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Permian carbonate facies Southern Big Horn Basin -Owl Creek Mountains area north central Wyoming

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PERMIAN CARBONATE FACIES, SOUTHERN BIG HORN

BASIN - OWL CREEK MOUNTAINS AREA,

NORTH CENTRAL, WYOMING

By

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ABSTRACT

The Permian Phosphoria Formation can be divided into three Units (I, II, III), each of which represents one transgressive-regressive cycle, and nine intervals (A - I) as follows:

Unit		Interval
III	GHI	Tosi chert, Ervay Member, Freezeout Shale
	F	Retort Member, Freezeout Shale
II	E	Forelle tongue
	D	Franson Member, Glendo Shale
	C	Minnekahta tongue
	B	Meade Peak Member, upper Opeche Shale
I	A	Grandeur Member, Lower Opeche Shale

The Grandeur Member consists of dolomite, sandstone, and anhydrite beds deposited on an irregular erosion surface in a sea apparently too toxic to support a normal marine fauna. These beds intertongue shoreward (north and east) with the lower Opeche red intertidal shale and represent the initial major Permain transgression.

The Meade Peak Member, in this area, consists of a thin pebbly sandstone bed which suggests that its contact with the underlying Grandeur is disconformable and therefore it probably represents the initial deposit of a second major Permian transgression. The remainder of Unit II consists of subtidal to supratidal carbonate beds (dominantly dolomite) which intertongue with normal marine (gray) and intertidal (red) shale beds.

The Retort (interval F) is a phosphatic, pebbly sandstone which disconformably overlies the Forelle and represents the initial deposit of the third and final major Permian transgression. The Ervay Member consists of a cyclic bioclastic limestone mound or bank facies in the west which grades shoreward to lagoonal and tidal flat carbonate mud and pellet-mud beds and finally to a pelletal dolomite which probably represents a supratidal beach ridge deposit.

INTRODUCTION

The major objective of this investigation involves the environmental study and interpretation of the Permian carbonate facies of the southern portion of the Big Horn basin and adjacent Owl Creek Mountains (Figs. 1 and 2). This project is part of a much larger study of the Permian carbonate facies in Wyoming and Idaho supervised by Dr. James A. Peterson and conducted under N.S.F. Grant GA-986.

Methods of Study

Rock samples were obtained from seven measured surface sections in the Owl Creek Mountains and seven oil well cores from the Big Horn basin. A binocular microscope study of these specimens and a petrographic study of 613 thin sections cut from them provided the basic lithologic data. The following features were noted for all carbonate rock specimens:

a. texture - composition and grain size of matrix and constituent grains.

b. structures - laminations, scour, etc.

c. organic content

d. porosity

e. alteration - silicification, replacement, etc.

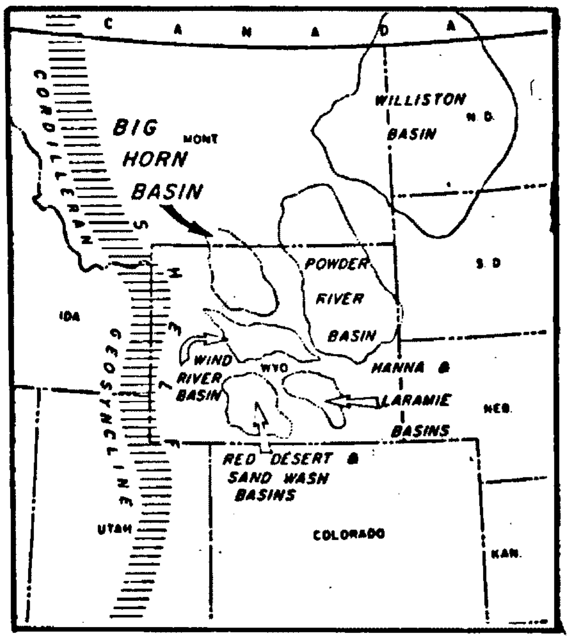

Fig. 1 - Index map showing location of Bighorn Basin (after Stone, 1967).

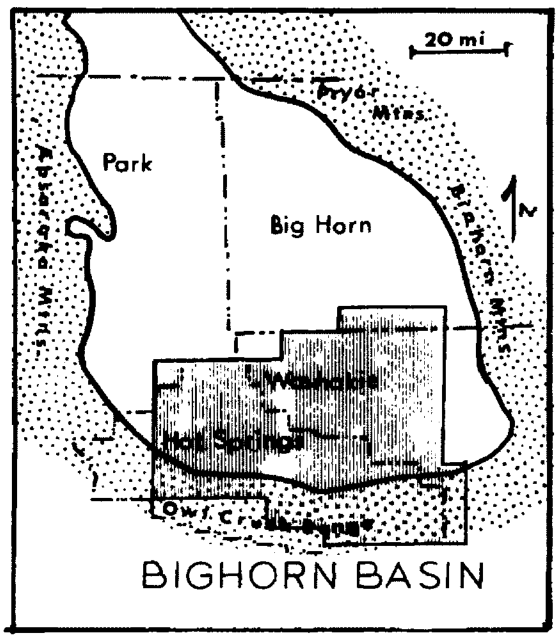

Fig. 2 - Index map showing location of study area.

DEPOSITIONAL TEXTURE RECOGNIZABLE					DEPOSITIONAL TEXTURE NOT RECOGNIZABLE
Original Components Not Bound Together During Deposition				Original components were bound together during deposition... as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices.	Crystalline Carbonate
Contains mud (particles of clay and fine silt size)			Lacks mud and is grain-supported		(Subdivide according to classifications designed to bear on physical texture or diagenesis.)
Mud-supported		Grain-supported			
Less than 10 percent grains	More than 10 percent grains				
Mudstone	Wackestone	Packstone	Grainstone	Boundstone	

Fig. 3 - Classification of carbonate rocks (after Dunham, 1962).

A classification scheme was devised based on a minor modification of Dunham's classification of carbonate rocks (Fig. 3). Dunham defines mud as being less than 20 microns, whereas the classification of this report uses 62 microns, a figure selected for the following reasons: 1) the assumption that recrystallization generally does not reduce the original grain size but, instead, increases it (Ginsburg, 1957), 2) 62 microns is readily observable under a magnification of 25x, and 3) 62 microns corresponds to the silt-free sand boundary as defined by Folk (1968) for clastic sediments.

Correlation of the surface exposures with the subsurface was carried out with the aid of twelve lithologic oil well logs obtained on loan from the American Stratigraphic Company and twenty-three radioactive logs. Appendix A and Plate A (in pocket) lists and locates all of the control points used in this study. Nine intervals, designated by the capital letters "A" through "I", were defined on the basis of their lithologic and gamma-ray characteristics. These intervals were correlated in the subsurface using wells on which both radioactive and lithologic logs were available. The same units were then correlated to surface sections bordering the south part of the basin. Correlations were completed along a network of nine cross-sections (Plates B_1, B_2 and B_3, in

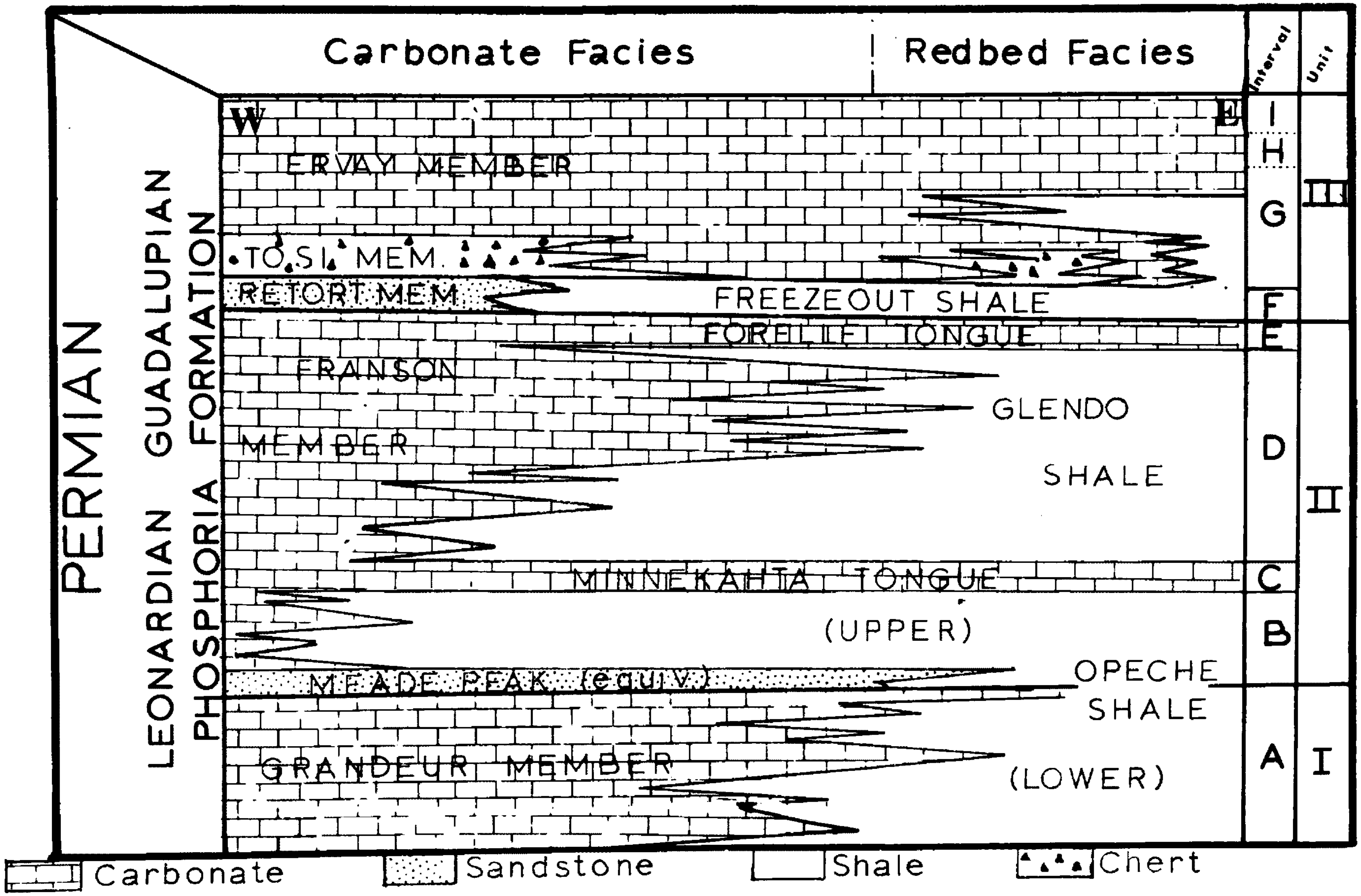

Fig. 4 - Stratigraphic terminology used in this report.

pocket), incorporating the surface sections, lithologic logs, and radioactive logs. Lithologic changes were identified wherever such control was available, although tentative identification of some shale and carbonate units was made on the basis of the radioactive logs. Using this correlation framework three "Units" were defined. Each Unit consists of one of the three carbonate members of the Phosphoria Formation and represents one major transgressive-regressive cycle. This system is illustrated in Figure 4.

Acknowledgements

The writer is deeply indebted to Dr. James A. Peterson for financial support in the form of a Research Assistantship under his grant from the National Science Foundation and for his encouragement, advise, and helpful criticism concerning this thesis. Thanks are also due to Drs. Robert M. Weidman and Richard L. Konizeski for reviewing the manuscript and making helpful suggestions, to Dr. Donald Winston for many discussions concerning my interpretations, and to many of the staff and students of the Department of Geology, University of Montana, who contributed to this thesis through discussions, suggest-ions and material help.

Special thanks are due to Dr. James A. McCaleb of

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I would also like to thank my father, George P. Cole, Sr., and Mrs. Penny Kirk for the drafting and Mrs. Sandy Winegar for typing the manuscript.

Finally I want to thank my wife, Tricia, for her support and encouragement throughout this project.

PREVIOUS WORK

During the late 1940's the United States Geological Survey began an intensive study of the geology and mineral resources of the Phosphoria Formation in the western phosphate field of Wyoming and adjacent parts of Idaho. The eastern margin of their study area included a part of the Big Horn basin and Owl Creek Mountains. McCue (1953) measured sections in the Owl Creek and Big Horn Mountains to demonstrate the facies change within the Phosphoria Formation. Campbell (1956, 1962) studied surface and subsurface samples from the southeastern part of the Big Horn basin in an attempt to reconstruct the depositional environments of the Phosphoria Formation. Campbell's investigation included the eastern half of the present study area. Wilkerson (1967) studied the fauna of the Ervay Member along the southern margin of the Big Horn basin to determine the paleoenvironment of that unit. In addition several workers, including Pedry (1957), Boyd (1958), Tebbutt, Conley, and Boyd (1965), and McCaleb and Willingham (1967) have published on their studies of the Cottonwood Creek oil field, which produces from the Ervay Member of the Phosphoria Formation.

REGIONAL GEOLOGY

Regional Geologic History

During Permian time Wyoming was the site of a large marine shelf bordering the Cordilleran miogeosyncline, the hinge line of which approximately coincided with the present Idaho-Wyoming border (Figs. 1 and 5). The Phosphoria Formation was deposited within the miogeosyncline and across the adjacent shelf during a series of west to east transgressions and regressions. The Big Horn basin, a northwest-trending Laramide structural basin, is located more or less in the central part of the shelf area.

The isopach map of the Permian in the Big Horn basin (Fig. 6) shows a general thinning of the System to the north. According to Thomas (1965) this is a result of loss of section by onlap of the underlying Tensleep Sandstone and also to post-Permian truncation due to a southerly tilting of the area. The irregular isopach pattern is probably caused by topographic relief on the pre-Permian erosion surface.

The Triassic Dinwoody Formation overlies the Permian in the Big Horn basin. This contact is generally considered to be unconformable, although the possibility of continuous deposition across this boundary has been

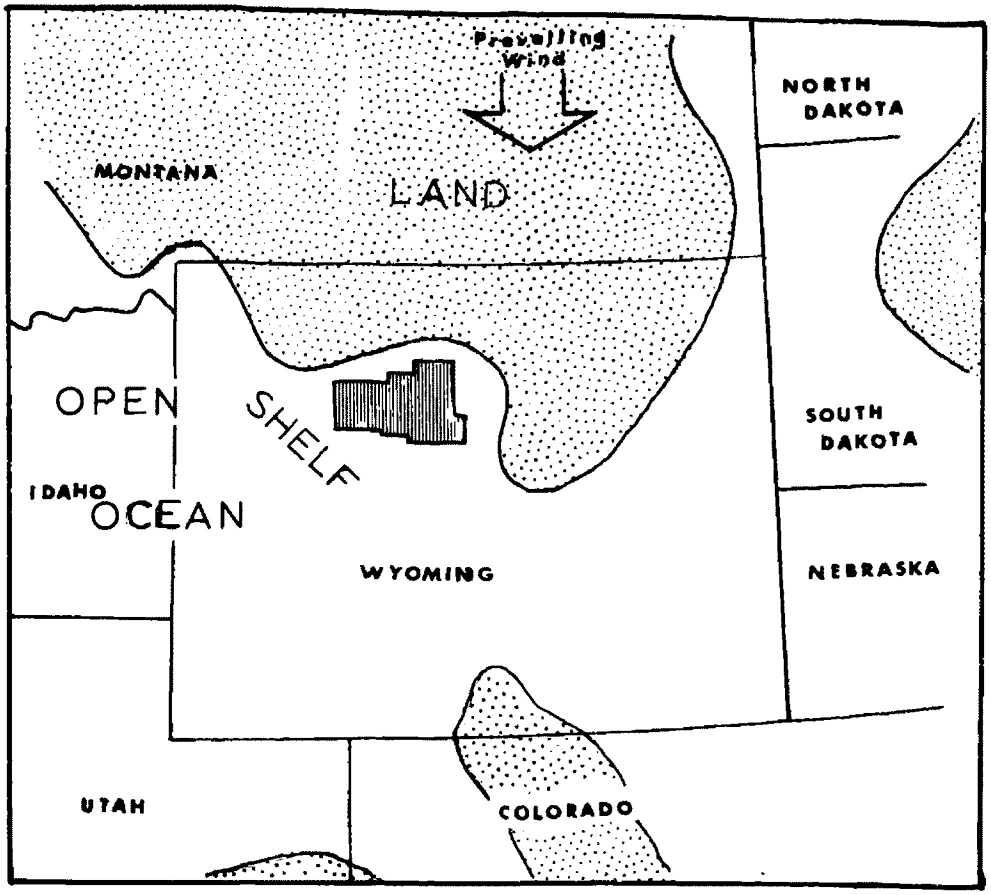


Fig. 5 - Paleogeography during Leonard transgression. Study area shaded. (modified from McKee, Oriel and others, 1967)

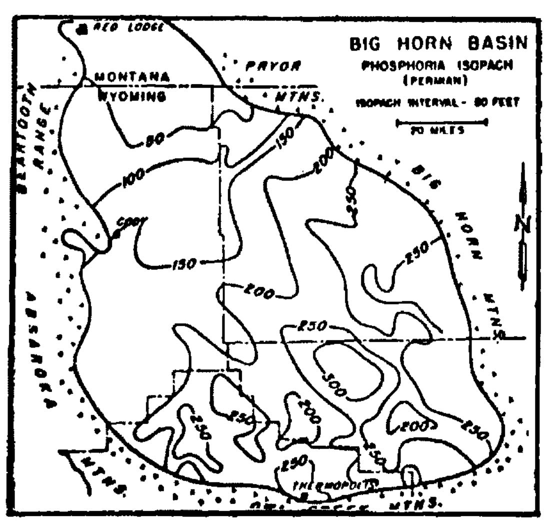


Fig. 6 - Permian isopach, Bighorn Basin (after Thomas, 1965).

suggested (Sheldon, 1963).

Evidence of the development of a structural basin is first noted in the isopach map of the Late Cretaceous Frontier Formation, although the peripheral mountain uplifts, which define the basin, did not begin their major growth until Paleocene time. Thickness changes and areal distribution patterns of the Permian rocks along a linear feature coinciding with the present Big Horn Mountains suggests an active fault in this area during Phosphoria and possibly pre-Phosphoria time (McKee and others, 1967).

