CHARACTERIZATION OF BELLOY AND DEBOLT WATER DISPOSAL ZONES IN THE MONTNEY PLAY FAIRWAY, NEBC

Prepared for

BC Oil and Gas Commission

December, 2014

Petrel Robertson Consulting Ltd.

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CERTIFICATE OF QUALIFICATION

BRAD J.R. HAYES, Ph.D., P.Geol.

I, Brad J.R. Hayes, Professional Geologist at Petrel Robertson Consulting Ltd., Suite 500, 736 – Eighth Avenue SW, Calgary, Alberta, Canada and author of a report dated December, 2014, do hereby certify that:

- I am a professional geologist employed by Petrel Robertson Consulting Ltd., which Company did prepare a report titled *Characterization of Belloy and Debolt Water Disposal Zones in the Montney Play Fairway, NEBC*, for the BC Oil and Gas Commission.

- I attended the University of Toronto, and that I graduated with a Bachelor of Science (Honours) Degree, Geology Specialist Program (1978), and obtained a Doctor of Philosophy Geology (1982) from the University of Alberta (Edmonton, Alberta); that I am a member of APEGGA; that I have in excess of 30 years experience including geological studies relating to both Canadian and international oil and gas properties.

- I have not, directly or indirectly, received an interest, and I do not expect to receive an interest, direct or indirect, in any associate or affiliate of BCOGC.

- The evaluation was prepared based on information available in the public domain.

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INTRODUCTION

Intensive development of the Montney tight siltstone and shale play in northeastern B.C. presents new challenges to operators and to the BC Oil & Gas Commission. One of the key challenges is in accessing appropriate water source and disposal zones to support horizontal drilling and multifrac completions. Source water can be obtained from surface water bodies, shallow non-saline aquifers, or deep saline aquifers. However, spent completion fluids and produced waters must be injected into deep saline aquifers to ensure complete isolation from surface waters and non-saline groundwater.

The Montney unconventional play fairway spans both Plains and Foothills areas in the Peace River region and northwestward, as outlined in the BC Oil & Gas Commission's Montney Play Atlas (Fig. 1). Potential disposal zones in deep saline aquifers exist across the fairway, but their distribution and injectivity characteristics are highly variable. Geoscience BC's Montney Water Project provides a comprehensive regional inventory of water resources and potential for deep geological disposal sites in the Montney (http://www.geosciencebc.com/s/Montney.asp), and is an excellent starting point for detailed local work on specific water disposal issues.

Recent injection activity has shown that more work is required, as performance of some existing injection wells has not been satisfactory. BC Oil & Gas Commission and Geoscience BC have collaborated to develop a scope of study that addresses many of the water disposal challenges currently facing OGC. The Belloy, Kiskatinaw and Debolt formations have been identified as high-priority disposal zone targets requiring detailed assessment.

Petrel Robertson Consulting Ltd. (PRCL) was engaged by Geoscience BC to undertake regional reservoir characterization of the Belloy, Kiskatinaw, and Debolt formations, with emphasis on identifying their capacity to act as secure disposal zones. This report summarizes PRCL's findings, and is designed to support future focused reservoir engineering assessments.

Funding to support this research was provided by BC Oil and Gas Research and Innovation Society (BCOGRIS) and Geoscience BC.

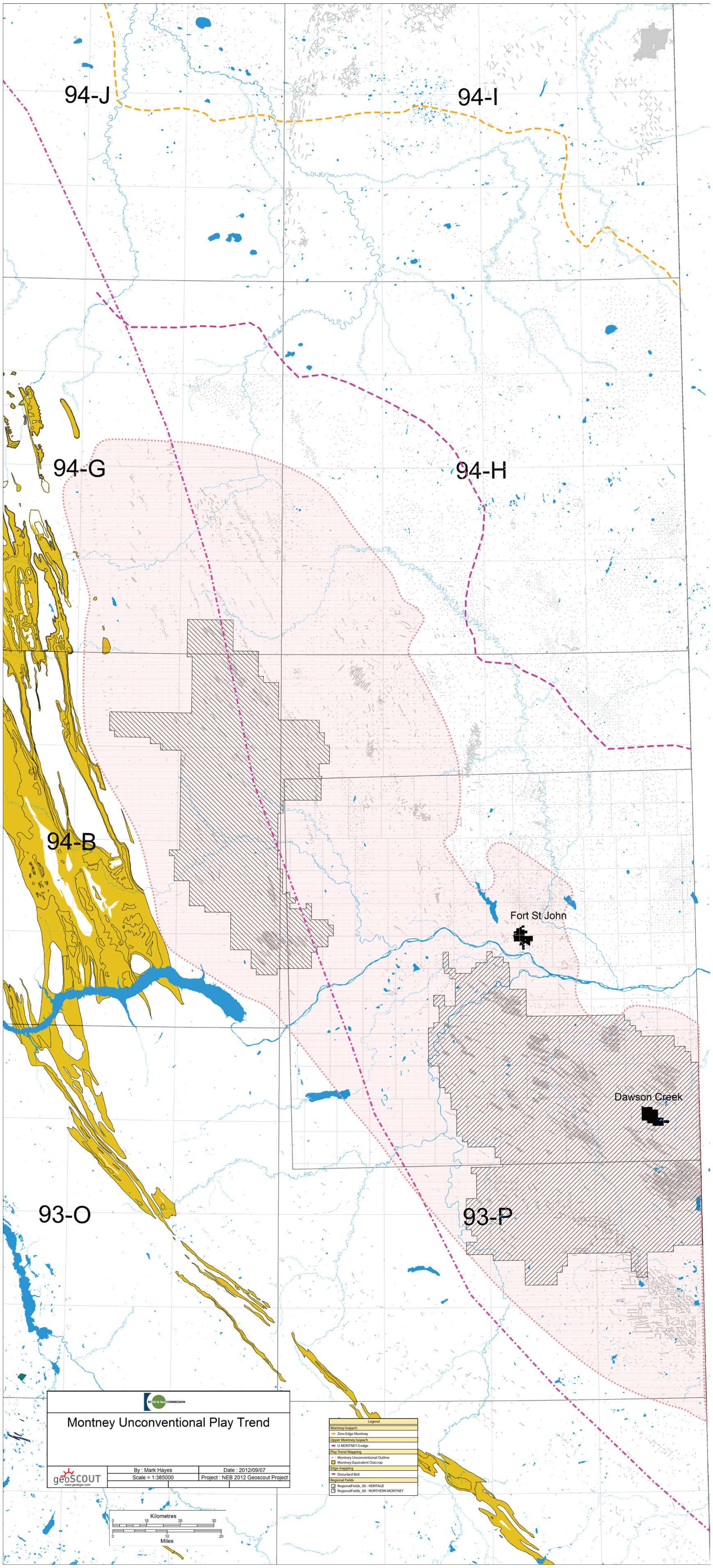


Figure 1. Montney play fairway, northeastern B.C. (from B.C. Oil & Gas Commission, 2012).

METHODOLOGY

PRCL's study included the following primary work components:

- Detailed regional mapping of the Debolt, Belloy, and Kiskatinaw formations, ensuring complete geographic coverage of the unconventional Montney play fairway, as defined by the Montney Play Atlas. This work included:
    - Detailed review of existing literature;
    - Employment of all available well control. Considerable effort was required to identify all applicable wells, as commercial databases are not well-suited for such comprehensive searches. We identified a total of about 2600 Belloy penetrations in the study area and picked stratigraphic tops (Appendix 1);
    - Obtaining relevant core logs and sample cuttings descriptions from literature and commercial databases. An additional 29 cores were logged at the B.C. core logging facility in Fort St. John, in order to augment our understanding of key reservoir intervals. Core logs are presented in Appendix 2, sample cuttings logs in Appendix 3, and core photographs in Appendix 4;
    - Characterization of each unit with:
        - Determination of porosity / permeability relationships;
        - Mapping of gross thickness and net porous reservoir thickness;
        - Production of structure and depth-to-formation maps;
        - Identification of reservoir heterogeneity and compartmentalization that can influence accommodation volumes for injection.
- Identification of known or potential hydrocarbon pools within the target formations that would be influenced by disposal activity.
    - Disposal too close to existing producers may adversely affect production volumes;
    - Existing depleted or semi-depleted pools may offer potential for present or future disposal activity.

