Reservoir Characterization by Means of Drill Cuttings; An Example of Hydrothermal Dolomite in Cuttings from the West Sukunka River Area of British Columbia

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Summary

If drill cuttings are collected correctly, they are a usefull tool for reservoir characterization. It goes without saying that core and logs are preferable over cuttings, but often we have no core and cuttings are the only direct observation of particle size, lithology and reservoir characteristics, in long and expensive horizontal wells. In this case our best option is to calibrate to observations in core or outcrop, and to extrapolate those larger scale observations to the millimeter scale observations in the cuttings.

The distance drilled represented by cuttings is typically much longer than the distance drilled in core. This presentation is a clear example of poor core coverage (3.2 m of core versus kilometers of cuttings), in which case core gives a hint of dolomitization and fracturing near the base, and where sample vials from a nearby well show a 50 m zone with “lost circulation material”, doubly-terminated prismatic quartz crystals and millimeter size fragments of saddle dolomite. This assemblage is characteristic of hydrothermal dolomite reservoirs around the world (Davies et al., 2005; Davies and Smith, 2006).

With the ever increasing resolution of both stereomicroscopes and camcorders, it is now possible to demonstrate matrix and fracture porosity as reflected in cuttings through “live feed” on a high definition screen, and add drill cuttings to the repertoire of a core conference.

Introduction

Generally, geologists use logs and core to map and characterize their reservoirs. Drill cuttings are considered unreliable by some, because they may not be representative of the reservoir because of poor sample collection techniques (dog housing) or dilution by cavings. In most cases however they do represent the drilled interval, albeit possibly with a little sample lag, and with a little training drill cuttings reveal by first order observation particle size, porosity, solid bitumen, clay types and chemical composition. These are important observations characterizing potential reservoir and they add certainty to petrophysical interpretation. Moreover some of these parameters, some of which are “un-seen” by logs because they simply can not resolve them, because of mud conditions such as when barite in the mud obscures the true PE character.

Generally one would prefer core data over data from cuttings, but coring is very expensive and therefore there are 2.5 to 4 times more wells with cuttings than core. For example, in Alberta there are 63,000 wells with cored intervalls and 152,000 wells with cuttings and in British Columbia (B.C.), there are roughly 7,000 cored wells with core and 30,000 wells with cuttings. In meters, Alberta collected over 1million boxes containing a total off 1,651,862 meters of core. In contrast 78,113,208 meters of drill cuttings were collected and washed (ERCB Fact Sheet, Jan. 2009). So in Alberta there are roughly 50 times more meters of cuttings than meters of core. This case study is a good illustration of the value of data from drill cuttings, especially in the presence of sparse core and log data, and also shows some limitations.

Setting, Stratigraphy and Lithologies

The Sukunka River area of NE B.C. is located on the SW end of the Peace River Re-entrant, a constriction in the Laramide Fold Belt, between the main bulge formed by the Alberta Arc and a less pronounced arc centred in northeastern B.C. and includes the Sukunka, Brazion and Boulder fields. The origin of this tectonic feature is thought to be related to northeast-trending geofractures, which in turn were responsible, since Carboniferous time, for the development of the Peace River embayment where a substantial thickness of sediments was deposited and preserved (Barrs and Montandon, 1981). The Sukunka area has long been successfully explored for Triassic gas in faulted, folded and fractured Baldonnel and Pardonnet dolomite reservoirs (Cooper et al., 2004). During the last 5 years Paleozoic strata of the Pensylvanian Taylor Flat Formation and the Permian Belcourt Formation have yielded similar results (Canadian Discovery, 2007). The example illustrated in this core display utilizes data from 3 wells with surface locations (in drilled / chronological order): b-060-E/093-P-05, a-093-D/093-P-05 and a-026-E/093-P-05 respectively, drilled in the Brazion and Sukunka fields of the Sukunka River Area (Figures 1 and 2). The reservoir targets are the Permo-Mississpian strata in the fractured crests of Laramide fold structures (McLeod and Brotea, 2007). Simplified local stratigraphy is depicted in Figure 3, which shows just two unconformities, of what are in outcrop at least 8 unconformities between the Mississippian and the Triassic (Henderson et al., 2010). Mixed lithological compositions reflect the transition between carbonate dominated Paleozoic and clastic dominated Mesozoic sedimentation, typical for the Western Canadian Sedimentary Basin.

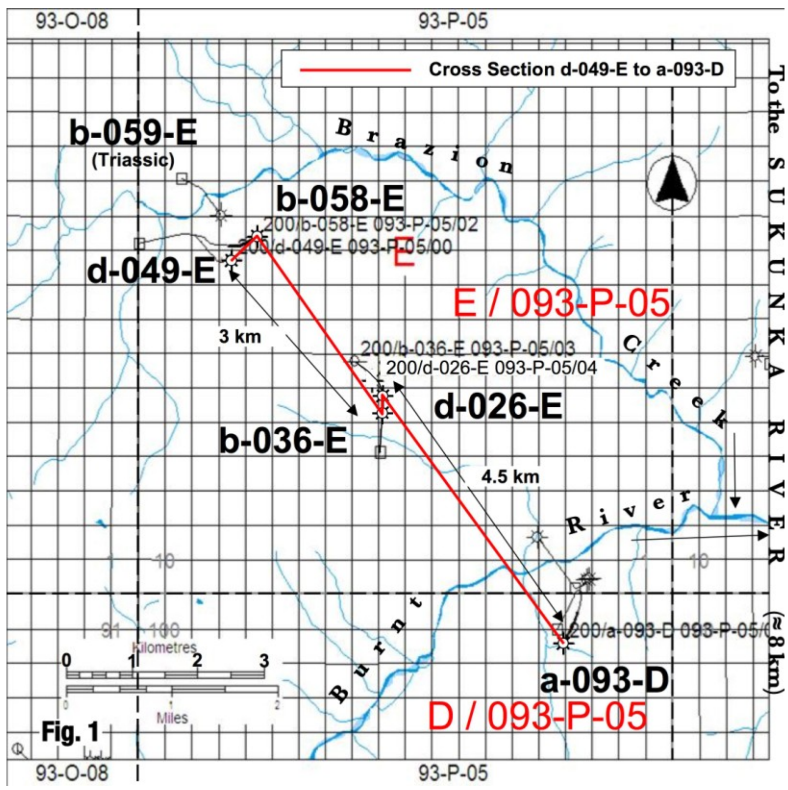

Figure 1 - Right. Location of blocks D and E in 093-P-05 in the Brazion Creek area of northeast British Columbia with well locations (GeoScout, 2009) and a (red) line of cross section for Figure 2.

