NIPER-258
Distribution Category UC92A
June 1987

Status Report

STATUS OF GEOLOGICAL MODEL DEVELOPMENT USING OUTCROP AND SUBSURFACE DATA

Project BE1, Task 8A, Milestone 8
FY87 Annual Research Plan

by

Susan Jackson, Liviu Tomutsa,
Michal Szpakiewicz, Bijon Sharma, and Matt Honarpour

Jim Chism, Project Manager
Bartlesville Project Office
U.S. Department of Energy

Work Performed for the
U.S. Department of Energy
Under Cooperative Agreement
DE-FC22-83FE60149

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

IIT Research Institute
NATIONAL INSTITUTE FOR PETROLEUM AND ENERGY RESEARCH
P.O. Box 2128
Bartlesville, OK 74005
(918) 336-2400

Status Report

STATUS OF GEOLOGICAL MODEL DEVELOPMENT USING OUTCROP AND SUBSURFACE DATA

SUMMARY

Detailed geological analysis of 17 subsurface cores was performed. The cores are from wells producing from the Muddy formation located in the Bell Creek field tertiary incentive project (TIP) pilot area, in southeast Montana. Thirteen outcrop exposures of the Muddy formation were described, from which five were selected for sampling and comparison with cores from Bell Creek field.

The following similarities were found between Muddy formation outcrop exposures and their subsurface occurrence in Bell Creek field: (1) facies division and characteristics; (2) sequence of facies and facies thickness; (3) general trends of upward increasing grain size and decreasing burrowing and clay content; and (4) degree of sorting, framework mineralogy, clay mineralogy and calcite cemented zones.

Comparison of outcrop and subsurface pemeabilities and porosities indicate: (1) permeability and porosity values for the upper shoreface facies in both outcrop and subsurface are comparable, with outcrop values being slightly higher, (2) larger permeability contrasts exist between outcrop facies than between the subsurface facies, and (3) outcrop foreshore facies are less permeable than subsurface foreshore facies due to calcite cementation in the outcrop.

Heterogeneities found in both outcrop and subsurface exposures of the Muddy formation which require further work are (1) diagenetic features; (2) valley fill deposits; (3) multiple, vertical stacking of barrier deposits; and (4) faults and fractures.

Productive and nonproductive facies were grouped into three classes according to their storage capacity and transmissivity. The spatial arrangement of these classes has been combined with surface and subsurface data to construct the first barrier-system reservoir model.

INTRODUCTION

Objective

One of the main objectives of the Department of Energy's geoscience research being performed by NIPER for Project BE1 is to develop a methodology for constructing accurate quantitative models of reservoir heterogeneities. The resulting models are expected to improve predictions of flow patterns, spatial distribution of residual oil after secondary and tertiary recovery operations, and ultimate oil recovery.

An important element of the methodology being developed is the use of information derived from outcrop exposures. Outcrops can provide information about the lateral distribution and continuity of reservoir properties and heterogeneities on a scale from inches to 100s of feet--information which cannot be obtained from subsurface data.

The first model to be developed is a geological model which incorporates information from the Muddy formation within the pilot area in Bell Creek field and outcrop exposures of the reservoir. After the geological model has been established, engineering data will be added, and appropriate modifications made, producing a geological/engineering model. The expected product of this research is the development of a methodology for constructing quantitative reservoir models, as well as a general quantitative model of barrier-island deposits, which will be applicable to other reservoirs producing from barrier deposits in other geographic locations.

This report documents the current status of task 8A in the 1987 Annual Plan, "Combine Outcrop Data With Reservoir Data from Waterflood Area," and is milestone 8, a status report on incorporation of outcrop data with reservoir data for geological model of waterflood area. The planned completion date for task 8A is June 30, 1987.

