Core Evaluation of the Newfield Peacemaker #1-5 and the Newfield Old West #1-9-16H Cores, Glacier County, MT

Introduction

The Duperow, Nisku, Potlatch, Three Forks, Bakken, and Lodgepole formations were cored in two wells in Glacier County, Montana to evaluate reservoir potential and depositional environments. This report summarizes data obtained from these cores. Detailed core descriptions are included with this report to shows stacking patterns and provide a graphic description to compare with wireline logs.

Methodology

Cores were examined after slabbing with a hand lens and binocular microscope. Graphic descriptions include: lithology, textures, fabric, sedimentary structures, biogenic structures, fractures, and oil staining. The drafted descriptions are presented here as hard copies and are also available in digital format.

Facies

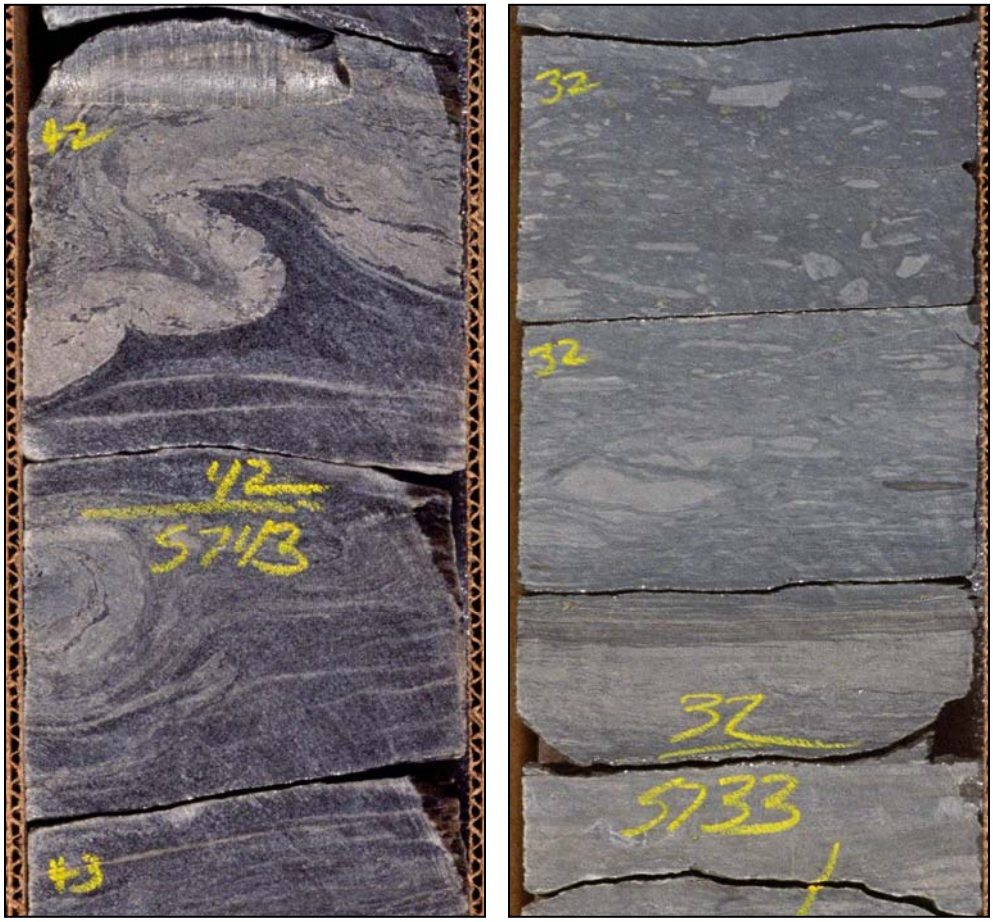
Rocks with similar lithology, sedimentary structures, and biogenic structures were grouped into facies. There are variations within facies, but these are generally insignificant. Facies should be evaluated in terms of their microscopic components, especially in rocks that have been dolomitized or subjected to anhydrite diagenesis.

Duperow Formation

Upper Duperow beds were cored in the Newfield Old West test and are nodular anhydrite at the base of the core, capping thin dolomitic beds with numerous dolomitic clasts (Figure 1), and nodular bedded dolomite with common replacive and vug-occluding anhydrite at top.

At the base of the core, nodular anhydrite beds contain thin dolomitic laminations that are commonly distorted because of the growth of gypsum nodules during deposition and/or compaction during shallow burial. Thin dolomite laminations (tidal flat?) and slightly dolomitic shale cap this interval. The shale indicates incursion of marine waters (deepening).

The upper Duperow is nodular bedded dolomite with common replacive and vug-occluding anhydrite (Figure 2).