- Identification of hydrocarbon exploitation potential in bounding formations that are expected to provide a seal to injected fluids, as hydraulic fracturing may compromise the integrity of this seal.
    - The primary focus here was on the Montney, investigating whether gas development in the lower Montney could be close enough to the top of underlying formations (primarily the Belloy) to affect the potential seal.
- Identification of hydrocarbon exploration and development potential in deeper strata (below potential disposal zones) – for which wells might be required to penetrate a high-pressure disposal zone.
- Identification of mapped faults, fractures, and/or structures that may pose seismic risks when significant water volumes are injected.
- Integration of mapping in all above categories to develop a high / medium / low "favourability" ranking for each formation across the study area.

GEOLOGICAL SETTING AND DEPOSITIONAL OVERVIEW

GEOLOGICAL SETTING

The Debolt through Belloy succession was deposited during Carboniferous (Mississippian) through Permian time; it lies conformably on older Mississippian strata, and is unconformably overlain by the Triassic Montney Formation (Fig. 2).

Tectonic quiescence and Devonian basin-filling sedimentation allowed broad, shallow-water carbonate ramp settings to develop throughout Western Canada near the end of the Devonian, and to persist through much of Mississippian time. In northwestern Alberta and northeastern British Columbia, carbonate ramps sloped northwestward into the Prophet Trough, where slope to basin sediments accumulated at the western edge of the North American craton (Richards *et al*., 1994) (Fig. 3). In the Peace River area of northeastern B.C. and adjacent Alberta, minor subsidence of the Devonian Peace River Arch is indicated by subtle regional thickening of the Debolt (O'Connell *et al*., 1990).

The Devonian/Mississippian Antler Orogeny had relatively little effect on the craton, but toward its western margin, structural deformation of the Devonian section can be observed, and reactivation of older basement features influenced the development of Mississippian reservoir facies in northeastern B.C. (Petrel Robertson, 1995).

Subsidence of the Peace River Arch accelerated after Debolt time, and profoundly influenced deposition of the later Mississippian through Pennsylvanian and Permian Stoddart Group (Golata, Kiskatinaw, and Taylor Flat formations) and Belloy Formation (O'Connell *et al*., 1990). Barclay *et al*. (1990) showed deposition to have occurred within the broad, west-east trending Peace River Embayment, focused within the structurally-bounded Fort St. John Graben (FSJG) / Dawson Creek Graben Complex (Fig. 4); they documented up to 1200 metres of syndepositional subsidence in distinct, fault-bounded compartments (Fig. 5).

By Permian time, subsidence of the Fort St. John Graben slowed markedly. Shallow marine, shelfal carbonates and sandstones of the Belloy Formation filled in the remaining relief, and were deposited more broadly across the Peace River Embayment and flanking areas (Naqvi, 1972; Barclay *et al*., 1990) (Fig. 5).

DEPOSITIONAL REVIEW

Debolt Formation

The Debolt can be subdivided into Upper and Lower Debolt units, which overlie argillaceous and clean bioclastic limestones and interbedded dark grey shales of the

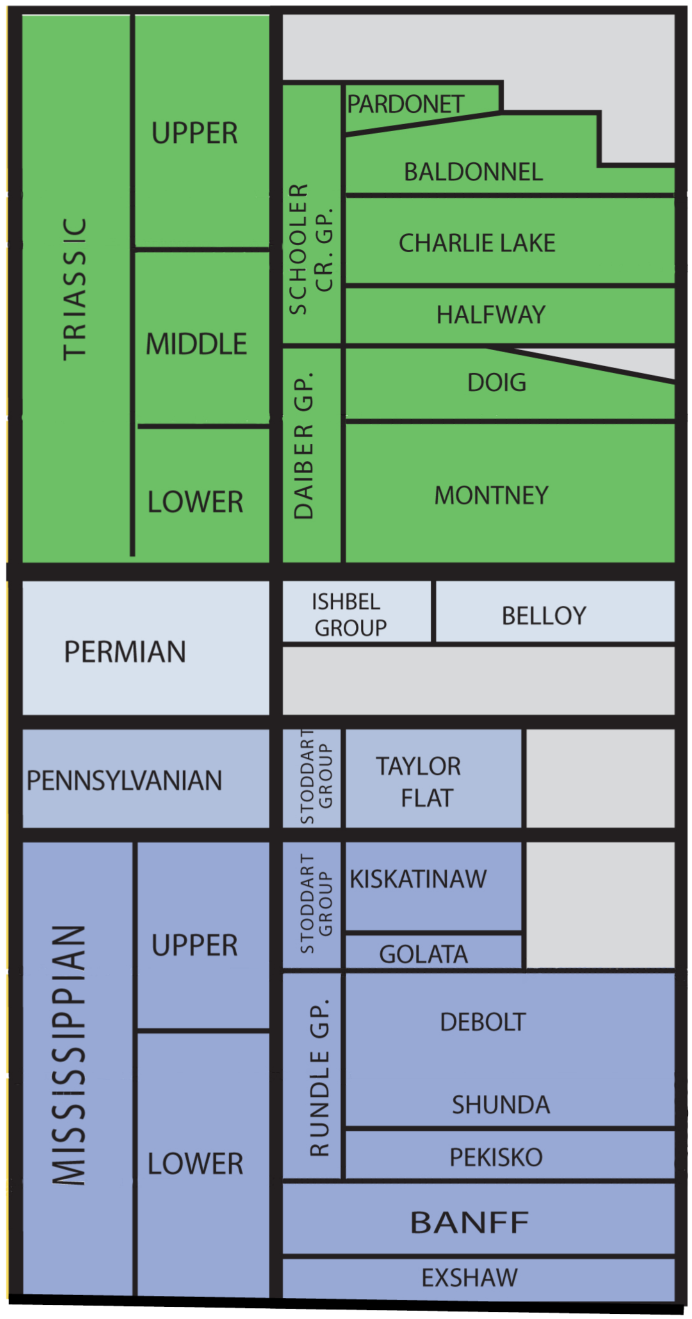


Figure 2. Stratigraphic column, Montney play fairway, NEBC (from B.C. Ministry of Energy and Mines; http://www.empr.gov.bc.ca/titles/ogtitles/otherpublications/documents/stratchart_nebc.pdf.).

