the position of the large byssal gap. The shells are generally subquadrate and elongate. The shells of Grammatodon haguei and Idonearca haguei are more ovate; margins are closed along the entire commissure, and the venter is slightly convex, indicating the absence of a byssal reentrant. These species were therefore not epifaunal nestlers but probably had a life mode like Anadara, which has a similar shape. They are interpreted to having been infaunal nonsiphonate suspension feeders (text-fig. 5).

A similar life mode is present in the Trigonacea (text-fig. 6). The family Trigonidae consists of genera that are active free-living bivalves, equipped with a large muscular foot enabling them to burrow rapidly (Gould, 1968). They are infaunal nonsiphonate suspension feeders with the posterior margin of the shell at the sediment water interface (McAlester, 1965).

The Crassatellacea are represented by



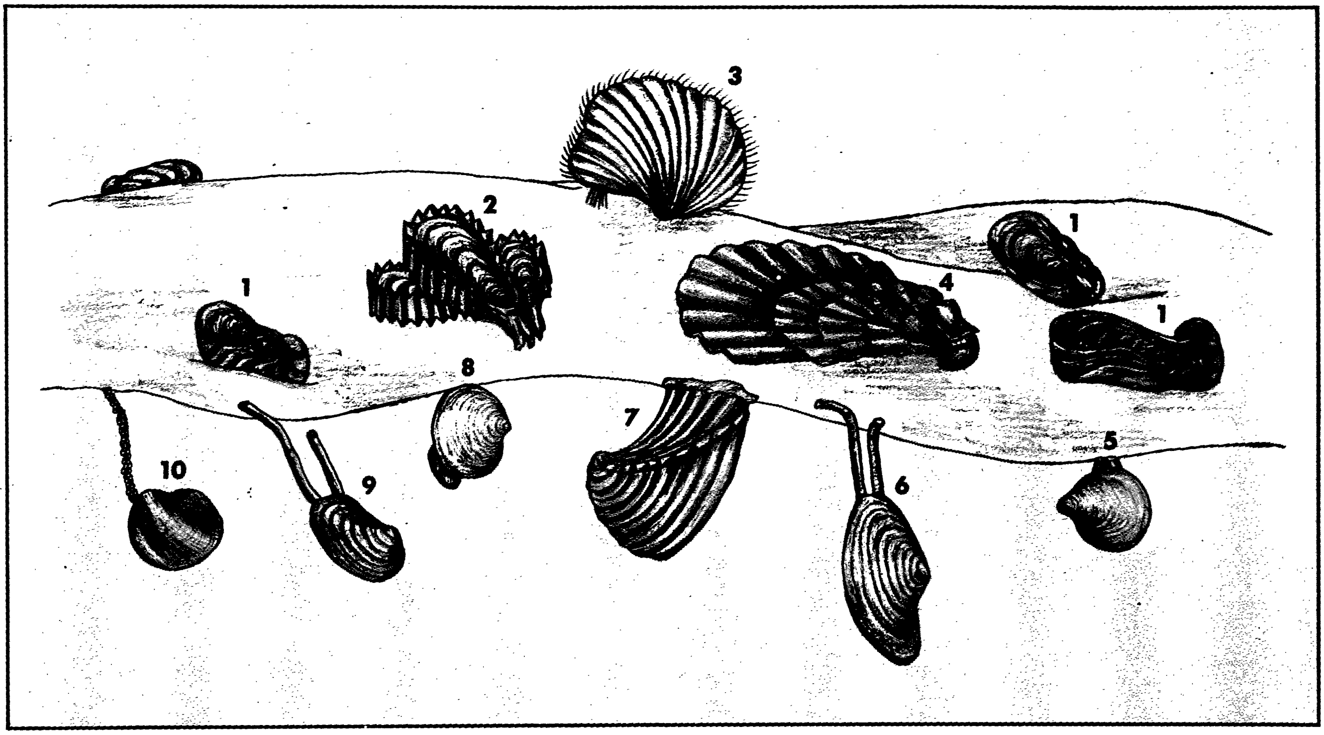
TEXT-FIG. 5 -- Bivalve life mode reconstructions. 1 - Camptonectes sp. (epifaunal suspension feeder). 2 - Gervillia montanaensis (epifaunal suspension feeder). 3 - Pinna kingi (semi-infaunal nonsiphonate suspension feeder). 4 - Modiolus subimbricatus (epifaunal suspension feeder). 5 - Isognomon perplana (epifaunal suspension feeder). 6 - Nucula sp. (labial palp deposit feeder). 7 - Grammatodon haguei (infaunal nonsiphonate suspension feeder).

Astarte meeki, A. packardi, Prorokia fontenellensis, and two poorly preserved specimens of Astarte sp. They were nonsiphonate suspension feeders (text-fig. 6). In recent Astarte the exhalant siphon extends about 2 mm out of the shell, but the mantle margin of the inhalant aperture is flush with the shell margin. They are shallow burrowers with the posterior shell margin flush with the sediment-water interface (Saleuddin, 1965).

Infaunal tube feeders. -- The one representative of this group is Mactromya? sp. It is rare; only two specimens were found, one from the Rich Member at Lower Slide Lake and the other from the lower part of the Stockade Beaver Shale at Maverick Springs. If the specimens are correctly identified as Mactromya, then they were equipped with a vermiform mucus-secreting foot which would construct the anterior inhalant respiratory and feeding tube like other Lucinacea (text-fig. 6) (Allen, 1953, 1958; Kauffman, 1967).

Infaunal siphonate suspension feeders. -- This feeding group includes the Tellinacea, Arcticacea, Myacea, Pholadomyacea, and Pandoracea. Recent Tellinacea are infaunal siphonate suspension or deposit feeders equipped with separate siphons, of which the inhalant siphon is the longer of the two and capable of sweeping the substrate for food (Yonge, 1949). They densely populate marginal marine and littoral environments, and may lie horizontally on one valve within the substrate or vertically within the substrate.

Jurassic Tellinacea, represented by Quenstedtia sublevis, Tancredia transversa, T. warrenana, Quenstedtia sp., and Tancredia sp., were all sand-bottom dwellers, and except Q. sublevis, are restricted to the Sundance Formation. Tancredia and Quenstedtia are reconstructed in a vertical position (text-fig. 6) because both lack a posterior lateral flexure, such as that commonly present in bivalves which lie on one valve. The sandstone bedding planes densely covered with molds of these genera may represent wave or storm-deposited shells rather than in situ populations of horizontally disposed individuals. Storm-wave action is able to churn up the upper few inches of littoral sand and dis-



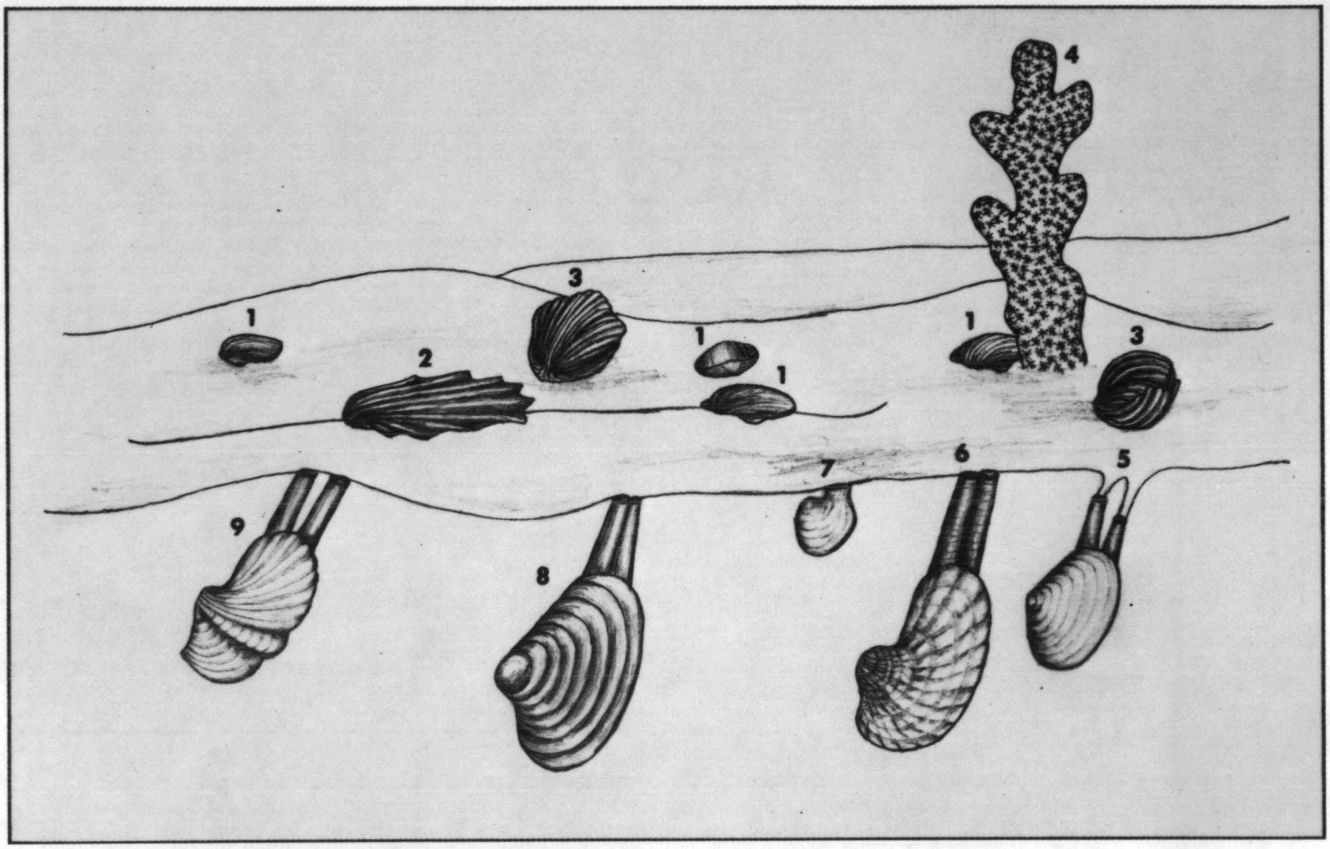
TEXT-FIG. 6 -- Bivalve life mode reconstructions. 1 - Gryphaea nebrascensis (epifaunal suspension feeder). 2 - Alectryonia procumbens (epifaunal suspension feeder). 3 - Lima occidentalis (epifaunal suspension feeder). 4 - Ostrea engelmanni (epifaunal suspension feeder). 5 - Pronoella cinnabarensis (infaunal siphonate suspension feeder). 6 - Tancredia warrenana (infaunal siphonate deposit feeder). 7 - Trigonia americana (infaunal nonsiphonate suspension feeder). 8 - Astarte meeki (infaunal nonsiphonate suspension feeder). 9 - Quenstedtia sublevis (infaunal siphonate deposit feeder). 10 - Mactromya sp. (infaunal tube feeder).

lodge the shallow-burrowing bivalve infauna.