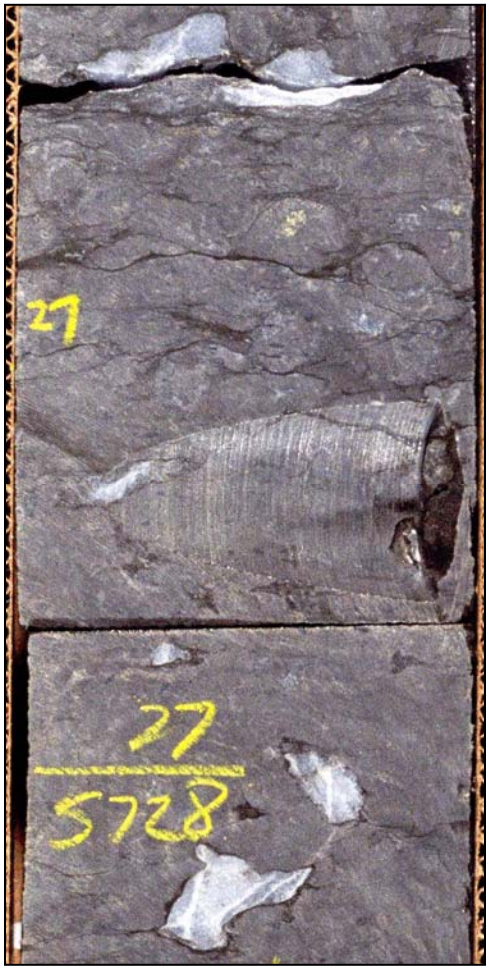


Old West (Facies 10) **Old West (Facies 9)**

Figure 1. At left, deformed dolomitic laminations at the top of the nodular anhydrite probably formed because of early compaction. At right, dolomitic clasts within shaley dolomite cap thinly laminated shale and dolomite at the base of the sample. Samples are from the upper Duperow Formation in the Old West core.

Nisku Formation

The middle and upper Nisku were cored in the Peacemaker and the entire Nisku Formation in the Old West test. The base of the Nisku is comprised of nodular bedded dolomite with rare to no fossils and common to abundant anhydrite-occluded fractures. Anhydrite also occluded vugs and replaced dolomite matrix. Reservoir potential in this facies is limited because of extensive anhydrite (Figure 3). Skeletal lime wackestone beds cap the nodular beds and are open marine deposits in the Old West core (Figure 3).



Old West (Facies D1)

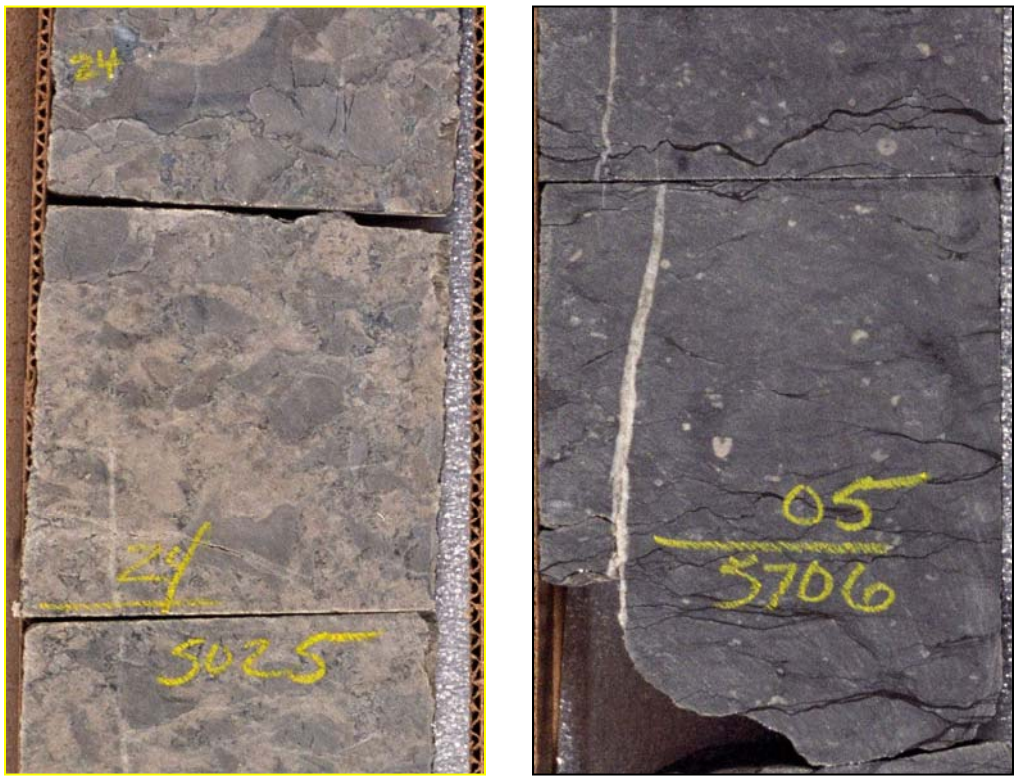
Figure 2. Anhydrite occluded vugs and anhydrite-replaced nodular-bedded dolomite in the upper Duperow Formation in the Old West core.

