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Field Growth Potential in Unconventional Fields, the Wattenberg Field Example, Denver Basin, Colorado

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Abstract

Field growth is a phenomenon where the estimates of known recovery tends to increase systematically over time. Generally field growth is associated with the following: 1) boundaries of proved areas are extended by drilling; 2) new pay zones, pools, reservoirs are found by drilling or recompletions; 3) infill wells or stimulation procedures; 4) improved drilling and completions costs; 5) secondary or tertiary recovery. Unconventional fields experience field growth just like conventional fields. The overall economics of conventional and unconventional systems benefit from the field growth phenomenon.

The giant Wattenberg Field area of Colorado was discovered in 1970 by Amoco Production Company with completions in the Lower Cretaceous Muddy (J) Sandstone. Wattenberg straddles the Denver Basin synclinal axis and is regarded as a basin-center stratigraphic petroleum accumulation. Additional production was encountered in five other formations during the development of the field (Dakota Plainview, Codell Sandstone, Niobrara Formation, Terry and Hygiene sandstone members of the Pierre Shale). The Terry and Hygiene were first produced in 1972; the Codell in 1981; the Niobrara in 1985; and the Dakota Plainview in 1998. Reservoir quality in the various horizons is generally poor which mandates hydraulic fracture stimulation for economic production.

The greater Wattenberg area (GWA) covers approximately 2600 square miles. Production occurs from approximately 4,000 to 8500 ft across the field. Cumulative production from the field is currently 812 MMBO and 7.5 TCFG from over 35,000 wells. The field is currently at peak production due to recent horizontal drilling activity in the Codell and Niobrara. Original reserves were estimated to be 1.1 TCFG for the Muddy (J) Sandstone. The addition of multiple productive horizons in the field area has significantly added to the total reserve number. The field is ranked by the EIA based on reserves as the fourth largest oil field and the ninth largest gas field in the US.

Source beds for oil and gas in Wattenberg are the Skull Creek Shale, Graneros Shale, Greenhorn Limestone, Carlile Formation, Niobrara Formation, and Sharon Springs member of the Pierre Shale. Total source rock thickness in Wattenberg is 200 to 250 ft (> 2 wt.% TOC). The source beds are dominantly Type II with some Type III being present. The source beds are in oil and/or gas windows in the Wattenberg Field depending on temperature gradients.

The Wattenberg area is a “hot spot” or positive temperature anomaly. This is an important reason the area is so prolific. Temperature gradients range from 1.6 – 1.8^{o}F/100 ft on the edges of the field to about 2.8 to 2.9^{o}F/100ft in high GOR areas. The temperature anomaly is related to where the Colorado Mineral Belt intersects the Denver Basin. The mineral belt is a northeast trending zone across Colorado of Late Cretaceous to early Tertiary mineralization. The mineralization is associated with high geothermal gradients and hot fluids. The high heat flow and hydrocarbon generation contribute to abnormal pressure in parts of the field.

Statement of the background

Wattenberg Field is a super-giant oil and gas field located in the synclinal part of the Denver Basin (Figure 1). The field was discovered by Amoco Production Company in 1970 with completions in the Lower Cretaceous Muddy (J) Sandstone. Initial reserves for the Muddy (J) Sandstone were estimated to be 1.1 TCFG (Matuszczak, 1973). After the Muddy (J) development commenced additional pays were discovered in the Terry and Hygiene Sandstones (1972); Codell Sandstone (1981), Niobrara Formation (1984), and Dakota Lytle Formation (1998). Each of these formations contribute to field growth for the field (Figure 2). Also occurring was infill drilling activities and commingling rule changes that encouraged additional completions. Starting in 2010, the field started seeing horizontal drilling in the Codell and Niobrara which has dramatically increased production (Figure 3).

The greater Wattenberg area (GWA) covers approximately 2600 square miles. Production occurs from approximately 4,000 to 8500 ft across the field. Cumulative production from the field is currently 812 MMBO and 7.5 TCFG from over 35,000 wells. The field is currently at peak production due to recent horizontal drilling activity in the Codell and Niobrara. The field growth observed in the field greatly exceeds original estimates of gas in place. The addition of multiple productive horizons in the field area has significantly added to the total reserve number. Other critical factors contributing to field growth are: infill drilling, commingling rules (all Cretaceous reservoirs can be commingled in a wellbore), technology advances (drilling, stimulation, and completion), horizontal drilling, pad drilling to reduce environment issues and concerns, and recompletions through time. The field is ranked by the EIA based on reserves as the fourth largest oil field and the ninth largest gas field in the US. The field is the largest field in Colorado based on cumulative production.