Background Work

After selection of the barrier-island deposystem,[1] the Bell Creek field reservoir and associated Muddy formation outcrops were selected for our study.[2]

Detailed geological analyses of subsurface cores and outcrops were performed, and 17 subsurface cores, from the tertiary incentive project (TIP) pilot area were described. Information collected included sedimentary features, lithology, interpretation of facies, log characteristics, and permeability and porosity characteristics.

Outcrops, selected as being depositionally analogous, were also described and data collected. Thirteen outcrop exposures of the Muddy formation were geologically described. Five outcrops were selected from among the 13 for sampling and permeability and porosity measurements. Outcrops were selected using the following criteria:

1. The outcrops had typical vertical sequences of facies of a barrier island.

2. The outcrops are located within the central part of the barrier island to match the location of the TIP pilot area (179 square acres).

3. The outcrops were distributed over an area comparable to the TIP pilot area (179 square acres).

EXPERIMENTAL

Preliminary Outcrop-Subsurface Comparison

Before incorporating outcrop and reservoir information, it was necessary to establish the degree of similarity between the two data sets and to determine what types of outcrop information are applicable to the subsurface.

The following similarities were found between Muddy formation outcrop exposures and their subsurface occurrence in Bell Creek field:

1. Similar facies designations, based on grain size, sedimentary structures, clay content, and burrows occur in both outcrop and subsurface. Facies divisions, in order of typical downward occurrence, are as follows:

Foreshore	Sand 175 microns
	Low-angle to subhorizontal stratification
	<2% burrowed (Skolithos type)
	Shale and siltstone-trace
Upper Shoreface	Sand 125-175 microns
	Mostly massive (due to burrowing)
	Some low-angle and high-angle stratification, swaley cross stratification
	Burrowing up to 60% (Diplocriterion, Rosellia, Ophiomorpha)
	Shale and siltstone up to 25% (by volume)
Lower Shoreface	Sand 100 microns
	Low angle to subhorizontal stratification
	Hummocky cross-stratification
	Burrowing 10 to 90% (Thallasinoides, Asterosoma, Rossellia)
	Shale and siltstone 25 to 60% (by volume)

2. Sequence of facies and facies thickness (Fig. 1).

3. General trends of upward increasing grain size and decreasing burrowing and clay content.

4. Petrographic features of grain size (fine to medium), degree of sorting (moderate to well-sorted), framework mineralogy (quartz-rich sandstone with up to 10% feldspar), clay mineralogy (predominantly kaolinite) and calcite cemented zones.

Petrophysical Properties

The statistical distribution of porosity values are close to those of a normal distribution, whereas permeability values are close to those of a log-normal distribution in both outcrop and subsurface samples.

A preliminary comparison of permeability and porosity within each facies is shown in figures 2 and 3. Data from 13 wells within the TIP project area and part of the outcrop samples (from one 1,500-ft-long outcrop) are included in the figure. The short vertical bars are the sample mean values, and the horizontal bars represent a 95% confidence interval for the mean which is calculated as follows: $(\sigma/\sqrt{N})2$. The following observations can be made from figure 2:

1. Subsurface samples exhibit the typical increasing permeability upward trend from Lower Shoreface through Upper Shoreface to Foreshore facies, whereas the outcrop foreshore facies is less permeable than the underlying upper shoreface facies.

This anomaly is due to the fact that the foreshore facies is cemented in the outcrop sampled. Another possible explanation of the difference is that the subsurface samples are distributed areally over 179 acres, whereas outcrop samples shown in figure 2 are taken from only 1,500 lateral ft of exposure. Inclusion of data from the remainder of the samples should give a clearer comparison of the two data sets.

2. Larger permeability contrasts exist between outcrop facies than between the subsurface facies. This difference can also be explained by cemented zones within outcrop lower shoreface and foreshore facies and possibly by an increase in secondary porosity caused by dissolution of cements by atmospheric weathering.

3. Permeability values of the upper shoreface facies in both outcrop and subsurface are comparable, with the outcrop values being slightly higher.