P. cinnabarensis is interpreted to have been a shallow-burrowing siphonate suspension feeder (text-fig. 6). It occurred predominantly in dense populations in the Stockade Beaver Shale at Maverick Springs. Arcticia islandica (a taxonomic cousin with morphologic resemblance to Pronoella sp.) is a shallow burrower with short siphons extending 5 to 8 mm out of the shell (Saleuddin, 1964). Siphons are fused and the animal lives in a vertical position. The shell morphology of both Pronoella cinnabarensis and Arctica islandica is very similar, no doubt reflecting similarity in life habits.

Corbula munda was also a shallow-burrowing infaunal siphonate suspension feeder with the posterior shell margin close to the substrate surface (text-fig. 7). Recent Corbula are byssally attached. The robust shell aids in maintaining a stationary position.

The Pholadomyacea, represented by Myopholas hardyi, Homomya gallatinensis, Pleuromya subcompressa, P. newtoni, Pleuromya sp., Pholadomya sp., and P. kingi, are all burrowers (text-fig. 7). Pholadomya kingi, common only in the Rich Member of the Twin Creek Limestone, has an elongate shell with a flaring posterior siphonal gap indicating the relatively large size of the siphons. The animal was a deep burrower whose only movements may have been the retraction and extension of the siphons, like those in other deep burrowers such as Panope and Mya. Homomya gallatinensis is similar in shape to Pholadomya kingi and probably had the same life mode. Although Pleuromya subcompressa has a deep pallial sinus and a moderate posterior siphonal gap, it is not as elongate as Pholadomya kingi and may not have burrowed as deeply. The posterior siphonal gap of Myopholas hardyi suggests that it was also a relatively deep burrower.



TEXT-FIG. 7 -- Bivalve life mode reconstructions. 1 - Meleagrinella curta (epifaunal suspension feeder). 2 - Plicatula sp. (epifaunal suspension feeder). 3 - Kallirhynchia myrina. 4 - Actinastrea hyatti. 5 - Thracia weedi (infaunal siphonate suspension feeder). 6 - Pholadomya kingi (infaunal siphonate suspension feeder). 7 - Corbula munda (infaunal siphonate suspension feeder). 8 - Pleuromya subcompressa (infaunal siphonate suspension feeder). 9 - Cercomya punctata (infaunal siphonate suspension feeder).

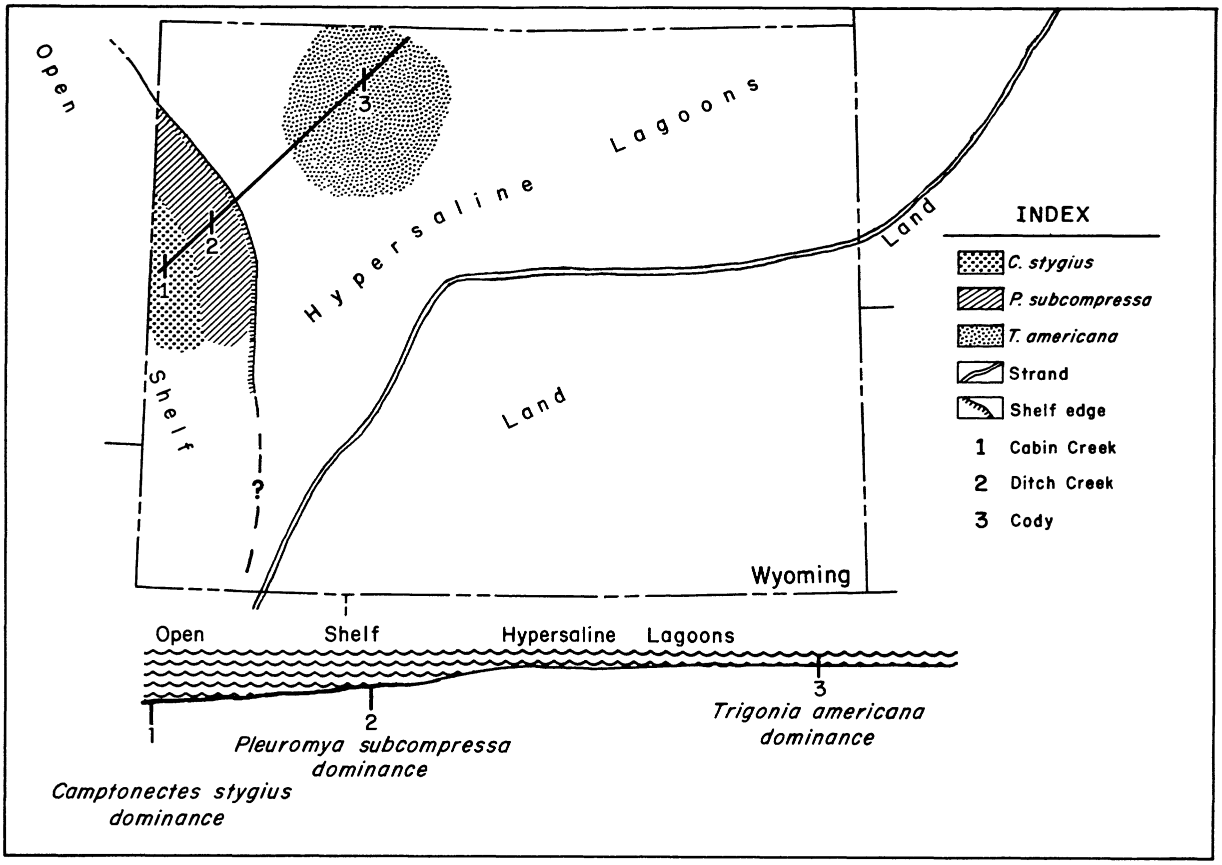
The majority of the Pandoracea are shallow burrowers, possessing short separate siphons which may or may not have built mucus-lined siphonal tubes (Allen & Allen, 1955; Yonge, 1937, 1952). The separated siphons were probably not used for the same purposes as those in the Tellinacea, which actively sweep the bottom sediments with the incurrent siphon, but for building the mucus-lined tubes. The Pandoracea may be vertically or horizontally disposed beneath the substrate.

Yonge (1937) has discussed the mucus-secreting habit of the Recent Thracia pubescens. T. weedi probably had the same life mode (text-fig. 7). The compressed shell of T. weedi indicates that the animal was stream-lined for rapid burrowing in a relatively firm mud substrate and capable of frequently moving about constructing new mucus-lined funnels. Platymyoidea rockymountana and Cercomya punctata (text-fig. 7) are more inflated than T. weedi. This may indicate that they were slower or shallower burrowers or both.

The coral Actinastrea hyatti and the rhynchonellid brachiopod Kallirhynchia myrina are included in text-fig. 7 because they made up a dominant part of the epifauna in their respective localities. A. hyatti is abundant in the Gypsum Spring Formation at Cody and K. myrina is common to sandstone deposits within the Redwater Shale Member at Maverick Springs and Bull Lake and the Stump Sandstone farther to the west.

JURASSIC PALEOENVIRONMENTS

The spatial and temporal distribution of sedimentary environments and fauna has been determined for Middle and Late Jurassic time

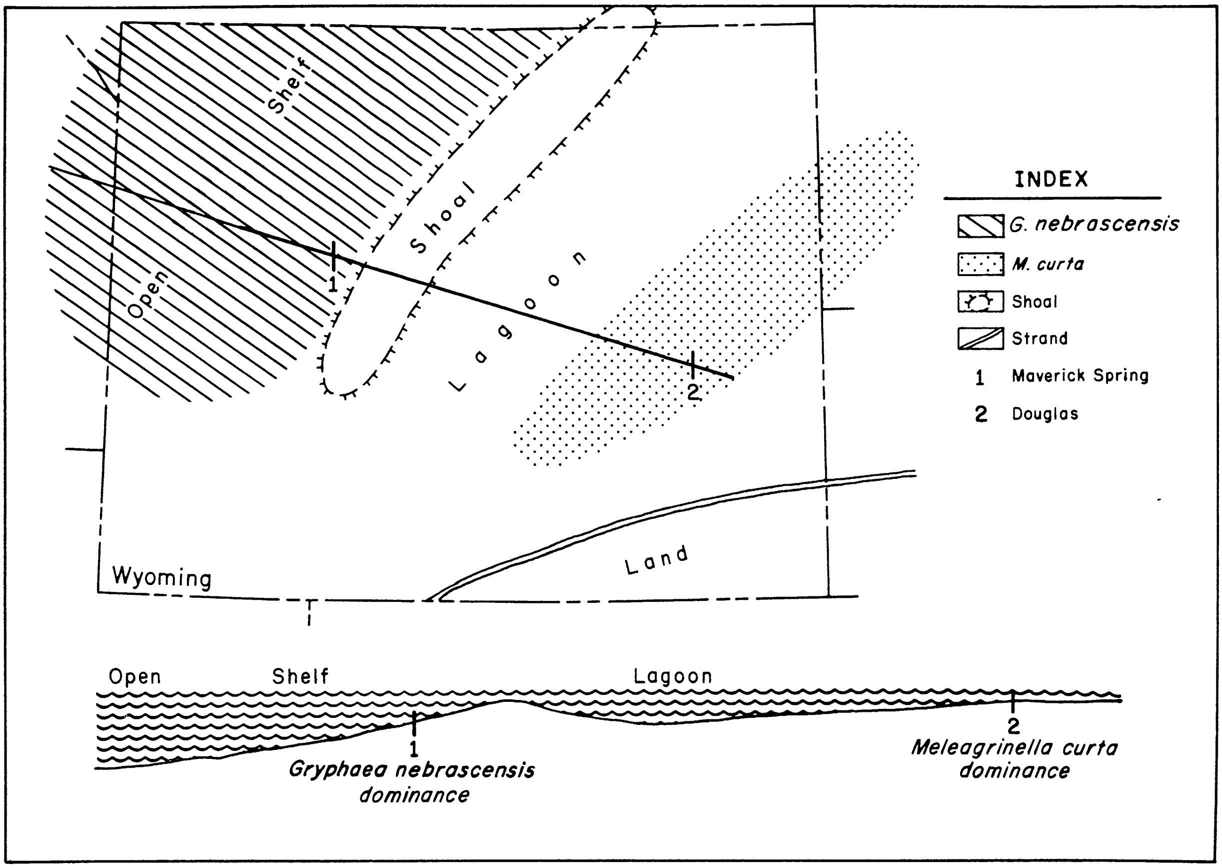


TEXT-FIG. 8 -- Bajocian paleogeography and bivalve paleobiogeography.

