BARRIER BAR SANDS IN THE SECOND FRONTIER FORMATION, GREEN RIVER BASIN, WYOMING

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ABSTRACT

Core samples of the Second Frontier Formation from several gas fields on the Moxa Arch exhibit many transgressive-regressive depositional cycles as a result of the oscillatory nature of Cretaceous sea level. During one of these regressions, a shoaling sequence of sediments was deposited, now recognized as the second bench sandstone of the Second Frontier Formation.

The progradational nature of sedimentation leading to the building of barrier bar sequences is recognizable in gas well log characteristics from the area as well as in cores. Subtle changes in porosity and other generalized log curve shapes can be recognized and correlated with core data.

Several photographs of a barrier island sequence as seen in cores further demonstrate the various types of rocks and reservoir characteristics resulting from sedimentation in the depositional model. This type of information is useful as a predictive tool by geologists in locating better hydrocarbon reservoirs and is needed by those required to make reserve estimations once discoveries are made.

INTRODUCTION

This discussion concerns an interpretation of the depositional environment evidenced in gas well core samples cut through the first and second bench sandstones of the Second Frontier Formation. These cores were cut in holes drilled over the last five years in the general vicinity of the confluence of Lincoln, Sublette, and Sweetwater Counties in the Green River Basin of Wyoming as shown in Figure 1. The cores are representative of the main gas reservoir being exploited in this area along the crest and flanks of the Moxa Arch at drilling depths ranging from less than 7,000 feet to over 12,000 feet.

The comments contained herein are intended only to point out some analogues to modern-day depositional patterns which are recorded and recognizable in the Frontier Formation in this area. For a more complete discussion of the Frontier Formation stratigraphy and regional depositional patterns, the reader is referred to McDonald (1973), De Chadenedes (1975), Conybeare (1976), Craig (1977), and Wach (1977).

DESCRIPTION OF THE MODEL

From the recently published work mentioned above, the Second Frontier is known to contain several transgressive-regressive cycles. These cycles were deposited as sea level oscillated many times in the Green River Basin in response to changes in sediment influx, eustatic changes in sea level, or other factors. Figure 2 represents an idealized model of one of the regressive half-cycles which can be recognized in the Second Frontier in the subsurface and which was deposited during a progradation, or net lowering of sea level. In the area under discussion, the average Second Frontier shoreline strike is north-northeast and south-southwest such that Figure 2, a dip section, runs roughly west-east. As time passes and progradation continues, the shoreline will move from west to east (left to right) in Figure 2 as the regression takes place; and lagoonal, tidal flat, and coastal plain environments will override those environments associated with the barrier island and more marine conditions. This gives rise to the subsurface sequence illustrated in Figure 3 as seen on a well log. The barrier sand is referred to by stratigraphers in this area as the second bench of the Second Frontier, and the overlying lagoonal and tidal flat sequence is referred to as the first bench of the Second Frontier.

Close examination of basin-wide correlations within the Second Frontier Formation indicate, however, that the "second bench" in one part of the basin is seldom if ever a lithostratigraphic or chronostratigraphic equivalent to the "second bench" in another part of the basin. Even when correlating within an area as small as a township, "stacked" en-echelon barrier sand systems can be defined which, at casual glance, are usually incorrectly interpreted as a single system. Failure to recognize this complexity can lead not only to erroneous geologic interpretations, but to erroneous reserve calculations as well.

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RECOGNITION ON WELL LOGS

Figure 3 is an actual example of a "compensated neutron-formation density" log run in a gas well from the discussion area and is typical of how the depositional model can appear in the bore-hole. The gamma-ray curve on the left side of the log exhibits an inverted bell, or funnel shape, moving up through the various sub-divisions of the barrier sand. This type of gamma-ray curve character is usually interpreted as being indicative of decreasing shale content from bottom to top through the sequence as the marine environment shoaled and depositional energy increased.

The barrier island proper is overlain by shales from the subtidal lagoon and tidal flat environments as well as intermittent channel sands, marsh coals, and coastal plain deposits. Through this part of the section the gamma-ray curve usually demonstrates a bell-shaped character or inverted funnel. These generalized log curve shapes are usually recognizable, but are a function of the location on the barrier island at which the hole was drilled, and to what extent earlier deposited sediments were affected by later deposition. It is not uncommon, for example, to encounter channels from a later distributary system that have overridden and locally removed portions of the earlier deposited barrier sand.