The Carboniferous Taylor Flat Formation

The middle Missippian to middle Pennsylvanian Taylor Flat Formation is the carbonate-dominated, uppermost formation of the Stoddart Group, and represents the waning of siliciclastic deposition in the Stoddart Group package (Richards et al., 1994). The Taylor flat comprises 2 units: 1) a lower unnamed interval of silty to sandy argillaceous carbonates with subordinate sandstone and shale of late Viséan age and Serpukhovian age and 2) an upper unit of Bashkirian and Moscovian (Pennsylvanian) age, that unconformably overlies the lower unit and has been informally called the Ksituan member of the Taylor Flat formation (Richards et al., 1994).

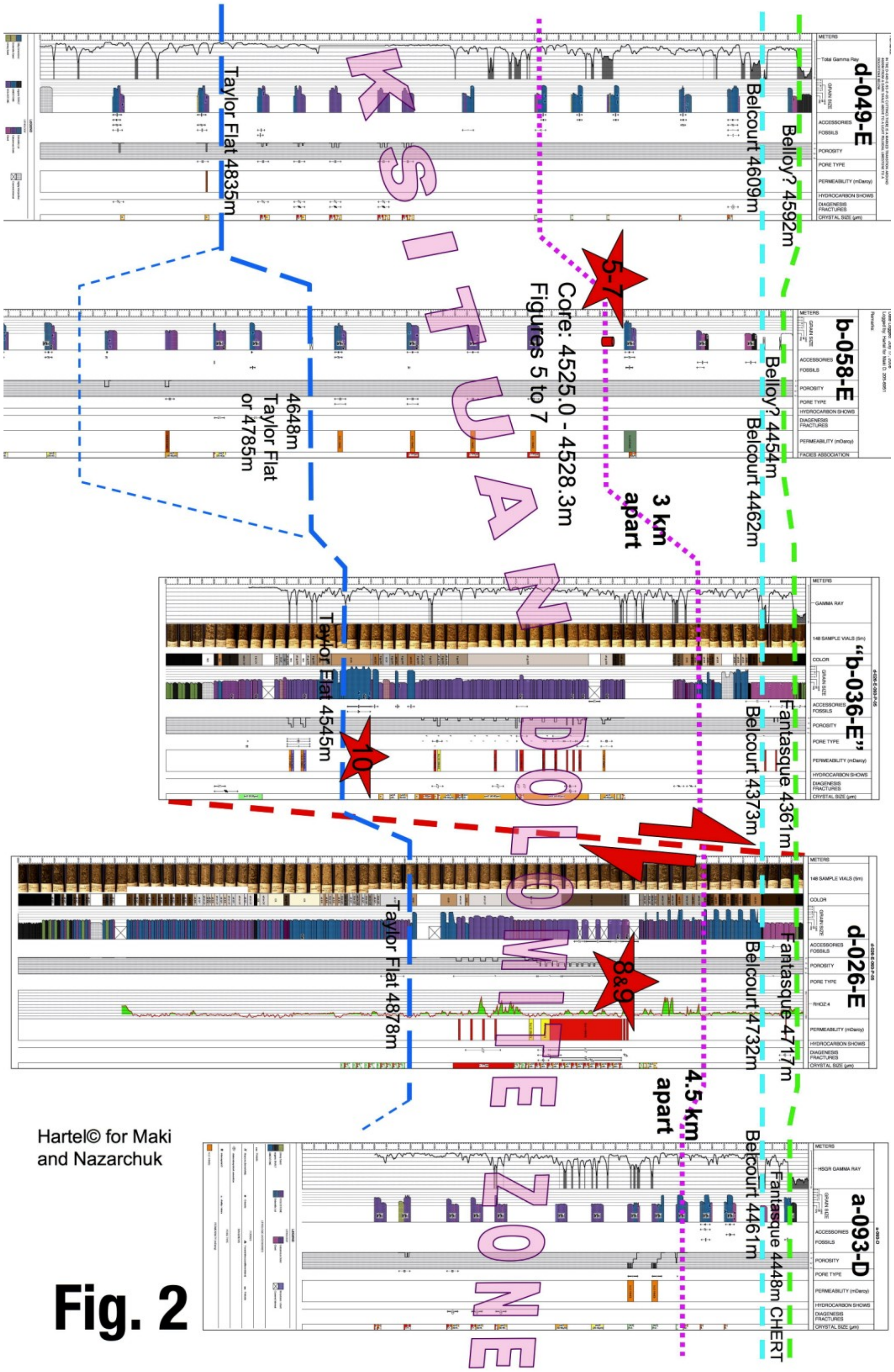

Fig. 2

Figure 2. Cross section over ≈8 km from d-049-B trough b-058-E, "b-036-E" and d-026-E to a-093-D. Location of other figures (core and photos) are indicated by red stars. Note that thickness variations can be due to variation in well bore orientation in highly deviated and sub-horizontal wells.

An upward change from restricted-marine carbonates and shale with minor anhydrite to highly fossiliferous open-marine limestone with mollusca, echinoderms, brachiopoda, bryozoa, foraminifera, ostracoda and other indeterminate bioclasts (Barclay et al., 1990; Barrs and Montandon, 1981) and sandstone (middle ramp), represents the contact between the Lower Taylor Flat and the middle Ksituan. Locally, oolitic carbonates indicate a shelf depositional setting (Richards, 1989). Regionally, cherty dolostone and subordinate sandstone of the middle Ksituan abruptly overlie the limestone-sandstone dominated lower Ksituan and are in turn, abruptly (unconformably) overlain by dolostone of the upper Ksituan (Richards et al., 1994).