(text-figs. 8-13). Natural associations of bivalves were defined on the basis of their geographic and stratigraphic recurrence and relative abundance. A particular association is named after the dominant taxon (i.e., Camptonectes stygius dominance). Individual taxa, although common to one association, may not be restricted to that one particular association but may occur in others. The use of recurrent species in recognizing associations is in accordance with Peterson's (1914) concept of marine bottom communities, which forms the basis of most bottom marine ecology (Thorson, 1957).

The usefulness of microfossils in paleoenvironmental studies is well established. Distribution of the major groups of foraminifera (arenaceous, hyaline, porcelaneous) is useful in mapping changes in bathymetry, salinity, and temperature (Bandy, 1956, 1960; Greiner, 1970; Walton, 1964). Greiner (1970) has shown that bathymetry, salinity, and temperature in the Gulf of Mexico determine the availability of $CaCO_3$ which is used in shell construction by the foraminifera. In general, normal saline, shallow, warm water has more available $CaCO_3$ than low saline, deep, cold water.

Arenaceous foraminifera are more abundant than calcareous (hyaline and porcelaneous) foraminifera wherever the $CaCO_3$ content of sea water is low, because calcareous foraminifera utilize $CaCO_3$ for shell secretion. Because arenaceous and calcareous (hyaline) foraminifera are well represented in Jurassic deposits in Wyoming and South Dakota, possible changes in water depth, salinity, and temperature may be determined. Changes in faunal dominance and faunal diversity were also useful. Walton (1964) defined faunal dominance as "the percentage occurrence of the most common species in a foraminiferal population." In nearshore environments the foraminiferal population characteristically has many individuals of one or a few species. Faunal diversity (the number of species) increases offshore.



TEXT-FIG. 9 -- Early Callovian paleogeography and bivalve paleobiogeography.

The use of ostracods as paleoecologic indicators, along with the ecology of recent forms, has been discussed at length by Puri and others (1964).

Ostracods are more abundant in numbers of individuals in marginal marine environments. The number of species increases away from the shoreline (Swain, 1955). Limited data also suggest that the foraminifera/ostracod ratio is lowest near shore (Bandy, 1964; Upshaw et al., 1966), and that ostracods dominate the microfauna to the exclusion of foraminifera in hypersaline lagoons (Upshaw et al., 1966).

Similar trends in Middle and Upper Jurassic ostracods have been useful in determining possible salinity and bathymetry changes in the Jurassic environments.

Middle Jurassic

Bajocian sedimentary environments. -- The Jurassic sea spread southward from the Arctic region in Early and Middle Jurassic times. Transgression extended only as far south as British Columbia in the Early Jurassic (Imlay, 1957) but reached the Wyoming area by the Middle Jurassic.

EXPLANATION OF PLATE 9

Fig. 1 -- Seminoe Dam. Cross-bedded Windy Hill Sandstone.
Fig. 2 -- Alcova. (2) Ripple-marked Windy Hill Sandstone overlying (1) the top of the Redwater Shale.
Fig. 3 -- Thermopolis. Lower sandstone member of the "Lower Sundance."
Fig. 4 -- Thermopolis. Sundance Formation. (1) Middle shale member and (2) upper sandstone member of the "Lower Sundance." The (3) lower shale member and (4) upper sandstone member of the "Upper Sundance."

PLATE 9

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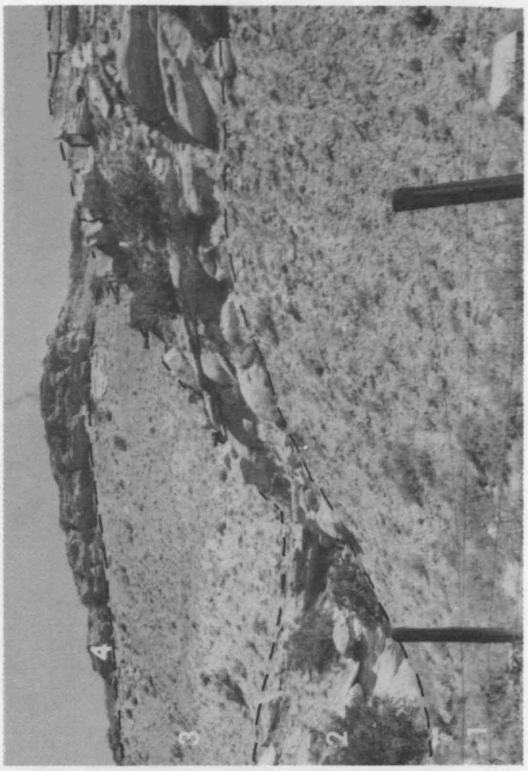

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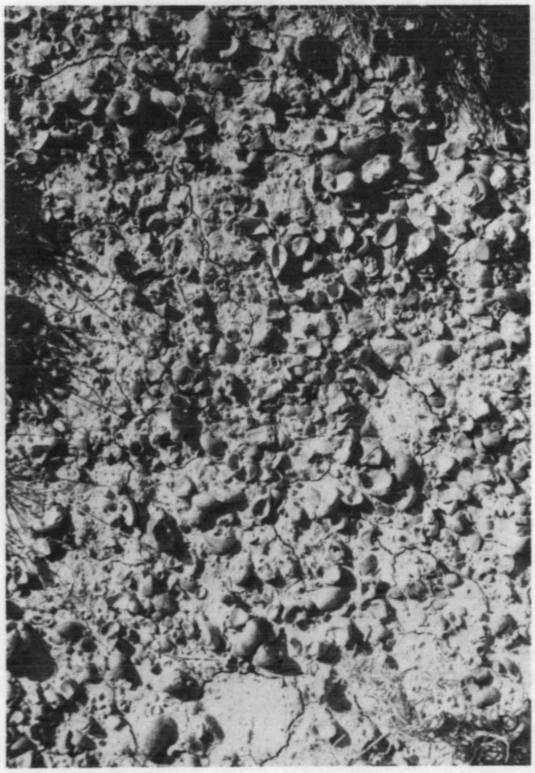
PLATE 10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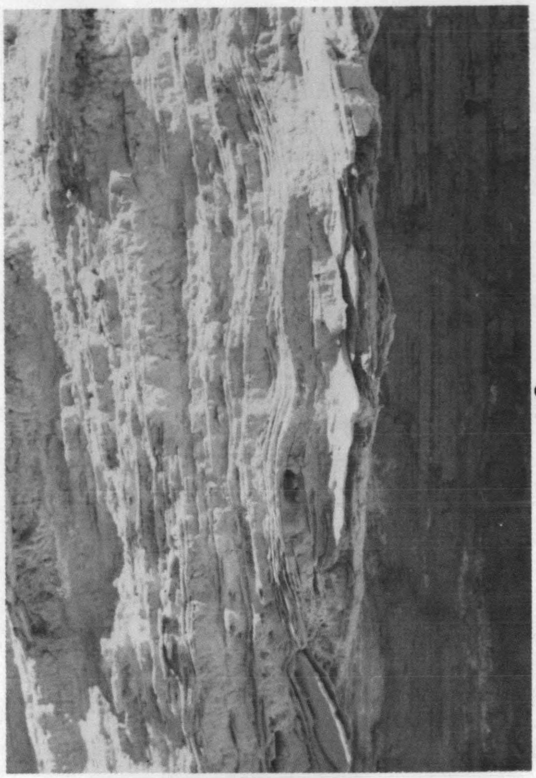
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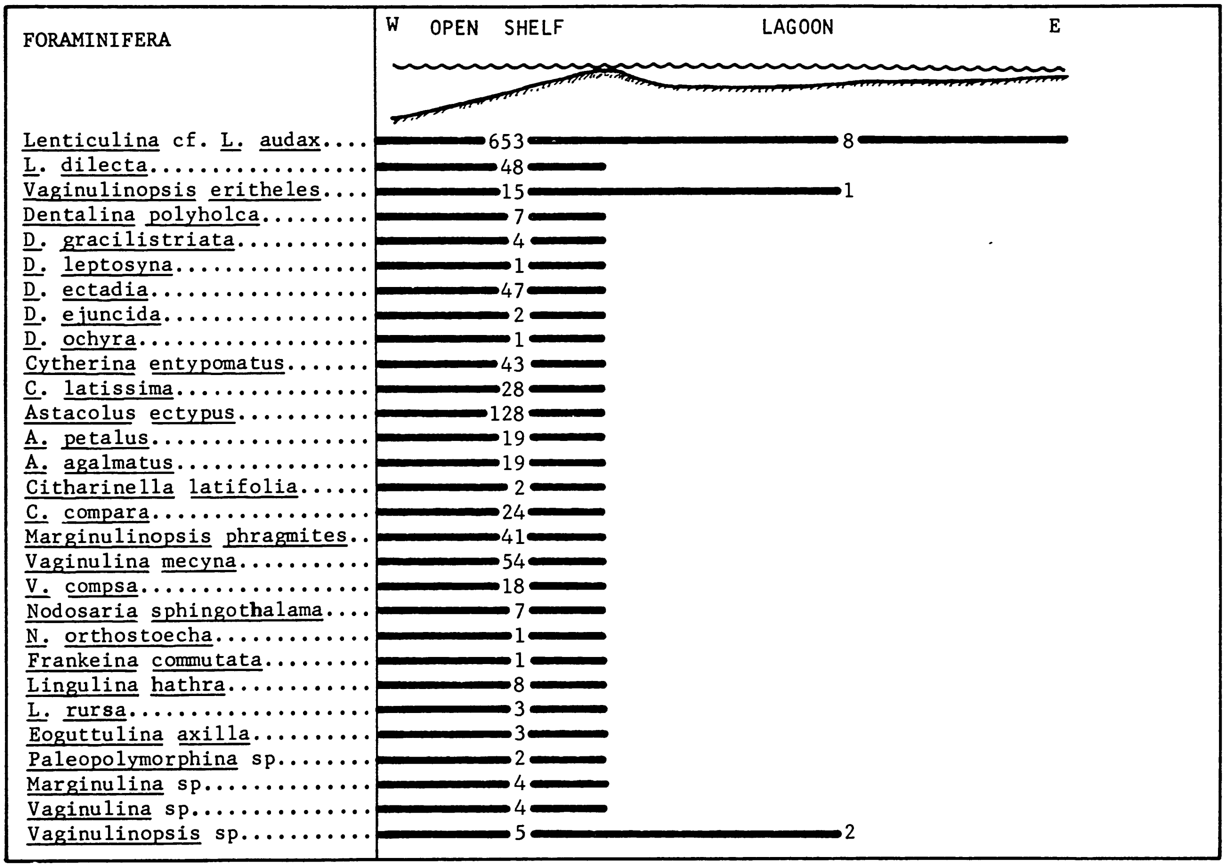


TEXT-FIG. 10 -- Paleobiogeography of early Callovian Foraminifera.