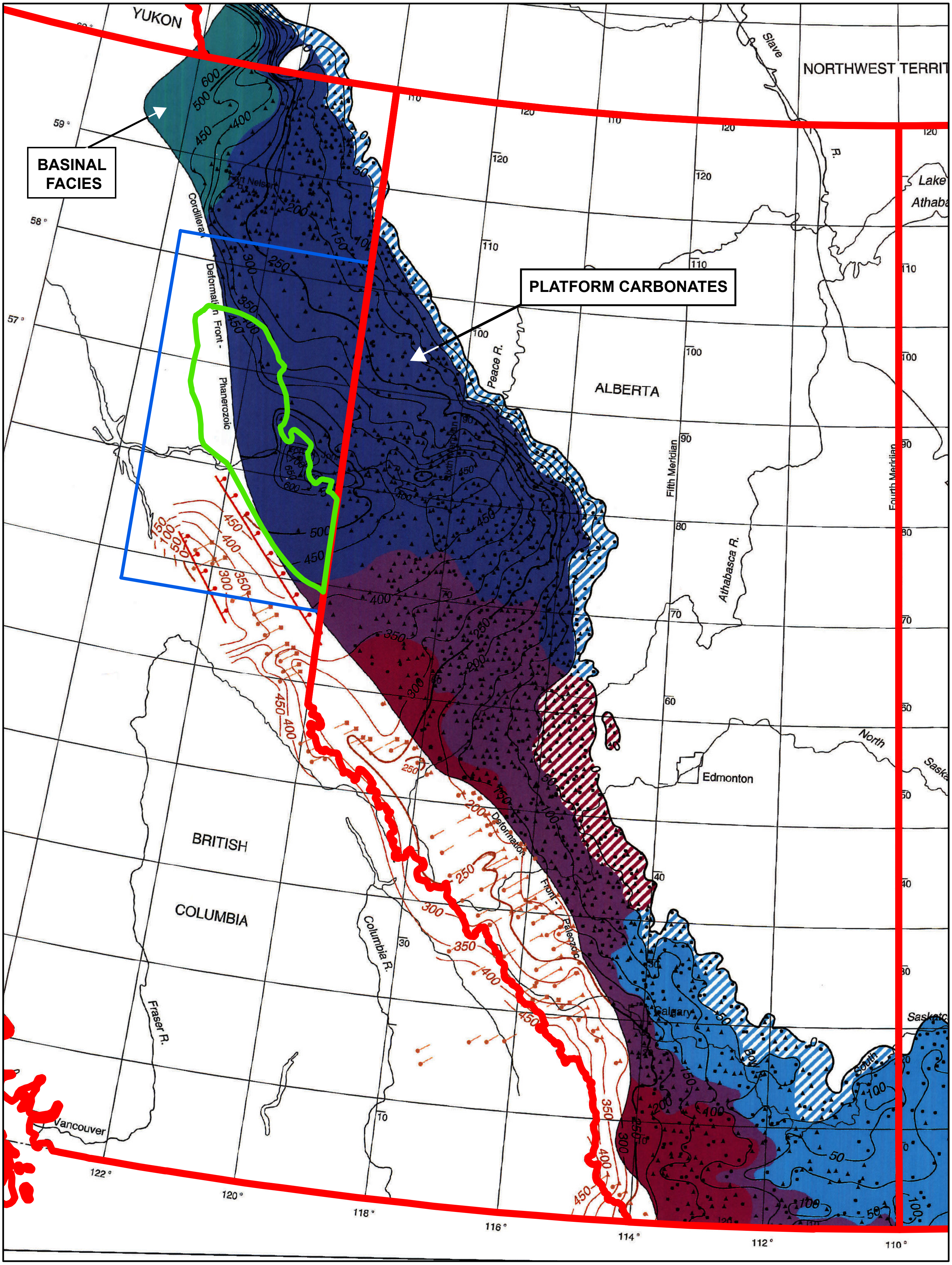


Figure 3. Mississippian carbonate platform deposition in western Canada during Debolt time, showing Montney play fairway situated in northern part of regional carbonate platform (from Richards et al., 1994).

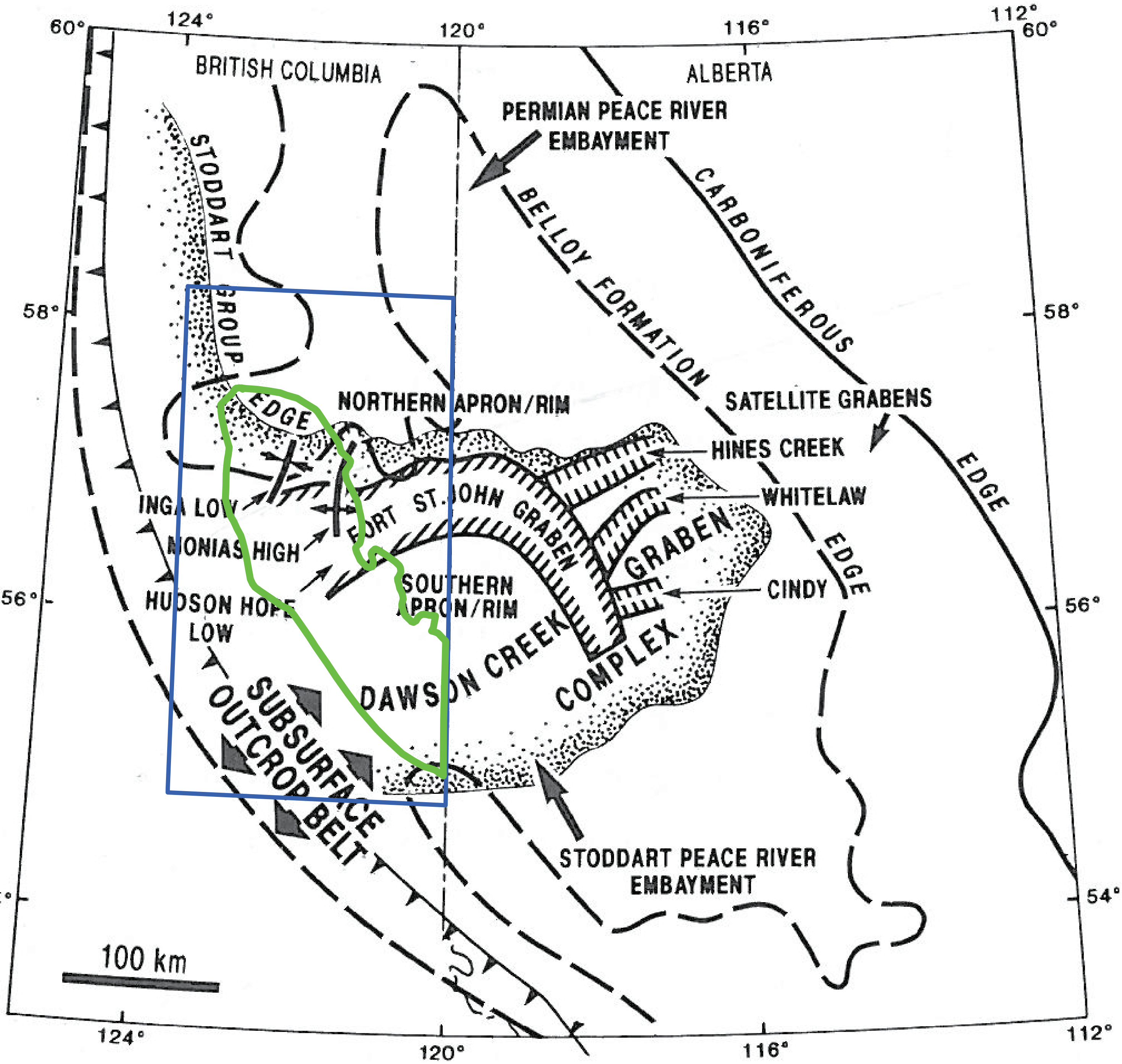
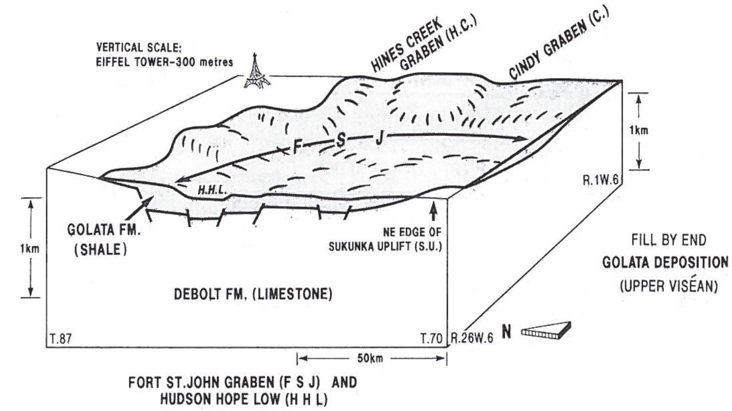
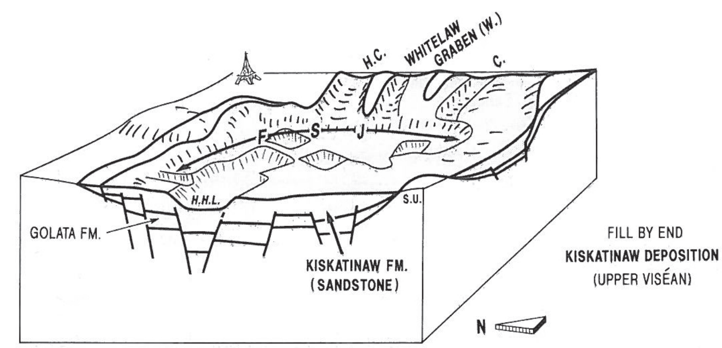