The middle and upper Nisku beds are interbedded dolomite with common anhydrite replacement of dolomite matrix. Dolomite beds are commonly laminated. The laminations are interpreted to be cyanobacterial in origin ("algal"). There is poor to fair oil staining in the Peacemaker. Oil staining is absent in the Old West because of extensive anhydrite cementation and anhydrite occlusion of fractures (Figure 4).

Potlatch Formation

The Potlatch Formation is comprised of nodular anhydrite, less common laminated dolomite, and sparse peloidal lime packstone beds. Anhydrite nodules are small cylindrical crystals to bulbous and massive crystals that commonly displaced dolomite (Figure 5). The precursor to this anhydrite is gypsum that precipitated in very shallow water salinas and in supratidal

environments where high rates of evaporation elevated the relative proportions of calcium and sulfate. During burial diagenesis, the water in the gypsum lattice was expelled, and anhydrite is the product of this diagenesis (dehydration).



Peacemaker (Facies N2) **Old West (Facies N1)**

Figure 3. Nodular bedding in the Peacemaker sample was probably produced by burrowing infauna and early cementation. Compaction contributed to this fabric. At right, crinoid debris is well displayed in this lime mudstone. Note the anhydrite filled fractures along the left edges of the sample.

Laminated dolomite beds are a combination of syndepositional dolomite and cyanobacteria that entrapped micrite. Dolomitization was probably syn-depositional and it occurred as the percentage of magnesium increased as calcium was utilized in gypsum precipitation (Figure 5). Some stromatolitic buildups were observed.

In the Peacemaker core, lime packstone and grainstone beds are rare and associated with minor flooding events that increased both relative bathymetry and depositional energy in intertidal environments.

Peacemaker (Facies 9) **Old West (Facies 9)**

Figure 4. In both samples, thin laminations were produced by algae (cyanobacteria) in intertidal-supratidal environments. Note the extensive anhydrite occlusion of fractures in the Old west sample at right.

Reservoir development is rare in the Potlatch, and any oil generated and entrapped within laminated dolomite beds will probably be non-producible because of limited aerial extent and reduced permeability related to anhydrite cementation.

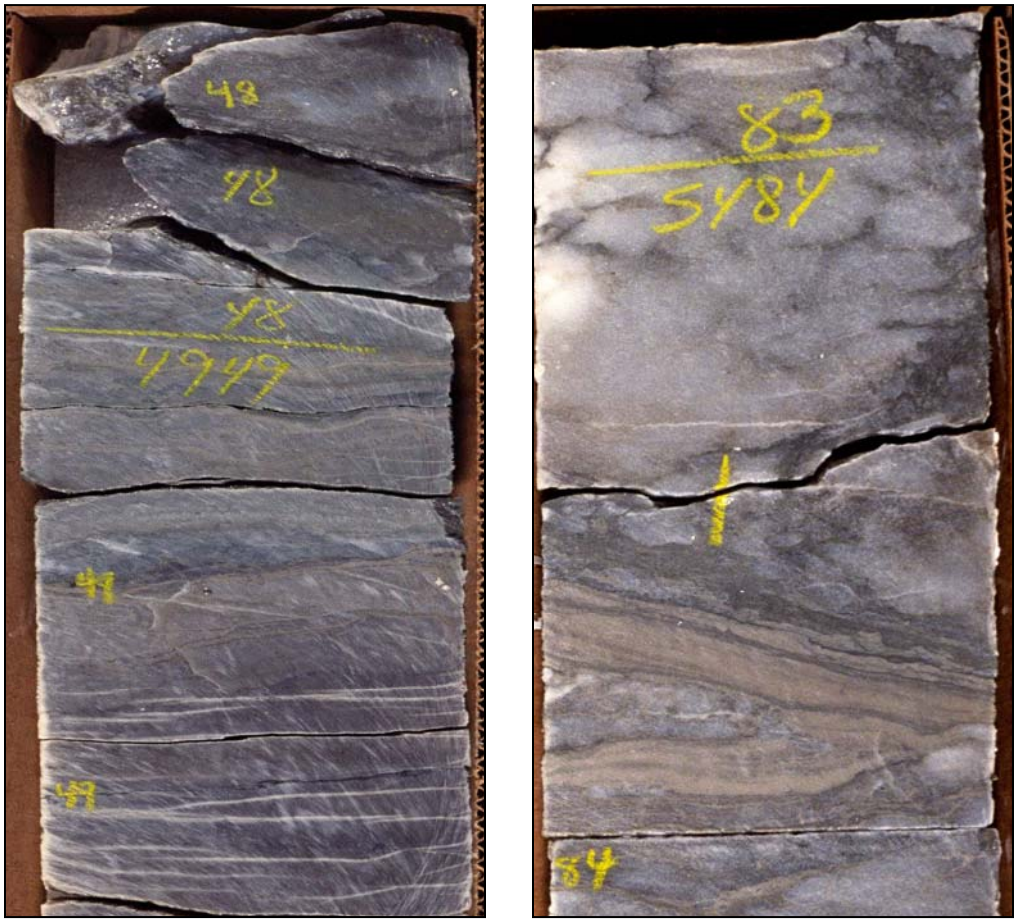
Fractures are common within nodular anhydrite beds, but the fractures are small and limited to individual nodules or nodular complexes. Fractures are rare to absent in the dolomite and grain-rich limestone beds.