In addition to the gamma-ray curve, there are subtle changes in the porosity readings on the log which are reflective of changes in depositional energy and position in the model. As an example, it is not unusual to find a thin, very low porosity (tight) zone at the top of the barrier sand due to carbonate cementation, or to see a so-called gas effect on porosity curves in the higher depositional energy intervals where gas has accummulated. Another example is the high porosity readings observed on certain logs across the lower shoreface interval. These high readings are due to the increased shale content in the lower shoreface and are misleading. Also, permeability in the lower shoreface is extremely low due to the extensive bioturbation, and gas reservoir quality is very poor.

RECOGNITION IN CORES

The photographs shown as Figures 4 through 11 are of portions of slabbed, four-inch diameter cores cut with a standard coring bit through the first and second benches of the Second Frontier Formation. The photographs describe the sequence from bottom to top as deposition took place. The scale shown in all the photographs is in centimeters.

While reading the following descriptions of the photographs, it should be remembered that, because of the usual gradational nature of one deposit into another and close areal proximity at the time of deposition, the position

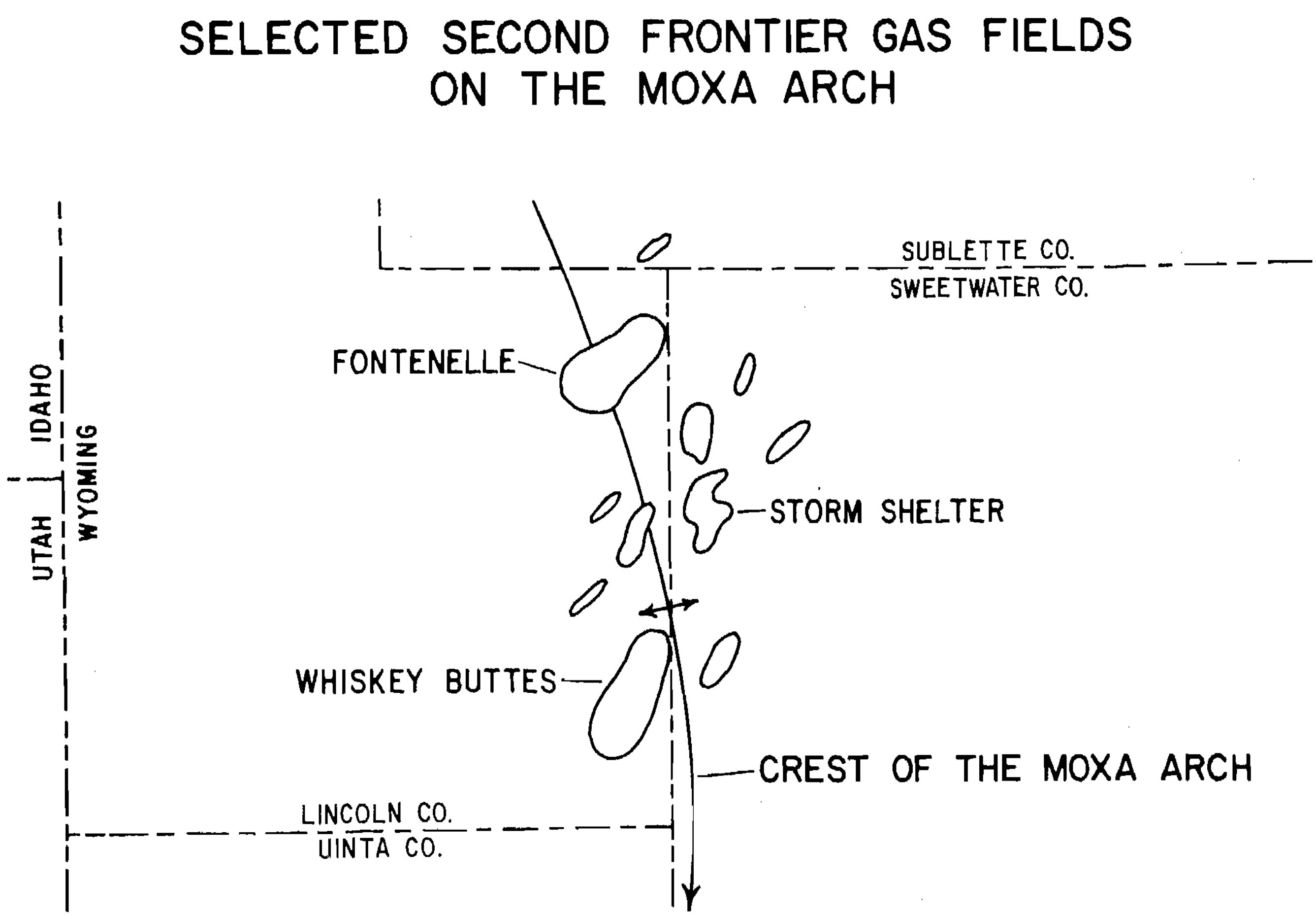

Figure 1: Core samples were taken from gas fields of this area.

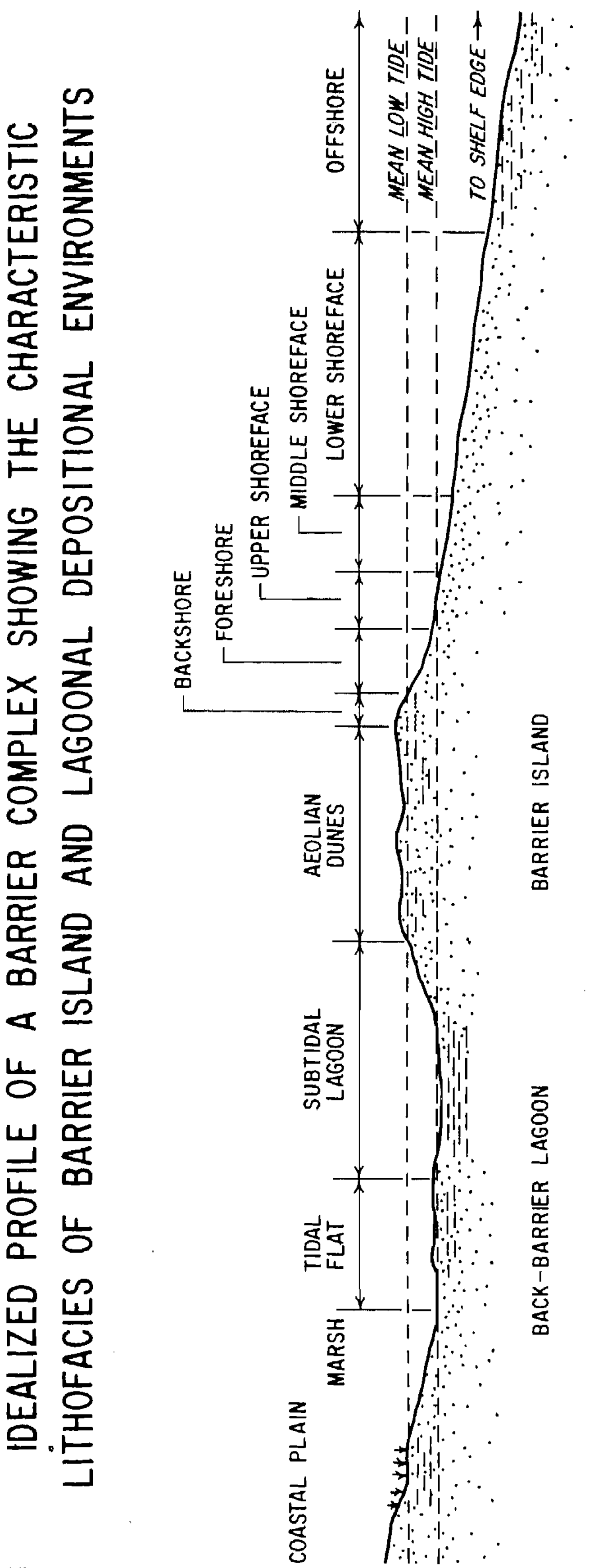

Figure 2: Depositional model with regression from left to right. NOTE: Vertical scale of landforms and tidal range is exaggerated.

in the overall sequence is an important consideration in interpreting the depositional environment of any particular section of core. Sequential position sometimes has to be as heavily weighted as grain size, bedding characteristics, or other specific characteristics that define depositional environment, but it is not a reliable indicator by itself because of the obvious complexities involved in coastal sedimentation.