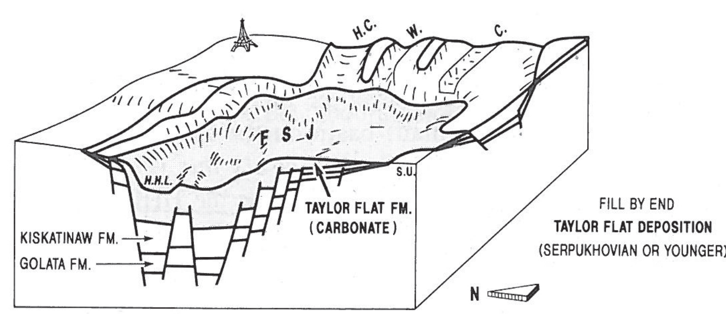
Figure 4. Peace River Embayment tectonostratigraphic elements, Mississippian-Permian time (from Barclay et al., 1990). Note study area outlines.



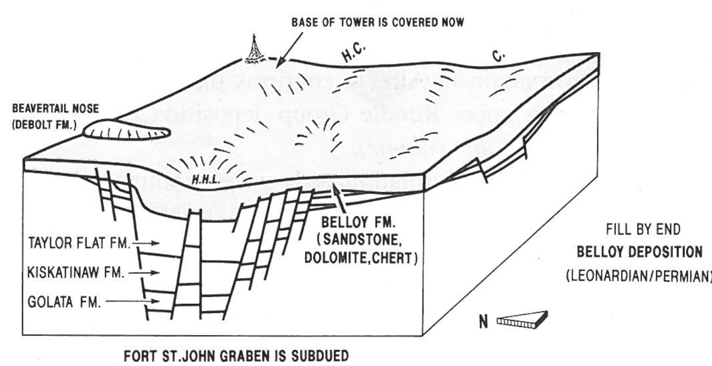
Top Golata Formation time.



Top Kiskatinaw Formation time.



Top Taylor Flat Formation time.



Top Belloy Formation time.

Figure 5. Schematic deposition of Stoddart Group and Belloy Formation during subsidence of Fort St. John Graben (from Barclay et al., 1990).

Shunda Formation, and are unconformably overlain by various younger units (Debolt Cross-section E-E’). Clean carbonates of the Elkton Formation, defined to the southeast in Alberta, are treated as a basal member of the Debolt in this study.

Limited core coverage over the lower Debolt shows it to consist of deep water crinoidal and skeletal mudstones, wackestones and grey shales deposited on a stable carbonate ramp (*e.g*., well 12-31-78-14W6, Appendix 1). Lower Debolt rocks are almost never dolomitized, and therefore have limited reservoir potential. At the end of Lower Debolt time, widespread erosion occurred, followed by onlap heralding Upper Debolt deposition (Plate 17).

Upper Debolt sedimentation is characterized by a series of shallowing-upwards facies, beginning with subtidal argillaceous limestones of the distal and medial ramp at the base, followed by increasing occurrence of proximal ramp and shoal facies upward.

Distal ramp facies were deposited in a subtidal depositional setting below fair weather wave base, and are characterized by abundant argillaceous material and rare fauna, particularly crinoids. A limited number of laminae and thin beds are present, but there are no clean carbonates (Plates 6, 15). The succeeding medial ramp facies are predominantly argillaceous with some clean carbonate interbeds, usually crinoid-coral-bryozoan wackestones and packstones with rare grainstones (Plates 6, 12, 13, 14, 17, and 18). The capping proximal ramp / shoal setting is characterized by deposition of skeletal packstones and grainstones with crinoids, solitary and colonial corals, coated grains, echinoid plates and spines and peloids. The presence of shoals is indicated by grain-supported packstones and grainstones (*e.g*., Plate 24). Cross-bedding and graded bedding are present, though not significant. Bioturbation of some massive intervals of packstone, wackestones and mudstones indicates limited deposition in a more sheltered lagoonal setting.

The top of the Debolt is an erosional unconformity, which is expressed in different fashions across the Montney fairway (Fig. 6). In the Fort St. John Graben, where the Debolt is overlain by a thick Golata-Kiskatinaw-Belloy succession, pure Golata shales lie sharply but nearly conformably on Debolt carbonates, although silty beds in the basal Golata can be confused in places with uppermost weathered Debolt. In the deformed belt to the northwest, clean Debolt carbonates are overlain by undifferentiated Stoddart Group, comprising thin beds of argillaceous limestone, siltstone and silty sandstones, shales and calcareous shales with characteristic elevated gamma log signatures (*e.g*., Belloy-Debolt Cross-section A-A’). North of the Fort St. John Graben and east of the deformed belt, the Debolt is overlain sharply by Montney siltstones; in many places a thin heterolithic lag characterized by elevated gamma log spikes is present at the contact (*e.g*., well c-36-I/94-A-14, Debolt Cross-section D-D’).

