NIPER-713
(DE94000106)

Field Guide to Muddy Formation Outcrops, Crook County, Wyoming

By
Viola Rawn-Schatzinger

November 1993

Performed Under Cooperative Agreement No. FC22-83FE60149

IIT Research Institute
National Institute for Petroleum and Energy Research
Bartlesville, Oklahoma

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U. S. DEPARTMENT OF ENERGY
Bartlesville, Oklahoma

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NIPER-713
Distribution Category UC-122

FIELD GUIDE TO MUDDY FORMATION OUTCROPS, CROOK COUNTY, WYOMING

Topical Report

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Work Performed Under Cooperative Agreement No. DE-FC22-83FE60149

Prepared for
U.S. Department of Energy
Assistant Secretary for Fossil Energy

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FIELD GUIDE TO MUDDY FORMATION OUTCROPS, CROOK COUNTY, WYOMING

Compiled By Viola Rawn-Schatzinger

INTRODUCTION

The data and analyses in this report resulted from work performed by NIPER for the U.S. Department of Energy under cooperative agreement DE-FC22-83FE60149, Base Program BE1, Reservoir Assessment and Characterization. The objectives of this research program are to (1) determine the reservoir characteristics and production problems of shoreline barrier reservoirs; and (2) develop methods and methodologies to effectively characterize shoreline barrier reservoirs to predict flow patterns of injected and produced fluids.

Two reservoirs were selected for detailed reservoir characterization studies—Bell Creek field, Carter County, Montana that produces from the Lower Cretaceous (Albian-Cenomanian) Muddy Formation, and Patrick Draw field, Sweetwater County, Wyoming that produces from the Upper Cretaceous (Campanian) Almond Formation of the Mesaverde Group. An important component of the research project was to use information from outcrop exposures of the producing formations to study the spatial variations of reservoir properties and the degree to which outcrop information can be used in the construction of reservoir models.

This report contains the data and analyses collected from outcrop exposures of the Muddy Formation, located in Crook County, Wyoming, 40 miles south of Bell Creek oil field. The outcrop data set contains permeability, porosity, petrographic, grain size and geologic data from 1-inch-diameter core plugs drilled from the outcrop face, as well as geological descriptions and sedimentological interpretations of the outcrop exposures. The outcrop data set provides information about facies characteristics and geometries and the spatial distribution of permeability and porosity on interwell scales. Appendices within this report include a micropaleontological analyses of selected outcrop samples, an annotated bibliography of papers on the Muddy Formation in the Powder River Basin, and over 950 permeability and porosity values measured from 1-inch-diameter core plugs drilled from the outcrop. All data contained in this report are available in electronic format upon request. The core plugs drilled from the outcrop are available for measurement. Published reports containing discussions of the analyses are cited in the text and figure captions.

Comparisons of outcrop and reservoir data were also included to illustrate the utility of outcrop data in characterizing subsurface reservoirs. Figure 1 shows the procedure for incorporating outcrop data into a reservoir model.

The purpose of this report, and a similar report containing Almond Formation outcrop data, is to provide the data and analyses generated from this research project so that other workers may use and build upon it. This data compilation can be used for educational purposes as a field guide to the outcrop exposures studied, and the closely-spaced outcrop data can be used for further study; for example, to test mapping algorithms or geostatistical techniques.

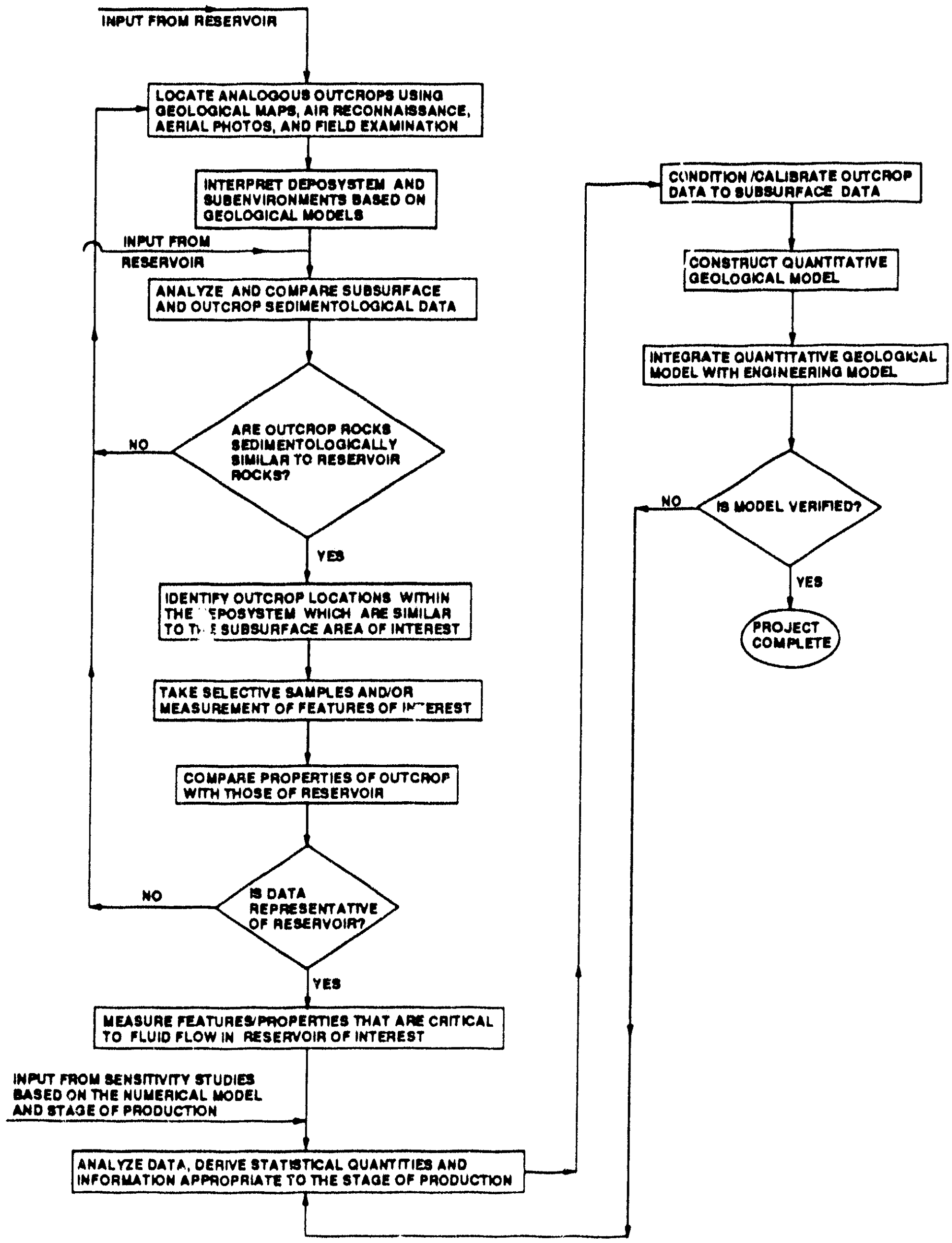


FIGURE 1. Procedure for outcrop characterization (Honarpour et al., 1990).

I. PALEOGEOGRAPHY

Geological Setting

The Bell Creek oil reservoir produces from the Lower Cretaceous Muddy Formation at an average depth of 4,500 ft (1,373 m). The Muddy Formation dips westward toward the center of the Powder River Basin. The stratigraphic position of the Muddy (Newcastle) sandstones within the Lower Cretaceous is between the Skull Creek Shale and the Mowry Shale (fig. 2). The productive and non-productive sandstones of the Muddy Formation are underlain by a thick series of marine shelf Skull Creek Shale and are overlain by Shell Creek and Mowry shales. Outcrops analogous to the reservoir rocks are exposed in northeastern Wyoming on the flank of the Black Hills Uplift approximately 30 miles southeast of Bell Creek field (fig. 3).

A regional isopach map reveals a variation of the total thickness of the Muddy Formation near Bell Creek field from less than 60 ft (18.3 m) to almost 100 ft (30.5 m). However, the maximum documented thickness of stacked barrier island sandstones in Unit 'A' of Bell Creek field does not exceed 30 ft (9.2 m). The thickest preserved sequence of stacked barrier island sandstones that occur in outcrops (New Haven type of Newcastle-Muddy Sandstone) was 28.4 ft (8.6 m).

Detailed sedimentological analysis of existing cores (this study) showed that the Lower Cretaceous Muddy Formation, which produces oil from Unit 'A' in Bell Creek field, is composed of two genetically different major sandstone reservoir units interpreted as (1) shoreline barrier and (2) valley fill deposits.

The Muddy Formation barrier island and related environments of deposition (lagoon, estuary, tidal flat, tidal channel, valley fill, etc.) are underlain and overlain by marine shales: Skull Creek Shale and Shell Creek/Mowry shales, respectively.

Depositional History of Muddy Formation in the Bell Creek Area

Paleogeographic and paleotectonic reconstructions of the Muddy Formation show the interrelationship between continental (delta channels and deltaic plain); brackish marine (lagoon, estuary, and tidal flat); and coastal marine (barrier islands) sedimentation in the northeastern Powder River Basin where Bell Creek field is located (Berg and Davies, 1968; McGregor and Giggs, 1968; Stone, 1972; Weimer et al., 1988; Forgotson and Stark, 1981; Slack, 1981)

Characteristics common to Bell Creek and supportive of a barrier island interpretation are: (1) washover facies predominate in cores on the landward side of Bell Creek; (2) washover sandstones are interbedded with lagoonal mudstones, indicating contemporaneity of these facies; (3) foraminiferal species indicate less than normal marine salinities in lagoonal facies; underlying Skull Creek shales are normal marine; (4) shoreface sandstones are thin or absent in wells on the landward side of the field; (5) in analogous outcrops and cores in the field, foreshore and upper shoreface deposits locally are present above middle shoreface deposits; and (6) backshore deposits with landward (SE) flow directions occur above washover deposits in analogous outcrops. The barrier island model presented herein also requires that the barrier be, in part, transgressive over lagoonal deposits.

At least four different concepts regarding relationships shoreline between barrier sandstones and valley fill deposits in the northeastern part of the Powder River Basin have been presented:

1. The barrier deposits lie stratigraphically above an unconformity which separates them from the underlying Skull Creek Shale (Stone, 1972; Almon and Davies, 1979).
2. The barrier islands and valley fills are in part synchronous (McGregor, 1968).
3. Valleys (and their subsequent fills) are incised into barrier island deposits and are stratigraphically younger. The barrier island deposits are generally related to the Skull Creek Shale (Weimer, 1981).
4. Two periods of valley cut and fill have incised the barrier. The earlier valleys are distributed over a large portion of the barrier. The later channels were narrow and were filled primarily with marine shale.

In some cores from Unit 'A', the lower shoreface barrier island facies conformably overlie the marine Skull Creek shales. There are indications, however, that lagoonal deposits also underlie part of the barrier sandstones in the Bell Creek Unit 'A' area. Lagoonal deposits also occur below analogous barrier island sandstone outcrops exposed near New Haven, Wyoming, about 30 miles (48 km) southeast of Bell Creek field. Foraminiferal analysis (Appendix A) indicates that the suite of foraminifers in samples interpreted sedimentologically as lagoonal deposits are distinct from those in the underlying Skull Creek marine shale. Incision of valley fills into the top of barrier deposits is, however, commonly observed in Bell Creek cores, and strongly supports number (3) above.

In addition to the subsurface cores, 21 outcrops representing a variety of analogous barrier island and valley fill facies were described and interpreted in the New Haven area, Wyoming (fig. 4). Some of the outcrops; e.g., no.

22 and 1-86, offered almost continuous lateral exposure for distances of up to 2,000 feet — distances that are comparable to interwell distances in Bell Creek field (600-1,320 ft). Permeability and porosity values measured from the outcrops are included in appendix C. Four of the outcrops (22a, 22, 23, and 3-86) were extensively cored in order to characterize the petrophysical properties of barrier island facies (see permeability section, figs. 30, 31 and 32). Photographs of selected outcrops illustrate general stratigraphy, characteristics of facies, and type of contacts (fig. 5).

The positions of the four thoroughly studied reservoir sections in Unit 'A' of Bell Creek field have been related to adjacent environs of the subsurface barrier island depositional system. A resulting map (fig. 6) of the depositional setting in the 16-square mile area (40 km^2) was based on geological interpretation of available cores and logs from wells located at the edges of production Unit 'A', within production Units B, C, and D, and eastward and westward of them in nonproductive areas. Similar interpretations based on 21 documented outcrop profiles (fig. 7) have been made.

The purpose of this preliminary, broader scale interpretation was to allow comparison of the position of individual outcrops within the deposystem with the position of a similar, studied area in the subsurface. Both maps (figs. 6 and 7) suggest general similarity in the distribution of barrier island and genetically associated facies within the subsurface and outcrop depositional systems. It was concluded that framework information regarding facies distribution, stacking pattern, and continuity of sandstone units could be applied from outcrops to the subsurface in Unit 'A'.

A typical stratigraphic cycle of major barrier island facies exhibited predictable characteristics (fig. 8). Dominant sedimentologic features of genetically related barrier island sandstone units are summarized in table 1. Engineering and production data as well as core, log, and outcrop interpretations indicate significant geological complexities in the study area of Bell Creek field. Appendix B provides a number of annotated references on the geological formations, deposition and oil fields in the Powder River Basin.

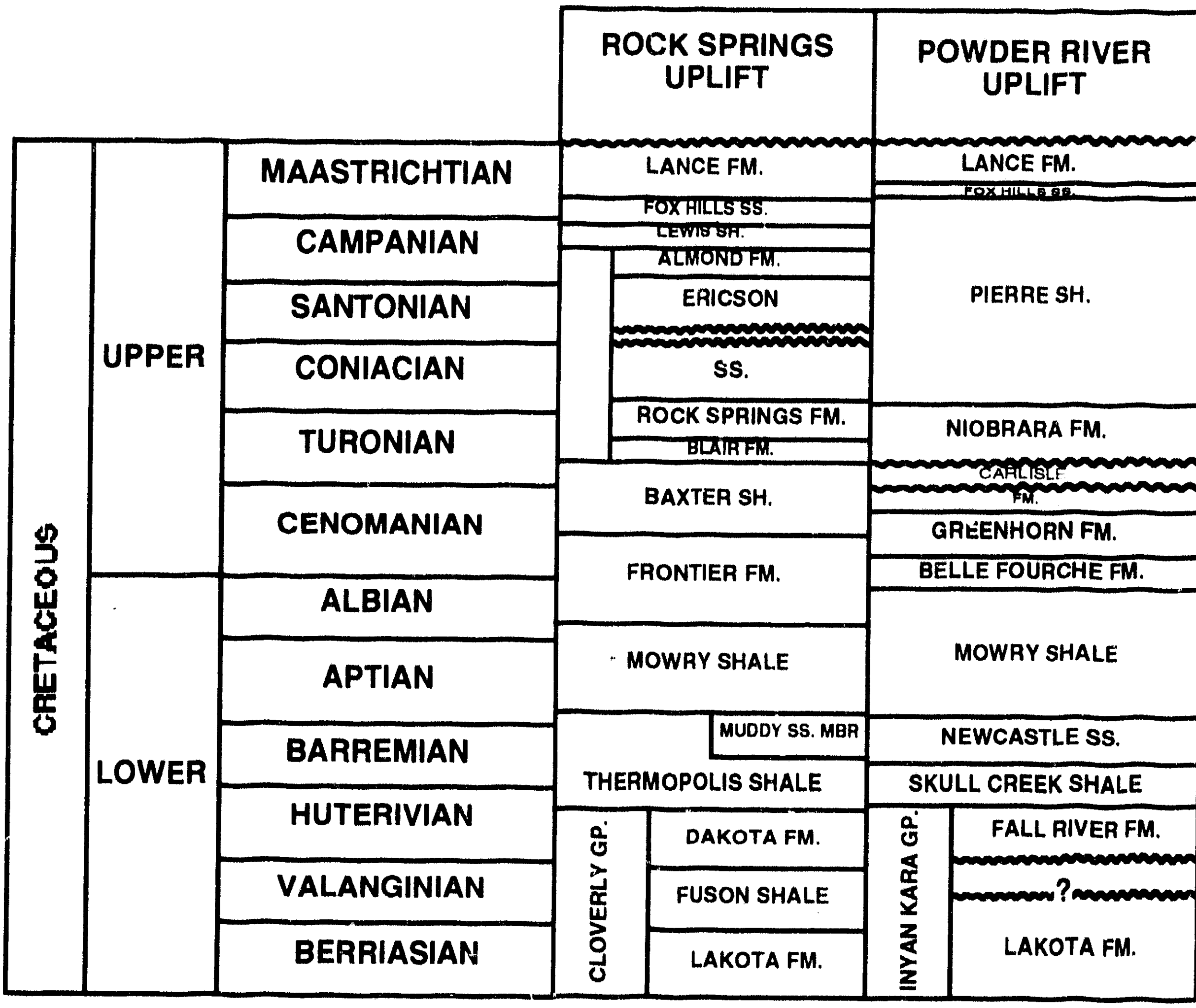
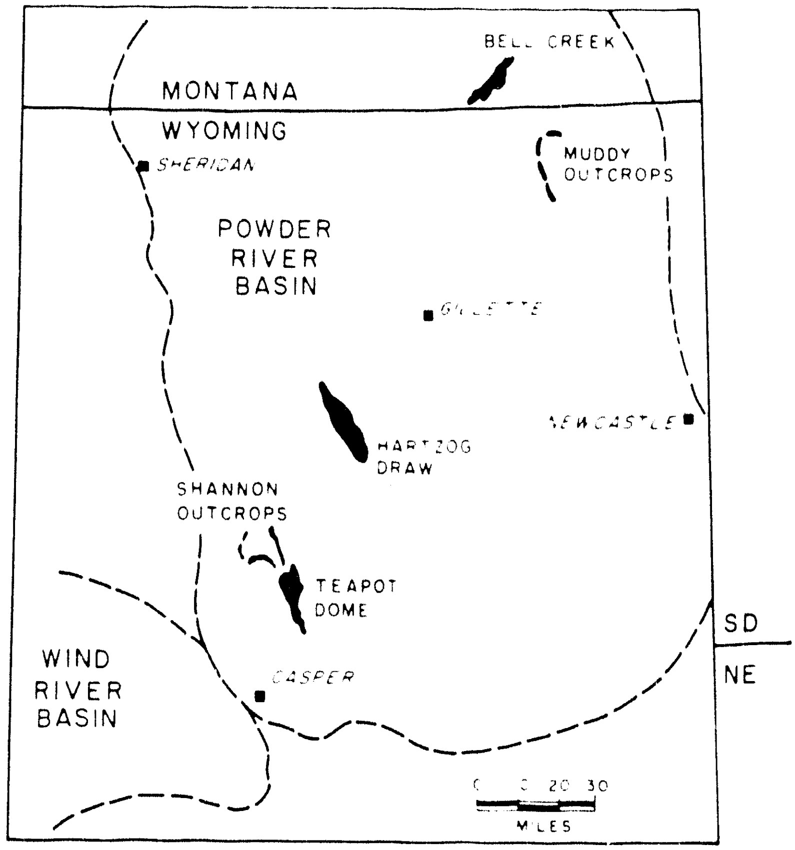


FIGURE 2. Stratigraphic correlation chart for the Cretaceous, comparing the Rock Springs Uplift, Wyoming to the Powder River Basin, Wyoming and Montana.



[illegible] MAN AND MARTINSEN, 1985

FIGURE 3. Location of Bell Creek field and Muddy Formation outcrops within the Powder River Basin (Honarpour et al., 1989).

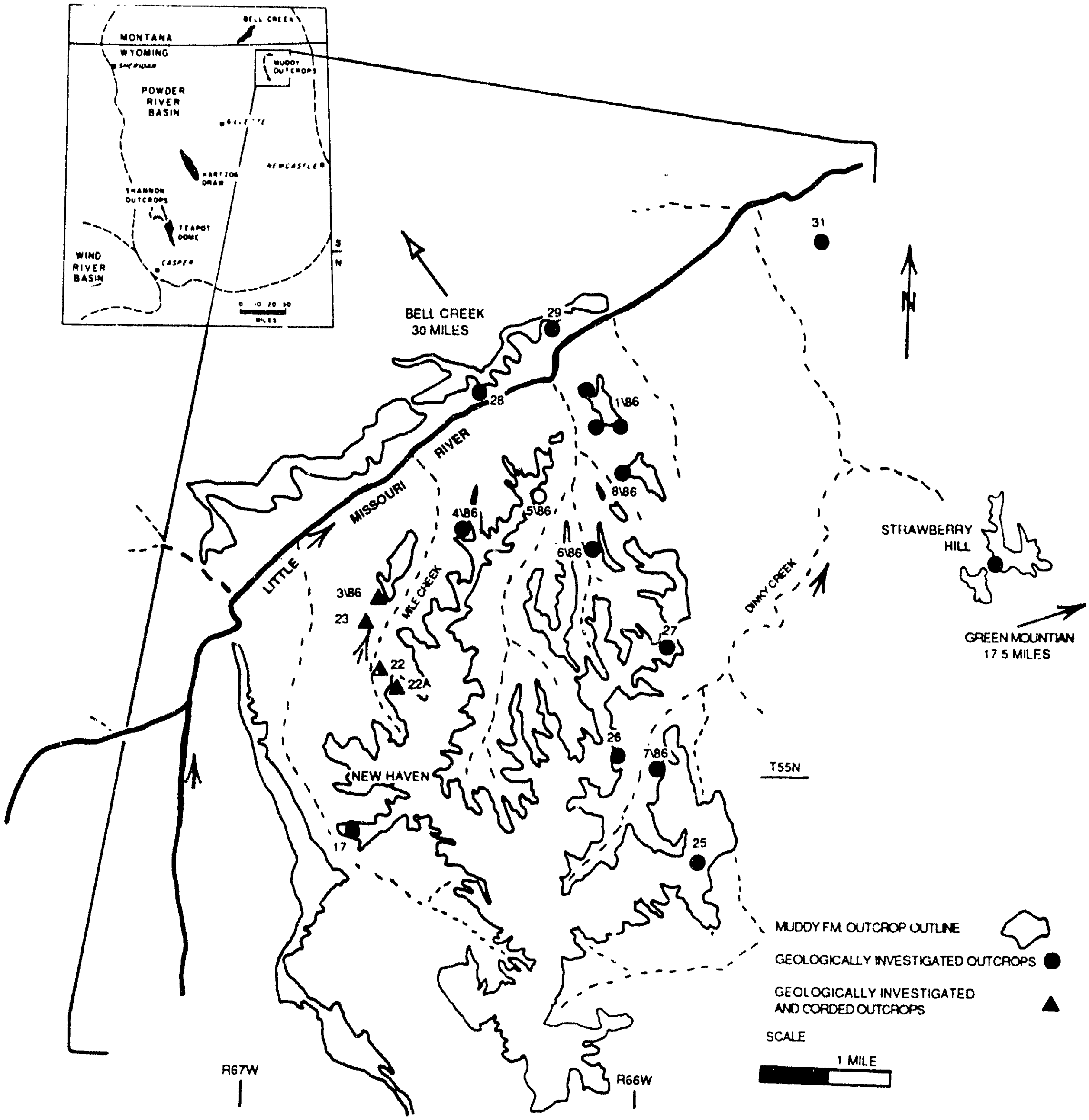


FIGURE 4. Location of Muddy Formation outcrops studied in Crook County, Wyoming. Outcrop locations, indicated by triangles, were cored for permeability and porosity measurements (Honarpour et al., 1989).

FIGURE 5. Photographs of Muddy Formation barrier island facies, in outcrops 26 and 27, Crook County Wyoming. For location refer to figure 4. A: measured section in outcrop 26, transition sandstones and siltstone (7.8 ft) interbedded with gray shale (1); lower shoreface sandstone (7.7 ft) subhorizontally laminated, 10% shale layers (2); lower section of upper shoreface sandstone (3). B: measured section in outcrop 27 transition sandstone (100 micron) intercolated with silty and sandy shale (1); lower shoreface with trace of shale drapes, hummocky cross-stratification (HCS), and pebbly layer, upper 1.5 feet interbedded with silty shale (2); middle shoreface sandstone, beds 0.5 to 1.5 ft thick (3). C: close up of lower shoreface facies (1) is hummocky cross-stratified layer (arrow) and pebbly layer (arrows at hammer level) indicating high energy events. D: 3-ft-diameter, highly calcite-cemented patch (arrow) within middle shoreface sandstone. Site located 24 ft east of measured profile at outcrop 23 (Honarpour et al., 1989).

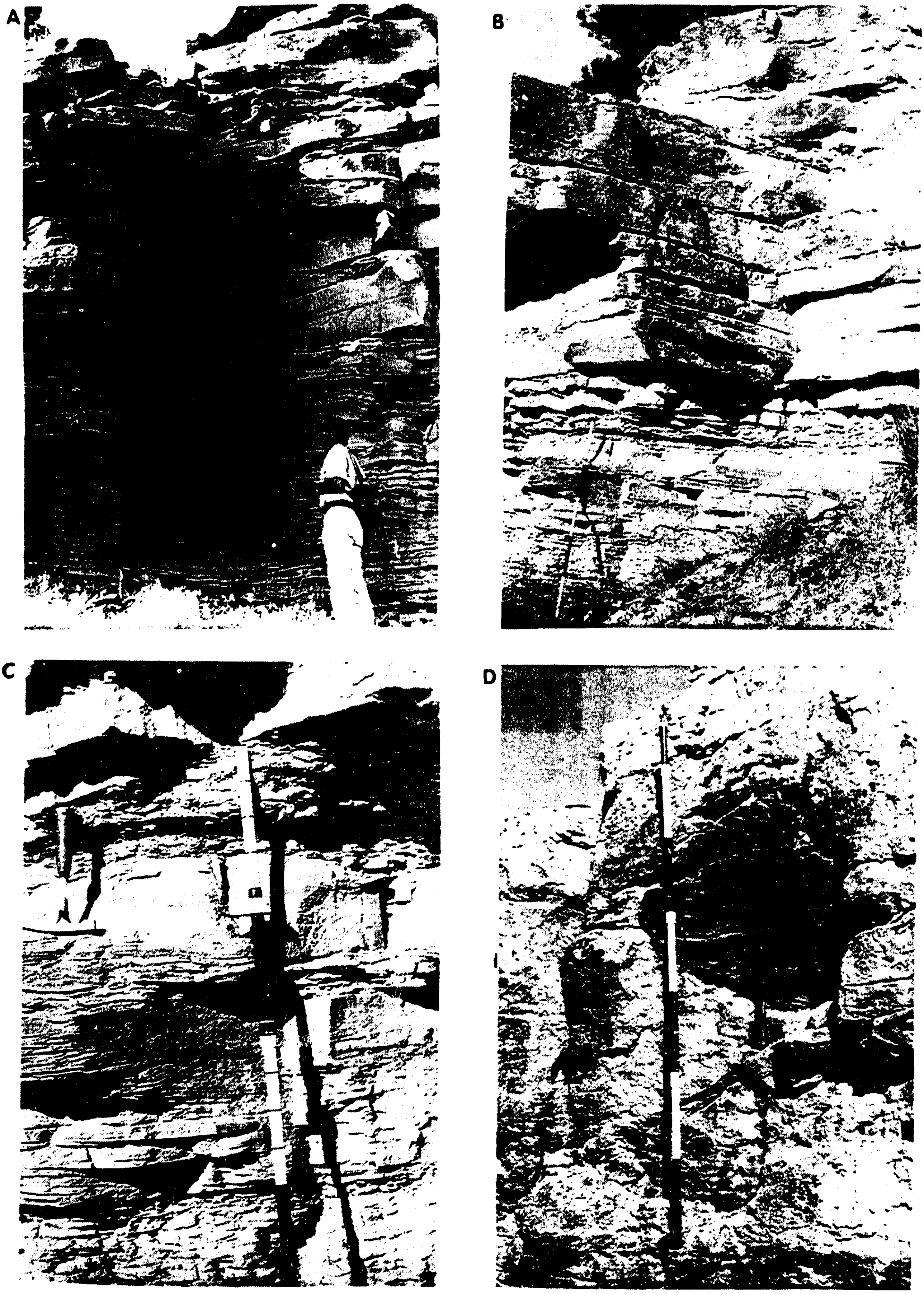


FIGURE 5

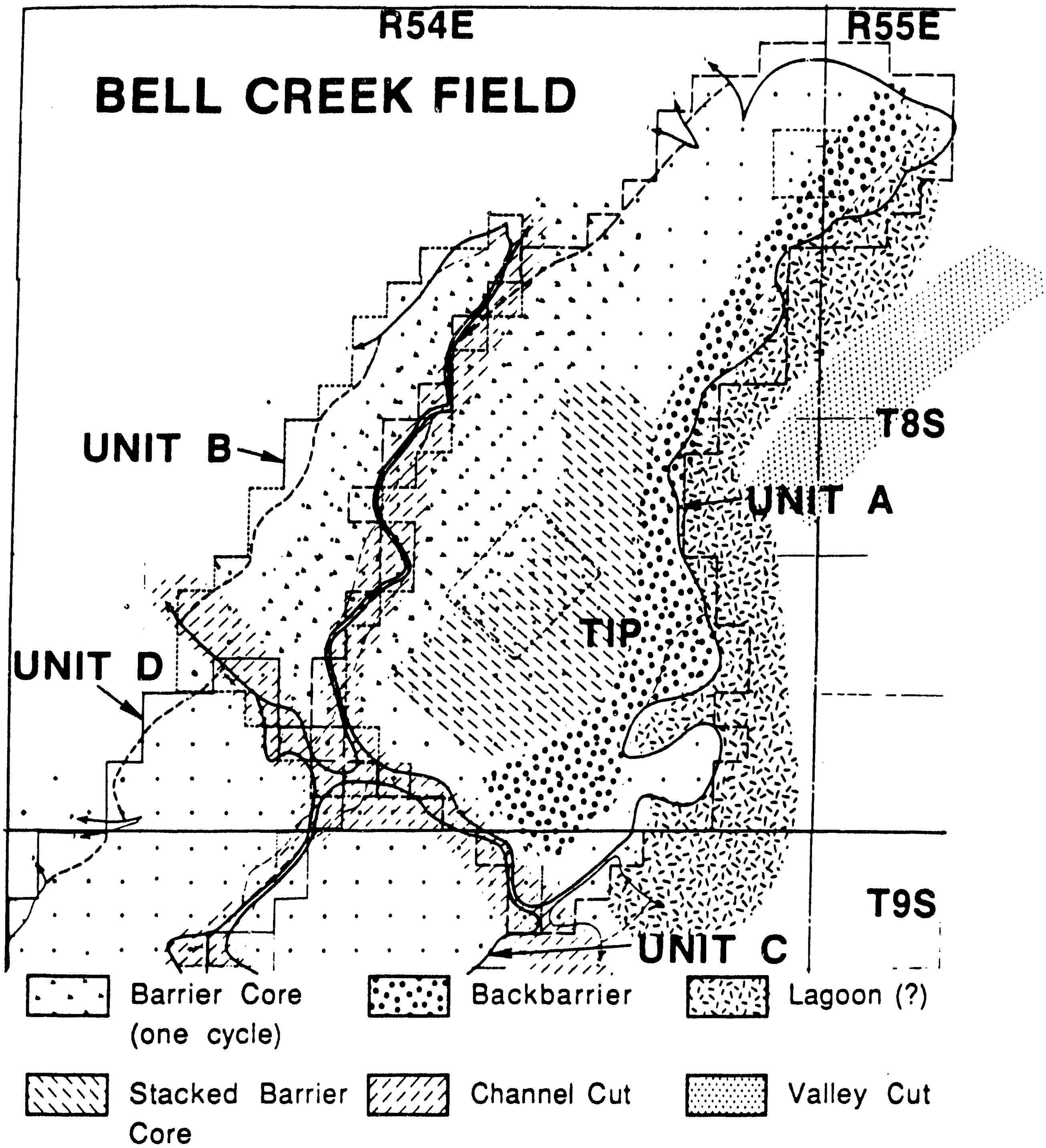


FIGURE 6. Distribution of facies based on geological interpretation of cores and logs in northern part of Bell Creek field.

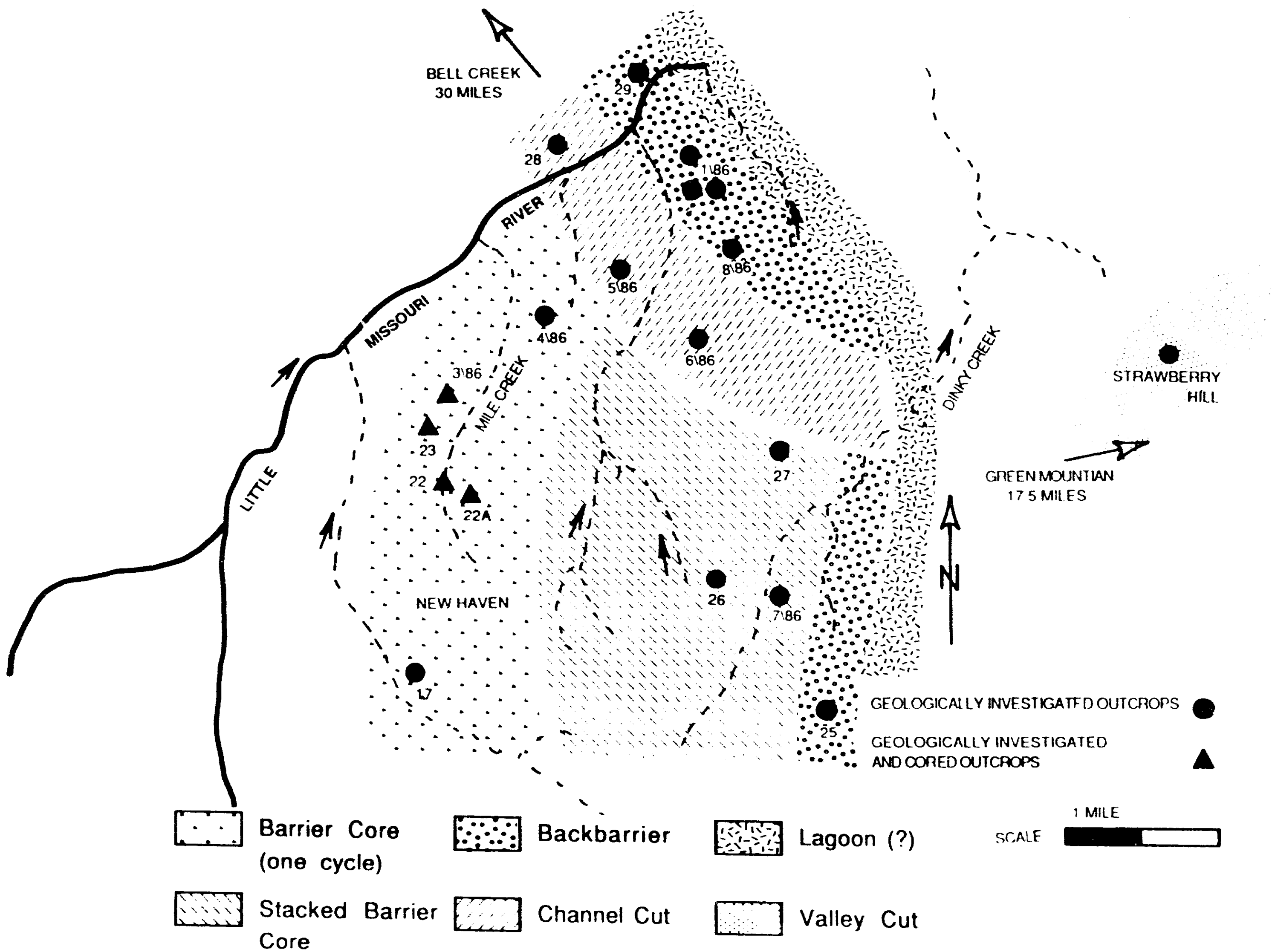


FIGURE 7. Depositional setting and facies distribution based on geological interpretation of Muddy (Newcastle) formation outcrop profiles in Crook County, Wyoming (Honarpour et al., 1989).

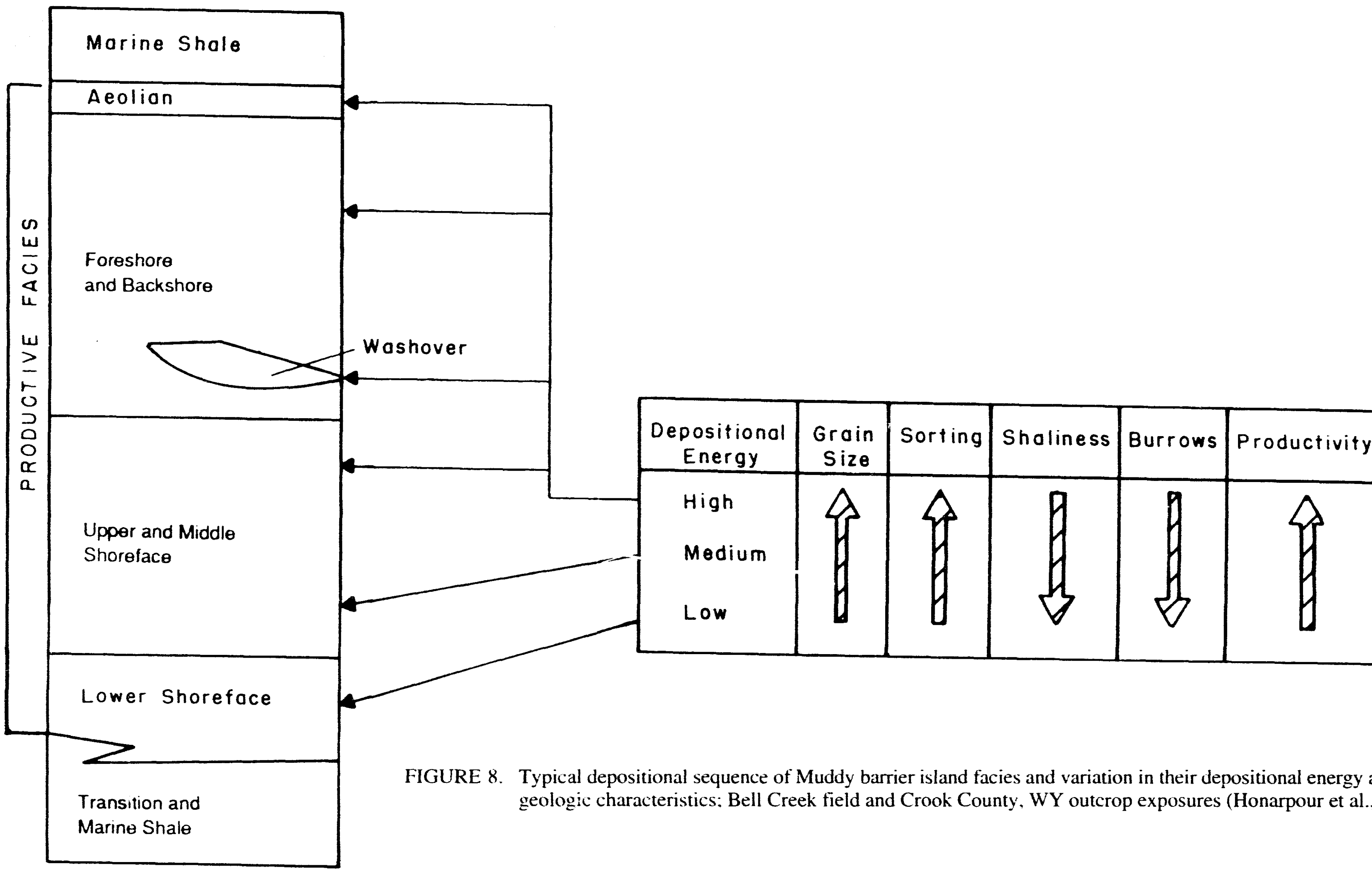


FIGURE 8. Typical depositional sequence of Muddy barrier island facies and variation in their depositional energy and geologic characteristics; Bell Creek field and Crook County, WY outcrop exposures (Honarpour et al., 1989).

TABLE 1
Dominant features identified in Barrier Island Sandstones, Muddy Formation (Bell Creek cores and New Haven outcrops) (Honarpour et al., 1989)

UPPER FORESHORE	Sandstone 150-200 μ, swash deposit. Moderately to well-sorted, low-angle to subhorizontal stratification. Trace to 5% burrowed (Skolithos, Corophiodes Diplocraterion). Trace of shale (rip-up clasts) and siltstone. Interruptions in sedimentation (subunits), poorer sorting, more burrowing and local bioturbation may indicate backshore deposit.
LOWER FORESHORE	Sandstone 125-150 μ, intertidal deposit. Moderately to well sorted. Subhorizontally laminated to low-angle troughs, wavy-bedded, not swash-laminated. Less than 10% burrowed. Trace of shale laminae.
WASHOVER	Sandstone 100-175 μ, storm overwash deposit. Poor to fair sorting. Massive appearing or subhorizontally to horizontally laminated planar beds. Possible ripple-form bedding. Typically nonburrowed and clean.
UPPER SHOREFACE	Sandstone 125-175 μ, fairweather current and/or wave deposit (subtidal). Occurs only rarely. Fair sorting. Cross-bedded or massive appearing, swaly cross-stratification (SCS), wave and current ripples. Hummocky cross stratification (HCS) absent. Few burrows (Diplocraterion, Rosellia, Ophiomorpha) Shaley siltstone up to 25%.
MIDDLE SHOREFACE	Sandstone 100-175 μ, wave dominated deposits Poor, or moderate to good sorting. Mostly massive due to burrowing (up to 60%) or bioturbation (>75%). Very low relief troughs to subhorizontal lamination. Shale drapes common but discontinuous.
LOWER SHOREFACE	Sandstone 100-150 μ. Poor sorting. Shale and siltstone 25-60% increasing downward. Low angle to subhorizontal stratification, Hummocky cross-stratification (HCS), rippled. Commonly bioturbated, burrowed 10-90% (Thallasinoides, Asterosoma, Rosellia, Corophioides).

