Continuity and Compartmentalization of Viking Formation gas production from the Ricinus / Bearberry area of the Rocky Mountain Triangle Zone

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The Ricinus / Bearberry Viking gas field is located in the Rocky Mountain Fold and Thrust Belt foothills about 100 km northwest of Calgary, Alberta. The field is composed of numerous thrust fault bounded pools positioned in the core of the Triangle Zone, which represents the easternmost limit of significant Mesozoic-level Laramide deformation (Figure 1). Drilling commenced in the area in the late 1960's, but the first producible Viking sweet gas well was drilled in 1972. Up to the end of 2000, there were 43 producing wells and cumulative production of approximately 8940 x 10^6 m^3 (316 BCF). Initial gas rates range from 25,000 m^3/d to 550,000 m^3/d (0.9 to 19.4 mmcf/d).

The Albian-age Viking Formation in the area was deposited as a series of stacked, northeast prograding, high energy shoreface deposits ranging from basinal and lower shoreface mudstones to fine / medium-grained quartz and chert sandstone and clast-supported chert pebble conglomerate with a sandstone matrix. The conglomerate is interpreted as having three depositional histories: storm deposits in a middle shoreface setting, high energy upper shoreface, and transgressive lags. Total reservoir thickness can be as much as 20 m, with most wells having 6 to 15 m of combined sandstone and conglomerate reservoir at an average porosity of about 6 to 9%. The most significant factor that improves reservoir quality and connectivity locally is the development of tectonically-induced natural fractures related to the creation of the thrust sheets during Laramide deformation. Fracture development, and the associated fracture permeability, is critical to improving reservoir quality and drainage area because of the low matrix permeability in the Viking Formation.

The structural geometry of the area at Viking Formation level can be described as a series of northeast-verging thrust faults that ramp off a basal detachment in the mixed continental section of the Mannville Group, which underlies the Viking Formation (Figure 2). The thrust faults ramp up through the Blackstone and Cardium sections locally following a secondary detachment level in the Second White Specks. These faults eventually merge with the roof thrust and back thrust in the Brazeau Group on the east limb of the Triangle Zone. Fault throws at Viking level range from 50 to 950 m above regional level, with associated displacements ranging from 200 to 3000 m. About 10 thrust sheets have been mapped in the area with strike lengths ranging from about 4 km to greater than 27 km. A substantial amount of high-quality 2-D seismic data has been acquired over the producing pools since development of the area began. These data have