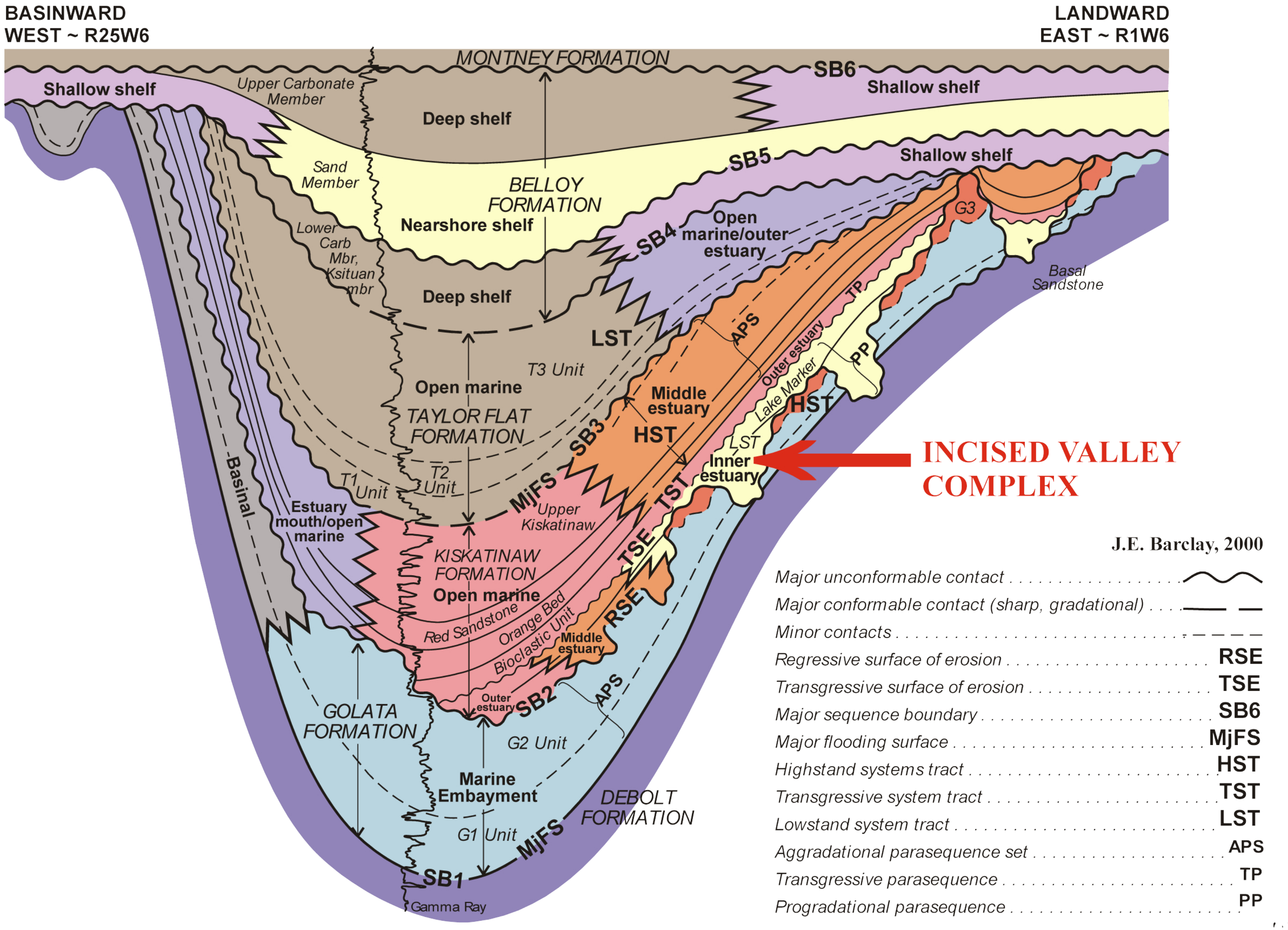


Figure 6. Schematic cross-section illustrating deposition of Stoddart Group and Belloy Formation in Fort St. John Graben (from Barclay et al., 2002).

Stoddart Group

As the FSJB subsided, shales and siltstones of the Golata Formation were deposited in a low-energy, restricted marine embayment that transgressed the Debolt platform (Barclay, 1988; Barclay *et al*., 1990). With accelerating subsidence of the Fort St. John Graben, the Golata was exposed in places, particularly over fault blocks that did not subside as rapidly. Barclay and Devaney (1986), Barclay (1988) and Barclay *et al*. (2002) documented deep local incision of the Golata beneath thick basal Kiskatinaw sandstones, and soil formation on interfluves on the top Golata erosional surface (Fig. 7) (*e.g*., well 6-27-84-13W6, Appendix 1).

The Kiskatinaw is a fluvial/estuarine to shallow marine succession, which prograded from an eastern deltaic source, westward to channelized estuarine and marginal marine environments near the B.C./Alberta border (Barclay *et al*., 1990; Barclay *et al*., 2002) (Fig. 8). The basal Kiskatinaw is dominated by sandstones, typically quartzose, exhibiting flaser bedding and other tidal features. To the west, it grades to more open marine limestones and shales (Fig. 6, 8). As graben subsidence and marine transgression continued, Kiskatinaw sandstones become thinner and less continuous upward, and grade to marine shales and thin-bedded carbonates and sandstones (*e.g*., wells 10-15-80-16W6, 10-22-80-15W6, Belloy-Debolt Cross-section E-E').

A highly-correlative flooding surface caps the Kiskatinaw, and is succeeded by open marine carbonates and shales of the Taylor Flat Formation; note continuity of this marker on Debolt-Belloy Cross-sections C-C', D-D', and E-E'. Bioclastic sandy packstones to grainstones and calcareous and bioclastic sandstones are common, but bedding is generally thin compared to more massive reservoir facies in the basal Kiskatinaw and upper Belloy (Barclay *et al*., 1990). Facies relationships are poorly understood within the Taylor Flat because of poor core control and lack of productive zones that would stimulate more detailed coring and study.

Picking the top Taylor Flat is "problematic", according to Barclay *et al*. (1990), because lithologies are similar to the lower part of the Belloy, and strong regional log markers are lacking. We have not attempted to make a Taylor Flat top pick for this study for these reasons, and because reservoir-quality facies appear to be rare and thinly-bedded in the Taylor Flat and lower Belloy (Belloy-Debolt Cross-sections C-C', D-D', and E-E').

In the northwest, Stoddart and Belloy strata become more thinly-bedded and difficult to correlate because of passage to more distal marine facies. As well, significant structural deformation introduces correlation uncertainties (Belloy-Debolt Cross-sections A-A' and F-F'). As a result, we have limited mapping of Belloy and Kiskatinaw reservoirs for this study to the central and southeastern parts of the Montney play fairway (Map 6, 11).

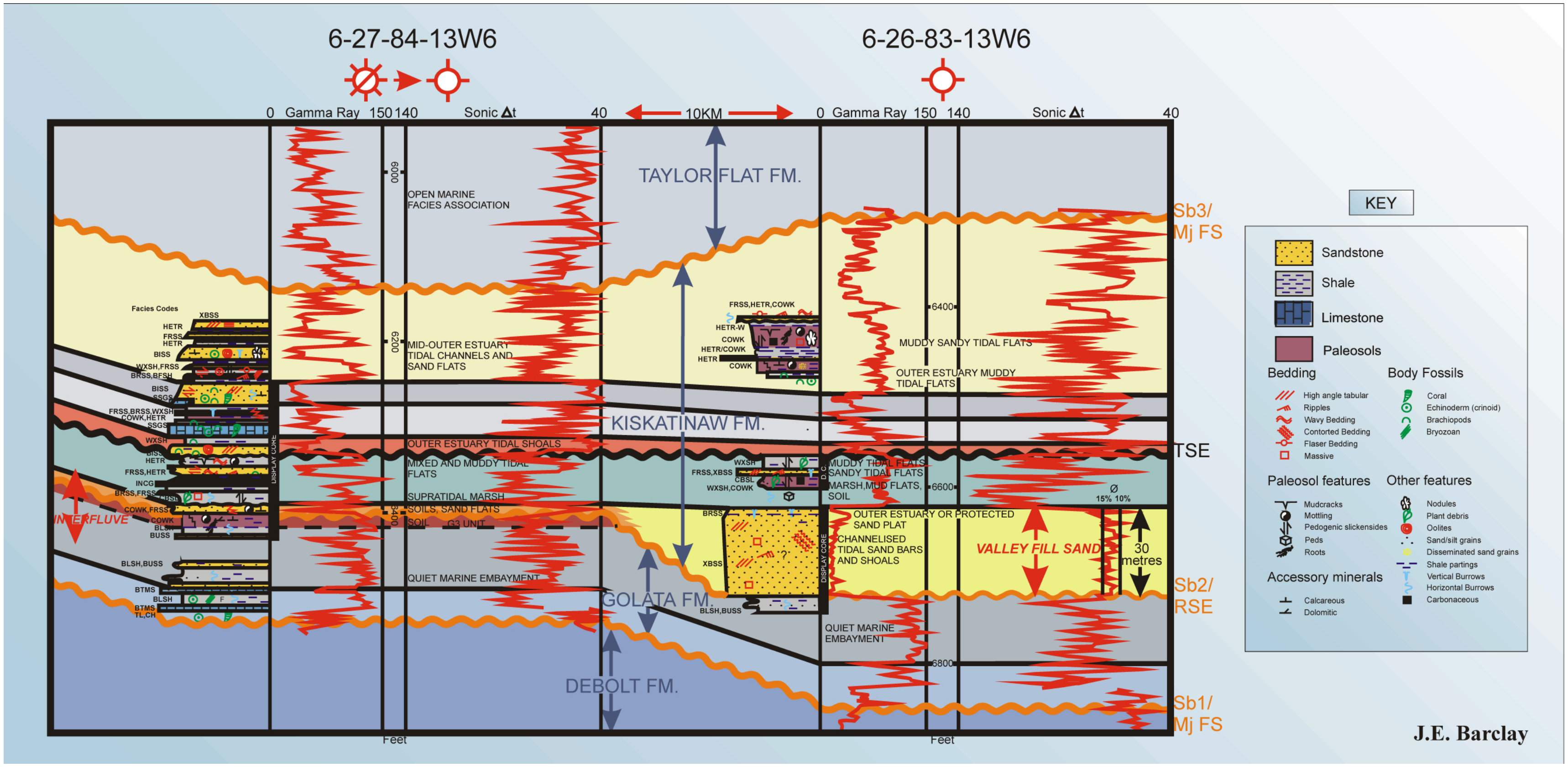


Figure 7. Kiskatinaw / Golata valley fill to interfluve relationship (from Barclay et al., 2002).