Figures 4 and 5 are of the lower shoreface interval and consist of very fine-grained sandstone which is conspicuously burrowed and churned. The lower water turbulence, with good oxygenation, make this a stable and productive environment for benthic organisms, and the resulting substrate is extensively bioturbated. The lower part of the thick lower shoreface interval (Fig. 5) is noticeably finer and darker than the upper part (Fig. 4), due to the increased amount of silt and clay in the sandstone. The coarsening and cleaning upward is due to higher wave energy as progradation proceeds and water depth decreases.

Overlying the lower shoreface are the middle and upper shoreface, and foreshore intervals. Figure 6 shows the foreshore overlying the middle shoreface with the intervening upper shoreface interval missing. In the foreshore interval, from 0 cm to 6 cm on the scale, high angle cross-laminations are visible. This interval was deposited in the zone between high and low tide and is composed of fine- to medium-grained sand. This zone may have been so heavily bioturbated that no bedding is preserved. Also, dark silts and clays are not present to outline the burrow traces as in underlying intervals shown in Figures 4 and 5. The lower portion of Figure 6 is the middle shoreface, composed here of very fine sand that is massively bedded. Bioturbation here may also have removed bedding traces.

Figure 7 shows the contact between the overlying backshore and underlying foreshore intervals at approximately 14 cm of the scale. The backshore sandstone here is fine-grained, usually with horizontal parallel-laminations, and some small-scale ripple-laminations. The underlying foreshore sandstone exhibits high-angle ripple cross-lamination and is fine- to medium-grained. The backshore sand was deposited above the tide zone, while the foreshore was deposited in the intertidal zone. In the sequence presented here, no aeolian or dune interval was present above the backshore. However, this zone is distinguished from the backshore by the evidence of plant root systems or other characteristics which describe a locale slightly more subaerial (higher) than the backshore, where plant life was established and sediment movement was mainly by wind action.

Behind the barrier sand lies an area characterized by low energy. The sediments deposited here are representative of sub-tidal lagoons, tidal flats, and associated channels, marshes, and coastal plain deposits. Figure 8 is of finely laminated sandstone, silt, and shale with wavy and lenticular bedding, lenses and stringers of sandstone, and sand-filled burrows. This is characteristic of mixed tidal flat and lagoon deposits from behind the barrier sand.

Figure 9 shows the contact between a foreshore interval composed of high-angle, cross-laminated, medium-grained sandstone above, and sandstone deposited in a tidal channel below. The channel sandstone contains shale rip-up clasts and coarsens to a pebble conglomerate just below the photographed interval.

Figure 10 is from a mixed tidal flat-lagoon setting with a concentration of vertical sand-filled burrows at the base of the interlaminated sequence. Figure 11 is a very shaly siltstone with parallel-laminations and very small-scale cross-laminations. Low velocity currents and fine-grained siliciclastic deposition on a tidal flat result in this type of deposit. This interval is bounded in the bore-hole by a marsh coal above and tidal flat interlaminated sands and clays below.

RESERVOIR CONSIDERATIONS

In terms of natural gas reservoirs, the interval from the middle shoreface up through the backshore probably represents the best exploration target. In the study area these intervals are collectively referred to as the upper part of the second bench of the Second Frontier Formation (as shown in Fig. 3). These intervals were deposited in the