Three Forks Formation

The Three Forks Formation is variable in the two cored wells. The Three Forks in the Peacemaker test is thicker than the Old West well, and comprised of limestone that was deposited in tidal flat, shoreline-shoal, and subtidal environments. The Three Forks in the Old West core is thinner and

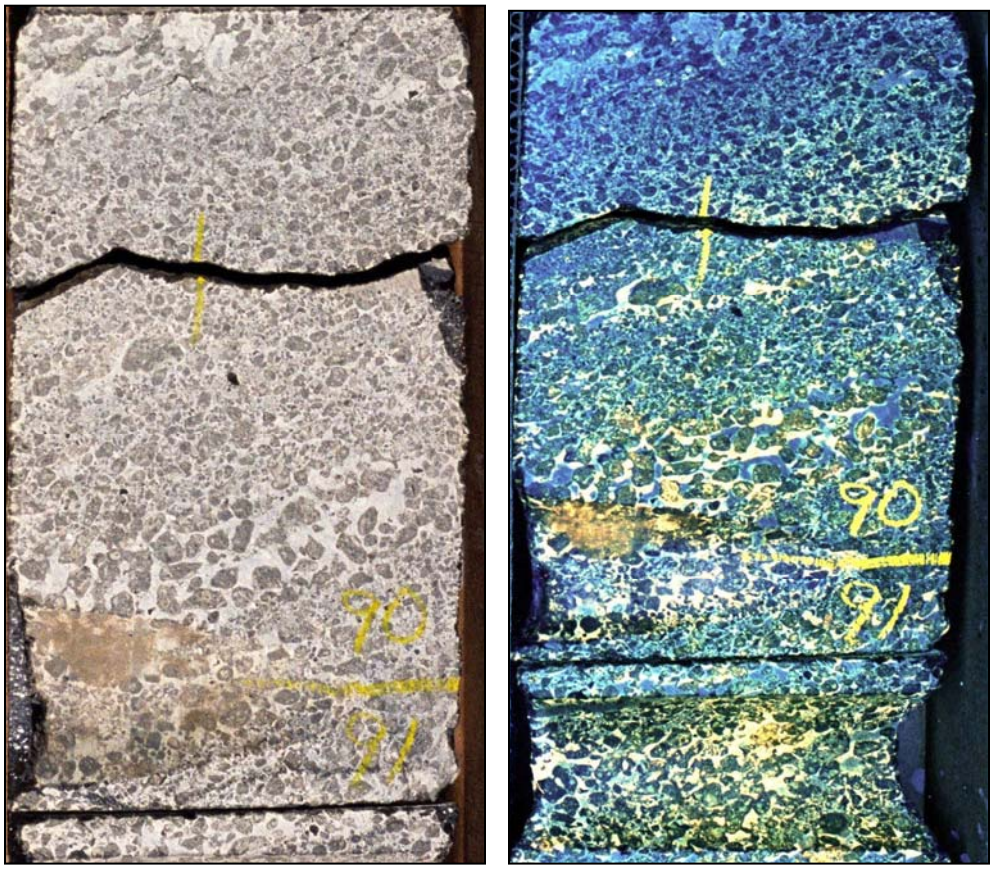
dolomitic beds were deposited in shallow subtidal and tidal flat environments.

<u>Peacemaker Core</u> – At the base of the Three Forks. Grain-rich beds are shoreline shoal and/or offshore shoals that developed across a broad, shallow shelf. The grains are composite grains and intraclastic grains that are coated, an indication of being rolled in agitated environments. Early calcite spar cement is sparse to common. Some of the beds are graded showing variations in depositional or possibly channelization. The interval is oil stained (Figure 6).



Peacemaker (Facies 10) **Old West (Facies 10)**

Figure 5. Anhydrite crystals (after gypsum) are present in the image at left. The crystals are bedded across the base and middle of the sample. Deposition was in salina and/or sabkha environments. Large anhydrite nodules are common in the sample at right. Brown dolomite is interbedded with the anhydrite and it was displaced (deformed) as the gypsum nodules precipitated in salina-sabkha environments.