Figure 1: Location & fault trace map for Ricinus / Bearberry Viking Production

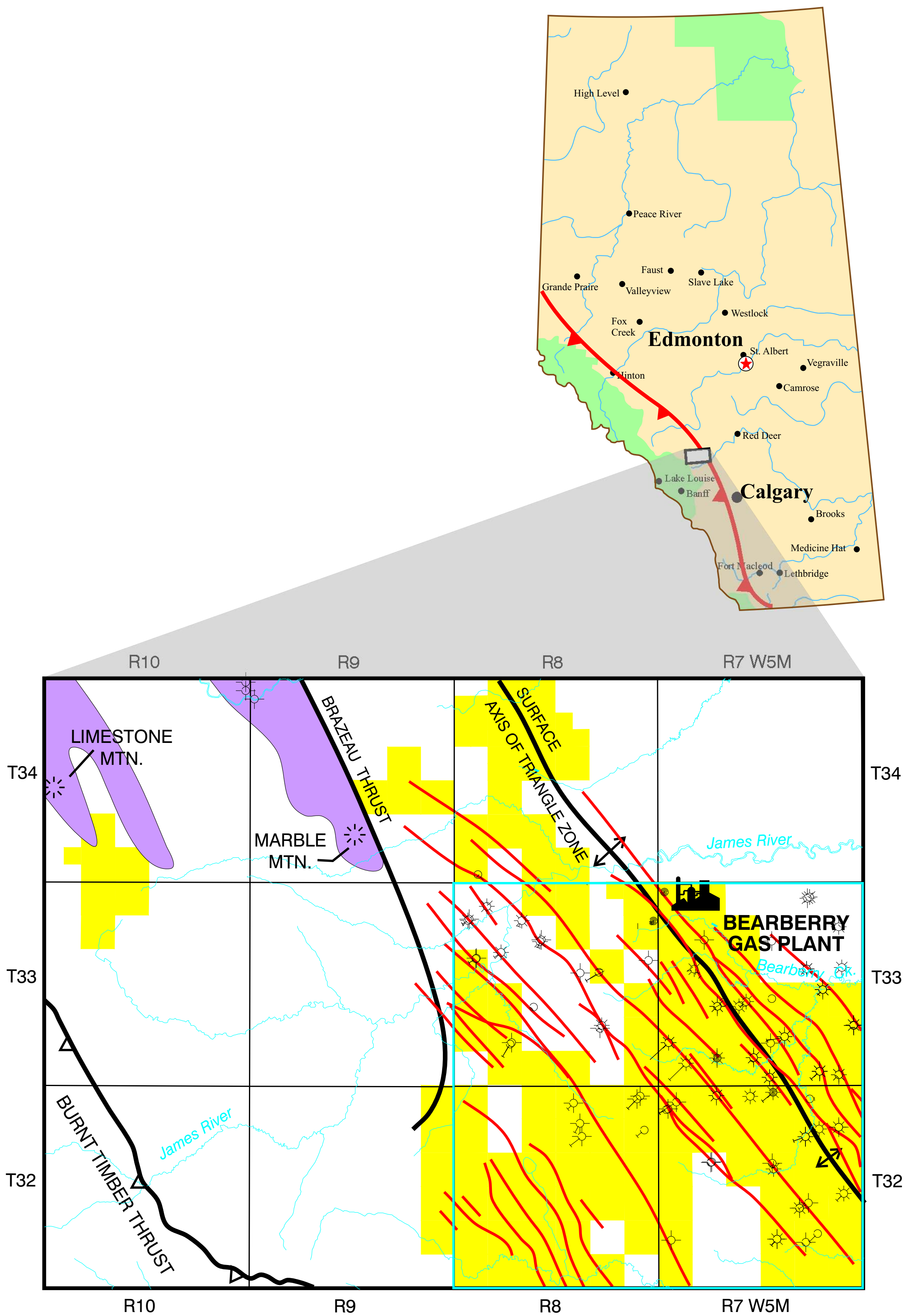
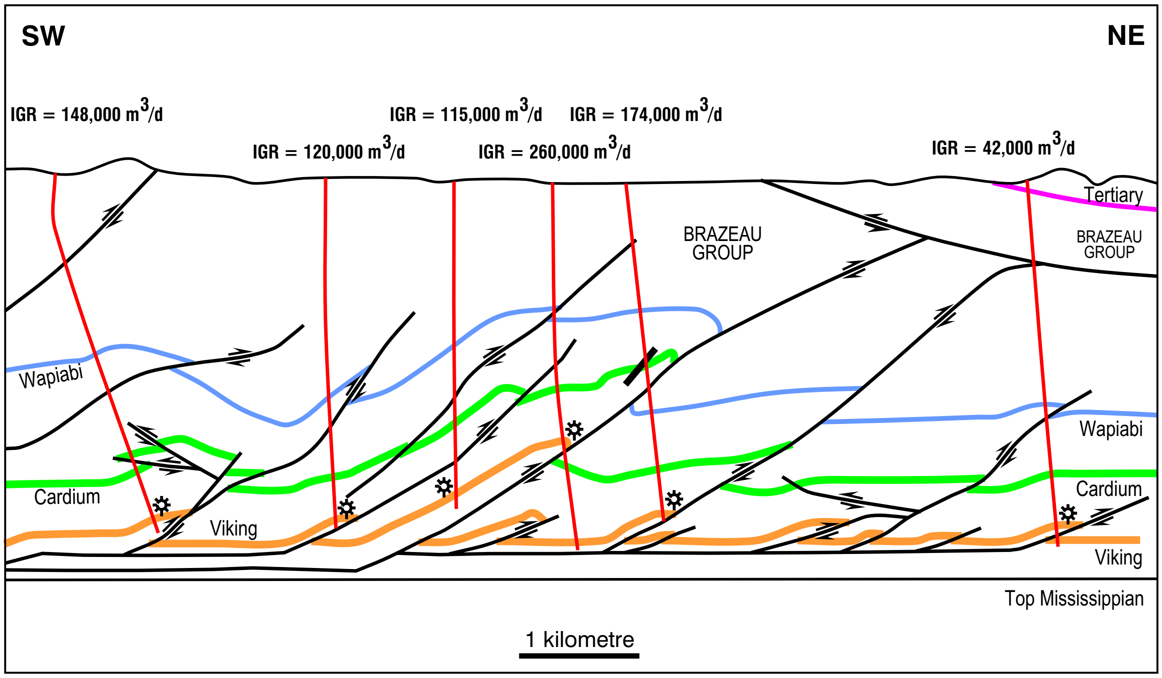


Figure 2: Cross section illustrates the structural styles from the basal detachment in the Mannville interval to the Triangle Zone roof thrust and back thrust. Viking gas production is indicated with initial gas rates (IGR).