Similar relationships as described above occur in porosity values (Fig. 3).

These comparisons illustrate the effects of diagenesis on permeability and underscore the need to document the occurrence and geometry of the cemented zones in the lower shoreface and foreshore facies. The upper shoreface permeability and porosity values, however, are comparable and indicate that the outcrop information from this facies may be used in the subsurface model.

SUBSURFACE STUDY RESULTS

Distinguishing facies in well logs is important for determining the geometry of facies and therefore permeability units. The lower shoreface facies can be distinguished in log responses; however, the upper shoreface and foreshore facies are difficult to distinguish on logs. Preliminary analyses of permeability data (Fig. 2) indicate that these two facies may be considered as one unit because the permeabilities do not differ significantly. Valley fill deposits can be distinguished in only some of the logs. Further work is needed to distinguish valley fill deposits with confidence. Anomolous log responses such as cemented zones can be identified in logs and therefore mapped.

Structure contour, isopach and isoporosity, and iso-clay content maps have been constructed. Structure maps indicate the possibility of small displacement faults oriented northwest-southeast, which is normal to the long axis of the barrier deposit. Isoporosity maps indicate that the central and east-central part of the barrier deposit is most porous. Mapping of the clay content indicates linear regions of cleaner sand. Clay content greatly affects fluid flow; therefore, understanding the spatial distribution of clays is important.

MODELS REQUIREMENTS

Heterogeneities which should be included in the model are as follows:

1. **Diagenesis**

As mentioned above, diagenetic features of cementation and secondary porosity have been identified in both outcrop and subsurface samples. Information which could be added to the model includes: (a) the occurrence of diagenetic features and (2) the dimensions and geometry of the cemented zones.

2. **Valley fill depositions**

Valley fill deposits result from channels cut into the barrier during low sea level and subsequent filling during high sea level stands. Valley fill deposits create flow barriers in Bell Creek field and may compartmentalize the field into separate, noncommunicating producing units. In some cases, however, the deposits are high-permeability channel deposits. Valley fill deposits can also be identified in our outcrop study area. Work required to incorporate this feature in our model is to (a) determine the characteristic lithologies and sequence of lithologies in the outcrop, (b) determine the spatial distribution and geometry of the deposits, (c) correlate the core descriptions with log responses in order to identify valley fill deposits on logs, and (d) map the distribution of valley fill deposits in the subsurface.

3. **Multiple depositional episodes**

Observations of both outcrop and subsurface rocks indicate at least two superimposed episodes of barrier deposition. The sequences are often incomplete in that not all the facies are present in each episode.

4. **Faults and fractures**

No reference to faults or fractures is given in the literature on Bell Creek field; however, the presence of fractures in outcrop indicated the possibility of their presence in the subsurface. Further analysis and detailed correlations within our study area indicate the possible presence of small displacement faults in Unit "A" of Bell Creek field. Well test and seismic data, however, do not indicate faulting. Further work is needed to locate other faults and to determine their effect, if any, on production and secondary recovery.

Although some of these heterogeneities may not be included in the first model, knowledge of their presence and distribution is essential in interpreting subsurface flow data such as primary production, secondary and tertiary production, and well test responses.

Preliminary Geologic Model and Reservoir Definition

At present, a general, simplistic barrier island model can be constructed for the Bell Creek reservoir, showing the distribution of observed barrier and related non-barrier facies (Fig. 4). The superposition of two barrier sequences further complicates the picture. Productive and nonproductive facies, documented in cores from Unit "A" of Bell Creek field and in analogous outcrops, were grouped into three classes (A, B, and C), according to their decreasing storage capacity and transmissivity (Fig. 5). The vertical sequence of the Muddy sediment classes in the central part of Unit "A" (TIP area) are shown in figure 6. Significant erosional reduction of barrier sediments and deep cuts filled with low-permeability sediments are commonly observed in Bell Creek cores. The interplay between barrier and valley fill deposits appears to be one of the most characteristic and significant reservoir heterogeneities affecting oil production from the Bell Creek reservoir. The following tasks must be performed to complete the first geological model:

1. Mapping of spatial distribution of productive facies and variations of thickness and permeabilities.

2. Analyses of the remaining outcrop samples and further comparison of outcrop and subsurface permeability and porosity data.