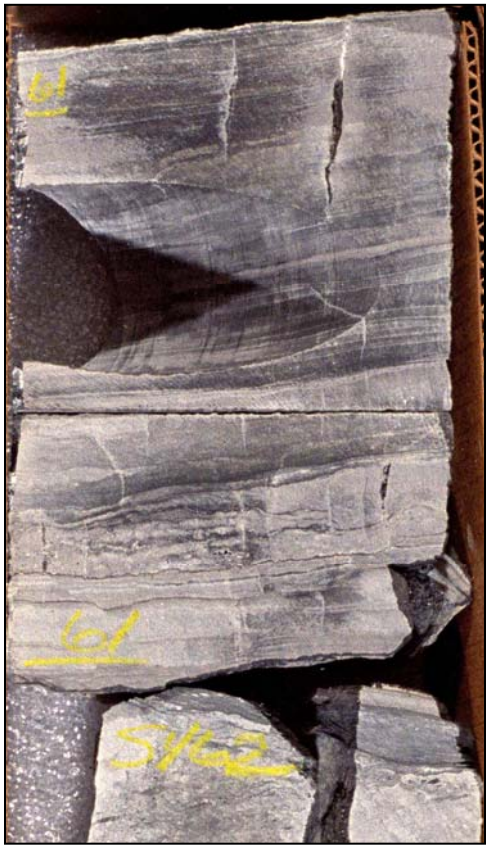


Peacemaker (Facies 8) 4791 ft

Figure 6. At left, composite grains and intraclasts are graded and encased in light gray-white calcite spar. At right, the same sample shows oil staining with fluorescent light.

The middle and upper Three Forks in the Peacemaker test are comprised of interbedded skeletal lime mudstone and rarely skeletal and cherty lime mudstone (Figure 6). Skeletal fragments are dominated by thin shelled brachiopod fragments and possible ostracod carapaces. Chert nodules that replaced lime mudstone are commonly fractured. These middle and upper Three Forks rocks were deposited in shallow subtidal environments.

Old West Core – Three Forks deposits in the Old West core are interlaminated silty dolomite and shale. These beds are typical shallow subtidal and tidal flats deposits. Figure 6 shows an example of thinly laminated silty dolomite and interbedded shale. These deposits resemble Three Forks tidal flat sediments in the Williston Basin.



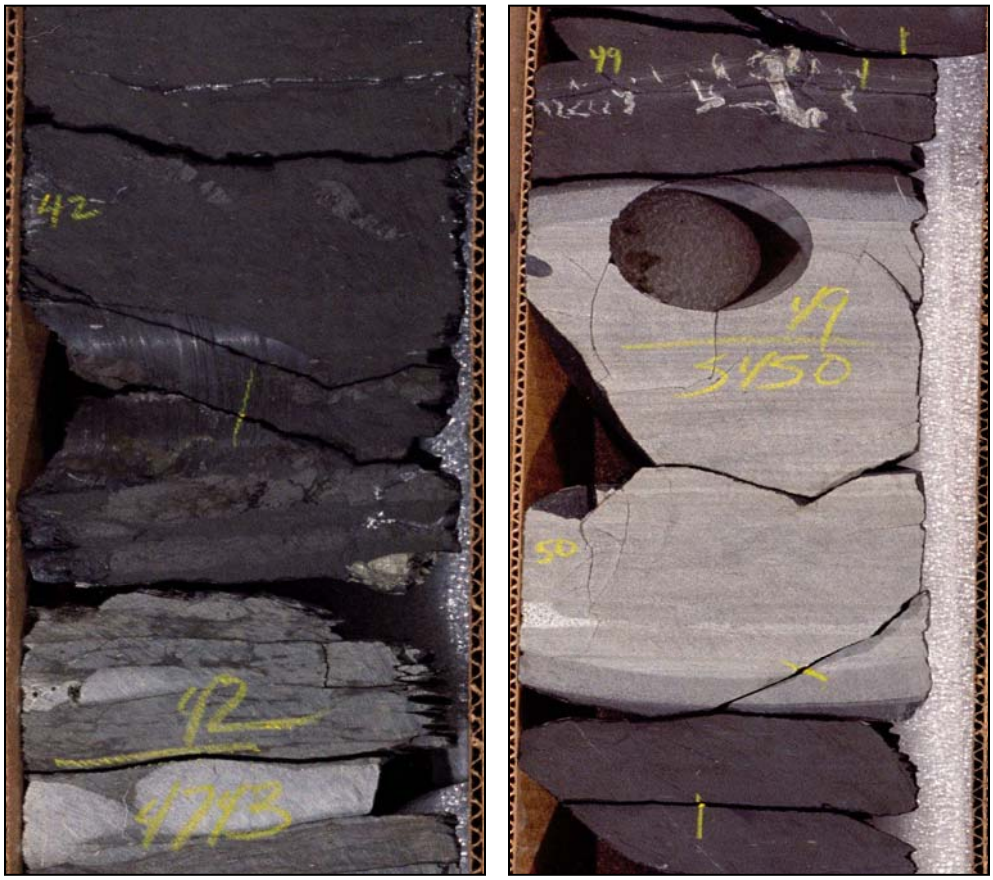
Peacemaker (Facies 7) **Old West (Facies 7)**

Figure 7. At left, dark gray chert nodules are common and interbedded with sparsely skeletal silty dolomite. Deposition was in shallow subtidal environments that persisted across a shallow shelf. At right, thinly laminated silty dolomite and shale are fractured. At the middle of the sample, mud cracks and dolomitic clasts indicate subaerial exposure.