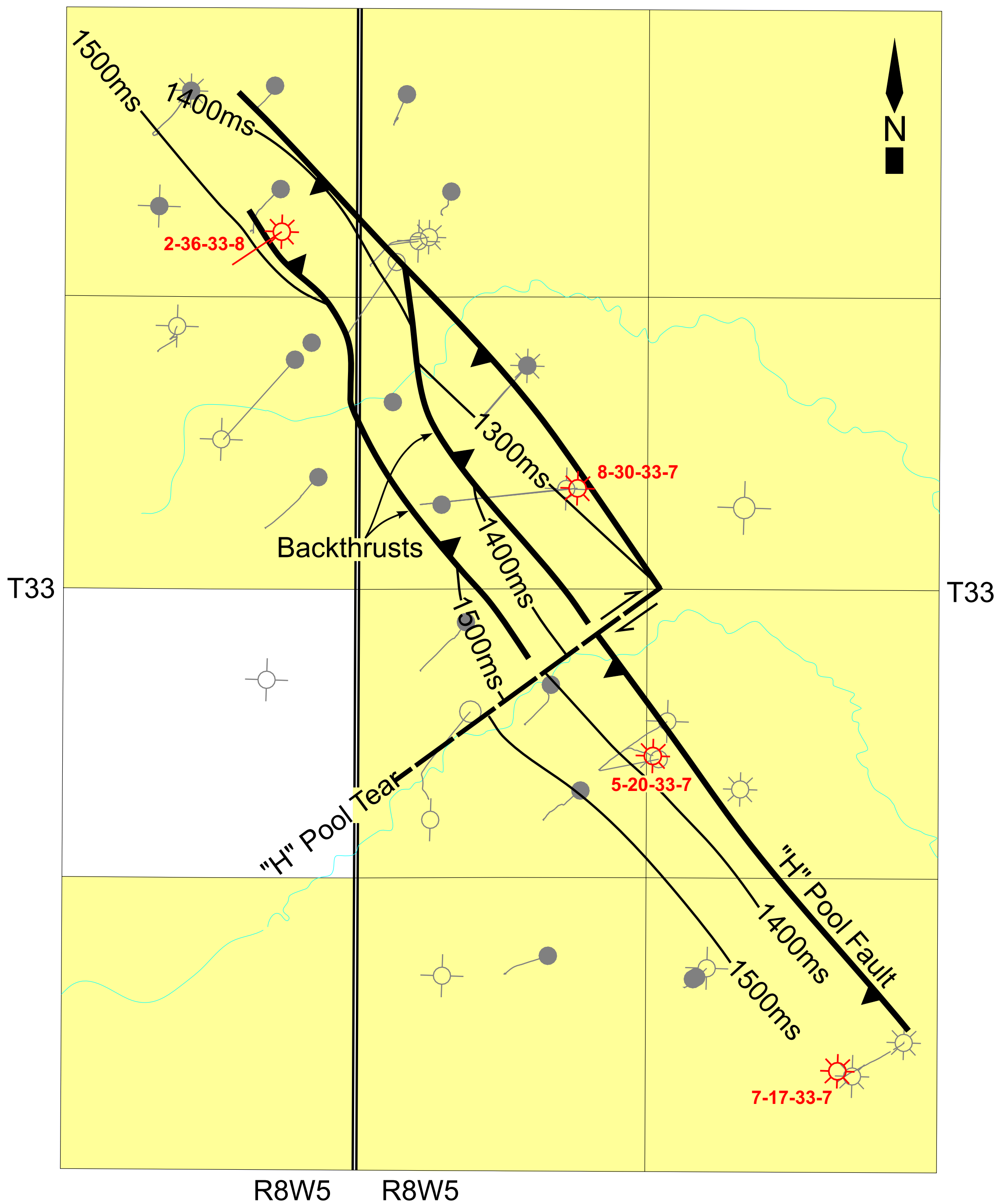


been combined with the well data to create depth structure maps for all of the producing pools. Of the 10 or so pools identified in the area, the three largest pools contain the great majority of the production and ultimate recoverable gas. With numerous wells and prolonged production histories, it is possible to evaluate connectivity / compartmentalization within these large pools from a production perspective and relate these observations back to the structural mapping and interpretations.