The sediments first deposited during Bajocian time indicate that hypersaline conditions were initially widespread. Gypsum and brownish siltstone of the Gypsum Spring Member of the Twin Creek Limestone in western Wyoming and gypsum and redbeds of the Gypsum Spring Formation throughout north-central and eastern Wyoming and the Black Hills region were deposited. Southeastern Wyoming was not submerged and was a lowland source area for fine sand and silt.

Further transgression or shelf deepening resulted in freshening the marine water in western and northern Wyoming as attested by the deposition of the limestone and shale in the Sliderock and Rich Members of the Twin Creek Limestone in western Wyoming, and limestone, shale, and claystone in the middle unit of the Gypsum Spring Formation in northern Wyoming. Gypsum and redbeds continued to be deposited in hypersaline lagoons in west-central Wyoming (text-fig. 8). Here, lagoonal, intertidal and supratidal environments persisted (Green, 1970). Flushing of the lagoons by sea water of normal salinity, which resulted in temporary cessation of evaporite deposition in the Big Horn basin area, did not occur in west-central Wyoming.

Westernmost Wyoming was the site of very

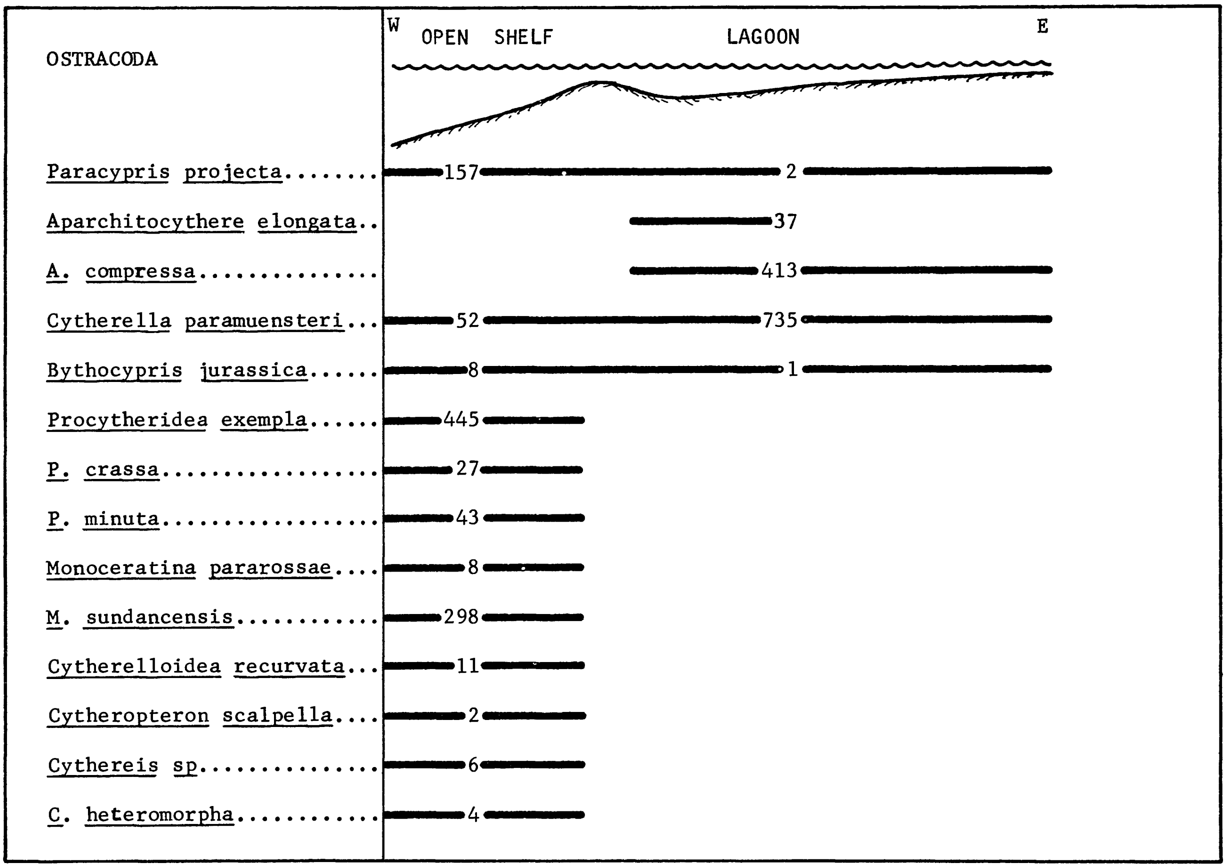
EXPLANATION OF PLATE 10

Fig. 1 -- Lovell. Gryphaea nebrascences covering exposed bedding planes of the middle shale member of the "Lower Sundance."

Fig. 2 -- Thermopolis. Thin-bedded ripple-marked sandstone in the upper sandstone member of the "Lower Sundance."

Fig. 3 -- Thermopolis. Ripple-marked sandstone in the upper sandstone member of the "Lower Sundance."

Fig. 4 -- Cody. Sandstone beds containing Tancredia sp. near the base of the "Upper Sundance."



TEXT-FIG. 11 -- Paleobiogeography of early Callovian Ostracoda.

rapid accumulation of lime mud and subsidence, which resulted in thick deposits of limestone. Oolites at the base of the Sliderock Member (Imlay, 1967) denote initial turbulent water conditions. Although the predominance of lime mud making up the Sliderock and Rich Members indicates that quiescent open-shelf conditions prevailed, several thin limestone beds containing intraclasts and broken shells suggests that either currents were strong or the water remained shallow enough for the sea bottom to be influenced by storms. Farther eastward (Ditch Creek and Lower Slide Lake) the rate of lime mud deposition or subsidence or both was not as great. The Sliderock and Rich Members are much thinner there than at Cabin Creek.

Bajocian bottom fauna. -- In westernmost Wyoming (i.e., Cabin Creek) the fauna was neither diverse nor abundant. It included the bivalves *Camptonectes stygius*, *Plicatula* sp., *Ostrea strigilecula*, *Gryphaea planoconvexa*, *Camptonectes platessiformis*, *Pleuromya subcompressa*, *Astarte meeki*, *Thracia weedi*, *Prorokia fontenellensis*, and *Corbula munda*.

Camptonectes stygius was the dominant bivalve (text-fig. 8). It lived in an area where lime mud was deposited rapidly. The rapid rate

EXPLANATION OF PLATE 11

All photomicrographs x 5

Fig. 1 -- Sandy oosparite. Lower sandstone member of the "Lower Sundance." Thermopolis.
Fig. 2 -- Sandy oosparite. Upper sandstone member of the "Lower Sundance." Thermopolis.
Fig. 3 -- Oobiosparite cut by oolitic sandstone. Oobiosparite contains bivalve fragments, pellets, and intraclasts. Upper sandstone member of the "Lower Sundance." Tensleep.
Fig. 4 -- Oosparite. Sliderock Member of the Twin Creek Limestone. Ditch Creek.

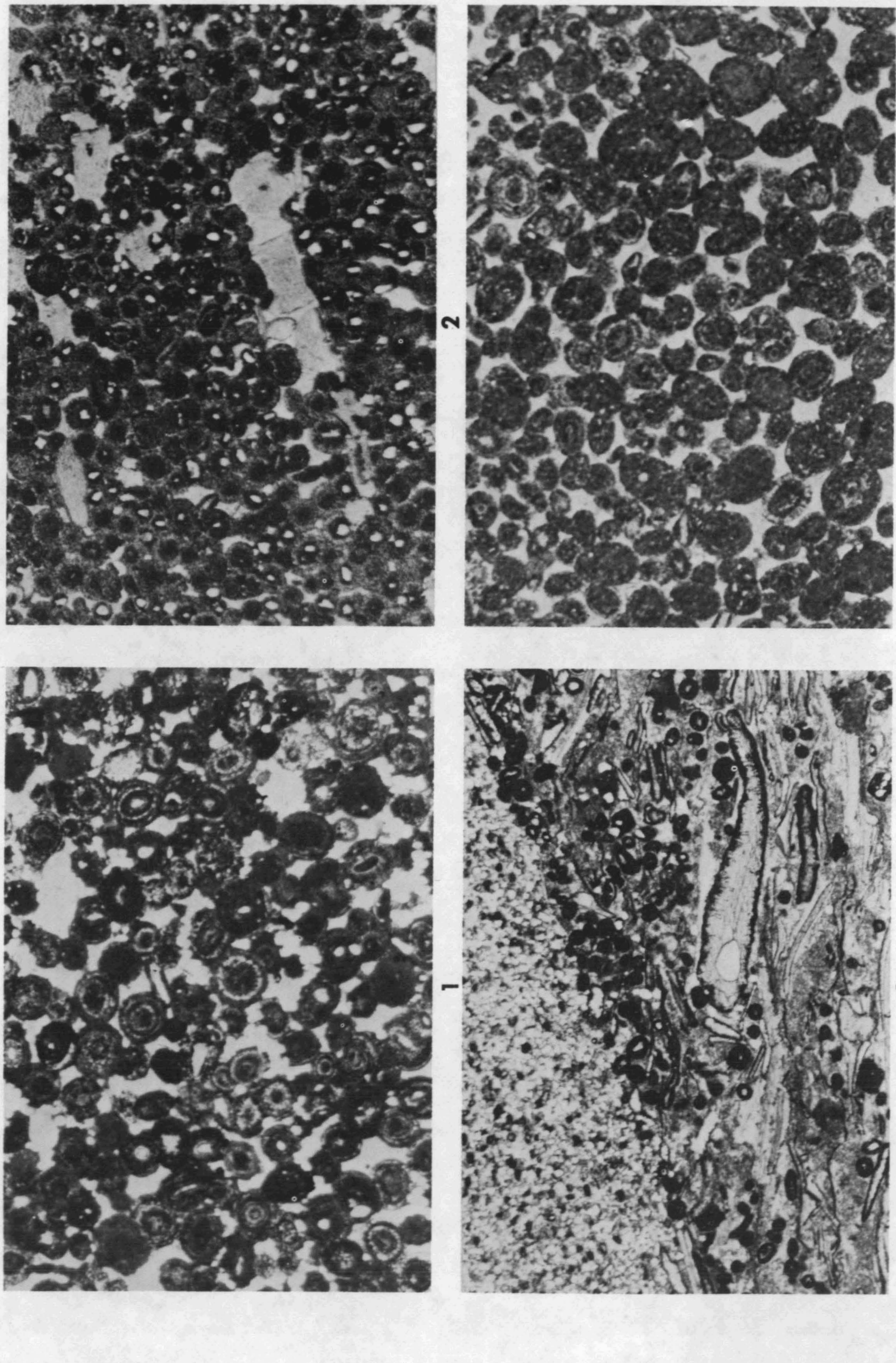


PLATE 11

PLATE 12

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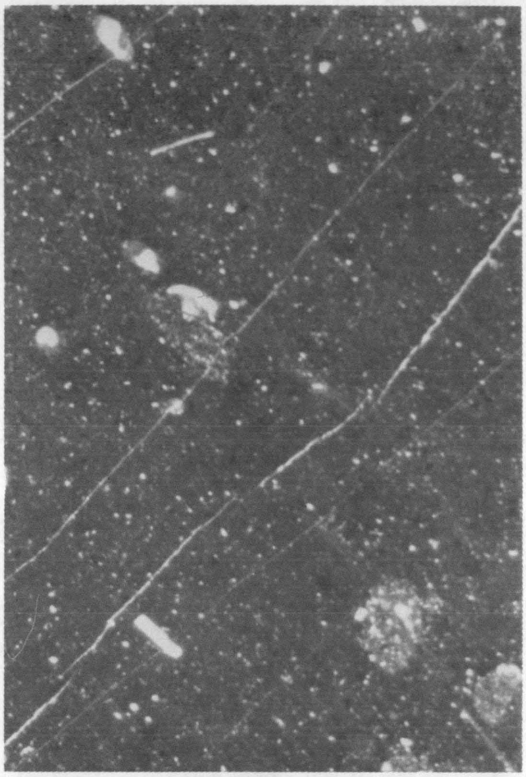