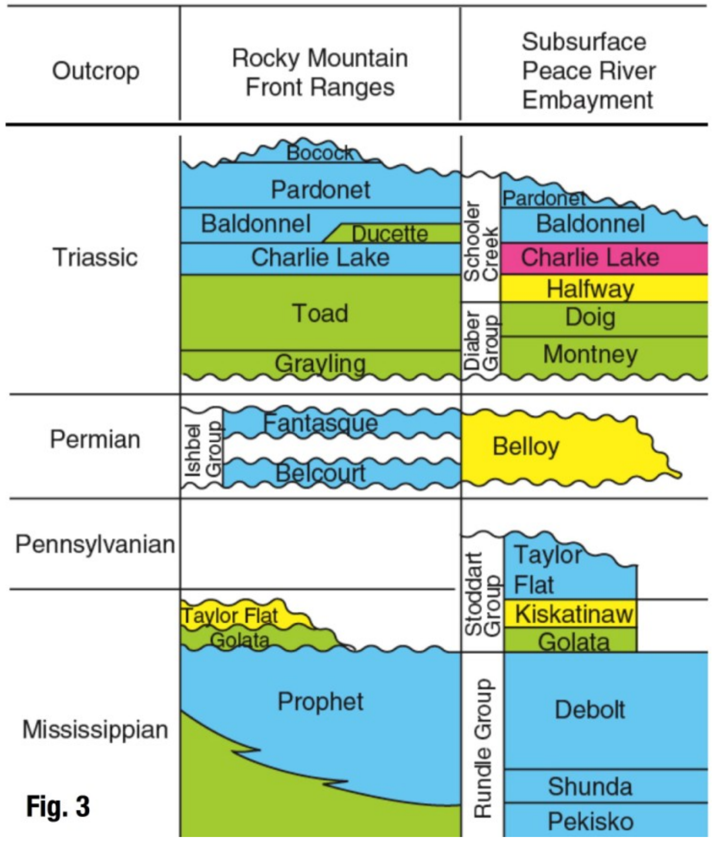

Figure 3 - Right. Permo-Carboniferous stratigraphy in the Sukunka River Area (with permission from Canadian Discovery Digest, 2007). The production of all 3 wells appears to come from the Permo-Mississippian part of the section (Taylor Flat and Belcourt).

Lower Permian Belcourt Formation

In outcrop in East Central BC, the Belcourt formation unconformably overlies the Taylor Flat, and appears to contain at least two intraformational unconformities separating it into Kasimovian-Gzhelian, Aselian and Artinskian aged units (Henderson, 2010). In outcrops to the west of Sukunka, Lower Permian Asselian to Lower Artinskian carbonates, consist mainly of silty, mixed-skeletal wackestone and packstone, and finely crystalline dolostone, possibly with chert nodules. An eastern facies, which contains the type section of the Belcourt Formation (Forbes and McGugan, 1959), includes shallow shelf, oolitic and skeletal dolostone grading eastward into thin (3-10 m), planar bedded, microcrystalline dolostone characteristic of intertidal to supratidal environments. Locally up to 35% porosity has been observed in the Belcourt Formation (McGugan and Rapson-McGugan, 1976). The Belcourt is equivalent to the lower part of the Belloy Formation (Fig. 3; and Henderson et al., 2010). The mixed siliciclastic-carbonate Belloy Formation represents deposition within a tectonically stable, shallow marine, shelf setting characterized by limited clastic input and an active chemical environment (Naqvi, 1972).

Drilling and Production History

Three wells, producing 110 mmcf/day (November, 2009) were drilled between 2003 and 2007 (Fig. 4). Leg d-49-E/093-P-05, was spudded in September 2003, from the surface location a-60-E. The Belcourt and Taylor Flat formations were encountered at 4607 m and the 4863 m measured depth, respectively. At 4970m just into the top of the Kiskatinaw formation, logging tools

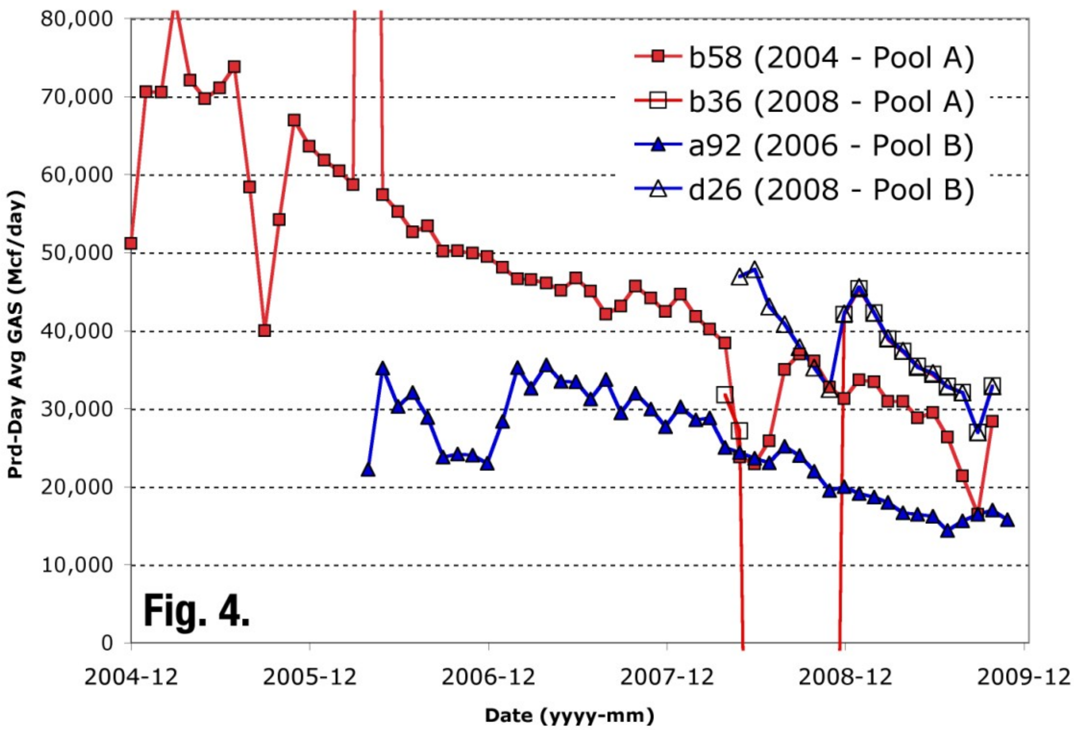

Figure 4. Daily gas production data from 3 wells in D and E/093-P-05 from 2004 until end 2009. It is unclear why production from b-058 drops by 15 million a day at the moment b-036 comes on stream. In December 2008 a request to comingle the two sheets intersected in the b-026 leg was granted; from that moment onwards production numbers overlap (traingles and squares).