II. FACIES DESCRIPTIONS AND PROFILES

Comparison of Muddy Formation (Bell Creek) and New Haven, Wyoming Outcrops Shoreline Barrier Facies Architecture

The depositional setting for the Muddy Formation at Bell Creek field (Powder River Basin, MT) and analogous Muddy Formation outcrops was one of a microtidal shoreline barrier which was syndepositionally and postdepositionally modified by valley cut and fill processes. The depositional model, (fig. 9) shows the relationship between the barrier-related facies and their incision by a valley cut. Foreshore and shoreface (supratidal, intertidal, and subtidal) facies not only have the best preservation potential, but comprise most of the producing barrier island sandstone interval. At Bell Creek field stacking of barrier sequences resulted from relative sea level drops (regressions) and sea level rise (transgression). During periods of regression older barrier island sequences were partially eroded, and during subsequent transgression, additional barrier island sequences were deposited over the remnants of older ones. Erosion of older barriers was partial to complete, sometimes extending below the base of the barrier sandstone. The erosion of significant portions of the barrier thickness strongly affected its storage capacity and transmissivity.

Based on outcrop and core study there is evidence for two periods of valley incision during late Muddy deposition: an earlier stage affected, usually, only barrier island deposits, and a later stage, that affected barrier island and earlier valley fill deposits. It was also determined that facies distribution patterns, stacking patterns, and continuity of sandstone units could be applied from outcrops to the subsurface in Unit 'A' of Bell Creek field (Honarpour et al., 1989).

Figure 10 is a location map for the outcrop sample areas in the New Haven area, Crook County, Wyoming. Facies descriptions and interpretations are presented in a series of profiles in figures 10 to 29.

Reservoir quality and productivity potential of barrier island sediments coincided with patterns of vertical stacking of facies, changes in barrier thickness due to erosion, and the range of permeability values in the productive facies. Foreshore, middle shoreface, and upper shoreface facies may be grouped together in the microtidal type of reservoir at Bell Creek because they contain similar reservoir properties. These facies have the highest reservoir quality and comprise most of the reservoir. The lower shoreface facies had distinct sedimentological and inferior reservoir quality characteristics. Paralic facies including washover, lagoon, estuarine, tidal channel, and tidal delta exhibit variable reservoir quality, with the washover facies having the best reservoir quality from this group, but a limited volumetric importance. The overlying valley fill deposits consist of both reservoir and nonreservoir quality sediments, but they are most often inferior reservoir quality facies at Bell Creek field.

Based on outcrop and subsurface studies it was found that while calcite cemented zones could be traced laterally for thousands of feet in outcrop, no such zones were present within the reservoir at Bell Creek (Jackson et al., 199[illegible]). Additionally, no tight clay-cemented zones were recognized in the outcrop, while in the reservoir such zones affect the entire reservoir section and vary over lateral distances of about 1,500 ft.

Conclusions

Critical heterogeneities. Similar critical heterogeneities have been identified in the subsurface and in studied outcrops. Comparable critical depositional heterogeneities in the Muddy Formation include the presence and magnitude of erosion-valley filling episodes and changes of facies succession within and between barrier cycles. Critical diagenetic heterogeneities include the type of clay cement, changes in total clay percent, and variations in compaction. Critical structural heterogeneities include the direction, amount of offset, and block size created by faulting.

Paragenetic sequence. The paragenetic sequence for outcrop and subsurface barrier island facies is essentially the same. Minor differences were found based on thin section work, such as increased hematite cement and more evident late-stage leaching in outcrop samples. However, the sequence and overall effect of diagenetic processes are not significantly different between sampled outcrops and subsurface barrier island sandstones. Similarities were found for the Muddy Formation outcrop middle shoreface and the subsurface foreshore and the outcrop lower shoreface and the subsurface lower shoreface facies.

Differences between outcrop and subsurface rocks. Differences found between outcrop and subsurface rocks consisted mainly of diagenetic differences due to atmospheric weathering. In the Muddy Formation, this consisted of a minor increase of hematite cement and slightly more late-stage leaching in outcrop samples, which resulted in slightly higher porosities. Laterally extensive calcite cement present in the outcrop foreshore facies was not identified in the subsurface.

Figure 10 has been newly drafted to show the locations of outcrop sampling. Figures 11 through 30 resulted from field work done in 1986 and 1987, but have not previously been published.

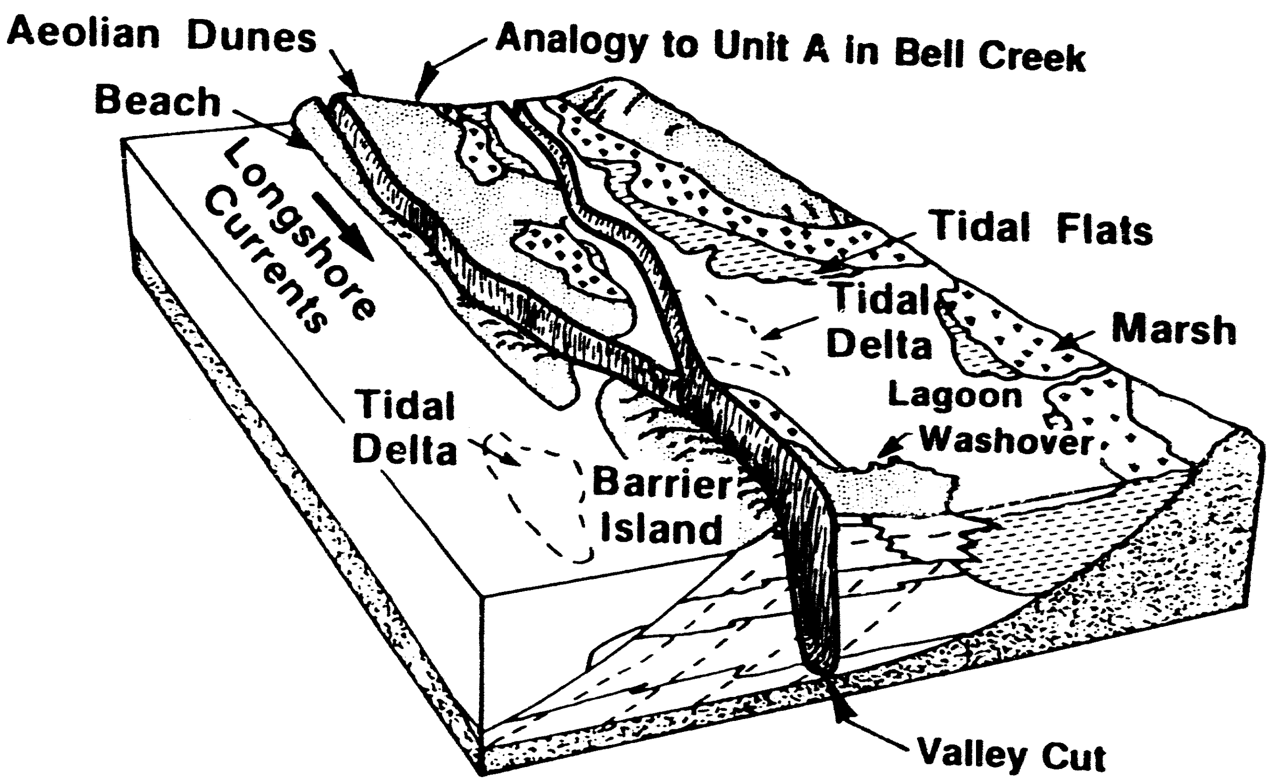


FIGURE 9. Depositional model for barrier island deposits and valley cut and fill at Unit 'A' in Bell Creek field. (Honarpour et al., 1989).

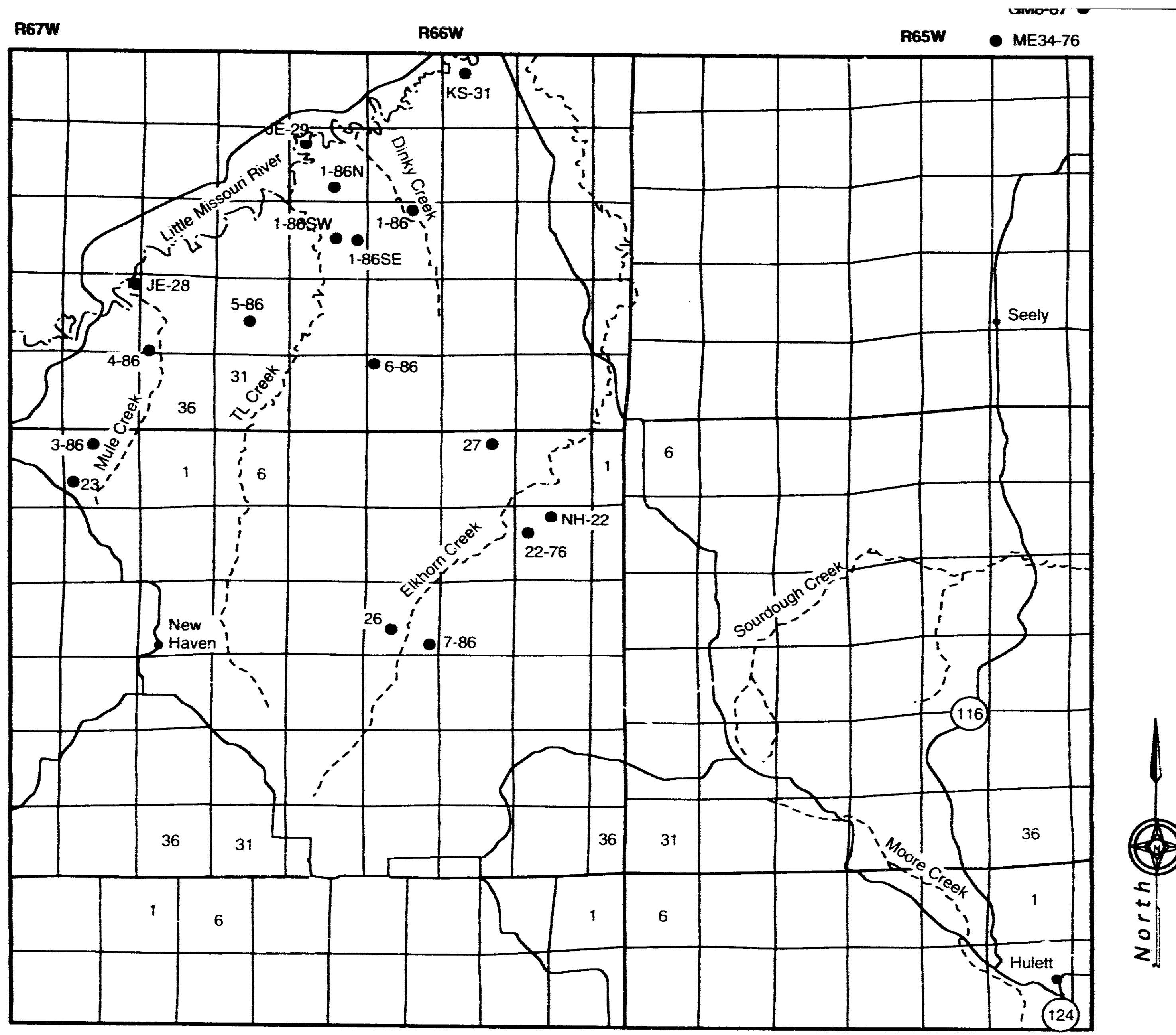


FIGURE 10. Location map for facies profiles for the Muddy Formation, Crook County, Wyoming. **116** and **124** are Wyoming state Highways, other roads are shown as solid lines, rivers and creeks are shown as dashed lines. Site ME (34)-76 (fig. 28) is located eight miles north of Seely, Wyoming in section 14 T57N R65W. Site GM8-87 is located at Green Mountain, section 30 T57N R63W, thirteen miles east and seven miles north of Seely.

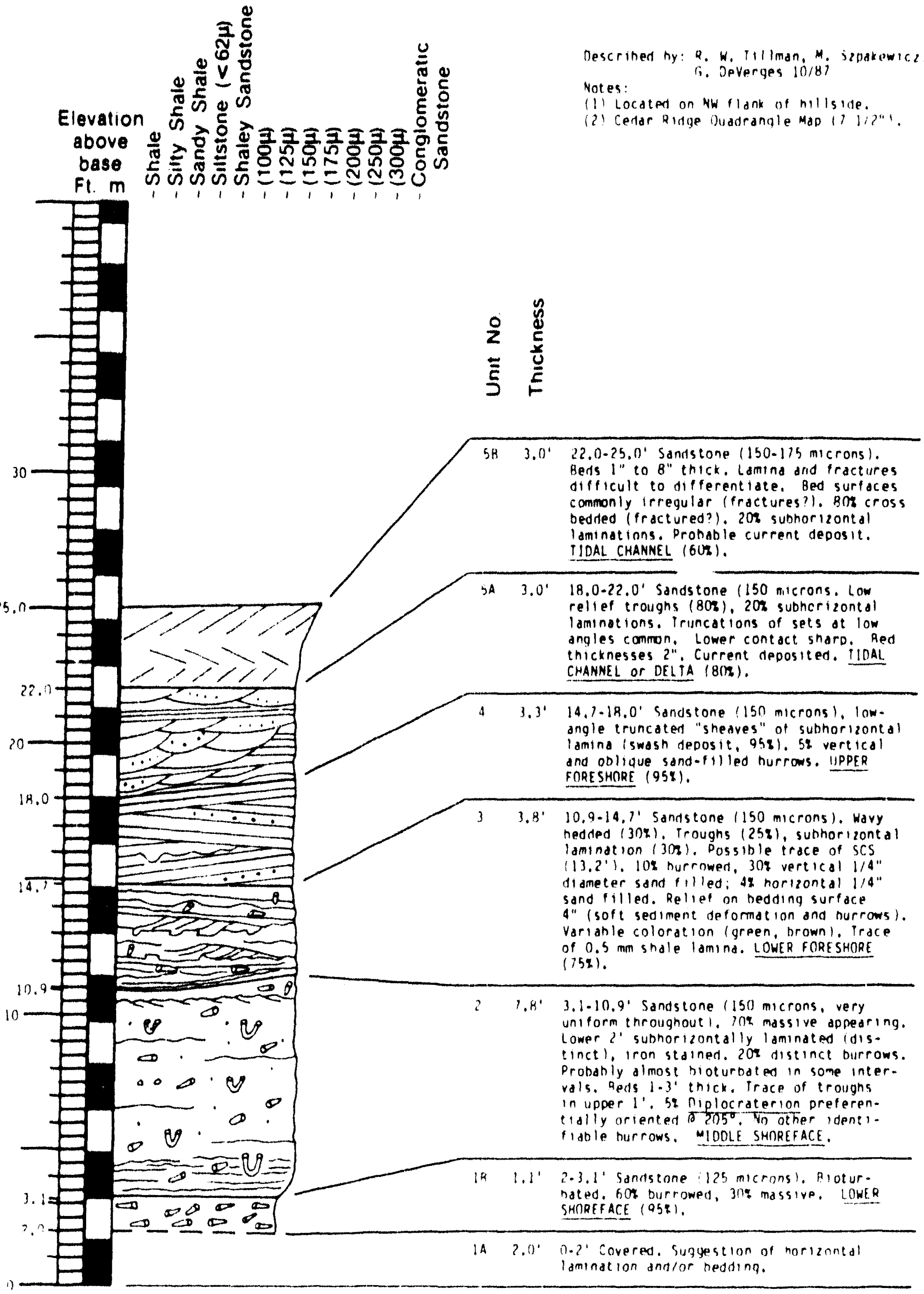


FIGURE 11. Measured section NH22N (-900') Muddy (Newcastle) sandstone SW NE NW Sec. 11 T55N R67W Crook County, Wyoming.

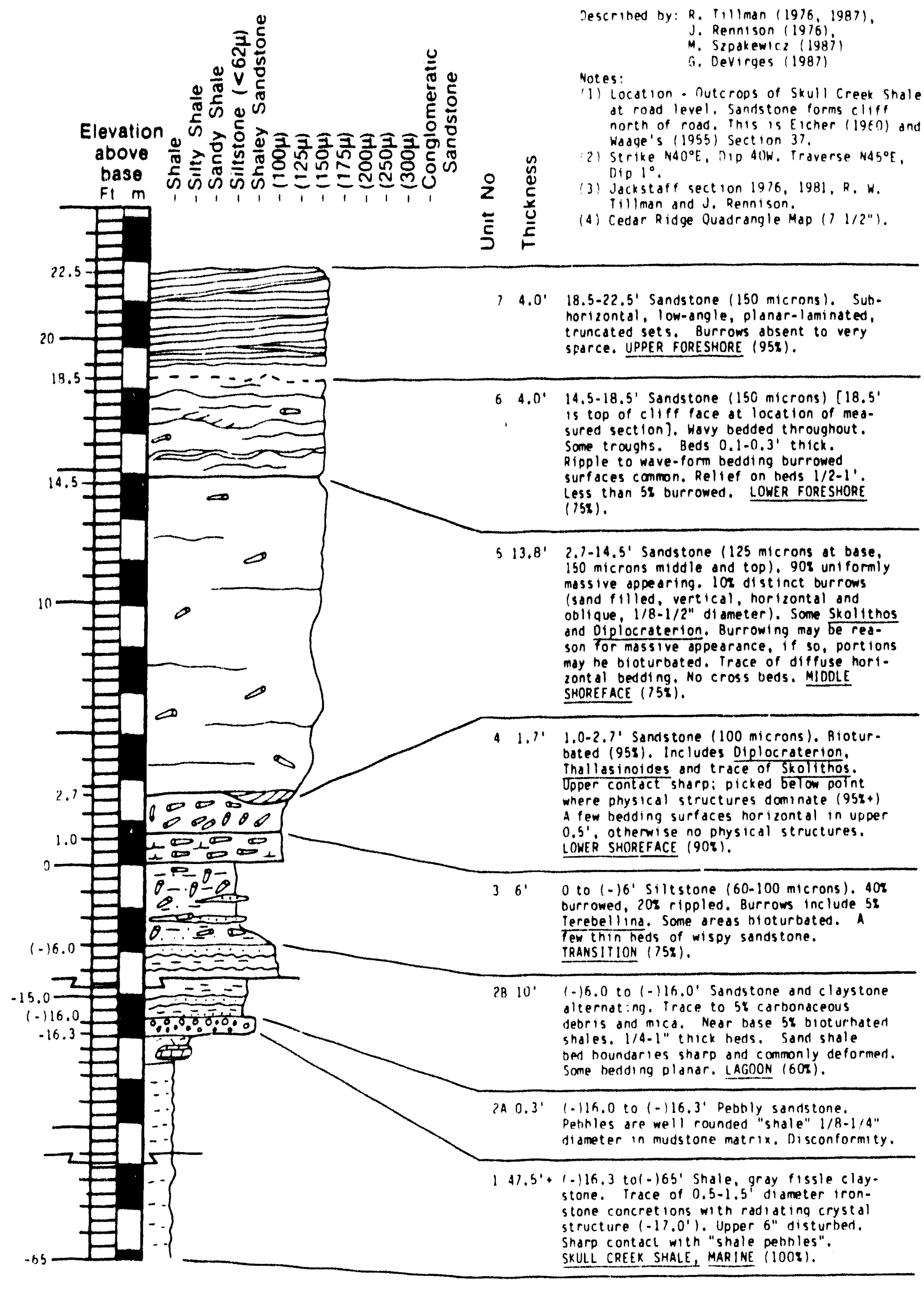


FIGURE 12. Measured section NH22-76(87) Muddy (Newcastle) sandstone SW NW Sec. 11 R67W Crook County, Wyoming.

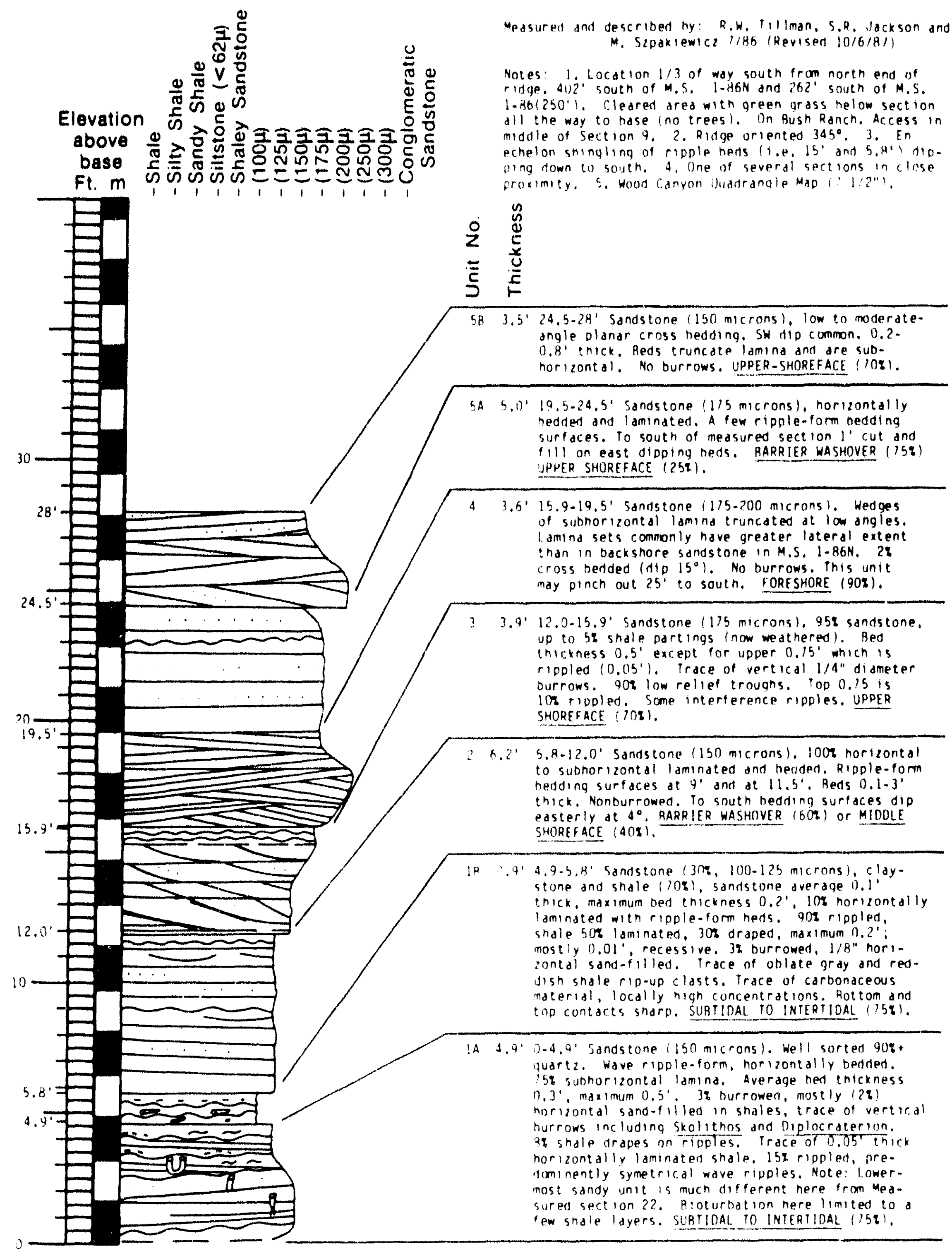


FIGURE 13. Measured Section 1-86, Muddy sandstone
NE NW NE Sec. 21 T56N R66W Crook County, Wyoming

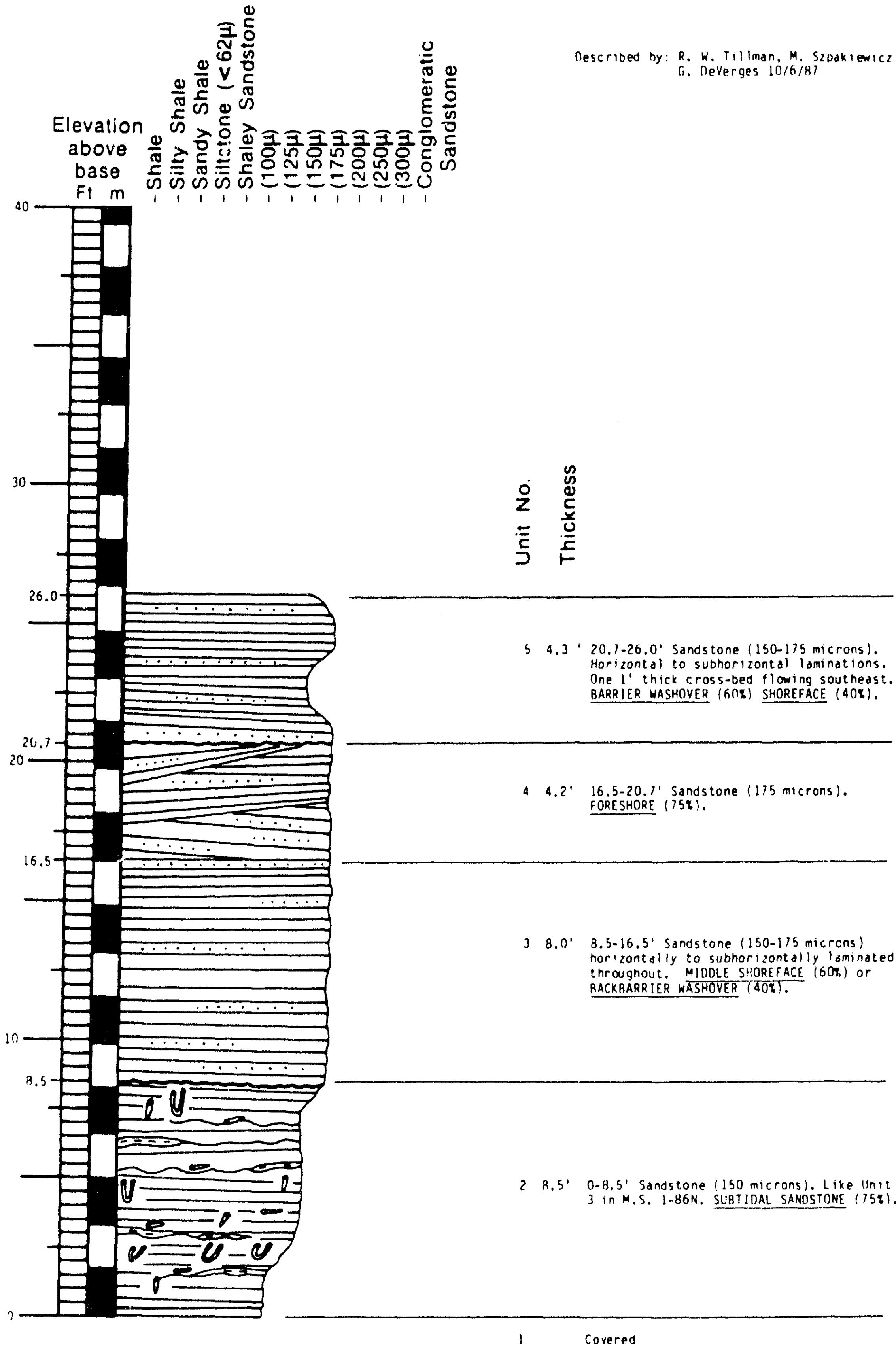
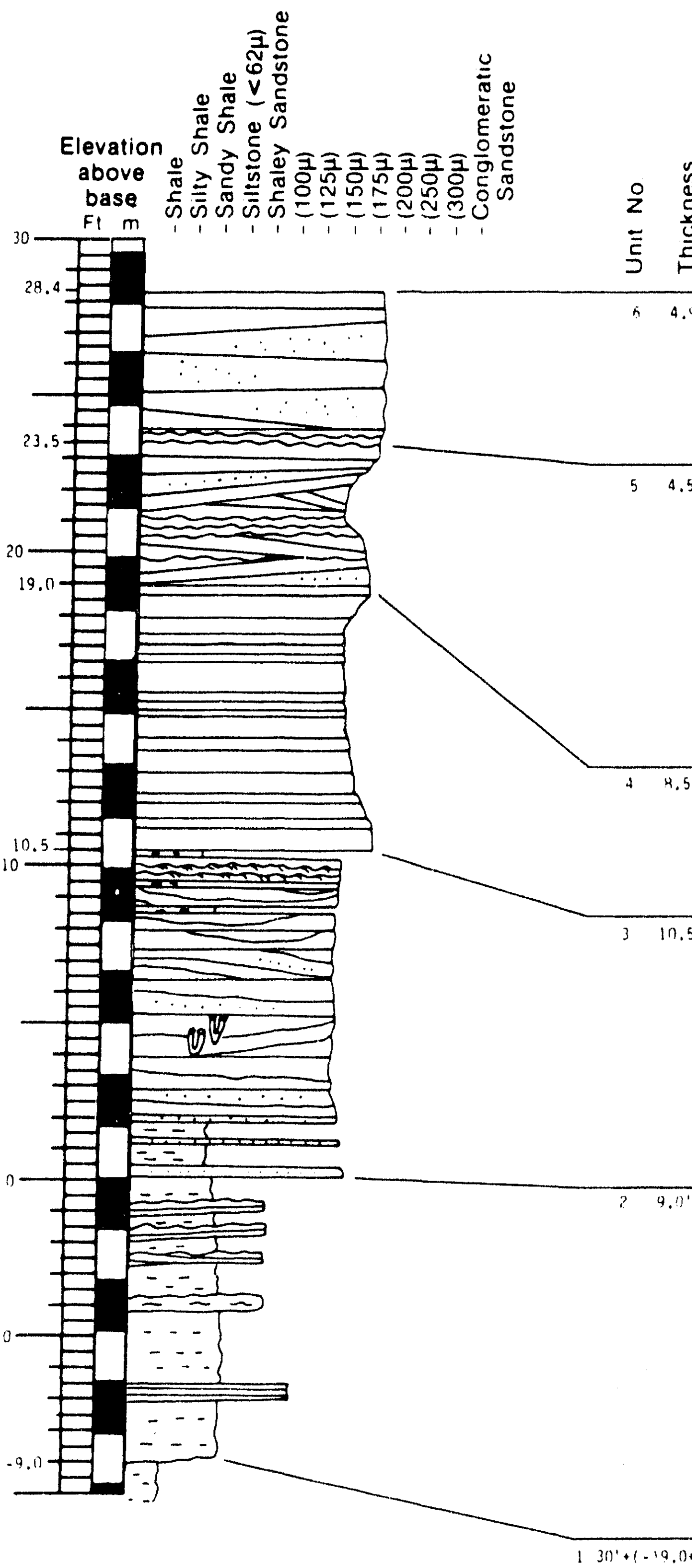


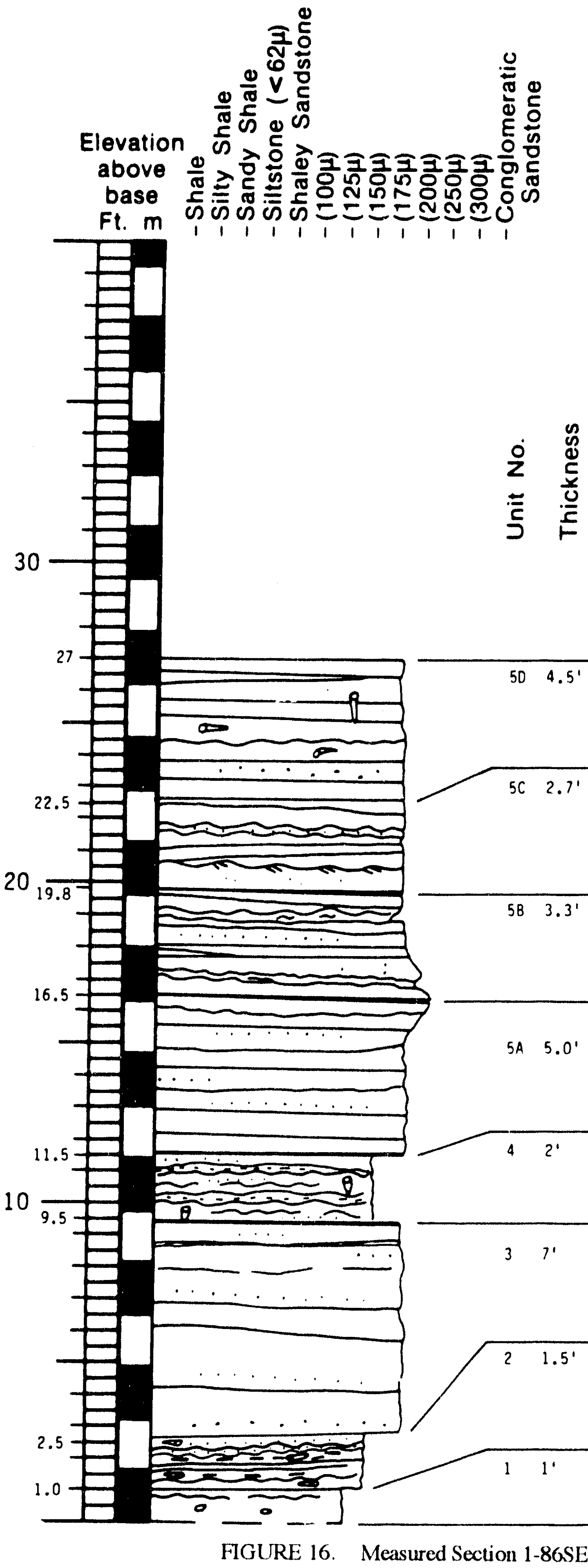
FIGURE 14. Measured Section 1-86 (250') Newcastle (Muddy) sandstone
SW SE Sec. 17 T56N R66W Crook County, Wyoming



Described by: R.W. Tillman, S.R. Jackson, M. Szpakiewicz and K. McGee, 8/8/86
Revised 10/6/87.
Section located at northernmost exposure of outcrop belt. Interval between Skull Creek and sandstones trenched.
Strike 145°, dip 3°SW. Traverse 145°, dip = 0°. Wood Canyon Quadrangle Map (7 1/2").

Unit No	Thickness	Description
6	4.9'	23.5-28.4' Sandstone (175 microns). Well sorted, 98% quartz. Massive appearing (90%), to horizontally laminated (5%). Some low-angle wedge set boundaries. Good sorting and mono-mineralogy (quartz) probably excludes possibility that this is channel fill (high-flow regime). BACKBARRIER WASHOVER (75%).
5	4.5'	19.0-23.5' Sandstone (150-175 microns). More poorly sorted than unit above. Combinations of (1) 65% low-angle truncating sheaves of planar beds, (2) 2% troughs truncated at top, (3) 30% ripple-form beds, some internally rippled. Ripple-form beds truncate low-angle cross-bedding. Top of unit marked by highest ripples. Flow directions: dips of lamina within sheaves 95° @ 8°, 75° @ 6°, 120° @ 5%, 75°, 155°, 95°, 70°, 78°, 95°. Trough flow directions: 143°, 235°, 145°. Flow directions suggest flow away from ocean into "Lagoon". Nonburrowed. BACKSHORE (90%).
4	8.5'	10.5-19.0' Sandstone (150, 175 microns at base and top). Subhorizontally to horizontally laminated throughout. Angle from horizontal does not exceed 3°. Beds 0.3-1.5' thick. Nonburrowed. Sharp horizontal upper and lower contacts. BACKBARRIER WASHOVER (60%).
3	10.5'	0-10.5' Sandstone (150-175 microns) 70% horizontally bedded, internally subhorizontally laminated. Beds 0.05-1.5' thick, most are 0.3' thick. Wave ripple-formed tops common. Ripple-form beds, 1" thick with 1 mm to 10 mm thick shale drapes. Shale beds light gray, 5% carbonaceous. 5% burrowed, trace of Corophoides burrows, trace of vertical burrows, 2% bedding plane and within shale burrows. Trace of Diplocraterion, up to 5% in some beds. Very sharp upper contact. INTERTIDAL TO SHALLOW SUBTIDAL (75%).
2	9.0'	0 to (-)19.0' Sandstone (75-100 microns) and shale interbedded. Most sandstones 0.07' thick or less, however at -8.0' includes 0.5' thick horizontal to subhorizontal (HCS?) 75-100 microns sandstone. Very finely laminated, "green and white", truncating at low angles. Glauconite(?). Shale is dark gray, fissile, somewhat burrowed. Commonly 1 cm thick shale laminae. Sandstones contain up to 5% carbonaceous material. Some 125 micron sandstones with ripple-form upper surfaces. Upper 3' 60% sandstone, lower 3' only 10% sandstone. Lower contact drawn at base of lowest noncarbonaceous 150-175 microns sandstone. Below +1.0' section exposed only in trenches (3). LAGOON (60%).
1	30'+(-19.0+	Shale, dark gray, fissile. MARINE (100%) SKULL CREEK SHALE

FIGURE 15. Measured Section 1-86N, Newcastle (Muddy) sandstone SW SE Sec 17 T56N R66W Crook County, Wyoming

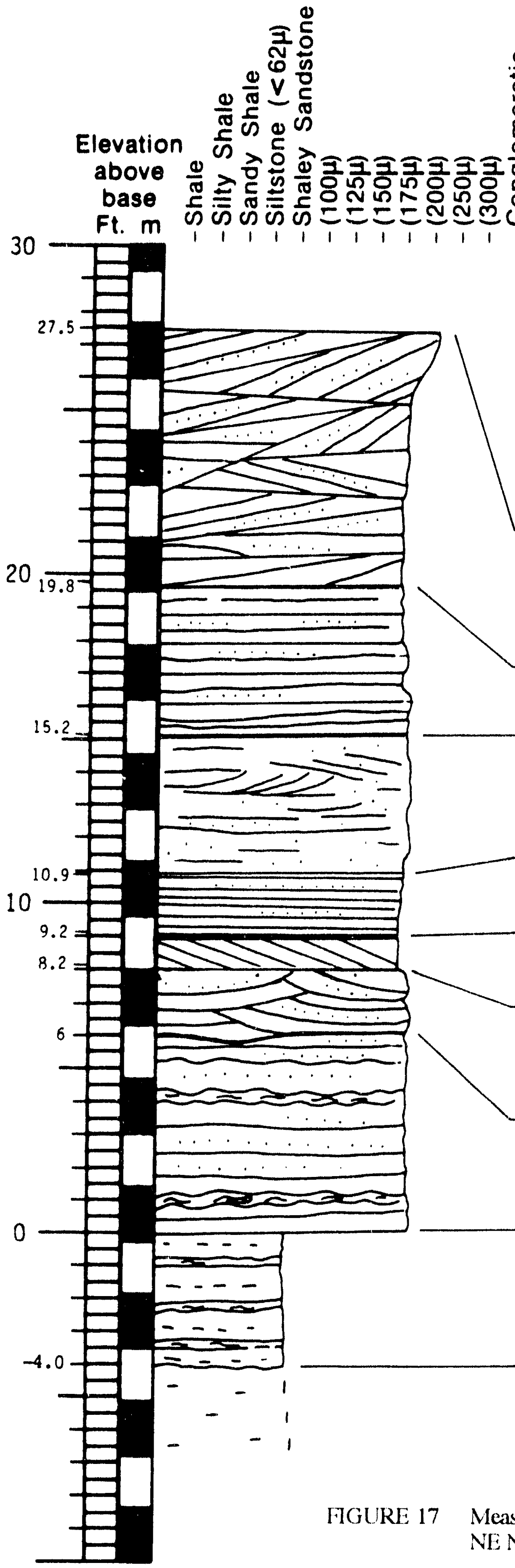


Described by: R.W. Tillman, S.R. Jackson and M. Szpakiewicz 8-3-86

Strike 245°, dip 4°S. Measured along azimuth 110°, dip 1.5° One of a series of measured sections in close proximity. Wood Canyon Quadrangle map (7 1/2").

Unit No.	Thickness	
5D	4.5'	22.5-27.0' Sandstone (175 microns). Subhorizontal to horizontal bedded (0.3-0.8'). Some set boundaries truncated at low angles. Nonburrowed. Trace of 1/8" vertical and horizontal burrows. Trace of ripple-form beds.
5C	2.7'	19.8-22.5' Sandstone (175 microns). Subhorizontal planar-tangential (80%) and ripple formed (20%) laminations. (Symmetrical and asymetrical ripples). Beds lenticular. 0.5' erosion at face. Trace of internal ripples(?). Trace of carbonaceous material.
5B	3.3'	16.5-19.8' Sandstone (175, 200 microns at base). Subhorizontally laminated (85%, 1.5'). 15% thin, 0.05-0.1' beds, ripple formed (internally subhorizontally laminated). Trace of recessive ripples (150 microns, carbonaceous).
5A	5.0'	11.5-16.5' Sandstone (175, 200 microns at top). Massive appearing, horizontally bedded (0.3') and laminated. Nonburrowed.
4	2'	9.5-11.5' Sandstone (150 microns, 175 microns at top, 80%) interbedded with laminated silty shale (20%). Sandstone (0.1-0.2' thick) ripple-form to massive. Trace of vertical burrows.
3	7'	2.5-9.5' Sandstone (175 microns, at top 150 microns). Massive appearing, horizontally bedded (0.5') and laminated. Sharp upper and lower contacts. Nonburrowed. Trace of lenticular beds.
2	1.5'	1-2.5' Sandstone (150 microns, 60%) interbedded with shale (40%). Shale silty, horizontally burrowed (20%). Most of shale in lower half, horizontally laminated, draped in upper half. Sandstone ripple-form bedded.
1	1'	0-1' Sandstone (125 microns). Massive appearing, 5% shale clasts, ripple-form bedded at top. Covered with grass below, base not exposed.

FIGURE 16. Measured Section 1-86SE, Newcastle (Muddy) sandstone NE NE SE Sec 20 T56N R66W Crook County, Wyoming



Described by: R.W. Tillman, S.R. Jackson and M. Szpakiewicz 8-3-86
On this block strike 100°, dip 11°S. Traverse directions 42°, used dip of 6°.
Wood Canyon Quadrangle map (7 1/2").