3. Variograms and horizontal permeability and porosity profiles have been constructed to describe the lateral variations which might be expected. Some additional work is needed to verify the variograms and complete the analysis of horizontal variability.

4. A short field trip is necessary to provide missing elements in the documentation of samples and to document geometry of the permeability and porosity zones.

REFERENCES

1. Jackson, Susan R. Selection of Deposystem for Heterogeneity Research. Status Report. National Institute for Petroleum and Energy Research. Department of Energy Report No. Niper-153. June 1986, 19 pp. Available from DOE Bartlesville (Okla.) Project Office.

2. Szpakiewicz, Michal. Selecting Outcrop For Use in Heterogeneity Research. Status Report. National Institute for Petroleum and Energy Research. Department of Energy Report No. NIPER-229. December 1986, 8 pp. Available from DOE Bartlesville (Okla.) Project Office.

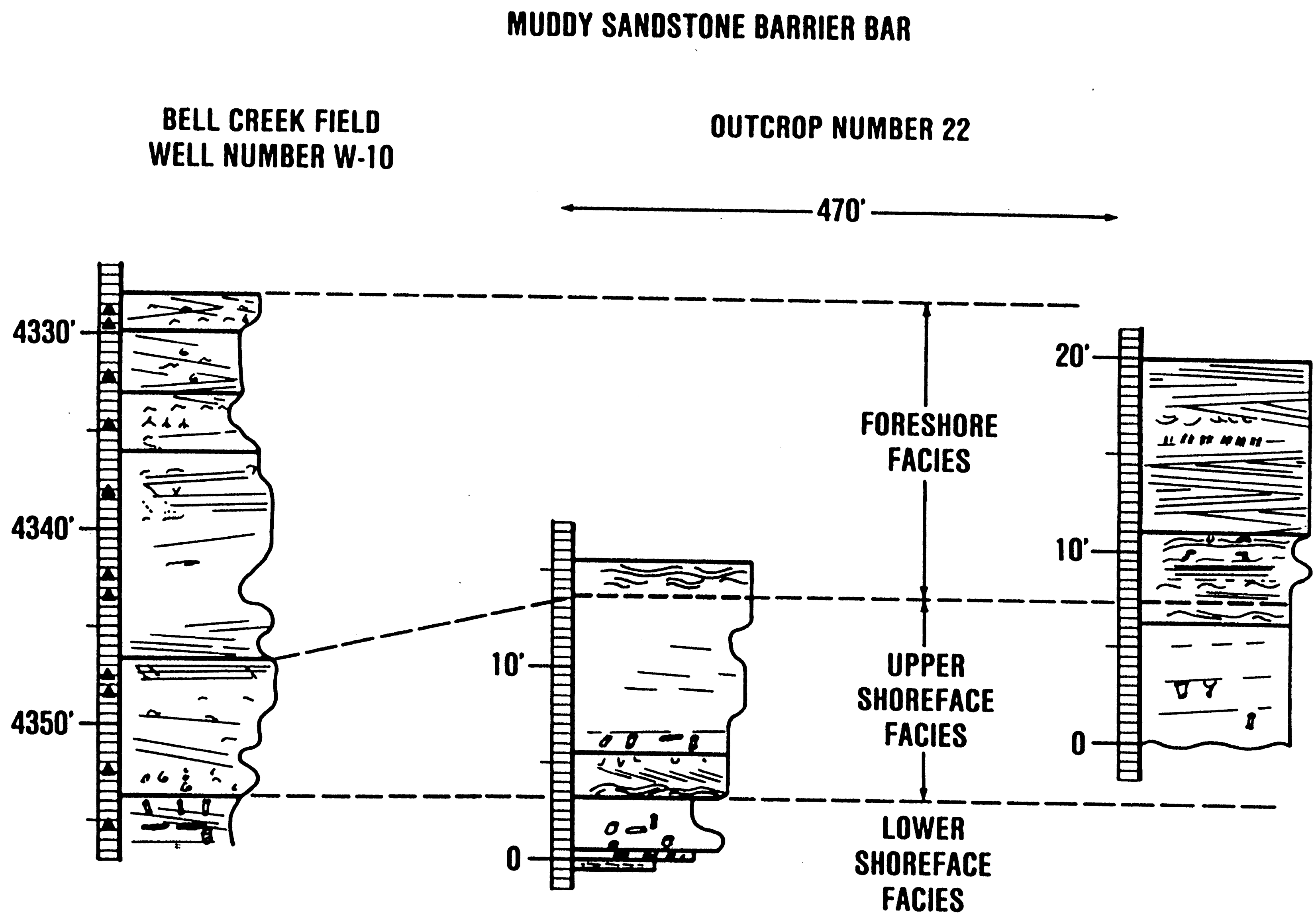

FIGURE 1. - Comparison of vertical sequence and thickness of facies of the Muddy formation in outcrop exposures and Bell Creek field reservoir.