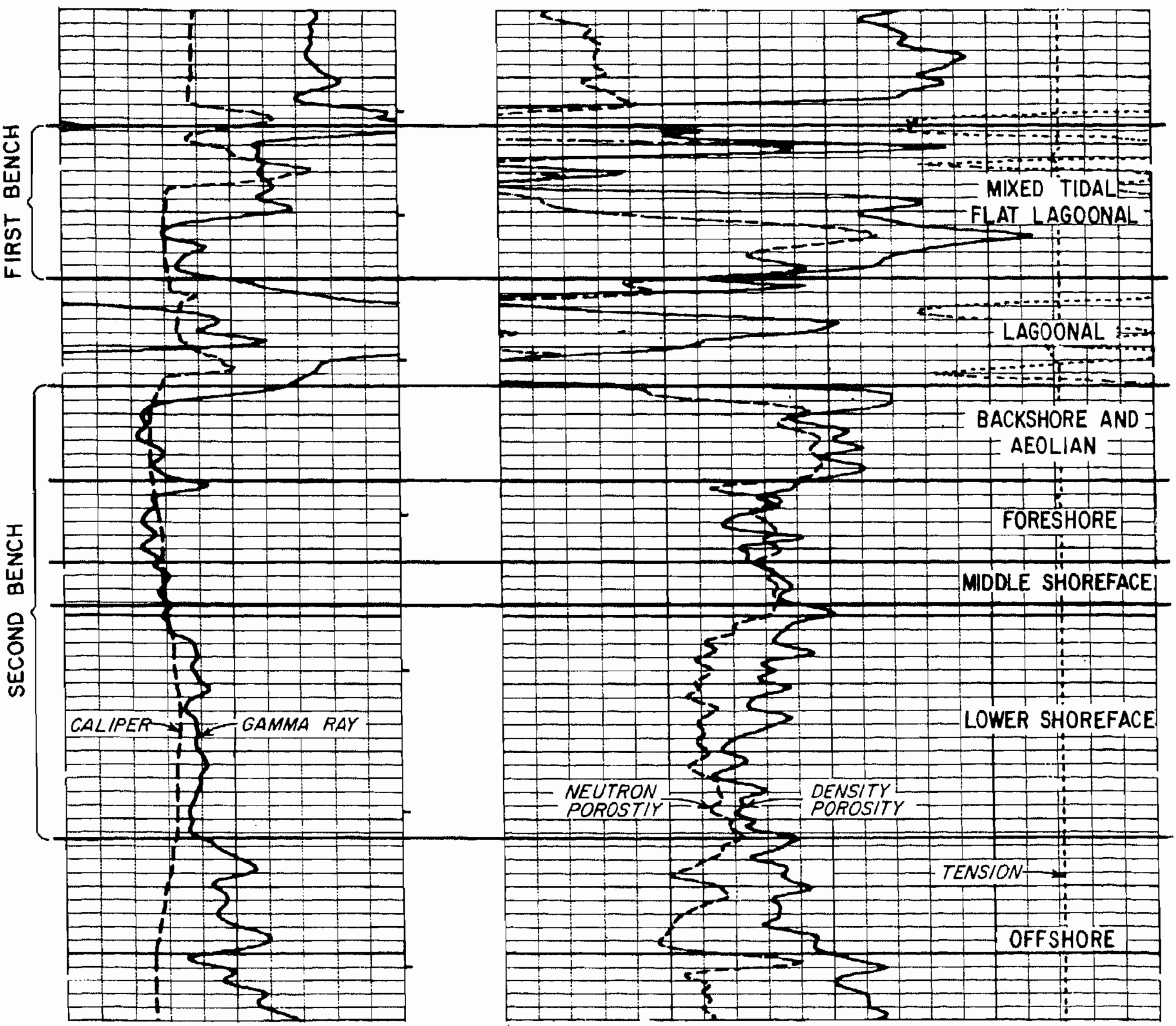

Figure 3: A typical "Compensated Neutron-Formation Density" log run over the first and second benches of the Second Frontier Formation showing the vertical arrangement in the bore-hole of the environments shown in Figure 2. The gamma-ray curve indicates the overall shoaling character of the system, while specific environments seen in the core are subtly reflected in porosity curve shifts. The upper shoreface interval is missing in this example.