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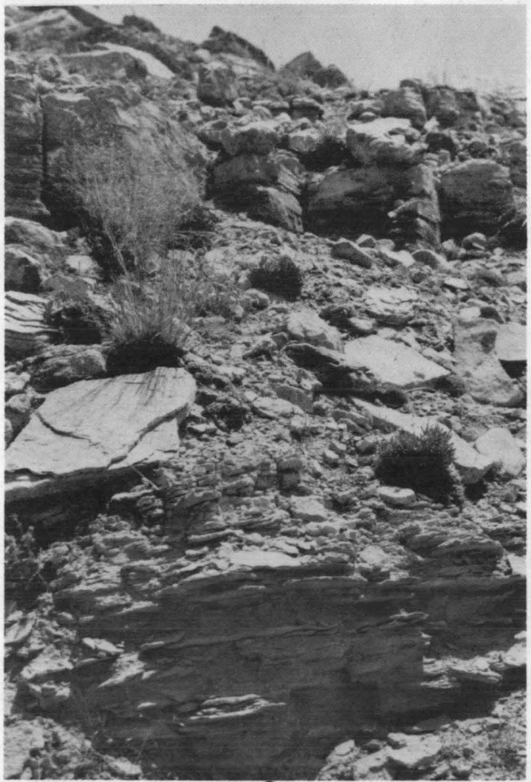

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of deposition may have accounted for the low diversity and abundance of the bivalve fauna, inasmuch as it would have hampered food gathering and respiration of most bivalves. The epifaunal bivalves associated with C. stygius were well adapted to a soft mud substrate. They are all flat-shelled and would not have passively settled too deeply into the mud.

Farther shoreward (i.e., Ditch Creek and Lower Slide Lake) the fauna was much more diverse and abundant. Pleuromya subcompressa was the most dominant bivalve of this zone (text-fig. 8). The bivalve fauna associated with P. subcompressa includes Astarte meeki, Thracia weedi, C. platessiformis, Ostrea strigilecula, Gryphaea planoconvexa, Pleuromya subcompressa, Corbula munda, Isognomon perplana, Trigonia americana, Mactromya? sp., Gervillia montanaensis, Vaugonia conradi, Myophorella sp., Homomya gallatinensis, Cercomya punctata, Pholadomya kingi, Pinna king, Lima occidentalis, Pronoella sp., Modiolus subimbricatus, Platymyoidea rockymontana, Idonearca haguei, Myophorella montanaensis, Grammatodon haguei, Pronoella cinnabarensis, and Mytilus whitei. Pronoella sp., P. kingi, A. meeki, G. montanaensis, C. platessiformis, G. planoconvexa, and O. strigilecula were common. The rest were rare.

The bivalves from the lagoons in northern Wyoming (i.e., Cody) include T. americana, P. cinnabarensis, A. meeki, P. fontenellensis, Corbula sp., M. subimbricatus, O. strigilecula, C. platessiformis and M. whitei. T. americana was the most abundant bivalve. The bottom fauna was less diverse and less abundant than that of the P. subcompressa zone. This would be expected, because faunal diversity decreases in marginal marine environments where conditions of salinity, pH, and water temperature change rapidly. The benthos which inhabited the flushed lagoons apparently were opportunistic species in the sense of rapidly immigrating into the lagoons whenever brief intervals of normal marine conditions prevailed. The coral Actinastrea hyatti was abundant with these bivalves. In local patches, it was apparently successful in setting up housekeeping in the shallow waters of the marginal lagoons.

Bathonian. -- Following deposition of Rich deposits and the claystone beds of the Gypsum Spring Formation, Bathonian shallowing reestablished widespread hypersaline conditions on the Wyoming shelf and in the lagoons. Gypsum and redbeds in the Gypsum Spring Formation were deposited in northern and west-central Wyoming. Maroon calcareous shale in the Boundary Ridge Member of the Twin Creek Limestone formed in western Wyoming. Imlay (1967) also substantiates the development of transient hypersaline lagoons and marginal marine conditions in westernmost Wyoming at this time. Shallowing is indicated by oolitic beds at the top of the Rich Member and by broken shell fragments and intraclasts in the lower part of the Boundary Ridge Member. Scarcely any bottom dwellers survived. I found only Camptonectes stygius in the Boundary Ridge Member and Imlay (1967) notes that very few identifiable species have been found except for fragments of species of Camptonectes, Myophorella montanaensis, Vaugonia conradi, Trigonia elegantissima, and species of Astarte.

Upper Jurassic

Earliest Callovian sedimentary environments. -- Earliest Callovian was a time of marked deepening of water across the Wyoming shelf. The sediments reflect the initial shallow, turbulent water conditions. In westernmost Wyoming, the Watton Canyon Member contains poorly washed oobiosparites containing shell fragments. Throughout western Wyoming, oolite beds occur at the base of the member and often throughout it (Imlay, 1967). In northern Wyoming crossbedded sandy oosparites of the

EXPLANATION OF PLATE 12

All photomicrographs x 5

Fig. 1 - Sandy biomicrite. Allochems include bivalve and echinoderm fragments and oolites. Quartz stringers common. Leeds Creek Member of the Twin Creek Limestone. Cabin Creek.

Fig. 2 -- Fossiliferous micrite. Bivalve and echinoderm fragments. Rich Member of the Twin Creek Limestone. Cabin Creek.

Fig. 3 -- Freezeout Mountains. Sundance Formation. Windy Hill Sandstone.

Fig. 4 -- Poorly washed sandy biosparite. Allochems include bivalve and echinoderm fragments, foraminifera, pellets, and intraclasts. Note sand-filled burrows. Boundary Ridge Member of the Twin Creek Limestone. Cabin Creek.

"Lower Sundance" occur at Thermopolis and Lovell. In the northern part of the Wind River Basin at Bull Lake and Maverick Spring the sequence of earliest Callovian deposits are much thicker than found elsewhere at the base of the Stockade Beaver Shale. Nearly the entire sequence of limestone and claystone in the lower part of the Stockade Beaver Shale contains sedimentary grains indicative of turbulent water, such as oolites, tightly packed shell fragments, and composite grains.

Away from the Maverick Spring area (e.g., Thermopolis to the north and Bull Lake to the south) the lower oolite sequence is thinner, suggesting that the rate of subsidence was greater at Maverick Spring yet the rate of sedimentation was also rapid and shallow turbulent water conditions prevailed.

In south-central and eastern Wyoming, the Canyon Springs Sandstone Member formed along the sea margin. The lower massive cross-bedded sandstone unit and upper flat-bedded symmetrically rippled oolitic sandstone unit represent terrestrial to littoral or shallow sublittoral environments.

Earliest Callovian bottom fauna. -- In western Wyoming tranquil bottom conditions persisted after the shelf water deepened and the area was again the scene of rapid formation of lime mud. The bivalve benthos of the open shelf was not diverse. Camptonectes stygius was the most abundant. Ostrea strigilecula, Lima sp., Gryphaea nebrascensis, Modiolus subimbricatus, Myophorella montanaensis, Trigonia elegantissima, Vaugonia conradi, Astarte meeki, Quenstedtia sublevis, and Myopholas hardyi were rare.

At Maverick Spring within the lower oolitic sequence of the Stockade Beaver, the benthos was more diverse. The bivalves included Modiolus subimbricatus, Ostrea strigilecula, Camptonectes platessiformis, Pleuromya subcompressa, Vaugonia conradi, Pronoella cinnabarensis, Tancredia sp., Trigonia elegantissima, Astarte packardi, Thracia sp., Mactromya? sp., Trigonia sp., Meleagrinella curta, Vaugonia sp., Mytilus sp., Tancredia warrenana, and Gryphaea nebrascensis. The dominant bivalves were P. cinnabarensis and P. subcompressa. There is a paucity of bivalves away from Maverick Spring in earliest Callovian oolite deposits. The persistence of shallow water at Maverick Spring (suggested by the thickness of the lower oolite sequence in the Stockade Beaver Shale) apparently was favorable for a diverse littoral or shallow sublittoral fauna.

Early Callovian sedimentary environments.-- By early Callovian time most of the Wyoming shelf was under water (text-fig. 9). Lime mud was deposited rapidly in westernmost Wyoming and formed the thick limestone beds of the Leeds Creek Member. The lime muds grade laterally to the east into calcareous clay muds of the Stockade Beaver Shale and middle shale member of the "Lower Sundance." Along the southeastern shoreline there was a facies change from clay mud of the Stockade Beaver Shale to sands of the Canyon Spring Sandstone.

The middle shale member of the "Lower Sundance" thins to almost zero in the Lander, Vinceants Ranch, Thermopolis, Hyattville, and Tensleep areas and sandstone dominates the facies. Also as discussed below there is a major change in the macro and microfauna northwest and southeast of this area. This thinning of the middle shale member of the "Lower Sundance" and the difference in spatial makeup of the fauna reflects the presence of a submarine topographic high (Sheridan Arch of Peterson, 1957) across the Wyoming shelf from approximately the Lander area northeast through Buffalo and into Montana. It may have initiated extensive shoal areas.

Early Callovian bottom fauna. -- Two distinct faunas existed. Northwest of the arch the fauna was dominated by Gryphaea nebrascensis. Other bivalves included O. strigilecula, C. stygius, C. platessiformis, M. subimbricatus, Astarte meeki, A. packardi, Grammatodon haguei, Pronoella cinnabarensis, and Myopholas hardyi. None of them were anywhere near as abundant as G. nebrascensis. Imlay (1967) also listed Plicatula sp., Lima occidentalis, Ctenostreon cf. C. gikshanensis, Lopha sp., Trigonia americana, T. elegantissima, Quenstedtia sublevis, Protocardia cf. P. schucherti, and Platymyoidea rockymontana from the Leeds Creek Member. I found none of these species, and they were apparently also rare elements of the shelf bottom fauna. Southeast of the arch Meleagrinella curta completely dominated the benthos. The other members of the fauna included Ostrea strigelecula, Gryphaea nebrascensis, Camptonectes platessiformis, Nucula sp., Lima sp., Myophorella montanaensis, Tancredia warrenana, Tancredia sp., Vaugonia conradi, Myophorella montanaensis, and Quenstedtia sublevis, but they were not abundant.