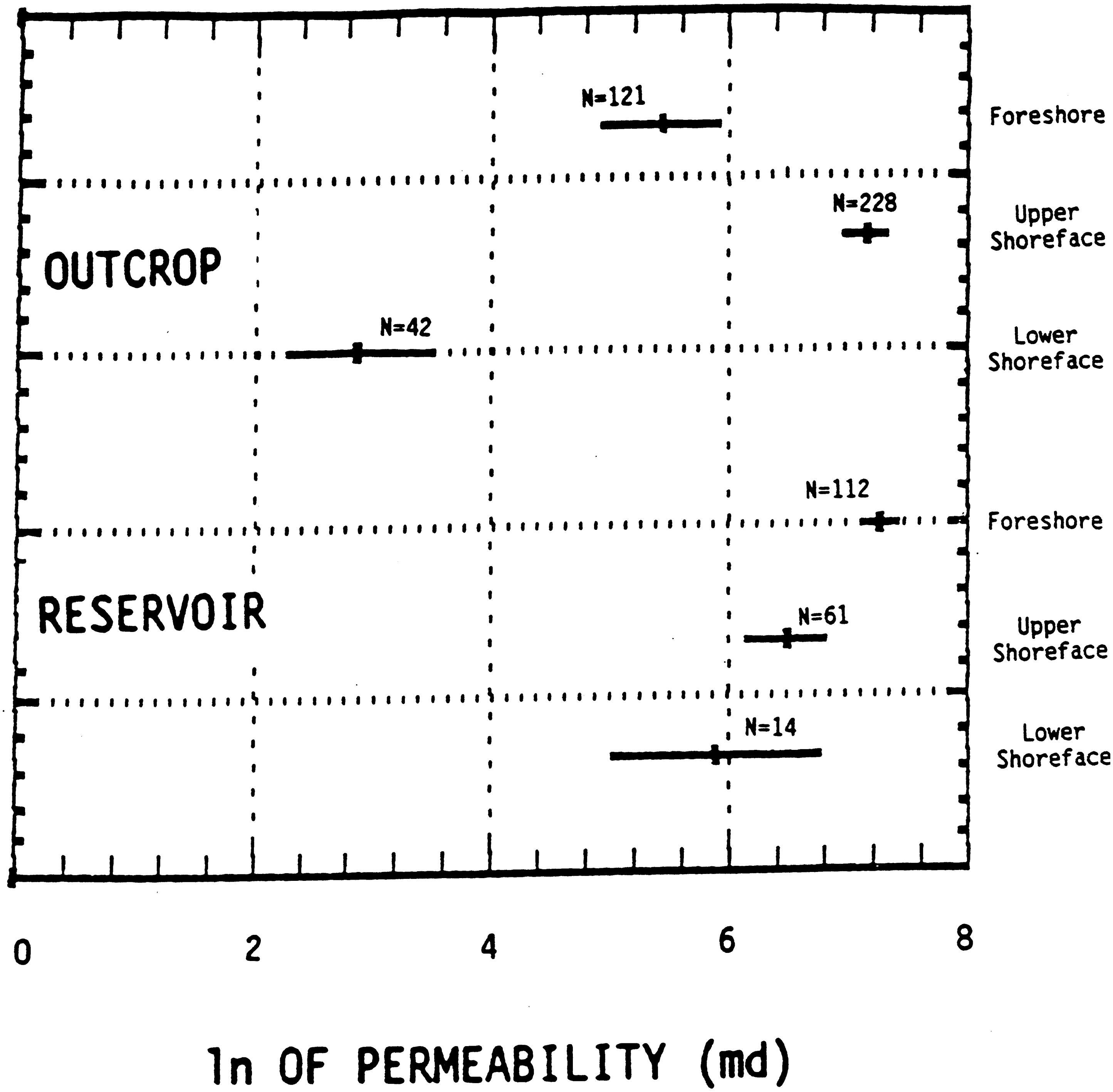

FIGURE 2. - Comparison of nature logarithm (ln) of permeability of Muddy formation facies in outcrops and the Bell Creek field reservoir. Short, vertical bars indicate mean permeability; extent of horizontal bars represent 95% confidence interval for the mean. N is the number of permeability values for each facies.