Lower Bakken Shale

The Lower Bakken Shale is black, organic-rich shale with common small pyrite nodules and thin pyrite laminations. The shale is thin in the Peacemaker core and significantly thicker in the Old West. In addition, there are thin to moderately thick lime mudstone beds in the Lower Bakken Shale in the Old West core (Figure 8). Calcite-occluded fractures are common in the Old West core, but less common in the Peacemaker.

The contact with the underlying Three Forks is abrupt to erosional in both tests and marked by a thin bed of reworked skeletal fragments, shale clasts, and grains (Figure 8).



Peacemaker (Facies 4) 4743 Old West (Facies 4)

Figure 8. At left, the contact between the upper Three Forks and the Lower Bakken Shale is well displayed. Anhydrite nodules are present across the base of the sample. At right, the contact between the Lower Bakken Shale and a thinly laminated lime mudstone bed within the Lower Bakken Shale indicates periods of oxygenated substrate and near-normal marine salinity. There are several of these lime mudstone beds within the Lower Bakken Shale in the Old West core.

Middle Bakken

Peacemaker Core - The Middle Bakken is comprised of skeletal lime mudstone, skeletal silty dolomite, limestone, dolomitic siltstone, and minor shale. The base of this member is skeletal limestone that is in erosional contact with the uppermost Three Forks. Skeletal allochems are dominantly crinoid and brachiopod fragments (Figure 9). The middle portion of this member is skeletal lime wackestone to packstone. Skeletal fragments include crinoid and brachiopod debris that was reworked during storms (tempestites). The top of the Middle Bakken is dolomitic siltstone capped by

skeletal lime wackestone beds that contain brachiopod and crinoid fragments. Reworked clasts occur near the contact with the Upper Bakken Shale (that is missing in this core. Deposition of the Middle Bakken Member was in oxygen-deprived, shallow subtidal environments.

Reservoir development in the Middle Bakken is rare with no visible porosity and limited fracturing. Anhydrite and calcite occluded fractures and vuggy porosity that developed along fractures (Figure 10).

Peacemaker (Facies 5) **Old West (Facies 5)**

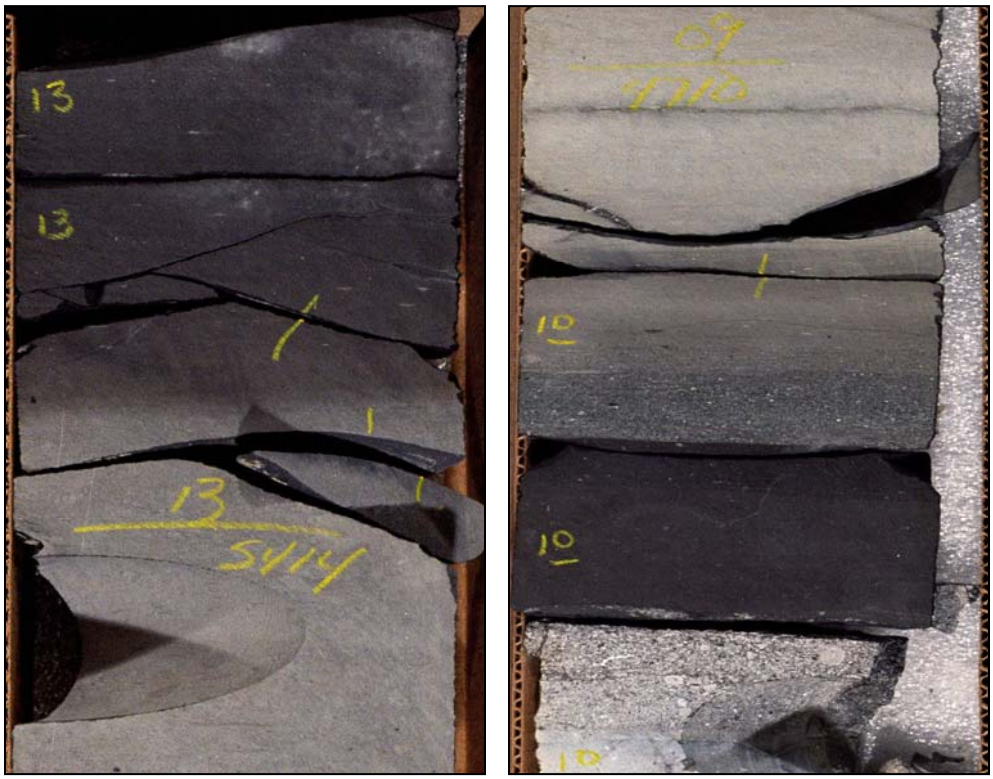
Figure 9. Brachiopod fragments are present in the dolomitic siltstone at left. At right, crinoid debris occurs within the Middle Bakken in the Old West test. Skeletal fragments from both cores are common shallow subtidal fauna.

Old West Core - The Middle Bakken is homogenous and comprised of skeletal lime mudstone, skeletal, shaley, and silty dolomite, dolomitic siltstone, and minor shale. The base of this member is skeletal lime mudstone that is probably in erosional contact with the uppermost Three Forks. The contact was not cored. Skeletal allochems are dominantly crinoid and brachiopod fragments (Figure 9). The top of the Middle Bakken is limey and the contact with the Upper Bakken Shale is abrupt. Deposition of the

Middle Bakken Member was in oxygen-deprived, shallow subtidal environments.