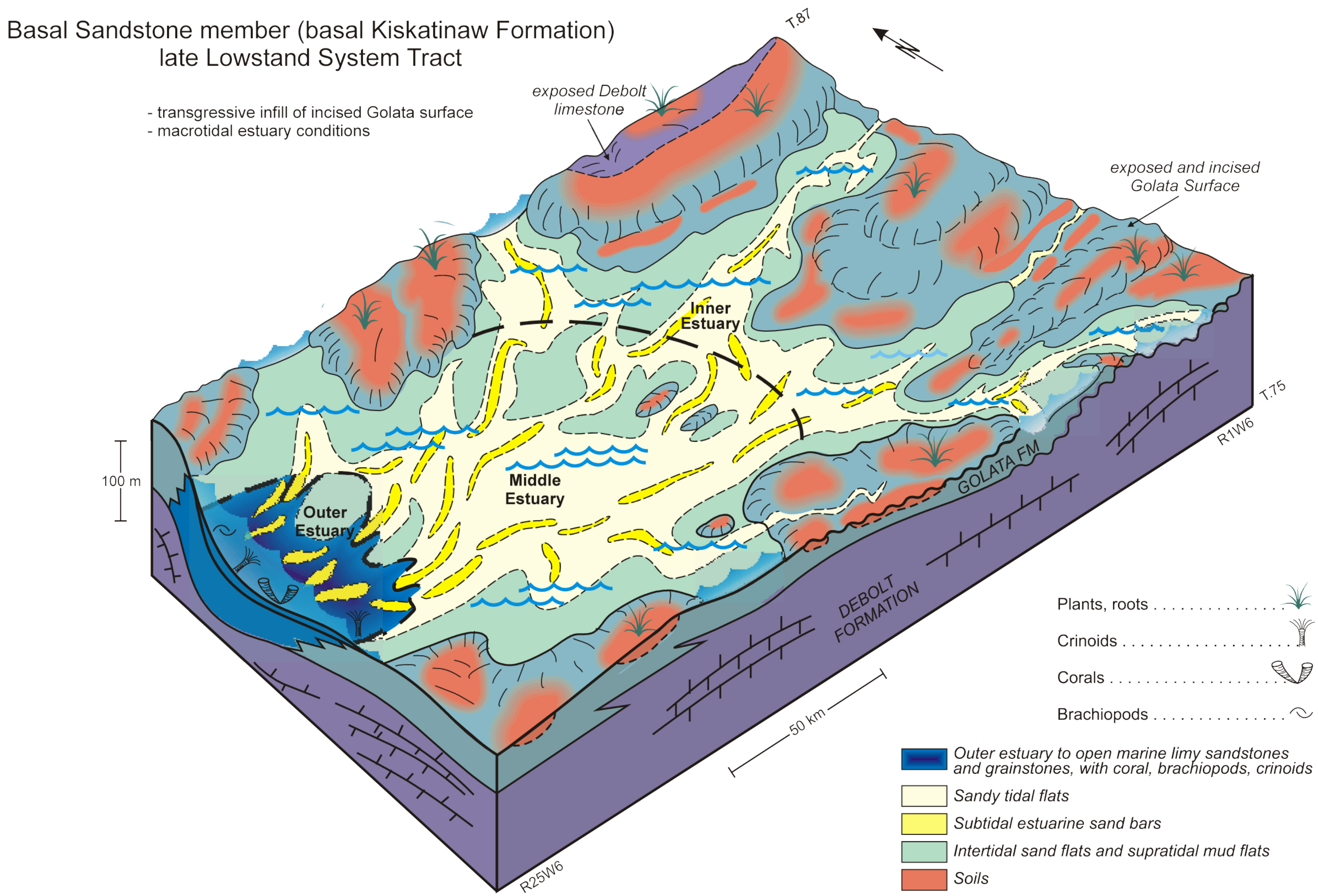


Figure 8. Schematic deposition of basal Kiskatinaw Formation (from Barclay et al., 2002).

Belloy Formation

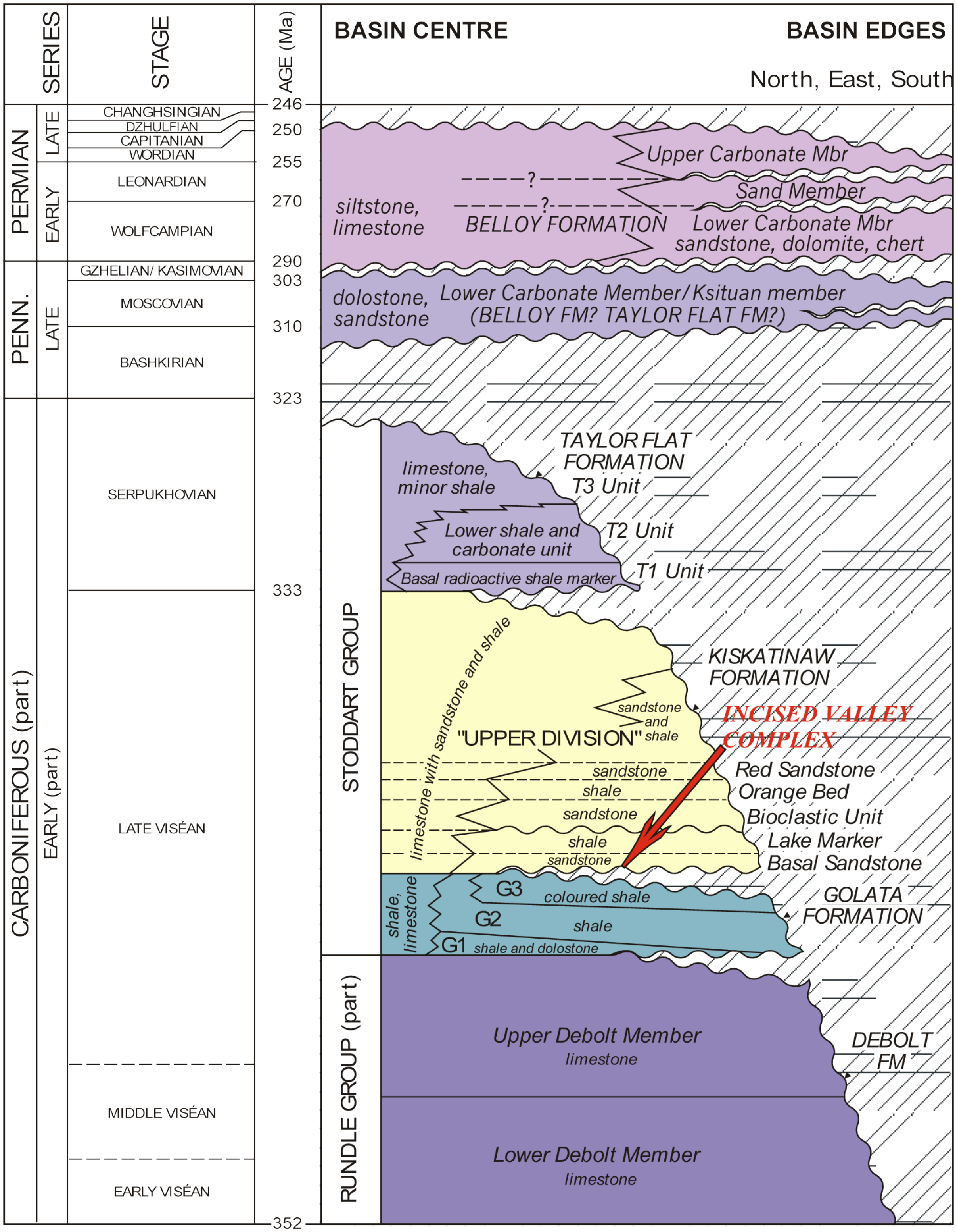
Regional correlations show the Belloy to overlie carbonate-dominated strata of the Taylor Flat Formation unconformably, and to contain considerable internal complexity marked by several unconformities (Fig. 9). As discussed above, Taylor Flat and Belloy strata have not been consistently and clearly distinguished in the literature, and thus were not differentiated in this study. Towards the margins of the Fort St. John Graben, Belloy strata lie unconformably on the Kiskatinaw and Golata (Fig. 6; Belloy-Debolt Cross-section B-B', C-C').