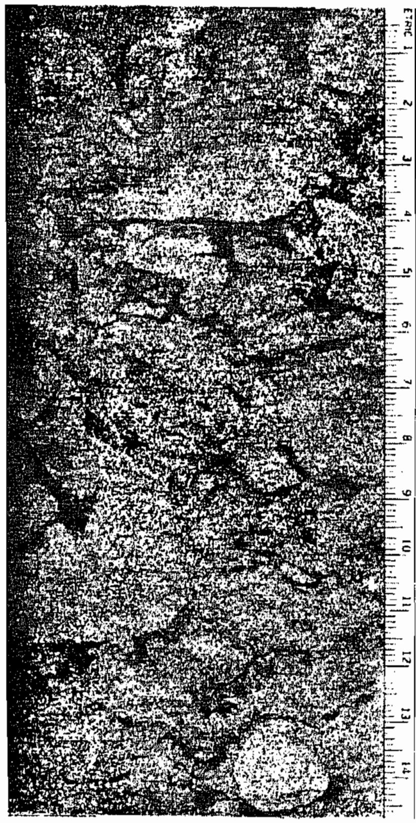

Figure 4: Upper portion of the lower shoreface showing heavy bioturbation. Found at a depth of 8644 feet.

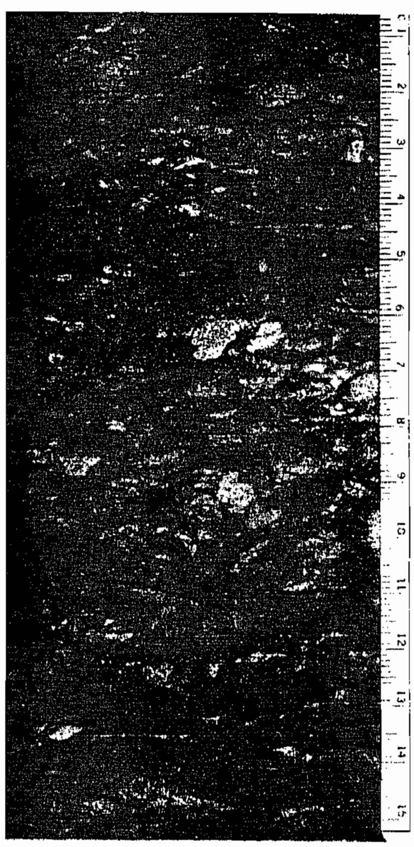

Figure 5: Lower portion of the lower shoreface found at a depth of 8678 feet. This interval is noticeably finer-grained and darker in color than that shown in Figure 4.

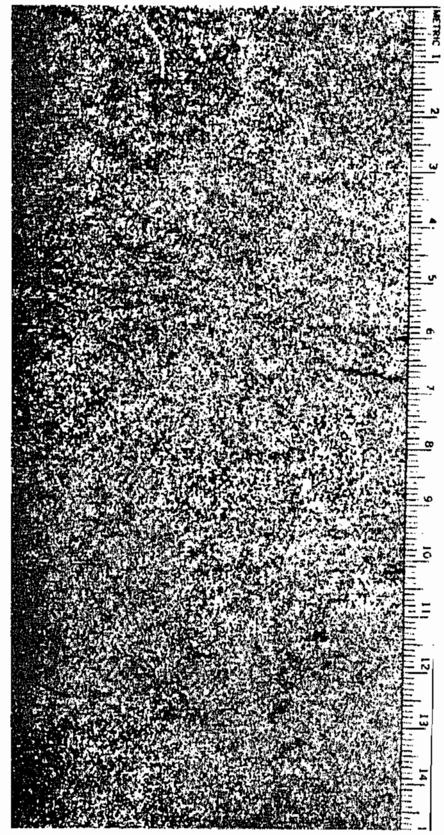

Figure 6: Foreshore sandstone from 0-6 on the scale overlying the massive middle shoreface. The intervening upper shore-face interval is missing. 8613 feet.