Permian Stratigraphy and Nomenclature

The Permian rocks of western Wyoming and adjacent areas are assigned to the Phosphoria Formation. At the type locality, Phosphoria Gulch, Bear Lake County, Idaho, the Phosphoria consists of chert, phosphatic and carbonaceous mudstone, phosphorite, cherty mudstone, and some dark carbonate. In parts of southwestern Montana and in northwestern Wyoming it contains considerable sandstone. In west-central Wyoming and northern Utah it is dominantly a carbonate, and in eastern Wyoming it is mainly redbeds and evaporites (Fig. 7). The intertonguing and laterally gradational relationships of these various facies (Fig. 8) have complicated the problems of stratigraphic nomenclature. An excellent review of the Permian nomenclatural

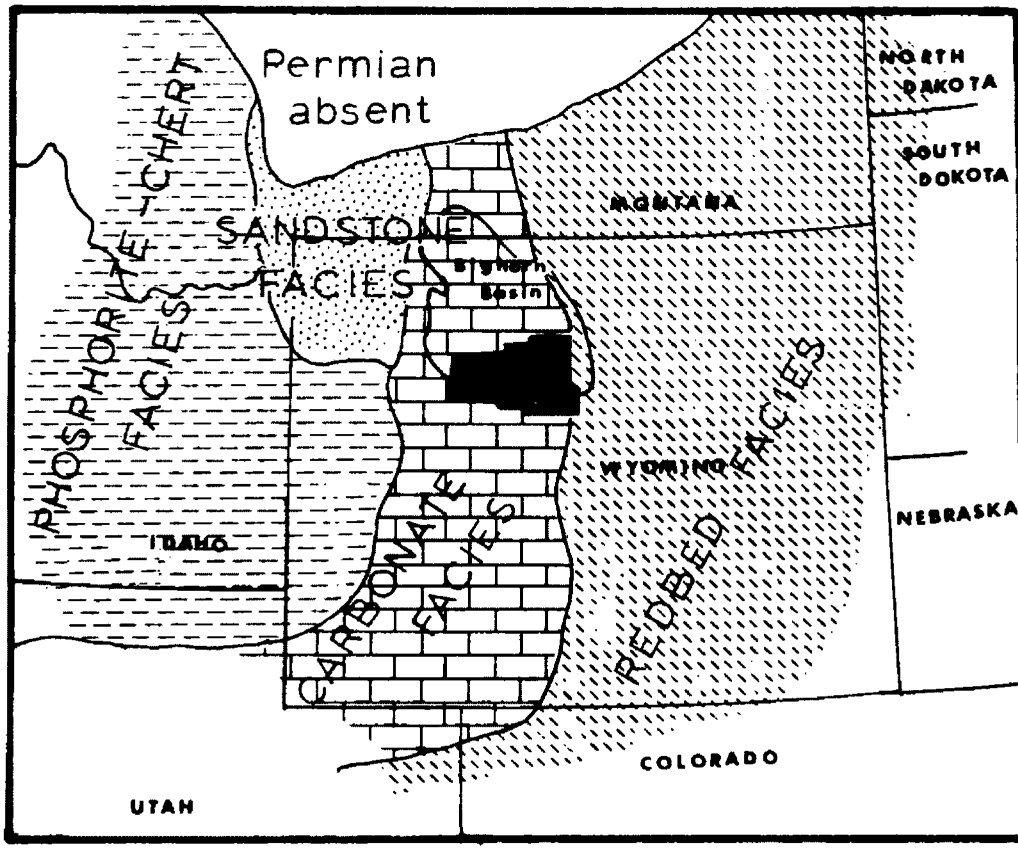


Fig. 7 - Generalized regional Permian lithofacies based on percentage of rock type. Study area shaded. (modified from Sheldon, 1963)

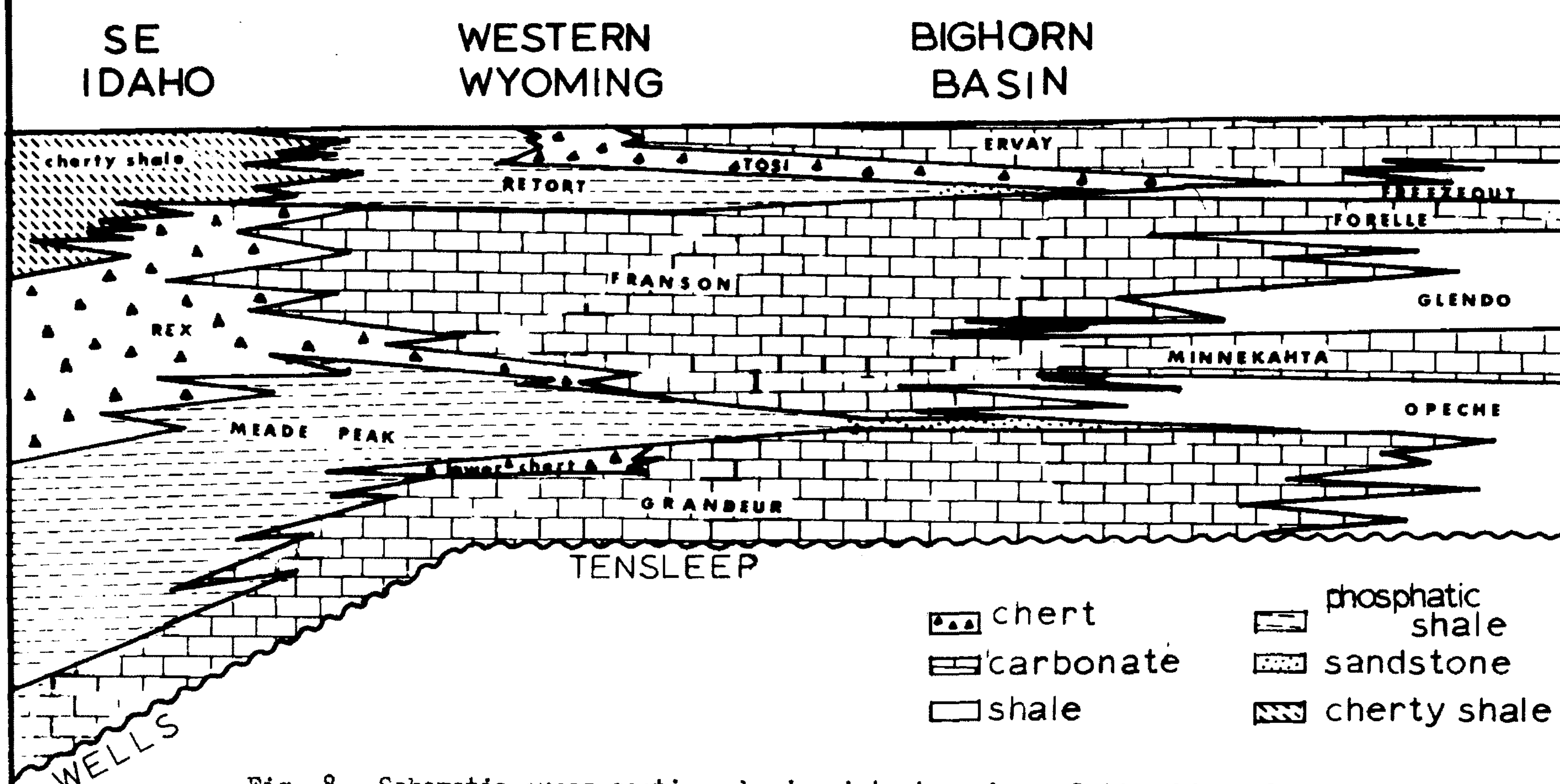


Fig. 8 - Schematic cross section showing intertonguing relationships of Permian facies (modified from McKelvey, 1959 and McKee, Oriel and others, 1967).

NOT TO SCALE

history, with specific references, is given by McKelvey and others (1956). McKelvey and coworkers (1956, 1959) proposed a nomenclatural scheme in which they defined four facies: The Phosphoria mudstone-chert facies, the Shedhorn sandstone facies, the Park City carbonate facies, and the Goose Egg redbed facies. Each facies consists of "members" and "tongues." Although this system has merit it has not been generally adopted -- especially within the petroleum industry.

In this report all Permian rock units are considered to be part of the Phosphoria Formation. Individual units are assigned member or tongue status as illustrated in Figure 4.

CARBONATE STRATIGRAPHY

The Permian System in this study area has been divided into three Units (Fig. 4), each of which contains one of the three carbonate members of the Phosphoria Formation and their lateral equivalents. Each Unit will be discussed separately.

Unit I

Unit I includes only interval A and is equivalent to the Grandeur carbonate, which occurs throughout most of the area, but which intertongues shoreward (to the north and east) with the lower Opeche Shale in the eastern part of the area.

In surface exposures in the Owl Creek Mountains the Grandeur carbonate beds are generally thin- to thick-bedded, cherty, gray to brown, dolomite with pinpoint to vuggy porosity. Lithologic well log data from the Big Horn basin indicates that locally the basal Grandeur contains beds of sandstone and anhydrite.

The lower Opeche Shale, which was observed in an outcrop only at the Stove Creek surface section (control point 7), is a thin-bedded, very fine-grained, calcareous, green, brown, and red shale with some anhydrite nodules. Subsurface lithologic logs show the lower Opeche to be

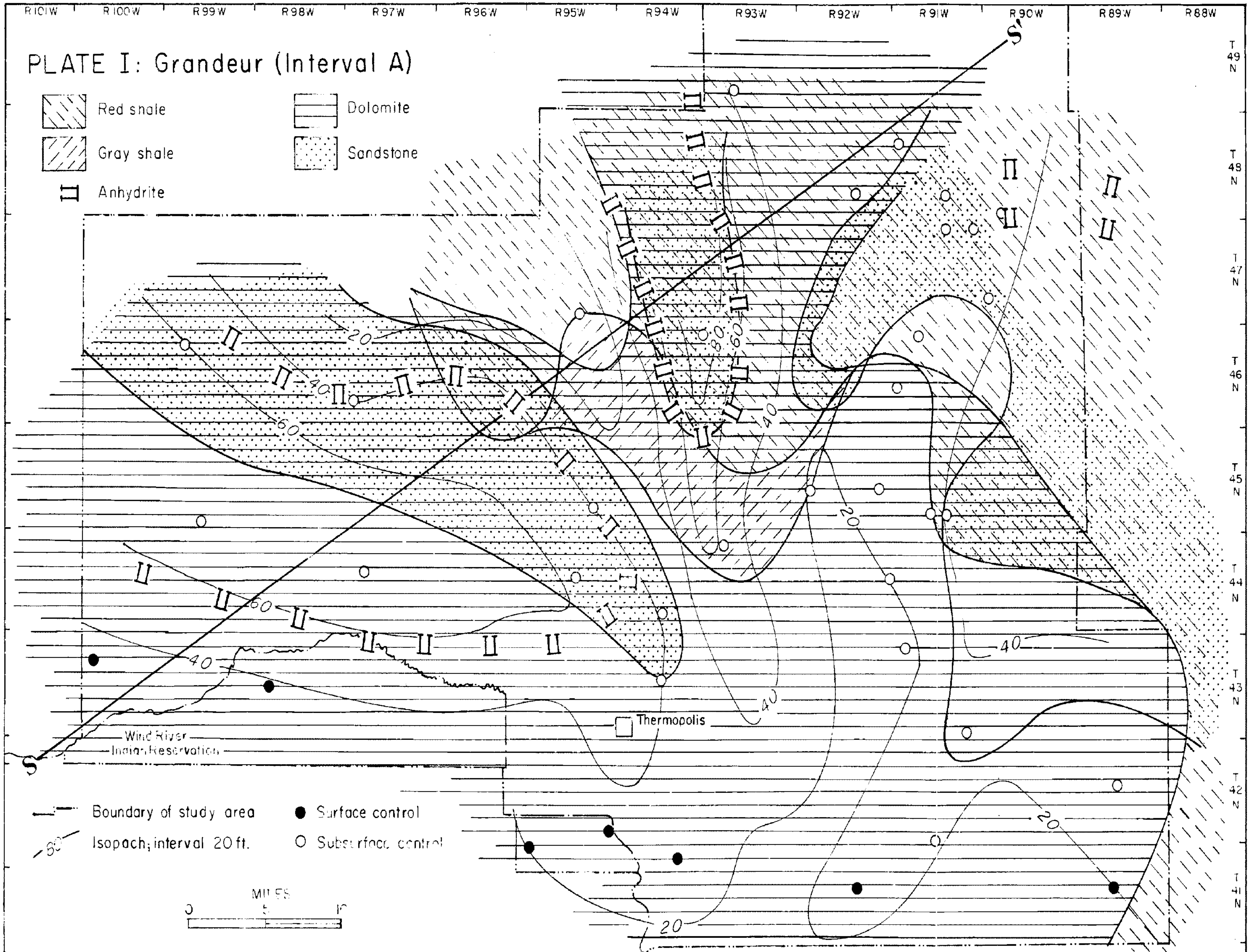


PLATE I: Grandeur (Interval A)
Red shale
Dolomite
Gray shale
Sandstone
Anhydrite
R101W
R100W
R99W
R98W
R97W
R96W
R95W
R94W
R93W
R92W
R91W
R90W
R89W
R88W
T 49 N
T 48 N
T 47 N
T 46 N
T 45 N
T 44 N
T 43 N
T 42 N
T 41 N
S
S'
Thermopolis
Wind River
Indian Reservation
Boundary of study area
Isopach; interval 20 ft.
Surface control
Subsurface control
MILES
0
5
10

dominantly red shale with minor occurrences of gray shale near the central part of the area. Campbell (1956, 1962) reports the presence of sandstone beds within the lower Opeche along the eastern margin of the area and further east. Plate I shows the distribution of interval A lithologies.

Interval A unconformably overlies the clean sandstones of the Middle Pennsylvanian Tensleep Formation. Throughout most of the area the contact is characterized by a relatively sharp lithologic change from sandstone upward to carbonate or shale. Occasionally a thin red oxidized zone defines this contact (Wind River Canyon, control point 4). Locally, where the lower part of the Grandeur contains beds of sandstone, several criteria had to be considered to determine the Pennsylvanian-Permian contact: 1) the characteristic Tensleep porosity which can be determined from the neutron log, 2) the individual Grandeur sandstone units are relatively thin, while the upper several tens of feet of Tensleep is dominantly sandstone with an occasional thin dolomite unit, and 3) Campbell (1956, 1962) determined the contact by a lithologic analysis of ditch cuttings and where his control coincided with the control points used in this investigation, his contact was used.

Lithofacies

The Grandeur carbonate beds are dominantly very finely-crystalline dolomite mudstones or crystalline dolomites which tend to become silty toward the north and east. These rocks are generally unfossiliferous with the exception of some minor phosphatic material which might be fish remains and a vague mottled appearance which could possibly be due to burrowing. A secondary rock type, a pellet dolomite packstone/grainstone, occurs at the top of interval A in the Stove Creek section (control point 7). The pellets are characteristically dark, oval to oblong, sand-sized features. Most of them have very sharp borders although some have a vague outline which grades into a finely-crystalline dolomite mud matrix. These rocks commonly have well-defined phylloid algal fragments that are usually leaf-shaped and are filled with coarsely-crystalline calcite spar. They are devoid of other fossil material.

Locally the Grandeur contains beds of anhydrite and sandstone, which apparently occur coincident with thickness increases of interval A. Plate I shows the association of the Grandeur-lower Opeche lithologies with the isopach pattern. The east-west cross-sections (A through D on Plates B_1 and B_2, in pocket) show the intertonguing relationship of Grandeur carbonate beds with lower Opeche

Shale beds.

Interpretation

Interval A represents the initial Permian transgressive deposit. The isopach and lithofacies patterns appear to directly reflect the irregular Tensleep erosion surface as described by Agatston (1954). Agatston observed several areas of closure on the isopach maps of both the Tensleep and Phosphoria Formations. However, a comparison of these two maps with a combined Tensleep-Phosphoria isopach map reveals the elimination of most of the closures. Agatston interpreted this to indicate a thickening of the Phosphoria over Tensleep topographic depressions. As the Grandeur sea inundated the area some of the depressions were restricted by the adjacent higher areas and became sites of evaporite deposition. The higher parts of the Tensleep topography were islands in the Grandeur sea and were probably the source for the sand of the lower Grandeur. As sea level rose and the depressions became filled with sediment, normal circulation was restored favoring calcium carbonate deposition. Most calcium carbonate is generally thought to precipitate due to the organic processes of organisms, although other physico-chemical factors are important. Organic remains are not evident in the carbonate beds of interval A, however, and at least three explanations seem possible: 1) the Grandeur sea was too toxic (penesaline) for a normal marine fauna, 2) evidence of organisms has been obliterated by dolomitization, or 3) some algae and bacteria with a higher than normal salinity tolerance may have been the only inhabitants of the Grandeur sea. Penesalinity of the Grandeur sea is suggested by the occurrence of anhydrite, therefore the organic processes of algae and bacteria are considered to be the most probable mechanism for the precipitation of the calcium carbonate.