A case history of one large pool, informally referred to as the “H” pool at Petro-Canada, was done using pool isopressure maps for a sequence of time periods to evaluate the extent of progressive drainage within the pool. The pool is currently being produced from 14 wells, but production began with the 4-3-33-7, 15-5-33-7, and 7-9-33-7 wells in the central part of the pool in 1988. After 2 production years these 3 wells, with an average cumulative production rate of about 420,000 m^3/d, had begun to deplete the pressure in the pool more than 6.5 km to the southeast. This is based on the 14-13-32-7 well that had been drilled, but not produced, in the southeast continuation of the pool. The reservoir pressure in this well had decreased by about 600 kPa in two years even though the well had not been put on production. By 1994 there were 8 wells on production in a 5 km x 1.5 km area in the central portion of the pool. These wells had depleted the pressure in the non-producing 14-13-32-7 well located 6 km to the southeast by about 3,800 kPa (20% of the 20,000 kPa original pressure) and in the 5-20-33-7 well 2.3 km to the northwest by about 6,100 kPa (30% of the 20,000 kPa original pool pressure). The estimated area of partial drainage / connectivity for the 8 wells in 1994 was about 18 km long and 3 km wide. In late-1999 and early-2000, two additional wells were drilled into the northwest continuation of this pool about 1.6 km and 3.6 km away from the nearest producing well in the pool at 5-20-33-7. These 2 productive wells, 8-30-33-7 and 2-36-33-8, demonstrated undepleted initial reservoir pressures. The interpreted cause of this pressure separation is a dip-parallel, right-lateral, tear fault within the pool that offsets the leading edge truncation of the Viking reservoir by about 440 m (Figure 3). This fault can not be seen on the 2-D seismic, but the lateral offset of the Viking leading edge and the overlying Cardium-level structures occurs in a 1.2 km interval between two seismic lines. Several hinterland-verging backthrusts are present in the Viking and Cardium intervals on the north side of the tear fault. These features may be related to oversteepening of the main thrust sheet as it is slightly rotated to a higher dip by motion on the tear fault.

Drainage in another large pool, informally referred to as the “E” pool at Petro-Canada, was also analyzed using isopressure mapping. The sequence of pressure maps showed that extensive pressure depletion had occurred at substantial distances from the producing wells. Two wells at 9-6-33-7 and 6-7-33-7 began production in early-1994 to early-1995 at rates of about 160,000 m^3/d and 390,000 m^3/d. In August of 1996 another well was drilled and completed in the pool at 5-23-33-8 about 4.7 km northwest of these producers. The reservoir pressure in this well was 12,800 kPa, which was about 35% less than the original

Figure 3: Simplified "H" Pool fault trace and time structure map illustrating the relationships and positions of the main thrust, tear fault, and secondary backthrusts. The tear fault is constrained by 2D seismic and well control. The backthrusts are poorly imaged at Viking level, but are well imaged at Cardium level. There is an interesting spatial coincidence between the tear fault and the path of a minor creek. The main part of the depleted "H" Pool lies south of the tear fault, while the two producing wells north of the tear fault demonstrated undepleted initial pressures.



pool pressure. An additional pressure survey for this well was done in August 1999 and showed reservoir pressure of 7720 kPa even though this well had been shut-in since the initial pressure survey in 1996. Over a period of about 5 years, the pressure had been depleted by about 60% even though this well is 4.7 km away from the nearest producing well.

A humbling example of structural compartmentalization was encountered in the 10-16-33-7 W5 well. This well drilled through a first Viking penetration, which was part of an existing producing pool, and then penetrated two additional Viking reservoir sections below the thrust fault that carried the first penetration (Figure 4). Wireline testing of the second and third Viking intervals indicated undepleted pressure and good permeability in the former and tight reservoir in the latter. After completion of these intervals, only the second Viking was capable of production. Production rates and reservoir pressures declined rapidly. Material balance analysis of these data indicated that this second interval was in a structural compartment that is approximately 2.6 hectares in area (75 m x 350 m). This interval is now interpreted to be an isolated section of overturned forelimb trapped between an anticlinal breakthrough fault above and a synclinal breakthrough fault below, which merge together along strike (Figure 4).

The Viking Formation Ricinus / Bearberry field provides excellent examples of both strike-extensive pools formed by thrust faults as well as abrupt fault-related breaks that may compartmentalize the pools. Recognizing potential compartmentalization continues to be challenging in this area due to inconsistent seismic imaging of the target formation, but these features can present significant opportunities even in such a mature field.

Figure 4: Structural cross section through the 10-16-33-7W5 well, which shows 3 Viking reservoir penetrations. The first interval was not completed due to connection to the 7-16-33-7W5 producer. The second interval was completed and put on production, while the third interval was too tight to produce. Rapid production and pressure decline, in combination with structural interpretation, indicate that this second interval is likely an isolated wedge of reservoir trapped between an anticlinal breakthrough fault above and a synclinal breakthrough fault below.