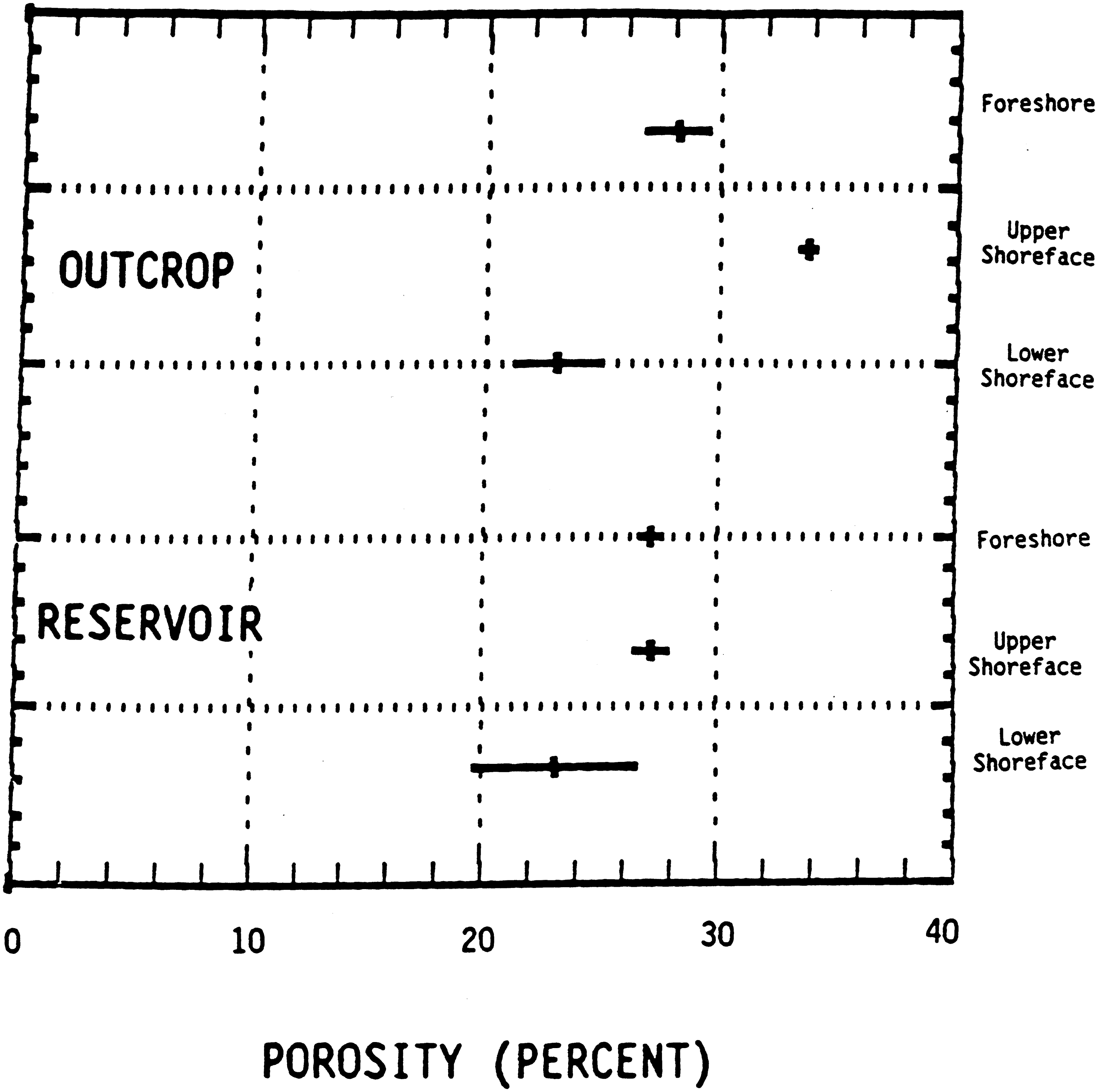

FIGURE 3. - Comparison of percent porosity of Muddy formation facies in outcrops and the Bell Creek field reservoir. See figure 2 caption for explanation of symbols and number of values for each facies.