The Wattenberg Field is regarded as a basin-center type of accumulation. Characteristics of a basin-center accumulation include: regionally pervasive accumulations that are hydrocarbon saturated; commonly lack down-dip water contact; have low permeability reservoirs; and have low recovery factors. Wattenberg meets all these criteria. Basin-center accumulations are one of the more economically important petroleum systems in the world. In general, they will produce 10 - 50% of the total annual oil and gas production in a region. Basin-center accumulations are often referred to resource plays in that they have somewhat predicable and repeatable results and economics. The low recovery factors and low permeability reservoirs mandate advanced completion and stimulation techniques (e.g., horizontal drilling and multi-stage hydraulic fracture stimulation).

The Wattenberg area is a “hot spot” or positive temperature anomaly (Figure 4). This is an important reason the area is so prolific. Temperature gradients range from 1.6 – 1.8^{o}F/100 ft on the edges of the field to about 2.8 to 2.9^{o}F/100ft in high GOR areas. The temperature anomaly is related to where the Colorado Mineral Belt intersects the Denver Basin. The mineral belt is a northeast trending zone across Colorado of Late Cretaceous to early Tertiary mineralization. The mineralization is associated with high geothermal gradients and hot fluids. The high heat flow and hydrocarbon generation contribute to abnormal pressure in parts of the field.

Previous Work

The Wattenberg Field has a long development history and also publication history. This paper attempts to update field growth concepts as they apply to the field. Previous studies on Wattenberg have been conducted by: Ladd (2001); Matuszczak (1973); Sonnenberg (2013, 2014, 2015, 2016); Thul and Sonnenberg (2018); Weimer (1978, 1980, 1996); Weimer and Sonnenberg (1982, 1989) and others.

The Muddy (J) Sandstone reservoir has previously been interpreted as a delta front and valley-fill deposits (Weimer, 1996); the Codell Sandstone as a shallow marine shelf sand (Weimer, 1996: Sonnenberg, 2014); the Niobrara as deeper water chalks and marls (Weimer, 1996; Sonnenberg, 2013); the Terry and Hygiene Sandstones as shelf sands (Weimer, 1996); and the Dakota Plainview as a fluvial deposits (Weimer, 1996). The reservoir quality of the various formations is generally low because of diagenesis in the basin-center setting.

Aims and Objectives

The aim and objective of this paper is to demonstrate the field growth history of the Wattenberg Field. Field growth shown mainly by the production curve shown in Figure 3 has been continuous through time. Reservoir quality in the various horizons is generally poor which mandates hydraulic fracture stimulation for production. Field growth has greatly contributed to the economic significance of this field.

Both technological and geological factors influence production in resource plays (Theloy and Sonnenberg, 2013). Geological factors influencing productivity include: reservoir thickness, reservoir quality, oil and gas saturations, hydrocarbon generation potential, maturity, overpressure, structure and lineaments, regional stress regime, mechanical stratigraphy, natural fractures, migration, trapping mechanisms. Technological factors include: well type, lateral length, number of hydraulic fracturing stages, proppant volume and type, proppant loading, fluid volume and type, fluid/proppant ratio, injection rate, treatment pressure, choke size, plug and perf versus sliding sleeves, and well spacing. All of these factors influence production in Wattenberg Field and other unconventional accumulations.

Materials and methods

The Wattenberg Field consists largely of unconventional reservoirs (tight reservoirs, general lack of water production, lack of down-dip water, requires fracture stimulation to produce), covers a large areal extent (approximately 2600 square miles), relatively shallow (4300 to 8000 ft vertical depths), reservoirs interbedded with thick mature source rocks (> 200 ft of Type II organics), appropriate thermal window (oil and gas windows both present), over pressuring present in main producers (Codell and Niobrara). In Wattenberg some of the source rock intervals are also reservoir units (e.g., Niobrara Formation).

Results and discussion

Field growth is a common phenomenon in oil and gas fields. The field growth potential in unconventional plays is driven by economics, recovery factors, and technology. Field growth is a key component of unconventional resource plays.

Conclusions

Wattenberg Field is perhaps the most significant field in the U.S. Rockies in terms of cumulative production, reserves, and field growth history. The field is a basin-center type of an accumulation with six producing horizons. The reservoirs are generally low permeability and require technology to produce (e.g., hydraulic fracture stimulation).

Unconventional fields such as Wattenberg illustrate the importance of the field growth phenomenon associated with improving technology in part driven by favorable economics.