got stuck and after 44 fishing expeditions, cementing tools into place, and discovering that d-49 was located on the back limb of a west verging anticline, d-049 was cemented back to 4040m and side tracked in March of 2004, to b-058-E/93-P-05 less than a km away (Mauel, 2004), which produced over 70 mmcf/day of gas for the first 6 months in 2005 (Fig. 4). In b-058 the Belcourt and Taylor Flat formations were encountered at 4462 m and 4648 m respectively. At 4505 m, an open fracture near the top of the Belcourt was penetrated, allowing an influx of sour gas. Mud weight was increased and drilling resumed. From 4525-4528.2 m depth a core was cut, which is on display (Fig. 5). The core shows some interesting dolomite and calcite fracture fills (Fig. 6) and some crystal druse (open fractures) in the rubble zone, but little furtherindication of exceptional reservoir quality. Well b-058-E was open hole acidized, June 2004, in in the interval from 4,490 m to 5,077 m deep in the Belcourt / Taylor Flat succession, and has produced 78 Bcf's of gas to November 2009. A set of thin sections from the Belcourt in b-058 contain crinoidal partially dolomitized mudstones, variably dolomitized crinoid brachiopod bryozoan wacke-grainstones and relatively coarse (up to ½ mm) dolomite mozaic with intercrystalline bitumen. Lithological descriptions (Mauel, 2004) indicate more chert and coarse dolomite (after crinoidal grainstone?) in the Belcourt and more silt-sand component and (porous) micro- to fine crystalline dolomudstones in the underlying Taylor Flat. Two thin sections from the Belcourt core (Fig. 5) show sandy crinoid bryozoa foraminifera grainstone with *Paleoaplysina* and *Protonodosaria* spp (Fig. 7) at 4526.1 m and an exceptionally coarse dolomite mozaic with intercrystalline pyro-bitumen and ghost textures of the pore structure of recrystallized crinoids at 4527.7 m. *Paleoaplysina* is a cm-scale tabular fossil of unknown taxonomic affinity (hydrozoan?; Bamber and MacQueen, 1979), which lived during Pennsylvanian and Permian times where as *Protonodosaria,* spp. (Fig. 7) was at least younger

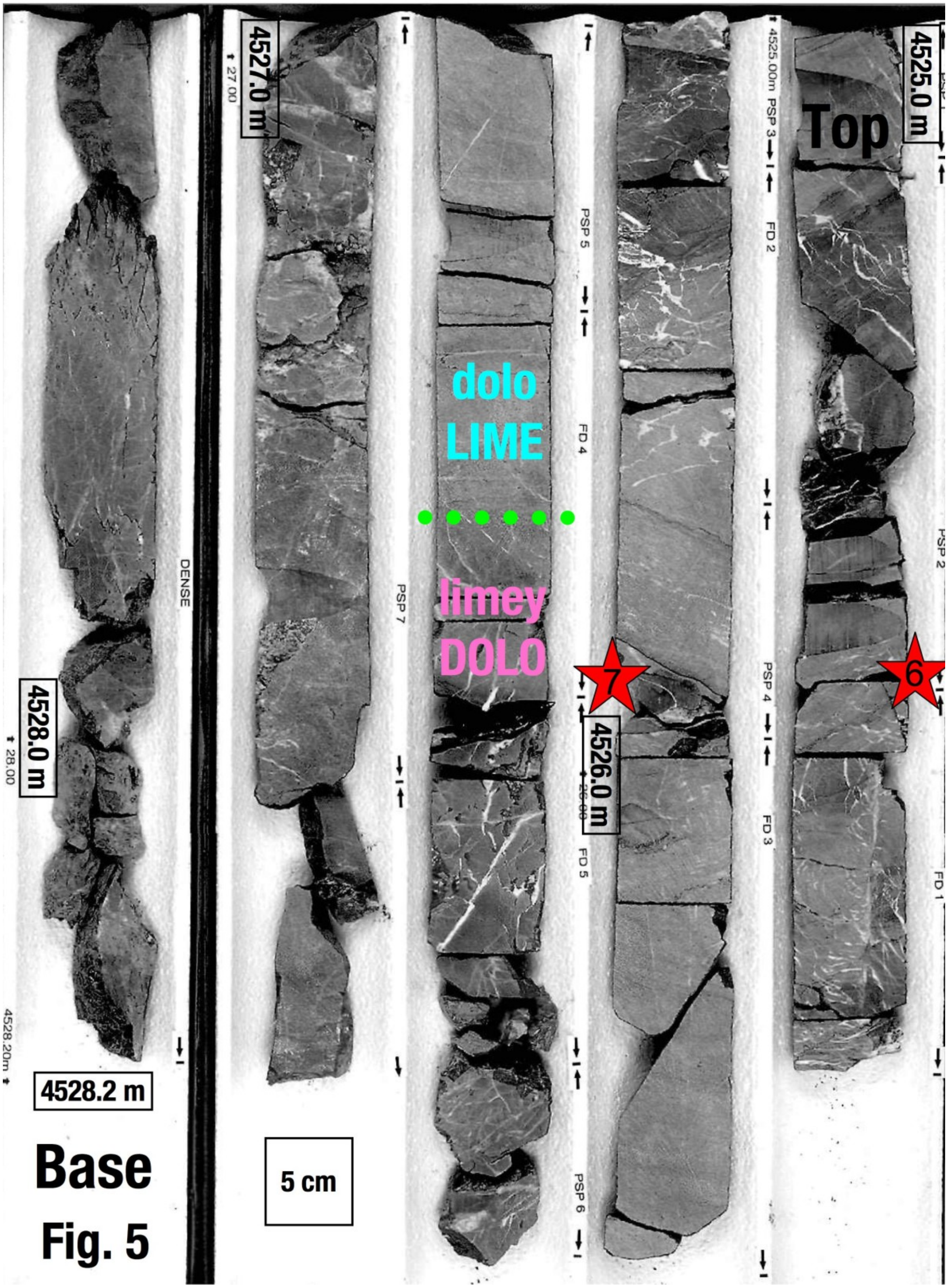

Figure 5. Core photo of b-058-E between 4525m and 4528.2m in the Belcourt (Core Laboratories). The core becomes increasingly dolomitic and fractured towards the base (bottom left). Green dots indicate a calcite to dolomite transition (top to bottom).