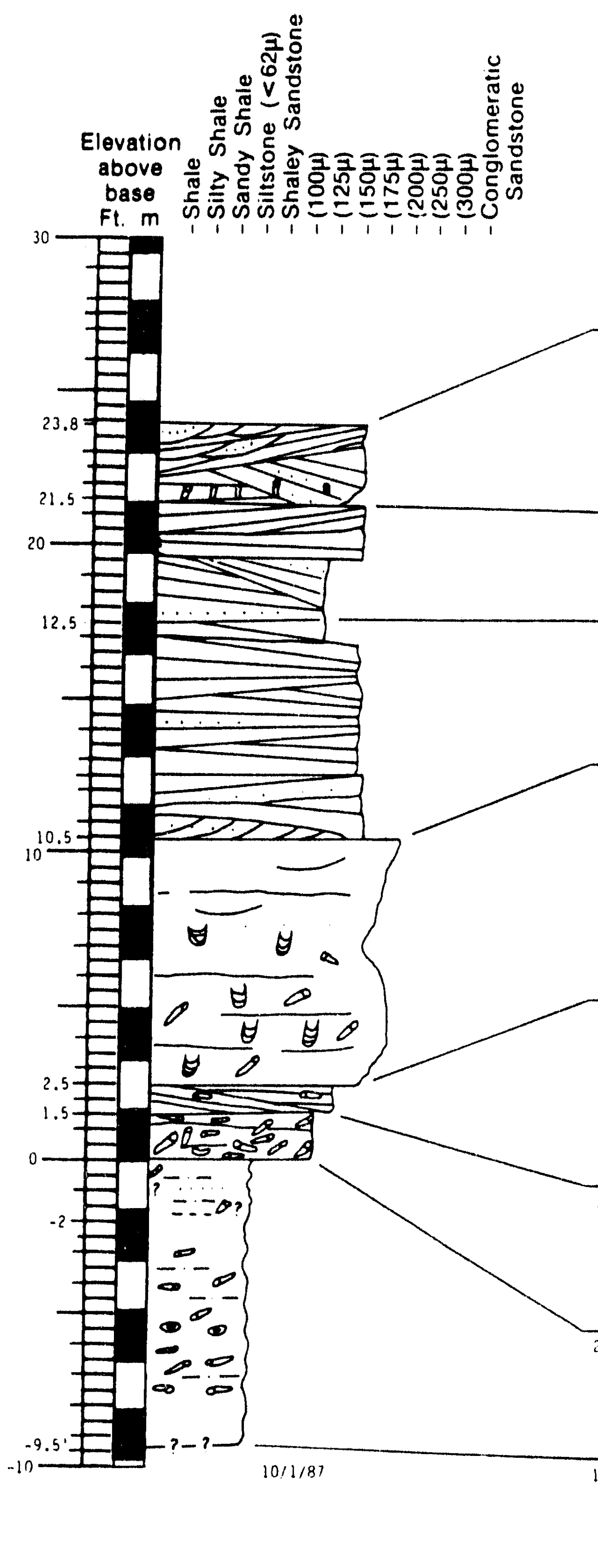
Note: No obvious barriers to vertical flow in this section.

Unit No.	Thickness	
6	7.7'	19.8-27.5' Sandstone (175 microns, 200 microns top) Sheaves of low angle lamina in low angle truncating sets. Dip of lamina azimuths measured: 210°, 230°, 235°, 240°. Upper part poorly exposed, weathers massive. Orthogonal weathering pattern forms small domes. FORESHORE (95%).
5C	4.6'	15.2-19.8' Sandstone (175 microns), very clean, white, micaceous. Horizontally bedded and laminated.
5B	4.3'	10.9-15.2' Sandstone (175 microns), massive with faint horizontal laminations, few troughs (transport toward 235°). Laterally, to the east, low-angle (2°) tangential-planar or low relief troughs. No burrows.
5A	1.7'	9.2-10.9' Sandstone (175 microns), horizontally bedded and laminated. Unburrowed. Thins laterally to 0.8' and disappears to east.
4B	1'	8.2-9.2' Sandstone (175 microns), southward inclined planar tabular laminae dipping at 4° toward 215°. Unburrowed.
4A	2.2'	6-8.2' Sandstone (175 microns, locally 200 microns) low relief troughs 0.5-1.0' thick. Locally lower contact marked by scour 0.5' deep. Trace of bedding plane ripples. Coarser sand is small troughs with ripples.
3	6'	0-6' Sandstone (175 microns) subhorizontally bedded (1.0-1.5' thick). Subhorizontally laminated. 10% ripple-form bedding surfaces, 5% ripples associated with some ripple-form beds. Beds amalgamate laterally.
2	4'	0-(-)4' Shale and sandstone (150 microns) 0.05-0.1' thick. Shale and sandstone are interbedded. Contact excavated.
1	30'+	(-)4 to-34' Shale, dark grey, fissle, claystone. Forms shale slope, base covered with grass.

FIGURE 17 Measured Section 1-86SW, Newcastle (Muddy) sandstone NE NE SE Sec 20 T56N R66W Crook County, Wyoming

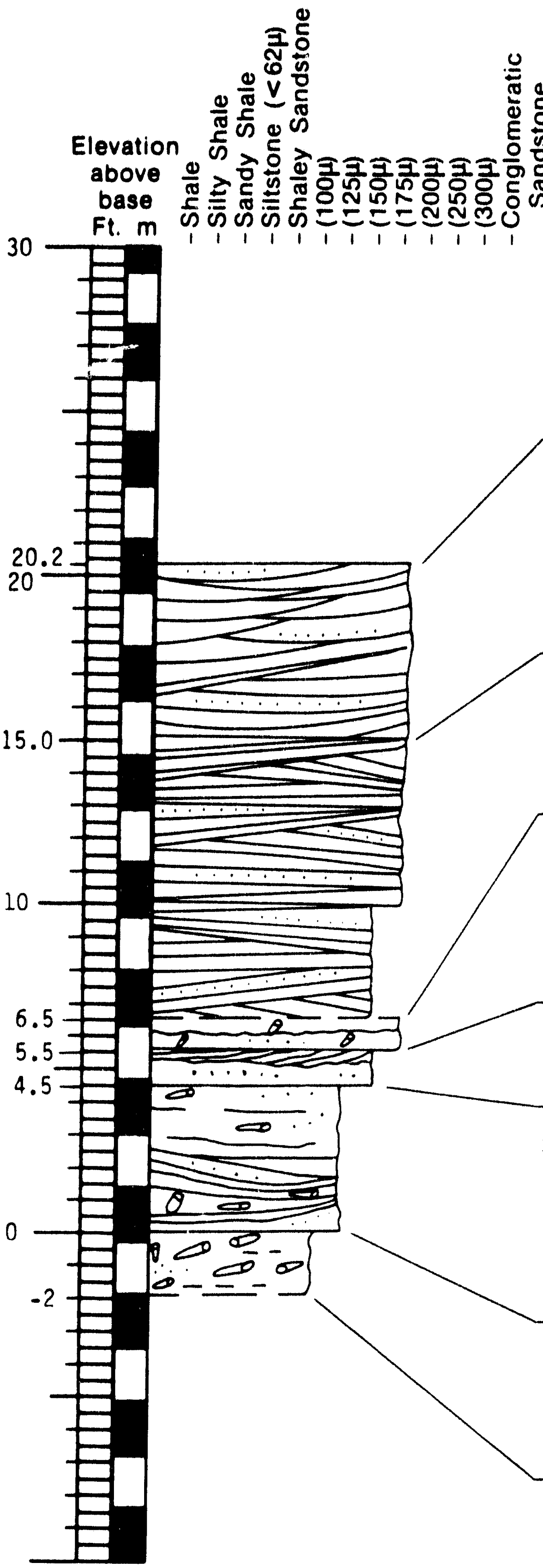
Described by: R.W. Tillman, S.R. Jackson and M. Szpakiewicz
8-5-86, 10-87

Notes: This location is on west side of flat topped mesa. Southern Lake (of 3) bears 310° to outcrop. Two "cliffs" in north-south line contain basal siltstone. Calcite cemented outcrop. Strike 10°, dip 1°E (a fault block?). Wood Canyon Quadrangle map (7 1/2").



Unit No.	Thickness	
8		Covered, grassy flat-topped butte.
7	2.3'	21.5-23.8 Sandstone (150 microns). Light brown. 75% low-relief planar-tabular laminations. Beds 1-4" thick. Flow direction northerly and southerly; (160°, 180°, 350°, 345°, 50°, 55°, 40°, 335°, 340°) 5% ripples. More calcite cemented and thicker bedded than below. Lower contact placed below concentration (5%) of Skolithos burrows. Skolithos limited to lower 1.0'. Current deposit. TIDAL CHANNEL (90%).
6	9.0'	12.5-21.5'. Sandstone (150 microns, 125 at top), White to buff (95%). Low-angle laminated, low-angle truncated sets. Beds thin upward from 2" to 1/4" at 20.2'. White, clay-filled (17.5-20.3') Nonburrowed. FORESHORE (90%).
5	2.0'	10.5-12.5'. Sandstone (150 microns). Subhorizontally laminated. Locally 50% small troughs. Beds 0.1-0.3' thick (thicker than above). Less than 5% burrowed, trace 1/4", vertical, sand filled; trace large diameter sand filled (1/2"+). Lower contact sharp; upper contact "gradational". LOWER FORESHORE (90%).
4B	8.0'	2.5-10.5'. Sandstone, buff colored (175 microns). Mostly massive appearing due to burrowing and/or good sorting. Bedding is diffuse and horizontal to subhorizontal. A few low-relief troughs. Laminations rarely visible. Obvious burrows (mostly Diplocraterion) are only 5% of section and mostly in lower half of unit. Burrowing may be up to 60%, but not visible. Forms steep vertical face. Diplocration rarely show borders of vertical tubes. Lower contact sharp, upper contact marked by lowest well laminated bed which is essentially unburrowed. MIDDLE SHOREFACE (75%).
4A	1.0'	1.5-2.5'. Sandstone (125 microns). 90% very low-relief troughs to subhorizontal bedded and laminated. 5% vertical Skolithos type 1/8" diameter sand-filled burrows. 5% horizontal sand filled 1/4" diameter burrows. Trace of Diplocraterion. Sharp upper and lower contacts. Differs from unit below in that physical structures predominate. Wave deposit. Contains calcite cemented lenses. MIDDLE SHOREFACE (75%).
3	1.5'	0-1.5'. Sandstone (100 microns). Brown to gray. Bioturbated (75%) to locally burrowed (60%). 5-30% of burrows visible, mostly vertical 1/8' diameter. Upper 0.3' somewhat less burrowed. Subhorizontal to low-relief troughs (20% visible). Very sharp erosional lower contact. Includes calcite lenses. LOWER SHOREFACE (90%).
2	9.5'+	0 to (-)9.5' Siltstone (-9.5') (Sandy 75-100 microns). Black to dark gray, heavily burrowed (partially bioturbated). Disturbed throughout. Observed in hand-dug pits (-3 to -9.5'). No "Lagoon" type facies above -9.5'. Contains Terebellina. TRANSITION (80%).
1		Covered, soil, grassy slope.

FIGURE 18. Measured Section 3-86, Newcastle (Muddy) sandstone
SE NE SE Sec 2 T55N R67W Crook County, Wyoming



Described by R. W. Tillman, S. R. Jackson and M. Szpakiewicz 8-5-86

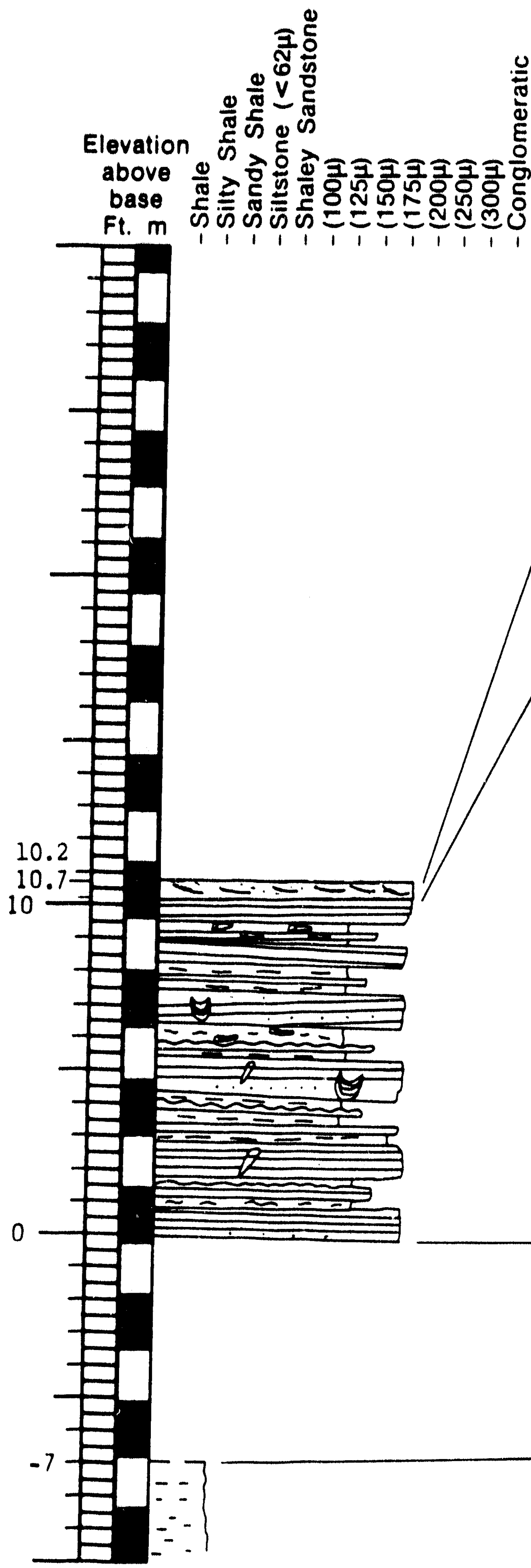
Section measured on west side of point along Mule Creek. Section located at second from north point where face is exposed; approximately 1/8 mile from NW end of outcrop.
Note: Transferred measured section. 20 meters north at 5.5'. (Grain size changes from 150 to 175 microns at 5.5' in thin recessive laminated bed.)

Unit No.	Thickness	
5B	5.2'	15.0-20.2'. Sandstone (175 microns, poorly sorted). Highly calcite cemented (brownish). Weathers more resistant then bed below. Some beds more low-relief troughs than those below, other beds like those below. Low angle truncated sets. FORESHORE (80%).
5A	8.5'	6.5-15.0'. Sandstone (175 microns). Very low-angle laminations and thin beds (1" to 2"). Beds and sets truncate at low angles. No burrows. FORESHORE (75%).
4	1.0'	5.5-6.5'. Sandstone (175 microns). Horizontally bedded (0.5' thick) "massive appearing". 5% obvious burrows, mostly vertical (3/8" diameter). Thicker bedded than above or below. UPPER SHOREFACE (75%).
3B	1.0'	4.5-5.5'. Sandstone (150 microns). Same as unit below but slightly coarser. UPPER SHOREFACE (75%).
3A	4.5'	0-4.5'. Sandstone (125 microns), where weathering emphasizes features 80% low-angle to subhorizontal laminated. Beds 0.2-0.3' thick and subhorizontal. 5-10% burrowed (visible). Weathers massive (no Diplocraterion). UPPER SHOREFACE (75%)
2	2'+	0 to (-)2'. Siltstone, sandy (100 microns), and shaly. 60% burrowed by variety of burrows. Most burrows are sand-filled. Recessive. TRANSITION FACIES (90%).
1		Covered, Skull Creek Shale.

FIGURE 19. Measured Section 4-86, Newcastle (Muddy) sandstone
North Boundary of Sec 36 T56N R67W Crook County, Wyoming

Described by R.W. Tillman, S.R. Jackson and M. Szpakiewicz 8-5-86

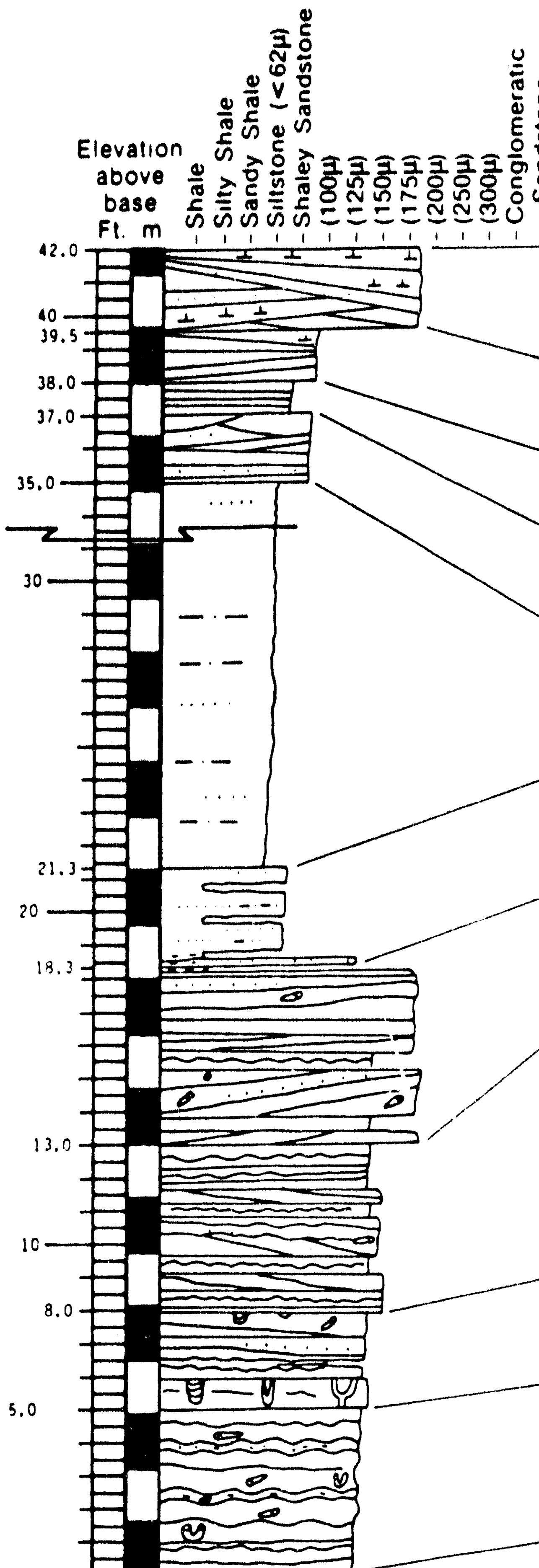
Wood Canyon Quadrangle map (7 1/2")
Strike 150° dip 4°SW.
Section measured on traverse of 150°, 0° dip.



Unit No.	Thickness	
4	0.5'	10.2-10.7'. Sandstone (175 microns). 0.5' thick bed, asymetrically rippled. Includes some wave ripples. Flow towards 230°. Top of unit apparently depositional top of Newcastle.
3	10.2'	0-10.2' Sandstone (175 microns). Blocky weathering cyclic deposit with alternation of up to 1' thick horizontally to subhorizontally laminated beds (>0.5' thick, 40%) with thin 0.05 to 0.2' thick horizontally to subhorizontally laminated beds. 10% interbedded gray marine shale. Shales 30% horizontally burrowed (sand filled). Some shales have abundant carbonaceous fragments (sand size). Trace of Diplocraterion and 1/8" vertical burrows. 5% horizontal burrows in shale and thin beds. Trace of ripples (1/2" thick) interbedded with shale. Trace of wave ripple crests on bedding (oriented 160°). Current ripple flow direction 65°. Trace of Corophoides on several beds. SUBTIDAL (UPPER SHOREFACE) (90%).
2	7'	0 to (-)7. Covered, soil and rocks.
1B	30'	(-)7' to (-)37'. Shale, dark gray, fissile. MARINE, SKULL CREEK SHALE.
1A		Covered, grass.

FIGURE 20. Measured Section 5-86, Newcastle (Muddy) sandstone
NE SW Sec 30 T56N R66W Crook County, Wyoming

Described by: R. W. Tillman, S. R. Jackson, and M. Szpakiewicz 8/86, 6/87
Strike 115°, Dip 8°NE
Traverse direction: 40°, "dip" 8°
Wood Canyon Quadrangle map (7 1/2").

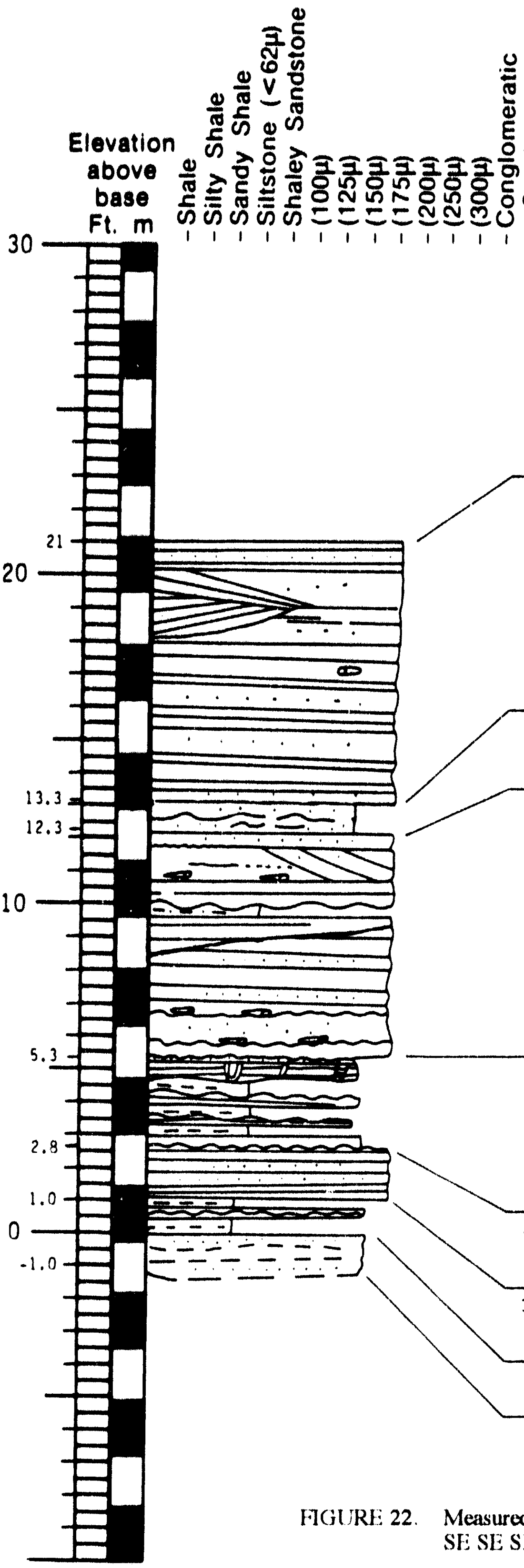


Unit No	Thickness	
6D	2.5'	39.5-42.0' Sandstone. Sheaves of low-angle laminations truncated by set boundaries at low angles. Highly calcite cemented, brownish and resistant. Trace of Skolithos. FORESHORE (95%).
6C	1.5'	38.0-39.5' Silty sandstone (100 microns) 80% subhorizontally laminated, 20% low relief (0.2') cut and fill 5% carbonaceous fragments concentrated on lamina.
6B	1.0'	37.0-38.0' Shaley sandstone (75 microns) non-resistent, difusely horizontally laminated. Poorly exposed. FLOOD PLAIN (90%).
6A	2.0'	35.0-37.0' Silty sandstone (100 microns) mostly 1' thick low-relief troughs. 10% carbonaceous disseminated grains. No burrows. FLOOD PLAIN SPLAY (80%) SHOREFACE (20%).
5B	12.7'	21.3-35.0' Siltstone, sandy (40%,100 microns). Slightly shaley, non-fissile, subhorizontally laminated on 1mm scale. Homogenous, fractures uniformly into cubes. Trace of carbonaceous fragments. Non-resistant, "weathers back" to form recessive slope. ESTUARY FILL (75%) FLUVIAL FILL(25%).
5A	4.0'	18.3-21.3' Sandstone, shaley. Silty (90 microns). Interlaminated with dark gray shale. Basal 1" is shale, overlain by 1" thick sandstone (125 microns). ESTUARY FILL (75%) MARINE FILL (25%).
4	5.3'	13.0-18.3'. Sandstone (175 microns laminated, 125-150 micron ripples) Mostly 0.8' thick or thicker subhorizontally laminated beds. Very few burrows. UPPER SHOREFACE (70%).
3B	5.0'	8.0-13.0' Sandstone (150 microns) Thin (0.2') horizontally laminated sandstone. 25% shale, rippled, fissile, subhorizontal, medium gray, in 0.1-0.2' thick beds. Thicker sandstone beds subhorizontally laminated. Thin beds rippled. 15% sandstone ripples (125-150 microns). 5% burrowed, mostly vertical 1/8-1/4" diameter, sand filled. Trace of Diplocraterion and Corophoides. Trace of wood fragments. LOWER SHOREFACE (80%).
3A	3.0'	5.0-8.0' Sandstone (125 microns) Beds thicker than above and below. Less interbedded shale. Horizontally laminated. LOWER SHOREFACE(80%).
2	5.0'	0-5.0' Sandstone (125 microns) interbedded with shale. Sandstone 0.1' thick. Shale 0.05' thick, dark gray fissile. Some interlamination of shale on 2 mm scale. Appears to be less than 10% burrowed including trace of Diplocraterion. TRANSITION ZONE (70%). TIDAL DELTA (30%).
1		Covered

FIGURE 21. Measured Section 6-86, Newcastle (Muddy) sandstone
NW NW NW Sec 33 T56N R66W Crook County, Wyoming

Described by R. W. Tillman, S. R. Jackson and M. Szpakiewicz

Strike 265°, Dip 5°N.
Traverse directly north at dip of 5°.
Outcrop face oriented 285°, on south facing cliff of westward jutting point near eastern location where outcrop swings "N-S". Access from Nieman Ranch.
New Haven Quadrangle map (7 1/2").



Unit No.	Thickness	
6C	7.7'	13.3-21.0'. Sandstone (175 microns). Beds 0.1-0.5' thick. Laminasets range upwards from 0.05' in thickness. Trace(?) of burrows. 98% horizontally laminated and bedded. Higher angle truncation surface absent. Laterally, horizontal lamina partially replaced by wave ripples which form beds and thin (1") clay layers. Laterally near the top is a 1.6' thick bed with low-angle laminations truncated at low angles, (FORESHORE, 90%) overlain by 1.2' of horizontal lamina which mark top of unit. UPPER SHOREFACE (90%).
6B	1.0'	12.3-13.3'. Sandstone (150 microns). Wavy to ripple-form bedded. Beds 0.1' thick. May include low-relief troughs.
6A	7.0'	5.3-12.3'. Sandstone (175 microns). 95% horizontally laminated and bedded. Beds up to 1.3' thick. A few low-relief truncations forming tabular beds. Basal 0.5' subhorizontal laminated with ripple-form upper surface. 2% ripple-form bedding surfaces, some with 2 mm shale drapes. 0.3' thick shaly silt deposit at 10'. Primarily wave deposited. Between 10 and 12' laterally, thick troughs flow toward 80°. Horizontal burrowing on some ripple-form surfaces. Trace of Diplocraterion at base. Trace of 1/2" diameter siderite clasts at base. UPPER SHOREFACE (80%).
5	2.5'	2.8-5.3'. Sandstone (150 microns) interbedded with claystone, light gray, silt and sand free. 10% sand size carbonaceous material in top 1/2" of unit and within sands. Upper bed 2% Corophoides and Diplocraterion burrows. Sand size Carbonaceous material top 1/2" and within sands. SHALLOW SUBTIDAL (80%).
4	1.8.	1-2.8' Sandstone (175 microns), subhorizontally to horizontally laminated. Upper surface is ripple-formed.
3	1.0'	0-1'. Sandstone (150 microns), rippled to wavy bedded. 20% laminated to rippled shale. UPPER SHOREFACE (80%).
2	1'	0 to (-)1'. Sandstone (150 microns) and silty shale. Both <1" thick. Exposed only by excavation.
1		(-)1' downward. Covered, grassy slope.

FIGURE 22. Measured Section 7-86, Newcastle (Muddy) sandstone
SE SE SE Sec 16 T55N R66W Crook County, Wyoming

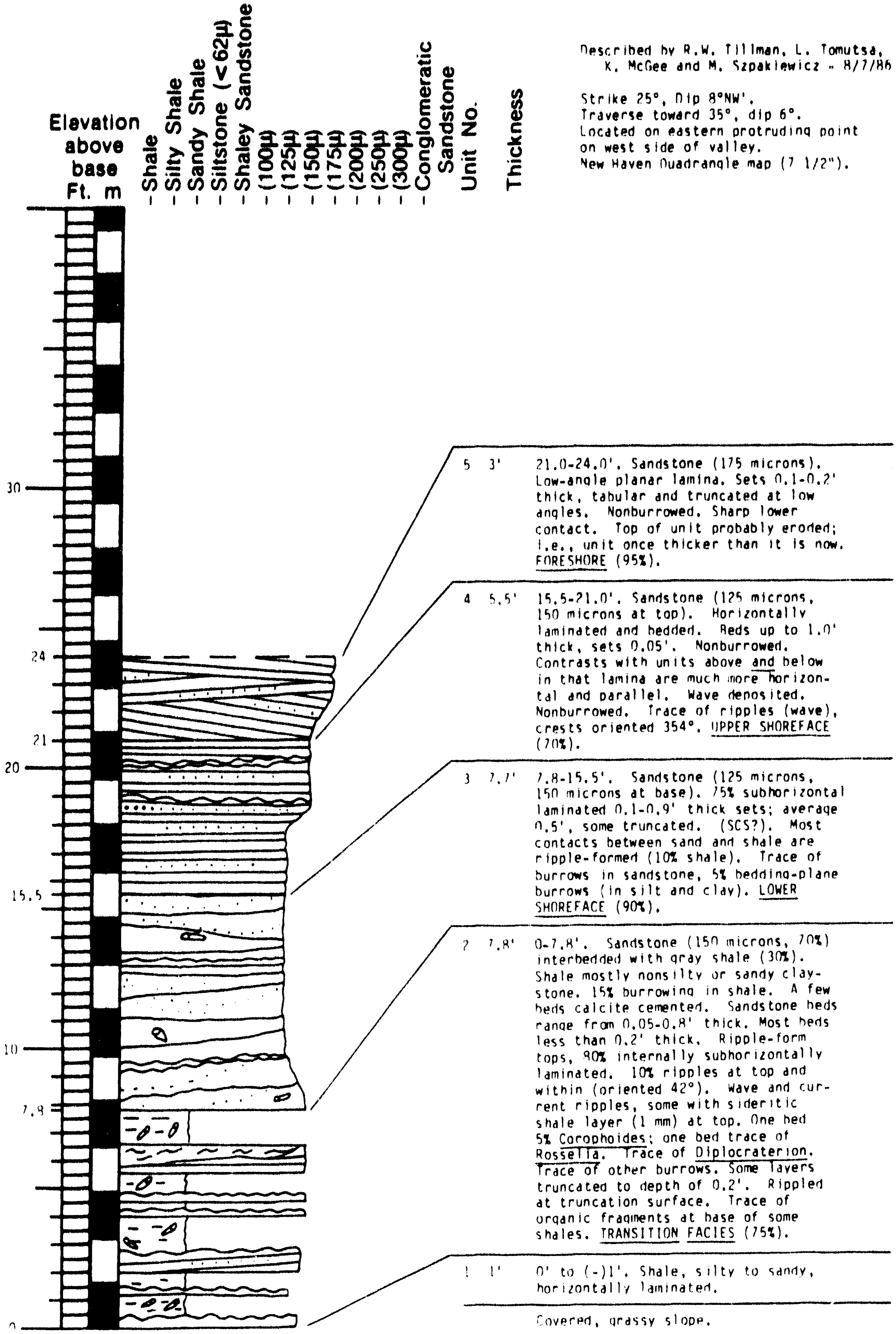
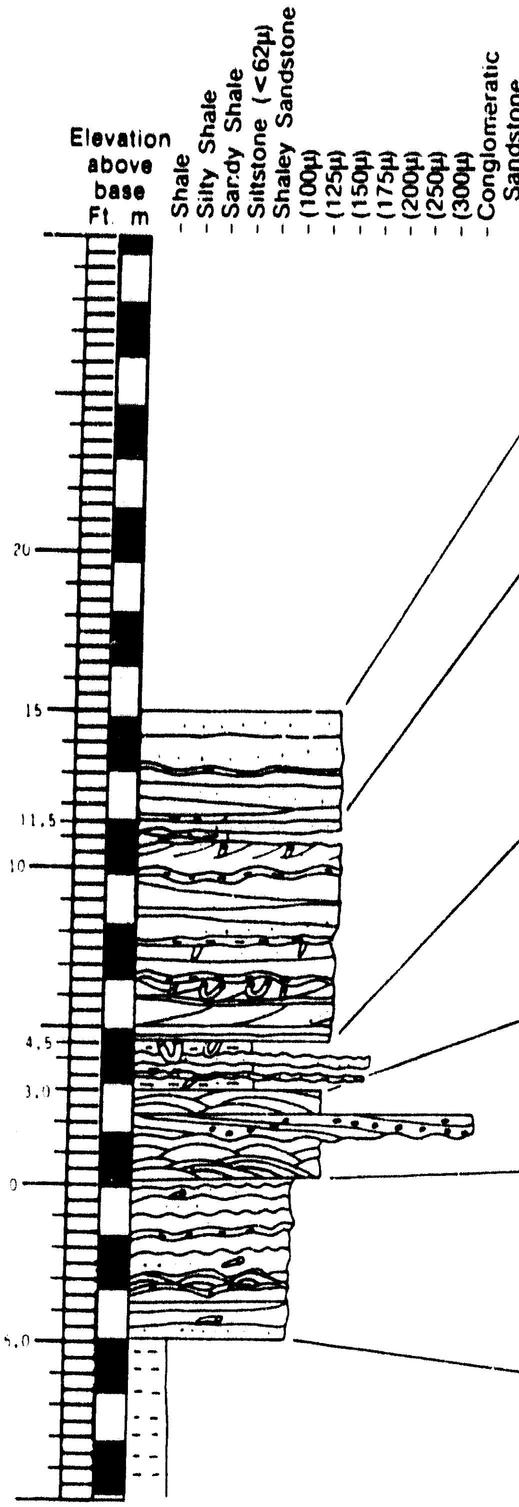


FIGURE 23. Measured Section 26, Newcastle (Muddy) sandstone
NW SW Sec 16 T55N R66W Crook County, Wyoming



Described by R. W. Tillman, L. Tomutsa, K. McGee and M. Szpakiewicz 8/86 11/87

Location immediately NE of Ranch House.
Strike 50°, dip 5°S.
Traverse direction: 170°, dip 3°.
Wood Canyon Quadrangle map (7 1/2").

Unit No.	Thickness	
7		Covered, grassy meadow.
6	3.5'	11.5-15.0' Sandstone (150 microns, 175 microns at base, well sorted 95%+ quartz), 95% horizontal to subhorizontal laminations. 2% shaley current ripples with flow to SW (230°). No burrows. More quartzose than unit below. Top not exposed. BARRIER WASHOVER (75%).
5	7.0'	4.5-11.5'. Sandstone (150 to 175 microns), 75%+ quartz, moderate sorting. Beds 0.5-1.5' thick. Within beds fairly massive weathering. Apparently mostly subhorizontally laminated; may be some horizontal laminations. Troughs (planar-tangential) with abundant clay clasts, 50% in lower 3'. Flow directions 350°, 130°. At 11', 0.5' thick shale (lt. gy) with mm thick silt lenses. Total of 5 1/2-1" thick shale beds in unit. 5-10% burrowed. Vertical burrows common in sandstone below clay layers. No burrows above 11.8' Diplocraterion at 7.5' mark top of bed (on south side). MIDDLE SHOREFACE (80%).
4	1.5'	3-4.5'. Sandstone (175 microns) interbedded with silty shale 1-2" thick. 60% sandstone and siltstone, low-angle laminated, ripple-form tops. Beds 0.05-0.2' thick. 5% vertical sand filled burrows. Some Corophoides. Trace of bedding plane burrows. 40% siltstone, light gray. Some layers more clayey. 10% carbonaceous in some bedding planes, less than trace throughout. LOWER SHOREFACE 70%, TRANSITION FACIES (30%).
3	3'	0-3'. Sandstone (100-125 microns, except for 1.5-2.0' which is 350 microns with maximum "granules", 1500 microns in HCS). 80% HCS. Trace of shale drapes. 10% ripples, 12" amplitude; mostly in 1.5-2.0' interval. Top 2" rippled also. Sharp, wavy upper contact at top of HCS. LOWER SHOREFACE (90%).
2	5'	0-(-)5'. Sandstone (100 microns), silty and sandy shale. In upper 1' 15% shale interbeds as thick drapes over rippled sandstone beds. Sandstone beds 0.05-0.2' thick, 10% thin (1" thick) HCS. Sandstone in upper 1' rippled. 6%+ burrowed. 2% Terebellina. Trace of carbonaceous material. Bottom 1' sandy, above 1' increase in sandstone upwards in unit. Base of unit is lowest sandstone bed. TRANSITION FACIES (75%).
1	50'	(-)5 to (-)55'. Shale, dark gray, fissile. MARINE INNER-SHELF SHALE (95%); SKULL CREEK SHALE.
0		(-)55' and below, covered, grassy slope (Skull Creek Shale).

FIGURE 24. Measured Section 27, Newcastle (Muddy) sandstone
NW NW Sec 3 T55N R66W Crook County, Wyoming

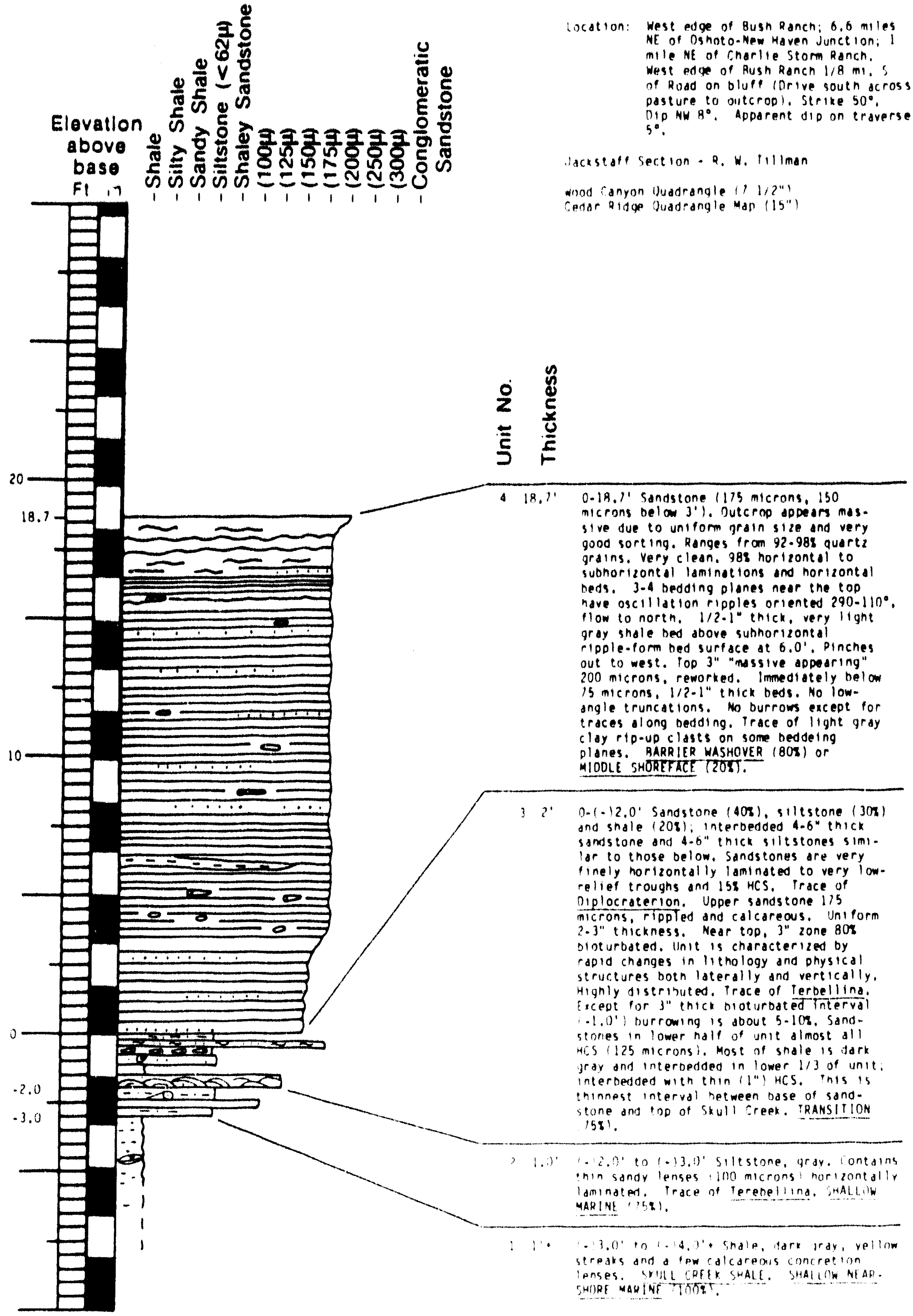


FIGURE 25. Measured Section JE(29) - 76(87), Newcastle (Muddy) sandstone NW 1/4 NW 1/4 Sec 17 T56N R66W Crook County, Wyoming

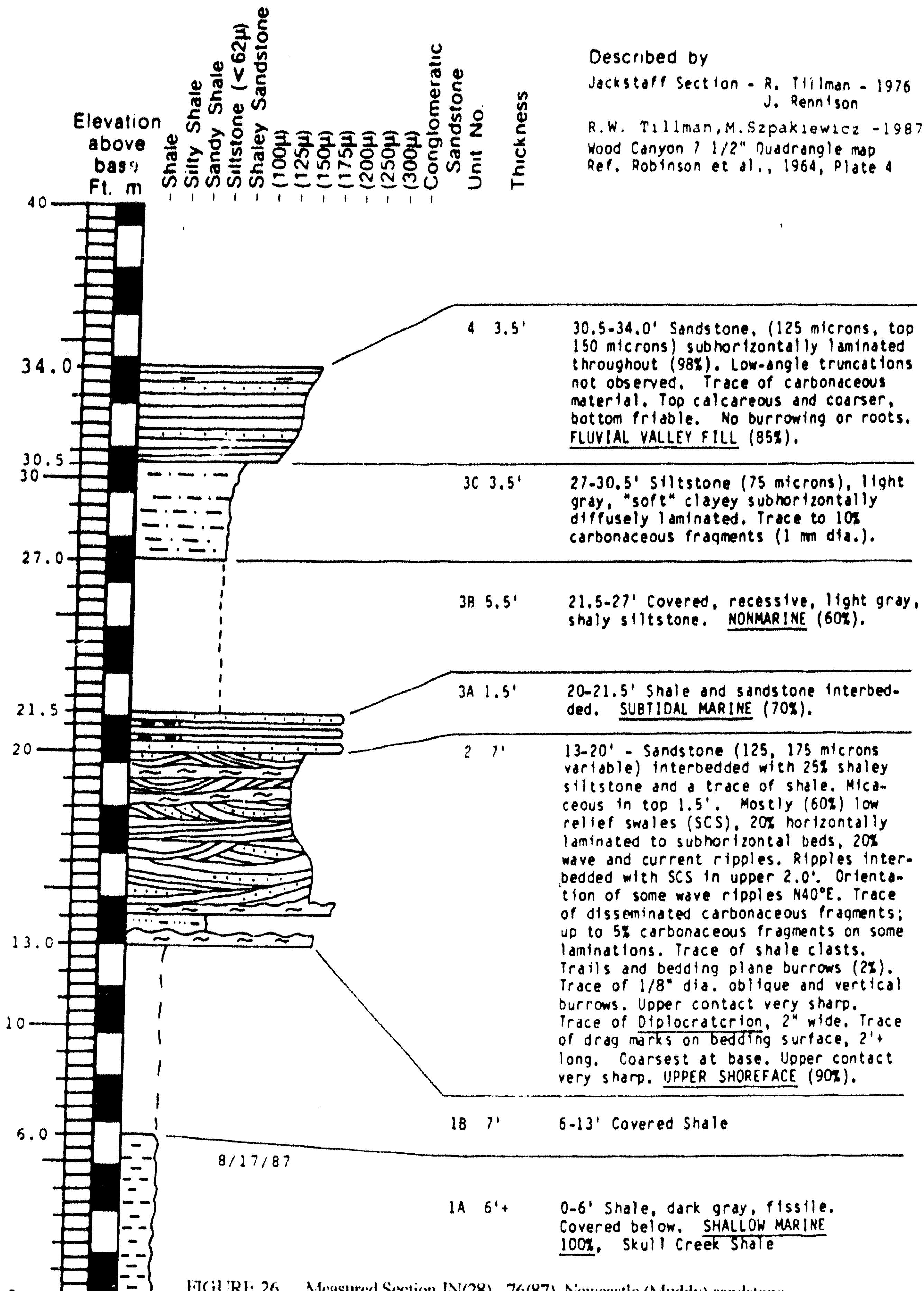
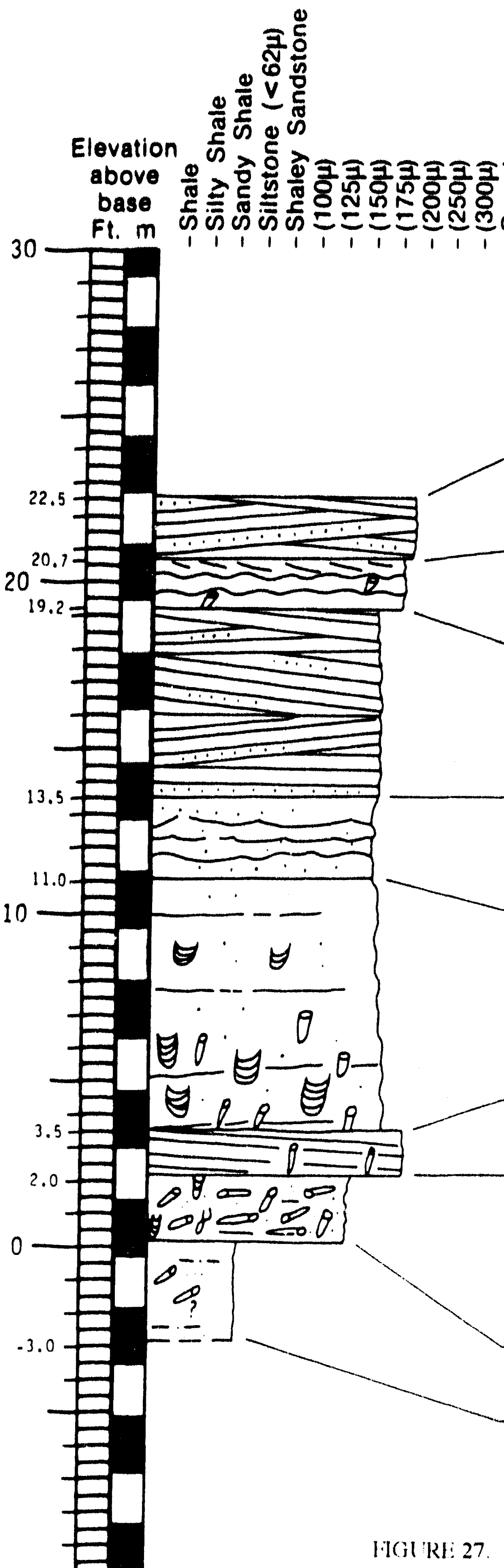


FIGURE 26. Measured Section JN(28) - 76(87), Newcastle (Muddy) sandstone
NE NE 1/4 Sec 24 T56N R67W Crook County, Wyoming
East of "Driveway" to Wilk Reisland (Charlie Sotrm) Ranch and S. of County Road

Described by: R. W. Tillman (1970,1986) and S. R. Jackson and M. Szpakiewicz (1986)
Location is 1/8 mile north of county road and one mile NW of M.S. 22. 30 yards north of south end on east side of outcrop are three USGS Bench Marks "New Haven No. 1, 1949" immediately at top of section.
Wood Canyon Quadrangle map (7 1/2")

Note: Units 3A, 3B of measured section 22A are missing here.