Figure 9 is a postulated diagrammatic cross-section of the Grandeur sea. The relationship of the Grandeur lithologies with the sea bottom irregularities suggest a shallow sea. Lithologic well log data at control point 25 reveals only 20 feet of interval A rock, which probably indicates that the Tensleep topography influenced the thickness of the entire interval. Intraformational breccia zones observed at Wind River Canyon (WR-B) and Grass Creek (GC-A) sections (control points 4 and 5) indicate probable periodic exposure. The pellet dolomite observed at Stove Creek suggests a calm environment, at least part of the time. Any slight mechanical action will destroy a fresh fecal pellet, although it may be indurated contemporaneous with deposition or soon after by the interstitial precipitation of aragonite by the organic

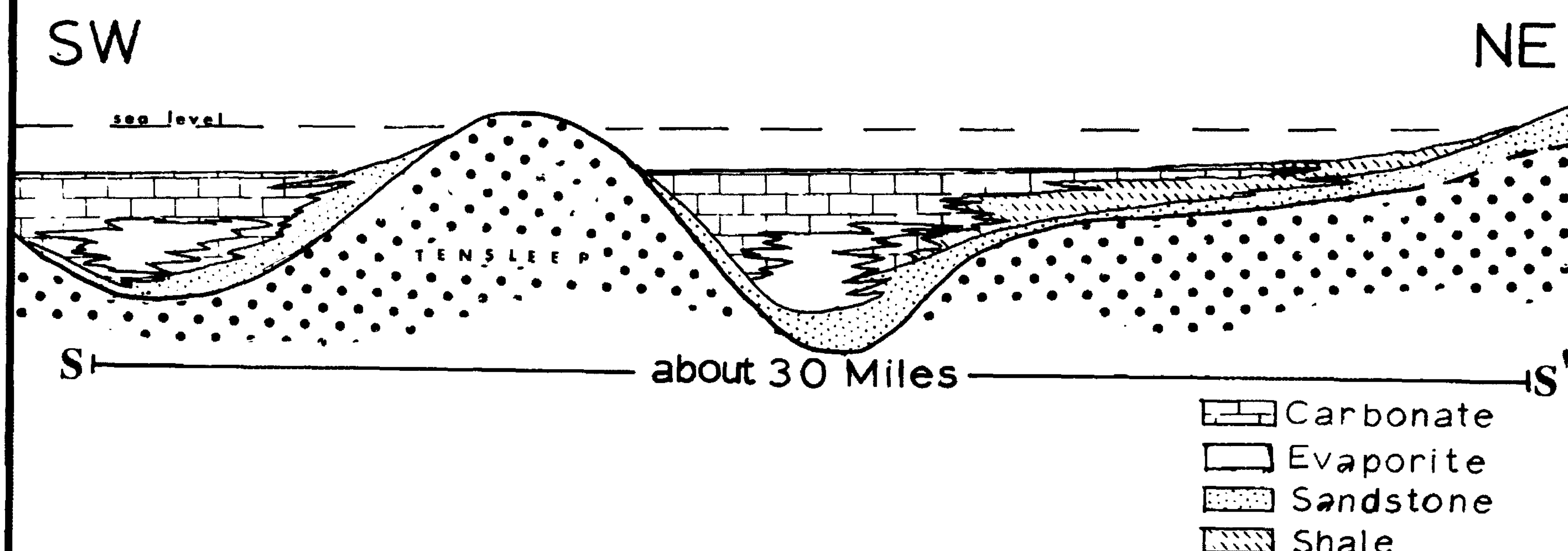


Fig. 9 - Diagrammatic cross section of the Grandeur sea.
Cross section along S - S' of Plate I.

processes of bacteria (Illing, 1954; Ginsburg, 1957; Purdy, 1963).

The Grandeur carbonate, for the most part, has been so thoroughly dolomitized that the depositional texture is in doubt. Several origins for dolomites have been proposed, but the most accepted general theory involves the replacement of calcium carbonate sediment or limestone. This replacement may occur within the depositional environment or after lithification. Evidence for the latter are lacking (dolomites associated with postdepositional structural features) for the Grandeur dolomite as well as the other Phosphoria dolomite units which will be discussed later. The mechanism for dolomitizing calcium carbonate sediment may be refluxion, penecontemporaneous replacement, or capillary concentration.

The refluxion method appears to explain the dolomitization of many carbonate buildups (Adams and Rhodes, 1960). The buildup serves as a barrier which restricts circulation causing a dense, Mg-rich brine to form behind the buildup. This brine sinks to the bottom and displaces the less dense normal sea water within the permeable carbonate buildup, progressively dolomitizing the limestone sediment. Penecontemporaneous replacement probably best accounts for the fine-grained, dense basin dolomites (J. A. Peterson, personal communication, 1969). Under restricted conditions a brine forms which increases in density with depth. Aragonite crystals, precipitating from the fresher surface waters, settle into this brine and become dolomitized. Capillary concentration explains supratidal dolomites (Friedman, 1966). In this method interstitial sea water of normal salinity transpires upward and evaporates at the sediment-air interface. The Mg-rich brine that remains dolomitizes the subaerially exposed sediment.

The Grandeur dolomite is considered to have been dolomitized by the penecontemporaneous replacement method. This is suggested by the homogeneity of the dolomite and the inferred penesalinity and shallowness of the sea. The lack of evidence for a suitable carbonate barrier and evidence for a supratidal environment tend to rule out the refluxion or capillary concentration method.

Initially, the Grandeur shoreline was defined by the Tensleep topography at which time sand and silt of the lower Opeche Shale spread westward and southward from the continental borderland, mixing with the Grandeur dolomite. As the sea bottom irregularities filled, the sea floor and littoral zone became a continuous surface sloping gently westward.

Unit II

Unit II comprises intervals B through E. Interval B includes the upper Opeche Shale and a thin sandstone bed at its base which has been tentatively correlated with the Meade Peak Member (see Fig. 8). Interval C is the Minnekahta carbonate tongue of the Franson Member, a thin unit which extends eastward as far as the Black Hills, South Dakota. Interval D includes the Glendo Shale and the seaward-equivalent Franson carbonate. Interval E is the Forelle carbonate tongue of the Franson Member, another eastward extending carbonate unit which intertongues with the Freezeout Shale in the Powder River basin. Each interval will be discussed separately.

Interval B

The basal unit of interval B is a five-foot pebbly sandstone bed which was observed at Wind River Canyon (WR-C), Grass Creek (GC-B) and Stove Creek (SC-D_1) sections (control points 4, 5 and 7), and reported in the lithologic logs from the southwestern half of the area. The remainder of interval B consists of the upper Opeche Shale. This shale is generally thin-bedded, occasionally fissile and rarely exposed. It is gray and calcareous in the western or seaward part of the area and red with

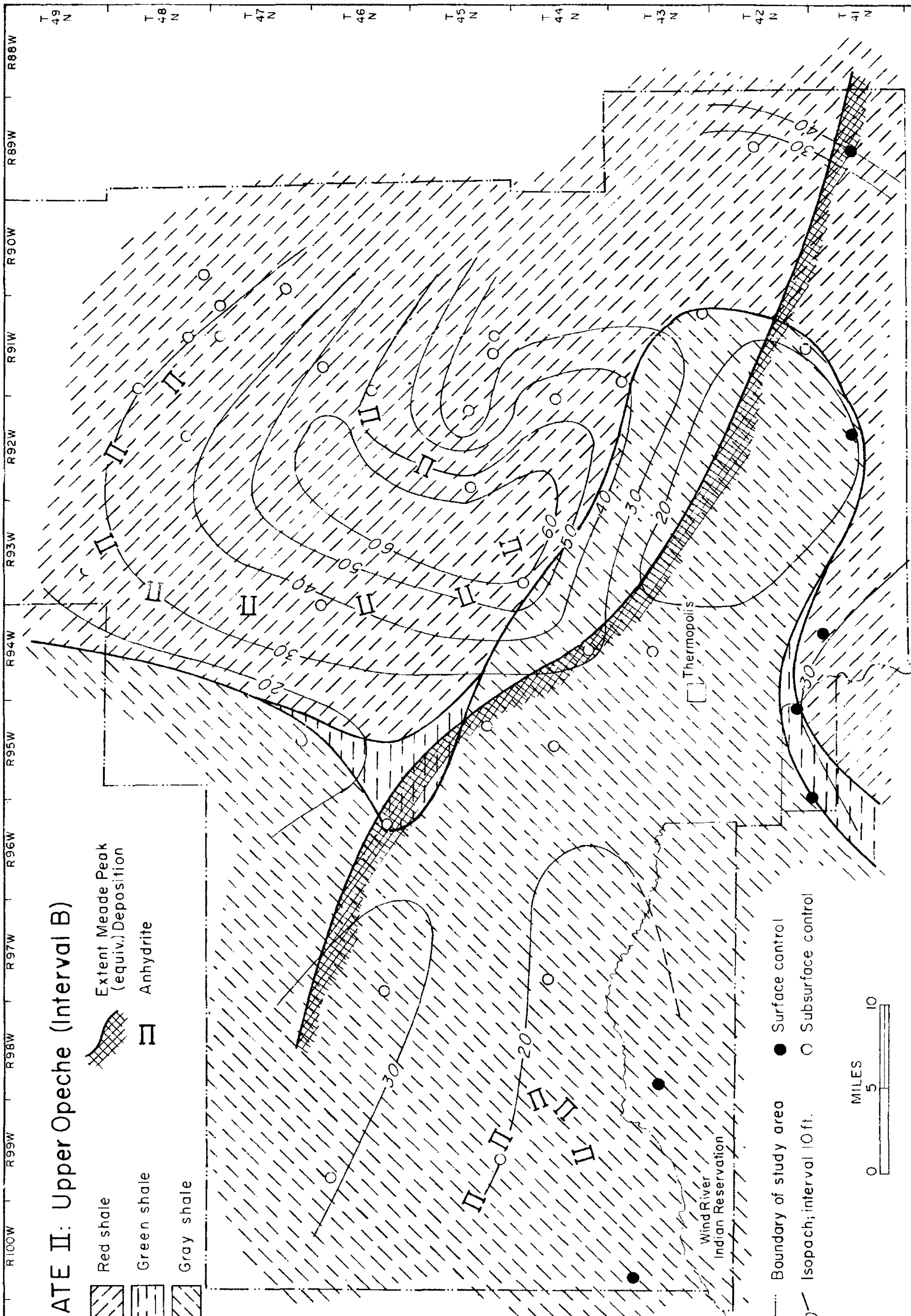


PLATE II: Upper Opeche (Interval B)
Red shale
Green shale
Gray shale
Extent Meade Peak (equiv.) Deposition
Anhydrite
Boundary of study area
Isopach; interval 10 ft.
Surface control
Subsurface control
MILES
0
5
10
Wind River Indian Reservation
Thermopolis
R101W
R100W
R99W
R98W
R97W
R96W
R95W
R94W
R93W
R92W
R91W
R90W
R89W
R88W
T 49 N
T 48 N
T 47 N
T 46 N
T 45 N
T 44 N
T 43 N
T 42 N
T 41 N

intraformational breccias, reduction spots, and anhydrite nodules in the eastern portion.

Interval B produces a characteristic shale deflection on the gamma-ray log between two carbonate deflections.

Lithofacies

The basal sandstone of this interval is composed of poorly-sorted, fine- to coarse-grained, angular quartz sandstone with large rounded carbonate lithoclasts. Minor dark, phosphatic, interstitial mud is present along with some small amber-colored fragments which may be phosphatic brachiopod shell pieces.

The upper Opeche red shale is similar to that of the lower Opeche. It dominates the eastern portion of the area, becoming gray to the west, with local occurrences of green shale between. Anhydrite beds are associated with an increase in shale thickness in the eastern portion of the area which is characterized by a closed 60 foot isopach line. Plate II shows the distribution of interval B lithologies, including the eastern limit of the basal sandstone.

Interpretation

The sandstone bed at the base of this interval lies at the approximate stratigraphic horizon of the Meade Peak Member and is here considered to be an eastern facies of that unit. The conglomeratic nature of this bed suggests an unconformity on top of the Grandeur. Sheldon (1963) defines two members of the Grandeur, a western member, which is probably of Middle or Late Pennsylvanian age, and a younger eastern member which outcrops in the Wind River and Owl Creek ranges. Sheldon finds a lateral gradation between the eastern Grandeur Member and the lower chert member (see Fig. 8) and therefore considers the Grandeur to be of "Phosphoria age" and conformable with the overlying Meade Peak. King (1957) suggested that an unconformity existed at the top of the Grandeur in the Wind River Mountains and correlated it with one described by McCue (1953) in the Owl Creek Mountains. Subsurface correlations by Sheldon showed the Meade Peak to pinch out within the Grandeur in the Wind River basin and therefore losing its identity in the Owl Creek Mountains. He also considers the lower Franson and Grandeur carbonate beds to be a single inseparable unit in the Owl Creek range. However, the present study suggests that the lowest Franson carbonate beds (Minnekahta tongue) are separated from the Grandeur by the upper Opeche Shale and a thin Meade Peak-equivalent sandy bed.

The petrographic and stratigraphic evidence presented here suggests the presence of the unconformity originally described by McCue (1953) and identified by King (1957), and that the Meade Peak equivalent extends at least as far as the Owl Creek Mountains, perhaps pinching-out in the Big Horn basin.

A lithologic study of the Opeche, Glendo and Freezeout Shale units was not included in this investigation. Campbell (1956, 1962), however, studied this eastern facies in outcrop, in thin-section, and by X-ray and concluded that all the red shale beds probably represent tidal flat deposits. Fine laminations, intraformational breccias and the red color of the shales, which were observed during the present study, seem to bear out Campbell's interpretation. The red color is probably due to the oxidation of iron-bearing minerals during intertidal exposure of the sediment. This process of red bed origin has been discussed by Walker (1957).

The gray shale facies of the Opeche, Glendo and Freezeout members probably represent normal marine shales, apparently deposited contemporaneously with the red intertidal shales but in an offshore environment which was not periodically exposed. Organic material deposited with the sediment was preserved in a reducing environment, imparting the gray color to the shale.

The inferred unconformity on top of the Grandeur suggests a major regression, during which time at least part of the Meade Peak phosphorite and phosphatic shale were deposited along the shelf edge in western Wyoming. Interval B represents the initial deposits of a second major Permian transgression. The constituents and source for the Meade Peak equivalent are lithoclasts eroded from the underlying Grandeur along with sand that was possibly carried in by longshore currents from northwestern Wyoming where the Shedhorn Sandstone was being deposited. The source for the upper Opeche Shale clastics was probably the low-lying land area to the east and north. The increased thickness of the interval in the eastern portion of the study area was apparently due to a greater influx of sediment, possibly the mouth of a tidal channel.

Interval C (Minnekahta)

The thin Minnekahta carbonate tongue of the Franson Member extends eastward over the entire area and is overlain and underlain by two major shale units: the lower Glendo and upper Opeche, respectively. On the gamma-ray log, interval C gives a characteristic carbonate deflection between two shale deflections.

In outcrop the Minnekahta is a brown to gray, finely-laminated, platy, silty, dolomite which is locally cherty.

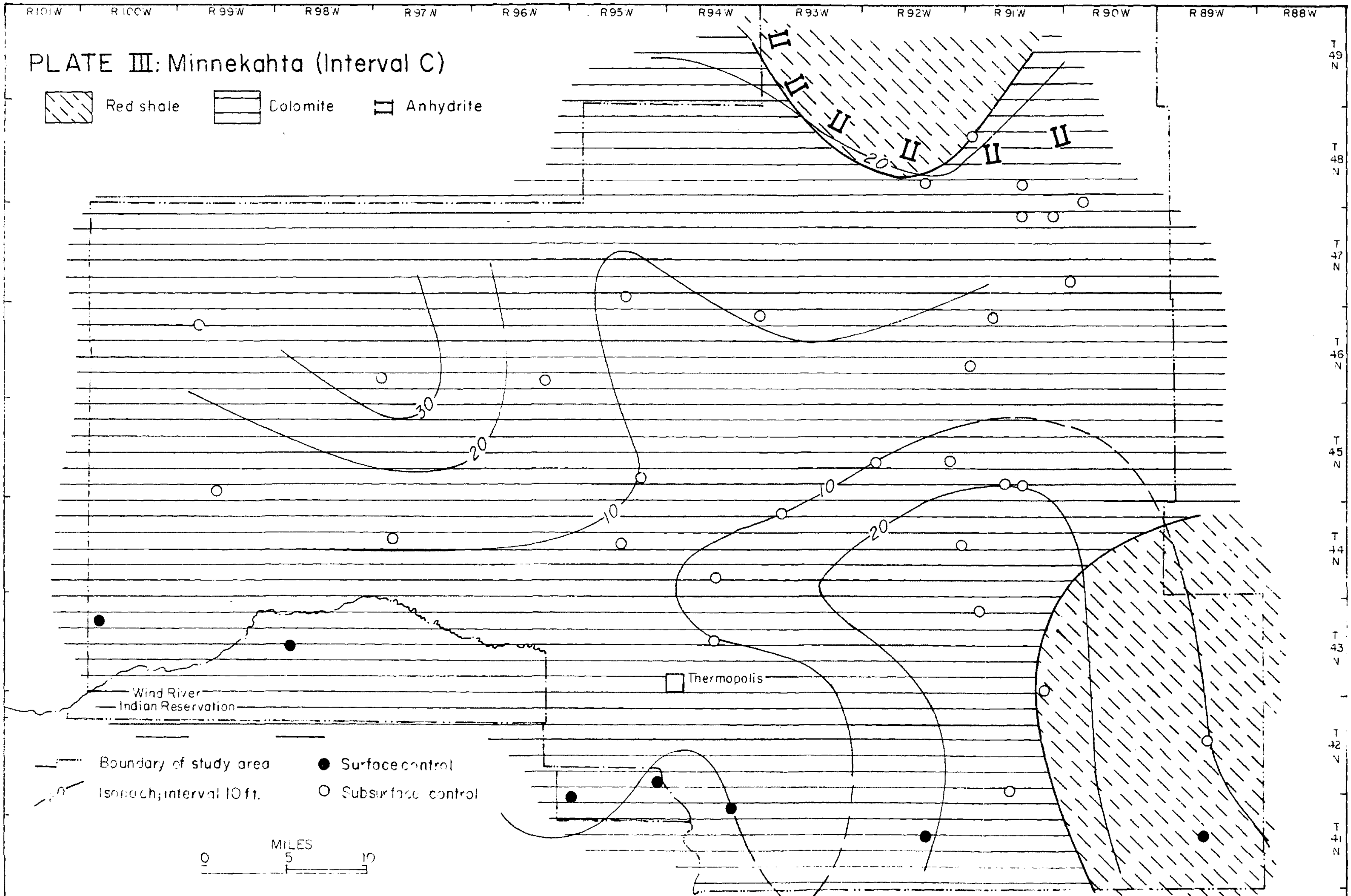


PLATE III: Minnekahta (Interval C)
Red shale
Dolomite
Anhydrite
R101W
R100W
R99W
R98W
R97W
R96W
R95W
R94W
R93W
R92W
R91W
R90W
R89W
R88W
T 49 N
T 48 N
T 47 N
T 46 N
T 45 N
T 44 N
T 43 N
T 42 N
T 41 N
30
20
10
Thermopolis
Wind River
Indian Reservation
Boundary of study area
Isopach; interval 10 ft.
Surface control
Subsurface control
MILES
0
5
10

Large, bulbous, finely-laminated stromatolite heads and intraformational breccias are common at the Stove Creek section (control point 7).