Upper Bakken Shale

The Upper Bakken Shale was not cored in the Peacemaker test, but appears to be anomalously thin (Figure 10). A thin, black shale bed at 4710 may be the Upper Shale. In the Old West core, the Upper Bakken Shale is much thicker, extensively fractured, and is black, organic-rich and resembles the Lower Bakken Shale in the Peacemaker core. Deposition of both the Upper and Lower Bakken Shales was in oxygen stratified basins.



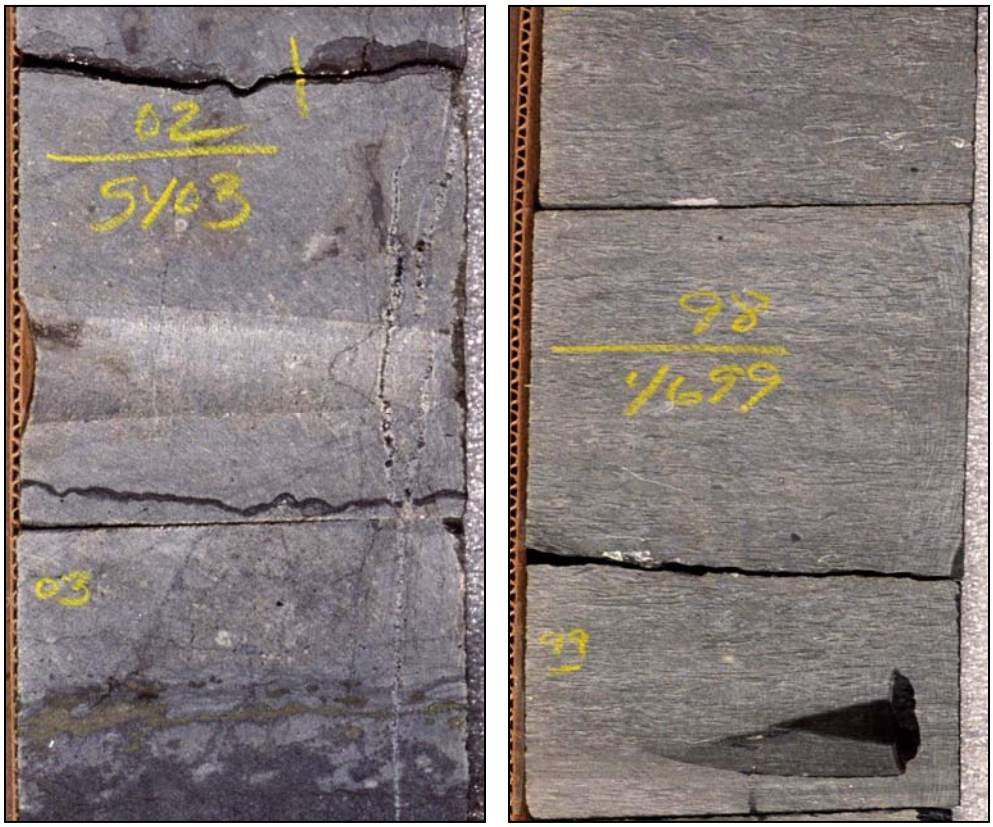
Old West (Facies 4) **Peacemaker (Facies 4?) 4710**

Figure 10. The contact between the top of the Middle Bakken and the base of the Upper Bakken shale is abrupt in the Old West core (left). At right, thin organic-rich shale near the base of the sample may be the Upper Bakken Shale. Reworked substrate and fossil debris are present above and below the shale.

Lodgepole Formation

The Lodgepole formation consists of a lower member informally named the Scallion (Figure 11), thin limey shale of the False Bakken (Figure 12), and

interbedded lime mudstone, shaley lime mudstone, and limey shale identified as the Lower Lodgepole and Banff intervals (Figures 11-13). These beds were deposited in moderately deep shelf to basin environments. Other than the Scallion interval, skeletal fragments are rare to absent and dominantly small crinoid ossicles and stems, small ostracod carapaces, and rare brachiopod fragments. Burrow structures are absent to common, but generally sparse.