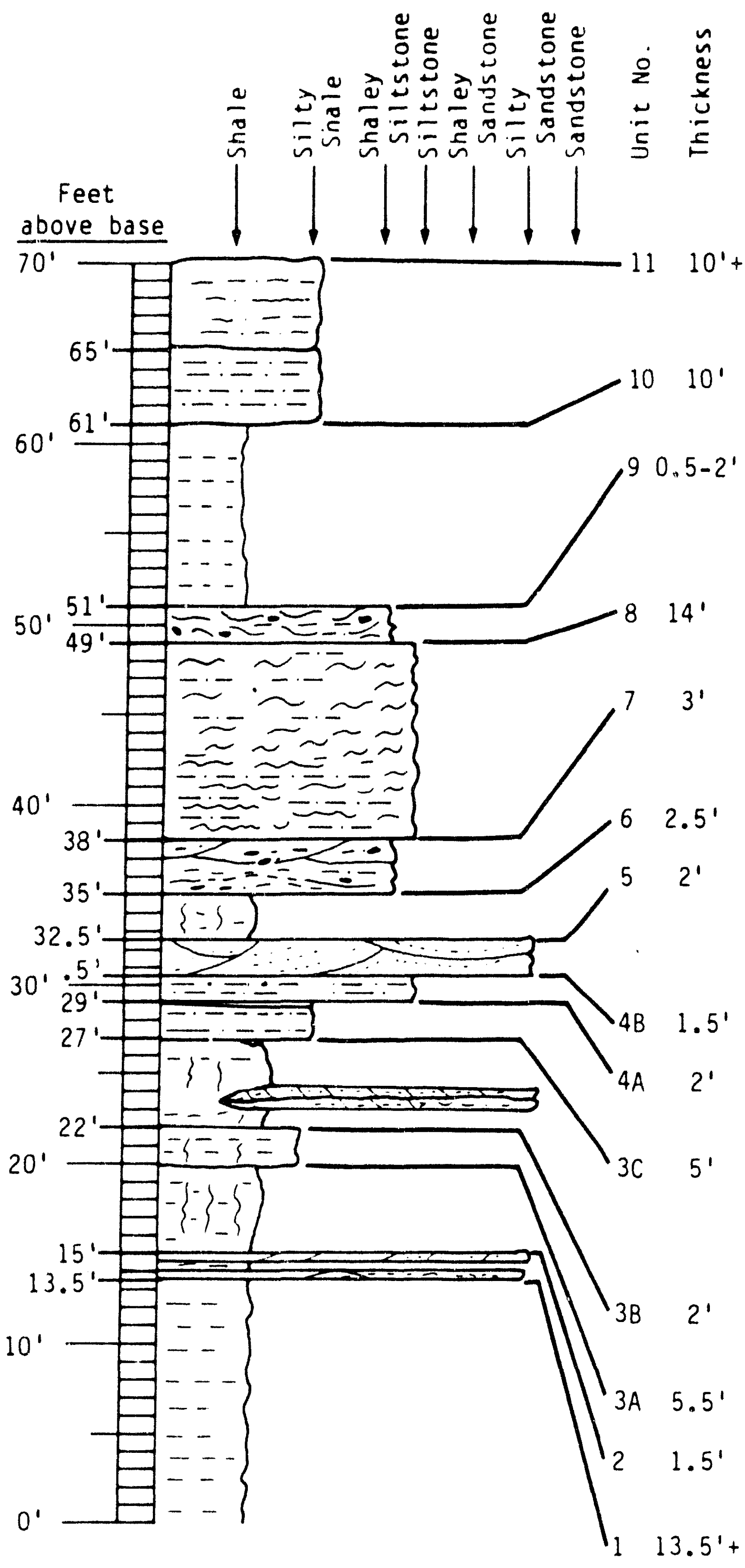
Unit No.	Thickness	
6C	1.8'	20.7-22.5' Sandstone (175 microns). 90% low-angle sheaves of cross-laminations. A few wave ripples; low amplitude (1/4"). Laminations can be traced 6-8' laterally (minimum). FORESHORE (95%).
6B	1.5'	19.2-20.7' Sandstone (175 microns). 90% ripples, some wave ripples, especially near middle. Trace of vertical burrows 2-3 mm in diameter. Unit may not persist laterally.
6A	5.7'	13.5-19.2' Sandstone (150 microns). Weathers white to very light gray. Low-angle laminations; sets truncated at low angles. Set thickness average 3/4-1". Maximum set thickness 1 1/2"; sets truncated so that maximum lateral extent of individual laminations is 3-6'. No burrowing. FORESHORE (95%).
5	2.5'	11-13.5' Sandstone (150 microns). "Wavy" beds 0.1-0.25' thick, nonburrowed to trace(?). Sharp lower contact (bedded in contrast to "massive appearance" of unit below). Upper contact gradational.
4	7.5'	3.5-11' Sandstone (150, 175 microns at top). Buff colored. Mostly massive appearing due to burrowing, clay(?) cement and sorting(?). Horizontal bedding surfaces truncate burrows locally. Obvious burrows 5% of unit; mostly Diplocraterion (without obvious vertical side tubes). Some small burrows 2-3 mm in diameter. Burrowing in upper half of unit 50% of that below. Diplocraterion spread uniformly throughout unit. UPPER SHOREFACE (90%).
3	1.5'	2-3.5' Sandstone (microns).
2	2'	0-2' Sandstone (125 microns), fine grained. Highly burrowed, (75%) bioturbated; burrows 3-4 mm in diameter. Unit somewhat "massive appearing" and bedding obliterated. Only 15% of burrows obvious. Abundant Thalassinoides; a trace of Diplocraterion. Grades laterally to burrowed "clean" sandstone including more Asterosoma burrows. LOWER SHOREFACE (90%).
1	3.0	0' to (-)3.0'. Siltstone, sandy (100 microns), clayey. Recessive "soft" weathering. OFFSHORE MARINE (80%).
0	10'+	(-)3 to (-)13'. Shale, dark gray, fissle, forms hillside below. SKULL CREEK SHALE, MARINE.

FIGURE 27. Measured Section NH(23) - 3(70), Newcastle (Muddy) sandstone SW NW SW Sec 2 T55N R67W Crook County, Wyoming

Location:
1/2 mile east of Bush Ranch,
Hillside N. of County Road
7.2 mi NE of Measured Section 29

Jackstaff Section; measured and described by: R. W. Tillman

Wood Canyon Quadrangle (7 1/2")
Seeley Quadrangle Map (15")



61-70'+ Shale, light silvery gray. Horizontally laminated on paper thin scale. Abundant fish scales. MOWRY SHALE FORMATION; MARINE 100%.

51-61' - Shale, dark gray, fissile claystone SHELL CREEK SHALE FORMATION, SHALLOW MARINE (95%)

49-51' - Shaley Siltstone, brown, highly carbonaceous (35%), abundant 1/4" wide fragments. TOP NEWCASTLE SANDSTONE, BRACKISH-CONTINENTAL (SWAMP) (75%)

35-49' - Siltstone, light gray, low amplitude ripple bedded, uniform throughout. SPLAY (50%).

35-38' - Shaley siltstone, brown, highly carbonaceous (25%). Abundant wood fragments. CONTINENTAL (60%).

32.5-35' Bentonite, light gray-green.

30.5-32.5' - Sandstone (125 microns). Predominently sub-horizontal laminations (40%) and low (2") relief troughs (30%). Some wave ripples. Trace of burrowing. TRANSGRESSIVE BEACH (80%).

29-30.5' - Siltstone gray (?)

27-29' - Silty shale, medium gray, fissile SHALLOW MARINE (60%).

22-27' - Bentonite, light gray. Laterally 1.0" thick sandstone (100 microns) splits the unit. Weathers black (Mn?). Calcareous resistant. Bedding surface subhorizontal to wavy.

20-22' - Claystone, carbonaceous, gray. CONTINENTAL (80%).

15-20' - Claystone, very light gray, bentonite.

13.5-15' - Interbedded 2" thick sandstone and shale. Current ripples SHALLOW MARINE 90%

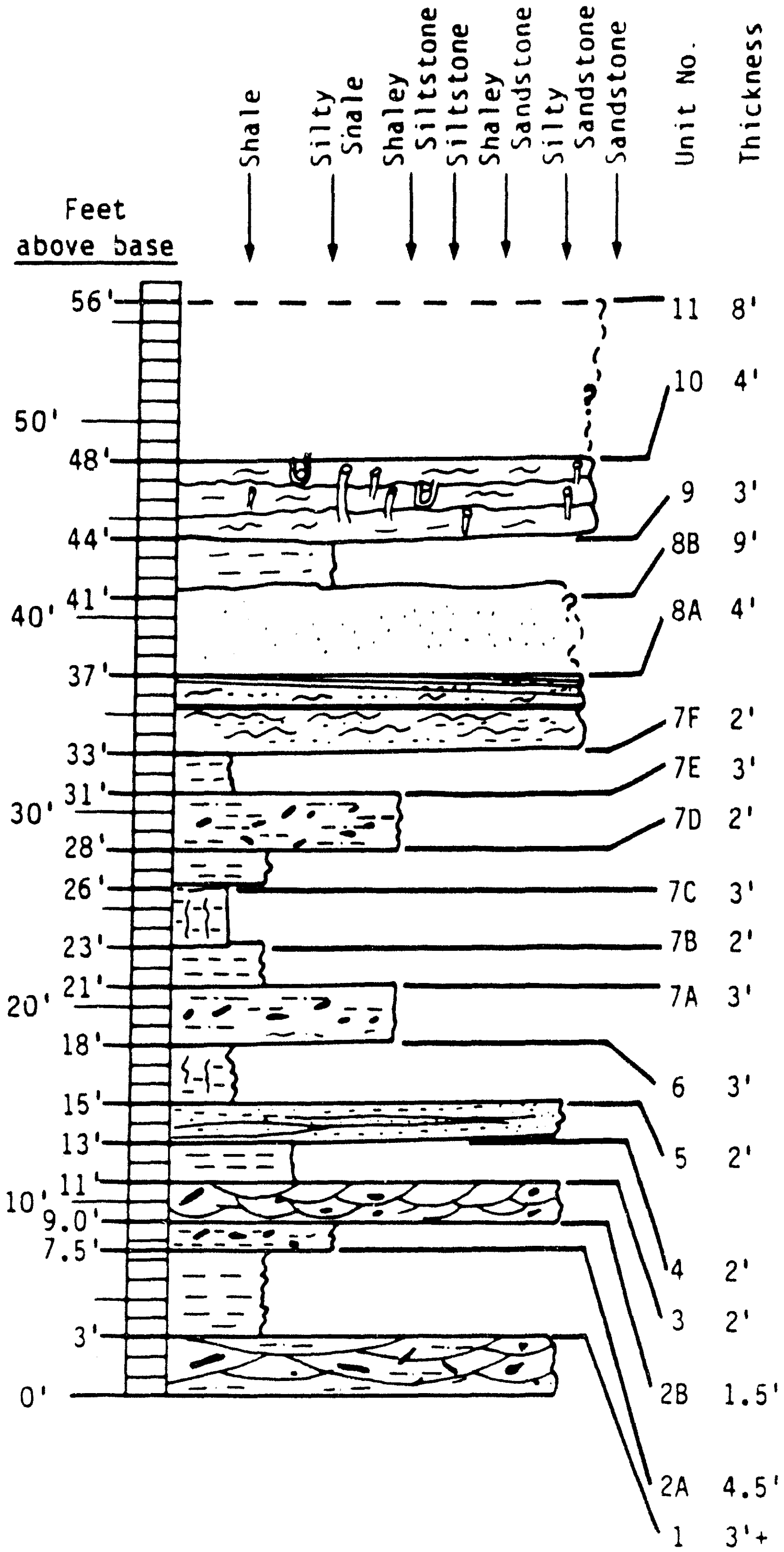
0-13.5' - Shale, dark gray, fissile. SKULL CREEK SHALE. SHALLOW MARINE (100%).

FIGURE 28. Measured Section KS(31)-76, Newcastle (Muddy) sandstone
NW 1/4 Sec 2 T56N R66W Crook County, Wyoming

Location:
Just north of Little Missouri River. Roadside stop on road to Alzada West of Government Canyon Intersection. 5.5 miles NE of Measured Section 31.

Measured and described by:
R. W. Tillman - 1976

Seeley Quadrangle Map



48-56' - Covered, friable sandstone; probably Newcastle (Muddy).

44-48' - Sandstone (100 microns) white, very fine grained, thin rippled beds. 15% Skolithos, trace of U-shaped Corophoides. TIDAL FLAT SANDSTONE (90%).

41-44' - Shale, gray, recessive.

32-41' - Covered, weathers back. Probably very friable sandstone.

33-37' - Sandstone (125 microns) white lower portion rippled and crossbedded. Upper part subhorizontal parting laminations oriented at 357°. TIDAL FLAT SANDSTONE & BEACH (TOP) (90%).

31-33' - Shale (same as units 7B, 7D).

28-31' - Shaley siltstone (same as Unit 7A).

26-28' - Shale (same as Unit 7B). BRACKISH CONTINENTAL (80%).

23-26' - Claystone, bentonite.

21-23' - Shale, gray, not highly bentonitic.

18-21' - Shaley siltstone, brownish-black, abundant very conspicuous fragments. BRACKISH-CONTINENTAL (90%)

15-18' - Shale, light gray, partly grass covered. (Section measurement translates to north).

13-15' - Sandstone (125 microns) blocky, top 3" highly rooted, roots 1/4" diameter. TIDAL FLAT (60%), DISTRIBUTARY CHANNEL (40%)

11-13' - Shale gray. SHALLOW MARINE (75%)

9-11' - Sandstone (125 microns) (same as Unit 1). DISTRIBUTARY SPLAY CHANNEL (95%)

7.5-9' - Silty shale, brownish-black, 25%+ carbonaceous fragments up to 1" long. CONTINENTAL SHALE (85%)

3-7.5' - Shale gray, slightly silty.

0-3' - Sandstone (100 microns) dark gray to brownish, massive. Suggestion of troughs. Abundant wood fragments in various orientations. (Exposed in "bar-ditch"). DISTRIBUTARY SPLAY CHANNEL (95%)

FIGURE 29. Measured Section ME(34)-76, Newcastle (Muddy) sandstone SW NW Sec 14 T57N R65W Crook County, Wyoming

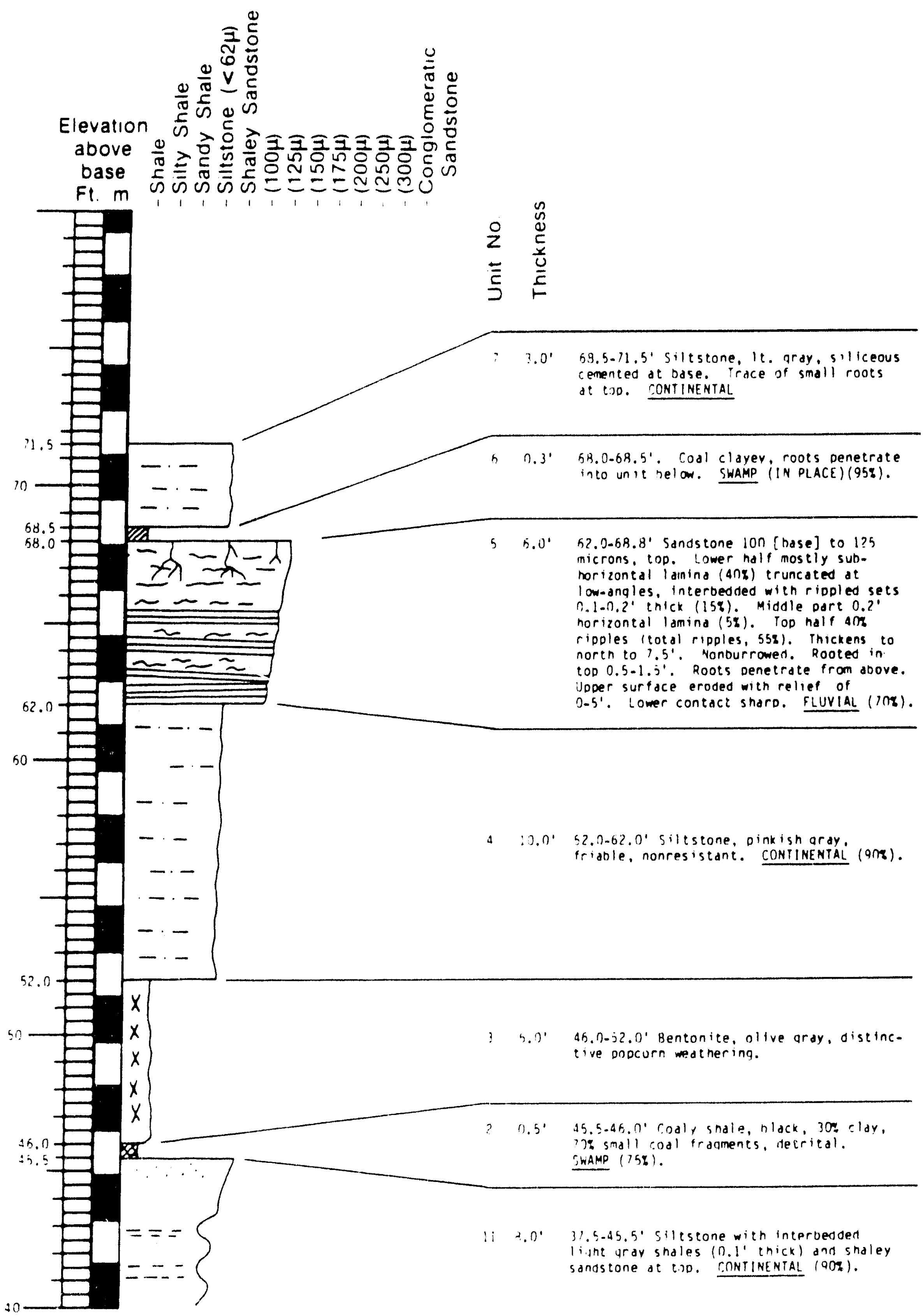


FIGURE 30. Measured Section GM-8- 87 (38-67), Muddy sandstone
C W 1/2 Sec 30 T57N R63W Crook County, Wyoming

III. PERMEABILITY AND POROSITY DATA

Outcrop Sampling Method

The sampling pattern was designed to allow analyses of lateral variability of reservoir parameters on scales of 1, 10's, 100's and 1,000's of feet over distances comparable to interwell distances on 40-acre spacing. In outcrops 22a and 22, 23 and 3-86 vertical profiles were drilled on a 1-ft vertical spacing. The vertical profiles were spaced between 20 and 500 ft apart (figs. 31, 32 and 33). Samples were taken horizontally on a 0.5-ft spacing along a few horizons to allow documentation of lateral variability on 1- and 10-ft scales. One-inch diameter cores 3 to 6 in. long were drilled with a portable, air-cooled drill. Cores were drilled generally parallel to bedding.

Standard techniques for measurements of air permeability and porosity were used. One-inch-long cores were cut from the end of each core sample farthest from the outcrop face to reduce the influence of weathering. These cores were dried overnight at 60°C. Permeability to air was calculated from the average of three flow rates (low, medium, and high) read from two electronic mass flowmeters (0 to 10 and 0 to 200 cm^3/min) for Klinkenberg corrections. Pressures were read from manometers--a water-column manometer for low pressures and a mercury-column manometer for high pressures. The apparatus was calibrated with metal calibration plugs, and the calculated error for permeability values was less than ±5%.

Porosity was determined by using Boyle's law porosimeter. To minimize error derived from the noncylindrical shape of some cores, lengths of 2 orthogonal diameters at each end were measured and used in computing the bulk volume of the sample.

Relationship Between Sedimentologic Units and Permeability

Permeability Contrasts Among Facies

Facies, which are sedimentologically defined units, were found to provide a good approximation of rock units with similar permeability characteristics, although in some cases different facies could be combined to form one permeability unit.

For permeability data from the Muddy Formation, Kolmogorov-Smirnoff (K-S) two-sample tests (Davis, 1973) were conducted to determine whether the permeability distributions from one facies were significantly different from those of another facies. The K-S test is a nonparametric test (it does not assume a normal frequency distribution) that calculates the maximum distance between cumulative distribution functions of the two samples. If this distance is large enough, the hypothesis that the distributions are the same is rejected. The K-S test is not very powerful; however, it may indicate which facies can be grouped for permeability layers.

Results of the K-S test suggest at least three distinct permeability groups or distributions in the Muddy Formation: one group includes higher energy deposits of the middle shoreface, upper shoreface, foreshore, and washover facies; a second group includes lower energy deposits of lower shoreface and backshore; and the third group includes the lowest energy lagoon deposit.

Figure 34 presents box-and-whiskers plots of permeabilities from facies in 19 described wells in Unit 'A' of Bell Creek field. In this plot, the box covers the middle 50% of the permeability values, between the lower and upper quartiles. The "whiskers" extend to the extremes (minimum and maximum values), whereas the vertical line within the box is at the median permeability value for that sample. A few values greater than 1.5 times the interquartile range (outliers) are not shown in the diagram.

The vertical arrangement of the facies in figures 31, 32 and 33 is typical for progradational cycles in barrier island deposits. The sequence shown in figures 31, 32 and 33 is a composite; complete sequences rarely occur in one well. The permeability values reflect the energy of the depositing currents, where middle shoreface, upper shoreface, foreshore, and washover facies are high-energy deposits; lower shoreface and backshore are lower energy deposits; and lagoon facies, the relatively lowest energy deposits. Figure 35 shows the vertical profiles of permeability in the outcrop exposures of the Muddy Formation.

A generalized, simplistic permeability layer model for progradational barrier island deposits was developed from previously described statistical analysis of permeabilities from Bell Creek (fig. 36). Alluvial valley fill facies and channel deposits are not included here because of the lack of permeability data; however, these facies are an important component of the depositional system and strongly affect the reservoir architecture in the Bell Creek reservoir. This simplistic model is based on data from the progradation units from Muddy sandstone. To obtain a more detailed model, other components such as permeability characteristics of transgressive depositional units, lateral facies changes, diagenetic features, fractures, and faulting must be incorporated.

Comparison of Sedimentological Features

Outcrop exposures of the Muddy Formation documented for this study are sedimentologically similar to the Muddy Formation in Unit 'A' of Bell Creek field which is located 40 miles away and produces oil at a depth of 4,500 ft. The similarities include (1) similar barrier and nonbarrier facies characteristics, (2) similar vertical sequence of facies which include components of both a progradational and a transgressive sequence, (3) similar postbarrier depositional history which consisted of valley incisions into the barrier sands and subsequent deposition of sediments into the valleys.

Facies are distinguished on the basis of grain size, lithology, and sedimentary and biogenic structures. The same criteria used to distinguish facies of the Muddy Formation in the subsurface were applicable to the outcrop exposures, suggesting operation of similar depositional processes (table 1). Similar facies characteristics were also found for valley fill facies (table 2).

Frequency distributions of grain sizes calculated by image analysis indicate similar distributions for subsurface upper shoreface facies and outcrop middle shoreface facies (fig. 53, see section on Petrographic data). Petrographic analyses of thin sections indicate that the framework mineralogies of barrier island sandstones and valley fill sandstones are similar for outcrop and subsurface samples (fig. 41, see section on Petrographic data). These similarities suggest similar depositional conditions for outcrop and reservoir rocks. The similarity in grain size distributions for the subsurface uppershore facies and outcrop middle shoreface facies supports the permeability groupings previously discussed.

Vertical sequences of facies typical for the Muddy Formation, both in outcrop exposures and subsurface cores studied, indicate a progradational sequence resulting in deposition of the lower shoreface overlain by middle and upper shoreface, followed by lower and upper foreshore, and often capped by an unconformity overlain by a valley fill or channel fill facies. Eolian deposits which typically overlay the foreshore and beach facies in modern environments are rarely preserved in examined outcrops and Muddy cores. Transgressive cycles within the Muddy deposition are indicated in outcrop measured section 22 profile 625 and well C-1 where backbarrier lagoon deposits are overlain by lower and upper shoreface facies.

Stacked barrier sequences and single-cycle sequences occur in both the outcrop area studied and in Unit 'A' of Bell Creek, (figs. 6 and 7, see section on Paleogeography). Although the outcrop data come primarily from an area of a single-cycle barrier and the subsurface data primarily from a stacked sequence, the thickness of individual facies is similar as are permeability and porosity characteristics.

Valley fill and channel fill deposits were present in both outcrop and subsurface areas studied. This was expected because the formation of valleys in coastal settings is a regional phenomenon.

Few significant sedimentological differences were noted between outcrop exposures and subsurface cores studied. The differences noted were primarily due to diagenetic processes.

Core analysis results for Muddy Formation outcrops are presented in table 3.

Comparison of Diagenetic Features

Scatter plots of permeability versus visual estimates of total clay (detritial plus diagenetic clay) showed a similar trend of decreasing permeability with increasing total clay content. Large decreases in permeability were associated with small increases of total clay.

Paragenetic sequences for outcrop and subsurface Muddy barrier island facies were found to be similar. Minor differences were found, based on thin section work, such as increased hematite cement and more evidence of late-stage leaching in outcrop samples. Diagenetic differences on a macroscopic scale included laterally extensive calcite cement in the outcrop foreshore facies, which was not found in the subsurface. This cementation was attributed to subaerial exposure of outcrop rocks as the foreshore facies caps the sandstone sequence.

The presence of cement affects the frequency distribution of permeability in both outcrop and subsurface samples. Histograms of permeability from the subsurface foreshore and upper shoreface facies of the Muddy formation indicate two distinct permeability distributions: a relatively sharp-peaked population occurring from 0 to 1,000 md and a broader population from 1,000 to 4,800 md (fig. 37). The samples which comprise the higher permeability are from wells that contain less than 1% clay cement, whereas those samples in the lower permeability population are from wells that contain 1 to 10% clay cement.

Frequency histograms of permeability from the outcrop middle shoreface facies (fig. 38) indicate a permeability distribution similar to that of subsurface samples from the foreshore and upper shoreface facies, in that they contain two permeability populations within ranges similar to subsurface samples (0 to 1,000 md, 1,000 to 4,000 md). Visual examination of outcrop samples from the lower permeability population indicates that calcite cementation and high amounts of matrix are prevalent, which is similar to that of subsurface lower permeability samples. The presence of two distinct permeability populations within one facies suggests that diagenetic features, when present, mask the primary depositional permeability fabric and underscores the importance of understanding and accounting for the diagenetic processes before predictive permeability models can be developed for Bell Creek field.

Comparison of Permeability Statistics

A comparison of outcrop and reservoir permeability vs. porosity scatter plots indicates a generally close agreement between data from the same facies in outcrop and subsurface, with the subsurface samples exhibiting slightly lower porosities. Table 4 presents the slope and intercept of the regression line calculated for the data.

Permeability distributions from the outcrop middle shoreface and lower shoreface facies are compared with the subsurface foreshore and lower shoreface facies, respectively, in figure 8. Both cumulative frequency distributions (figs. 39a and 39b) and frequency histograms (figs. 39c and 39f) are presented. The Kolmogorov-Smirnoff two-sample test indicated no difference between the two sets of facies.

The comparison of the outcrop middle shoreface to the subsurface foreshore facies is justified in that the subsurface middle shoreface, upper shoreface, and foreshore appear to have similar permeability distributions. The similarity in permeability statistics in outcrop and subsurface facies encourages the necessary further comparison of additional outcrop and subsurface facies to establish the utility of outcrop petrophysical data to analogous reservoirs.

The distances over which mean permeabilities can be correlated were also compared. Samples were taken from three outcrops spaced about 3,550 ft (0.67 mile) apart in a north-south direction (or parallel to depositional strike). Visual inspection of permeability versus height plots indicates a generally similar pattern which is continuous over 1.3 miles (6,850 ft) (fig. 3). Mean permeability values calculated for all samples within the middle shoreface facies varied by 25% from outcrop 22 to outcrop 23 and by 3% from outcrop 23 to outcrop 3-86.

Figure 40 demonstrates the similar frequency pattern for outcrop and subsurface examples of a middle shoreface facies.

Conclusions

1. Sedimentological units and permeability. Sedimentologically defined units provide a good approximation of rock units with similar permeability characteristics. This was found in the study of outcrop and reservoir rocks of the Muddy Formation. In some cases, however, different facies did not have statistically different permeability frequency distributions and could be grouped together in one permeability unit.

2. Stratification types and permeability. Stratification types and sedimentary structures are related to permeability classes in both outcrop and subsurface rocks. Similar relationships have also been reported for a barrier island deposit, an aeolian (dune) deposit, and a fluvial deposit.

3. Vertical sequence of facies and permeability profiles. Comparison of geologically described cores and outcrops indicates that similar vertical sequences of facies of comparable thickness are present in the subsurface and at sampled outcrops in the Muddy Formation.

Permeability trends for the vertical sequence are frequently similar for comparable vertical successions of facies in outcrop and subsurface, with permeability decreasing through generally the same sequence of facies and stratification types and decreasing permeability corresponds to decreasing depositional energy.

4. Permeability versus total clay content. Scatter plots of permeability versus total clay content show similar trends for outcrop and subsurface data sets and indicate a drastic decrease in permeability with small increases of total clay.

5. Permeability/porosity relationships. Scatter plots of reservoir and outcrop permeability/porosity data indicate parallel trends for the same facies, with the outcrop samples having about 4% greater porosity.

6. Permeability frequency histograms for similar facies. Statistical analysis and comparison of permeability populations of outcrop and subsurface facies indicate similar frequency distributions for depositionally analogous facies. Similarities were found for the Muddy Formation outcrop middle shoreface and the subsurface foreshore and the outcrop lower shoreface and the subsurface lower shoreface facies.

7. Scale of permeability changes. Subsurface maps and continuous outcrop data both indicate that the average permeability of facies and the permeability profile of the entire barrier section remain constant over considerable distances along a depositional strike. Changes in average permeability occur on a scale of miles in both outcrop and subsurface rocks.

Appendix C presents the permeability and porosity data measured from 1-inch diameter cores drilled from Muddy Formation outcrops in Crook County, Wyoming. Table 3 lists results from research done in 1986 and 1987, but not previously published.

TABLE 2
Sedimentologic division of typical valley fill sandstones associated with barrier island deposits, Muddy Formation (Honarpour et al., 1989)

(Dominant features identified in Bell Creek cores and New Haven outcrops)

	<u>Continental</u>
FLUVIAL CHANNEL FILL (High Energy)	Sandstone (100-200μ), alluvial deposit. Fair to moderately well sorted. Abundant troughts, horizontally or subhorizontally laminated in thin sets; massive appearing where thoroughly rooted, sometimes recognizably rooted or burrowed; 5-10% current ripples associated with shale. Carbonaceous (5%) Trace of shale as rip-up clasts or drapes on ripples. Lower boundaries erosional and abrupt.
	<u>Brackish Marine</u>
SANDY ESTUARY OPEN LAGOON	Sandstone (75-125μ) interlaminated with silt (30%) and shale (30%). Carbonaceous (15%) Very poorly sorted. Massive appearing or horizontally to subhorizontally very finely laminated; subordinate wavey bedding; low amplitude current ripples; common soft sediment deformation. Burrowed (5-50%); locally thoroughly bioturbated or rooted.
TIDAL CHANNEL AND DELTA	Sandstone (150-175μ), current deposit. Poorly sorted Cross-bedded or low-relief planar tabular laminations. Rare burrows (<u>Skolithos</u>).

TABLE 3
Core analysis results Muddy sandstone outcrops Western Black Hills, Wyoming

Outcrop location and feet above base	Permeability, mD	Porosity, %	Bulk density	Grain density
Measured Section OS-8A-76				
35'	500	22.12	2.07	2.66
24'	72	16.37	2.21	2.65
20.0'	–	21.75	2.07	2.65
9'	–	14.65	2.28	2.67
1.5'	147	17.79	2.16	2.63
Measured Section OS-8C-76				
20.5'	–	21.36	2.08	2.64
16.0'	300	22.16	2.06	2.65
5.0'	106	21.30	2.08	2.65
0.5'	–	20.06	2.11	2.64
Measured Section W9 (Newcastle Type Section)				
71.5'	640	24.37	2.02	2.67
68.5'	860	17.55	2.15	2.61
3.5'	–	18.63	2.14	2.63
Measured Section OSG-11S-76(S1)				
41.5'	300	24.30	2.00	2.64
23.5'	.05	16.37	2.24	2.68
21.0'	1.11	18.67	2.13	2.62
3.0'	.46	13.29	2.28	2.63
-3.5'	.14	13.36	2.29	2.65
-9.0'	.13	14.64	2.25	2.63
-19.5'	1.54	18.52	2.15	2.64
-31.5'	.13	6.27	2.49	2.66
Measured Section UPT-12A (Tidal Flat Sandstone)				
33'	27	17.70	2.18	2.65
29'	126	24.85	1.99	2.65
26'	10.1	25.19	1.99	2.66
23'	39.8	25.18	1.99	2.66
Measured Section UPT-12B				
9.5'	126	24.22	2.01	2.65
-5.5'	29.9	32.45	1.78	2.64
Measured Section NH-22 (Foreshore-Shoreface)				
55.5'	–	32.32	1.80	2.66
Measured Section NH-22A (Foreshore-Shoreface)				
29'	–	7.16	2.50	2.69
22.5'	–	9.21	2.44	2.69
18.5'	3340	32.31	1.79	2.65
11.3'	1620	32.29	1.79	2.65
9.3'	270	28.78	1.89	2.65
7.5'	.01	3.91	2.60	2.71
6.8'	.17	14.45	2.50	2.92

TABLE 3 (continued)
Core analysis results Muddy sandstone outcrops Western Black Hills, Wyoming

Outcrop location and feet above base	Permeability, mD	Porosity, %	Bulk density	Grain density
Measured Section NH-23 (Foreshore-Shoreface)				
17'	39	18.76	2.17	2.67
1.5'	.28	10.81	2.41	2.70
-7.5'	240	32.59	1.79	2.66
Measured Section JN-28 (Foreshore Sandstone)				
33.5'	.55	6.74	2.50	2.68
19'	1460	30.15	1.85	2.65
17'	2400	30.36	1.84	2.65
Measured Section JN-29 (Foreshore Sandstone)				
17'	–	32.64	1.79	2.65
5.0'	–	33.22	1.77	2.65
2.7'	2.6	21.70	2.09	2.66

TABLE 4
Comparison of slope and intercept of natural logarithm permeability versus porosity plots in outcrop and subsurface facies (Honarpour et al., 1989)

Facies	Outcrop		Subsurface	
	Slope	Intercept	Slope	Intercept
Foreshore	0.299	-2.97	0.18	-2.2
Upper shoreface	0.370	-5.00	0.41	-4.5
Middle shoreface	0.280	-2.00	0.25	-0.9
Lower shoreface	0.320	-4.20	0.22	0.4

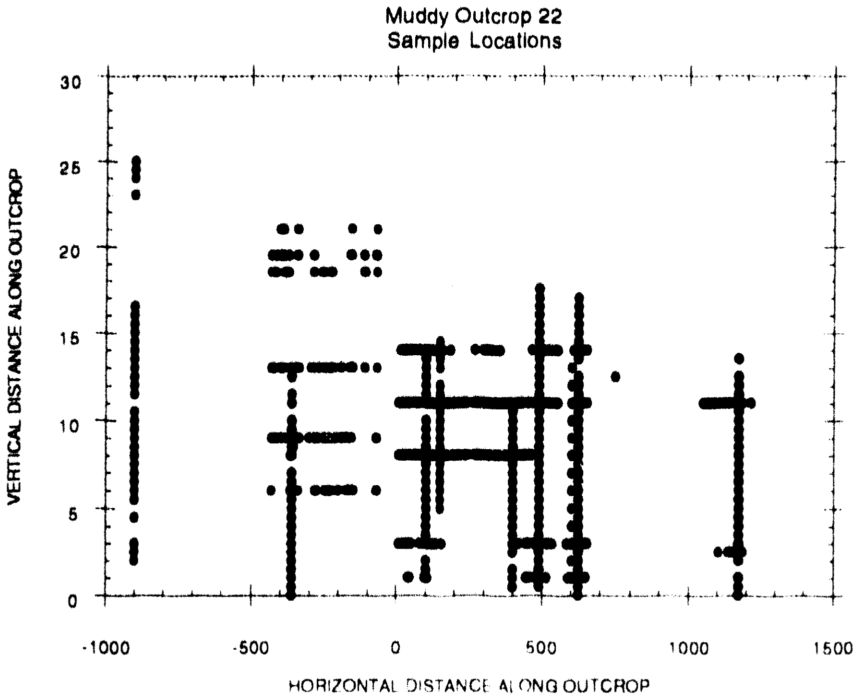


FIGURE 31. Outcrop 22 sample locations, values in feet.