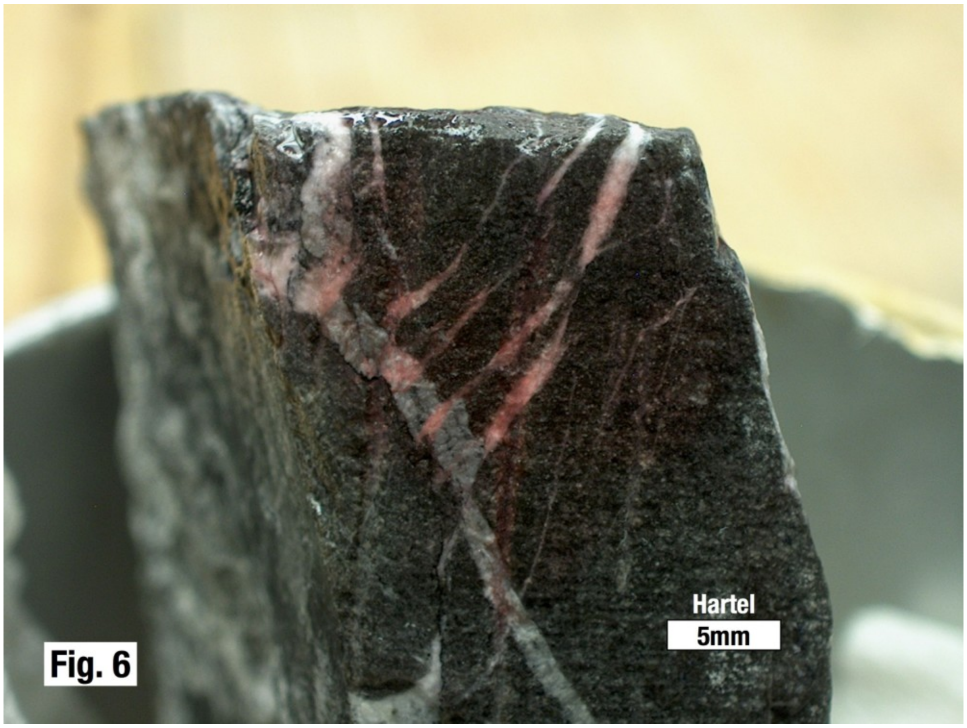

Figure 6. Macro photo of an approximately one inch wide fragment of core from b-058-E/093-P-05 at 4525.3m depth. The matrix is a mixture of calcite with coarse dolomite crystals. The matrix is cut by white dolomite filled fractures or veins, which are in turn cut or off-set along “en-echelon” calcite richer veins, stained reddish by means of Alizarin Red.

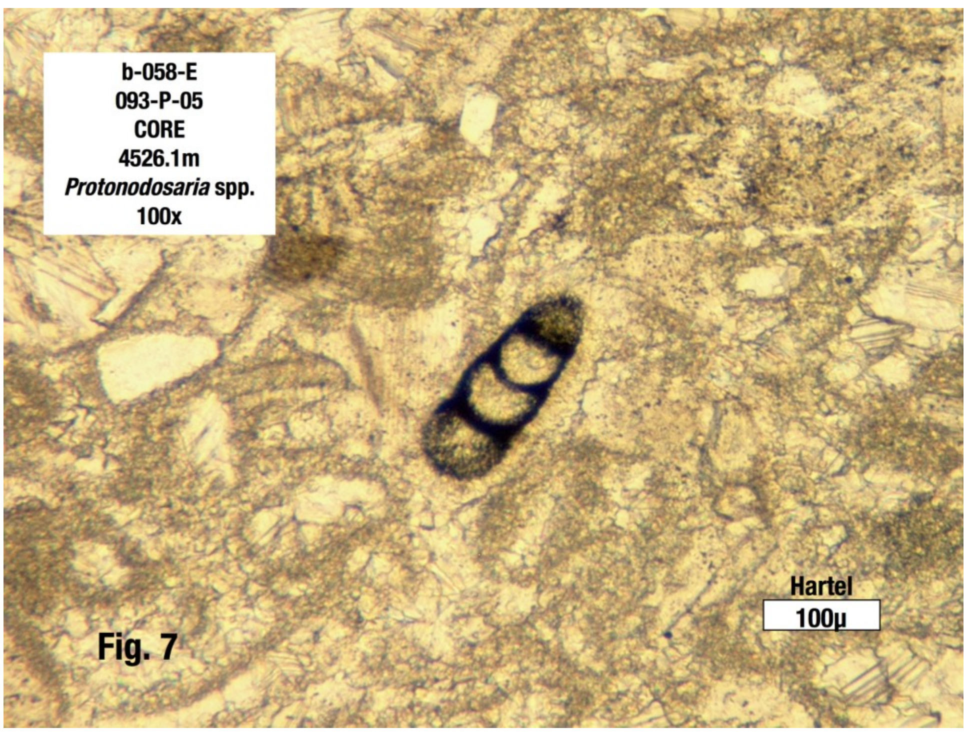

Figure 7. Photomicrograph of Protonodosaria, a foraminifer which is probably Permian, but possibly Pennsylvanian, in a *crinoid-bryozoa-paleoaplysina* grainstone taken from the core in well bore b-058-E-093-P-05, at 4526.1 m deep. The 100µm scale bar indicates this organism is 0.1 mm wide and 0.2 mm long.

then Moscovian (Kasimovian or Gzhelian; Henderson et al., 1995), but is locally very common in the Permian, suggesting that the lime-grainstones at the top of the Ksituan Dolomite Zone, are at least upper Pennsylvanian, and most likely Permian in age (Fig. 2).