Fossenier's (2001) comprehensive analysis of Belloy strata in B.C., including core descriptions (Appendix 1) and extensive biostratigraphic analysis focused on conodonts, illustrates an extreme degree of lithological and stratigraphic complexity. Comparing these interpretations to well logs, we concluded that it is not possible to carry Fossenier's biostratigraphic correlations with confidence in thousands of wells over such a large area. Instead, we have mapped the Belloy as a single unit, and have focused reservoir characterization efforts on the uppermost beds, where porosity and permeability are most consistently developed, and where core and log data are most abundant.

Furthermore, where Belloy carbonates were deposited directly on the Debolt (as at the western and eastern edges of Fig. 6), they cannot be reliably distinguished without core and biostratigraphic control. At d-80-I/94-A-14, Fossenier (2001) interpreted a 15-metre dolowackestone as Moscovian (Belloy) age using biostratigraphic control (Appendix 1), but it cannot be distinguished from underlying Debolt carbonates on well logs. The uppermost Debolt sections correlated at a-55-B/94-A-13 and b-5-J/94-A-13 on Belloy Debolt Cross-section B-B' have very similar log signatures, and may well be equivalent to Fossenier's Moscovian section. For the purposes of this study, where the Montney lies directly on a carbonate section with no direct evidence of Stoddart Group strata below, we have chosen to assign the entire carbonate succession to the Debolt.

Various workers have interpreted Belloy stratigraphy and reservoir distribution locally. In the Eagle / Stoddart area (Twp 83-86, Rge 17-21W6), Young *et al*. (1993) and Leggett *et al*. (1993a, b) documented sandstone-dominated shallow marine facies cut by a variety of channels filled with sandstones, exhibiting excellent reservoir quality in places (Fig. 10). Channel-fill successions are illustrated in core logs from wells 15-25-84-18W6 and 14-22-85-20W6 (Appendix 1).

At Boundary Lake (Twp 84-14W6), Bloy and Scott (1993) showed Belloy reservoirs to occur in stacked shoaling-upward successions capped by carbonate grainstones and sandstones (Fig. 11). Local faulting controlled both reservoir preservation (protecting it from post-Belloy erosion) and structural entrapment of gas. Bloy and Scott's study provides a good illustration of the intricate interbedding of sandstone and carbonate reservoirs in the Belloy.



G1: *Basal transition unit of shales and carbonates*
G2: *Black shales*
G3: *Coloured shale exposure surface*

Figure 9. Schematic internal stratigraphy of Kiskatinaw through Debolt succession, Fort St. John Graben of northeastern B.C. and adjacent Alberta (from Barclay et al., 2002).

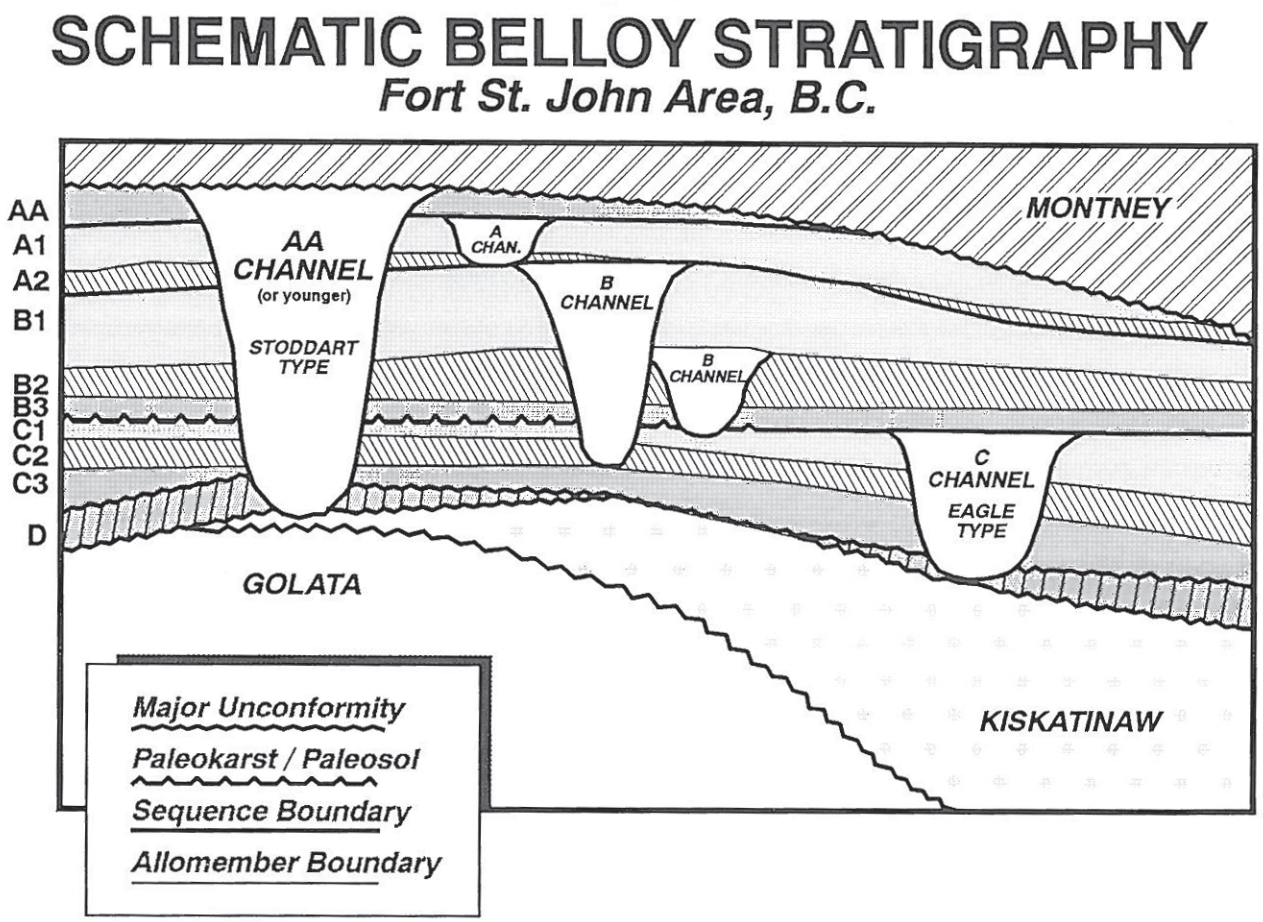


Figure 10. Schematic Belloy stratigraphy, Eagle / Stoddart area (from Leggett et al., 1993b).