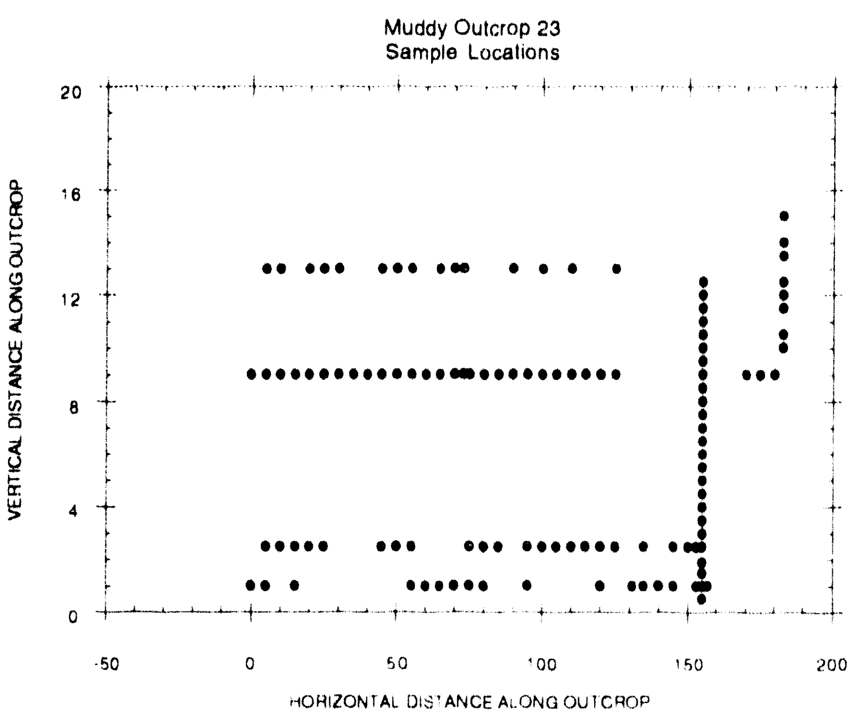


FIGURE 32. Outcrop 23 sample locations, values in feet.

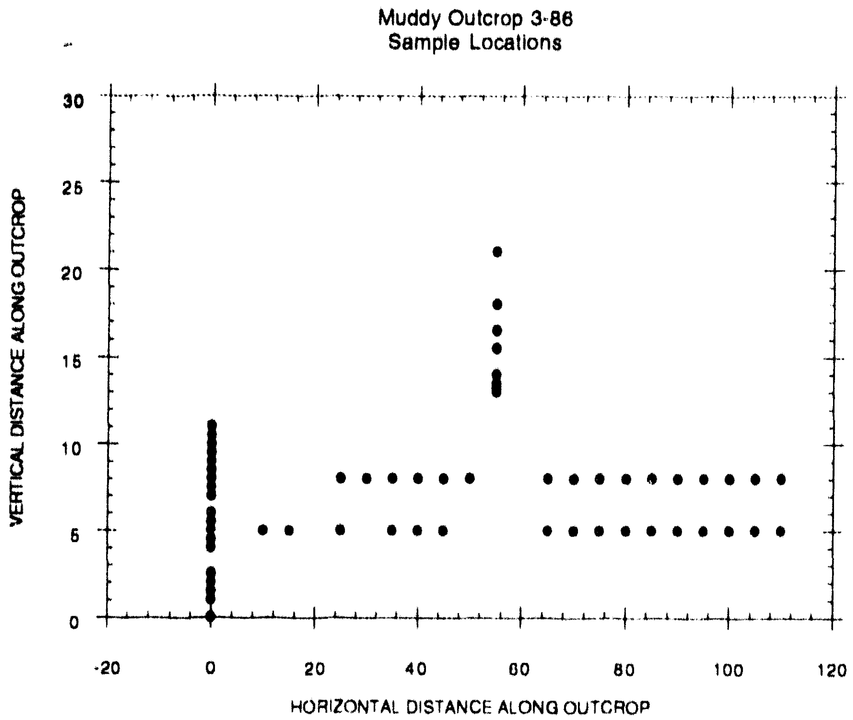


FIGURE 33. Outcrop 3-86 sample locations, values in feet.

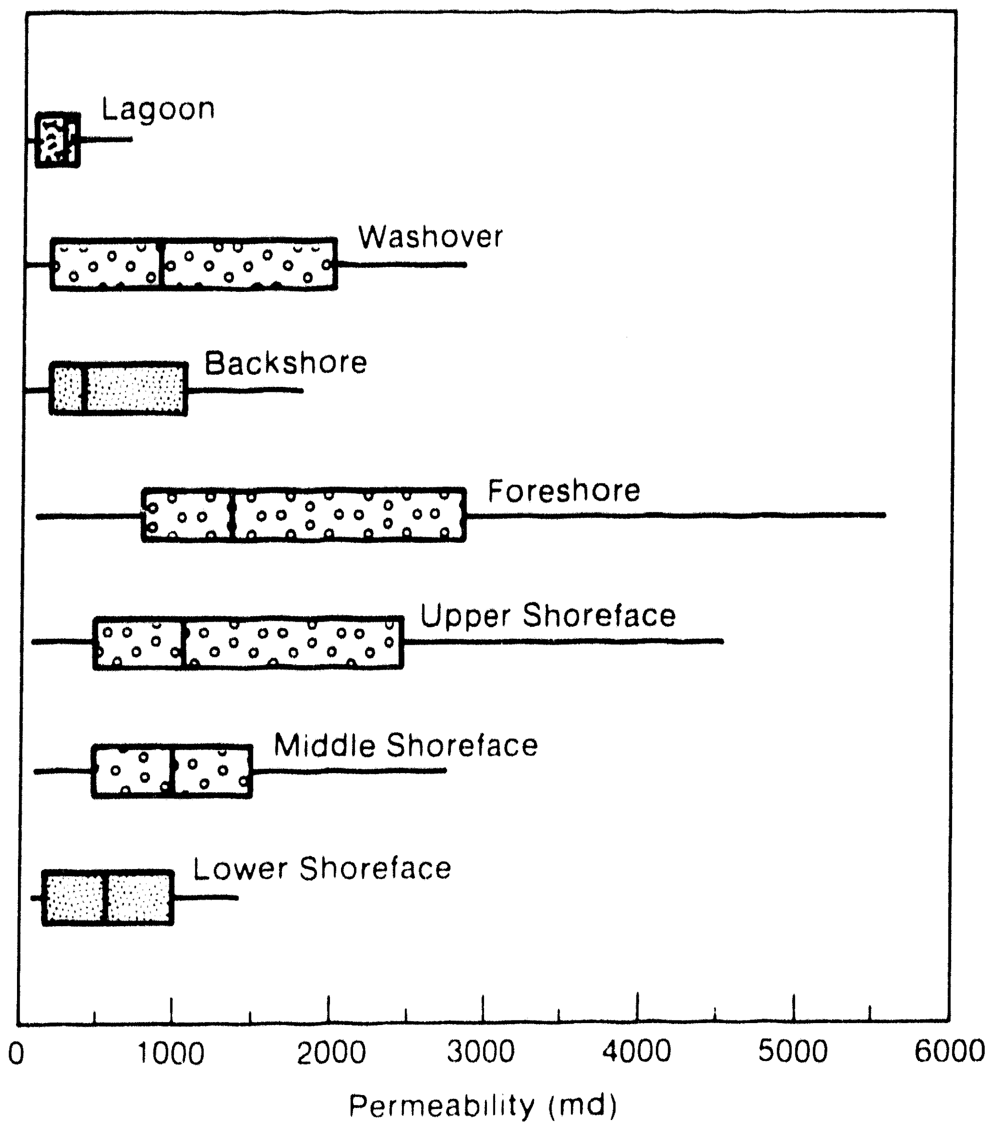


FIGURE 34. Box-and-whiskers plot of facies permeability values in Unit 'A' of Bell Creek field. The box covers the middle 50% of the permeability values, while the "whiskers" extend to 1.5 times the box (or interquartile range). The few values which are greater than this are considered outliers and are excluded from the diagram (Jackson, et al, 1991).

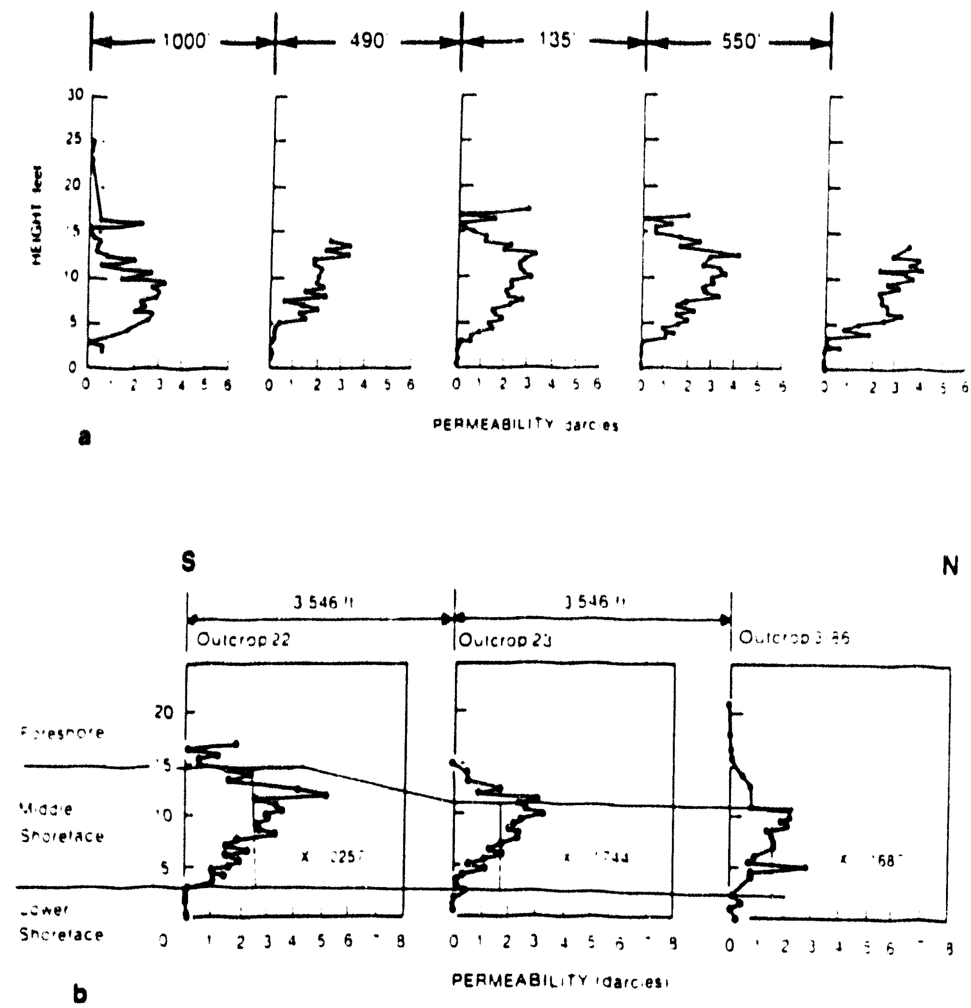


FIGURE 35. Vertical profiles of permeability across a 2,000 ft. face of an outcrop exposure of the Muddy Formation, WY (a) and from 3 outcrops over a distance of 1.3 miles (k). Note the similar profiles and average values over distances of 2,000 ft and those greater than a mile (Jackson et al., 1991).

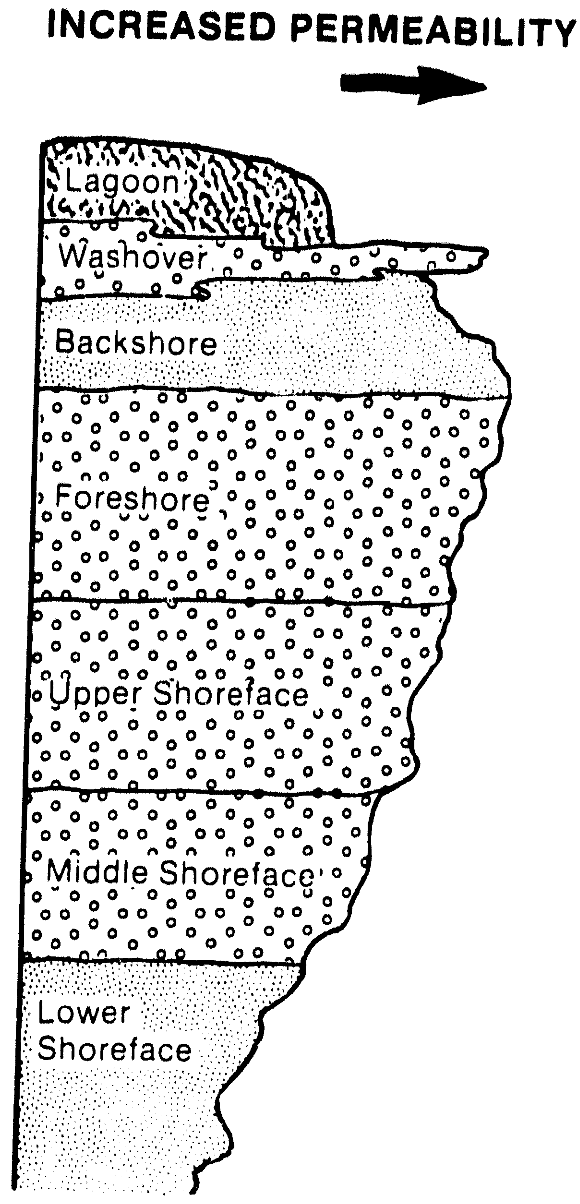


FIGURE 36. Generalized permeability layer model for a progradational barrier island deposit based on permeability data from Unit 'A' of Bell Creek field (Honarpour et al., 1989).

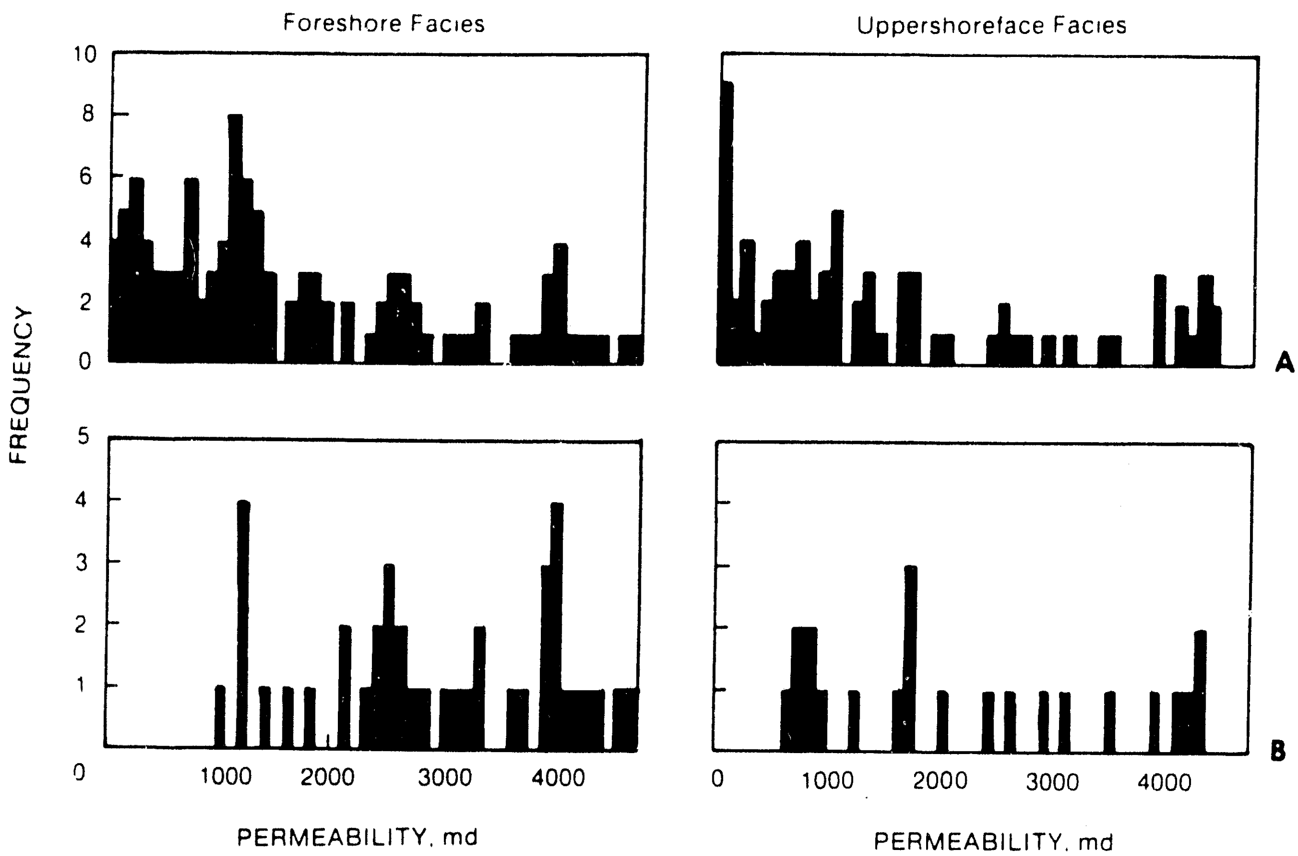


FIGURE 37. Frequency histograms of permeability in foreshore and upper foreshore facies in (a) all described wells from Bell Creek TIP pilot area and (b) wells which contain less than 1% cement and 3% matrix as determined by petrog . phic analysis (Honarpour et al., 1989).

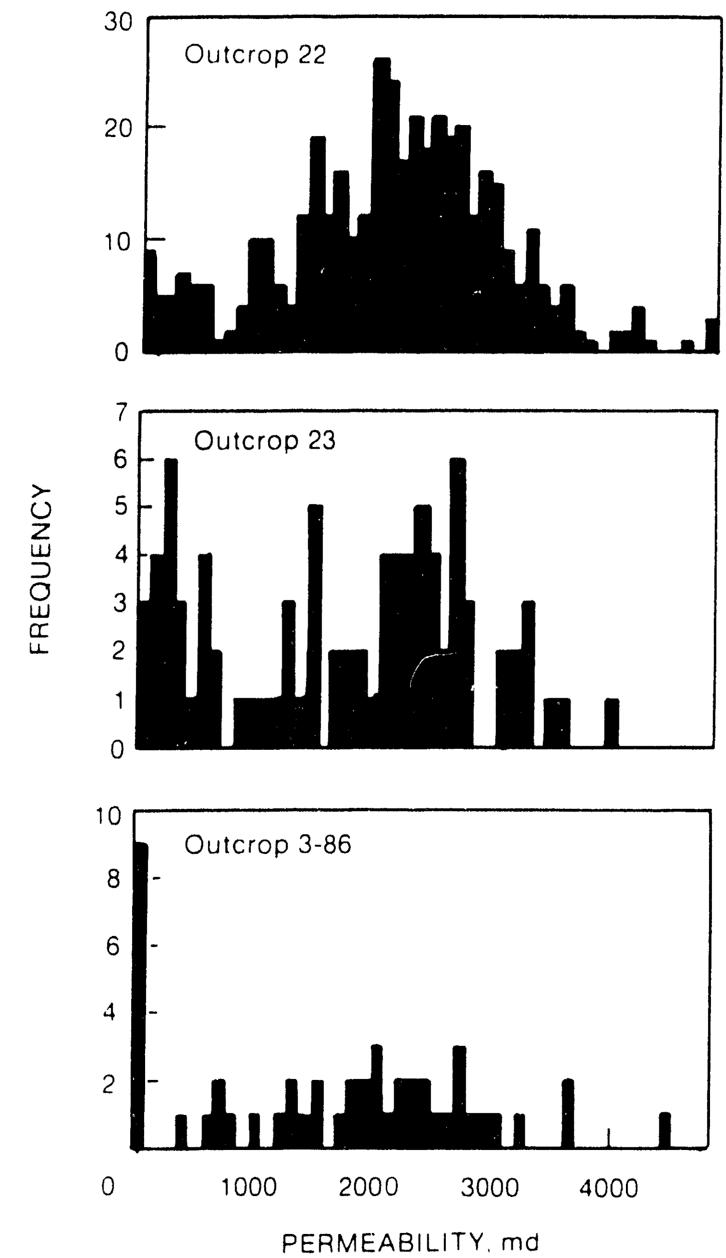


FIGURE 38. Frequency histograms of permeability from the middle shoreface facies in the three outcrops samples. Distance between each pair of outcrops is approximately 0.7 miles (Honarpour et al., 1989).

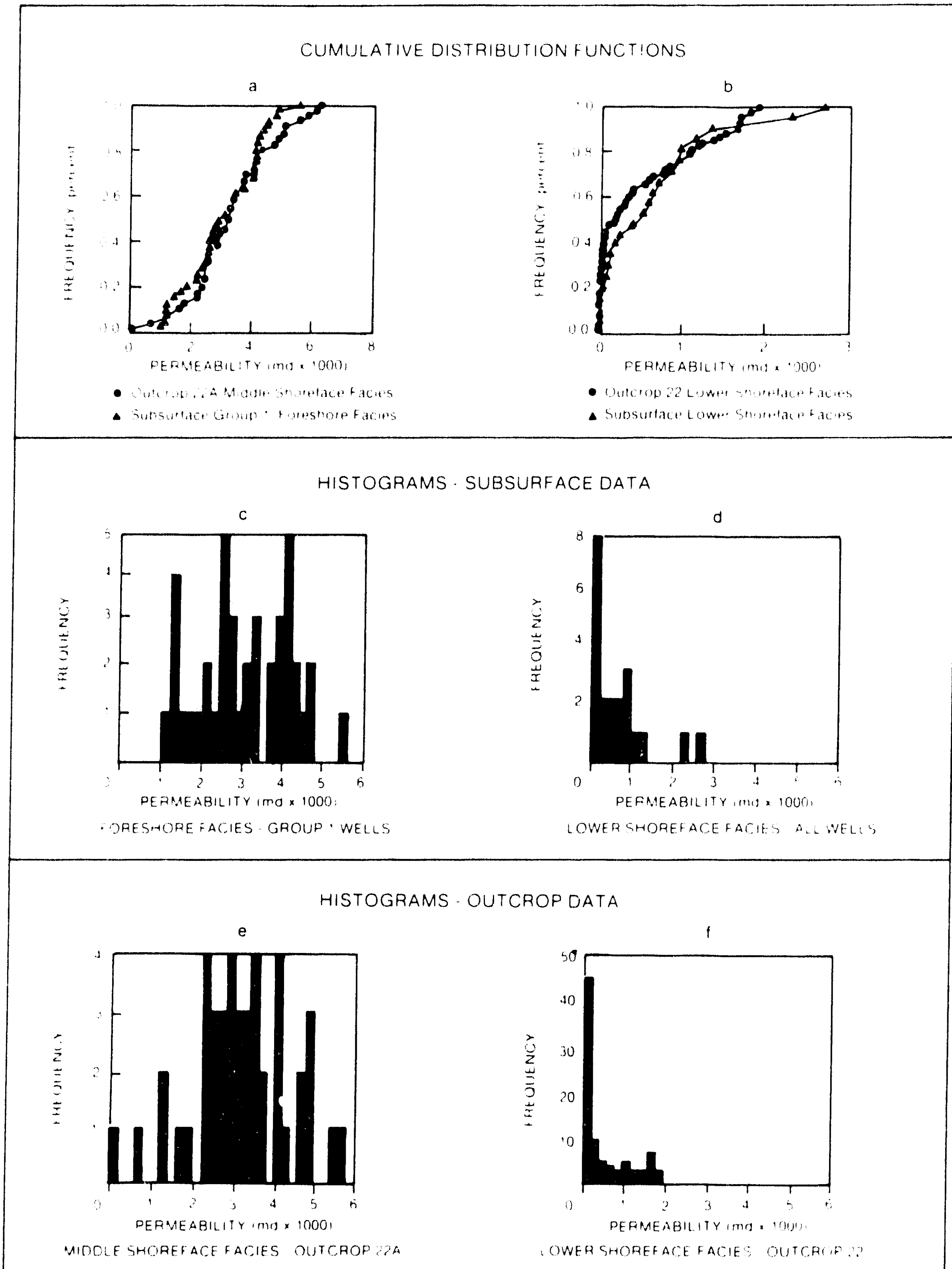


FIGURE 39. Comparison of subsurface and outcrop facies permeability frequency distributions, including comparison of cumulative distribution functions (a and b), and frequency histograms (c-f) (Honarpour et al., 1989).

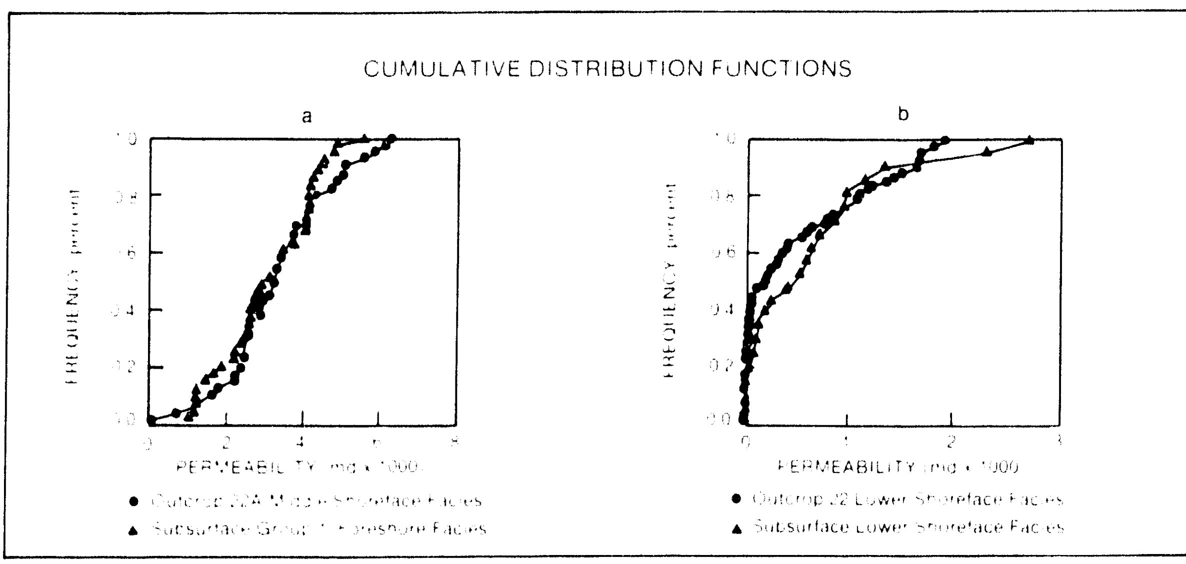


FIGURE 40. Comparison of subsurface and outcrop permeability cumulative distribution functions. Similar frequency functions exist for outcrop middle shoreface facies and subsurface, low-diagenetic cement content foreshore facies (a), as well as outcrop and subsurface lower shoreface facies (b) (Jackson et al., 1991).

IV. PETROGRAPHY AND COMPARISON OF OUTCROP AND SUBSURFACE DATA

Muddy Formation, Surface and Subsurface Sandstone Mineralogy and Petrography

Quantitative X-ray diffraction (XRD) mineralogical analyses of Muddy Formation samples from Bell Creek field and one outcrop are presented in table 5. Individual barrier facies cannot be distinguished by either framework mineralogy or clay content alone. The high quartz content of Muddy Formation barrier sandstones from Bell Creek reservoir averages 89%. XRD analysis of Muddy Formation barrier island and valley fill sandstones from the subsurface and analogous outcrops revealed different clay assemblages. Within the barrier island sandstones the clays generally exhibit a 2:1 ratio between kaolinite and illite and comprise less than 15% by weight. In valley fill sandstones and mudstones, smectite and kaolinite dominate the clay assemblage.

Smectite is very abundant in Muddy valley fill facies. In the Muddy reservoir sandstones the presence of diagenetic kaolinite appears to be derived from the decomposition of feldspars and other less-stable grain such as rock fragments. In the Muddy Formation samples, chert is the most common surviving lithic fragment, and K-feldspars are virtually the only type of feldspar represented, accounting for no more than 2 to 3% of the total rock volume.

When the essential framework components of sandstones are recalculated to 100% and plotted on a quartz-feldspar-rock fragments (Q-F-R) diagram (fig. 41), the characterization of the Muddy Formation shoreline barrier sandstones become apparent. Muddy reservoir sandstones tend to be sublitharenites, subarkoses, and some quartzarenites.

The diagenetic history of the Muddy marine reservoir sandstones is complex. Eight paragenetic stages have been recognized in Muddy reservoir sandstones. The fine- to very fine-grained Muddy reservoir sandstones also contain some chert rock fragments; however, petrographic analysis has indicated that most sedimentary rock fragments have been removed by dissolution (Szpakiewicz et al., 1989) often resulting in oversized pores. Carbonate minerals are extremely rare in the Muddy reservoir rocks, probably having been removed by the same strong early diagenetic stage of dissolution that leached rock fragments and produced the oversize pores. The Muddy Formation, contains relatively few fine-grained rock fragments; however, the dominance of kaolinite in the Muddy Formation makes the barrier reservoir sensitive to the migration of fines during completion and production (Priisholm et al., 1987, Honarpour et al., 1989, Keighin et al., 1989).

In the Muddy reservoir, early stage leaching was important with respect to modifications of the pore system which in turn has a strong control on the petrophysical properties of the reservoirs. At Bell Creek, early leaching may have been the dominant process controlling petrophysical properties within much of the reservoir. In the Muddy Formation reservoir at Bell Creek, virtually all diagenetic stages subsequent to early stage leaching affected the evolution of the rock in a potentially negative manner. Late-stage leaching of grains and prior cements had a positive effect on Muddy reservoir sandstones (Honarpour et al., 1989).

Calcite replacement and pore filing calcite cement in the Muddy Formation, is only locally significant. However, where it does occur, calcite in the Muddy Formation strongly decreases effect on porosity and permeability. When calcite is abundant (more than about 2 to 5%), permeability is generally less than a few tens of millidarcies in the Muddy Formation.

Comparison of Grain Size, Sorting, and Petrophysical Properties of the Muddy Formation

Grain size and sorting (standard deviation of grain size) was determined for 79 thin sections from the Muddy Formation by petrographic image analysis. Table 6 gives grain size data on Muddy Formation outcrop samples. Forty-three of the samples were from the subsurface at Bell Creek field and 36 were from nearby analogous outcrops (Appendix C).

Grain size from sandy marine facies (ie. ignoring lagoonal and valley fill facies) in the Muddy Formation thin sections is remarkably uniform, being in the fine to very fine-grained sand range (95 to 150 microns) for the mean values from all facies (fig. 3). The mean and range of grain size from valley fill facies is also quite similar for samples from outcrop and from the subsurface. However, the range in mean grain size values for the valley fill samples is greater than that for all other facies except those samples from the lagoonal facies, which was identified only in the outcrop.

There is a similarity of mean grain size for outcrop and subsurface, a general lack of sands with mean values coarser than 150 microns, and a similarity of mean grain size for various facies within the Muddy Formation (compare figs. 42 and 43) .

Standard deviation of grain size (sorting) of corresponding Muddy outcrop and subsurface facies (fig. 44) is also quite similar. The range of standard deviation values for Muddy samples overlaps in both outcrop and subsurface. The Muddy marine facies generally do not show a wide range in standard deviation. Grain size and standard deviation of grain size are very comparable for outcropping and subsurface middle shoreface in the Muddy Formation (fig. 42 and fig. 44). Because of the close correspondence between parameters, plots of mean grain size versus standard deviation of grain size (figs. 44 and 45) show the same good correlation. Due to the similarity of grain size these plots show very similar distributions of data for subsurface and outcropping Muddy data.

By comparing the scatter plots of sorting versus mean grain size in figures 44 and 45 it can be seen that Muddy data can be divided into two overlapping groups. First is a finer grained, better sorted (lower standard deviation) valley fill and transitional facies group. Second is a generally coarser grained, less well sorted composite group of barrier facies. Thus we may conclude that there is an overall good correspondence between grain size and standard deviation of grain size (sorting) for the Muddy Formation data.

Distribution of porosity for Muddy Formation facies is presented in figure 46. Most of the barrier facies have porosities that are similar, although there is a shift in equivalent outcrop facies to higher porosity values (Honarpour et al., 1989). Scatter plots show more clearly the differences in distribution between Muddy outcrop and subsurface porosity and permeability. The porosity versus permeability scatter plot for the Muddy Formation (fig. 47) indicates that for a given permeability the outcrop data are more porous, and this relationship has been demonstrated on a facies basis (see fig. 60 of Honarpour et al., 1989). The distribution of outcrop and subsurface permeability for the Muddy Formation (fig. 48) shows the similarity of Muddy mean permeabilities for equivalent facies.

Scatter plots of permeability versus mean grain size for outcrop and subsurface facies in the Muddy Formation (figs. 49 & 50) exhibit visual (not statistically significant) trends. In the Muddy Formation the slope of the visual trend is steep, indicating that large increases in permeability are associated with modest increases in mean grain size. The transition facies in outcrop is finer grained and has very low permeability, while foreshore and middle shoreface facies have increased permeability and are somewhat coarser grained. Muddy subsurface data show much the same relationship between permeability and mean grain size. In the subsurface, valley fill and transition facies have low permeabilities and are slightly finer grained while foreshore, middle shoreface and upper shoreface facies are significantly more permeable and show a tendency to be slightly coarser grained. Both outcropping and subsurface middle shoreface samples showed a wide range of permeability values in the Muddy Formation.

Porosity and mean grain size relationships are also different for samples from the subsurface and outcrop. The wide range of porosity in Muddy outcrop facies (fig. 51) is associated with relatively little change in mean grain size (from about 100 to 150 microns) indicating a general independence of the two parameters. Subsurface Muddy Formation data (fig. 52) show a well defined visual trend (but still not statistically significant) between porosity and mean grain size where valley fill and transition facies are finer grained and less porous than middle shoreface, upper shoreface, and foreshore facies. Once again, lower shoreface porosity values are widely divergent. Figure 53 shows the frequency distribution of grain sizes as determined by thin-section analysis.

ACKNOWLEDGMENTS

This report is a compilation of work done by the BEI research group. I wish to acknowledge its members; M. M. Honarpour, R. A. Schatzinger, M. J. Szpakiewicz, S. R. Jackson, B. Sharma, M. M. Chang, L. Tomutsa and M. K. Tham. The research and field work by D. H. Dailey, R. W. Tillman, G. DeVerges and J. Rennison greatly contributed to this work. The editorial support of Bill Linville, Mike Madden, Min Tham and Edith Allison is greatly appreciated. I appreciate the financial support of this research by the U. S. Department of Energy through Cooperative Agreement DE-FC22-83FE60149. Thanks to Edna Hatcher for word processing this manuscript.

TABLE 5
Quantitative XRD determination in weight percent of mineralogy for subsurface samples from Bell Creek field and a nearby outcrop (GM = Green Mountain outcrop) (Honarpour et al., 1989)

Well	Depth, ft	Depositional setting	Quartz	Feldspar	Calcite	Dolomite	Anhydrite	Barite	Pyrite	Kaolinite	Illite	Smectite	Ill./Smectite	Siderite
Subsurface														
C-8	4351	Lagoon	76	3	–	4	–	–	–	7	8	tr	–	2
27-16	4303-3	Washover	88	2	tr	tr	–	–	–	6	4	–	tr	tr
W-14	4309.3	U./L./Shoreface	89	3	tr	tr	–	–	tr	5	3	tr	–	–
27-14	4309.5	U. Shoreface/foreshore	94	tr	tr	tr	–	–	–	4	2	tr	–	–
27-14	4331.5	U. Shoreface/foreshore	90	2	–	2	–	–	tr	4	2	tr	1	–
W-16	4308.6	Foreshore	91	2	1	1	–	tr	–	3	3	1	–	–
W-16	4318	U. Shoreface	88	2	1	1	–	tr	–	5	3	tr	–	–
W-7	4405.5	Estuarine	88	4	–	tr	–	–	–	2	tr	6	–	–
W-7	4410.0	Estuarine	79	4	–	–	–	–	–	2	tr	15	–	–
W-7	4417.5	Swamp	92	3	–	–	–	–	–	3	tr	2	–	–
W-7	4418.9	Alluvial Channel, Valley Fill	96	1	–	–	–	–	–	3	tr	tr	–	–
W-7	4419.5	U. Shoreface	94	2	–	–	–	–	–	2	2	tr	–	–
W-7	4431.3	U. Shoreface	91	3	–	–	–	2	–	2	2	tr	–	–
Outcrop														
GM	0	Fluvial channel ss	93	2	–	tr	1	–	–	3	1	tr		
GM	10	Fluvial channel ss	97	tr	–	–	–	–	–	2	tr	1		
GM	52	Continental silts.	96	tr	–	tr	tr	–	–	2	tr	2		
GM	65	Fluvial ss	97	tr	–	tr	tr	–	–	1	tr	22		

TABLE 6
Muddy Formation outcrop grain size data

Sample ID	Facies *	Permeability, mD	Porosity, %	GRAIN SIZE (microns) Minimum	Maximum	Number of points	Mean	Median	Standard Deviation	Variance	Skewness	Kurtosis	Trask Coefficient
MO 22 625 14.5	LF	1584.80	32	1.16	534.26	300	126.60	123.95	59.70	3563.90	1.39	6.48	1.33
MO 22 625 -5.0	TRANS.			12.92	101.83	299	45.77	44.53	16.21	262.66	0.43	0.18	1.32
MO 22 625 1.7	LS	10.62	22	1.16	542.13	301	77.42	67.19	47.08	2216.10	3.75	31.04	1.49
MO 22- 625 -14.5	LG					300	214.34		107.79				
MO 22-625 -14.0	MS			29.01	706.09	300	165.68	153.72	89.77	8059.00	1.55	4.73	1.43
MO 22-625 -6.5	LG			17.47	224.66	300	78.84	74.48	32.74	1072.20	0.98	1.64	1.30
MO 22-625 0.5	TRANS.	0.08	4	12.70	149.82	299	47.59	44.24	20.30	412.05	1.45	3.64	1.29
MO 22-625 1	TRANS.			1.16	134.59	299	46.39	42.65	18.42	339.21	0.98	1.93	1.30
MO 22-625 16	LF	179.63	31	21.29	340.20	302	112.01	108.18	51.41	2642.60	0.88	1.65	1.38
MO 22-625 21.5	UF			23.09	370.01	300	106.20	100.49	44.57	1986.10	1.50	5.93	1.31
MO 22-625 22.5	UF			1.16	456.46	300	129.75	122.51	60.81	3698.30	1.56	5.21	1.33
MO 22-625 4	MS	1048.90	34	3.46	247.32	300	95.66	95.37	39.05	1525.00	0.42	0.4	1.36
MO 22N-B3/380	MS	1044.30	32	35.58	400.97	300	131.78	126.04	48.54	2356.40	1.32	3.68	1.23
MO 3-86-B3/45	MS	0.83	11	23.46	294.52	300	121.75	118.18	44.62	1990.90	0.81	1.47	1.27
MO 3-86-B3/70	MS	0.37	12	17.61	369.72	300	118.79	110.81	48.41	2343.40	1.35	3.78	1.24
MO GM 5	VF/FCH					300	107.55		46.38				
MO GM O	VF/FCH					300	86.48		51.78				
MO GM 15	VF/FCH			17.03	210.51	300	80.79	73.58	38.70	1497.90	0.81	0.34	1.44
MO GM 25	VF/FCH			16.31	250.50	301	99.34	93.75	47.75	2279.70	0.66	0.06	1.42
MO GM 29	VF/OBS			17.32	235.99	307	74.96	66.61	40.46	1636.80	1.17	1.46	1.47
MO GM 35	VF/S			18.04	191.68	300	84.24	80.86	36.74	1349.50	0.63	0.12	1.39
MO GM 52	VF/C			4.84	257.35	301	58.06	49.72	32.66	1067.00	2.01	6.37	1.33
MO GM 65	VF/C			11.04	163.97	309	50.15	46.12	19.89	395.51	1.74	5.68	1.29
MO GM 67	VF/FCH			2.74	104.28	300	15.72	13.17	10.30	106.03	3.95	26.04	1.37
MO M 625- 11.5	MS	2563.40	34	28.36	303.68	300	113.67	112.26	43.15	1862.10	0.87	1.83	1.26
MO M 625- 12	MS	5177.00	38	23.09	309.31	300	112.42	109.05	46.87	2196.60	0.91	1.97	1.32
MO SH 0	VF		28	11.98	338.61	300	143.58	138.78	56.07	3144.30	0.39	0.08	1.30
MO SH 5AB	FS		30	33.99	626.92	300	166.25	153.86	73.12	5346.10	1.38	5.25	1.32
MO SH-11	VF		32	24.25	262.26	300	103.22	100.64	41.32	1707.30	0.79	1.02	1.31
MO SH-16	VF		25	18.69	286.94	300	111.74	109.08	47.30	2237.40	0.46	0.07	1.39
MO SH-25	VF		28	23.46	290.84	300	122.83	120.41	49.00	2400.60	0.47	0.19	1.35
MO SH-29	VF		30	25.84	245.01	301	115.66	115.33	43.19	1865.30	0.32	-0.21	1.29
MO SH-32	VF		30	32.69	304.26	300	142.96	137.62	56.15	3152.40	0.33	-0.19	1.31
MO SH-5	VF		35	14.79	554.03	301	116.95	112.15	57.64	3322.80	1.96	11.02	1.36

*LF= Lower Foreshore; Trans. = Transition; LS = Lower Shoreface; LG = Lagoon; MS = Middle Shoreface; US = Upper Shoreface; UF = Upper Foreshore; VF/FCH = Valley Fill/Fluvial Channel; VF/OBS = Valley fill/ Over bank splay; VF/S = Valley fill/ Splay, VF/CH = Valley fill/ Fluvial channel; VF/C = Valley fill/ Continental; VF = Valley fill.