Early Callovian microfauna. -- The distribution of foraminifera (text-fig. 10) and ostracods (text-fig. 11) reflects the presence of the Sheridan Arch. Note the near exclusion of foraminifera southeast of the arch and the dominance there by large numbers of only a few kinds of ostracods.

Recent foraminifera and ostracoda are more abundant in numbers of individuals in marginal marine environments, whereas the number of species increases away from the shore line (Walton, 1964; Bandy & Arnel, 1960; Swain, 1955). Limited data also suggest that the foraminifera/ostracod ratio is lowest near shore (Bandy, 1964; Upshaw et al., 1966), and that ostracods dominate the microfauna to the exclusion of foraminifera in hypersaline lagoons (Upshaw et al., 1966). Some of these trends are apparent in the Sundance microfauna.

The great number of foraminifera and ostracod species northwest of the arch indicates prevailing normal marine conditions there. Southeast of the arch, foraminifera are excluded except for a sparse fauna of Vaginulinopsis sp., Lenticulina cf. L. audax, and V. eritheles. The ostracods occurring southeast of the arch show large numbers of individuals belonging to a few species. This decrease in faunal diversity of both groups is indicative of marginal marine conditions, in this case lagoonal environments.

Concerning the ostracods, Peterson (1954) suggests that the arch acted as a barrier separating cool water of the Powder River Basin from warm water of the "Twin Creek Trough." He suggests that the Powder River Basin was the early phase of the Mesozoic trough system, with the water coming from the Arctic, and that the "Twin Creek Trough" might have been the final phase of the Paleozoic trough system, which contained warm water from the south.

Peterson also suggests that since cooler water faunas contain the ostracod Cytherella in abundance (Swain, personal communication to Peterson) the presence and great abundance of C. paramuensteri southeast of the arch suggests that cooler water was present there than north of the arch. Also, the decrease in faunal diversity southeast of the arch supports his contention.

It is quite possible that the controlling factor which determined the faunal distribution on both sides of the arch was change in salinity and not primarily temperature. First, the inference that all species of Cytherella inhabit cool water is not very sound (Neale, 1964). Whereas some species of Cytherella are prominent in cool water, others can tolerate warm water (Kornicker, 1963). Second, the water southeast of the arch may have been very shallow. This broad expanse of shallow water would have resulted in warm-water conditions, and water here would be expected to attain higher temperature (not lower as Peterson supposes) than that north of the arch.

If salinity was the controlling factor, were the lagoons brackish or hypersaline? This is difficult to answer. Although the lack of gypsum in the Stockade Beaver Shale suggests that the water was not hypersaline, the salinity may well have exceeded the tolerance level of most of the biota and yet been too low to result in evaporite formation.

The abundance of Meleagrinella curta and associated bivalves southeast of the arch may argue against persistent hypersalinity. Indeed, if hypersalinity were prevalent Ostrea strigilecula and Gryphaea nebrascensis should not have occurred along with M. curta at Newcastle because oysters are endemic to marine waters of lowered salinity (Yonge, 1960). This problem is solved as M. curta was euryhalic and inhabited brackish water in one area (i.e., Newcastle) and hypersaline water everywhere else.

I suggest that the water was brackish because (1) gypsum is absent from the Stockade Beaver Shale, (2) oysters occurred in the lagoons, and (3) ostracods dominated the microfauna in the lagoons, but not to the exclusion of the foraminifera as is the case in hypersaline lagoons.

Middle Callovian sedimentary environments. -- In middle Callovian time, following deposition of the Leeds Creek Member of the Twin Creek Limestone, the Stockade Beaver Shale, and the middle shale member of the Sundance Formation, there began a marked change in regional sedimentation throughout the Western Interior. To the west a new clastic source area began to develop which would provide in late

Callovian and early Oxfordian the sands of the Preuss Sandstone and Stump Sandstone that were deposited on lime muds of the Twin Creek Limestone.

Shallowing across the Wyoming in middle Callovian time resulted in the formation of littoral and upper sublittoral sediments. Along the southeastern Wyoming shoreline the Hulett Sandstone, characterized by cross-bedding, ripple marks, oolites, and broken shells, was formed. Redbeds and gypsum of the Lak Member followed deposition of the Hulett sands as hypersaline conditions persisted throughout central and southeastern Wyoming and the Black Hills.

The upper sandstone member of the "Lower Sundance" was deposited over the Sheridan Arch.

Shallowing of the shelf environment along westernmost Wyoming resulted in deposition of oolitic sandstone and ripple-marked limestone of the Giraffe Creek Member of the Twin Creek Limestone.

Middle Callovian bottom fauna. -- The sands of the Hulett Sandstone and Upper Sandstone Member of the "Lower Sundance" were inhabited by Tancredia transversa, T. warrenana, Tancredia sp., Quenstedtia sp., Meleagrinella curta, Mytilus whitei, and Camptonectes platessiformis. Tancredia sp. was the most abundant bivalve. Tancredia preferred sandy substrates and dominated the sandy marginal marine environments not only during middle Callovian but in early Oxfordian as well. It appears to have had an affinity for intertidal sands, inasmuch as Waage (1968) also noted it in intertidal sands of the Cretaceous Fox Hills Formation. In northern Wyoming the fauna was dominated by Meleagrinella curta, although Tancredia was common.

Late Callovian and Early Oxfordian sedimentary environments. -- Shelf deepening and possibly transgression occurred in late Callovian time (text-fig. 12). At these times, the Pine Butte Member and Redwater Shale was deposited throughout central, southern, and eastern Wyoming and the "Upper Sundance" in northern Wyoming. The effect of the western clastic source area was now evident, for sandstone is the predominant lithology at such localities as Bull Lake, Maverick Spring, and Lovell. At the same time, sands of the Stump Sandstone were forming in western Wyoming.

The Sheridan Arch was submerged deep enough to prevent it from acting as an effective barrier across the Wyoming shelf.

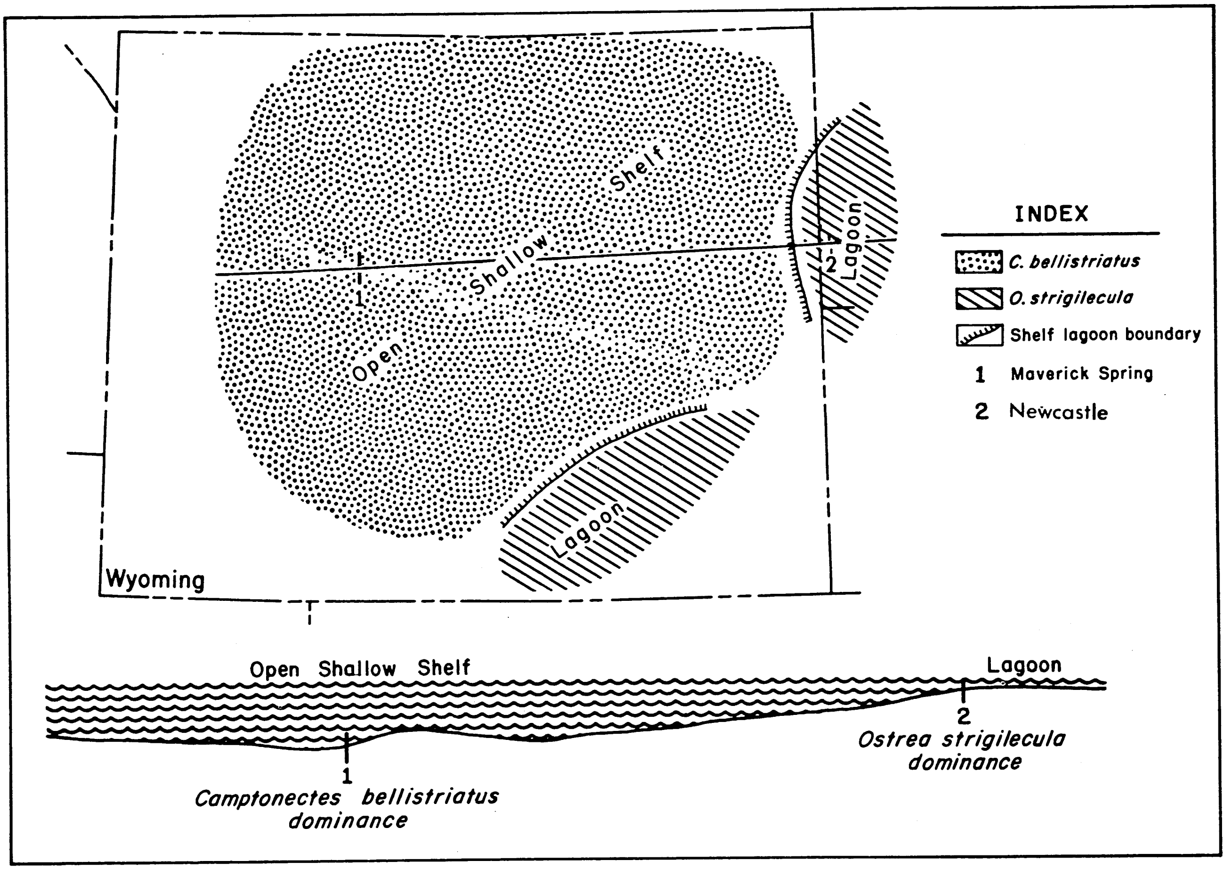
Late Callovian and Early Oxfordian bottom fauna. -- Camptonectes bellistriatus dominated the bivalve fauna across most of the Wyoming shelf. The C. bellistriatus fauna included Ostrea strigilecula, O. engelmanni, Tancredia transversa, Tancredia sp., Pleuromya newtoni, Pleuromya sp., Grammatodon inornatus, Gryphaea nebrascensis, Modiolus formosa, Astarte packardi, Modiolus sp., Pronoella sp., Vaugonia sturgisensis, Pholadomya sp., Idonearca sp., Alectryonia procumbens, and the brachiopod Kallirhynchia myrina. Of these, only O. strigilecula and A. procumbens were abundant.

In eastern and southeastern Wyoming Ostrea strigilecula makes up entire shell-hash beds and is the most abundant bivalve. These oyster shell-hash beds may represent oyster banks that flanked marginal lagoons.