Lithofacies

The dominant carbonate lithology in interval C is a silty laminated dolomite mudstone (Photo-plate 1a). The laminae are about one-half millimeter thick and are laterally discontinuous, sometimes giving the appearance of cross-bedding. Some laminae are 80 percent silt containing microscour features which are filled with dolomite mud (Photo-plate 1b). The association of these laminated dolomites with the stromatolite origin, although a purely physical genesis seems just as likely. Small anhydrite nodules are rather common in the eastern surface sections. The dolomite mud is dark brown, submicroscopic, sometimes with a vague mottled appearance.

The isopach-lithofacies map of interval C (Plate III) reveals a well-defined east-west thin trend within which the interval is less than 10 feet thick (compared to about 30 feet on either side). Lithologic log data from the northeastern part of the area and the Stove Creek section (control point 7) indicate the presence of red shale beds of either the Glendo or Opeche Shales which intertongue with the Minnekahta dolomite.

Interpretation

Stromatolites, laminations, and intraformational breccias indicate quiet water deposition with periodic exposure, suggesting either an intertidal or supratidal environment. The thin trend across the area may represent a tidal channel, the mouth of which was probably somewhere west of this area. The Minnekahta, therefore, represents a slightly regressive phase of the Phosphoria sea. However, viewed regionally this may have been only a local regression in a generally transgressive sea (Shinn, Lloyd and Ginsburg, 1969).

The capillary concentration process of dolomitization appears to be the most compatible with the environmental interpretation suggested above. Capillary concentration requires periodic exposure which is implied in an intertidal or supratidal environment. Penecontemporaneous replacement may have been a secondary process in evaporite pans (broad shallow, isolated basins) which are common on tidal flats in an arid climate.

Interval D

Interval D includes the Glendo Shale and its lateral equivalent Franson carbonate Member. This interval is bounded above and below by the Forelle and Minnekahta

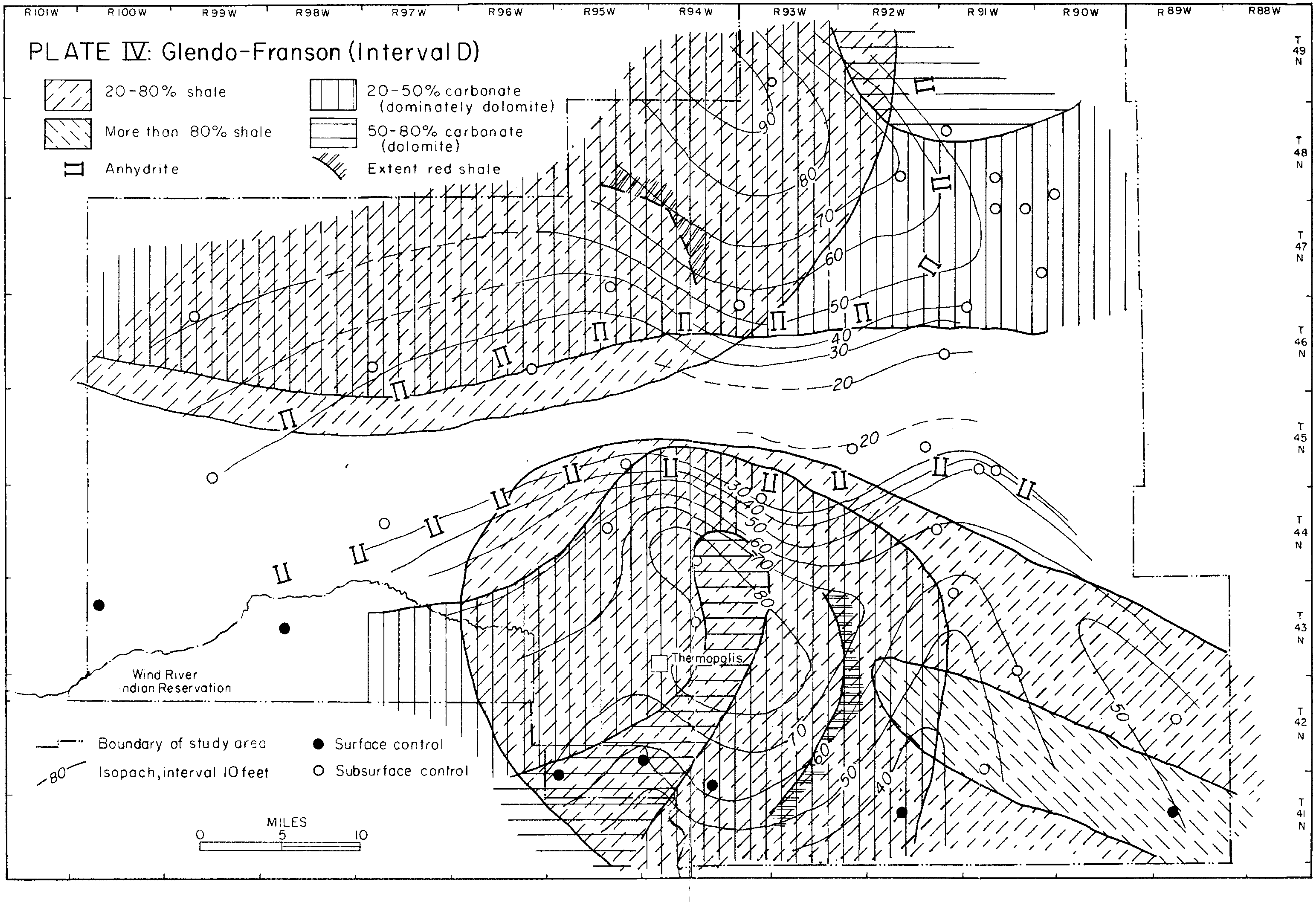


PLATE IV: Glendo-Franson (Interval D)
20-80% shale
More than 80% shale
Anhydrite
20-50% carbonate (dominately dolomite)
50-80% carbonate (dolomite)
Extent red shale
R101W
R100W
R99W
R98W
R97W
R96W
R95W
R94W
R93W
R92W
R91W
R90W
R89W
R88W
T 49 N
T 48 N
T 47 N
T 46 N
T 45 N
T 44 N
T 43 N
T 42 N
T 41 N
Thermopolis
Wind River Indian Reservation
Boundary of study area
Isopach, interval 10 feet
Surface control
Subsurface control
MILES
0
5
10

tongues, respectively.

The Franson carbonate beds are thinly laminated to massive, silty, cherty dolomites or limestones. In the western part of the area they are interbedded with thin gray shale beds which grade to red shale eastward. Argillite clasts and chert pebbles were found near the base of the carbonate at Wind River Canyon (WR-G) (control point 4) and stromatolites were observed at West Kirby Creek (control point 6).

The Glendo Shale consists of red and gray shale beds which are lithologically and environmentally similar to the Opeche Shale (interval B).

Lithofacies

A variety of carbonate lithic types were identified in the Franson Member of interval D. The dominant lithology seems to be a dark, submicroscopic, laminated, dolomite mudstone which is commonly silty and often contains some pellets and algal fragments. Mottling is common. In the south part of the area, between the Red Canyon Creek and Grass Creek sections (control points 3-5) a carbonate thick trend (see Plate IV) coincides with a non-skeletal buildup which is composed of three types of sand-sized particles: fecal pellets, intraclasts, and oolites. The pellets are well-rounded with a sharp, and sometimes optically distinct border and an interior of mud, spar or smaller pellets (Photo-plate 2a). The intraclasts are dark, angular mud grains. The oolites are similar to the pellets, although accretion layers can be observed under a magnification of about 75x (Photo-plate 2b).

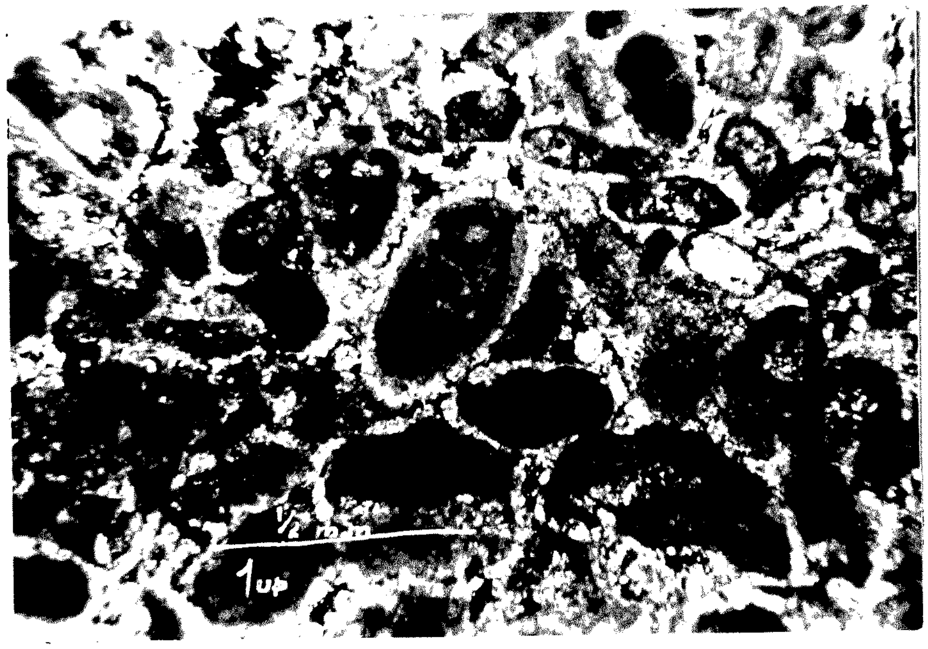
Associated with the nonskeletal particles are short, straight to slightly curved, sparry features which commonly have a darker center. The origin of these features is unknown although possibly they may be algal. There are also some crinoid plate fragments in the muds adjacent to the buildup.

Plate IV shows the percentage distribution of the carbonate and shale units of interval D and their association with the thickness changes of the interval. It also indicates the presence of an east-west thin trend (less than 20 feet thick) which contains about 80 percent anhydrite.

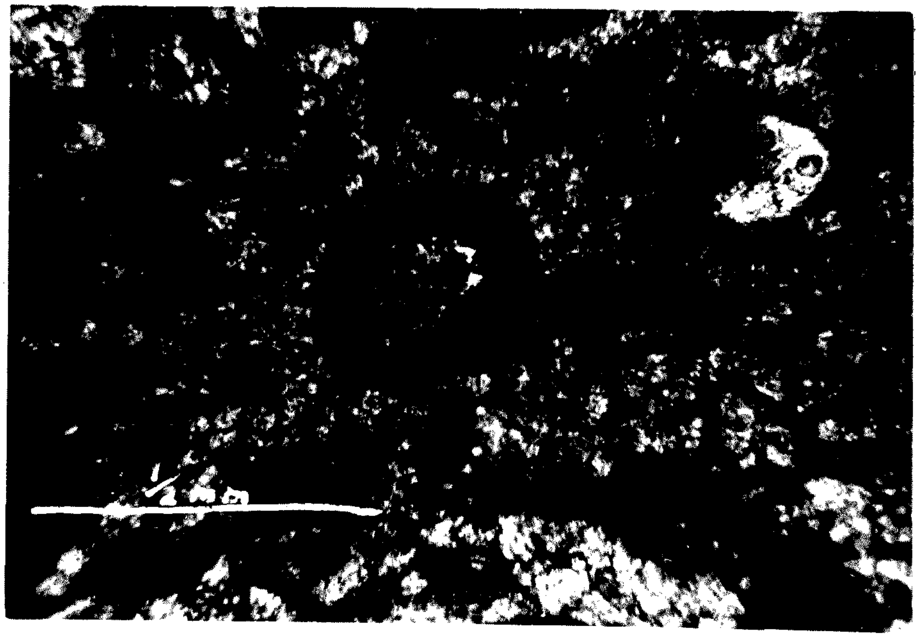
Interpretation

The Glendo red shale, as previously stated, probably represents an intertidal environment which grades westward to a gray normal marine shale. It was apparently derived from sources to the north and east. This unit

PHOTO-PLATE 2



A



B

Explanation of Photo-plate 2

A) Franson Member (GC-F3u): Nonskeletal, dolomite packstone. Prominent pellet near center of photo has optically distinct margin and contains smaller pellets. Dark grains below center are intraclasts.

B) Franson Member (GC-F3u): Oolite from same thin section as 2a.

dominates the lower half of interval D, but intertongues with the Franson carbonate in the upper half.

The thin trend of this interval (Plate IV) appears to coincide with a similar feature, which was interpreted as a tidal channel, in the underlying interval (Minnekahta). The predominance of anhydrite within this lineament suggests that it was a depression or trough-like feature which may have been restricted by Glendo clastic deposition at its mouth or by sea level fluctuations. This trend apparently remained thin during the deposition of interval D, suggesting the possibility that it continued to function as a tidal channel, at least part of the time.

The Franson carbonate Member dominates the southwestern portion of the area in the upper half of interval D. The thin shale interbeds apparently represent periods of increased fine clastic deposition which stifled the organic activity necessary to precipitate calcium carbonate. Laminations and stromatolites, observed in some of these carbonate beds, suggest they may be of tidal flat origin.

The nonskeletal bank in the south-central part of this area represent a shallow water environment which was alternately calm then agitated, probably in response to periodic sea level changes. Initially the environment must have been calm enough to prevent the destruction of fresh pellets. But after the pellets became indurated and capable of withstanding more agitated conditions, some served as nuclei for oolites which acquired their accretionary layers by being rolled about in an area of precipitating calcium carbonate. The intraclasts represent even more agitated or turbulent conditions, probably storms, in which bottom mud is torn up.

The Franson Member of interval D is dominantly a dolomite, although there are some limestones and dolomitic limestones in the western or seaward part of the area. The implied periodic exposure of the tidal flat carbonate beds suggests that capillary concentration was the dominant dolomitization process here. The nonskeletal buildup, on the other hand, was probably dolomitized by refluxion. The bank may have effectively restricted the back-bank area where a dense, hypersaline, Mg-rich brine could form and seep through the permeable bank material, displacing the less dense normal sea water and progressively dolomitizing the sediment.

Interval E (Forelle)

The Forelle tongue of the Franson Member is a thin- to massive-bedded, fossiliferous dolomite or limestone which grades eastward to a medium-bedded, silty to

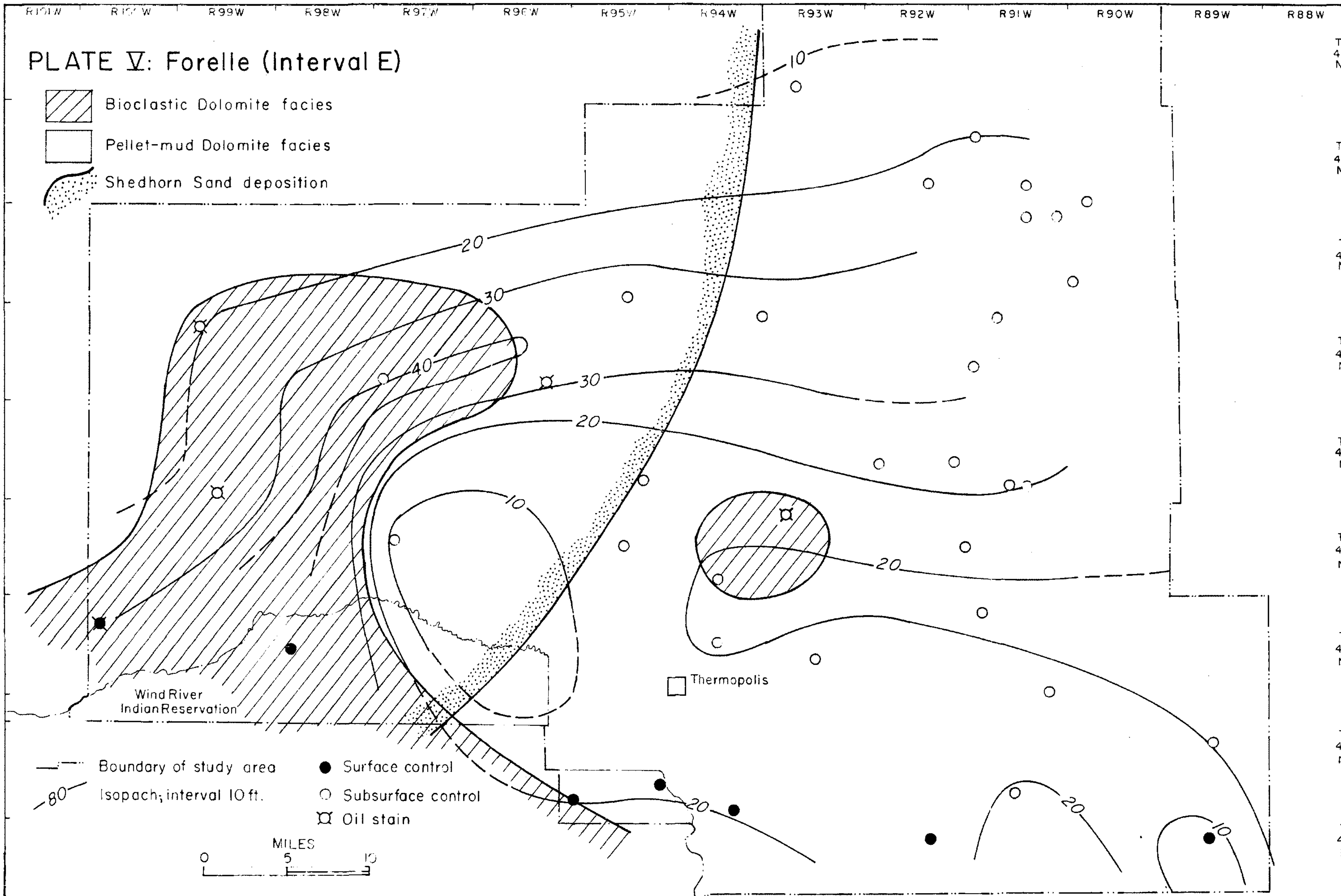


PLATE V: Forelle (Interval E)
Bioclastic Dolomite facies
Pellet-mud Dolomite facies
Shedhorn Sand deposition
R99W
R98W
R97W
R96W
R95W
R94W
R93W
R92W
R91W
R90W
R89W
R88W
T 49 N
T 48 N
T 47 N
T 46 N
T 45 N
T 44 N
T 43 N
T 42 N
T 41 N
10
20
30
40
30
20
10
20
20
10
Thermopolis
Wind River Indian Reservation
Boundary of study area
80
Isopach; interval 10 ft.
Surface control
Subsurface control
Oil stain
MILES
0
5
10