BARRIER SANDSTONES

Muddy Formation
● Outcrop
▲ Subsurface

Almond Formation
△ Outcrop
○ Subsurface

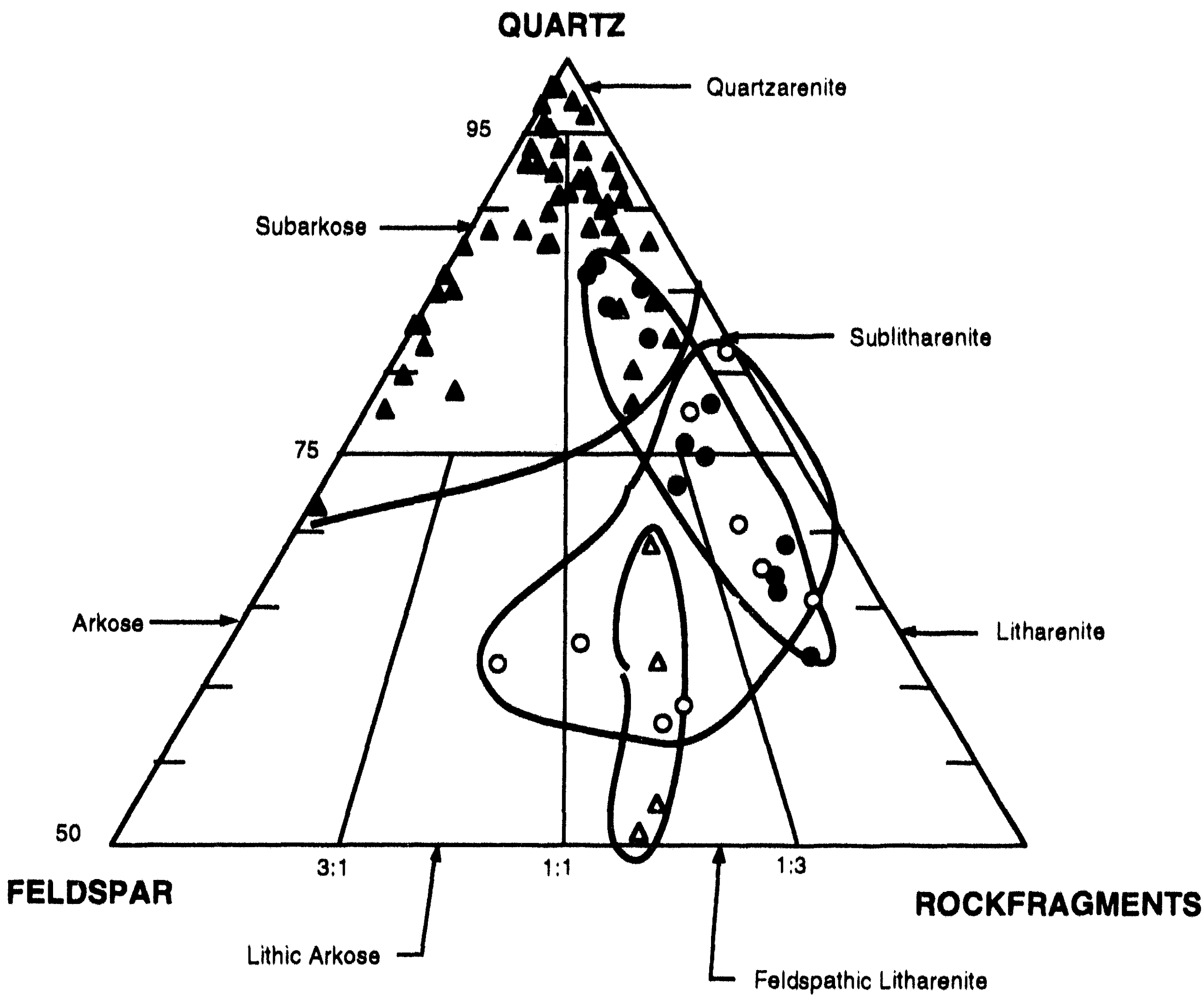


Figure 41 Ternary plot of quartz-feldspar-rock fragment composition of outcrop and subsurface Almond and Muddy Formations. (Schatzinger et al., 1992)

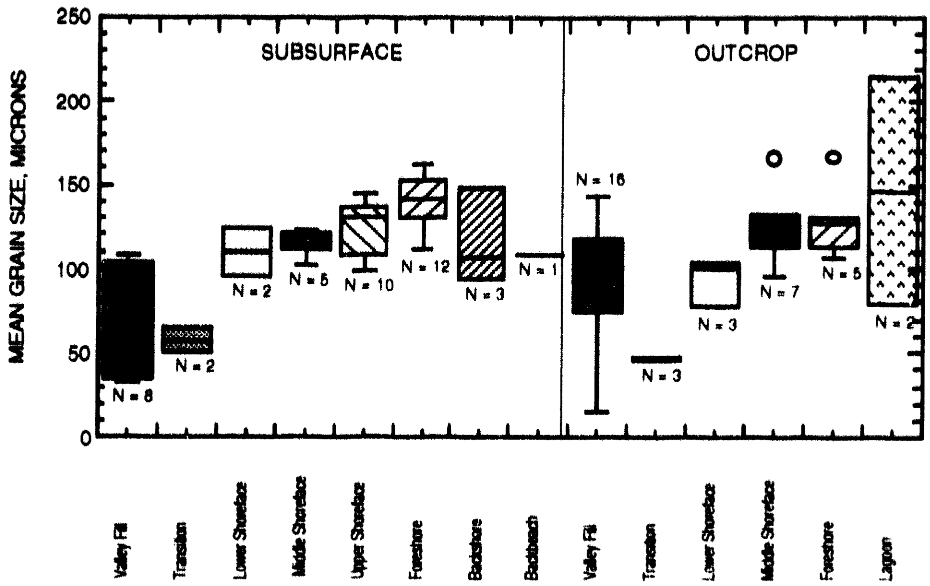


Figure 42 Comparison of outcrop and subsurface grain size distribution for various Muddy Formation facies in and around Bell Creek Field, MT. Boxes indicate limits of second and third quartiles, "whiskers" indicate ranges of data to 5th and 95th percentiles, circles indicate data outliers beyond 5th and 95th percentiles."N" represents number of samples in each class of data. (Schatzinger et al., 1992)

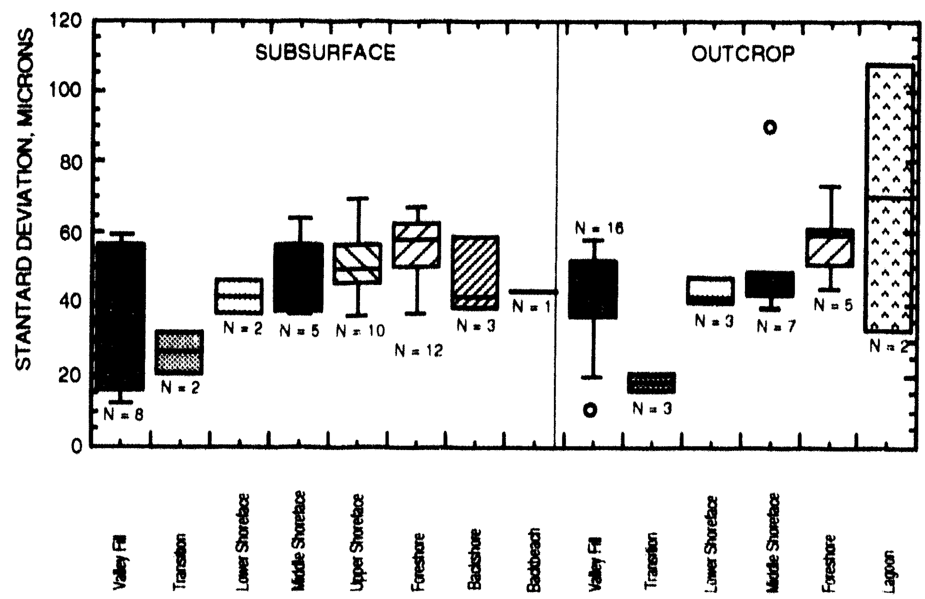


Figure 43 Comparison of outcrop and subsurface standard deviation of grain size for various Muddy Formation facies in and around Bell Creek Field, MT. For explanation of symbols see fig. 42. (Schatzinger et al., 1992)

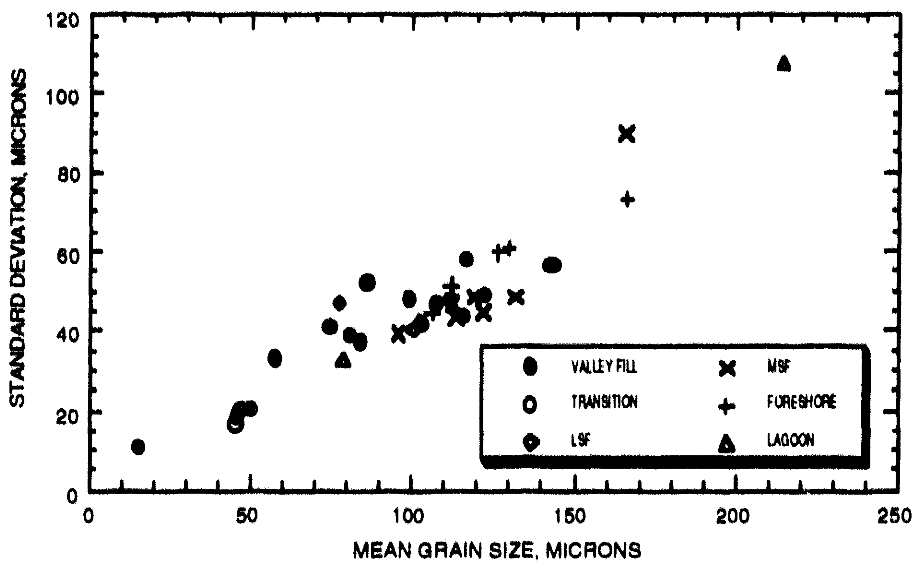


Figure 44 Standard deviation of grain size versus mean grain size for Muddy Formation outcrop facies. Abbreviations: LSF, lower shoreface; MSF, middle shoreface; USF, upper shoreface. (Schatzinger et al., 1992)

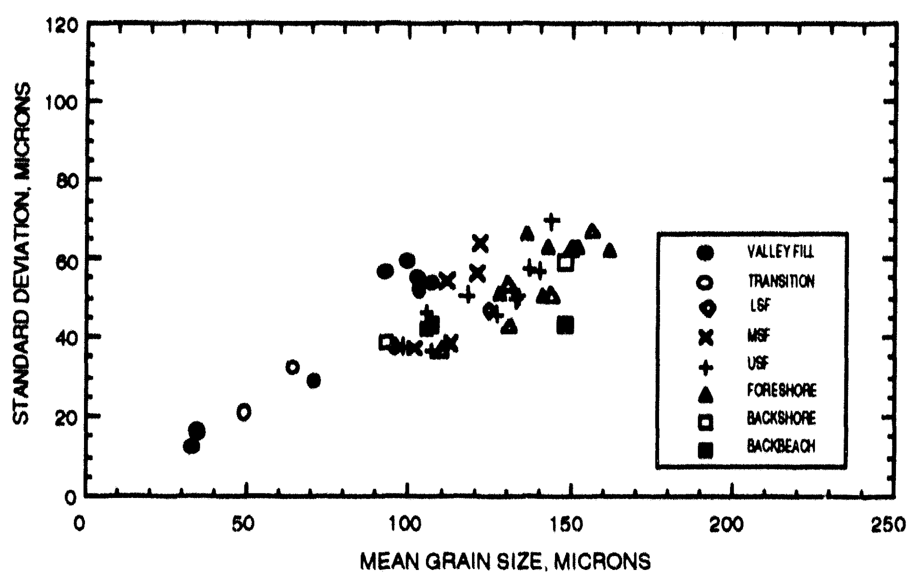


Figure 45 Standard deviation of grain size versus mean grain size for Muddy Formation subsurface facies. Abbreviations listed in fig. 44. (Schatzinger et al., 1992)

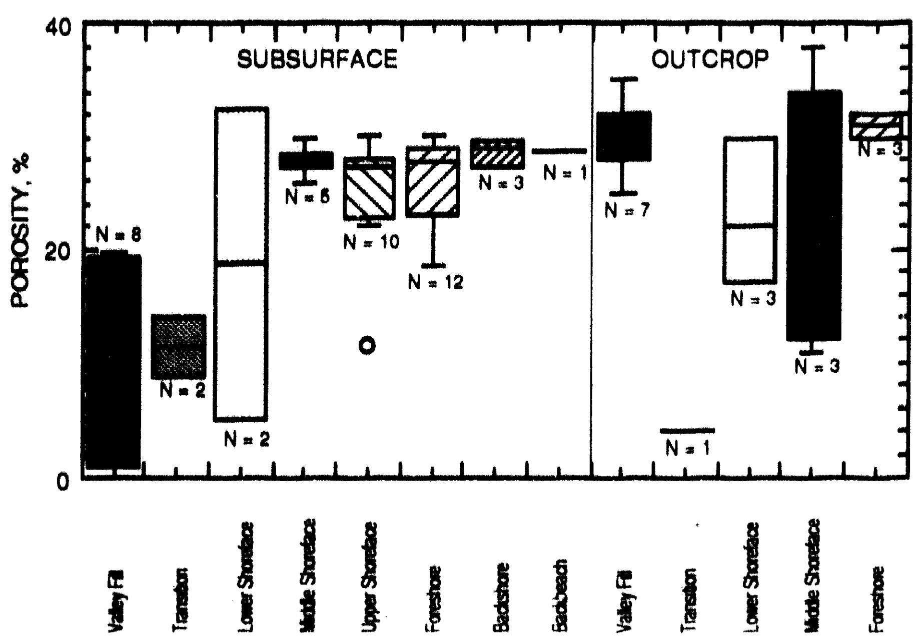


Figure 46 Comparison of outcrop and subsurface porosity for various facies in the Muddy Formation in and around Bell Creek field, MT. For explanation of symbols see fig. 42. (Schatzinger et al., 1992)

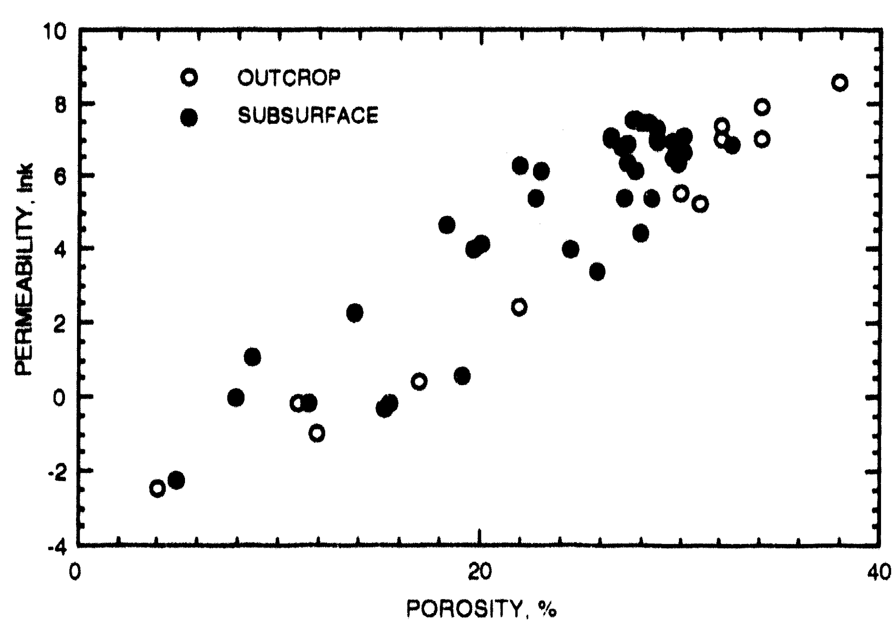


Figure 47 Natural log of permeability (lnk) versus porosity for combined outcrop and subsurface Muddy Formation samples. (Schatzinger et al., 1992)

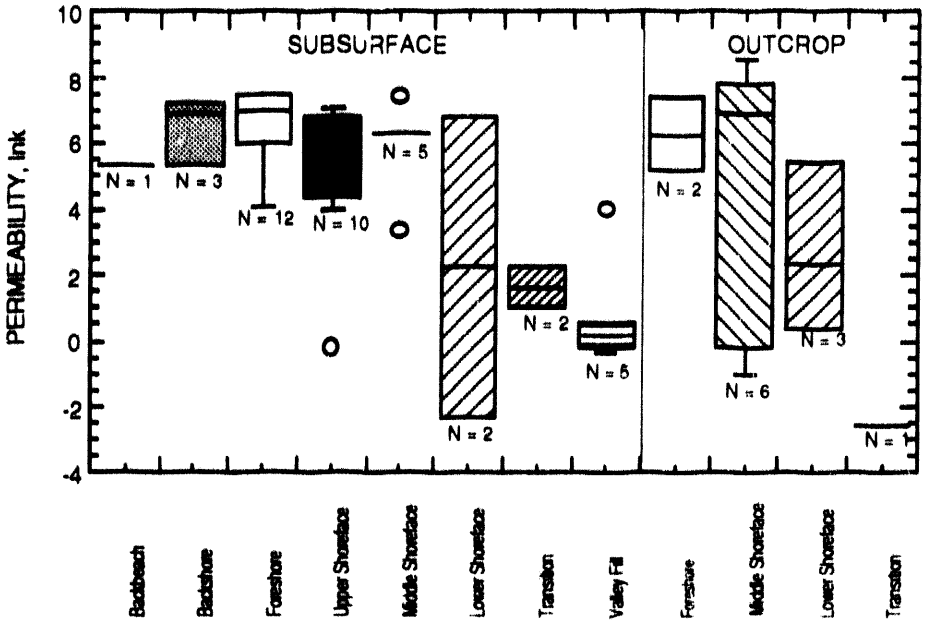


Figure 48 Comparison of outcrop and subsurface natural log of permeability for various facies in the Muddy Formation in and around Bell Creek Field, MtT For explanation of symbols see fig. 42. (Schatzinger et al., 1992)

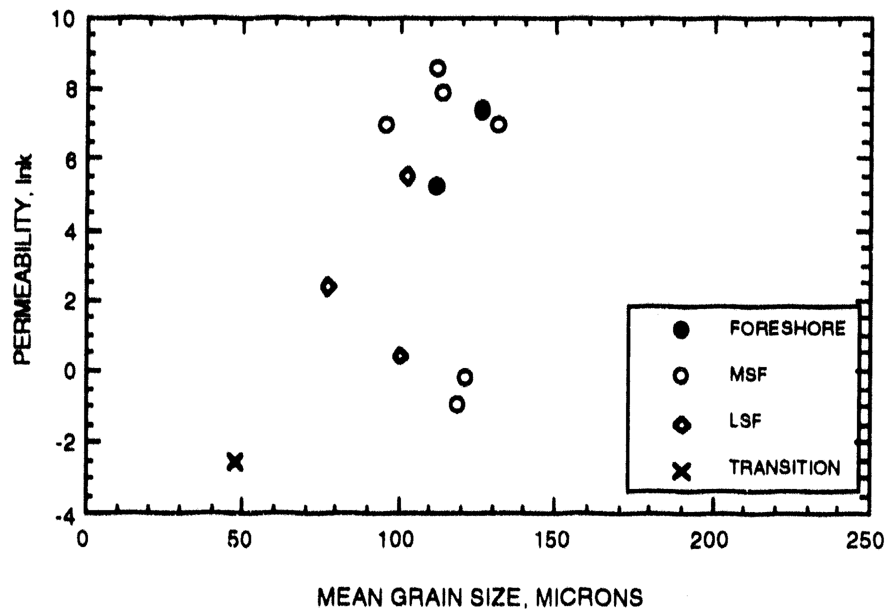


Figure 49 Natural log of permeability (lnk) versus mean grain size for outcropping Muddy Formation facies. Abbreviations listed in fig. 44. (Schatzinger et al., 1992)

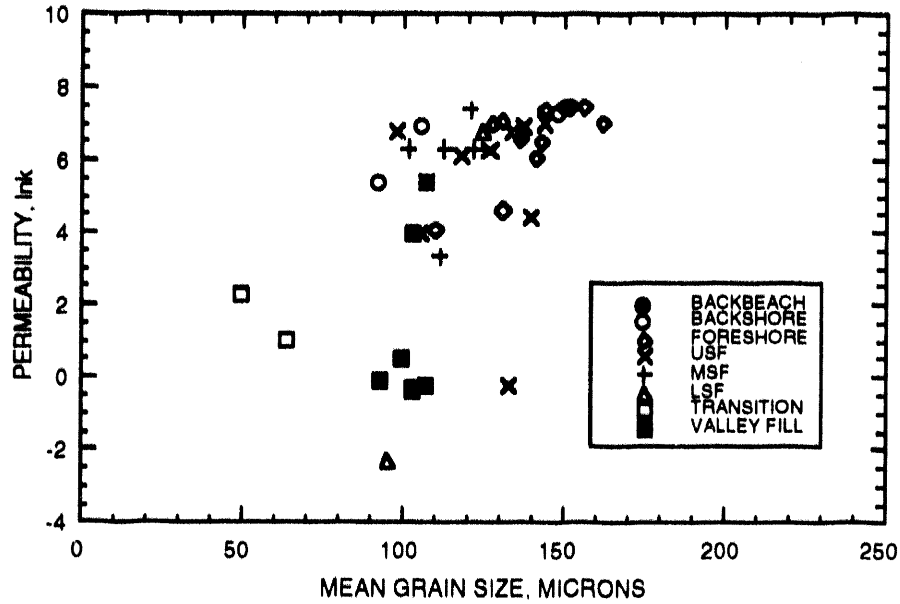


Figure 50 Natural log of permeability (lnk) versus mean grain size for subsurface Muddy Formation facies. Abbreviations listed in fig. 44. (Schatzinger et al., 1992)

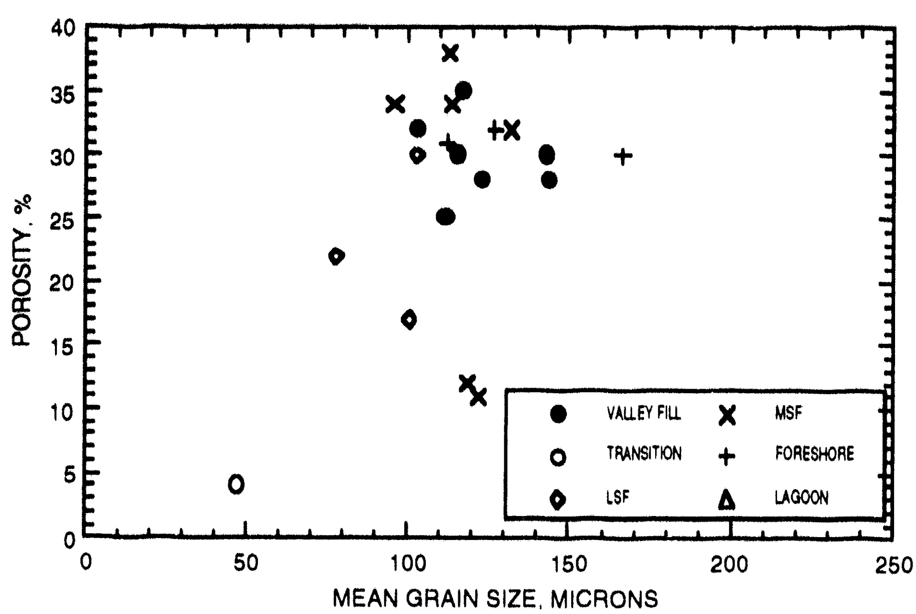


Figure 51 Porosity versus mean grain size for outcropping Muddy Formation facies. Abbreviations listed in fig. 44. (Schatzinger et al., 1992)

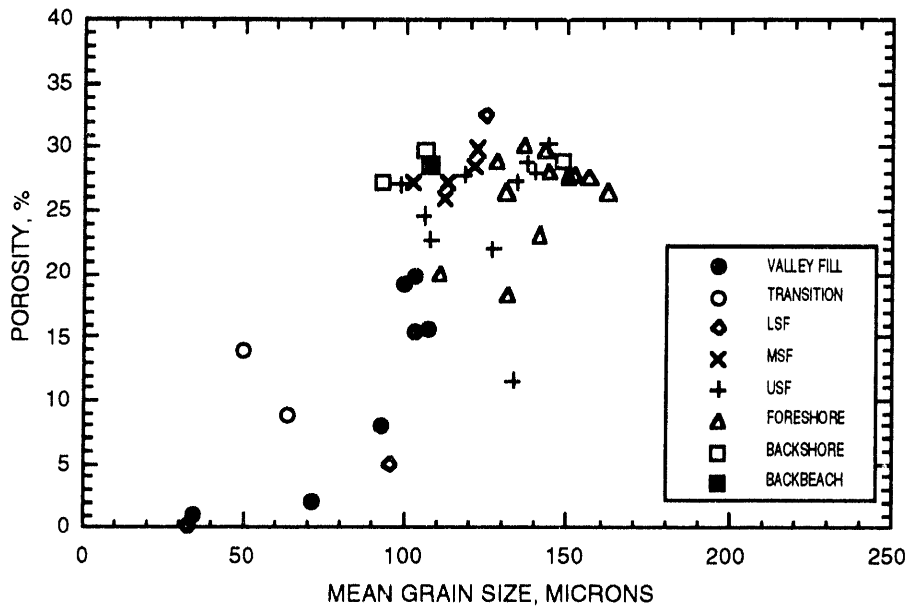


Figure 52 Porosity versus mean grain size for subsurface Muddy Formation facies. Abbreviations listed in fig. 44. (Schatzinger et al., 1992)

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APPENDIX A

Surface Samples, Crook County, Wyoming

Micropaleontological Report

D. H. Dailey

The study is based on 20 samples (originally 21) from six sections through the uppermost Skull Creek Shale-Muddy Sandstone-lowermost Shell Creek Shale sequence. Of these, 11 proved to be fossiliferous and are described in this report; a twelfth sample has been excluded as it yields only duplicate data from an adjacent sample at the base of one of the sections. The remaining nine samples are barren of foraminifera and other microfossils recognizable under a binocular microscope.

A complete list of species is recorded for each sample. Samples yielding more than 300 individuals usually are half or three-quarter fractions of the true number of individuals available, 300 individuals being considered a statistically valid representation of a fossil foraminiferal faunule (= community). All specimens were recovered and examined from those samples yielding fewer than 300 individuals.

The format presented here includes a summary listing age determinations and depositional environment interpretations followed by a presentation of the data on which my conclusions are based.

SURFACE SAMPLES, CROOK COUNTY, WYOMING

ANALYSIS

SECTION NH22(625)

FAUNA:

	Samples			
	-3.2 ft	-7.0 ft	-18.0 ft	-40.0 ft
Ammobaculites euides L&T		3	3	67
Ammobaculites petilus Eicher			1	62
Ammobaculoides whitneyi (C&A)				21
Ammodiscus kiowaensis L&T				4
Arenaceous spp indet.	5		3	12
Haplophragmoides gigas Cushman				62
Trochammina gatesensis S&W		2		
Verneuilinoides hectori Nauss				66
Verneuilinoides kansasensis L&T	97	23	2	23
Total specimens	102	28	9	317

SAMPLE: -3.2 ft

Age: Middle Albian-Cenomanian

The stratigraphic range of the single identifiable foraminifer recognized in this assemblage, i.e., Verneuilinoides kansasensis, is middle Albian-Cenomanian.

Environment: Bay, lagoon or estuary

Ninety-seven individuals assignable to Verneuilinoides kansasensis and five indeterminant specimens constitute this assemblage. Faunules of exclusively arenaceous character and moderate numbers, but limited to one or two species, reflect brackish shallow conditions of the transition zone. The taxon present (V. kansasensis) is commonly reported from Cretaceous intertidal and inner shelf environments. The forams are further characterized by very coarse test walls, which together with the sediment type (clayey siltstone), indicate at least moderate energy levels and attendant turbidity and turbulence. A brackish, shallow, somewhat turbid environment, such as a bay, lagoon or estuary setting, seems a reasonable interpretation.

SAMPLE: -7.0 ft

Age: Late Albian (probable Haplophragmoides gigas Zone - Miliammina manitobensis Zone transition)

The occurrence of Ammobaculites euides, an index for the Haplophragnoides gigas Zone, and Trochammina gatesensis, a species reportedly limited to the overlying Miliammina manitobensis Zone, suggests this horizon probably falls within a transition interval between the two zones.

Environment: Bay, lagoon or estuary

This faunule is chracterized by its totally arenaceous composition, modest numbers of individuals, high faunal dominance and low diversity. It compares with Recent assemblages encountered in paralic environments. The dominant taxon, i.e., Verneuilinoides, suggests intertidal to inner shelf depths. As with the previous sample, the enclosing rock is a clayey siltstone and the foraminifers exhibit very coarse test walls, suggesting some turbidity and turbulence. This assemblage probably lived under conditions not unlike those postulated for the faunule at -3.2 ft.

SAMPLE: -18.0 ft

Age: Early late Albian (Haplophragmoides gigas Zone)

The presence of Ammobaculites euides and A. petilus indicates a correlation with the Haplophragmoides gigas Zone.

Environment: Probable inner shelf

This sample is deeply weathered but fortunately nine foraminifer individuals, seven of which can be identified, were recovered. They include, primarily, Ammobaculites, whose Recent analogs are widely distributed from shallow shelf to deep slope, and Verneuilinoides, which prefers intertidal to inner shelf depths. The overlapping modern depth ranges of these two genera suggest probable inner shelf depths.

SAMPLE: -40.0 ft

Comment: Foraminifera from the following five samples compare very closely in abundance and faunal character:

Section	Sample
NH22(625)	-40.0 ft
1-86N	-9.5 ft
27	-6.0 ft
29	+2.0 ft
29	-3.0 ft

They are treated here as a single unit so identical data and analysis are not repeated several times in the following pages. However, the proposed age correlation and depositional environment interpretation are listed for the remaining four samples under their appropriate section headings.

Age: Early late Albian (Haplophragmoides gigas Zone)

Characteristic species of the Haplophragmoides gigas Zone occurring in all five samples are the following: Ammobaculites euides, A. petilus, Ammodiscus kiowaensis and Haplophragmoides gigas. An additional zonal index, i.e., Ammobaculoides whitneyi, is present at NH22(625), sample -40.0 ft; and 1-85N, sample -9.5 ft.

Environment: Inner shelf

These foraminiferal assemblages, distinguished by their totally arenaceous character, relatively large numbers of individuals (>300), medium-low diversity (five to seven species) and moderate faunal dominance (28 to 38%), are most similar to modern faunas developed in shallow, probably stressed, marine environments. The dominant taxonomic elements support this conclusion. Ammobaculites, although widely distributed in modern seas, prefers nearshore conditions (Chamney, 1975, p. 599), while Verneuilinoides is generally restricted to intertidal-inner shelf habitants (ibid., p. 590). Haplophragmoides and the accessory element, Ammodiscus, tend to develop especially smooth test walls that Chamney (ibid., p. 598) proposes is evidence for low energy levels. Additional evidence is the character of the enclosing sediment, i.e., shale with very little included silt. Finally, the majority of individuals, especially those of Haplophragmoides, are flattened or otherwise distorted, suggesting brackish conditions. The evidence at hand indicates these assemblages lived in the inner shelf district, with the water generally quiet and probably of subnormal salinity.

SECTION NH3-86

FAUNA:	Samples: -5.0 ft.	Samples: -8.5 ft.
Arenaceous spp. indet.	10	4
Miliammina cf. sproulei Nauss	1	3
Verneuilina sp.	16	31
Verneuilinoides kansasensis L&T	7	15
Total specimens	34	53

SAMPLES: -8.5 ft and -5.0 ft.

Comment: Both assemblages are analyzed together as they are essentially identical in character:

Age: Early late Albian (Haplophragmoides gigas Zone)

The presence of Miliammina cf. sproulei at both horizons suggests a correlation with the Haplophragmoides gigas Zone.

Environment: Bay or lagoon (Transition (80%) in sedim. interpr.)

The NH3-86 microfauna is entirely arenaceous. It is further characterized by low species diversity and moderately high faunal dominance, faunal attributes suggesting living conditions were below minimum tolerance levels for the majority of foraminifera. Most abundant is Verneuilina sp., a species not previously reported in Western Interior foram literature. Modern representatives of this genus are encountered from intertidal to middle shelf depths. Accessory elements are Verneuilinoides, an indicator for intertidal-inner shelf depths, and Miliammina, a form consistantly found in very shallow hyposaline environments. These two assemblages are interpreted as representing brackish, shallow conditions within a bay or lagoon.

SECTION 1-86N

FAUNA:

	Sample -9.5 ft
Ammobaculites euides L&T	66
Ammobaculites petilus Eicher	155
Ammobaculoides whitneyi (C&A)	2
Ammodiscus kiowaensis L&T	57
Arenaceous spp. indet.	16
Haplophragmoides gigas Cushman	76
Trochammina sp.	2
Verneuilinoides hectori (Nauss)	95
Total specimens	469

SAMPLE: -9.5 ft

Age: Early late Albian (Haplophragmoides gigas Zone; see page 3)

Environment: Inner shelf (see page 3)

(OK)
(with lagoon above)

SECTION 27

FAUNA:	-2.0 ft	-6.0 ft
Ammobaculites euides L&T		24
Ammobaculites petilus Eicher		90
Ammodiscus kiowaensis L&T		19
Arenaceous spp. indet.		10
Haplophragmoides gigas Cushman		90
Haplophragmoides sp.		5
Pseudobolivina variana (Eicher)		4
Trochammina gatesensis S&W	36	
Verneuilinoides hectori (Nauss)	15	102
Total specimens	51	344

SAMPLE: -2.0 ft

Age: Probable late late Albian (Miliammina manitobensis Zone)

A Miliammina manitobensis Zone correlation is proposed for this horizon on the basis of the occurrence of the zonal index Trochammina gatesensis and the absence of Haplophragmoides gigas Zone indicators.

Environment: Bay or lagoon, possibly tidal flat (Transition (75%) in sedim. interpr.)

An improverished, entirely arenaceous assemblage of about 50 individuals assignable to two species is present. The dominant morphotype--Trochammina--indicates a shallow brackish setting such as the upper reaches of a bay or lagoon, possibly even a tidal flat.

SAMPLE: -6.0 ft

Age: Early late Albian (Haplophragmoides gigas Zone; see page 3)

Environment: Inner shelf (see page 3)

OK! (95%)

SECTION 29

FAUNA:

	Samples -3.0 ft	Samples +2.0 ft
Ammobaculites euides L&T	27	59
Ammobaculites petilus Eicher	124	137
Ammodiscus kiowaensis L&T	37	35
Arenaceous spp. indet.	31	62
Haplophragmoides gigas Cushman	94	52
Verneuilinoides hectori (Nauss)	86	13
Total specimens	399	358

SAMPLES: -3.0 ft and +2.0 ft (-2.0 ?)

Age: Early late Albian (*Haplophragmoides gigas* Zone; see page 3)

Environment: Inner shelf (see page 3)

OK

SUPPLEMENT

The following samples have been processed and examined and found to be barren:

Section	Sample
NH22(625)	-5.0 ft
NH22(625)	-14.0 ft
NH22(625)	-15.0 ft
NH22(625)	-16.7 ft
1-86N	-2.0 ft
27	+9.0 ft
Green Mtn.	-1.5 ft
Green Mtn.	-2.0 ft
Green Mtn	-3.0 ft

A palynological study of the barren samples should be considered. They may yield spores and pollen and possibly dinoflagellates that can provide useful stratigraphic information.

One sample, i.e., section NH22(625), sample -55.0 ft, was processed and the foraminiferal assemblage given a cursory examination. However, the faunule was not analyzed as it is not materially different from that in the immediately superjacent horizon (-40.0 ft).

D. H. Dailey
December, 1987

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Chamney, T. P., 1976. Foraminiferal morphogroup symbol for paleoenvironmental interpretation of drill cuttings samples: Arctic Canada. Maritime Sediments, Spec. Pub. 1, Pt. B, p. 585-624.

Eicher, D. L., 1960. Stratigraphy and micropaleontology of the Thermopolis Shale. Peabody Mus. Nat. Hist., Yale Univ., Bull. 15, 126 p., 6 pls.

Eicher, D. L., 1962. Biostratigraphy of the Thermopolis, Muddy and Shell Creek formations. Wyo. Geol. Assoc. Guidebook, 17th Ann. Field Conf., p. 72-93.

SURFACE SAMPLES, CROOK COUNTY, WYOMING

Age Correlation and Depositional Environment Summary

Section	Sample	Age Correlation	Depositional Environment
NH22(625)	-3.2 ft	Middle Albian-Cenomanian	Bay, lagoon or estuary
	-5.0 ft	Barren	Barren
	-7.0 ft	Probable early late Albian-late late Albian transition	Bay, lagoon or estuary
	-14.0 ft	Barren	Barren
	-15.0 ft	Barren	Barren
	-16.7 ft	Barren	Barren
	-18.0 ft	Early late Albian	Probable inner shelf
	-40.0 ft	Early late Albian	Inner shelf
NH3-86	-5.0 ft	Early late Albian	Bay or lagoon
	-8.5 ft	Early late Albian	Bay or lagoon
1-86N	-2.0 ft	Barren	Barren
	-9.5 ft	Early late Albian	Inner shelf
27	+9.0 ft	Barren	Barren
	-2.0 ft	Probable late late Albian	Bay or lagoon, possibly tidal flat
	-6.0 ft	Early late Albian	Inner shelf
29 ?	+2.0 ft	Early late Albian	Inner shelf
	-3.0 ft	Early late Albian	Inner shelf
Green Mtn.	-1.5 ft	Barren	Barren
	-2.0 ft	Barren	Barren
	-3.0 ft	Barren	Barren

D. H. Dailey
December, 1987

SECTION 1-86N

Lithology - samples superficially similar.

Sample -2.0 ft. Shale, 200% more silt content than at -9.5 ft, abundant tiny mica flakes, common carbonaceous fragments.

Sample -9.5 ft. Shale, slightly silty.

Micropaleontology - samples not similar.

Sample -2.0 ft. Barren

Sample -9.5 ft. Abundant foraminifera, characteristic of Eicher's Ammobaculites euides biofacies, 100% arenaceous medium-low diversity and moderate faunal dominance.

Interpretation

Sample -2.0 ft. Indeterminant

Sample -9.5 ft. Skull Creek Formation; inner shelf, quiet, subnormal saline.

SECTION 29

Lithology - Samples more or less the same.

Sample +2.0 ft. Shale medium-gray, silty, mica flakes and carbonaceous fragments common.

Sample -3.0 ft. Shale, medium-gray, silty, pale green ?glauconite (or chamosite) pellet flood.

Micropaleontology - identical foraminiferal faunules.

Abundant foraminifera, characteristic of Eicher's *Ammobaculites euides* biofacies, 100% arenaceous, medium-low diversity; moderately low faunal dominance @ -3.0 ft, but moderate @ -2.0 ft.

Interpretation - Skull Creek Formation; inner shelf, quiet, subnormal saline.

SECTION 27

Lithology - each sample different from others.

Sample +9.0 ft. Sandstone: clayey, grains angular, quartoze, friable, abundant tiny mica flakes, flood carbonaceous matter. With accessory siltstone, as above.

Sample -2.0 ft. Probably interbedded shale and siltstone.
Shale: medium light-gray, soft.
Siltstone: clayey, very friable, minor number individual sand grains, grains angular, abundant tiny pale green ?glauconite (or chamosite) pellets.

Sample -6.0 ft. Shale: light-tan, soft, silty, abundant tiny mica flakes, flood tiny ?glauconite (or chamosite) pellets.

Micropaleontology - each sample different from others.

Sample +9.0 ft. Barren

Sample -2.0 ft. Sparse numbers of foraminifera, characteristic of Eicher's *Verneuilinoides kansasensis* biofacies, 100% arenaceous, very low diversity, moderately high faunal dominance.

Sample -6.0 ft. Abundant foraminifera, characteristic of Eicher's *Ammobaculites euides* biofacies, medium-low diversity, moderately low faunal dominance.

Interprettion

Sample +9.0 ft. Indeterminant

Sample -2.0 ft. Lithologic unit uncertain if based on fossils; probably Skull Creek-Muddy Transition. Most common taxon (*Trochammina gatesensis*) restricted to Shell Creek Formation by Eicher, but I don't believe it. (See discussion on page 4). Microfauna is suggestive of shallow brackish environment, probably bay, lagoon or, possibly, tidal flat.

Sample -6.0 ft. Skull Creek Formation, inner shelf, more or less quiet, subnormal saline.

SECTION NH22(625)

Sample -3.2 ft.

Lithology - Siltstone, clayey and sandy, very friable, flood carbonate fragments.

Micropaleontology - Modest number of foraminifera, characteristic of Eicher's *Verneuilinoides kansasensis* biofacies, 100% arenaceous, very low diversity, very high faunal dominance, very coarse foram test walls.

Interpretation -Lithologic unit uncertain; brackish, shallow turbid, bay, lagoon or estuary.

Sample -5.0 ft.

Lithology - Probably interbedded shale and siltstone; abundant carbonaceous fragments and dark mica flakes, flood of tiny pale green ?glauconite (or chamosite) pellets.
Shale: silty, medium gray, soft.
Siltstone: clayey, very friable, grains angular, quartoze.

Micropaleontology - Barren

Interpretation -Indeterminant

Sample -7.0 ft.

Lithology - Interbedded shale and siltstone, flood pale green ?glauconite (or chamosite) pellets, common carbonaceous fragments.
Shale: silty, medium light-gray, soft.
Siltstone: clayey, very friable, grains angular, quartoze, common tiny mica flakes.

Micropaleontology - Few foraminifera, probably characteristic of Eicher's *Verneuilinoides kansasensis* biofacies, 100% arenaceous, low diversity, high faunal dominance, very coarse foram test walls.

Interpretation - Probably Skull Creek Formation or Skull Creek-Muddy Transition (see page 4); shallow, brackish, turbid; bay, lagoon or estuary.

Sample -14.0 ft.

Lithology - Interbedded sandstone, siltstone and shale; common carbonaceous fragments, weathered.
Sandstone: very friable, fine- to medium-grained, subround to angular, quartzose and feldspathic.
Siltstone: friable, clayey, grains like sandstone above but grains angular, weathered reddish-brown.
Shale: as pale olive laminae, silty, very soft.

Micropaleontology - Barren

Interpretation - Indeterminant

Sample -15.0 ft

Lithology - Interbedded sandstone and siltstone; more or less as at -14.0 ft.

Micropaleontology - Barren

Interpretation - Indeterminant

Sample -16.7 ft

Lithology - Probably shale with interbedded siltstone and common discontinuous siderite laminae but shale washed away during processing.
Siltstone: sandy and clayey, very friable.

Micropaleontology - Barren

Interpretation - Indeterminant
This horizon differs from other NH22(625) samples in presence of siderite laminae. It differs from overlying samples in its less silt content and from underlying samples in its greater silt content and absence of microfossils.

Sample -18.0 ft

Lithology - Shale: light medium-gray, soft, weathered.

Micropaleontology - Rare foraminifera (probably result of weathering), characteristic of Eicher's *Ammobaculites euides* biofacies, 100% arenaceous.

Interpretation - Probability is high samples -18.0 ft and -40.0 ft are similar; unfortunately -18.0 ft microfauna is mostly destroyed. Both samples differ from younger horizons in lithology and microfossil content.

Sample -40.0 ft

Lithology - Shale: medium gray, soft.

Micropaleontology - Abundant foraminifera, characteristic of Eicher's *Ammobaculites euides* biofacies, 100% arenaceous, medium-low diversity, moderately low faunal dominance.

Interpretation - Skull Creek Formation; inner shelf, quiet, subnormal salinity.