Late Callovian and Early Oxfordian microfauna. -- Ostracods and foraminifera ranged across the entire shelf although many were local in their occurrence (text-fig. 13). A sharp faunal break, like that of early Callovian time, did not develop across the Wyoming shelf, probably because the water was deeper. Free of barriers, normal marine conditions existed everywhere. Decrease in the diversity of microfauna near the Ostrea strigilecula biofacies in southeastern Wyoming suggests that water was shallower here than elsewhere, possibly lagoonal.

Arenaceous foraminifera make up 45 percent of the total foraminifera fauna. In contrast, arenaceous forams were virtually absent in the early Callovian fauna. This increase in arenaceous forams might have been caused by lower water temperature in Late Jurassic time, which resulted in a decrease in calcium carbonate availability. Arenaceous foraminifera increase in numbers in water of low calcium carbonate availability, inasmuch as they do not need such a high concentration of carbonate for test construction as do the calcareous forms (Greiner, 1970).

Cooling of the Arctic seas is suggested by Imlay (1965) as a mechanism for Late Jurassic



TEXT-FIG. 12 -- Late Callovian and early Oxfordian paleogeography and bivalve paleobiogeography.

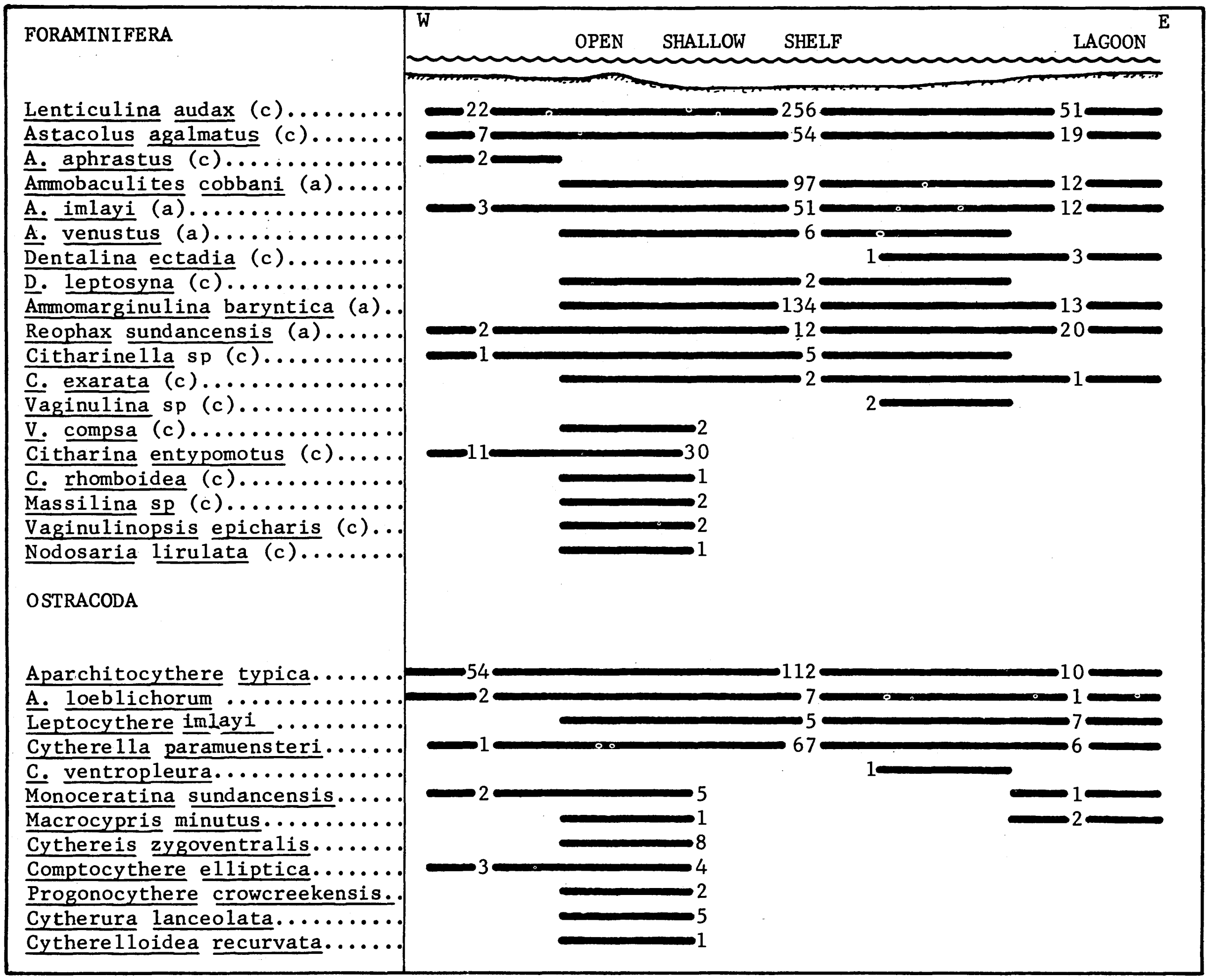
faunal differentiation. However, this is not the only possible cause. Hallam (1969) suggests that a decrease in salinity rather than temperature was the mechanism for Jurassic faunal differentiation. He proposes the existence of an extensive inland sea of slightly reduced salinity in the Northern Hemisphere serving as the source area.

A reduction in either salinity or temperature or a combination of the two could have reduced the calcium carbonate availability, thus causing faunal changes. A reduction in temperature is favored because the diverse marine benthos of the Oxfordian across the Wyoming Shelf probably would not have existed under abnormal conditions of salinity.

sedimentary environments. -- Slow regression brought an end to clay mud deposition and C. bellistriatus dominance on the shelf in late early Oxfordian. Throughout south-central and southeastern Wyoming, regressive beach and dune deposits of the Windy Hill Sandstone formed at this time. In central Wyoming, the break between shale deposition and regressive sands was represented by much of the sandstone of the "Upper Sundance." In northern and western Wyoming, this change is not evident, since sand deposition continued here for some time.

Oxfordian bottom fauna. -- The Tancredia sp. fauna inhabited the regressive marginal marine and littoral sand environments. The fauna included Tancredia transversa, Tancredia sp., Meleagrinella curta, Ostrea strigilecula, Camptonectes sp., Vaugonia sturgisensis, Pleuromya sp., Platymyoidea sp., Modiolus sp., Idonearca sp., and the brachiopod Kallirhynchia myrina. Only Tancredia and Ostrea were abundant.

Oxfordian regression was slow and not everywhere marked by sandy beaches. The contact with the overlying Morrison Formation is gradational at many localities as the marine environment gradually gave way to fluvial and



TEXT-FIG. 13 -- Paleobiogeography of late Callovian and early Oxfordian Foraminifera and Ostracoda. Index to Foraminifera: a = arenaceous, c = calcareous.

lacustrine environments of the Morrison.

CONCLUSIONS

Middle and Upper Jurassic marine sediments in Wyoming and South Dakota reflect open shelf, littoral, and lagoon environments. The marine fauna reflects each environment. The bivalves were prolific in number and diverse in life mode being represented by infaunal siphon, nonsiphonate, mucus-tube, and labial-palp feeders, and epifaunal suspension feeders.

In Bajocian time the Camptonectes stygius fauna inhabited the open shelf in westernmost Wyoming in an area of rapid lime-mud deposition (Sliderock and Rich Members of the Twin Creek Limestone). The Pleuromya subcompressa fauna occurred farther shoreward where mud deposition was not as great. The Trigonia americana fauna occurred in lagoons along the eastern shoreline, site of the deposition Gypsum Spring Formation.

In Callovian time Camptonectes stygius and Pronoella cinnabarensis-Pleuromya subcompressa initially dominated the bottom fauna in western Wyoming and along the shoreline respectively but gave way to Gryphaea nebrascensis and Meleagrinella curta. The Sheridan Arch was a dominant feature on the Wyoming shelf during early and middle Callovian and acted as a marine barrier which determined the geography of bivalves and microfossils. The Gryphaea nebrascensis fauna was restricted to an area of normal marine conditions northwest of the Arch (attested by the abundance and variety of foraminifera and ostracods) where the Leeds Creek Member of the Twin Creek Limestone, the "Lower Sundance," and Stockade Beaver Shale (at Bull Lake and Maverick Springs) were deposited. The Meleagrinella curta fauna (occurring in the Stockade Beaver Shale) was restricted to brackish lagoons southeast of the Arch (attested by the absence of foraminifera and high faunal dominance of ostracods). The Hulett Sandstone and the Lak redbeds were later deposited southeast of the Arch.

In late Callovian time, the water on the Wyoming shelf deepened. The Sheridan Arch ceased being a major influence, and the Camptonectes bellistriatus fauna, ostracods, and foraminifera ranged across the entire shelf. The abundance of arenaceous foraminifera suggests that the water was cooler than earlier in the Jurassic.

Sediments laid down during these times became the Pine Butte, Redwater Shale, and Windy Hill Sandstone Members of the Sundance Formation in central and eastern Wyoming. The Redwater Shale formed when water was at its deepest over the Wyoming Shelf. The Pine Butte and Windy Hill Sandstone Members represent in part the shallow littoral deposits that formed respectively before and after Redwater Shale deposition. The "Upper Sundance" in northern Wyoming, and the Preuss and Stump Sandstones in western Wyoming were deposited at those times.

Oxfordian regression ended the marine era in Wyoming and South Dakota.

