New Reserves is An Old Field, The Niobrara Resource Play in the Wattenberg Field, Denver Basin, Colorado

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Summary
The Niobrara is one of seven horizons that are productive in the giant Wattenberg Field area (GWA) of Colorado. GWA covers approximately 3200 square miles. The field was discovered in 1970 (J Sandstone) and first Niobrara production was established in 1975 from vertical completions. Horizontal Niobrara drilling began in the field in 2009.

Wattenberg straddles the Denver Basin synclinal axis and is regarded as a basin-center (continuous) petroleum accumulation. The Niobrara is overpressured and drilling depths are 6500 to 7000 ft. The Wattenberg area is a “hot spot” or positive geothermal anomaly. Geothermal gradients range from 16 – 18°F/1000 ft on the edges of the field to about 28 to 29°F/1000ft in high gas-oil ratio areas.

The Niobrara consists of four limestone (chalk) units and three intervening marl intervals. The lower limestone is named the Fort Hays Member and the overlying units are grouped together as the Smoky Hill Member. The chalk units are referred to in descending order as the A, B, C, and Fort Hays. Erosional unconformities exist at the top and base of the Niobrara (Weimer, 1978). The upper unconformity removes the upper chalk bed in some areas of the Wattenberg Field. The A, B, and C chalks are the current focus of horizontal drilling by operators in the field. Recent completions have also targeted the basal Fort Hays Member and the underlying Codell Sandstone.

Recent horizontal completions (2009-P) have initial production of approximately 100 to 700 BOPD with a GOR of 500 to 3000 cu ft per barrel. Estimated ultimate recovery per well is greater than 300,000 BOE. The Wattenberg area has a resource estimate from the Niobrara of 3-4 billion barrels equivalent. The combined technologies of horizontal drilling and multistage fracture stimulation have brought significant new life into this 50 year old field.

Introduction
The most important mineral extraction activity over the past 50 years in Colorado has been the discovery and development of Wattenberg Field (Fig. 1). The Wattenberg Field is located northeast of Denver, CO and produces oil, gas, and condensate from the following Cretaceous horizons: Dakota-Lakota, J Sandstone, D Sandstone, Greenhorn, Codell, Niobrara (A, B, C, and Fort Hays), Hygiene (Shannon), Terry (Sussex), and Larimer-Rocky Ridge (Parkman).

The Denver Basin is a large asymmetric basin formed largely during the Laramide orogeny. The basin has a steep west flank (>10 degree dips) and a gentle east flank (< than ½ degree dip, Fig. 1). The deepest part of the basin lies close to and parallels the Front and Laramie ranges of Colorado and Wyoming, respectively. The Wattenberg Field straddles the deep basin axis. Both thermogenic and biogenic petroleum accumulations occur in the Niobrara. The accumulations in the deep part of the basin are thermogenic oil and gas; whereas, the accumulations along the shallow east flank of the basin are biogenic gas (Rice and Claypool, 1981; Lockridge and Scholle, 1978).

Wattenberg Field was discovered in 1970 by Amoco Production Company with gas completions in the Lower Cretaceous J Sandstone (Matuszczak, 1973). The field turned out to have multiple pays and each new horizon has added significant reserves to the field. The Upper Cretaceous Hygiene, Terry, and Larimer-Rocky Ridge became development targets in the early 1970s (Weimer, 1996).
Codell and Niobrara became important targets in the early 1980s. The Dakota-Lakota interval became important in the 1990s. Recent drilling activity is targeting the Greenhorn. All these reservoirs require fracture stimulation. The main risk in early development of the J reservoir was the completion design. The Niobrara through Dakota pays in Wattenberg are regarded as unconventional. The Hygiene, Terry, and Larimer-Rocky Ridge pays are regarded as conventional reservoirs.

The Niobrara Formation became a focus of vertical drilling activity in the early 1980s with completions being made in the Codell Sandstone. It was easy for operators to add perforations in vertical wells in the Niobrara for extra production. The newest phase of drilling in Wattenberg is horizontal drilling targeting mainly the middle benches of the Niobrara and the underlying Codell Sandstone. The horizontal targets are completed using multistage fracture stimulation.