In August 2005 a-093-D/093-P-5 was spudded in the Sukunka River region, 8 km to the southwest of b-058-E, along the strike of the mountains. The Belcourt was intersected from 4461 m measured depth to Total Depth at 5164 m. It was completed open hole in February 2006 and started production at about 30 mmcf/day (Fig. 4). Lithologies are similar to those in b-058, except for greater dolomite porosity in the top of the Belcourt (Brotea and Keppler, 2006). In February 2007, d-026-E/093-P-05 was spudded (1st event), from the surface location a-026-E, 2.5 kilometers to the SE from b-058-E (Figures 1 and 2). It was drilled directionally almost due north and encountered two sheets with Belcourt and Taylor Flat, in an upper thrust sheet at 4373 m and 4544 m, and in a second deeper sheet at 4727 m and 4890 m. Again tools and cones were lost and d-026 was terminated at total depth of 5084 m in September 2007. After a first unsuccessful side track (2nd event), a second side track, b-036-E (3rd event), was successfully launched in September 2007. Side track b-036-E cut trough Mississippian rocks from 5021 m to 5654m, which included the Debolt. After an open hole acid job, b-036-E (3rd event) was abandoned in November of 2007 (McLeod and Brotea, 2007). During the drilling of d-026 (1st event) circulation was lost into the lower thrust sheet between 4783 m and 4787 m (Fig. 8). No cuttings were recovered at that point, but below 4787 m sample vials contain abundant lost circulation material (ground up peloidal grainstone; Fig. 9), clusters of white saddle dolomite, euhedral, sometimes doubly-terminated quartz crystals and micro spherules

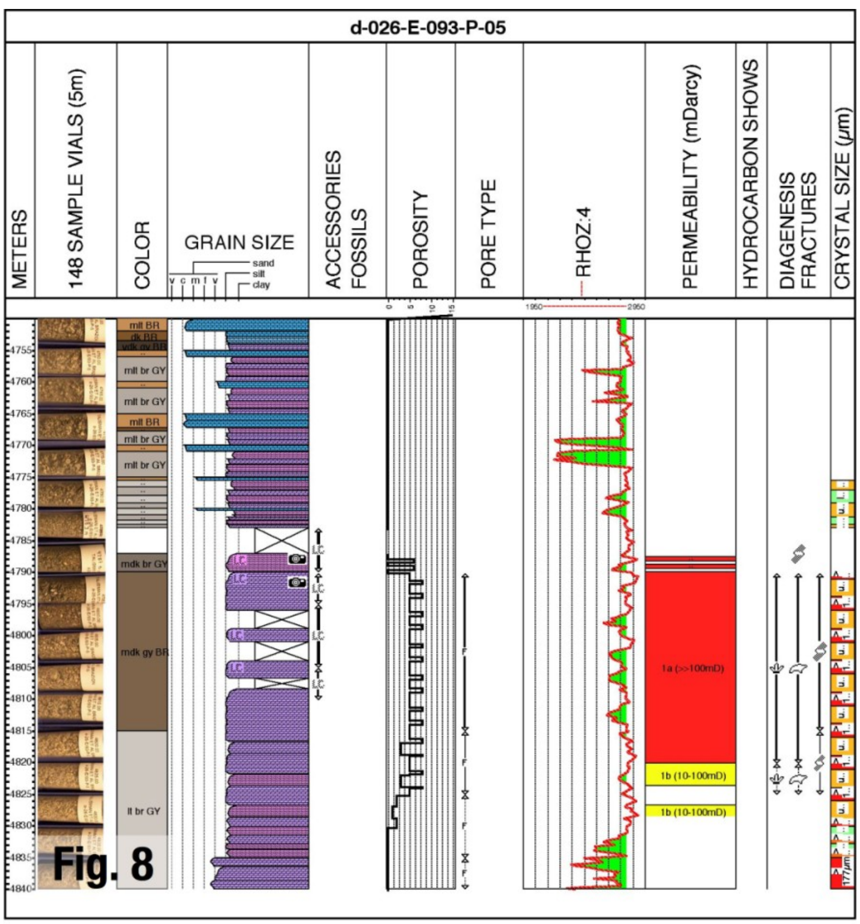

Figure 8. Interpretation of porosity and permeability from drill cuttings with image of actual sample vials corresponding to the sample depth along the side (in AppleCore©) (Part of Fig. 2).