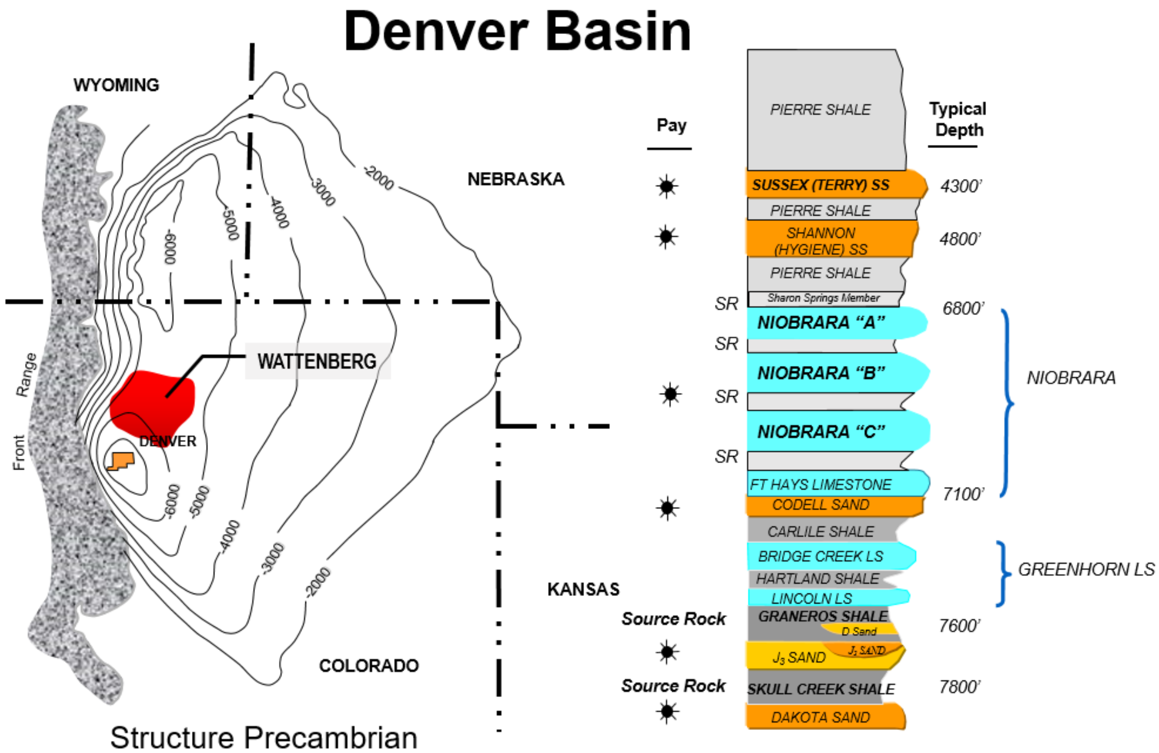

Figure 1: Structure contour map Denver Basin showing location of Wattenberg Field along the basin axis northeast of Denver. Stratigraphic column of producing horizons in Wattenberg also illustrated along with approximate drilling depths.

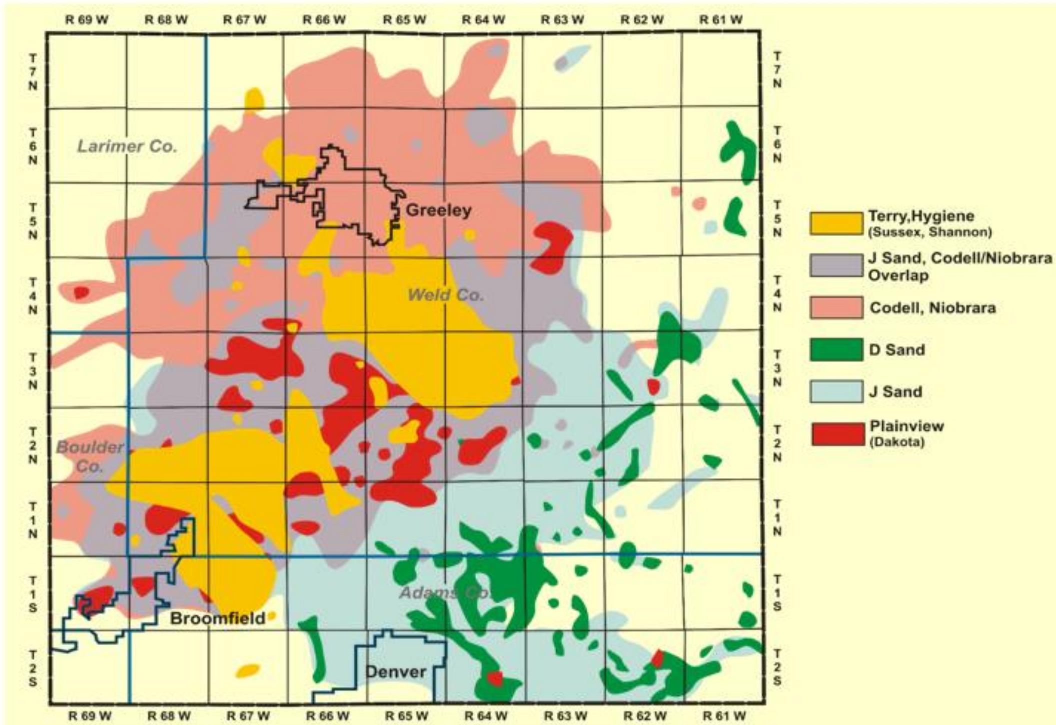

Figure 2: Production map for Wattenberg Field with various producing horizons color coded.

