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Status Report

SELECTING OUTCROPS FOR USE IN HETEROGENEITY RESEARCH

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By Michal Szpakiewicz*

ABSTRACT

A barrier island depositional environment represented by the Bell Creek oil reservoir in Montana and by analogous outcrops of the Newcastle (Muddy) sandstone in NE Wyoming was selected for reservoir heterogeneity research. Selection was based on criteria previously reported[1] and a review of geologic and engineering data gathered from several oil companies, core repositories, and candidate outcrops.

The Newcastle sandstone appears to be a typical model of a transgressive barrier island/strand plain environment of deposition. Field work on outcrops confirmed the stratigraphic and sedimentologic analogy of exposures and reservoir rocks. The studied outcrops contain a representative suite of the major barrier facies identified in the subsurface. The outcrops are also adequate in terms of representative length and thickness for comparison to analogous modern environments.

Results of two EOR projects implemented within Bell Creek Unit A indicate a strong influence of heterogeneities in controlling fluid movement in the reservoir. Preliminary examination of reservoir cores, logs, and exposed rocks also indicates sedimentologic and diagenetic differences of the barrier sediments at different locations.

Current research is concentrating on the following aspects of refining the geological analogy between the selected outcrops and the subsurface reservoir:

1. Paleogeography -- outline of the barrier sand bodies and their internal architecture due to progradation of the barriers.
2. Sedimentology -- facies development and characteristics (horizontal and vertical sedimentary heterogeneity).
3. Diagenesis -- origin magnitude and distribution of secondary porosity.

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INTRODUCTION

The objective of this study was to select a candidate reservoir with suitable outcrops representing the shallow marine environment of deposition and meeting the following requirements:

1. It must be a good EOR candidate with an EOR project under implementation.
2. The analogous formation must be exposed near the producing field.
3. Subsurface data for the producing field must be available to NIPER.
4. EOR performance indicates a strong influence of reservoir heterogeneity.
5. The reservoir should not have extensive fractures.

The shallow marine barrier island/strand plain or the shelf sand ridge deposystems were suggested for reservoir heterogeneity research.[1] The barrier island sands mark the landward boundary of the shelf and together with the midshelf ridges (offshore bars) belong to a large family of shallow marine, major-oil-productive depositional environments. Barrier islands and shelf ridges represent, however, two different geologic models of shelf sedimentation. Final selection of the candidate reservoir representing the chosen environment of deposition and the analogous outcrops for augmenting subsurface reservoir data for heterogeneity research was left open, depending upon the availability of subsurface data and results of the reconnaissance field trip to the candidate outcrops.

SELECTION OF DEPOSYSTEM, RESERVOIR, AND ANALOGOUS OUTCROPS FOR FURTHER STUDY

Two reservoirs with completed or ongoing EOR pilot projects were suggested for detailed study:

1. The Lower Cretaceous Newcastle (Muddy) sandstone in Bell Creek oilfield, Montana, representing the barrier island/strand plain deposits.
2. The Upper Cretaceous Shannon sandstone in Teapot Dome oilfield, Wyoming, representing the shelf ridge deposits.

Analogous outcrops are available for field study in close proximity (25 miles and 5 miles, respectively) to both candidate reservoirs. Other general selective criteria previously reported[1] were also met in both cases.

To allow concentration of simulation effort on sedimentary and diagenetic heterogeneities, fractures should not be present in a candidate reservoir. The Salt Creek anticline and the Shannon formation are heavily fractured and composed of a mozaic of tectonic blocks, while fracture-related problems are not reported from EOR pilot areas in the Bell Creek oil reservoir. Two recent (Tertiary Incentive) chemical EOR projects located within Unit A of Bell Creek field performed differently, indicating a strong influence of reservoir heterogeneity on oil recovery.[2]

A number of cores, logs, maps and engineering data including production history are available to NIPER from Gary Williams Co. We also benefit from Dr. Rod Tillman's (NIPER consultant) previous work on the Bell Creek cores and on geologically equivalent outcrops of the Newcastle sandstone.

Two field trips to the Newcastle sandstone exposures in NE Wyoming confirmed their overall geological analogy in facies development to the reservoir rocks. The outcrops are also adequate in terms of representative length and thickness of facies exposure for comparison to modern environments.

The Newcastle sandstone appears to be a typical model of a barrier island/strand plain environment of deposition and is comparable with many Gulf Coast barrier producing fields. It is also considered analogous to classic modern environments from which the recognition of ancient barrier coastlines was largely derived.

On the basis of the criteria discussed above, the Bell Creek reservoir was selected for further research along with analogous accompanying outcrops in the Newcastle sandstone.

ADDITIONAL INFORMATION FOR DETERMINING SUITABILITY OF MUDDY SANDSTONE

Nine cores from the Bell Creek TIP pilot project area located in Unit A of the field have been geologically described (seven of them partially and two completely). Relevant logs have been collected and analyzed in a preliminary way.

The following lithofacies have been identified in the examined cores from the barrier island deposits in the Bell Creek oil reservoir:

1.	Back-barrier (landward facies)	- lagoon - storm washover and tidal flats
2.	Barrier	- upper and lower foreshore (beach) - upper and lower shoreface (intertidal and subtidal)
3.	Fore-barrier (offshore marine facies)	- shallow nearshore marine - (transition to shelf deposition)

Berg and Davies[3] have further identified marsh (brackish-continental) and aeolian (dune) facies in some of the Bell Creek cores.

Similar sediments have been identified in the outcropping belt of Lower Cretaceous Newcastle (Muddy) sandstone about 25 miles southeast of Bell Creek field, on the northeast flank of the Powder River Basin in Crook County, Wyoming.