Question: Can any samples in this section be Shell Creek or Muddy rather than Skull Creek?

Answer: Sample -3.2 ft yields one identifiable species, i.e., *Verneuilinoides kansasensis*. Eicher reports its local range as no higher than the Thermopolis-Skull Creek sequence but its true range elsewhere extends up through the Shell Creek Formation and into the Cenomanian Stage. Hence, the range of *V. kansasensis* is too great to draw a conclusion.

Sample -7.0 ft is probably assignable to the Skull Creek Shale or to a Skull Creek-Muddy Transition interval. It includes Ammobaculites euides which is reported from middle Albian rocks of Texas, Oklahoma and Kansas. Its youngest occurrence is the Thermopolis-Skull Creek sequence (early late Albian). The highest occurrence of A. euides reported by Eicher is in Thermopolis-Muddy Transition beds at his localities 19 and 22 (Big Horn Basin). It has not been found elsewhere. An argument for Shell Creek sediments at -7.0 ft is the rare occurrence of Trochammina gatesensis, a species first described from the middle Albian of Alberta and later from the Shell Creek Formation. Therefore, its range is at least middle to late Albian age, allowing for its occurrence below Shell Creek strata. I believe it extends down into the upper Skull Creek Formation in northeastern Wyoming and that Eicher unfortunately didn't recognize it there. Note that T. gatesensis also occurs in sample -2.0 ft at Section 27.

As for the Muddy Sandstone, no foraminifera recognized during this study are reported from that formation. In fact, foraminifera generally cannot indicate the presence of Muddy Sandstone rocks. Eicher lists only two species from Muddy strata, both from the uppermost beds. One is reported to range through the Thermopolis-Shell Creek sequence, while the second is limited to the Shell Creek Shale.

APPENDIX B
POWDER RIVER BASIN, ANNOTATED BIBLIOGRAPHY

The references in this appendix were selected from a more extensive annotated bibliography on shoreline/barrier deposits (Rawn-Schatzinger and Schatzinger, 1993). The Powder River Basin is a large sedimentary basin in northeast Wyoming and southeast Montana. Structurally the Powder River Basin is bounded on the north and east by the Black Hills Uplift and on the west by the Wyoming Thrust Belt and the Big Horn Mountains and on the south by the Hartville Uplift. The Belle Fourche Arch is the only major structural feature within the Powder River Basin. It has a northeast trending axis resulting from tectonic movements in the Cretaceous. Hydrocarbon productive formations includes Permian aged Minnelusa Formation sediments and Cretaceous aged deposits from the Dakota, Muddy, Turner, Shannon, Sussex and Parkman formations of the Dakota Group. The uppermost Dakota Formation, the Muddy Sandstone, is overlain by Benton Group shales of the Mowry and Shell Creek formations. Hydrocarbon discoveries in the Powder River Basin are primarily stratigraphic traps.

Almon, W. R., and D. K. Davies, 1979, Regional diagenetic trends in the Lower Cretaceous Muddy Sandstone, Powder River Basin: SEPM Special Pub No. 26, p. 379-400.

Hydrocarbon reservoirs in the Powder River Basin are found in Lower Cretaceous rocks of the Muddy Formation. The environments represented are fluvial, deltaic, and shallow marine. Diagenetic clay minerals greatly affect the porosity and permeability of the Muddy sandstones. An assemblage of kaolinite-chlorite-illite-quartz with some smectite dominated the clays. A changing trend in the clay content is matched by changes in the detrital composition. Older Muddy sandstones have more feldspars, more rock fragments, and less quartz than younger sandstones. The diagenesis must be taken into account in well stimulation and completion tests. Illustrations include maps, cross-sections, and SEM photomicrographs of clays and detrital rock fragments.

Berg, R. R., and D. K. Davies, 1968, Origin of lower Cretaceous Muddy Sandstone at Bell Creek Field, Montana: AAPG Bull., v. 52, p. 1888-1898.

Geological study of the Muddy Sandstone at Bell Creek Field in Montana gives an analysis of grain size, sediment content and textures to account for the range of porosity and permeability values charted. The Muddy Sandstone is recognized as a barrier bar, and changes in bar texture and morphology are related to the environments of deposition. Isopach maps, log data, and grain analysis are used to support the conclusion of barrier bar.

Berg, R. R., G. M. Larberg, and J. T. Lin, 1980, Hydrodynamic flow in Lower Cretaceous Muddy Formation, northeast Powder River Basin, Wyoming and Montana (abst.): AAPG-SEPM-EMD Convention, Denver, CO., p. 676.

Hydrodynamic gradient in the Muddy Formation averages 25 ft/mi (5 m/km) in a downdip direction. Isolated high pressure areas are suggested by local gradients and a reduction of the oil column in some areas. The oil columns are in equilibrium with vertical and cross formational flow. Migration of oil from the Mowry Shale source rock is still continuing. Dehydration of montmorillonite in the Mowry shale occurs at temperatures above 200° F (94° C) which results in oil flow. Oil traps in the Muddy Formation are post-Laramide in development. Earlier fluid flow in the area may have been updip and prevented oil accumulation.

Berg, R. R., G. M. Larberg, and L. D. Recker, 1985, Hydrodynamic flow in Lower Cretaceous Muddy Formation, northeast Powder River Basin, Wyoming and Montana: Wyoming Geol. Assoc. 36th Field Conf. Guidebook, p. 149-156.

An average Hydrodynamic flow gradient of 50 ft/mi (10 m/km) reaches from the Muddy outcrop westward into the Powder River Basin. The distribution pattern of the porous sandstone controls the flow direction and rates. The Mowry Shale serves as a source rock for the Muddy.

The Muddy sandstones are irregular lenses and oil collects in stratigraphic traps. Flow rates vary from field to field within the Powder River Basin. The oil column for several fields is calculated as follows; 130 ft (40 m) at Recluse Field, 208 ft (63m) at Draw Field, 429 ft (150 m) at Bell Creek Field, and 700 ft (214 m) at Kitty Field. Vertical flow results in larger oil columns, caused by the vertical pressure gradient and hydrostatic head.

Cheng, A. M. and B. Sharma, 1991, Determination of Favorable Areas for EOR From Differential Oil-in-Place Calculations in Bell Creek Field, Montana: SPE 21824, Rocky Mountain Regional Meeting, Denver, CO., 20 p.

The theory that positive differential OIP areas could indicate the presence of geological heterogeneities like high clay content, sealing faults or different types of flow barriers was tested on data from Bell Creek Field, Montana. DOIP equals volumetric oil-in-place at a given well spacing minus the material balance equation OIP.

Geological and engineering data from 54 wells was analyzed. A differential OIP map indicated several areas with significantly positive and negative differential OIP anomalies.

Differential OIP is dependent on geological heterogeneities and proved an effective index for measuring the importance of such heterogeneities on oil production at Bell Creek Field. Drainage efficiency and effective drainage volume for each well was determined. Optimal well spacing and determination of the best wells for injection and production by waterflood, infill and EOR processes can be analyzed by this method.

Dalziel, M. C. and T. J. Donovan, 1980, Biogeochemical evidence for subsurface hydrocarbon occurrence, Recluse oil field, Wyoming: Preliminary results: U. S. Geological Survey Circular 837, 13 p.

The discovery that anomalous mineral ratios in plants can indicate petroleum leakage into the soils is suggested as a new biogeochemical prospecting tool. Pine needles and sage leaves from plants growing on the surface of Recluse Field in the Power River Basin, Wyoming were tested for manganese to iron ratios. Anomalously high ratios led to study of the soils. Carbon and oxygen isotope ratios suggested that oil leakage was producing a reducing environment that allowed high absorption of iron and manganese. Plant testing can thus be used to monitor oil leakage and to suggest new areas for drilling.

Dolson, J., D. Muller, M. J. Evetts, and J. A. Stein, 1991, Regional paleotopographic trends and production, Muddy Sandstone (Lower Cretaceous), central and Northern Rocky Mountains: AAPG Bull. v. 75, no. 3, p. 409-435.

As of early 1991 more than 1.5 billion BBL of hydrocarbons have been produced from the Muddy Formation. Unconformities caused by sea level changes are the main control on production. Ten or more paleodrainage basins existed when the seas were at their lowest levels. A regional divide in southern Wyoming separated southeast and northwest flowing alluvial systems. Erosion cut into underlying Skull Creek sediments. The best reservoirs developed from coarse grained fluvial systems.

Valley fill and channel reservoirs are the main source of hydrocarbon production. Within a given field the best resources are from marine sandstones. The Skull Creek and Mowry Shale formations are considered the source for hydrocarbons and form traps in the overlying Muddy Sandstone. Numerous maps, correlations and cumulative production data are presented.

Gardner, M. H., and E. R. Gustason, 1987, Valley-fill sequences and onlap geometries, Lower Cretaceous Muddy Sandstone, Kitty Field, Powder River Basin, Wyoming (abst.): AAPG. Bull., v. 71, p. 558.

The valley-fill sequence of Muddy Sandstone at Kitty Field, Wyoming, comprises a series of depositional units which onlap the erosional surface. The main reservoirs in the sequence are channel belt sandstones at the base and barrier bar sandstones at the top.

Gustason, E. R., 1988, Depositional and tectonic history of the Lower Cretaceous Muddy Sandstone, Lazy B Field, Powder River Basin, Wyoming: Wyoming Geol. Assoc. 39th Field Conf. Guidebook, p. 129-146.

The Lazy B Field is a large producing oil field located in the center of the Powder River Basin. Production from the Lower Cretaceous Muddy Sandstone by 1988 was over 2.2 MMBBL liquid and 4800 MMCF gas. The unconformable contact of the Muddy Sandstone over the underlying Skull Creek Shale at Lazy B Field reveals over 40 ft of erosion into the shale.

The sandstones at Lazy B Field are chert-rich subarkoses and arkose. Sandstone reservoirs at Kitty and Recluse fields are fluvial quartz arenites. The morphology and texture of the Muddy Sandstone at Lazy B Field suggests wave dominated or storm modified marine deposition. The sandstone sequences coarsen and thicken upward in progradational strandline deposits. The northeast trend of the Lazy B sandstones is an erosional remnant of a sheet strandplain deposit preserved in this small area. The preservation was caused by tectonic movements which produced a graben. The Lazy B Field may overlie a strike-slip fault in the Precambrian basement rocks.

Gustason, E. R., T. A. Ryer, and S. K. Odland, 1988, Stratigraphy and depositional environments of the Muddy Sandstone, Northwestern Black Hills, Wyoming: Wyoming Geol. Assoc., Earth Science Bull., v. 20, p. 49-60.

The Muddy Formation at Bell Creek Field is interpreted as a topographic feature formed during prolonged subaerial erosion of a once widespread regressive sand sheet.

Honarpour, M., R. A. Schatzinger, M. J. Szpakiewicz, S. R. Jackson, L. Tomutsa, and M. M. Chang, 1990, Integrated Methodology for Constructing a Quantified Hydrodynamic Model for Clastic Shallow Marine Petroleum Reservoirs: DOE Report NIPER-439, 152 p.

A methodology for integrating geological and reservoir engineering information is presented. The methodology addresses: (1) data collection, organization, evaluation and integration; (2) hydrodynamic model construction and verification; and (3) prediction and ranking of reservoir parameters by numerical simulation. The types of data used include; petrophysical analyses, core descriptions, structural analyses, petrographic analyses, rock-fluid interaction analyses, well tests, wireline log analyses, production/injection data analyses, pressure history, drive mechanisms and analogous reservoir, outcrop and modern depositional descriptions. These factors can be combined to construct a three-dimensional hydrodynamic model for an oil reservoir. The basis for construction of this model was the shoreline barrier island system at Bell Creek, Field, Montana.

Honarpour, M, M. Szpakiewicz, B. Sharma, M. M. Chang, R. Schatzinger, S. Jackson, L. Tomutsa and N. Maerefat, 1989, Integrated Reservoir Assessment and Characterization: DOE Report NIPER-390, 336 p.

The Lower Cretaceous Muddy Formation at Bell Creek Field, Montana was the site of a multidisciplinary evaluation of barrier island and associated overlying valley fill deposits. The objective was to present an integrated reservoir model for the prediction of fluid flow and entrapment of residual oil through an understanding of reservoir heterogeneities. Knowledge of the heterogeneities that affect the production can improve EOR project management and design.

The second objective was to develop a methodology for reservoir characterization of barrier island reservoirs. The barrier island facies at Bell Creek Field are described and their influence on production is discussed. The most productive facies at Bell Creek Field was the high energy barrier island core. Heterogeneities includes: fluid related parameters, depositional features, the structural framework, diagenesis and faulting. After ten years of waterflooding the remaining oil saturation was highest in the most geologically heterogeneous part of the reservoir. The Dykstra-Parsons coefficient was used to identify these areas.

Honarpour, M. M., M. Szpakiewicz, R. A. Schatzinger, L. Tomutsa, H. B. Carroll, Jr. and R. W. Tillman, 1988, Integrated Geological/ Engineering Model for Barrier Island Deposits in Bell Creek, Montana: SPE/DOE paper 17366, Sixth Symposium on Enhanced Oil Recovery, Tulsa, OK., p. 491-512.

The Lower Cretaceous Muddy Formation in Bell Creek Field produces from geological heterogeneities that control fluid flow. Production, injection, core, log and structural data were used to develop a model for Bell Creek Field.

Engineering parameters used in the model include: analysis of initial production rates; cumulative primary, secondary and tertiary production; pressure test data; electrical resistivity; tracking of injected water; oil depletion; and simulated fluid flow patterns and residual oil saturation distributions.

Geological parameters including stratigraphy, facies dimensions, valley incisions, high permeability channels, reduction in net pay caused by diagenetic clay, fault and structural features all contributed to the multigenetic heterogeneities found in Bell Creek Field.

The techniques used, and descriptions of all the engineering and geological findings are integrated into a model for barrier island deposits in general. Numerous maps; tables of rock and fluid properties, production history, core analysis and structural representations are used to illustrate the model and describe Bell Creek Field in detail.

Honarpour, M., M. Szpakiewicz, et al., 1989, Integrated Reservoir Assessment and Characterization: Dept. of Energy, Bartlesville, Oklahoma, NIPER-390, 336 p.

An integrated multidisciplinary evaluation of the barrier island and associated overlying valley fill deposits of the Lower Cretaceous Muddy Formation at Bell Creek Field, Montana. Two objectives of the study were to improve the predictability of fluid flow and entrapment of residual oil in interwell areas and to develop a generic methodology for characterization of barrier island reservoirs. Understanding fluid movement in enhanced oil recovery (EOR) requires the integration of depositional, diagenetic, structural, and fluid flow models that define heterogeneities within the hydrocarbon reservoir. The study shows that the productive unit in Bell Creek Field is associated with a well-developed, high-energy barrier island facies with low amounts of diagenetic clay cement. Heterogeneities in the field result in large production and residual oil saturation contrasts over small distances.

Jackson, S. R., L. Tomutsa, M. Szpakiewicz, M. M. Chang, M. M. Honarpour, and R. A. Schatzinger, 1991, Construction of a Reservoir Model by Integrating Geological and Engineering Information—Bell Creek Field, a Barrier/Strandplain Reservoir: *in* L. W. Lake, H. B. Carroll, Jr., and T. C. Wesson, eds., Reservoir Characterization II, Academic Press, p. 524-556.

Bell Creek Field, Montana, was studied using a reservoir model which incorporates both geologic and engineering information. A simple, permeability layer model is based on sedimentologically defined units. This model is used to calculate reservoir volumetrics and forecast field and well primary production performance. A flow unit model uses all available geological and engineering information to provide a reservoir description. It is used to predict production performance from secondary and tertiary recovery processes.

Larberg, G. M. B., 1980, Depositional environments and sand body morphologies of the Muddy sandstones at Kitty Field, Powder River Basin, Wyoming: Wyoming Geol. Assoc. 31st Field Conf. Guidebook, p. 117-135.

Kitty Field produces from a stratigraphic trap in the Lower Cretaceous Muddy Formation in Campbell County, Wyoming. The reservoir has an effective porosity of 17% and a maximum permeability of 442 mD. The sandstone body averages less than 15 ft thick. Electric logs have been used to define four zones in the Muddy Sandstone at Kitty Field. The upper three zones were deposited during a transgression of the Lower Cretaceous Sea. The lowest zone was fluvial in origin and deposited unconformably over the Skull Creek Shale. Lateral flood plain deposits and channel sands suggest a stream traversing a coastal swamp. The middle two zones represent strandline deposits, facies recognized include; offshore bar, beach, estuarine, lagoonal and fluvial.

Core data and isopach maps of the logs were used to interpret the environments. The strandlines in the 2nd and 3rd zones were reworked into a wide linear trend by longshore drift, wind and wave-generated bottom currents.

Lin, J. T. C., 1981, Hydrodynamic flow in Lower Cretaceous Muddy Sandstone, Gas Draw Field, Powder River Basin, Wyoming: The Mountain Geologist, v. 18, no. 4, p. 78-87.

The Gas Draw Field in the Powder River Basin produces from the Lower Cretaceous Muddy Sandstone. The trap is a simple stratigraphic trap formed by layers of sandstones and shales. The Muddy Sandstone at Gas Draw has six distinct units. The lowest unit (6th) is fluvial in origin. The next unit (5th) is a transgressive marine deposit grading into a fluvial to shallow marine 4th unit. The 3rd unit is fluvial overbank deposits of bay-lagoonal origin. The 2nd unit is a fluvial-deltaic environment. The upper (1st) unit is lagoon and marsh environments.

The 2nd unit of the Muddy is the major producing zone at Gas Draw Field. It has a permeability of 209 mD and porosity of 22.6%.

Drill stem tests have been used to interpret the fluid flow relationships within the Muddy units at Gas Draw. The oil column is 210 ft with a potentiometric gradient of 32 ft/mi.

Magara, K., 1975, Importance of hydrodynamic factor in formation of Lower Cretaceous combination traps, Big Muddy-South Glenrock area, Wyoming: discussion: AAPG Bull. v. 59, no. 5, p. 890-893.

The author disagrees with the methods and conclusions of Stone and Hoeger (1973) on the hydrodynamic environment of the Big Muddy-south Glenrock field area. Stone and Hoeger postulate a 500 ft/mi tilt in the Dakota Sandstone which alters the hydrodynamics of the area allowing for abnormally high oil columns. The potentiometric map interpreted by the author shows this tilt as much less sufficient. The author suggests that the heights of the oil column result from the lateral facies changes in the reservoirs. "Trapping capacity should be determined by the high-displacement-pressure layers (shales) rather than the low-displacement-pressure layers (sands or silts)."

Marrs, R. W., and G. L. Raines, 1984, Tectonic framework of Powder River Basin, Wyoming and Montana, interpreted from Landsat Imagery: AAPG Bull., v. 68, no. 11, p. 1718-1731.

Landsat images were used to interpret linear features in the Powder River Basin of Wyoming and Montana. Several features were identified trending northwest and one prominent northeast trend. Smaller subparallel trends were interreted as joints, fractures, folds or lithologic changes. Comparison with geological maps and structural data suggests that the prominent lineaments represent surface expression of the boundaries of crustal blocks. The authors suggest that study of lineaments may be useful in petroleum and mineral exploration.

McGregor, A. A., and C. A. Biggs, 1968, Bell Creek Field, Montana: A rich stratigraphic trap: AAPG Bull., v. 52, p. 1869-1887.

A description of the early history and production at Bell Creek Field is presented. Bell Creek is a Lower Cretaceous stratigraphic trap along the east flank of the Powder River Basin. The deposits are at the intersection of nearshore marine bars and deltaic deposits. The nearshore environments formed during a regressive phase of two major advances of the Early Cretaceous sea. The sand bodies are very porous and permeable and are overlain by the Mowry Shale. Drilling is expected to be the best method of exploration for this kind of stratigraphic trap.

Merschat, W. R., 1985, Lower Cretaceous Paleogeography, Big Muddy-South Glenrock area, southeast Power River Basin, Wyoming: Wyoming Geol. Assoc. 36th Field Conf. Guidebook, p. 81-90.

The Big Muddy Anticline was first discovered in 1916 during early exploratory mapping in Wyoming. The first production from the Big Muddy Anticline was from the Shannon Sandstone of Cretaceous Age. More recent deeper drilling has produced from the Frontier, Muddy, Dakota and Lakota formations.

The upper Muddy sands along the eastern and southeastern flanks of the Big Muddy anticline were deposited as near-shore and off-shore bars. The lower Muddy sands were deposited as channel point-bar sands downcut into the Skull Creek Shale. The channel fill of the lower Muddy is nine miles long and averages one mile wide. Log correlations, outcrop samples and production data was used to suggest further areas of potential production.

Michael, R. C., and I. S. Merin, 1986, Tectonic framework of Powder River Basin, Wyoming and Montana, interpreted from Landsat Imagery: Discussion: AAPG Bull., v. 70, no. 4, p. 453-455.

Lineaments mapped from satellite images mark structural features. The authors disagree with Marrs and Raines (1984) that lineaments should be defined by the type of statistical approach used to analyze them. This statistical treatment obscures the individual linear features.

Specific linear features can be correlated with recognizable geological features. The Powder River Basin is used as an example to explain the authors' method of interpreting satellite imagery. Landsat imagery shows northwest and northeast trending linear features in the Hilight Field in the Powder River Basin. These features correlate with isopachs of thickness for the Muddy Sandstone.

Nelson, G. E., 1985, The Cretaceous Geology of Wyoming: Wyoming Geol. Assoc. 36th Field Conf. Guidebook, 184 p.

A series of papers on the geology and hydrocarbon potential of the Cretaceous rocks of Wyoming. Included are papers on structure, stratigraphy, sedimentalogy and hydrology on both large basins and specific oil fields. One section (several papers) is on the production from the Muddy Sandstone in the Powder River Basin.

Noll, J. H., and K. M. Doyle, eds., 1986, Rocky Mountain Oil and Gas Fields: Wyoming Geol. Assoc. Symposium, 272 p.

A series of papers on the geology and hydrocarbon exploration/production in northeast Wyoming and the Dakotas are presented. Five papers cover the Williston Basin. Three papers are on the structure of large oil fields in central Wyoming. Six papers cover topics of stratigraphy, structure and seismic exploration in the Powder River Basin. Illustrations include maps, photographs of core samples, logs and interpretative stratigraphic correlations.

Reynolds, M. W., 1976, Influence of recurrent Laramide structural growth of sedimentation and petroleum accumulation, Lost Soldier Area, Wyoming: AAPG Bull., v. 60, no 1, p. 12-33.

Uplift and anticlinal folding of sediments in the eastern Powder River Basin, Wyoming during the Laramide resulted in the structural features of the Lost Soldier Area. Very thick sandstone sequences accumulated in the Lost Soldier Area. Two periods of anticlinal folding and erosion truncated the older deposits. Folding continued at Lost Soldier through the early Oligocene and thick arkosic sediments filled the basin. Closure of the Lost Soldier anticline occurred during the Paleocene and entrapment of oil continued into the Eocene. Folds formed later than the Eocene are barren of hydrocarbons.

Schatzinger, R., M. Szpakiewicz, and B. Sharma, 1989, Applicable Corelations and Overall Characteristics of Barrier Island Deposystems: DOE Report NIPER 427, 39 p.

Five types of shoreline barriers are described; spits, shoals, barrier islands, barrier peninsulas, and barrier bars. These fall into three genetic groups; aggradational, progradational and transgressive. All shoreline barriers are strongly effected by wave- or tide-dominated coasts. Differences in external dimensions, internal structures, facies sequences and sand body thickness occur in all the types of shoreline barriers. Descriptions and examples of these five types of shoreline barriers are given.

In ancient barriers diagenetic processes may have strongly modified the original sand composition, texture and petrophysical properties of the barriers. Bell Creek Field, Montana was studied as a model of a barrier island shoreline deposit. Three geological facies at Bell Creek were defined by log characteristics. These include a high productive facies (high energy barrier island), an upper sand facies of nonbarrier channel or valley fill deposits and a lower shoreface/lagoonal facies (low energy barrier island/nonbarrier). The high productive facies is the thickest and has the best reservoir quality.

Sharma, B., M. M. Honarpour, S. R. Jackson, R. Schatzinger and L. Tomutsa, 1989, Determining the Productivity of a Barrier Island Sandstone Deposit From Integrated Facies Analysis Based on Log and Core Data and Fluid Production: SPE paper 19584, 64th Tech. Conf., San Antonio, TX., p. 133-148.

Two crossplot techniques are used to distinguish barrier island sandstones. Bell Creek Field, Montana is a shoreline barrier island deposit with a high quality oil producing reservoir. The techniques are based on core-calibrated resistivity, porosity and gamma ray log interpretation. The crossplot pattern was able to distinguish the barrier and nonbarrier sandstones and separate the barrier island sandstone into two facies. Lithologic properties used to differentiate the facies include grain size, pore throat size, sorting, pore-size geometry and amount and distribution of detrital clays. The upper sandstone has a variable thickness and deep valley incisions. The lower shoreface has less variation in lithologic properties.

Results from primary, secondary and two EOR pilot projects indicate that the barrier island reservoir at Bell Creek Field is influenced by heterogeneities which strongly affect waterflood sweep efficiency, and distribution of residual oil saturation.

Sharma, B., M. M. Honarpour, M. J. Szpakiewicz, and R. Schatzinger, 1987, Critical Heterogeneities in a Barrier Island Deposit and Their Influence on Primary, Waterflood and Chemical EOR Operations: SPE 16749, 62th Tech. Conf., Dallas, TX., p. 83-98.

The Muddy Formation productive in Bell Creek, Field, Montana was used as a study area for geological heteogeneities which control fluid production. The facies relationships within the barrier island and adjacent environments are described using core and log correlations, a structural contour map and an isopach map. Faulting and valley incisions occur within the barrier island, and valley fill deposits act as barriers to fluid migration. Permeability and porosity analysis of the barrier island sandstones indicate that the best reservoir quality is in the core of the bar.

A log-derived heterogeneity index map was used with analysis of clay content and sonic and density logs, petrographic analysis and XRD data to chart the distribution of clays in the reservoir. The geological information was integrated with the production data from primary, secondary and tertiary production to identify heterogeneities that significantly affect the capacity of the reservoir.

Sharma, B., M. M. Honarpour, M. J. Szpakiewicz, and R. Schatzinger, 1990, Critical Heterogeneities in a Barrier Island Deposit and Their Influence on Various Recovery Processes: SPE Formation Evaluation, March, p. 103-112.

Geological heterogeneities were studied at Bell Creek Field, Montana using log and core data. Literature from other field studies was examined and the information compared with the Bell Creek Field data. Correlations were made between geologic heterogeneities and fluid production from barrier island reservoirs. The integration of various geological, geophysical and engineering techniques allowed for the identification of heterogeneities that influence production.

Sharma, B., and S. Jackson, 1991, A Crossplot Technique for Discrimination of Various Sandstone Facies in Barrier Island Sandstone Deposits: *in* L. Lake, H. Carroll, Jr., and T. Wesson eds., Reservoir Characterization II, pp. 689-691.

Data from Bell Creek Field, Montana was used to develop a crossplot technique which discriminates between barrier and nonbarrier sandstone facies. The technique is based on interpretation of density, resistivity and gamma ray logs. The technique allows for prediction of productivity from barrier island sandstones based on the distribution of clay, porosity, permeability and oil saturation within each facies.

Slack, P. B., 1981, Paleotectonics and hydrocarbon accumulation, Powder River Basin, Wyoming: AAPG Bull., v. 65, p. 730-743.

The Belle Forche Arch is a vertical uplift of Cretaceous Age extending from the central part of the Powder River Basin. Structural lineaments trend northeast toward the Black Hills Uplift. The topography is marked by escarpments and drainages following deep fracture zones. The deep zones of basement weakness reflect shear zones of Precambrain Age. The shear zones and stresses that formed the Belle Forche Arch occurred repeatedly throughout the Phanerozoic.

Depositional environments and hydrocarbon accumulation was affected by movements along the lineaments. (1) The Minnelusa Formation had localized hydrocarbon production along the crest of the Arch. (2) The Dakota Formation had alluvial point-bar production along the crest. (3) The Lower Muddy Formation formed channel deposits on the downthrown sides of the lineament trends. (4) The Upper Muddy Formation formed marine bars close to the Arch demonstrating changes in lineament strike. (5) The Turner Sandstone deposits overlay the trend of the Muddy channels. (6) The Upper Cretaceous Shannon and Sussex sandstones form offshore marine-bars along the crest of the Belle Fourche Arch.

Smith, D. A., 1988, The integration of hydrodynamics and stratigraphy, Muddy Sandstone, northern Powder River Basin, Wyoming and Montana: *in* Diedrich, R.P., M.A. K. Dyka and W.R. Miller, eds., Wyoming Geol. Assoc. Guidebook, 39th Field Conf., p. 179-189.

Hydrodynamic analysis of total dissolved solids (TDS) data for the Muddy Sandstone reveals regional and localized fluid flow patterns. Variations reflect the isolated and discontinuous nature of the Muddy Sandstone as observed in permeability, sandstone thickness, and anomalously high pressure areas. Bell Creek Field is in the area of low hydraulic gradient. A potentiometric surface ΔP map is used to delineate pressure systems and show barriers to oil migration. The Bell Creek Field map shows significant pressure differences updip from the producing area.

Stone, D. S., and R. L. Hoeger, 1973, Importance of hydrodynamic factor in formation of Lower Cretaceous combination traps, Big Muddy-South Glenrock area, Wyoming: AAPG Bull., v. 57, no. 9, p. 1714-1733.

The Big Muddy-South Glenrock field area in the Powder River Basin has three sandstone reservoirs. The oldest sandstone in the Dakota Formation, followed by the Lower Muddy Sandstone and the Upper Muddy Sandstone. Entrapment of oil in all three reservoirs is stratigraphic, by updip pinchout or facies changes. Shales, siltstone and non-porous, impermeable sandstones are the facies which seal hydrocarbon migration.

The Dakota Sandstone was deposited by a fluvial-deltaic system with a lateral assist by destructive marine processes. The Lower Muddy is a single continuous reservoir along the east flank of the Big Muddy anticline. It is a fluvial deposit with the classic channel pattern of deposition. The Upper Muddy has two sandstone units lying parallel, deposited as barrier bars.

Hydrocarbon production from these fields has been and continues to be high. The oil column in the Dakota oil pool is 2,800 ft, in the Lower Muddy the oil column is 3,000 ft and 1,500 ft in the Upper Muddy. These very high oil columns are the result of a "downdip hydrodynamic flow which has enhanced the oil holding capacity of the low-displacement pressure, updip barrier zones".

Stone, D. S, and R. L. Hoeger, 1975, Importance of hydrodynamic factor in formation of Lower Cretaceous combination traps, Big Muddy-South Glenrock area, Wyoming: reply: AAPG Bull., v. 59, no. 5, p. 894-899.

The authors discuss the comments made by Magara (1975) on their 1973 paper on the hydrodynamics of the Big Muddy-South Glenrock field area. They feel that Maraga has rejected the principles of hydrodynamic theory. Specific points of Magara are discussed and the original explanation for the high oil columns are reiterated. The anomalous oil-water contact of the Dakota at South Glenrock is a fact and can't be disputed. Mathematical equations used by Magara are reinterpreted and used to confirm the author's original claims.

Szpakiewicz, M., K. McGee and B. Sharma, 1987, Geological Problems Related to Characterization of Clastic Reservoirs for Enhanced Oil Recovery: SPEFE, December, p. 449-60.

Reservoir heterogeneities were grouped into four categories: depositional, diagenetic, structural and formation-fluid composition. Study areas for analysis of reservoir heterogeneities were: Big Muddy Field, Wyoming; North Burbank Field, Oklahoma, Bell Creek Field, Montana and El Dorado Field, Kansas. EOR pilot projects in each field encountered geological problems in the areas of deposition, diagenesis, structure and interstitial fluid distribution. Each of these problems were found to cause heterogeneities that affected the production from the field. The problems within each category are listed, defined and suggestions to correct the problems are given where applicable.

Szpakiewicz, M., R. A. Schatzinger, S. R. Jackson, B. Sharma, A. M. Cheng, and M. M. Honarpour, 1990, Selection of a Second Barrier Island Reservoir System for Expanding the Shoreline Barrier Reservoir Model and Refining NIPER Reservoir Characterization Methodology: DOE Report NIPER-472, 55 p.

A review of eighteen shoreline barrier reservoirs was conducted in order to select a second barrier island system for comparison with the Bell Creek Field, Montana barrier model. The criteria for selection included: (1) a reservoir with a shoreline barrier that will expand the model developed based on Bell Creek Field; (2) a prolific oil producer (OOIP greater than 100 MM STB); (3) geological and engineering data from the reservoir available for research; (4) outcrops near the reservoir of analogous age; (5) the reservoir should have had primary and secondary production and be a potential EOR candidate; (6) reservoir should be in the United States, preferably in the Rocky Mountain Region. Using these criteria the Almond Formation in Patrick Draw Field, Sweetwater County, Wyoming was selected for further study.

Szpakiewicz, M., R. Schatzinger, M. Honarpour, M. Tham, and R. Tillman, 1989, Geological and Engineering evaluation of Barrier Island and Valley-Fill Lithotypes in Muddy Formation, Bell Creek Field, Montana: *in*,

Coalson, E.B., ed., Petrogenesis and Petrophysics of Selected Sandstone Reservoirs of the Rocky Mountain Region, The Rocky Mountain Association of Geologist, Denver, Colorado, p. 159-182.

The Lower Cretaceous Muddy Formation produces oil from barrier-island and overlying valley-fill deposits at Unit "A" of Bell Creek Field, Montana. A combined geological and engineering study was made of the depositional, diagenetic, and architectural aspects of the barrier-island and valley-fill deposits; the classification and scaling of geological heterogeneities that affect production; and the petrophysical and production characteristics of the Muddy reservoir rocks. Data were from both Muddy Formation cores from Unit "A" and outcrops around the Powder River Basin.

The productive interval consists of stacked, upward-shallowing barrier-island sandstones. They are confined on the basinward side by valley fills and on the landward side by nonproductive lagoon or estuarine facies. Non-barrier sediments form a large part of the valley fill, generally have low permeability, and contribute little to total oil production. An unconformity separates valley-fill and barrier-island reservoirs. Erosion removed a significant portion of the barrier-island sequence, the best reservoir sandstone.

Depositional, diagenetic, and structural heterogeneities at a variety of scales define the geometry, continuity, and transmissivity of flow units. Large scale heterogeneities include fluid properties, depositional features, and structural framework. Among medium and small scale features are diagenesis and faults. Depositional trends such as sequence of facies, rock textures, and distribution of detrital clays are the most predictable heterogeneities in the barrier-island facies. The least predictable heterogeneities are diagenetic, erosional, and fault-related features.

Tillman, R. W., 1990, Sequence stratigraphy and sedimentology of non-tidal-inlet "channels" through a barrier island, Bell Creek Field, Montana (abst.): *in* Davis, R.A., Jr., D. Nummedal, and R.W. Tillman, Conveners, Tidal Inlet and Related Sand Bodies: Modern and Ancient: SEPM Research Conference San Juan Basin, New Mexico, May, 1990, pages unnumbered.

Only a single barrier was deposited in the area designated as production Units A and B. During a post-barrier drop in sea level several narrow, possibly dendritic, valleys were cut into and locally entirely through the barrier island. These relationships are indicated by:

1. Ability to correlate barrier facies and thicknesses on either side of the valleys.
2. The fill of the valleys varies, bottom to top, from continental to shallow marine.
3. Secondary clays formed as part of an inferred soil zone below an unconformity surface that separates the barrier island sandstones and the valley fill sandstones, siltstones, and shales.
4. Dendritic valleys that cut the barrier island may be connected to a larger valley system recognized over a large portion of the northern Powder River Basin in NE Wyoming.
5. Some valleys are entirely filled with marine shales.

Two periods of post-barrier erosion and sandstone and shale valley-fill are postulated to result from two falls in relative sea level. Earlier valley incisions are broad and relatively shallow and commonly involve erosion of only the top of the barrier. Younger valley fill deposits along the northwest side of Unit A are 30 ft thick where erosion has cut completely through the barrier island and the valleys are filled with marine shale.

One unconformity, interpreted to be a sequence boundary, occurs below the Muddy Sandstone barrier island and it separates back barrier and other facies of the barrier island from the underlying Albian marine Skull Creek Shale. A second sequence boundary occurs between the valley fill and the underlying barrier. No true barrier inlet fills are recognized in the portion of the field designated as Units A and B.

Tillman, R., M. Szapkiewicz, M. Honarpour, and S. Jackson, 1988, Reservoir Description and Production History; Bell Creek Field, Muddy Sandstone, Barrier Island, and Valley Fill Deposits (abst.): AAPG Bull, v. 72, p. 254.

Barrier-island sandstone and related deposits were analyzed to improve our understanding of reservoir management. The model for Bell Creek Field was based on sedimentologic and stratigraphic interpretation. 70 wells were logged and 15 cores were used in the interpretation. The barrier island sandstone is composed of stacked shallowing-upward sequences. Facies present in the Bell Creek Field Unit A include; foreshore, upper shoreface, lower shoreface, transition, washover and perhaps backshore. There were two periods of erosion and valley fill incised into the original barrier island sediments.

Heterogeneities within the field vary from small scale diagenetic effects to large scale faces changes and faults. Twenty years of production have required several techniques to produce oil from these heterogeneities. Mapping of the waterflood history indicates significant injection anomalies which have affected production.

Weimer, R. J., J. J. Emme, C. L. Farmer, L. O. Anna, T. L. Davis, and R. I. Kidney, 1982, Tectonic influence on sedimentation, Early Cretaceous, east flank Powder River Basin, Wyoming and South Dakota: Quarterly of Colo. School of Mines, v. 77, no. 4, 62 p.

A review of the effect of structural changes on stratigraphic units in the Powder River Basin. Most oil entrapment in the basin is due to structural development following sedimentation.

Weimer, R. J., C. A. Rebne, and T. L. Davis, 1988, Geologic and seismic models, Muddy Sandstone, Lower Cretaceous, Bell Creek-Rocky Point area, Powder River Basin, Montana and Wyoming: Wyoming Geol. Assoc. 39th Field Conf. Guidebook, Eastern Powder River Basin-Black Hills, p. 161-177.

The Muddy Sandstone in the northern Powder River Basin consists of two genetic units (members) that are separated by a widespread subaerial surface of erosion. The older sandstone member, comprising the reservoir rock at Bell Creek Field, was deposited in shoreline and associated nearshore marine environments. The younger member is a valley fill deposit of fluvial, estuarine and tidal flat environments.

Deposition and distribution of these two genetic units was controlled primarily by relative sea level changes. The Bell Creek sandstone (the older unit) was deposited as a widespread regressive sandstone during a high stand of sea level. A following sea level lowstand caused valley cutting, erosion of all or portions of the Bell Creek sandstone, and paleosoil development causing early diagenesis. A rising sea level resulted in valley filling (the younger unit); coastal onlap and a transgressive surface of erosion that is overlain by black marine shale.

Recurrent movement on basement-controlled fault blocks appears to have controlled distribution of the Muddy members, drainage incisement patterns, present structure and heat flow, and possibly petroleum migration.

Seisimic modeling indicates that it is possible to seismically distinguish Muddy facies changes. A strong Muddy amplitude is associated with a thick valley fill facies, while a low amplitude corresponds to the Bell Creek sandstone.

Wheeler, D. M., E. R. Gustason, and M. J. Furst, 1988, The distribution of reservoir sandstone in the Lower Cretaceous Muddy Sandstone, Hilight Field, Powder River Basin, Wyoming: *in* Giant Oil and Gas Fields, a core workshop, SEPM Core Workshop, Houston, TX., p. 179-228.

The Lower Cretaceous Muddy Sandstone produces oil from thin fluvial and shallow marine sandstones in the Hilight Field. Sea level changes and tectonic movements governed the deposition of the units. The Muddy Sandstone was deposited during a rise in sea level. The Muddy Sandstone was deposited as valley fill in channels cut into the underlying Skull Creek Shale. Two lower members of the Muddy Sandstone are fluvial and fluvial-estuarine deposits in the valley fill. These deposits are scattered and thin and produce only minor amounts of oil. The upper members are fluvial-deltaic and barrier island deposits. The barrier island sands are thicker and good oil producers as are the delta front sands.

Three northeast-trending structural lineaments cross the Hilight Field. Tectonic movement occurred along these lineaments before and during the early Cretaceous, and developed the drainage system which the Muddy Sandstone fills. Recurrent movement allowed the barrier islands sands to become stacked. Maps, cores, and reconstructions are used to illustrate the stratigraphic and structural development of the Hilight Field.

Wyoming Geological Association, 1981, Powder River Basin Oil and Gas Fields (2 vols.): Wyoming Geol. Assoc., 472 p.

A complete survey through 1980 of the oil and gas fields drilled in the Powder River Basin of Wyoming. The fields are listed alphabetically by name. Information for each field includes: range and township location; date of discovery; general field data on number of wells, dates, and production; reservoir data on formation, lithology and oil statistics; a general discussion of the field history; and maps of the structure of the field.

APPENDIX C

This file contains permeability and porosity data measured from 1-inch diameter cores drilled from Muddy Formation outcrops in northeast Wyoming. X and Y values are an arbitrary grid imposed on the outcrop for sample locations.

Facies abbreviations are as follows: LS= Lower Shoreface; MS=Middle Shoreface; US=Upper Shoreface; LF= Lower Foreshore; F=Foreshore; UF= Upper Shoreface; TC= Tidal Channel.