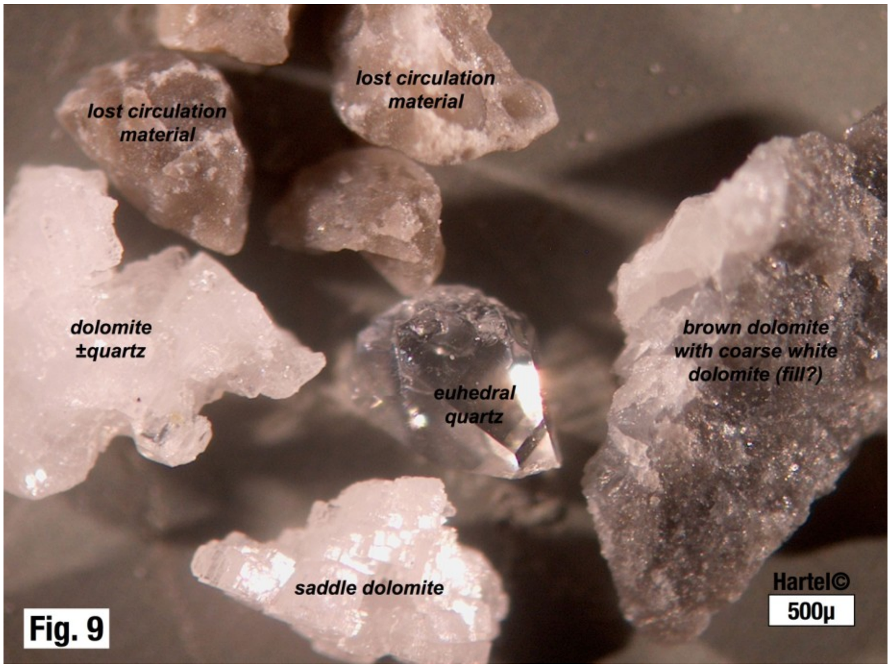

Figure 9. Microscope image of selected cuttings from d-026-E/093-P-05 corresponding to a depth from approximately 4790m to 4795m. The four brown fragments are approximately 1mm fragments of ground up micritized peloidal grainstone used as a lost circulation material. In the centre is a fragment of prismatic quartz (just over 1mm). To the right a fragment of brown crystalline dolomite which becomes more milky and coarser to the left edge (fracture fill). At the bottom a fragment of milky white saddle dolomite with curved surfaces on it, and to the left an aggregate of dolmite and quartz (location of photo in Figs. 2 and 8).

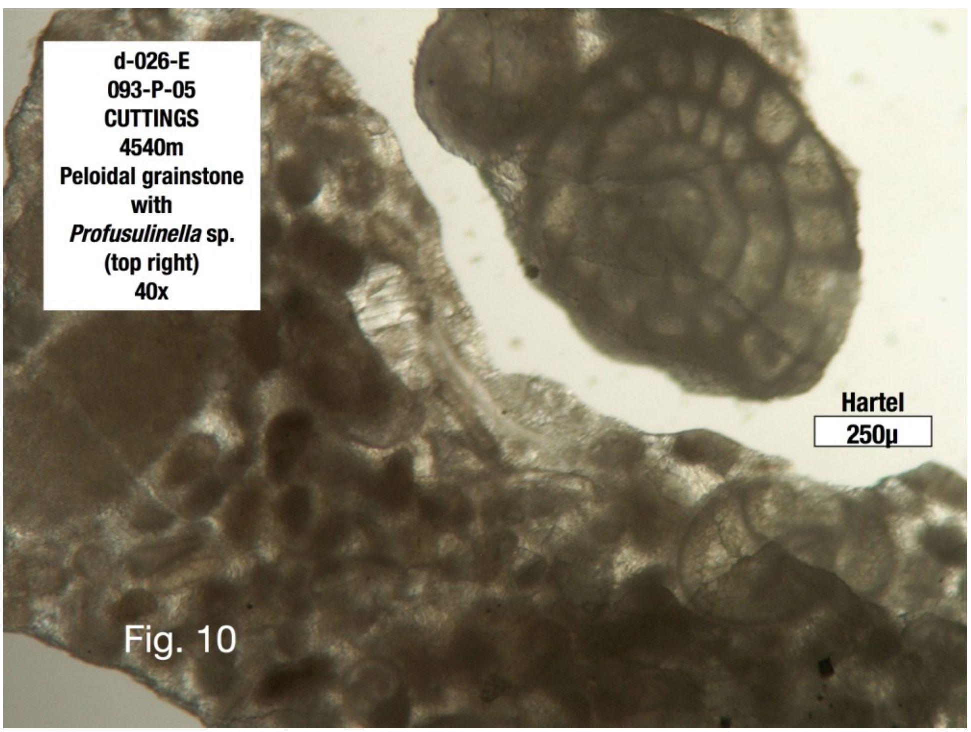

Figure 10. Cuttings from 4540m depth in d-026-E-093-P-05 with peloidal skeletal grainstone and a fusulinid Foraminifera. This foram is smaller than what is typical for Permian forams, and it is therefore most likely Moscovian in age, but in any case Permo-Pennsylvanian.

of silica. This cuttings assemblage, observed from 4787 m to 4830 m measured depth, are interpreted as a fractured hydrothermal dolomite reservoir (Fig. 8). This footwall zone was acidized between 4775 and 4831m measured depth (4^{th} event), and produced 30 to 50 mmcf/d of gas. The hanging wall was acidized between 4360 and 4576 m measured depth (5^{th} event) and produced about 30 mmcf/d (Fig. 4). The zones have been comingled since December 2008 (Fig. 4).

Note that both zones were completed in the part of the well bore which underlies quarter unit d-026, and that the deeper footwall section to the north is labelled d-026, while the shallower hanging wall section to the south is labelled b-036-E. This is erroneous since neither footwall nor hanging wall underlie unit 036 to the north.

No core was pulled from this well bore at all, so all we have are the cuttings. The peloidal skeletal grainstones may show *fusulinid Foraminifera* like of which the larger ones are generally typical for the Permian Belcourt and the smaller ones, as shown in cuttings from 4540m (Fig. 10) are more likely to be *Profusulinella*, which is likely of Moscovian age (B.C. Richards, pers. comm.; C.W. Henderson, pers. comm.) Therefore the contact between the Ksituan member and the Taylor Flat was choosen below the basal limegrainstones. However, the position of this contact remains highly uncertain (Fig. 2). There are many unconformities, and in cuttings one can not observe those, because mm-scale cuttings are ill-suited to detect up to meter scale carbonate blocks observed in the unconformities. In this erosional setting, a single foram like the Profusu linea depicted in figure 10 can be out of place. This illustrates once more the importance to calibrate with core (Fig. 7).

Material Balance and Pressure Tests

All locations are aligned along the SE-NW strike of Laramide fold structures (Cooper et al., 2004) and lie perfectly on one line (Fig. 1). The hanging wall (b-036-E) and footwall (d-026-E) of the surface location (a-026-E) lie on different pressure gradients (Fig. 11), while they are in very close proximity, only separated by what is likely a reverse fault, and approximately 127 meters of rock. Rather than connect with each other, the hanging wall (b-036) appears to be in communication with b-058-E, 3km to the NW and the foot wall (d-026) appears to be in communication with d-093-D, located 4.5 km to the SE. Pressure data may corroborate the conclusion that large aperture SE-NW striking sub-vertical type 2 fractures oriented parallel to the grain of the mountains, which were found to be a major factor in deliverability for the Triassic in this area (Joubert, 1998; Henderson et al., 2010), also play an important role in the Permo-Pennsylvanian strata.