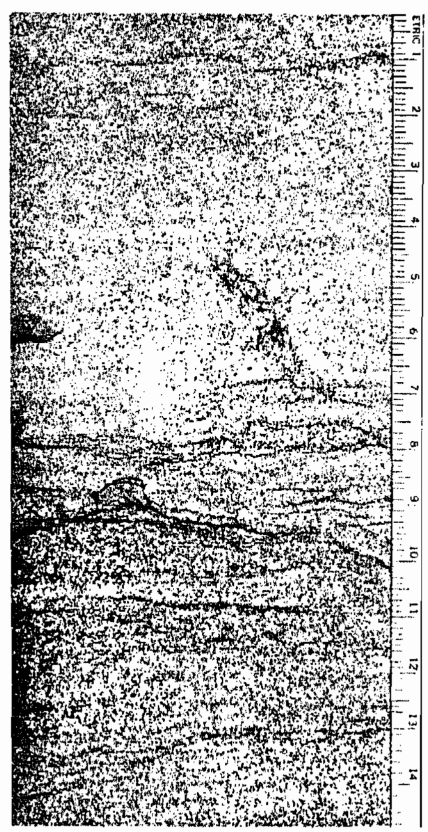

Figure 7: Contact between the overlying backshore sandstone at 14 on the scale with the underlying foreshore sandstone. Found at a depth of 8610 feet.

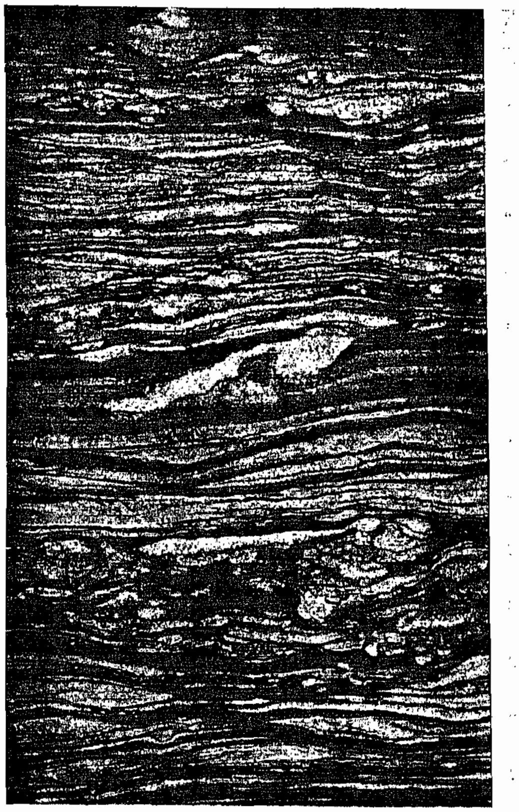

Figure 8: Mixed tidal flat lagoon deposits from a depth of 8348 feet. Note sand-filled burrows.

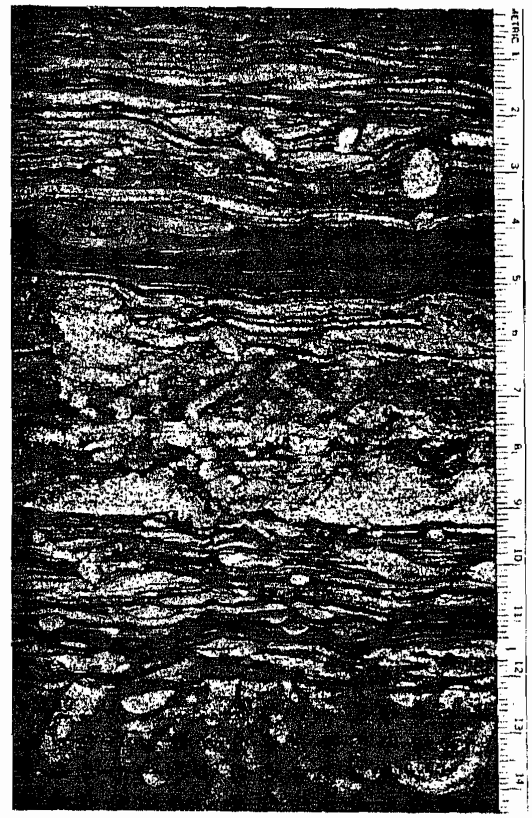

Figure 10: Mixed tidal flat and Lagoon deposit with a concentration of sand-filled burrows. Depth: 8349 feet.