Outcrop	X	Y	Permeability	Porosity	Facies
22	-900	15.5	0.26	0.09	UF
22	-900	13.5	326.68	0.30	LF
22	-900	25	69.63	0.19	TC
22	-900	14	467.34	0.30	LF
22	-900	9.5	3216.95	0.33	US
22	-900	14.5	184.24	0.27	LF
22	-900	8.5	3008.58	0.33	US
22	-900	2	579.33	0.30	LS
22	-900	7.5	2200.84	0.33	US
22	-900	2.5	587.93	0.30	LS
22	-900	6.5	1987.76	0.33	US
22	-900	3	102.12	0.77	LS
22	-900	11.5	471.22	0.32	LF
22	-900	23	0.08	0.07	?TC
22	-900	12	1893.56	0.36	LF
22	-900	24	0.25	0.12	?TC
22	-900	4.5	1660.56	0.32	US
22	-900	16.5	435.81	0.29	UF
22	-900	10	1344.22	0.32	US
22	-900	16.5	1606.08	0.33	UF
22	-900	8	2866.84	0.33	US
22	-900	16	2220.51	0.33	UF
22	-900	6	2715.95	0.33	US
22	-900	10.5	2597.86	0.32	US
22	-900	12.5	714.47	0.32	LF
22	-900	15	0.15	0.09	UF
22	-900	9	2675.69	0.32	US
22	-900	15	2509.74	0.34	UF
22	-900	5.5	2548.03	0.34	US
22	-900	7	2398.52	0.33	US
22	-900	13	279.65	0.30	LF
22	-900	24.5	28.82	0.16	?TC
22	-360	6	1420.22	0.34	LF
22	-360	4	4076.36	0.31	US
22	-360	4.5	2315.19	0.34	US
22	-360	11.5	469.40	0.30	UF
22	-360	5	894.53	0.30	US

Outcrop	X	Y	Permeability	Porosity	Facies
22	-360	0	2231.68	0.34	US
22	-360	5.5	4580.09	0.36	US
22	-360	1	2581.13	0.35	US
22	-360	10	477.29	0.30	LF
22	-360	2	2429.12	0.33	US
22	-360	9.5	180.06	0.27	LF
22	-360	3	4142.40	0.35	US
22	-360	9	354.20	0.29	LF
22	-360	11	1416.22	0.32	UF
22	-360	8.5	461.72	0.29	LF
22	-360	0.5	2108.21	0.36	US
22	-360	8	765.12	0.30	LF
22	-360	2.5	3773.67	0.34	US
22	-360	7	1334.67	0.35	LF
22	-360	12.5	143.55	0.30	UF
22	-360	3.5	2983.89	0.34	US
22	-360	1.5	530.56	0.33	US
22	-360	6.5	689.29	0.33	LF
22	100	12	1719.05	0.32	MS
22	100	8.5	1421.71	0.36	MS
22	100	4	162.62	0.28	LS
22	100	8	2238.98	0.36	MS
22	100	14	2405.02	0.33	LF
22	100	3.5	177.32	0.28	LS
22	100	5.5	1438.24	0.33	LS
22	100	6.5	1925.29	0.36	MS
22	100	12.5	3250.26	0.38	MS
22	100	3	23.30	0.24	LS
22	100	10	1918.24	0.33	MS
22	100	9.5	1855.10	0.33	MS
22	100	7.5	573.28	0.33	MS
22	100	1	1.52	0.17	LS
22	100	7	1314.20	0.36	MS
22	100	11	2059.34	0.32	MS
22	100	6	1177.37	0.35	LS
22	100	5	397.18	0.33	LS
22	100	1.5	73.35	0.26	LS
22	100	13	2221.86	0.33	MS
22	100	13.5	3316.34	0.33	MS
22	100	9	2153.52	0.34	MS
22	100	2	6.43	0.23	LS
22	100	11.5	1755.15	0.33	MS
22	150	10	2276.16	0.33	MS
22	150	12	2536.87	0.34	MS
22	150	14	1894.48	0.33	LF
22	150	8.5	2212.72	0.36	MS
22	150	7.5	1660.67	0.35	MS
22	150	9	1353.17	0.33	MS

Outcrop	X	Y	Permeability	Porosity	Facies
22	150	7	2088.11	0.34	MS
22	150	11	3060.17	0.34	MS
22	150	8	340.71	0.24	MS
22	150	13	2343.41	0.33	MS
22	150	5	306.29	0.31	LS
22	150	10.5	2319.23	0.34	MS
22	150	9.5	1050.35	0.33	MS
22	150	11.5	2916.86	0.34	MS
22	150	5.5	1046.19	0.34	LS
22	150	6.5	1405.70	0.35	MS
22	150	13.5	2208.69	0.32	LF
22	150	14.5	1103.12	0.33	LF
22	150	6	1916.14	0.34	MS
22	400	6.5	2466.51	0.32	MS
22	400	0.5	1678.67	0.32	LS
22	400	8	2547.17	0.37	MS
22	400	1	765.21	0.32	LS
22	400	4.5	998.30	0.33	MS
22	400	5	161.94	0.21	MS
22	400	4	1584.81	0.33	MS
22	400	9.5	2944.05	0.33	MS
22	400	3.5	942.16	0.32	LS
22	400	5.5	2036.11	0.34	MS
22	400	7.5	2934.95	0.34	MS
22	400	7	2650.95	0.35	MS
22	400	3	1895.70	0.35	LS
22	400	10	2485.76	0.33	MS
22	400	6	2167.02	0.33	MS
22	400	8.5	3245.82	0.35	MS
22	400	2.5	1776.34	0.36	LS
22	400	1	1802.97	0.33	LS
22	400	1.5	946.04	0.33	LS
22	400	9	2007.87	0.31	MS
22	490	5.5	1904.18	0.34	MS
22	490	17.5	2908.95	0.34	UF
22	490	9.5	2233.42	0.36	MS
22	490	8	2132.95	0.35	MS
22	490	6.5	1441.04	0.33	MS
22	490	7	2261.91	0.35	MS
22	490	16.5	1460.57	0.33	UF
22	490	0.5	16.50	0.23	LS
22	490	15	611.13	0.30	LF
22	490	4.5	1480.89	0.34	MS
22	490	9	2325.37	0.33	MS
22	490	2.5	49.04	0.28	LS
22	490	3	546.80	0.32	MS
22	490	17	56.58	0.28	UF
22	490	3	162.37	0.30	MS

Outcrop	X	Y	Permeability	Porosity	Facies
22	490	8.5	2041.50	0.34	MS
22	490	12	2816.02	0.34	MS
22	490	2	41.94	0.21	LS
22	490	13	1897.30	0.36	MS
22	490	5	1273.50	0.35	MS
22	490	10.5	2797.10	0.34	MS
22	490	10	3085.91	0.36	MS
22	490	7.5	2735.79	0.35	MS
22	490	13.5	2192.12	0.37	MS
22	490	16	76.32	0.24	UF
22	490	14	1060.12	0.36	LF
22	490	15.5	194.71	0.30	UF
22	490	14.5	1145.64	0.33	LF
22	490	6	1561.34	0.34	MS
22	490	11	2660.79	0.34	MS
22	490	11.5	2616.22	0.35	MS
22	490	14.5	1145.67	0.37	LF
22	490	0.5	0.05	0.07	LS
22	603	12	3592.40	0.36	MS
22	603	6	2547.41	0.35	MS
22	603	10	2613.37	0.33	MS
22	603	3	1543.70	0.36	MS
22	603	1	23.69	0.23	LS
22	603	13	1408.44	0.35	MS
22	603	5	1061.84	0.36	MS
22	603	7	2064.61	0.34	MS
22	603	4	1306.11	0.34	MS
22	603	2	207.16	0.30	LS
22	603	9	2773.75	0.35	MS
22	603	8	2855.08	0.35	MS
22	620	3	22.01	0.24	MS
22	625	10.5	3586.87	0.37	MS
22	625	7.5	1874.53	0.35	MS
22	625	8.5	2706.67	0.36	MS
22	625	3	60.74	0.28	MS
22	625	12.5	4126.89	0.35	MS
22	625	0.5	0.08	0.04	LS
22	625	11.5	2563.38	0.34	MS
22	625	8	3261.59	0.36	MS
22	625	2	6.54	0.22	LS
22	625	5	1561.51	0.34	MS
22	625	5.5	1958.95	0.36	MS
22	625	17	1923.04	0.36	LF
22	625	14.5	1584.84	0.32	LF
22	625	16	1208.34	0.32	LF
22	625	9.5	3050.76	0.33	MS
22	625	15	572.86	0.32	LF
22	625	4	1389.60	0.34	MS

Outcrop	X	Y	Permeability	Porosity	Facies
22	625	6.5	2231.53	0.36	MS
22	625	2	5.72	0.24	LS
22	625	6	1457.37	0.36	MS
22	625	7	1486.33	0.35	MS
22	625	0	0.09	0.04	LS
22	625	12	5177.04	0.38	MS
22	625	16.5	179.63	0.31	LF
22	625	2.5	18.76	0.19	LS
22	625	10	2968.93	0.35	MS
22	625	4	1048.89	0.34	MS
22	625	9	2585.82	0.34	MS
22	625	3.5	1009.95	0.36	MS
22	625	15.5	561.35	0.31	LF
22	625	13.5	1621.92	0.34	MS
22	625	1.5	10.62	0.22	LS
22	625	4.5	938.76	0.34	MS
22	750	12.5	3114.25	0.35	MS
22	1175	0	0.26	0.11	LS
22	1175	4.5	798.30	0.34	US
22	1175	5	1376.55	0.36	US
22	1175	2	18.13	0.23	LS
22	1175	5.5	2457.05	0.38	US
22	1175	1	5.48	0.08	LS
22	1175	6	3208.83	0.38	US
22	1175	2.5	61.66	0.23	LS
22	1175	6.5	2617.18	0.37	US
22	1175	2.5	656.06	0.38	LS
22	1175	9	3115.05	0.37	US
22	1175	10.5	3385.07	0.37	US
22	1175	12	3924.68	0.48	US
22	1175	10	3668.37	0.38	US
22	1175	11.5	3536.04	0.35	US
22	1175	11	4007.44	0.32	US
22	1175	12.5	2821.76	0.35	US
22	1175	9.5	2605.23	0.34	US
22	1175	3.5	123.29	0.30	US
22	1175	7	2615.22	0.37	US
22	1175	3	86.56	0.29	LS
22	1175	7.5	2365.98	0.36	US
22	1175	0.5	0.07	0.03	LS
22	1175	8	2354.31	0.35	US
22	1175	4	1804.50	0.36	US
22	1175	13.5	3508.98	0.36	UF
22	1175	11.5	3739.09	0.36	US
22	1175	8.5	2220.41	0.36	US
22	490	1	56.60	0.23	LS
22	490	4	870.14	0.32	MS
22	40	1	353.52	0.31	LS

Outcrop	X	Y	Permeability	Porosity	Facies
22	45	1	25.51	0.23	LS
22	95	1	14.92	0.24	LS
22	105	1	17.01	0.26	LS
22	105	1	25.23	0.24	LS
22	445	1	76.43	0.28	LS
22	450	1	45.34	0.26	LS
22	455	1	67.54	0.25	LS
22	475	1	43.50	0.25	LS
22	480	1	24.81	0.24	LS
22	485	1	16.72	0.24	LS
22	490	1.5	13.39	0.21	LS
22	495	1	14.88	0.22	LS
22	500	1	19.41	0.23	LS
22	515	1	7.89	0.18	LS
22	590	1	28.43	0.25	LS
22	595	1	8.87	0.25	LS
22	600	1	15.19	0.22	LS
22	605	1	515.75	0.33	LS
22	630	1	19.83	0.21	LS
22	635	1	8.64	0.23	LS
22	640	1	35.03	0.28	LS
22	640	1	24.50	0.23	LS
22	650	1	39.99	0.23	LS
22	1105	2.5	30.35	0.38	LS
22	1140	2.5	15.17	0.38	LS
22	1145	2.5	12.66	0.38	LS
22	1150	2.5	22.94	0.38	LS
22	1155	2.5	91.14	0.38	LS
22	1160	2.5	73.28	0.38	LS
22	1165	2.5	93.79	0.38	LS
22	1175	2.5	226.83	0.38	LS
22	1180	2.5	106.04	0.38	LS
22	1185	2.5	35.92	0.38	LS
22	1185	2.5	87.34	0.38	LS
22	1185	2.5	85.35	0.38	LS
22	10	3	1629.88	0.35	LS
22	20	3	402.62	0.22	LS
22	25	3	1202.82	0.30	LS
22	30	3	1022.63	0.35	LS
22	35	3	824.73	0.34	LS
22	40	3	1084.31	0.34	LS
22	45	3	1679.50	0.34	LS
22	50	3	1650.39	0.35	LS
22	80	3	1495.08	0.34	LS
22	95	3	1092.44	0.35	LS
22	100	4.5	241.05	0.30	LS
22	105	3	222.65	0.31	LS
22	110	3	779.47	0.34	LS

Outcrop	X	Y	Permeability	Porosity	Facies
22	120	3	1480.49	0.34	LS
22	125	3	547.90	0.33	LS
22	130	3	1340.77	0.35	LS
22	135	3	748.37	0.35	LS
22	155	3	636.78	0.33	LS
22	400	3	387.12	0.28	LS
22	405	3	1680.86	0.35	LS
22	415	3	1641.70	0.36	LS
22	420	3	302.03	0.32	LS
22	445	3	309.96	0.28	LS
22	450	3	166.24	0.28	LS
22	455	3	53.14	0.24	LS
22	470	3	1214.42	0.34	LS
22	475	3	1874.94	0.34	LS
22	480	3	89.16	0.26	LS
22	485	3	104.40	0.27	LS
22	490	3.5	589.43	0.32	MS
22	495	3	322.40	0.25	MS
22	500	3	281.60	0.29	MS
22	515	3	27.13	0.32	MS
22	520	3	993.43	0.32	MS
22	520	3	1223.18	0.35	MS
22	525	3	1402.88	0.34	MS
22	535	3	1004.31	0.34	MS
22	585	3	1408.78	0.33	MS
22	590	3	2015.03	0.34	MS
22	600	3	1069.16	0.35	MS
22	610	3	917.23	0.32	MS
22	615	3	578.49	0.33	MS
22	615	3	578.49	0.33	MS
22	630	3	247.03	0.32	MS
22	635	3	323.89	0.31	MS
22	640	3	130.30	0.32	MS
22	645	3	1964.63	0.38	MS
22	645	3	1637.47	0.38	MS
22	645	3	1637.47	0.38	MS
22	650	3	1354.77	0.37	MS
22	655	3	403.27	0.33	MS
22	655	3	1471.50	0.35	MS
22	655	3	852.18	0.33	MS
22	655	3	403.27	0.32	MS
22	655	3	469.98	0.45	MS
22	-430	9	1679.27	0.32	MS
22	-425	9	1.99	0.17	MS
22	-420	9	0.33	0.07	MS
22	-415	9	1.61	0.11	MS
22	-410	9	2890.36	0.33	MS
22	-400	9	1711.24	0.31	MS

Outcrop	X	Y	Permeability	Porosity	Facies
22	-395	9	2394.58	0.33	MS
22	-380	9	1044.31	0.32	MS
22	-365	9	1431.82	0.32	MS
22	-355	9	4013.20	0.33	MS
22	-350	9	3732.98	0.32	MS
22	-345	9	1310.85	0.33	MS
22	-340	9	3928.48	0.33	MS
22	-335	9	2856.92	0.33	MS
22	-300	9	2581.04	0.33	MS
22	-285	9	123.95	0.20	MS
22	-280	9	3057.54	0.35	MS
22	-275	9	4524.23	0.33	MS
22	-270	9	2996.45	0.34	MS
22	-250	9	2964.50	0.35	MS
22	-245	9	2976.83	0.33	MS
22	-240	9	2527.04	0.34	MS
22	-235	9	2645.38	0.34	MS
22	-230	9	2835.93	0.34	MS
22	-225	9	1814.42	0.34	MS
22	-215	9	3051.38	0.34	MS
22	-210	9	3606.48	0.33	MS
22	-210	9	3379.18	0.36	MS
22	-200	9	2586.55	0.33	MS
22	-190	9	3326.69	0.22	MS
22	-185	9	2030.31	0.32	MS
22	-180	9	2236.90	0.33	MS
22	-175	9	2529.68	0.33	MS
22	-170	9	2876.87	0.34	MS
22	-165	9	4043.98	0.35	MS
22	-160	9	4154.85	0.38	MS
22	-155	9	2191.29	0.33	MS
22	-72	9	2933.84	0.33	MS
22	-67	9	3247.21	0.33	MS
22	10	11	3223.09	0.33	MS
22	15	11	1912.18	0.33	MS
22	20	11	453.15	0.35	MS
22	25	11	2564.28	0.32	MS
22	30	11	2245.16	0.35	MS
22	35	11	2415.72	0.32	MS
22	40	11	2122.11	0.34	MS
22	45	11	2440.78	0.34	MS
22	50	11	2623.87	0.34	MS
22	55	11	376.34	0.34	MS
22	60	11	1939.49	0.33	MS
22	65	11	2694.61	0.35	MS
22	70	11	1409.83	0.33	MS
22	75	11	1694.76	0.31	MS
22	80	11	1731.08	0.34	MS

Outcrop	X	Y	Permeability	Porosity	Facies
22	105	11	1465.51	0.34	MS
22	110	11	2232.36	0.34	MS
22	115	11	2425.69	0.34	MS
22	125	11	2695.42	0.34	MS
22	130	11	2011.31	0.34	MS
22	135	11	2073.81	0.34	MS
22	140	11	2107.24	0.35	MS
22	145	11	1867.17	0.34	MS
22	155	11	2767.02	0.35	MS
22	160	11	447.52	0.34	MS
22	165	11	2483.41	0.34	MS
22	170	11	3086.90	0.33	MS
22	175	11	1933.28	0.32	MS
22	180	11	2539.02	0.32	MS
22	185	11	2394.11	0.32	MS
22	190	11	2484.92	0.33	MS
22	195	11	2043.85	0.34	MS
22	200	11	2080.47	0.34	MS
22	205	11	2211.31	0.33	MS
22	210	11	3184.91	0.34	MS
22	215	11	1908.17	0.34	MS
22	218.5	11	1678.11	0.34	MS
22	219	11	1500.90	0.33	MS
22	220	11	2678.63	0.32	MS
22	225	11	2619.52	0.34	MS
22	230	11	2525.86	0.35	MS
22	235	11	1116.37	0.32	MS
22	240	11	1081.10	0.34	MS
22	245	11	3986.26	0.34	MS
22	265	11	2812.44	0.35	MS
22	270	11	2876.07	0.33	MS
22	272.5	11	1330.49	0.33	MS
22	275	11	2203.48	0.33	MS
22	277.5	11	1512.18	0.33	MS
22	280	11	384.23	0.34	MS
22	282.5	11	1954.86	0.33	MS
22	285	11	2133.69	0.33	MS
22	287.5	11	2375.35	0.35	MS
22	290	11	2971.46	0.35	MS
22	292.5	11	1651.21	0.33	MS
22	295	11	2953.23	0.34	MS
22	297.5	11	1644.22	0.32	MS
22	300	11	2702.64	0.34	MS
22	300	11	1985.25	0.35	MS
22	302.5	11	2343.48	0.35	MS
22	303	11	3382.77	0.37	MS
22	303.5	11	2684.97	0.60	MS
22	304	11	3160.05	0.36	MS

Outcrop	X	Y	Permeability	Porosity	Facies
22	304.5	11	2445.58	0.34	MS
22	305	11	2702.00	0.36	MS
22	305.5	11	2665.64	0.35	MS
22	306	11	2520.43	0.35	MS
22	306.5	11	2202.19	0.34	MS
22	307	11	2737.33	0.35	MS
22	307.5	11	2287.19	0.32	MS
22	308	11	2329.26	0.33	MS
22	308.5	11	3046.07	0.34	MS
22	309	11	2468.04	0.33	MS
22	309.5	11	1489.68	0.32	MS
22	310	11	2983.29	0.35	MS
22	310.5	11	2398.00	0.34	MS
22	311	11	1891.27	0.33	MS
22	311.5	11	2083.34	0.35	MS
22	312	11	2346.83	0.33	MS
22	312.5	11	2805.70	0.34	MS
22	313	11	2026.60	0.33	MS
22	313.5	11	2578.71	0.33	MS
22	314	11	2611.83	0.34	MS
22	314.5	11	2135.58	0.34	MS
22	315	11	2362.45	0.34	MS
22	315.5	11	2402.43	0.33	MS
22	316	11	2205.15	0.35	MS
22	316.5	11	1477.28	0.33	MS
22	317	11	2477.12	0.33	MS
22	317.5	11	1980.16	0.34	MS
22	318	11	1975.13	0.34	MS
22	320	11	2045.77	0.34	MS
22	322.5	11	1765.90	0.35	MS
22	325	11	2419.85	0.34	MS
22	327.5	11	1802.19	0.34	MS
22	330	11	2813.69	0.36	MS
22	332.5	11	873.44	0.33	MS
22	335	11	3473.67	0.39	MS
22	337.5	11	2714.83	0.35	MS
22	340	11	1590.46	0.34	MS
22	342.5	11	2369.39	0.35	MS
22	345	11	2561.13	0.35	MS
22	347.5	11	959.91	0.33	MS
22	350	11	2970.57	0.34	MS
22	352.5	11	1248.66	0.32	MS
22	355	11	2135.92	0.33	MS
22	357.5	11	2054.03	0.34	MS
22	360	11	2705.90	0.35	MS
22	362.5	11	1445.10	0.34	MS
22	365	11	3246.52	0.35	MS
22	367.5	11	1898.43	0.33	MS

Outcrop	X	Y	Permeability	Porosity	Facies
22	370	11	2818.58	0.36	MS
22	375	11	3398.98	0.35	MS
22	380	11	2975.79	0.35	MS
22	385	11	2616.98	0.34	MS
22	390	11	3477.43	0.34	MS
22	395	11	2550.99	0.36	MS
22	410	11	2372.33	0.34	MS
22	415	11	2389.38	0.33	MS
22	420	11	3581.98	0.35	MS
22	425	11	3183.38	0.34	MS
22	430	11	2671.92	0.34	MS
22	435	11	3296.41	0.34	MS
22	450	11	3514.61	0.36	MS
22	455	11	3628.76	0.36	MS
22	455	11	3121.04	0.35	MS
22	455	11	2430.10	0.34	MS
22	465	11	3567.87	0.36	MS
22	470	11	3082.78	0.37	MS
22	470	11	1855.69	0.32	MS
22	470	11	2884.06	0.35	MS
22	490	12.5	3256.62	0.34	MS
22	490	12.5	1658.00	0.36	MS
22	505	11	2408.37	0.34	MS
22	510	11	2617.44	0.32	MS
22	520	11	2335.97	0.34	MS
22	525	11	1615.27	0.34	MS
22	535	11	2772.71	0.34	MS
22	545	11	15.11	0.25	MS
22	547	11	42.03	0.27	MS
22	550	11	550.07	0.32	MS
22	555	11	239.00	0.29	MS
22	603	11	2638.86	0.35	MS
22	605	11	3234.90	0.38	MS
22	610	11	1992.84	0.33	MS
22	615	11	2722.39	0.36	MS
22	625	11	3358.05	0.37	MS
22	640	11	1077.34	0.35	MS
22	645	11	238.76	0.30	MS
22	655	11	138.51	0.28	MS
22	1050	11	5491.13	0.31	MS
22	1055	11	3198.50	0.31	MS
22	1060	11	4136.53	0.32	MS
22	1065	11	4744.81	0.34	MS
22	1070	11	4956.73	0.32	MS
22	1075	11	4963.78	0.32	MS
22	1080	11	4283.55	0.33	MS
22	1085	11	4795.85	0.34	MS
22	1090	11	3296.11	0.32	MS

Outcrop	X	Y	Permeability	Porosity	Facies
22	1095	11	5797.17	0.33	MS
22	1105	11	6904.30	0.30	MS
22	1110	11	4974.80	0.34	MS
22	1110	11	4711.05	0.35	MS
22	1120	11	6256.90	0.30	MS
22	1130	11	4109.67	0.38	MS
22	1140	11	3560.74	0.32	MS
22	1145	11	2931.58	0.28	MS
22	1155	11	3062.57	0.29	MS
22	1165	11	3428.00	0.32	MS
22	1175	11	2241.12	0.32	MS
22	1176 5	11	3427.69	0.32	MS
22	1180	11	2845.47	0.33	MS
22	1180	11	2471.35	0.34	MS
22	1185	11	2494.17	0.24	MS
22	1215	11	1717.01	0.29	MS
22	1215	11	1336.43	0.31	MS
22	125	8	2642.83	0.35	MS
22	-430	6	1679.27	0.32	MS
22	-365	6	1119.47	0.33	MS
22	-365	8	1153.90	0.34	MS
22	-340	6	927.74	0.29	MS
22	-280	6	2009.37	0.34	MS
22	-275	6	2416.84	0.34	MS
22	-245	6	1196.72	0.32	MS
22	-240	6	2136.12	0.34	MS
22	-235	6	2137.46	0.34	MS
22	-230	6	1954.64	0.34	MS
22	-225	6	1594.58	0.35	MS
22	-200	6	1961.78	0.34	MS
22	-170	6	2202.24	0.32	MS
22	-165	6	2847.15	0.36	MS
22	-160	6	2120.04	0.34	MS
22	-155	6	1358.15	0.31	MS
22	-150	6	1452.08	0.34	MS
22	-72	6	1365.43	0.33	MS
22	-67	6	2820.44	0.35	MS
22	10	8	2189.75	0.36	MS
22	15	8	1428.25	0.36	MS
22	20	8	862.63	0.32	MS
22	25	8	1873.15	0.36	MS
22	30	8	2344.94	0.36	MS
22	35	8	315.72	0.25	MS
22	40	8	789.92	0.31	MS
22	45	8	59.60	0.21	MS
22	50	8	3269.50	0.38	MS
22	55	8	1682.65	0.34	MS
22	60	8	1597.68	0.33	MS

Outcrop	X	Y	Permeability	Porosity	Facies
22	65	8	1777.48	0.35	MS
22	70	8	1888.05	0.34	MS
22	75	8	1384.86	0.33	MS
22	80	8	998.18	0.34	MS
22	105	8	1976.86	0.33	MS
22	110	8	2388.41	0.34	MS
22	115	8	2278.14	0.34	MS
22	120	8	640.41	0.29	MS
22	130	8	1843.22	0.34	MS
22	140	8	1564.14	0.34	MS
22	155	8	2256.22	0.34	MS
22	160	8	1999.65	0.34	MS
22	165	8	1552.10	0.33	MS
22	170	8	1166.13	0.33	MS
22	175	8	1980.75	0.35	MS
22	190	8	300.23	0.25	MS
22	195	8	2129.59	0.36	MS
22	200	8	1919.32	0.35	MS
22	205	8	1737.94	0.32	MS
22	210	8	2029.74	0.33	MS
22	215	8	1335.01	0.33	MS
22	225	8	2144.59	0.33	MS
22	235	8	941.36	0.34	MS
22	235	8	1986.57	0.33	MS
22	240	8	1165.18	0.33	MS
22	245	8	2960.15	0.37	MS
22	270	8	2054.57	0.35	MS
22	275	8	1559.02	0.36	MS
22	280	8	2520.75	0.36	MS
22	285	8	1707.54	0.34	MS
22	290	8	2053.91	0.36	MS
22	300	8	1266.92	0.32	MS
22	305	8	2614.74	0.36	MS
22	310	8	1987.23	0.35	MS
22	315	8	1431.23	0.34	MS
22	320	8	1055.50	0.34	MS
22	325	8	911.93	0.32	MS
22	335	8	2453.91	0.35	MS
22	340	8	1934.71	0.34	MS
22	345	8	2033.18	0.34	MS
22	350	8	2259.27	0.34	MS
22	352.5	8	2441.83	0.34	MS
22	360	8	2346.24	0.34	MS
22	370	8	254.55	0.25	MS
22	375	8	1668.49	0.34	MS
22	380	8	2071.85	0.33	MS
22	385	8	2078.16	0.34	MS
22	410	8	2487.61	0.35	MS

Outcrop	X	Y	Permeability	Porosity	Facies
22	415	8	2674.66	0.35	MS
22	420	8	1794.33	0.34	MS
22	425	8	1978.79	0.35	MS
22	430	8	732.39	0.32	MS
22	435	8	2538.82	0.36	MS
22	440	8	1940.21	0.36	MS
22	445	8	2536.36	0.34	MS
22	445	8	928.55	0.31	MS
22	455	8	429.31	0.34	MS
22	460	8	2181.90	0.35	MS
22	465	8	2275.38	0.35	MS
22	10	8	1639.21	0.36	MS
22	350	8	2874.20	0.35	MS
22	360	8	1955.46	0.33	MS
22	-430	13	1279.58	0.34	LF
22	-425	13	588.40	0.30	LF
22	-420	13	643.59	0.29	LF
22	-400	13	160.81	0.28	LF
22	-395	13	995.14	0.33	LF
22	-390	13	728.22	0.32	LF
22	-365	13	1130.65	0.32	LF
22	-365	13	138.58	0.27	LF
22	-355	8.5	266.05	0.38	LF
22	-350	13	488.34	0.24	LF
22	-340	13	889.65	0.33	LF
22	-335	13	1200.86	0.32	LF
22	-295	13	1531.74	0.33	LF
22	-285	13	1296.36	0.32	LF
22	-270	13	781.84	0.31	LF
22	-265	13	1667.56	0.34	LF
22	-250	13	679.20	0.32	LF
22	-240	13	1834.35	0.31	LF
22	-230	13	2131.44	0.35	LF
22	-225	13	1506.61	0.35	LF
22	-220	13	201.80	0.32	LF
22	-215	13	805.91	0.34	LF
22	-190	13	2666.91	0.34	LF
22	-160	13	1857.77	0.33	LF
22	-155	13	1123.89	0.32	LF
22	-151	13	1175.84	0.31	LF
22	-110	13	749.32	0.04	LF
22	-67	13	885.37	0.38	LF
22	15	14	1234.84	0.32	LF
22	20	14	1156.60	0.31	LF
22	25	14	363.43	0.28	LF
22	30	14	540.48	0.30	LF
22	35	14	950.91	0.21	LF
22	40	14	2276.29	0.33	LF

Outcrop	X	Y	Permeability	Porosity	Facies
22	45	14	928.70	0.32	LF
22	45	14	927.93	0.33	LF
22	50	14	868.13	0.32	LF
22	55	14	738.48	0.32	LF
22	65	14	1933.95	0.34	LF
22	65	14	2090.02	0.32	LF
22	65	14	1933.95	0.33	LF
22	75	14	2200.77	0.32	LF
22	80	14	2085.83	0.34	LF
22	95	14	2311.01	0.33	LF
22	105	14	312.22	0.28	LF
22	110	14	3057.24	0.36	LF
22	115	14	1051.24	0.34	LF
22	120	14	272.92	0.33	LF
22	120	14	1594.97	0.35	LF
22	125	14	440.51	0.33	LF
22	130	14	678.18	0.31	LF
22	135	14	1166.99	0.32	LF
22	140	14	1715.64	0.35	LF
22	145	14	1254.58	0.32	LF
22	157	14	1349.40	0.32	LF
22	160	14	2623.50	0.34	LF
22	188	14	1600.80	0.31	F
22	270	14	729.03	0.35	F
22	300	14	3172.79	0.34	F
22	305	14	1780.92	0.32	F
22	310	14	1943.30	0.32	F
22	315	14	1611.42	0.31	F
22	320	14	1794.97	0.32	F
22	325	14	991.47	0.31	F
22	330	14	1554.71	0.31	F
22	340	14	671.02	0.31	F
22	350	14	91.57	0.29	F
22	350	14	368.54	0.29	F
22	355	14	745.91	0.30	F
22	400	10.5	1654.17	0.31	MS
22	465	14	2490.45	0.36	F
22	493	14	358.99	0.29	F
22	505	14	586.72	0.32	F
22	510	14	317.26	0.30	F
22	520	14	56.48	0.23	F
22	525	14	1517.15	0.33	F
22	535	14	481.57	0.32	F
22	545	14	98.97	0.29	F
22	550	14	9.44	0.25	F
22	555	14	39.39	0.29	F
22	610	14	855.43	0.37	F
22	615	14	1269.38	0.33	F

Outcrop	X	Y	Permeability	Porosity	Facies
22	625	14	2402.39	0.34	MS
22	640	14	355.59	0.32	F
22	645	14	428.82	0.32	F
22	655	14	120.35	0.29	F
22	-430	18.5	181.47	0.28	UF
22	-420	18.5	118.50	0.23	UF
22	-415	18.5	302.27	0.30	UF
22	-385	18.5	0.39	0.15	UF
22	-380	18.5	216.22	0.26	UF
22	-375	18.5	250.92	0.26	UF
22	-370	18.5	83.19	0.23	UF
22	-365		1128.52	0.38	LF
22	-285	18.5	40.38	0.26	F
22	-255	18.5	0.64	0.13	F
22	-250	18.5	311.71	0.28	F
22	-225	18.5	660.06	0.32	F
22	-220	18.5	394.44	0.37	F
22	-112	18.5	188.47	0.29	F
22	-110	18.5	610.14	0.32	F
22	-108	18.5	258.93	0.30	F
22	-67	18.5	136.06	0.28	F
22	-67	18.5	88.11	0.29	F
22	-430	19.5	100.57	0.25	F
22	-415	19.5	18.41	0.24	F
22	-410	19.5	55.93	0.26	F
22	-400	19.5	0.06	0.12	F
22	-395	19.5	0.15	0.10	F
22	-390	19.5	39.31	0.24	F
22	-385	19.5	0.17	0.13	F
22	-372	19.5	0.80	0.09	F
22	-340	19.5	38.45	0.21	F
22	-285	19.5	2.05	0.14	F
22	-160	19.5	7.73	0.23	F
22	-155	19.5	7.23	0.24	F
22	-112	19.5	53.51	0.26	F
22	-72	19.5	265.21	0.26	F
22	-67	19.5	158.63	0.27	F
22	-400	21	0.04	0.05	F
22	-395	21	15.49	0.03	F
22	-390	21	0.07	0.08	F
22	-340	21	0.37	0.04	F
22	-155	21	0.15	0.10	F
22	-67	21	0.08	0.11	F
23	0	1	10.77	0.27	LS
23	0	9	3934.81	0.35	MS
23	0	9	2282.46	0.35	MS
23	0	9	2319.25	0.35	MS
23	5	1	29.67	0.28	LS

Outcrop	X	Y	Permeability	Porosity	Facies
23	5	1	12.16	0.26	LS
23	5	2.5	974.64	0.33	MS
23	5	9	2788.43	0.35	MS
23	5	9	-4665.15	0.36	MS
23	5	13	2194.41	0.33	LF
23	10	2.5	351.13	0.32	MS
23	10	9	3239.50	0.37	MS
23	10	13	3196.61	0.37	LF
23	15	1	44.85	0.29	LS
23	15	2.5	290.63	0.30	MS
23	15	9	2199.39	0.33	MS
23	20	2.5	5.87	0.17	MS
23	20	9	1703.28	0.33	MS
23	20	9	2560.00	0.36	MS
23	20	13	4709.17	0.39	LF
23	25	2.5	680.48	0.35	MS
23	25	9	1406.27	0.35	MS
23	25	13	2500.01	0.35	LF
23	30	9	3044.50	0.35	MS
23	30	9	2645.73	0.38	MS
23	30	13	2682.23	0.34	LF
23	35	9	2184.76	0.37	MS
23	40	9	5010.81	0.35	MS
23	40	9	3139.27	0.35	MS
23	45	2.5	566.81	0.33	MS
23	45	9	1223.37	0.31	MS
23	45	9	2077.08	0.34	MS
23	45	13	2791.19	0.34	LF
23	50	2.5	17.48	0.16	MS
23	50	9	2623.27	0.35	MS
23	50	13	2117.61	0.32	LF
23	50	13	2673.37	0.33	LF
23	55	1	7.12	0.23	LS
23	55	2.5	387.49	0.32	MS
23	55	9	1937.48	0.33	MS
23	55	9	1452.04	0.33	MS
23	55	13	2082.67	0.33	LF
23	60	1	11.91	0.21	LS
23	60	9	3179.39	0.37	MS
23	65	1	8.77	0.21	LS
23	65	9	2690.30	0.35	MS
23	65	13	1649.84	0.32	LF
23	70	1	15.30	0.24	LS
23	70	9	2153.53	0.35	MS
23	70	13	1016.89	0.35	LF
23	73	9	1828.67	0.08	MS
23	73	13	2642.11	0.36	LF
23	73	13	2604.13	0.35	LF

Outcrop	X	Y	Permeability	Porosity	Facies
23	75	1	7.80	0.23	LS
23	75	2.5	215.46	0.31	MS
23	75	9	2382.26	0.35	MS
23	80	1	6.60	0.22	LS
23	80	2.5	191.99	0.30	MS
23	80	9	1488.62	0.36	MS
23	85	2.5	280.54	0.31	MS
23	85	9	2482.36	0.35	MS
23	85	9	2669.05	0.36	MS
23	90	9	2192.99	0.34	MS
23	90	9	898.84	0.32	MS
23	90	13	2778.52	0.35	LF
23	95	1	21.20	0.25	LS
23	95	2.5	67.25	0.29	MS
23	95	9	1678.30	0.35	MS
23	100	2.5	3003.78	0.35	MS
23	100	9	2308.25	0.35	MS
23	100	9	2748.64	0.35	MS
23	100	13	885.52	0.32	LF
23	105	2.5	1486.22	0.34	MS
23	105	9	1382.65	0.34	MS
23	110	2.5	166.14	0.27	MS
23	110	9	5849.74	0.34	MS
23	110	9	1628.65	0.36	MS
23	110	13	2263.94	0.37	LF
23	115	2.5	449.05	0.33	MS
23	115	9	2027.61	0.35	MS
23	120	1	10.83	0.23	LS
23	120	2.5	187.22	0.30	MS
23	120	9	2510.70	0.34	MS
23	120	9	2225.96	0.34	MS
23	120	9	1463.35	0.34	MS
23	125	2.5	132.87	0.30	MS
23	125	2.5	531.80	0.34	MS
23	125	9	3515.09	0.35	MS
23	125	9	2059.59	0.34	MS
23	125	13	1544.83	0.31	LF
23	131	1	26.17	0.26	LS
23	135	1	67.27	0.29	LS
23	135	2.5	582.09	0.34	MS
23	140	1	15.52	0.26	LS
23	145	1	26.61	0.28	LS
23	145	2.5	302.19	0.32	MS
23	150	2.5	259.49	0.29	MS
23	153	1	38.72	0.27	LS
23	153	2.5	250.98	0.32	MS
23	155	0.5	4.50	0.21	LS
23	155	1	7.13	0.23	LS

Outcrop	X	Y	Permeability	Porosity	Facies
23	155	1.5	19.94	0.26	LS
23	155	1.9	21.34	0.26	LS
23	155	2.5	443.03	0.32	storm
23	155	3	123.58	0.26	storm
23	155	3.5	53.39	0.28	storm
23	155	4	275.48	0.32	MS
23	155	4.5	1142.07	0.34	MS
23	155	5	542.93	0.32	MS
23	155	5.5	1073.03	0.34	MS
23	155	6	1812.98	0.34	MS
23	155	6.5	1265.02	0.33	MS
23	155	7	1710.01	0.34	MS
23	155	7.5	2377.28	0.33	MS
23	155	8	2404.89	0.33	MS
23	155	8.5	2039.44	0.33	MS
23	155	9	2227.81	0.33	MS
23	155	9.5	2483.85	0.34	MS
23	155	10	3248.80	0.33	MS
23	155	10.5	2674.30	0.33	MS
23	155	11	2396.67	0.33	MS
23	155	11.5	3026.12	0.33	LF
23	155	12	905.65	0.32	LF
23	155	12.5	1722.89	0.34	LF
23	157	1	15.28	0.24	LS
23	170	9	668.60	0.32	MS
23	170	9	2422.16	0.35	MS
23	170	9	3492.22	0.35	MS
23	175	9	2667.74	0.36	MS
23	175	9	1237.71	0.36	MS
23	180	9	2775.55	0.35	MS
23	183	10	3231.00	0.35	MS
23	183	10.5	2253.67	0.35	MS
23	183	11.5	1487.95	0.33	LF
23	183	12	1903.84	0.34	LF
23	183	12.5	2093.53	0.34	LF
23	183	[illegible]	8247.20	0.94	LF
23	183	14	478.40	0.29	LF
23	183	15	0.13	0.11	LF
386	55	16.5	77.13	0.26	F
386	55	18	40.12	0.26	F
386	55	15.5	76.34	0.27	F
386	55	13.25	142.57	0.28	F
386	55	13.5	169.64	0.30	F
386	55	14	496.94	0.31	F
386	0	11	782.51	0.21	LF
386	0	10.5	2143.61	0.34	LF
386	55	13	523.75	0.38	LF
386	0	1	6.25	0.23	LS

Outcrop	X	Y	Permeability	Porosity	Facies
386	0	0	239.51	0.26	LS
386	0	1.5	422.97	0.31	LS
386	80	8	0.10	0.07	MS
386	40	8	0.09	0.07	MS
386	70	8	0.07	0.08	MS
386	85	8	0.14	0.10	MS
386	45	8	0.83	0.11	MS
386	90	8	0.52	0.12	MS
386	70	8	0.37	0.12	MS
386	0	6	883.36	0.23	MS
386	0	2.5	87.08	0.26	MS
386	0	2	61.18	0.28	MS
386	0	9.5	1832.32	0.32	MS
386	105	8	440.22	0.32	MS
386	0	9	2082.73	0.33	MS
386	0	5.5	688.36	0.33	MS
386	0	8.5	1290.64	0.33	MS
386	0	8	1488.22	0.33	MS
386	0	10	2207.86	0.33	MS
386	0	7.5	1558.25	0.33	MS
386	30	8	2421.01	0.34	MS
386	0	4.5	765.81	0.34	MS
386	75	8	1350.74	0.34	MS
386	110	8	1797.85	0.34	MS
386	0	4	763.44	0.34	MS
386	25	8	1038.34	0.34	MS
386	50	8	1370.87	0.34	MS
386	75	5	1994.29	0.34	MS
386	40	5	1877.26	0.35	MS
386	10	5	2151.71	0.35	MS
386	80	5	2357.56	0.35	MS
386	0	7	1589.93	0.35	MS
386	40	5	2331.48	0.35	MS
386	45	5	2739.45	0.35	MS
386	100	8	2443.41	0.35	MS
386	65	8	2003.22	0.35	MS
386	110	5	2050.39	0.35	MS
386	25	5	2238.48	0.35	MS
386	90	5	2868.39	0.35	MS
386	70	5	1990.10	0.35	MS
386	95	8	2598.72	0.36	MS
386	95	5	2745.34	0.36	MS
386	35	8	3611.80	0.36	MS
386	0	5	2753.76	0.36	MS
386	100	5	2698.31	0.36	MS
386	65	5	2954.25	0.36	MS
386	105	5	3299.28	0.37	MS
386	35	5	3031.42	0.37	MS

Outcrop	X	Y	Permeability	Porosity	Facies
386	15	5	3619.81	0.38	MS
386	85	5	4469.30	0.38	MS
386	55	21	4.84	0.09	TC

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