**Theory and/or Method**

The Niobrara represents one of the two most widespread marine invasions and the last great carbonate producing episode of the Western Interior Cretaceous basin (Barlow, 1985, 1986; Kauffman, 1977, 1985; Weimer, 1960). The dominant lithologies of the Niobrara Formation are limestones (chalks) and interbedded marls (Figs. 2, 3). The chalk-marl cycles are interpreted to represent changes from normal to brackish water salinities possibly related to regional paleo-climatic factors or sea level fluctuations.

The chalks of the Niobrara are rich in organic matter and organic related material (e.g., pyrite). On the east side of the WIC basin, the Niobrara consists of four chalk beds and three shale intervals. The basal chalk bed is known as the Fort Hays limestone member and the unit contains some of the purest chalk in the Western Interior. The Fort Hays is regionally extensive and ranges in thickness from 50 feet in southeast Colorado to 120 feet in New Mexico to less than 10 feet in southeast Wyoming. Carbonate content persists from the Denver Basin to southwest Colorado into the Laramie, North Park, South Park, and Sand Wash basins.

The Fort Hays is overlain by the Smoky Hill member. The Smoky Hill consists of organic-rich shales to chalky shale (marls) to massive chalk beds. The interval has been subdivided by Longman et al. (1998) into 9 intervals and six to seven distinct units by Scott and Cobban (1964) and Hann (1981). Figures 2 and 3 illustrate the six member subdivision.

**Source Rocks**

Important and recognized source rocks in the Cretaceous of the Denver Basin include in ascending order the Mowry, Huntsman, Graneros, Greenhorn, Carlile, Niobrara, and Sharon Springs Member of the Pierre Shale (Clayton and Swetland, 1977, 1980; Gautier et al., 1984; Meissner et al., 1984). Other potential source units exist in the Skull Creek and other parts of the Pierre Shale.

Several workers have discussed the organic-rich nature of the Niobrara Formation and the increased thermal maturity and resistivity with increased burial depth (Longman et al., 1998; Landon et al., 2001; Sonnenberg and Weimer, 1993).

The Niobrara Formation has been analyzed using pyrolysis by several workers (Rice, 1984). Organic-rich beds in the formation have organic carbon values which range from 0.5 to 8 weight percent and average 3.2 weight percent. The kerogen present in the Niobrara is Type-II or oil-prone (sapropelic).

**Reservoir Rocks**

The lithology of the Niobrara changes from east to west across the Western Interior Basin. In the Denver Basin, the lithology consists of interbedded calcareous shale, shaley limestones, marls, and limestones (Longman et al., 1998; Figs. 2, 3). Westward, the lithology becomes shalier and sandier. The carbonates are still present in the western area but clastics begin to dominate.

Most of the Niobrara reservoir rocks have undergone mechanical and chemical compaction and are low porosity and permeability rocks. Burial depth is the single most important factor affecting porosity in the Niobrara. Chalks have high original porosities (50% or greater). Initial dewatering and mechanical compaction is the first diagenetic phase. Grain and fossil breakage and re-orientation reduce porosity. Initial coccolith grain sizes are 0.2 to one micron (Longman et al., 1998). Chemical
compaction is characterized by calcite dissolution along wispy dissolution seams ("horsetail stylolites"), microstylolites, and stylolites (Precht and Pollastro, 1985). Grain-to-grain dissolution along microstylolites is common and the dissolved calcite is reprecipitated locally. The chalks have an average porosity of 6 percent at 7000 feet. Shallow and deeply buried chalks have low permeabilities. The initial average pore throat sizes are a few tenths of a micron which are further reduced with diagenesis (Pollastro and Scholle, 1986). Fracturing, thus, is an important aspect for reservoir performance.

The sequence stratigraphy of the Niobrara in the Wattenberg Field was described by Weimer and Sonnenberg (1989).

Davis (1985) described shear faults observed from seismic in the Wattenberg area. These faults are generally dipping at approximately 45 degrees and are slightly listric. The faults influence fractures within the Niobrara which are important for production. Sonnenberg and Underwood (2013) interpret the low angle faults as part of polygonal fault systems.