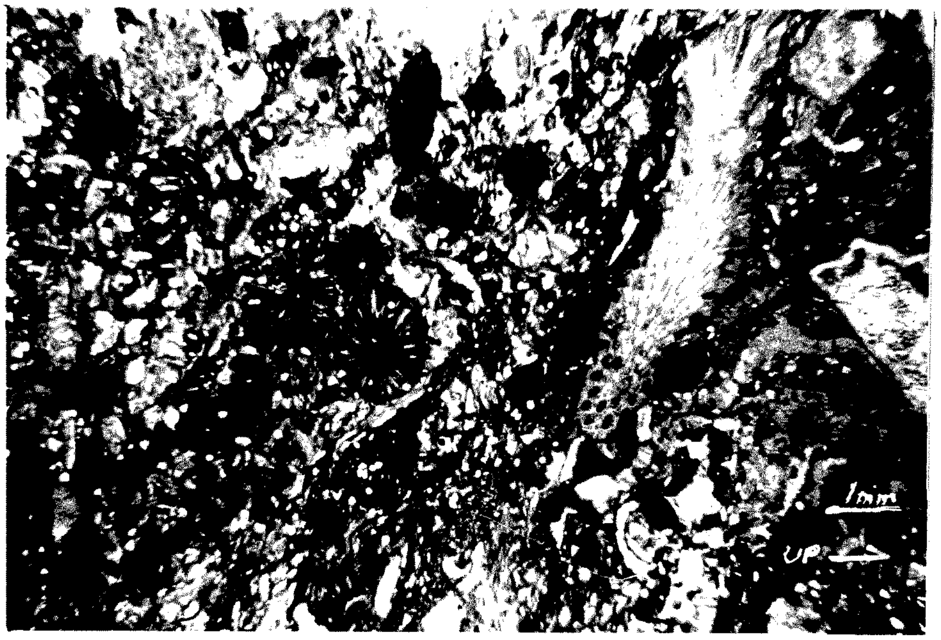
argillaceous dolomite. This interval gives a "clean carbonate" deflection on the gamma-ray log which differentiates it from the more subdued or impure carbonate deflection of the interval D Franson carbonate.

Lithofacies

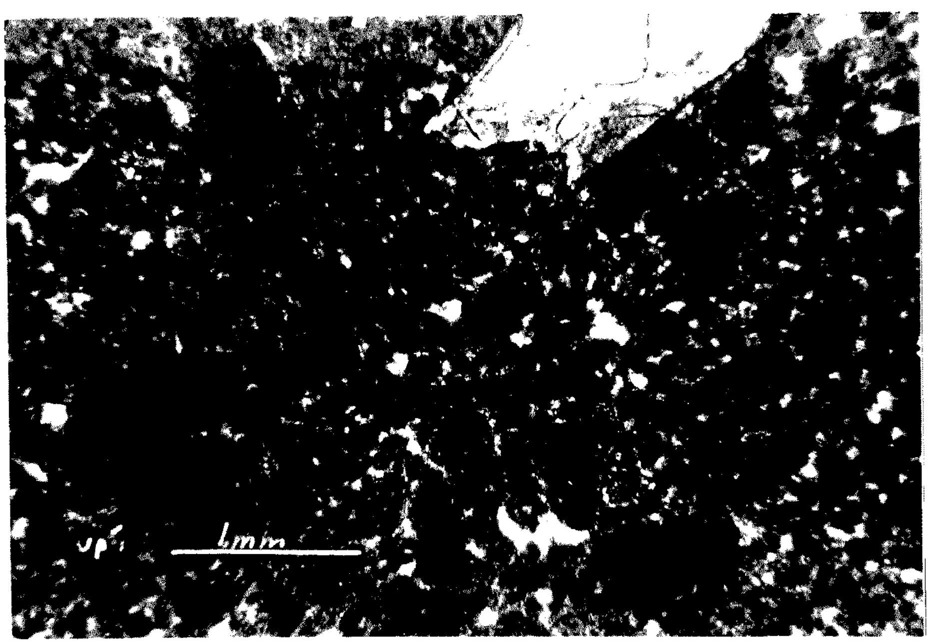
Two facies were recognized in the Forelle: a western or seaward bioclastic facies which grades eastward to a pellet-mud facies.

Bioclastic facies: This facies, which coincides with a northeast trending thickening of the interval along the western edge of this study area (see Plate V), is dominantly a bioclastic limey dolomite packstone with a matrix of brownish calcite or dolomite. The bioclastic constituents are medium sand to small pebble-sized fragments of ramose (trepostome) bryozoans, crinoid stem pieces and calyx plates, and brachiopod shells (see Photo-plate 3a). Crinoid stems and plates are composed of single calcite crystals having a reticulate or cross-hatched pattern which is generally readily apparent in thin-sections of the calyx plates. The stem pieces, however, are more massive and usually do not display this pattern. The stem pieces are also quite regular in outline with a central opening, while the calyx plates are very irregular and appear fragmented. This difference is apparently a

PHOTO-PLATE 3



A



B

Explanation of Photo-plate 3

A) Forelle tongue (RDC-1u): Bioclastic lime packstone from bioclastic facies. Prominent feature just right of center is a bryozoan. A punctate brachiopod shell and a silicified crinoid stem piece lie along the middle of the photograph, just right of the bryozoan. Several smaller fragments of bryozoans and crinoids, many replaced by fluor-apatite, are scattered throughout the photo. The white specks are quartz grains.

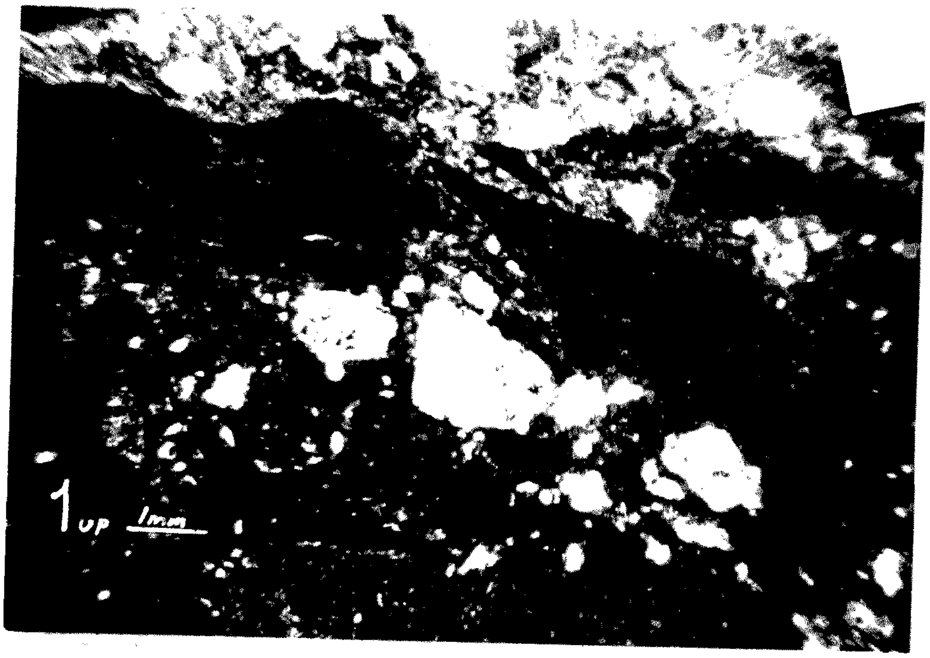
B) Forelle tongue (GC-F5m): Pelletal dolomite packstone from pellet-mud facies. Larger, more angular grains are intraclasts, some of which can be seen to contain pellets. Large feature at the top of the photo is a fish fragment (?).

reflection of the ability of these particles to withstand a turbulent environment. Much of the bioclastic material has been replaced by silica or phosphate. Crinoid stems and brachiopod shells appear to be preferentially replaced by silica, while phosphate replaces crinoid plates and bryozoans. Laminations, burrows and oil stains are common in this facies.

Pellet-mud facies: This facies dominates the east and central parts of the study area (see Plate V) and is composed of a pellet dolomite packstone-grainstone (Photo-plate 3b) and a submicroscopic to finely-crystalline dolomite mudstone. The pellets are homogeneous, dark brown, sand-sized, vaguely outlined spheres which are surrounded by a finely-crystalline mud matrix. Phylloid algae fragments are commonly associated with the pellets but are also found in the mudstone. At West Kirby Creek (control point 6) a mudstone containing large, often fractured, carbonate clasts and anhydrite nodules was observed in a three to five inch bed between two pellet beds (Photo-plate 4a).

Plate V shows the areal distribution of the two facies of this interval as well as the southeastern limit of a thin sandstone bed which is reported on lithologic logs and which appears to be present in outcrop at Anchor Dam and Red Creek (control points 1 and 2) as a sandy

PHOTO-PLATE 4



A

B

Explanation of Photo-plate 4

A) Forelle tongue (WKC-5m): Intraclastic dolomite wackestone from pellet mud facies. White grains are anhydrite nodules.

B) Retort Member (RDC-4): Bioclastic, phosphatic, pebbly sandstone. Brachiopod shell fragments surrounded by phosphatic mud pebbles, quartz sand grains, and a phosphatic mud matrix.

carbonate.

Interpretation

The Forelle carbonate probably represents an eastward transgression of the Franson sea. The pellet-mud facies accumulated in quiet, shallow water and was probably periodically exposed, at which time anhydrite may have been precipitated interstitially. The original sediment may have been considerably more pelletal than the rock indicates, but burrowing organisms could have destroyed some pellet beds making them indistinguishable from the mud. Occasional storms apparently tore up partially consolidated bottom mud or pellet beds to form the intraclastic dolomite beds.

Seaward of the pellet-mud facies a crinoid-bryozoan bank became established. Both crinoids and bryozoans prefer a shallow, agitated environment of near normal salinity with a relatively firm substrate on which to attach. After the bank became established it grew vertically, keeping pace with sea level rise. Periodic fluctuations of sea level, due either to tides or some larger cyclic phenomena, caused shoaling over the bank which fragmented and reworked the skeletal material. No faunal constituents were found which could be considered in place, although the relatively sharp margins of the bank suggest that the live bank was probably not far from this site.

The bioclastic bank is predominantly limestone while the pellet-mud facies is entirely dolomite. The bank may have periodically restricted the back-bank area sufficiently for penecontemporaneous replacement to have been the dominant dolomitization process in the pellet-mud facies. Refluxion apparently was only partially effective in dolomitizing the bank, due either to a lack of original porosity or other unfavorable physico-chemical conditions.

The deposition of the upper Forelle beds was temporarily interrupted by an influx of clastics which may have been associated with the Shedhorn Sandstone deposition in northwestern Wyoming and possibly carried into this area by longshore currents.

Unit III

Unit III includes intervals F through I. Each interval produces a characteristic pattern on the gamma-ray log which cannot be readily correlated to specific rock types. Interval I, at the top of the Ervay, produces a sharp carbonate deflection which distinguishes it from the more subdued impure carbonate deflection characteristic of the overlying Dinwoody Formation. Interval H is a carbonate which contains fine-grained, black, radioactive grains (J. A. McCaleb, personal communication, 1969) which produces sharp radioactive deflections. Intervals F and G produce an alternating series of radioactive and non-radioactive deflections. Generally a radioactive or shale deflection occurs at the base (interval F), while a thicker non-radioactive (carbonate ?) deflection is found at the top (interval G). In core samples or outcrop, intervals G, H, and I cannot be distinguished (see Fig. 4).

Unit III will be discussed in two sections: interval F and interval GHI.

Interval F (Retort)

Interval F consists of the Retort Member, a thin, phosphatic sandstone, and its lateral equivalent, the lower Freezeout Shale.

Lithofacies

The dominant lithology of the Retort Member is a pebbly, pelletal, calcareous, phosphatic sandstone which is commonly bioclastic. Angular quartz sand and silt make up as much as 30 to 50 percent of the rock. The pebbles are rounded carbonate, chert, and phosphate lithoclasts and the pellets are black, generally with an

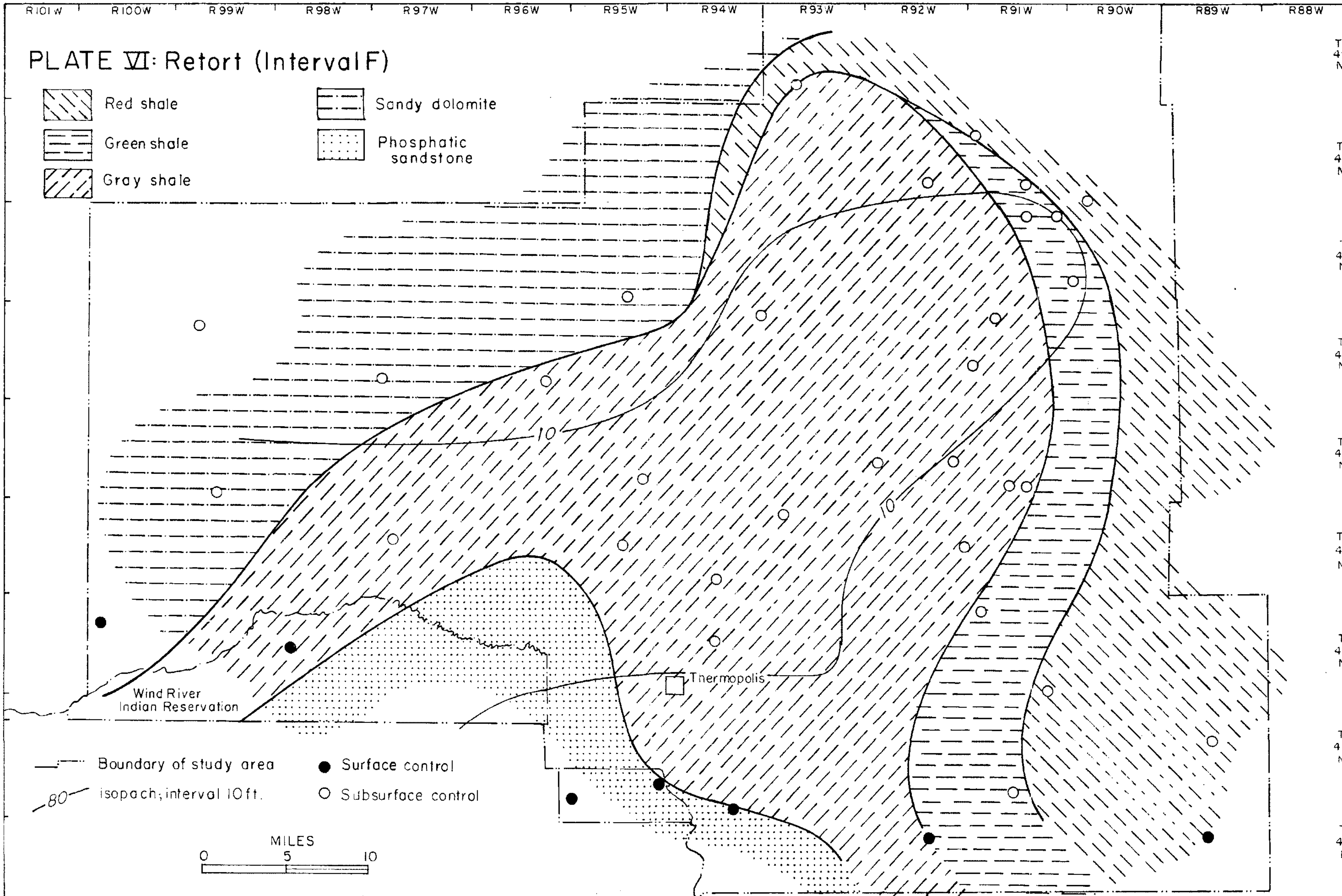


PLATE VI: Retort (Interval F)
Red shale
Green shale
Gray shale
Sandy dolomite
Phosphatic sandstone
R101W
R100W
R99W
R98W
R97W
R96W
R95W
R94W
R93W
R92W
R91W
R90W
R89W
R88W
T 49 N
T 48 N
T 47 N
T 46 N
T 45 N
T 44 N
T 43 N
T 42 N
T 41 N
10
10
Thermopolis
Wind River Indian Reservation
Boundary of study area
80 isopach; interval 10 ft.
Surface control
Subsurface control
MILES
0
5
10

amber colored margin. The matrix material is a dark brown, submicroscopic, limey mud. Productid brachiopod shell fragments are the dominant bioclastic constituent (Photo-plate 4b).

A gray shale, associated with the phosphatic sandstone, is composed of dark muds with some brachiopod shell fragments and black pellets similar to those described above.

The phosphatic sandstone crops out between Red Creek and Grass Creek (control points 2-5) and grades northeastward to gray and finally red shale of the Freezeout. Northward and westward the gray shale grades to a sandy dolomite (see Plate VI).