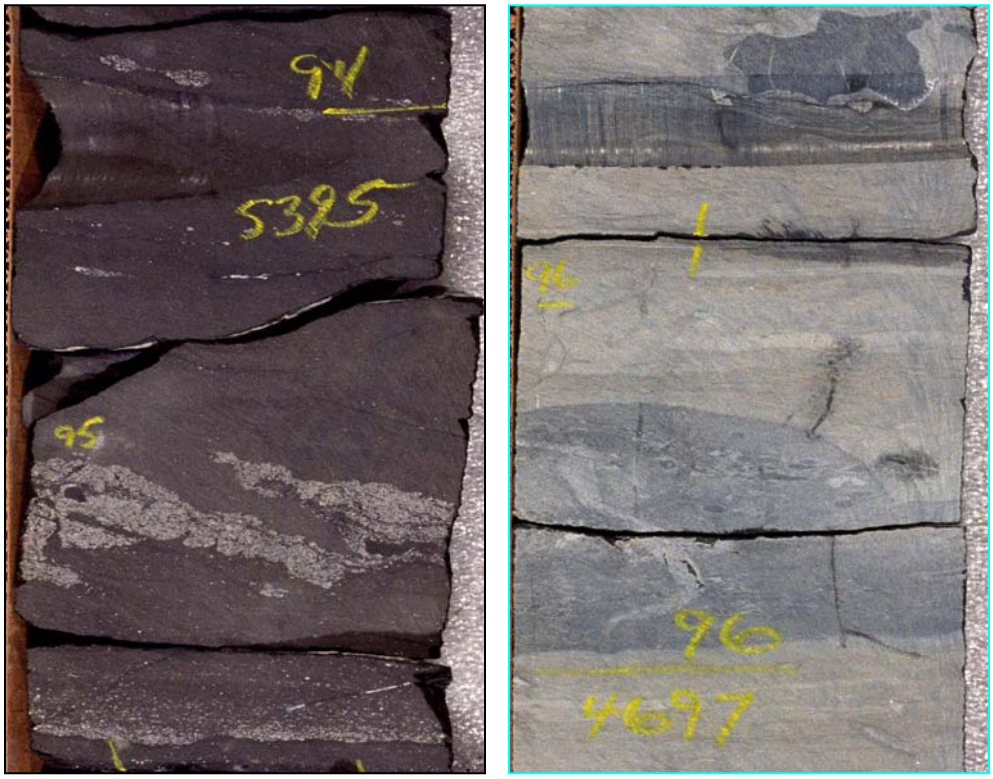


Old West (Facies 2) **Peacemaker (Facies 2)**

Figure 11. At left, vertical fractures are present in this skeletal lime mudstone sample (Scallion). The base of the sample is near the contact with the Upper Bakken Shale (Old West core). At right, black Helminthopsis burrow structures are common in shaley lime mudstone from the Peacemaker core.

Both calcite nodules and chert nodules occur in the Lodgepole limestone beds. Chert nodules replaced lime mudstone and are commonly fractured (Figure 12). Fractures are thin and do not propagate far into the overlying and underlying limestone beds.

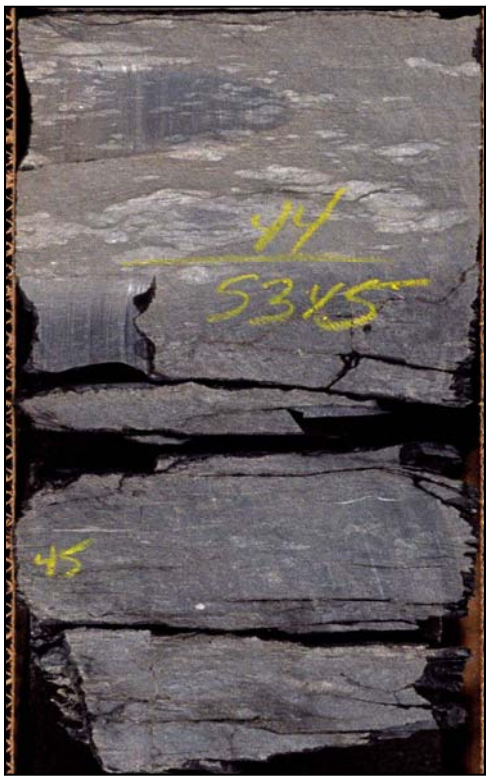
Fractures in the lower Lodgepole are more common in the Peacemaker and fractures in the upper Lodgepole are more common in the Old West core. Figure 11 shows well developed fractures in Scallion in the Old West core. Fractures in the upper Lodgepole are well developed and preserved in the Old West core (Figure 13).



Old West (Facies 1) False Bakken **Peacemaker (Facies 2)**

Figure 12. At left, light gray calcite patches occur within dark gray to black shale in the False Bakken. Note the reworked skeletal material at the base of the sample. At right, fractures are common in the dark gray chert nodules at lower center and top center. Fractures in the overlying lime mudstone propagated into (or from) the chert nodules. Deposition was in moderately deep shelf environments.

Lodgepole fractures may produce sufficient storage capacity and conductivity for reservoir development. Anhydrite and calcite occluded fractures and anhydrite replaced matrix in the middle and upper Lodgepole, but there are common partly open fractures that should provide sufficient storage and permeability for petroleum production.



Peacemaker (Facies 1) **Old West (Facies 1)**

Figure 13. Dark gray to black limey shale occurs near the top of the cored interval in the Peacemaker test. Note the small calcite-filled fractures at top and the subvertical fracture at the base of the sample. The limey shale at the base of the sample at right is capped by shaley lime mudstone with silty beds that are tightly cemented with calcite.