Conclusions

The 3 wells described above were aimed to intercept the Permo-Pennsylvanian fractured crests of Laramide fold structures. Rough mass balance calculations suggest these 3 wells may eventually produce over 300Bcf of gas. The Belcourt seems to be composed of a ±sandy grainstone over top of a predominantly dolomitic section with up to 30% microporosity (Ksituan?), which is locally fractured and altered by hydrothermal fluids. This zone may also have contained *Paleoaplysina* spp. bioherms, likely composed of aragonite, which may have been chemically metastable, and more reactive than the over- and underlying limestones.

The *Profusulinella* in d-026-E, would indicate an early to mid Moscovian (mid-Pennsylvanian) age and correlate with the “middle” Ksituan. The *Protonodosaria* spp. in the core from b-058-E could be either uppermost Ksituan (late Kasimovian-Gzhelian) or Lower Permian (Asselian-Sakmarian) and correlate with the Belcourt. Therefore the reservoir dolomites, which are stratigraphically positioned between the two limestones (Fig. 2), can be either Permian or Pennsylvanian.

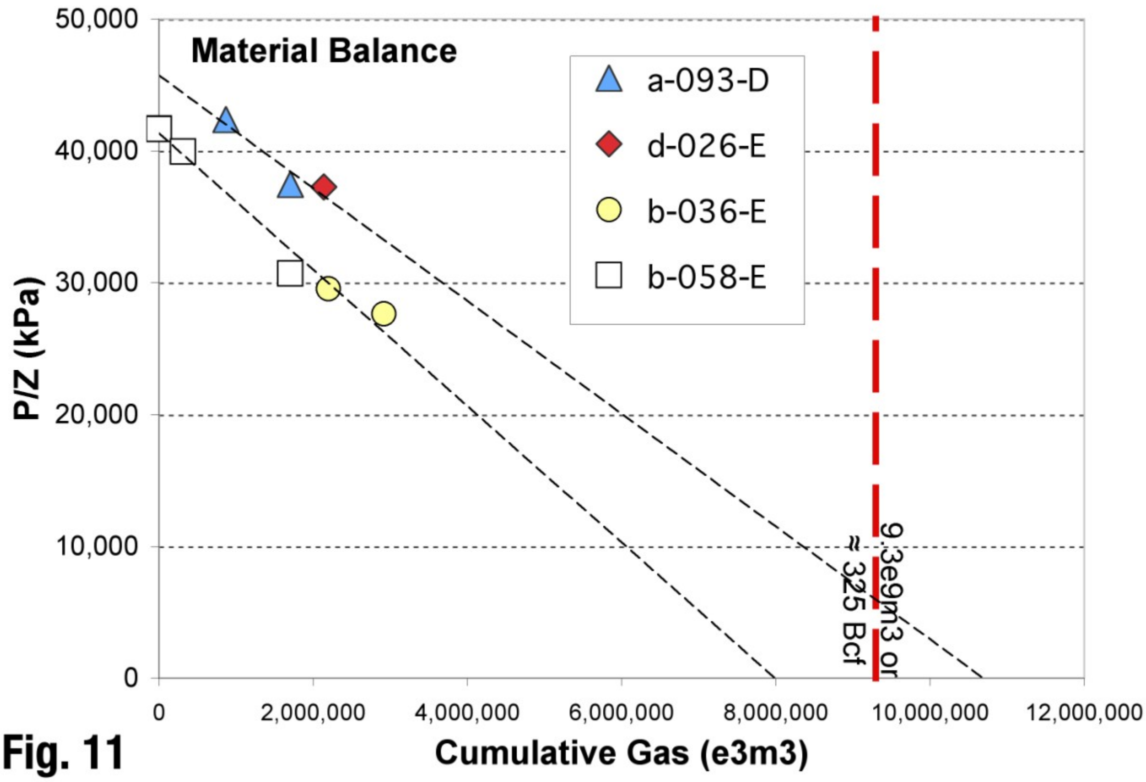

Figure 11. Mass Balance calculations demonstrate communication on kilometer scale between wells in “Pool A” (b-036-E and b-058-E) and wells in “Pool B” (a-093-D and d-026-E). Note that despite b-036-E and d-026-E originating from the same surface location, they do not seem to communicate with each other, but are likely on separate thrust sheets and communicate with legs of other wells, that are 3 and 4.5 km away, rather than 100’s of meters apart.

The 3.2 meter core from b-058-E also demonstrates the presence of open fractures near the base, where it has been more dolomitized. Like the core drill cuttings also show (sub) parallel crystal covered surfaces, indicating the presence of closely spaced open fractures. Cuttings from the leg labeled b-026-E (foot wall) demonstrate a 50 meter interval with coarse white dolomite fracture fills, saddle dolomite and doubly-terminated euhedral quartz. This assemblage and micro-textures are interpreted as a hydrothermal dolomite reservoir. Cuttings demonstrate that although production has been exclusively contributed to the draining of matrix porosity through fractures, there is an added component of hydrothermal dolomite reservoir. Although the age of the hydrothermal event is far beyond the scope of this presentation, it is noted that in this, perhaps exceptional case, the youngest rocks are most likely of Permian age. If this is the case, than this particular hydrothermal dolomite event was not of Carboniferous age, which is the generally suggested age for most Devonian hosted hydrothermal reservoirs in the Western Canada Sedimentary Basin (e.g. discussion in Wendte et al., 2009, page 301).

The hanging wall (b-036-E) and footwall (d-026-E) of the central well (a-026-E), lie on different pressure gradients. This is surprising because the producing zones are separated by only 127 meters (measured depth) of rock, and rather than being connected with each other, the hanging wall appears to be in communication with b-058-E, 3 km to the NW and the foot wall with d-093-D, located 4.5 km to the SE. Therefore, pressure data suggest that large aperture SE-NW striking sub-vertical type 2 fractures play an important role in the production from the Permo-Pennsylvanian strata.

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