Interpretation

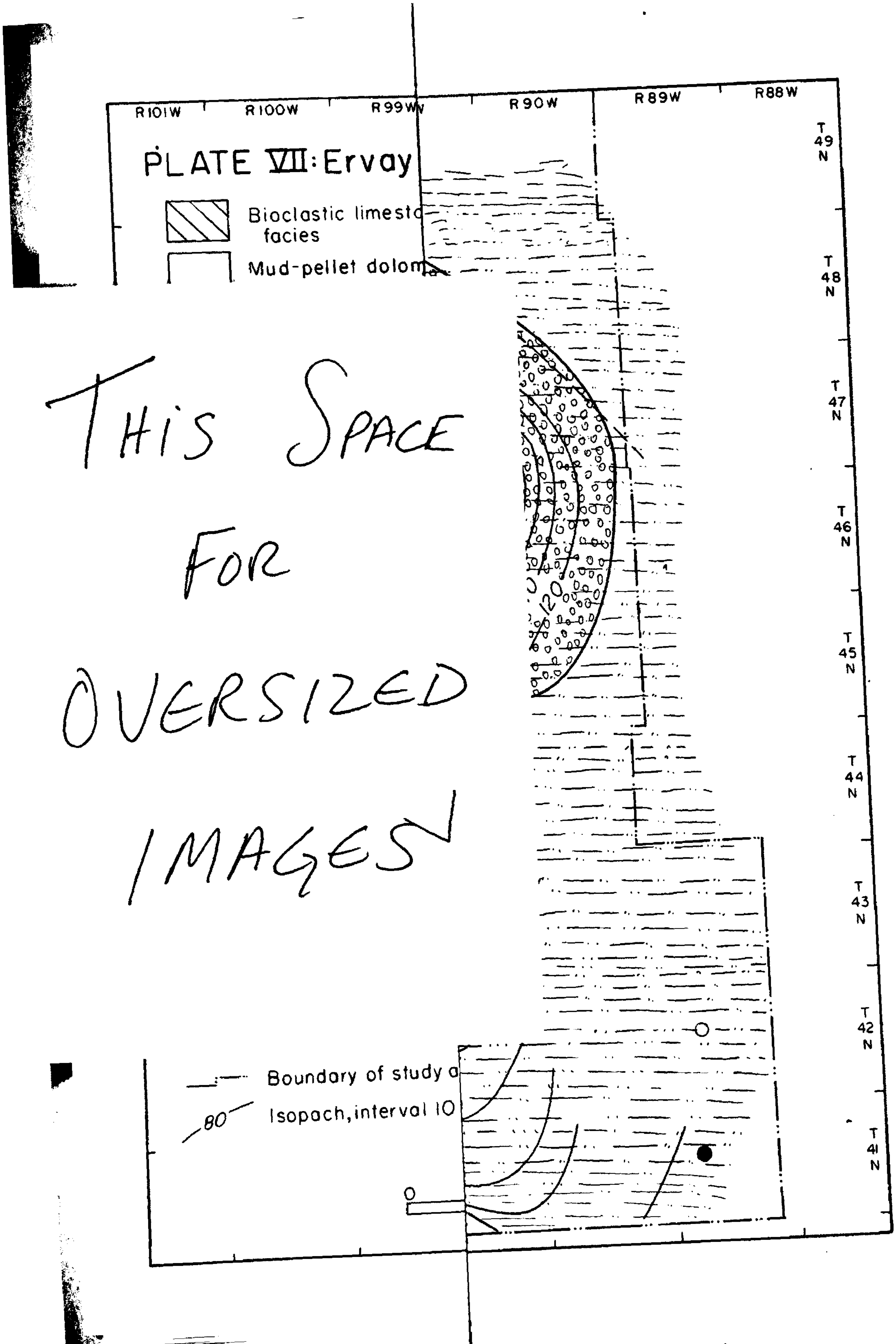
Interval F apparently represents a set of conditions and environments similar to those previously described for the Meade Peak (interval B). The pebble content of the phosphatic sandstone suggests exposure and erosion of the Forelle surface before Retort deposition. The Shedhorn Sandstone, which was being deposited to the northwest at this time, was probably the source for the sand which may have been carried into this area by longshore currents. The Freezeout Shale represents an influx of fine clastics from land areas to the northeast and east, deposited in near shore marine and tidal flat environments.

The petrographic and stratigraphic evidence presented here and under the discussion of the Meade Peak seems to substantiate the evidence presented by Peterson (1968), who suggested that the Meade Peak and Retort Members were deposited during a regressive or initial transgressive stage of the Phosphoria sea. This interpretation is somewhat different from that proposed by Sheldon (1963), who considers the phosphatic units to represent maximum transgression and the underlying Franson Member (intervals C, D and E) to represent regression. Sheldon bases his interpretation on two factors: 1) the geochemical similarities of phosphates and carbonates which suggests contemporanity of the two in the sedimentary environment, and 2) the western extension of the Franson carbonate beds into southeastern Idaho, considered to indicate regression of the Franson sea. However, the geochemical and organic processes which control the deposition of phosphates are not entirely understood and there may be some reason to question whether chemical similarities of the phosphates and carbonates preclude contemporaneous deposition as Sheldon suggests. Secondly, studies of modern and ancient carbonate environments indicate that warm transgressive seas are generally required for significant carbonate deposition. Such seas require relatively unrestricted circulation, and it might then be expected that the area of carbonate deposition would tend to spread laterally as the sea transgressed rather than regressed. Therefore, the western extension of the Franson carbonate is probably more indicative of transgressive rather than regressive conditions.

Interval GHI (Ervay)

This interval includes the Ervay carbonate, the Tosi Chert and the upper part of the Freezeout Shale. The Tosi, the basal unit of this interval over most of the area (Plate VII), extends eastward and crops out in the Big Horn Mountains (McCue, 1953). In the Owl Creek Mountains the Tosi crops out as a resistant, irregular-bedded, nodular, blue-gray chert which is commonly interbedded with thin shale and dolomite beds.

The Ervay carbonate is a cyclic alternation of thin-bedded, siliceous dolomites and massive fossiliferous limestones in the western half of the study area. At the Red Creek section (control point 2), where these cycles are best developed, at least five cyclic repetitions were observed. Outcrops of the Ervay at the eastern sections are generally thin- to thick-bedded silty dolomites. Sub-



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surface data, obtained from lithologic well logs and core samples from wells drilled in the northeastern part of the area indicate the Ervay is dominantly a medium to coarsely-crystalline dolomite interbedded with minor chert, mud and bioclastic beds.

The lower Ervay Member intertongues eastward with red shale and anhydrite of the Freezeout Shale. The upper Ervay beds continue eastward into the Powder River basin.

Lithofacies

This interval is characterized by two, 130-foot carbonate buildups which are separated by a broad thinner area less than 80 feet thick. The western or seaward buildup represents a bioclastic bank while the eastern one is dominantly a pellet buildup which grades eastward to dense dolomite, red shale and anhydrite beds. The thinner area between the two buildups is mostly composed of mud and pellet beds. Plate VII shows the distribution of these facies and their relationship to the isopach pattern as well as the reported extent of Tosi deposition and the furthest eastward occurrence of limestone.

Bioclastic facies: This facies is composed of cyclic alternations of siliceous dolomite mudstone and bioclastic lime wackestone-grainstone. The mudstone consists of a dark submicroscopic, commonly mottled mud, containing silt to fine sand-sized, hollow, siliceous rods which are probably sponge spicules. Pellets, bioclastic material, and phylloid algae fragments are occasionally present.

The bioclastic rocks of this facies are very similar to the bioclastic rocks of the Forelle (interval E). The major faunal constituents are ramose bryozoans, crinoids, and brachiopods with some fenestrate bryozoans. Generally this material is highly fragmented and occurs in a dark, submicrocrystalline, calcite or dolomite mud. Replacement of the bioclastic material by silica and phosphate is much more common than in the Forelle. The phosphate is generally reddish to brown or amber in color and isotropic to slightly anisotropic. A green substance, with the same occurrence as the phosphate, and which was originally identified as glauconite, may be fluorapatite according to preliminary X-ray diffraction patterns run on similar samples from the Wind River Mountains by Dennis C. Ahlstrand in October, 1969 (Photo-plate 5a).

Mud-pellet facies: The dominant lithology of this facies is a submicroscopic to finely-crystalline dolomite mudstone with some phylloid algal leaves. At Stove Creek (control point 7) the mudstones are laminated, possibly indicating stromatolites. A pellet dolomite packstone is a secondary lithology which becomes more dominant to the

PHOTO-PLATE 5

A

B

Explanation of Photo-plate 5

A) Ervay Member (AD-21): Bioclastic lime packstone from bioclastic facies. Prominent dark feature near center of photo is a crinoid stem piece which has been replaced by green fluor-apatite. Other fossil material includes bryozoan and brachiopod fragments and unreplaced crinoid stem pieces.

B) Ervay Member (RDC-6_1): Bioclastic lime packstone from bioclastic facies. The "chicken wire" patterned features are large ramose bryozoans. The NW quadrant of the photo is dominated by silicified crinoid stem pieces.

northeast as the adjacent pellet facies is approached (Photo-plate 6a).

Pellet facies: Previous investigations have suggested this facies consists of: 1) oolites and fossils, possibly a reef (Pedry, 1957), 2) relic pellets, relic oolites, and relic skeletal grains (Campbell, 1956, 1962), 3) particulate materials, dominantly carbonate sand, superficial oolites, and aggregate particles (Boyd, 1958), and 4) litho-bioclastic particulate dolomite (McCaleb and Willingham, 1967). A lithologic study, including thin section analysis, of core samples, given to the author by Pan American Petroleum Corporation, indicates that this facies is primarily composed of pellets with lesser amounts of oolites and intraclasts. The pellets are variable in size and texture, ranging from fine pebbles to medium or fine sand and apparently size-sorted from north to south (larger to smaller). Some are homogeneous masses while others contain fine debris and skeletal material including ostracode shells (Photo-plate 6b). Non-concentric accretionary layers, observed around a few pellets, are thought to have developed when the particles rested on the sea bottom and acted as nucleating bodies in an area of carbonate precipitation. Most of the pellets of this facies are well-rounded and have a sharp, optically distinct border.

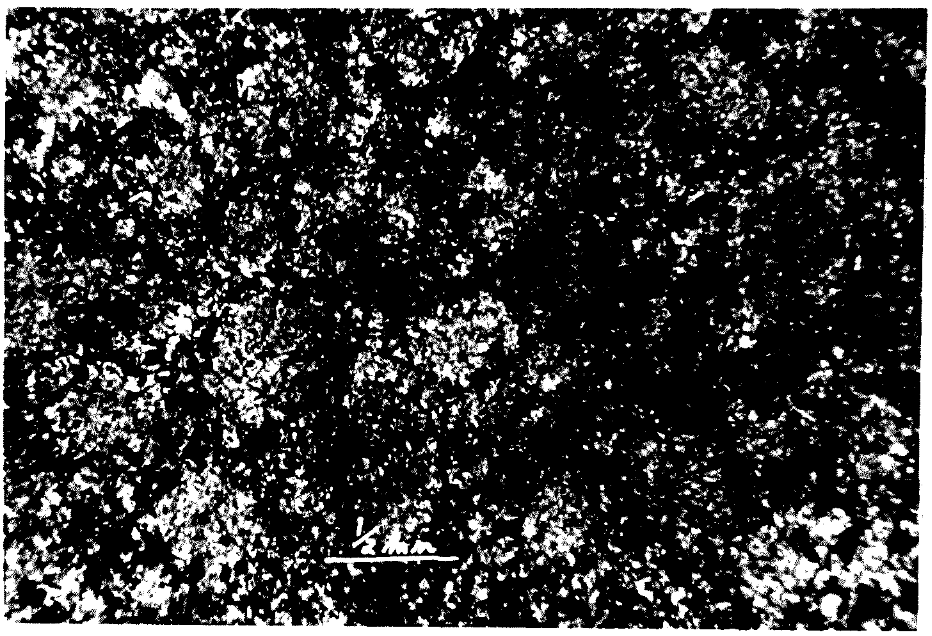
A few oolites and intraclasts were observed. The oolites were generally poorly formed and might better be described as superficial or incipient oolites. Grapestone was locally common, especially in the northern part of this facies. They are considered to be aggregates of pellets which acted as an individual grain prior to final deposition.

A distinct type of porosity characterizes this facies. The pore spaces are elongate, concave-up features which have a smooth floor and irregular roof and are occasionally filled with calcite or anhydrite (Photo-plate 6b). Tebbutt, Conley, and Boyd (1965) termed these features "fenestrae" and suggested they may represent molds of decaying organic matter, possibly algae, which were initially filled with gas or water while the sediment was being lithified.

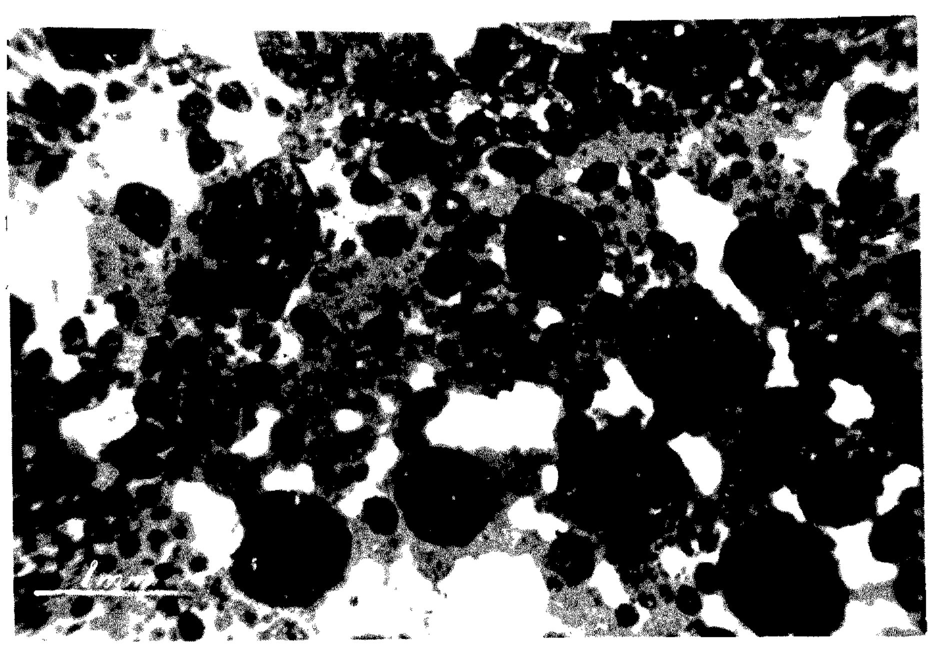
Interpretation

Interval GHI represents a third and final eastward transgression of the Phosphoria sea. The initial deposits of this transgression were the siliceous sediments of the Tosi Member, the origin of which, can only be inferred since there is no modern analog. Yochelson (1968) suggests that the bulk of the Phosphoria cherts (lower chert, Rex Chert and Tosi Chert) owe their origin to siliceous

PHOTO-PLATE 6



A



B

Explanation of Photo-plate 6

A) Ervay Member (B45G-1): Pelletal dolomite packstone from mud-pellet facies. Dolomitization has almost obliterated the pellets. Rock is heavily oil stained.

B) Ervay Member (PA-H 7766): Pellet dolomite wackestone from pellet facies. Large pellet near lower left corner contains ostracode shell. Fenestrae porosity (white areas) is typical of this facies.

sponges which lived on an ooze bottom in a calm environment at shallow depths.

Ervay carbonate sedimentation followed the deposition of the Tosi. A bryozoan-crinoid bank established itself offshore (see Plate VII) in shallow waters with a firm substrate and brisk currents as suggested by the ecologic requirements of these organisms. The bank built vertically as sea level rose and was periodically fragmented and reworked by shoaling waters. Following the shoaling the bank may have been exposed, at which time the back-bank sediments were probably dolomitized by penecontemporaneous replacement.

The cyclic aspect of this bank may have been due to shoaling which caused a lateral spreading of the bioclastic material onto off-bank deposits. This is suggested by the presence of siliceous sponge spicules in the thin-bedded dolomites which underlie the bioclastic limestones in each cycle. Okulitch and Nelson (1957) indicate that the lithistid sponges (siliceous) lived on the muddy bottom in quiet waters close to the margins of the Leonardian reefs in the Glass Mountains, Texas. If an analogy can be made, the siliceous dolomites of the Ervay bioclastic facies may have been deposited off the bank, contemporaneous with the growth of the bank. Shoaling then fragmented and reworked the skeletal bank and redeposited the constituents on top of the off-bank sponge muds.

The bioclastic facies intertongues shoreward with the slightly deeper, quiet water deposits of the mud-pellet facies. The pellets apparently increase in abundance shoreward (eastward) and may, in part, represent an intertidal environment. This is suggested by a recent study of the tidal flat on the northeast side of Andros Island by Shinn, Lloyd, and Ginsburg (1969), which shows intertidal sediments to be composed primarily of non-laminated, pelletal carbonate mud. They also observed "fenestrae" type pore spaces to be diagnostic of supratidal deposits. The Ervay pellet facies, which is characterized by fenestrae porosity, is therefore considered to represent a supratidal environment, and the geometry of the facies (Plate VII) further suggests a beach ridge deposit.

Peterson (personal communication, 1969) observed tidal flat characteristics in Ervay beds exposed north of this area in the Big Horn Mountains, further substantiating a tidal flat origin for these eastern interval GHI units.

Dolomitization of these carbonates was probably by capillary concentration during supratidal exposures and by penecontemporaneous replacement in hypersaline ponds that form on the tidal flat.

GENESIS OF CARBONATE CYCLES

The evidence presented on the preceeding pages suggests three major Permian transgressions: the Grandeur, Franson, and Ervay, each characterized by dominantly carbonate deposition. Two major regressions, the Meade Peak and Retort, are suggested by thin pebble and sand beds overlying the Grandeur and Franson transgressive deposits. The transgressive and regressive units are illustrated in Figure 10.