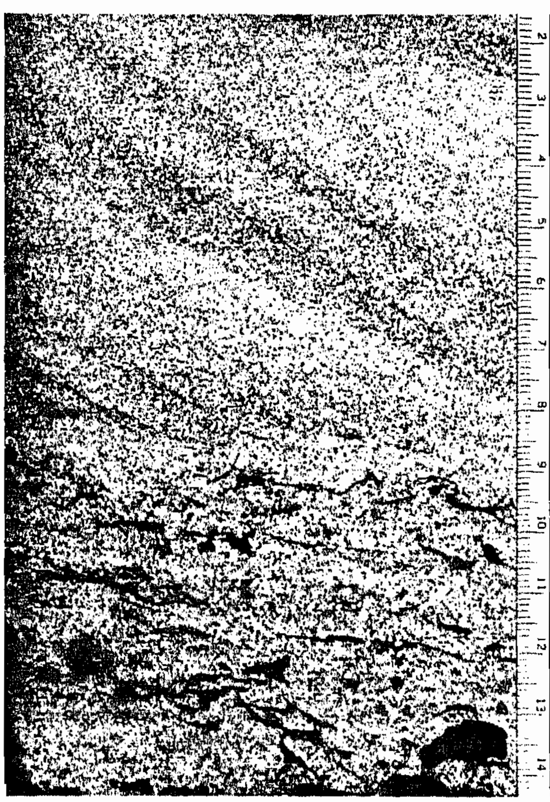

Figure 9: Photograph of a foreshore sandstone overlying a tidal channel. Depth: 8303 feet.

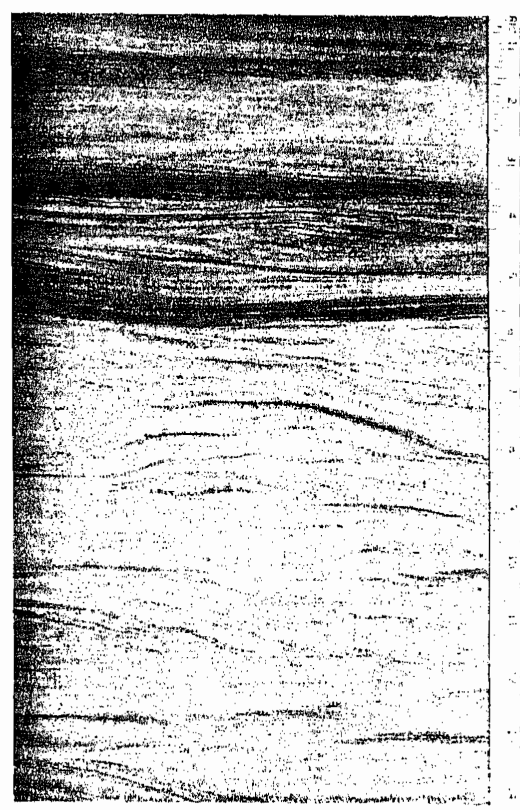

Figure 11: Fine-grained deposit from a tidal flat environment. Depth: 8351 feet.

highest energy environments available to the system and are generally characterized by increased grain size, better porosity and permeability, and decreased clay content. All of these sandstones, however, are typical of many other Rocky Mountain Cretaceous sandstones in terms of diagenetic clay content and exhibit the attendant flow problems of hydrocarbons into the well-bore. Sediments forming these sandstones were transported only a short distance from southeastern Idaho before entering the depositional basin and a large proportion of mineralogically immature feldspar fragments were deposited in the system. These feldspars have since degraded to various clays which line pores and pore throats, hold tremendous amounts of bound water, and greatly reduce the sandstone's permeability to gas (as well as porosity). The type and distribution of the diagenetic clays present is another subject; however, by exploring for sandstones from high energy depositional settings, the depositional or so-called structural clay fraction present in the system can be minimized.

Gas reservoirs with excellent flow characteristics can also be found in the intervals overlying the barrier sequence, such as tidal channels; however, these reservoirs can deplete rapidly because of their relatively small areal extent. They are also difficult to predict in the subsurface, whereas the barrier sand proper has a somewhat more predictable geometry, trend, and size. Other complicating factors, such as differential compaction, multiple depositional cycles, storm deposits, etc., compound the problem of interpreting and correlating, but the recognition of an overall depositional model within which to interpret can greatly improve our understanding of ancient depositional environments on a local scale.

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