**Wattenberg Field Example**

The Wattenberg Field straddles the deep synclinal axis of the Denver Basin and extends over 50 townships (Fig. 1). Niobrara vertical well production is present over most of the Wattenberg area (area within the dashed line on Fig. 3). Niobrara depths are approximately 6200 to 7800 ft (Fig. 2).

The Wattenberg field coincides with a temperature hot spot (Higley et al., 2003). The bottom-hole temperatures recorded on logs or drill-stem tests are elevated compared to surrounding areas. The source of the high heat flow is thought to be an igneous intrusion at depth in basement rocks. The temperature anomaly coincides with where the Colorado Mineral Belt (a northeast trending zone across Colorado of Tertiary mineralization associated with high heat flow) intersects the Denver Basin. The result is higher heat flow and vitrinite reflectance values for this area of the basin. The temperature anomaly also affects oil gravities and gas-oil ratios (GOR) in producing Niobrara wells, the higher the temperature, the higher the oil gravity and GOR.

The Niobrara ranges in thickness from 300 to 400 ft across the field area (Fig. 3). The thickness changes in the Niobrara were described by Weimer and Sonnenberg (1982). The west to east thin area shown on Figure 3 was thought to be caused by a paleostructural feature of similar orientation (i.e., basement fault block). The thinning is due in part to erosional truncation of the A chalk unit over the broad east-west trending area (Fig. 3).

The B, C, and Fort Hays are currently being drilled by horizontal laterals. The main target appears to be the B chalk interval where it is well developed. Additional laterals are targeting the Codell/Fort Hays interval. The A chalk is prospective but operators report difficulties drilling the curved part of a lateral through the Sharon Springs interval.

Figure 2 illustrates the log porosity for the chalk intervals in the Wattenberg Field. The neutron and density track each other through the chalk intervals and have porosities values of 7-10%. The resistivities in the chalk intervals is generally greater than 15 ohm-m. XRD analysis illustrates that the chalks are high in carbonate content and relatively low in clay content. The marls are generally high in clay and TOC content.

The production from the Niobrara has been steadily increasing in the Wattenberg field since the middle 1980s. The production over the last five years has increased dramatically and is expected to increase even more dramatically in the future. Current production from the Niobrara is approximately 20,000 BOPD and 180 MMCFGD. Resource estimates for recoverable reserves from the Niobrara appear to be 2 to 4 billion barrels equivalent of oil (Noble and Anadarko estimates).

The typical drilling and spacing unit for the new horizontal wells is generally 640 acres. Most of the laterals are drilled in a north-south orientation. The well orientation enables up to 18 laterals to be drilled in a section (laterals generally alternate between Niobrara chalk zones and the Codell Sandstone). The wells are fracture stimulated with up to 20 fracture stages. Production information is tight but is reported to be 300 to 700 barrels oil equivalent for the wells. Estimated ultimate recoveries range from 300,000 to 600,000 barrels oil equivalent.
Conclusions

New reserves are being found in the Wattenberg Field in both the Niobrara and Codell intervals with horizontal drilling and multistage fracture stimulation. It is remarkable how a 40 plus year old field continues to see new plays and new reserves. Technology is the key driver in Wattenberg as it has always been.

Figure 1. A) Structure contour map Denver Basin showing location of Niobrara oil and gas fields. Wattenberg Field is located along the synclinal axis of the Denver Basin. B) West to east schematic cross section through central part of Denver Basin. Niobrara Formation is in a thermally mature area in the deep part of the basin. Biogenic gas accumulations occur in the Niobrara along the shallow east flank of the basin.

Figure 2. Type log for the Niobrara Formation, Wattenberg Field (Gill # 2, Sec. 22, T6N, R64W). Composite log illustrates volume clay (V %), TOC (wt. %), quartz content (V %), and carbonate content (V %). The well was cored from 6660 to 6886 ft. Resistivities greater than 15 ohm-m shaded in light red. High resistivities (shaded) coincide with chalk units and lower resistivities with marl units.
Figure 3. A) Isopach Niobrara Formation, Wattenberg Field. The Niobrara ranges in thickness from over 400 ft to less than 250 ft across the field area. Note the west to east area of thinning which turns to the northeast in the area. B) South to north cross section Wattenberg Field, datum on top of Niobrara. Note thinning in ‘A’ chalk across the Wattenberg area.

References