Eustatic changes in sea level attributed to southern hemisphere glaciation have been suggested as a possible cause of Permian cycles in the southern Rocky Mountain basins (Silver and Todd, 1969). However, the apparent lack of fusilinids in the Phosphoria Formation (Yochelson, 1968) prevents correlation of the Wyoming Permian cycles with those in other areas.

The several smaller fluctuations of sea level, suggested by the intertongueing of the carbonate and red bed facies, may also be related to glaciation or they may be associated with local tectonism. Based on isopach and lithofacies studies, McKee and coworkers (1967) proposed a Permian (?) fault scarp (west block down) to be approximately coincident with the present Big Horn Mountains. If, as previously suggested, the land surface sloped gently and merged with the sea floor then any

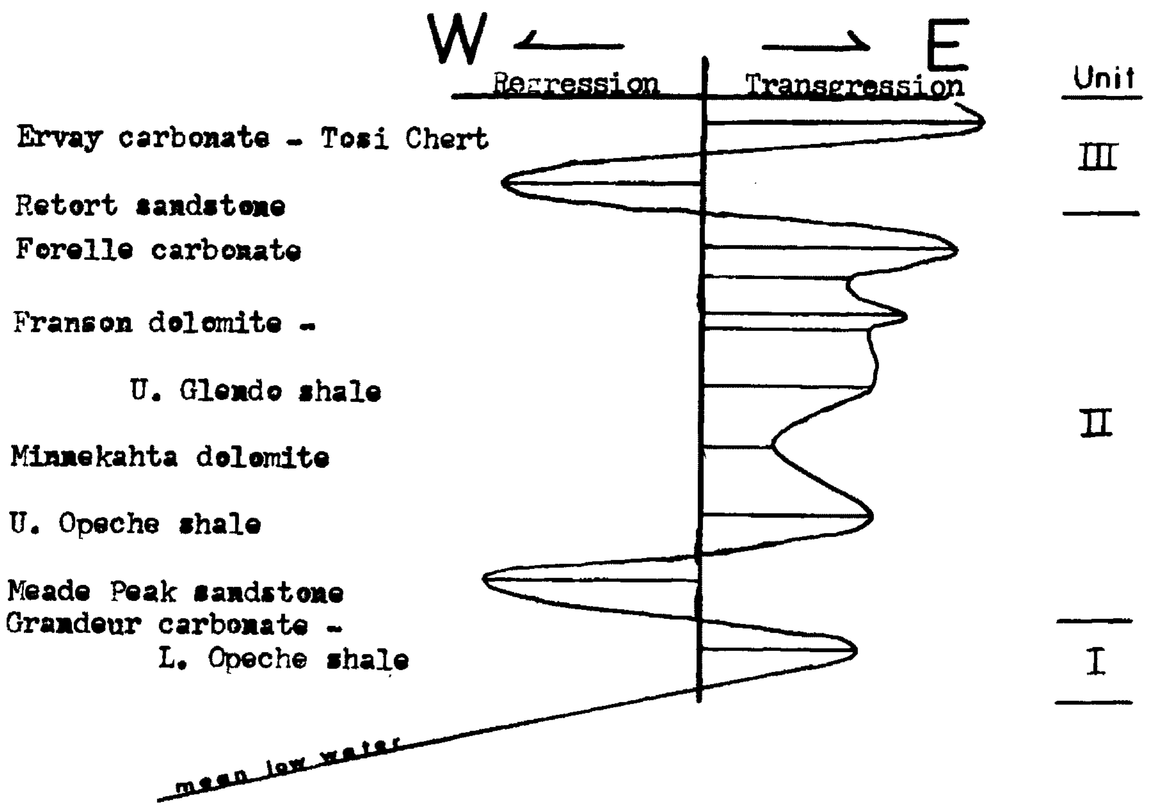


Fig. 10 - Transgressive and regressive relationships of the various Phosphoria units as determined by this investigation.

slight vertical movement would be expected to cause a significant shift in the position of the strand line.

PETROLEUM RESERVOIRS, SOURCE ROCKS, AND POSSIBLE RESERVES

The Big Horn basin is one of the most prolific petroleum provinces in the Rocky Mountains. Phosphoria carbonate reservoirs yield about 15 percent of the total basin production, second to the Tensleep Sandstone which produces about 60 percent. The Cottonwood Creek field, in the northeastern part of the study area (Plate A, in pocket), is the largest Phosphoria field in the basin. A summary discussion of the field's history and reservoir characteristics has been given by McCaleb and Willingham (1967). The field is a stratigraphic trap located at the carbonate to red bed transition. The reservoir is the Ervay pellet facies (see Plate VII) with an average net pay thickness of 20.5 feet and an average effective porosity of 10.4 percent (McCaleb and Willingham, 1967).

McCaleb and Willingham suggest that the source for the Cottonwood Creek hydrocarbons is a very fine-grained, carbonaceous dolomite which intertongues with the reservoir facies along the western edge of the field. This rock is probably the mud-pellet facies of this report. Other authors, including Stone (1967) and Keefer (1969), show evidence to indicate that the thicker western Phosphoria facies, the dark, carbonaceous shales, mudstones, and phosphorites may be the primary source for petroleum in the Phosphoria reservoirs as well as the other Paleozoic and Triassic reservoirs in central Wyoming. Some of their evidence includes:

a) Volumetrically and lithologically these are the only probable source rocks.

b) Composition, API gravity, etc., of all the Paleozoic oils suggest a common source.

c) Pre-Laramide structural dip was to the west.

d) Five times as much sediment was piled on top of the potential source beds in western Wyoming as over the central Wyoming reservoirs, thereby providing the necessary hydrostatic pressure required to move the hydrocarbons from the source to the reservoirs.

e) There are very few single-zone Paleozoic fields in the Big Horn basin.

The isopach-lithofacies maps of intervals F and GHI (Plates VI and VII) suggest a possible source rock-reservoir relationship for the Cottonwood Creek field which is different from previous ideas. Interval F, the Retort, in the study area, is an eastward extension of the proposed source beds. Interval GHI, the Ervay, is commonly oil stained throughout and is somewhat porous on the basis of neutron log data. It is suggested, therefore, that the western Ervay facies as described in this report might have served as a migration route between the underlying Retort source and the Ervay pellet facies reservoir in the Cottonwood Creek field to the east.

Future petroleum exploration programs might consider searching for tidal channel systems which should have dominated the area just seaward of the pellet facies (supratidal beach ridge). Tidal channel sediments are generally permeable, and lateral migration and abandonment of the channels may have caused pinch outs and subsequent stratigraphic traps. However, the possible reworking and destruction of the intertidal sequences by the transgressing sea must also be considered.

SUMMARY OF CONCLUSIONS

1. The Grandeur sea was the initial Permian transgression. Dolomite, anhydrite, and reworked Tensleep sandstone were deposited in, and filled up, the topographic depressions of the underlying Pennsylvanian Tensleep erosion surface.

2. A thin pebbly sandstone unit, overlying an inferred unconformity at the top of the Grandeur, has been tentatively correlated with the Meade Peak Phosphatic Shale Member and is thought to pinch out within the Big Horn basin.

3. The upper Opeche Shale and the thin Meade Peak equivalent bed are considered to represent the initial deposits of a second Permian transgression, which is dominated by the carbonate beds of the Franson Member (intervals C, D and E).

4. The Minnekahta dolomite probably represents a supratidal environment and a slightly local regressive pulse within the major Franson transgression (Fig. 10).

5. A non-skeletal bank (Plate IV), described in the interval D Franson carbonate, is thought to have developed in shallow water in an environment which was alternately calm then agitated, possibly due to minor fluctuations of sea level.

6. The Forelle carbonate tongue apparently represents a final and maximum transgression of the Franson sea. A crinoid-bryozoan bank developed offshore and sea level fluctuations periodically caused fragmentation and reworking of the bank material due to shoaling. Pellets and muds accumulated in the quiet back-bank waters.

7. The Retort Member overlies an unconformity on top of the Forelle and is considered to represent regression or initial transgression. The sand which dominates this interval, and also the Meade Peak equivalent, is thought to be associated with Shedhorn Sandstone deposition in northwestern Wyoming.

8. The Tosi Chert owes the bulk of its siliceous sediment to siliceous sponges (Yochelson, 1968).

9. The Ervay Member represents the third and final Permian transgression. A bryozoan-crinoid bank developed offshore and was periodically reworked by shoaling during sea level fluctuations. This shoaling spread bioclastic material laterally on top of back-bank, quiet water muds which were inhabited by siliceous sponges. This process was repeated at least five times and gives the bank its cyclic nature.

10. The Ervay pellet facies probably represents a supratidal deposit, possibly a beach ridge.

11. Either refluxion, capillary concentration, or penecontemporaneous replacement can be demonstrated to have been the dolomitization process for the various Phosphoria dolomite beds in this study area.

12. The thick dark, carbonaceous mudstone and shale units of the Phosphoria Formation in western Wyoming and south-eastern Idaho are considered to be the primary source for petroleum in the Paleozoic reservoirs of the Big Horn basin (Stone, 1967; Keefer, 1969).

13. The western Ervay facies of this study area is thought to have been a migration route between the underlying Retort source and the pellet facies, which is the reservoir rock for the Cottonwood Creek oil field.

14. Additional stratigraphic traps may possibly exist seaward of the pellet facies in tidal channel deposits.

15. Minor sea level fluctuation may have been caused by movements along an active Permian fault just east of this area.

SELECTED REFERENCES

Adams, J. E., and Rhodes, M. L., 1960, Dolomitization by seepage refluxion: Am. Assoc. Petroleum Geologists Bull., v. 44, pp. 1912-1920.

Agatston, R. S., 1954, Pennsylvanian and Lower Permian of northern and eastern Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 38, pp. 508-583.

Boyd, D. W., 1958, Observations on the Phosphoria reservoir rock, Cottonwood Creek field, Washakie County, Wyoming: Am. Assoc. Petroleum Geologists, Rocky Mtn. Sec., Geol. Record, pp. 45-53.

Campbell, C. V., 1956, The Phosphoria Formation in the southeastern Big Horn basin, Wyoming: Ph.D. dissertation, Stanford Univ., 178 p.

____________, 1962, Depositional environments of the Phosphoria Formation (Permian) in the southern Big Horn basin, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 46, pp. 478-503.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture: in Classification of carbonate rocks, W. E. Ham (Ed.), Am. Assoc. Petroleum Geologists Mem. 1, pp. 108-121.

Folk, R. L., 1968, Petrology of Sedimentary Rocks: Univ. Texas, Austin, Texas, 170 p.

Freidman, G. M., 1966, Occurrence and origin of Quaternary dolomite of Salt Flat, West Texas: Jour. Sed. Pet., v. 36, pp. 263-267.

Ginsburg, R. N., 1957, Early diagenesis and lithification of shallow-water carbonate sediments in south Florida: in Regional aspects of carbonate deposition, R. J. Le Blanc and J. G. Breeding (Ed.), Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 5, pp. 80-100.

Illing, L. V., 1954, Bahaman calcareous sands: Am. Assoc. Petroleum Geologists Bull., v. 38, pp. 1-95.

Keefer, W. R., 1969, Geology of petroleum in Wind River Basin, Central Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 53, pp. 1839-1865.

King, R. H., 1957, Stratigraphy of the Phosphoria Formation in the Wind River Mountains: in Wyoming Geol. Assoc. Guidebook, 12th Ann. Field Conf., pp. 35-38.

McCaleb, J. A., and Willingham, R. W., 1967, Influence of geologic heterogeneities on secondary recovery from Permian Phosphoria reservoir, Cottonwood Creek field, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 51, pp. 2122-2132.

McCue, J., 1953, Facies changes within the Phosphoria Formation in the southeast portion of the Big Horn basin, Wyoming: M.A. thesis (unpub.), Univ. Wyoming.

McKee, E. D., Oriel, S. S., and others, 1967, Paleotectonic maps of the Permian System: U. S. Geol. Survey, Misc. Geol. Invest. Map I-450.

McKelvey, V. E., Williams, J. S., Sheldon, R. P., Cressman, E. R., Cheney, T. M., and Swanson, R. W., 1956, Summary description of Phosphoria, Park City and Shedhorn Formations in Western Phosphate Field: Am. Assoc. Petroleum Geologists Bull., v. 40, pp. 2826-2863.

____________, 1959, The Phosphoria, Park City, and Shedhorn Formations in the Western Phosphate Field: U. S. Geol. Survey Prof. Paper 313-A, pp. 1-47.

Okulitch, V. J., and Nelson, S. J., 1957, Sponges of the Paleozoic: in Treatise on marine ecology and paleoecology, Geol. Soc. Am. Mem. 67, pp. 763-769.

Pedry, J. J., 1957, Cottonwood Creek Field, Washakie County, Wyoming, carbonate stratigraphic trap: Am. Assoc. Petroleum Geologists Bull., v. 41, pp. 828-838.

Peterson, J. A., 1968, Permian carbonate mound facies, western United States Phosphate Province (Abs.): Geol. Soc. Am. Ann. Meeting, Mexico City, Mexico.

Purdy, E. G., 1963, Recent calcium carbonate facies of the Great Bahama Bank. I. Petrography and reaction groups: Jour. Geol., v. 71, pp. 334-355.

Sheldon, R. P., 1963, Physical stratigraphy and mineral resources of Permian rocks in western Wyoming: U. S. Geol. Survey Prof. Paper 313-B, pp. 49-273.

Shinn, E. A., Lloyd, R. M., and Ginsburg, R. N., 1969, Anatomy of a modern carbonate tidal flat, Andros Island, Bahamas: Jour. Sed. Pet., v. 39, pp. 1202-1228.

Silver, B. A., and Todd, R. G., 1969, Permian cyclic strata, northern Midland and Delaware basins, West Texas and Southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 53, pp. 2223-2251.

Stone, D. S., 1967, Theory of Paleozoic oil and gas accumulation in Big Horn basin, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 51, pp. 2056-2114.

Tebbutt, G. E., Conley, C. D., and Boyd, D. W., 1965, Lithogenesis of a distinctive carbonate rock fabric: Contributions to Geology, Univ. Wyoming, v. 4, no. 1, pp. 1-13.

Thomas, L. E., 1965, Sedimentation and structural development of the Big Horn basin: Am. Assoc. Petroleum Geologists Bull., v. 49, pp. 1867-1877.

Walker, T. R., 1967, Formation of red beds in modern and ancient deserts: Geol. Soc. Amer. Bull., v. 78, pp. 353-368.

Wilkerson, B. H., 1967, Paleoecology of the Permian Ervay Member of the Park City Formation in North-Central Wyoming: unpublished M.S. thesis, University of Wyoming.

Yochelson, E. L., 1968, Biostratigraphy of the Phosphoria, Park City, and Shedhorn Formation: U. S. Geol. Survey Prof. Paper 313-D, pp. 571-660.

APPENDIX A

List of control points used in the preparation of maps and cross sections in this report. Numbers refer to location on index map.

Surface Sections (Owl Creek Mountains):

1.	Anchor Dam		43N	100W
2.	Red Creek	8	8N	2E
3.	Red Canyon Creek	29/30	7N	5E
4.	Wind River Canyon	19	7N	6E
5.	Grass Creek	3/10	41N	94W
6.	West Kirby Creek	15	41N	92W
7.	Stove Creek	16	41N	89W

Radioactive Logs

8.	Champlin Pure State #1	16	42N	89W
9.	Phillips Hays Ranch #3	33	42N	91W
10.	Texas Co. Weller #2	35	43N	91W
11.	Farmers Union Gov't Shad #17	6	43N	91W
12.	Clarke F4393214C	21	43N	93W
13.	McAlester Wyoming State #1-B	16	43N	94W
14.	Skelly Reidy Gov't #1	13	44N	92W
15.	Continental Kiraly #28-1	28	44N	94W
16.	Hamilton Dome Gov't Skelton #11-A	18	44N	97W
17.	Texaco Gov't McGrady Hammond #1	29	45N	91W
18.	California Co. Unit #11	23	45N	92W
19.	Continental Unit #1	27	45N	95W
20.	Mobil F2232G	32	45N	99W
21.	Phillips Nowater #3	6	46N	91W
22.	Texas Co. Walton Gov't #1	25	46N	98W
23.	Superior Kinahan #27-7	7	46N	99W
24.	Stanolind Unit #1	2	47N	91W
25.	Anderson-Prichard Unit #1	33	47N	95W
26.	Ohio Co. Tensleep OPC-1 #5-T	31	48N	90W
27.	Pan Am USA-H	28	48N	91W
28.	Trigood Hess #1	28	48N	92W
29.	Husky Torgeson #1	29	49N	93W

Lithologic Logs

11.	Farmers Union Shad #1	6	43N	91W
30.	Greer Davis Gov't #1	7	44N	93W

31.	Sinclair Unit #1	28	45N	91W
32.	G and G Unit #1	19	45N	92W
20.	Mobil F2232G	32	45N	99W
33.	General Pet. Gov't 88-24-G	24	46N	92W
34.	Gulf Stockham Federal #1	2	46N	94W
35.	Phillips Mesa #1-A	27	46N	96W
23.	Superior Kinahan #27-7	7	46N	99W
25.	Anderson-Prichard Unit #1	33	47N	95W
36.	Mobil Unit #80	12	48N	92W
29.	Husky Torgeson #1	29	49N	93W

Well Core Samples

37.	Brinkerhoff Gebo #45	16	44N	95W
21.	Phillips Nowater #3	6	46N	91W
38.	Pan Am Unit #47	4	47N	91W
39.	Pan Am Unit #93	25	47N	91W
27.	Pan Am USA-H	28	48N	91W
36.	Mobil Unit #80	12	48N	92W
29.	Husky Torgeson #1	29	49N	93W

APPENDIX B

Description of surface sections in the Owl Creek Mountain Range sampled for this report.

Anchor Dam, T. 43 N., R. 100 W., 1/4 mile north of dam. Measured and sampled by J. A. Peterson, August, 1967.