The outcrops were geologically reviewed in the field on a scale comparable to that of Bell Creek Unit A and were accurately measured, described, and sampled at a scale comparable to the EOR pilot scale. (Outcrops numbered: 22A, 22, 23 and 3/86).

Regional paleogeographic reconstruction of the Lower Cretaceous sediments in the area[4] indicates that the outcropping series represents a chronostratigraphic zone of barrier sediments deposited parallel to those producing oil in Bell Creek field at a depth of about 4,600 ft.

The reconnaissance and surveying trips during the summer of 1986 confirmed the stratigraphic and sedimentologic analogy of the oil-producing and outcropping rocks. The 20- to 24-ft-thick complex of transgressive barrier island deposits is enveloped by the (non-reservoir) shallow marine Skull Creek shale (underlying) and by the overlying Mowry shale. The studied analogous outcrops contain a representative suite of the major barrier facies identified in the subsurface, except aeolian, marsh, and lagoonal sediments which have not been found in outcrops thus far. However, some outcrops located near the studied barrier deposits (northeast and east of the area), as well as a chain of outcrops between Upton and Newcastle, Wyoming, located southward of the barrier, revealed the development of continental and brackish marine facies (swamp, valley fill/tidal flat, tidal channel) in the Newcastle sandstone. Geographic distribution of the surrounding non-barrier deposits allows us to outline the approximate eastern and southern limits of the barrier although the direct lateral contacts have not been determined.

Additional field work is needed to define the extent and the exact position of the barrier island body and to identify the appropriate areas in subsurface and in the outcrops for comparative study leading to better interpretation of the reservoir anatomy. Recognition of barrier deposition type (prograding, stationary, or migrating landward) in the Bell Creek reservoir and in the outcrop area and determining resulting trends in shifting of the barrier facies in space or reduction of area occupied by a given facies due to barrier migration appear to be important tasks in geologic modeling for prediction of reservoir response during EOR.

The facies within the outcropping and subsurface barrier were distinguished on the basis of quantitative sedimentologic criteria such as type and abundance of lithologies and physical and biogenic structures (indicative for the energy and depth of deposition), type of sedimentary contacts, and grain size distribution. Distribution, continuity, and development of sedimentary features were observed in the outcrops at a lateral scale of hundreds or thousands of feet.

For determining spatial characteristics of engineering properties, however, a more complex approach is needed, including a consideration of mechanical, chemical, and biological mechanisms forming the sediment. Hydrodynamic, geochemical, and sedimentologic properties must be differentiated in "x", "y" and "z" directions. Such analyses will enable proper geological and engineering interpretation of porosity and permeability distribution from about 1,000 core plugs drilled from the Newcastle sandstone exposures, as well as a more realistic spatial interpretation of core and log data from the reservoir. Application of outcrop study to reservoir characterization was reported in table 5 of reference 5, with subdivision into: A -- Limitations/Constraints/Considerations and B -- Advantages.

The field work completed thus far on Newcastle sandstone outcrops also indicates that the transportation energy of the environment generally increases upward within individual sedimentary cycles, with corresponding increasing frequency of cross-bedding, coarsening of grain size, decreasing clay content, and better sorting. A similar trend was observed in subsurface cores. There are some indications in the subsurface that superimposed cycles of barrier sedimentation may be encountered. For example, the possible wash-over sediments at the base of the pay zone in Gary Energy well W-16 may belong to a different barrier than overlying shoreface and foreshore sediments. Existence of fluid flow barriers or semibarriers in the Bell Creek reservoir, which correspond to subdivision of the field into units, requires geological and engineering definition based on combined analyses of subsurface and outcrop data. Variation in net pay thickness results in a corresponding variation in hydraulic communication between wells and accompanying drastic variations in the rate of oil production. These relationships also need to be determined using subsurface and outcrop data.

Screening of decisive geologic factors observed in outcrops and cores which may be responsible for the reservoir anatomy and performance has been reported.[6] Superposition of diagenetic cycles (facies) observed in exposures and in cores seems to play an important role in final distribution of porosity and permeability values. Evidence of synsedimentary or very early cementation has been documented in outcropping foreshore facies, where ferruginous and calcite cementation affected soft sediment before burrowing. The origin of commonly observed zonal calcareous cementation (both in subsurface and in outcrops) affecting different facies at different stratigraphic levels for a lateral distance of a few to a few tens of feet is not yet clear. Predictability of the position and extent of this phenomenon in the subsurface seems to be poor. However, the tight calcite/Fe/Mn cementation of the topmost parts of the outcrops, the upper foreshore (beach) facies, is of much larger (regional) scale and may affect the entire barrier.

More field observations and laboratory studies are needed to establish the stratigraphic, sedimentologic, and diagenetic analogy of outcropping and oil-producing barrier sediments. Establishment of the genetic, structural, mineralogic, and petrographic criteria facilitates paleoenvironmental interpretation of subsurface data and improvement of reservoir models.

CONCLUSIONS AND RECOMMENDATIONS

Acquisition of more core, log, and engineering data from Unit A and adjacent areas is needed to define:

1. Type and geometry of stacked barrier sand bodies.
2. Nature of semibarriers between units.
3. Reason for characteristic shape of the net-pay isopachs within Unit A.
4. Character of lateral heterogeneities within pay facies resulting in different rate of oil production within TIP pilot area.

Acquisition of additional data should concentrate preferably on cross-sections parallel and perpendicular to the inferred extent of the barrier body. 2-D geological (sedimentologic and petrologic) characteristics of analogous facies in outcrops should supplement the subsurface data.

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