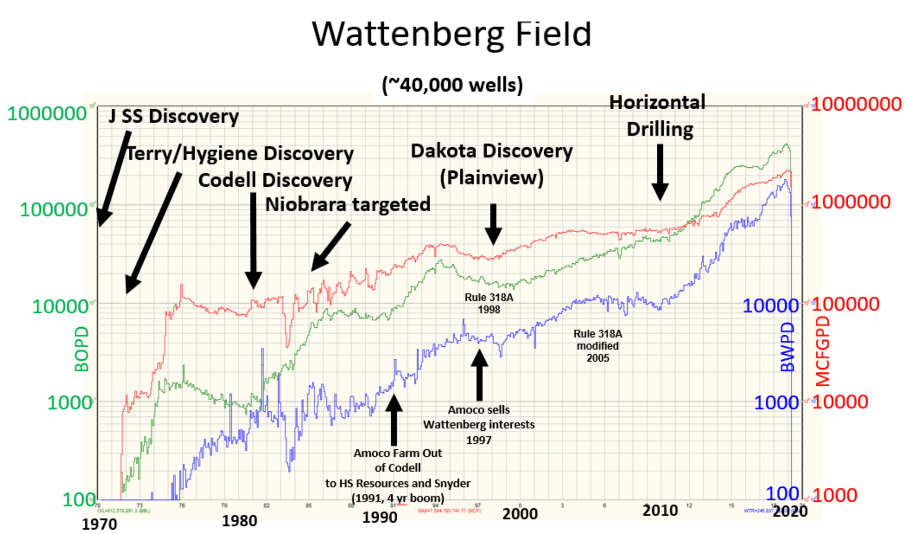

Figure 3: Production curve for Wattenberg Field. The field was discovered in 1970. Horizontal drilling commenced in 2010.

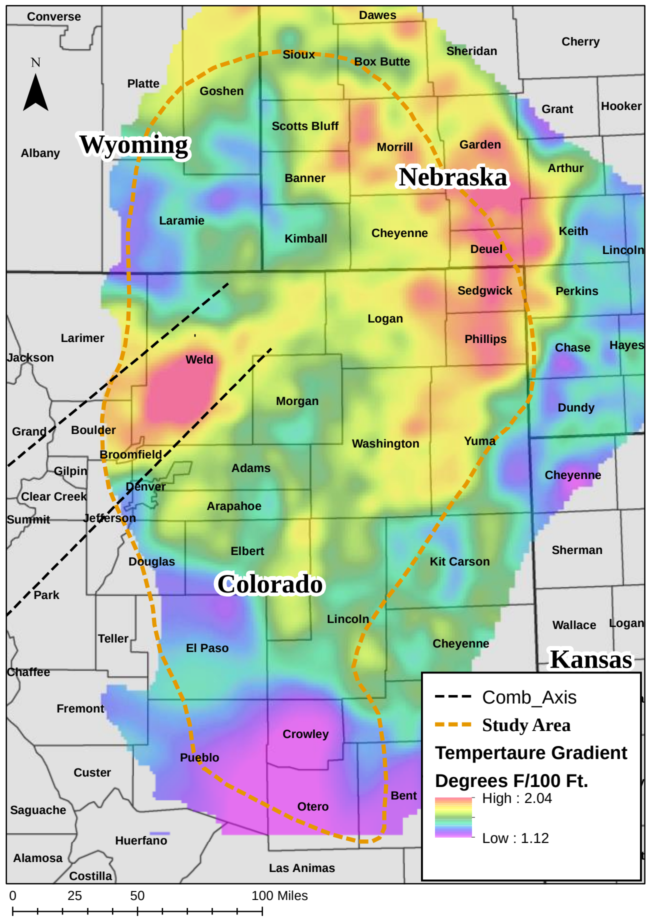

Figure 4: Temperature gradient map Denver Basin. Colorado Mineral Belt axis shown by dashed lines. Wattenberg field is located in an area where thermal gradients are high (>2oF/100 ft). From Thul and Sonnenberg, 2018

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