Unit	Thickness	Description
Dinwoody Fm.	---	Limestone and shale; buff, rubbly.
Ervay Member		
AD-24	15-20 ft.	Limestone; fossiliferous with brachiopods and large productids.
AD-23	5-6 ft.	Limestone; bioclastic (?).
AD-22	10 ft.	Covered.
AD-21	20 ft.	Limestone; abundant fossils; productids, bryozoans, etc.
AD-20	4 ft.	Dolomite; shaly, rubbly, cherty with abundant fossil material, bryozoans.
AD-19	13 ft.	Shale; green to gray, abundant small bryozoans and small brachiopods, scattered crinoid stems.
AD-18	10 ft.	Limestone; dolomitic (?), gray, bioclastic with productids.
AD-17	5 ft.	Limestone; dark gray, abundant fossil material, large productids and ramose bryozoans.

AD-16	5 ft.	Limestone or dolomite; shaly, abundant fossil material, irregular chert nodules.
AD-15	3 ft.	Limestone; green, shaly, fossiliferous, abundant bryozoans.
AD-14	5 ft.	Limestone; green bioclastic, abundant productids, some bryozoans.
AD-13	2 ft.	Shale; green gray to gray, abundant productids.
AD-12	2 ft.	Limestone; bioclastic.
AD-11	3 ft.	Limestone; green to gray green, some green shale, abundant bryozoans.
AD-10	5 ft.	Limestone; black, bioclastic, phosphatic (?).

Tosi Chert

AD-9	12 ft.	Chert; very dolomitic, nodular, thin bedded.

Retort Member

AD-8	5 ft.	Dolomite; dark gray, fine chert nodules, oil stained.
AD-7	10 ft.	Dolomite; sandy, some dolomitic sandstone (?), occasional chert nodules.

Franson Member (Interval C, D and E)

AD-6	50 ft.	Covered; 8 - 10 ft. interval with some carbonate about 20 ft. below top.
AD-5	5 ft.	Dolomite; cherty, poorly exposed.

AD-4	5 ft.	Covered.
AD-3	5 ft.	Dolomite; massive, occasional chert nodules.
AD-2	5 ft.	Covered.

Grandeur Member

AD-1	30 ft.	Dolomite; massive, sandy (?), cherty in part.
Tensleep Ss.	---	Sandstone.

Red Creek, Sec. 8, T. 8 N., R. 2 E., Wind River Meridian. Originally measured by McCue (1953), remeasured and sampled for this report by J. A. Peterson and the writer, September, 1968.

Unit	Thickness	Description
Dinwoody Fm.	---	Limestone; platy, shaly.
Ervay Member		
RDC-17	15 ft.	Dolomite, grades up into massive limestone; chalky, thin chert bed 5 ft. from base.
RDC-16	7 ft.	Dolomite; sucrosic at base becoming fossiliferous toward top, oil stained (?).
RDC-15	12 ft.	Dolomite; cherty, grading up into massive fossiliferous limestone, brachiopods, bryozoans, crinoids (?).
RDC-14	8 ft.	Dolomite at base (2 ft.), fossiliferous limestone above; brachiopods, bryozoans.
RDC-13	8 ft.	Dolomite at base, platy, becoming extremely fossiliferous above; bryozoans, crinoids, scattered chert nodules.
RDC-12	7 ft.	Dolomite; abundant chert nodules, crinoids, bryozoans in lower few feet, upper 3 ft. brown limestone with productids and bryozoans, some chert.
RDC-11	3.5 ft.	Limestone; abundant chert nodules, glauconite, brachiopods, ramose bryozoans.

RDC-10	6.5 ft.	Limestone; brown, phosphatic (?), fish remains (?), brachiopods, bryozoans.

Tosi Chert

RDC-9	3.5 ft.	Chert; very calcareous, bryozoans, gastropods, glauconite.

Retort Member

RDC-8	2 ft.	Limestone; bryozoan coquina.
RDC-7	8 ft.	Dolomite; brown, very abundant chert nodules, bryozoans in upper part, platy in part.
RDC-6	14 ft.	Dolomite; brown, very abundant chert nodules, some fossils, 1-2 ft. limestone bed near top with abundant bryozoans, dolomite on top with bryozoans, phosphatic (?).
RDC-5	12 ft.	Shale; dark brown to gray, phosphatic, platy to blocky, green-gray in part, chert nodules.
RDC-4	3 ft.	Phosphorite; with abundant productids and other fossils.

Franson Member (Interval C, D, and E)

RDC-3	13 ft.	Dolomite; silty (?), reddish weathering, platy, brachiopods; upper part very fossiliferous, phosphatic (?).

RDC-2	11 ft.	Dolomite; finely sucrosic, large chert nodules at base decrease in size and abundance toward top, ramose and fenestrate bryozoans, productids, partially silicified.
RDC-1	12 ft.	Dolomite; very fossiliferous, brachiopods, ramose and fenestrate bryozoans, large chert nodules in upper part, thin gray shale bed just above base.
RDC-FG	10 ft.	Dolomite; silty, platy, nonresistant, rusty weathering in part.
RDC-CDE	16.5 ft.	Shale; gray, interbedded with dolomite, sandy, chert nodules, white chert pebble bed 5 ft. from base.
RDC-B	4 ft.	Dolomite; white chert nodules in upper half.
RDC-A3	11 ft.	Dolomite, platy, interbedded with shale, green-gray to gray, fissile; chert pebble lens 5 ft. from base, large chert nodules at top, upper 3-4 ft. well-laminated, stromatolitic (?).
RDC-A2	6-7 ft.	Dolomite; platy, interbedded with shale, gray, green-gray, fissile, papery.

Grandeur Member (?)

RDC-A1	70-75 ft.	Covered.
Tensleep Ss.	----	Sandstone; clean.

Red Canyon Creek, Sec. 29/30, T. 7 N., R. 5 E., Wind River Meridian. Measured and sampled for this report by the writer, June, 1969.

This section is located on the southeast side of a small tributary of an east fork of Red Canyon Creek. It is well exposed except for the Phosphoria-Dinwoody contact and a 20 foot interval near the base. The Tensleep is exposed on the stream bottom as a narrow window through the Permian. The section is most easily approached by a very poor road which follows a power line up the north facing Permain dip slope. From the crest of the hill the section lies about 1/4 mile due west of this road.

Unit	Thickness	Description
----	----	Covered.
Ervay Member		
RCC-21	4 ft. (?)	Limestone; light gray, massive, Dinwoody not exposed.
RCC-20	11 ft.	Limestone; thin bedded, chalky, minor porosity.
RCC-19	6 ft.	Dolomite; limey, light colored, medium to thick bedded, minor porosity.
RCC-18	18 ft.	Dolomite, thin bedded, grading up to limestone, fossiliferous, bryozoans, brachiopods, glauconite.
RCC-17	8 ft.	Limestone; chalky, fossiliferous, glauconite, porous at base.
RCC-16	9 ft.	Dolomite; limey, thin bedded, platy, cherty, brachiopods, bryozoans, glauconite, base is phosphatic and pelletal.

Tosi Chert

RCC-15	21 ft.	Chert; blue-gray, nodular dolomitic.

Retort Member

RCC-14	3 ft.	Phosphorite; calcareous, fossiliferous, pelletal.

Forella Tongue

RCC-13	29 ft.	Dolomite; thin limestone beds near top, white chert nodules in middle, silty at base, fossiliferous (?), medium to massive bedded.

Franson Member (Interval D)

RCC-12a	10 ft.	Dolomite; white, limey, pinhole porosity, chert nodules.
RCC-12	10 ft.	Dolomite; medium bedded, grading up to massive limestone, thin white chert bed near top, chert nodules, thin gray shale beds.
RCC-11	4 ft.	Dolomite; silty, thin shale beds, top is 1/2 ft. gray calcareous shale.
RCC-10	7 ft.	Dolomite; lime at base.
RCC-9	4 ft.	Limestone; thin bedded, clasts at top.

Glendo Shale

RCC-8	26 ft.	Shale; interbedded green and gray, thin zone of nodular limonite near base.

Minnekahta Tongue

RCC-7	7 ft.	Dolomite; lower part interbedded with gray shale, thin blue chert beds, chert nodules.

Upper Opeche Shale

RCC-6	2 ft.	Shale; green, platy, blue-gray chert bed at base.
RCC-5	4 ft.	Shale; gray, fissile, 1 ft. dolomite bed at top.
RCC-4	10 ft.	Shale; green, fissile, platy, 2-5 inch beds of sandy dolomite near base.
RCC-3	19 ft.	Covered; green and gray shale, phosphorite (?), and sandstone float.

Grandeur Member

RCC-2	5 ft.	Dolomite; limey (?), brown.
Tensleep Ss.	----	Sandstone; clean.

Wind River Canyon, Sec. 19, T. 7 N., R. 6 E., Wind River Meridian. Originally measured by McCue (1953), remeasured and sampled for this report by J. A. Peterson and the writer, September, 1968.

Unit	Thickness	Description
Dinwoody Fm.	----	Limestone; shaly, sandy, dolomitic.
Ervay Member		
WR-N7	10 ft.	Dolomite; upper part massive with abundant gastropods, scaphopods (?), top 3 ft. covered.
WR-N6	13 ft.	Dolomite; shaly, chert nodules, upper 9 ft. massive, fossiliferous.
WR-N5	8 ft.	Dolomite; light, cherty, upper more massive, glauconite.
WR-N4	7 ft.	Dolomite; glauconite.
WR-N3	8 ft.	Dolomite; light, cherty bed 1.5 ft. from base, upper massive with glauconite, fossils.
WR-N2	7 ft.	Limestone; very fossiliferous, chert nodules.
WR-N1	11 ft.	Dolomite; limey, chert nodules, bryozoans, brachiopods, glauconite, phosphatic (?).
Tosi Chert		
WR-M	16 ft.	Chert.

Retort Member

WR-L	3 ft.	Phosphorite.

Forelle Tongue

WR-K	17 ft.	Dolomite; phosphatic (?), clams (?).
WR-J	4 ft.	Dolomite; yellow brown, sucrosic, platy, silty, laminated.

Franson Member (Interval D)

WR-I	7 ft.	Limestone; sandy, chert nodules.
WR-H	16 ft.	Dolomite or limestone; tan, silty, thin chert beds.
WR-G	4.5 ft.	Dolomite; pebbly at base, yellowish, phosphatic (?), limonitic in part.

Glendo Shale

WR-F	25 ft.	Shale; bright green, well laminated, fissile.

Minnekahta Tongue

WR-E	6 ft.	Dolomite; white, clean, thin shale beds, upper part dense brown-gray dolomite.

Upper Opeche Shale

WR-D	33 ft.	Shale; green and brick red in lower part, upper entirely green, 7 ft. from top is thin dolomite bed, white, laminated, ripple marked (?), some chert nodules.

Meade Peak (equivalent ?)

WR-C	4 ft.	Sandstone; calcareous, pebbly, phosphatic (?), shaly at base, limey at top.

Grandeur Member

WR-B	25 ft.	Dolomite; yellowish-tan, fair porosity, large chert nodules at top, brecciated zone 10 ft. above base.
WR-A	10 ft.	Dolomite; silty, 1 inch oxidized zone at base.
Tensleep Ss.	----	Sandstone.

Grass Creek, Sec. 3/10, T. 41 N., R. 94 W. Originally measured by McCue (1953), remeasured and sampled for this report by J. A. Peterson and the writer, September, 1968.

Unit	Thickness	Description
Dinwoody Fm.	----	Shale; green, calcareous.
Ervay Member		
GC-J	25 ft.	Dolomite; light gray, mostly covered.
GC-I2	15 ft.	Dolomite; thin bedded, glauconite, very cherty at top.
GC-I1	20 ft.	Dolomite; abundant chert nodules.
Tosi Chert		
GC-H	9 ft.	Chert; interbedded gray shales.
Retort Member		
GC-G2	4 ft.	Shale; greenish gray, white chert pebbles.
GC-G1	5 inches	Phosphorite; chert pebbles.
Forelle Tongue		
GC-F5	9.5 ft.	Dolomite; white to gray.
GC-F4	12 ft.	Covered; (carbonate exposed across gully).
Franson Member (Interval D)		
GC-F3	8 ft.	Dolomite; massive, finely sucrosic.

GC-F2	14 ft.	Dolomite; cherty, upper part massive and porous.
GC-Fl	14 ft.	Dolomite; finely laminated at base grading up to more massive unit.

Glendo Shale

GC-E	41 ft.	Shale; brownish, some grays and red.

Minnekahta Tongue

GC-D	10 ft.	Dolomite; platy, laminated, interbedded with thin beds of gray shale.

Upper Opeche Shale (?)

GC-C	15-20 ft.	Covered.

Meade Peak (equivalent ?)

GC-B	5 ft.	Sandstone; conglomeratic.

Grandeur Member

GC-A	31 ft.	Dolomite; fossiliferous (?), lower 2-3 ft. is pebble conglomerate, 1 inch shale bed at base, some brecciated zones, few chert nodules.
Tensleep Ss.	----	Sandstone; calcareous, white to buff.

West Kirby Creek, Sec. 15, T. 41 N., R. 92 W. Originally measured by McCue (1953), remeasured and sampled for this report by the writer, June, 1969.

Unit	Thickness	Description
Dinwoody Fm.	----	Siltstone; calcareous, platy.
Ervay Member		
WKC-11	15 ft.	Dolomite; silty, platy.
WKC-10	28 ft.	Dolomite, light colored.
WKC-9	4 ft.	Dolomite; some porosity at base, chert nodules at top.
WKC-8	6 ft.	Dolomite; thin bedded grading up to massive to thick bedded, crinoids, bryozoans, gastropods, glauconite.
WKC-7	5 ft.	Dolomite; thin bedded, fossils (?), top 1 ft. is nodular chert bed.
WKC-6	18 ft.	Dolomite; large chert nodules at base.
Tosi Chert		
WKC-5a	9 ft.	Chert; nodular, interbedded with gray shale and dolomite.
Franson Member (Interval D and E)		
WKC-5	20 ft.	Dolomite; poorly exposed, interbedded with greenish gray shale, middle part contains clasts.

WKC-4	15 ft.	Dolomite; partially covered, thin bedded, laminated, interbedded with red shale.

Glendo Shale

WKC-3	25 ft.	Shale; red, poorly exposed.

Minnekahta Tongue

WKC-2	20 ft.	Dolomite; limey, platy.

Upper Opeche Shale (?)

WKC-1C	25 ft.	Covered.

Grandeur Member

WKC-1b	15 ft.	Dolomite; chert nodules.
WKC-1a	10 ft.	Dolomite; chert nodules, some porosity.
WKC-1	10 ft.	Dolomite; thick bedded to massive, vuggy porosity, chert nodules.
Tensleep Ss.	----	Sandstone.

Stove Creek, Sec. 16, T. 41 N., R. 89 W. Originally measured by McCue (1953), remeasured and sampled by J. A. Peterson and the writer, September, 1968.

Unit	Thickness	Description
Dinwoody Fm.	----	Limestone; shaly.
Ervay Member		
SC-U	16 ft.	Dolomite; argillaceous.
Freezeout Shale		
SC-T	10.5 ft.	Shale; calcareous, irregular laminations, reduction spots.
SC-S	7 ft.	Dolomite; light gray, silty, platy, cherty.
Tosi Chert		
SC-R	19 ft.	Chert; nodular, sandy.
Retort Member		
SC-Q	9 ft.	Shale; red, calcareous.
Forelle Tongue		
SC-P	6 ft.	Limestone; dolomitic, argillaceous, anhydrite blebs.
Glendo Shale and Franson Member (Interval D)		
SC-O	3 ft.	Shale; red, calcareous, silty, mottled.
SC-N	5 ft.	Limestone; dolomitic, anhydrite, irregular laminations.

SC-M	3 ft.	Chert, nodular, calcareous.
SC-L	6 ft.	Dolomite; angular clasts, some anhydrite.
SC-K	18.5 ft.	Shale; red, calcareous, brecciated zones.

Minnekahta Tongue

SC-J	3 ft.	Dolomite; light gray, some anhydrite, shale and carbonate clasts in upper part.
SC-I	6 ft.	Shale; red, calcareous, reduction spots.
SC-H	2 ft.	Dolomite; argillaceous, anhydrite, clasts.
SC-G	3 ft.	Shale; red.
SC-F	2 ft.	Dolomite; considerable anhydrite, stromatolite heads.

Upper Opeche Shale

SC-E	1 ft.	Shale; red, reduction spots, calcareous.

Meade Peak (equivalent ?)

SC-D1	3 ft.	Sandy conglomerate.

Grandeur Member

SC-D	8 ft.	Dolomite; lower part brecciated, chert nodules, stromatolite heads.

Lower Opeche Shale

SC-C	16 ft.	Shale; red, calcareous.
SC-B	24 ft.	Shale; brown, calcareous.
SC-A	16 ft.	Shale; green, calcareous, basal 2-3 ft. red sandstone conglomerate containing Tensleep pebbles.
Tensleep Ss	----	Sandstone.

SC-M	3 ft.	Chert, nodular, calcareous.
SC-L	6 ft.	Dolomite; angular clasts, some anhydrite.
SC-K	18.5 ft.	Shale; red, calcareous, brecciated zones.

Minnekahta Tongue

SC-J	3 ft.	Dolomite; light gray, some anhydrite, shale and carbonate clasts in upper part.
SC-I	6 ft.	Shale; red, calcareous, reduction spots.
SC-H	2 ft.	Dolomite; argillaceous, anhydrite, clasts.
SC-G	3 ft.	Shale; red.
SC-F	2 ft.	Dolomite; considerable anhydrite, stromatolite heads.

Upper Opeche Shale

SC-E	1 ft.	Shale; red, reduction spots, calcareous.

Meade Peak (equivalent ?)

SC-D1	3 ft.	Sandy conglomerate.

Grandeur Member

SC-D	8 ft.	Dolomite; lower part brecciated, chert nodules, stromatolite heads.

Lower Opeche Shale

SC-C	16 ft.	Shale; red, calcareous.
SC-B	24 ft.	Shale; brown, calcareous.
SC-A	16 ft.	Shale; green, calcareous, basal 2-3 ft. red sandstone conglomerate containing Tensleep pebbles.
Tensleep Ss	----	Sandstone.

THIS SPACE

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