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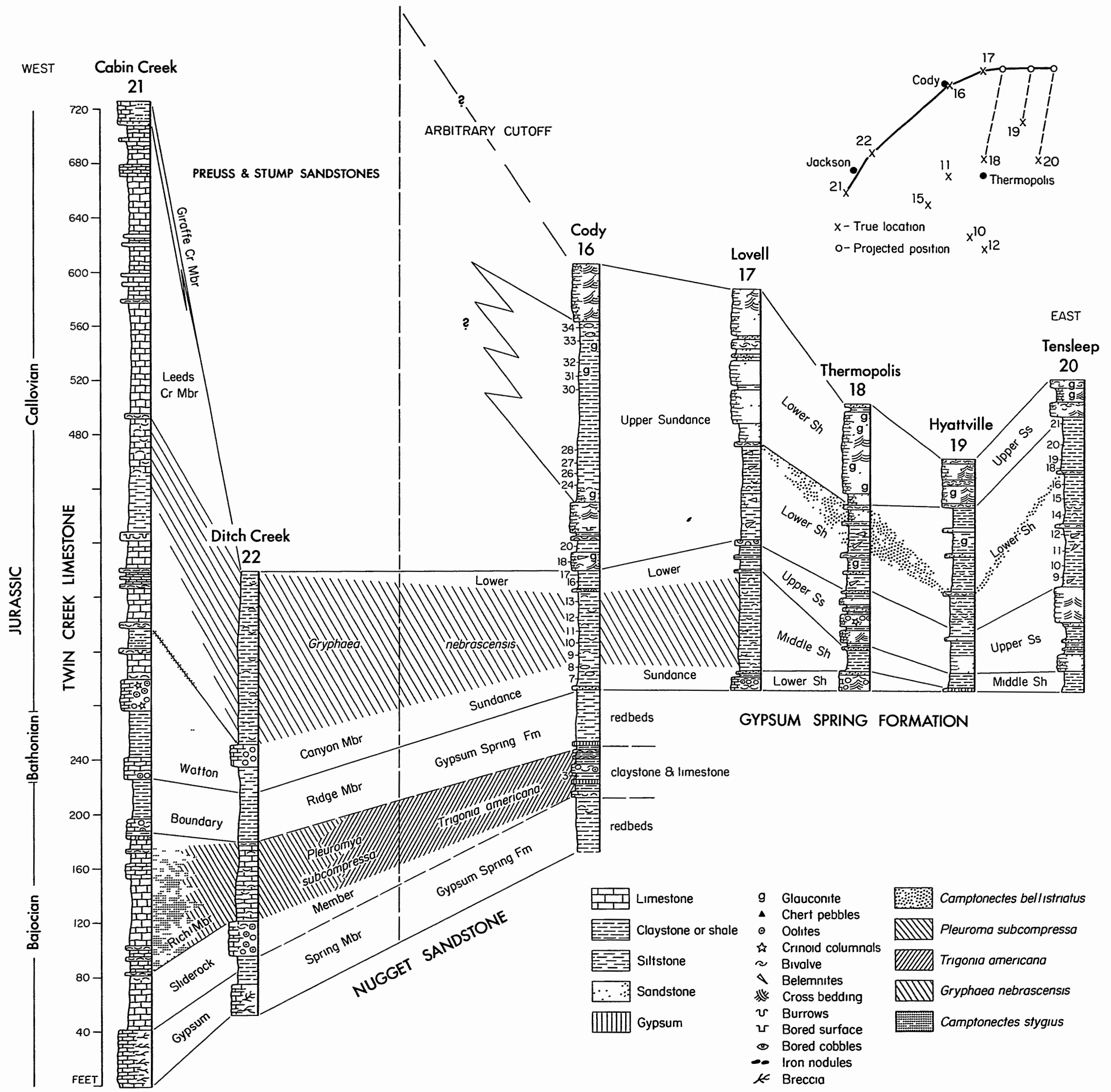
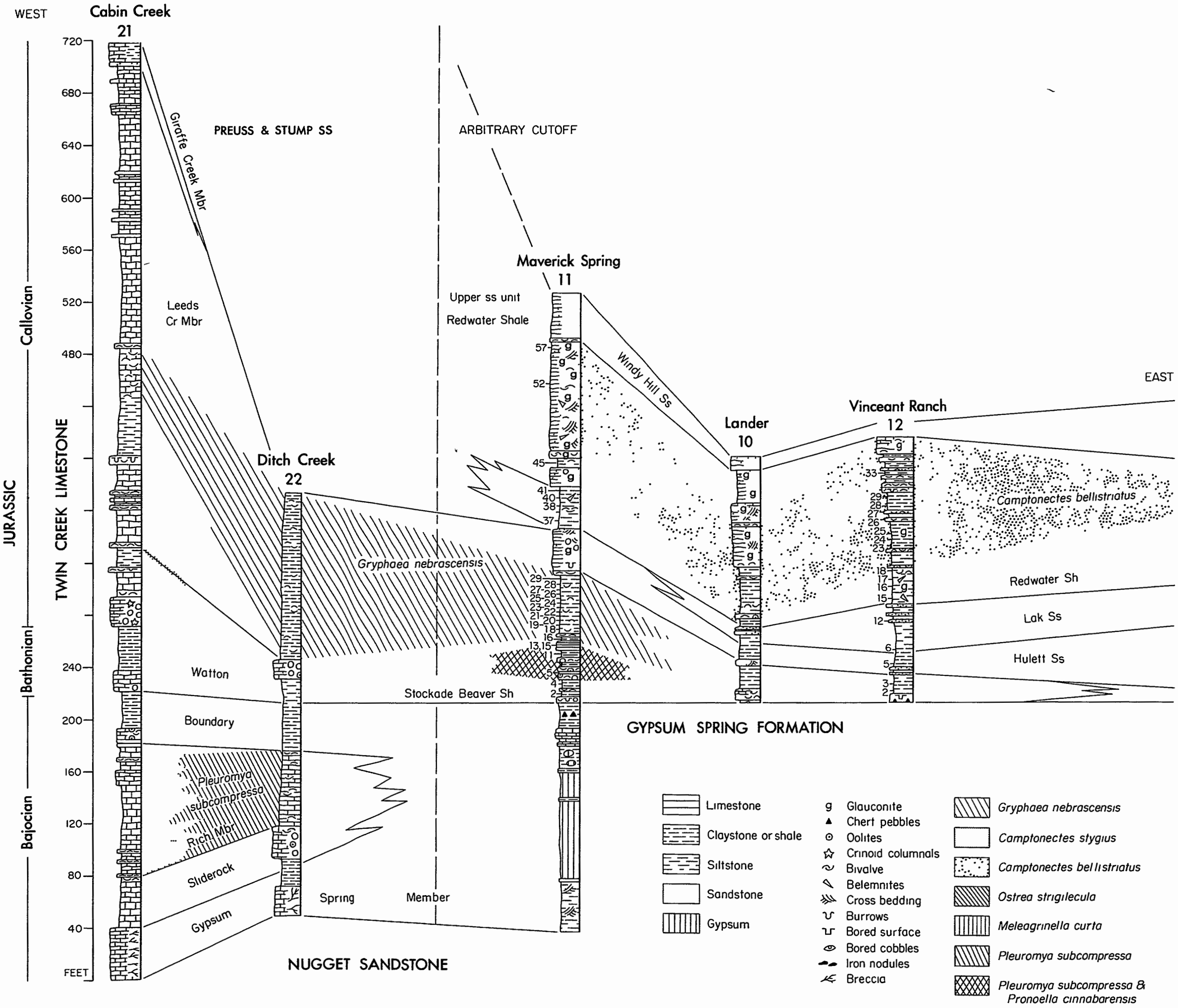
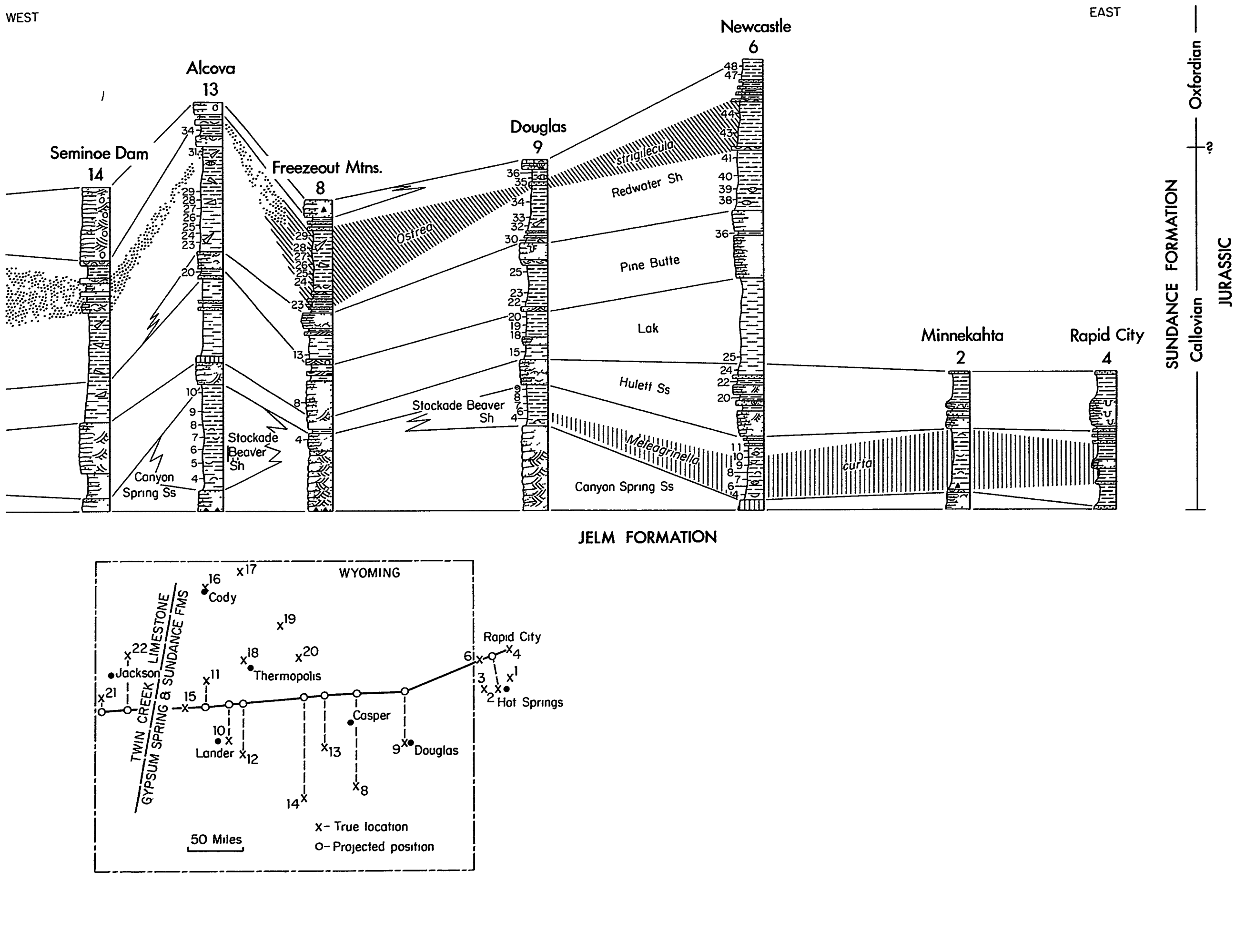


TEXT-FIG. 14 -- Middle and Upper Jurassic deposits in Wyoming.



TEXT-FIG. 15 -- Middle and Upper Jurassic deposits in Wyoming and South Dakota.


WEST
EAST
Seminoe Dam
14
Alcova
13
Freezeout Mtns.
8
Douglas
9
Newcastle
6
Minnekahta
2
Rapid City
4
Oxfordian
Callovian
SUNDANCE FORMATION
JURASSIC
strigilecula
Redwater Sh
Ostrea
Pine Butte
Lak
Hulett Ss
Stockade Beaver Sh
Stockade Beaver Sh
Meleagrinella
curta
Canyon Spring Ss
Canyon Spring Ss
JELM FORMATION
WYOMING
Cody
Thermopolis
Jackson
Lander
Casper
Douglas
Rapid City
Hot Springs
TWIN CREEK LIMESTONE
GYPSUM SPRING & SUNDANCE FMS
50 Miles
x- True location
o- Projected position

PAPERS ON PALEONTOLOGY

Robert Paul Wright: Jurassic of Wyoming and South Dakota