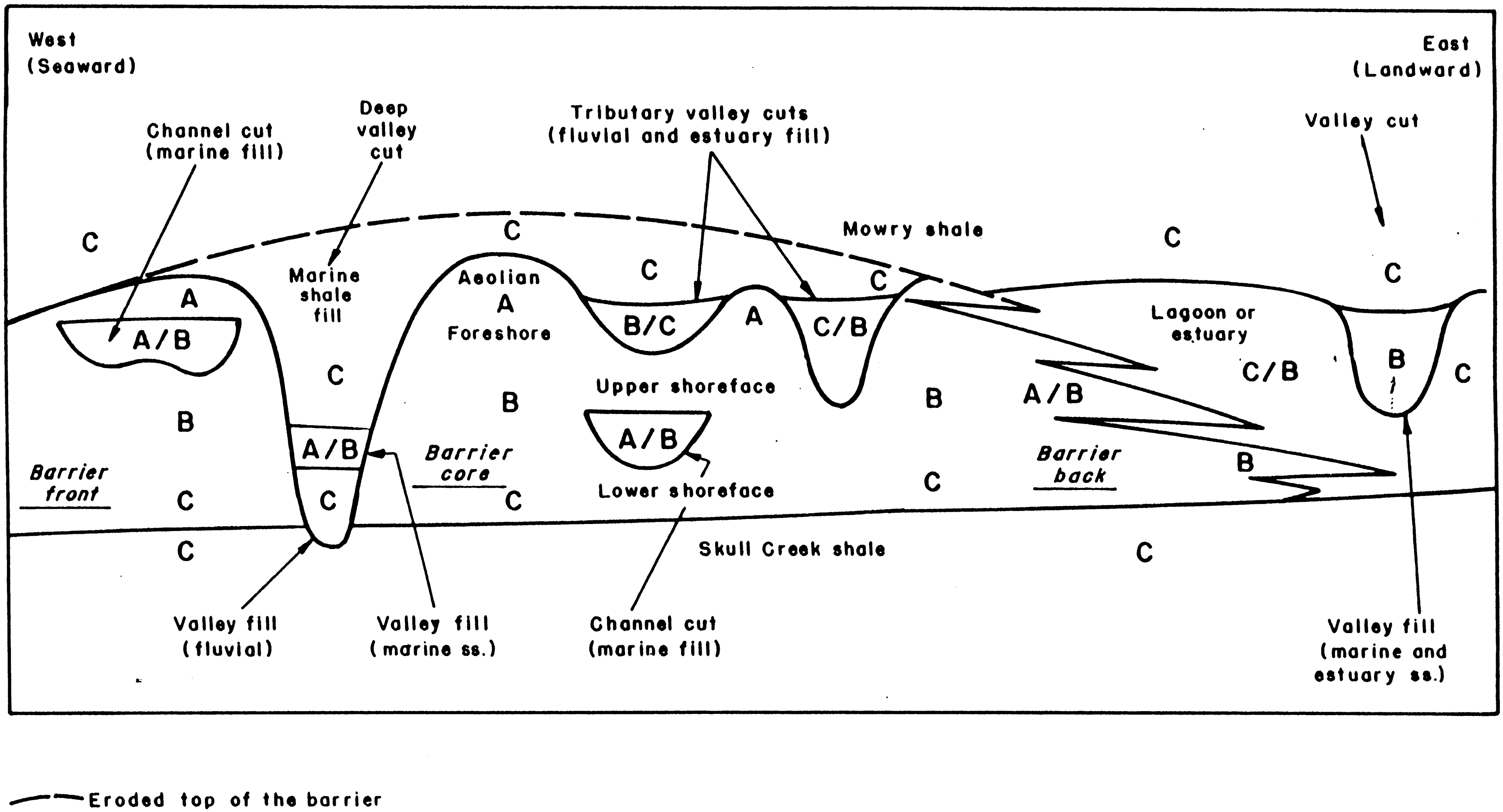

FIGURE 4. - Conceptual model of the distribution of barrier and non-barrier facies in Bell Creek field, Montana, based on outcrops and subsurface cores. Letters A, B, and C refer to sediment classes defined in figure 5.

CLASS		FACIES	B - BARRIER NB - NON-BARRIER
A	PRODUCTIVE	FORESHORE (UPPER/LOWER) AEOLIAN AEOLIAN FLAT UPPER SHOREFACE (HIGHER ENERGY) WASHOVER (TAIL & CORE) CHANNEL CUT FILL (HIGH ENERGY) MARINE VALLEY FILL (HIGH ENERGY)	- B - B - B - B - B - NB - NB
B	PRODUCTIVE	UPPER SHOREFACE (LOWER ENERGY) WASHOVER (INTO LAGOON) MARINE VALLEY FILL (LOW ENERGY) CHANNEL CUT FILL (LOW ENERGY) ALLUVIAL VALLEY FILL (HIGH ENERGY) LAGOONAL WIND BLOWN SAND	- B - B - NB - NB - NB - NB
C	NON-PRODUCTIVE	LOWER SHOREFACE LAGOON FILL ESTUARY FILL ALLUVIAL VALLEY FILL (LOW ENERGY) SWAMP & MARSH MARINE TRANSITION TO THE BARRIER	- B - NB - NB - NB - NB - NB

FIGURE 5. - Classification of productive and nonproductive facies of the Muddy formation in the Bell Creek field, Montana. Facies underlined are predominant.

	COMMON		LESS COMMON	
UPWARD ↑	C A B C	C B A B C	C A C	C B C

FIGURE 6. - Vertical sequences of sediment classes in central part of Unit "A", Bell Creek field, based on core descriptions. Classes are defined in figure 5.