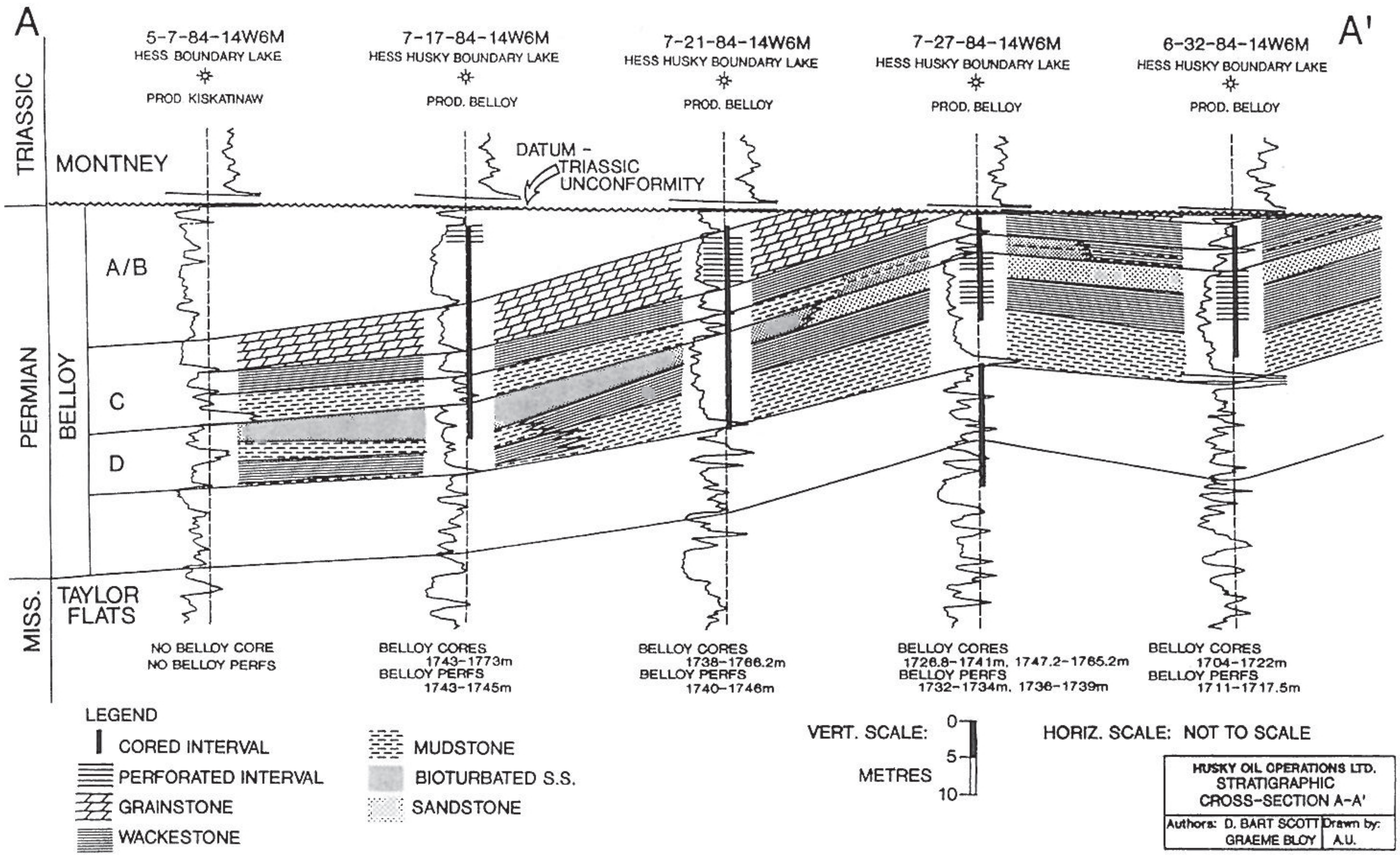


Figure 11. Stacked shoaling-upward Belloy reservoirs at Boundary Lake (from Bloy and Scott, 1993).

The top of the Belloy is a regional unconformity surface, and is overlain everywhere by distinctive thick siltstones of the Montney Formation. In most places, the contact is marked by “hot” gamma log spikes on well logs (well developed on most of the regional Belloy-Debolt cross-sections) and an unconformity surface mantled by chert-pebble conglomerate (*e.g.*, well 6-11-83-16W6, Appendix 1).

MAPPING AND RESERVOIR CHARACTERIZATION

DEBOLT FORMATION

Mapping

The Debolt Base Map (Map 1) illustrates well control, oil and gas production, injector wells, distribution of cores and sample logs, and lines of cross-section drawn to illustrate Debolt stratigraphy and reservoir development across the Montney play fairway. The “area of detailed mapping” outlines a smaller map area, where we have sufficient data to characterize Debolt reservoir quality and distribution. Debolt oil and gas production occurs primarily along structural trends in the northwest, where Laramide thrusting and folding is well-developed.

There is very little Debolt well control south of Twp 81. Most wells in Twp 80-81, Rge 14-16W6 were drilled to evaluate and develop gas production from the Kiskatinaw and Wabamun formations, so there has been little Debolt evaluation other than well logs and sample cuttings. More Debolt penetrations are evident north of Twp 83, where the Stoddart section thins and wells drilled to evaluate the Belloy or Montney penetrate the top Debolt – but penetrations are incomplete in most wells, and there has been little specific evaluation of the Debolt. Debolt well control is generally better in the northwestern part of the Montney fairway, where Debolt oil and gas pools associated with Foothills structure have been developed – but even here, partial penetrations are common.

Map 2, a total isopach map of the Debolt (top Debolt to top Shunda), illustrates the scarcity of complete Debolt penetrations across the Montney fairway. The map is computer contoured, as total Debolt thickness is fairly consistent across the area, and does not appear to influence net porous reservoir development. More abrupt thickness variations are evident in the northwest; some of these may arise from structural deformation, although best efforts were made to map undeformed sections (see Belloy-Debolt Cross-sections A-A’ and F-F’ for examples of fault-related structures).

Fault lines shown on Map 2 and succeeding maps were derived from a variety of sources, including all available technical literature, and pool studies published by the B.C. Ministry of Natural Gas and its predecessors. These sources were augmented by PRCL studies, particularly in the northwest, where intensive work (including seismic) in the PRCL (1995) study outlined both northwest-southeast trending Laramide faults, and orthogonal-trending fault sets, some associated with the Devonian Antler Orogeny. Some smaller faults in the southeastern half of the study area were added during the course of the current study.

Map 3 shows structure on top Debolt. It is hand-contoured in the northwest, taking fault offsets into consideration, based on well control alone. Where data points are less dense in the southeast, the map is computer contoured. Note the change of contour interval from 20m in the northeast to 100m elsewhere. NW-SE fault trends in the west reflect thrusting and folding associated with the Laramide Orogeny, overprinted on Antler orogenic structures. In the southeast, predominantly SW-NE faults represent structure associated with the Fort St. John Graben complex, as demonstrated by sharp offsets of the Debolt surface.

Map 4 illustrates drill depth to the top of the Debolt – and so is influenced both by Debolt structural elevation and by surface topography. Well density is inadequate to accurately reflect surface topography, and so the map serves only as a general guideline. With this in mind, it is computer contoured using a 100m contour interval. Fault lines were used to constrain the contouring, resulting in unrealistic, closely-spaced contours in some fault blocks. While drill depths to the Debolt are 2500m or less over much of the northern Montney fairway, they are generally >3000m south of Twp 80.

Reservoir Characterization

Good reservoir quality in the Upper Debolt depends upon the occurrence of primary intergranular porosity in grainstone facies, but reservoir enhancement by later diagenetic processes, including leaching, is also required. The proximal ramp-shoal group of facies are the main reservoir facies in most of the producing Debolt gas pools, because they had the best primary porosity, and therefore invariably experienced the most diagenetic porosity enhancement, as discussed below (Plates 5, 9, 16, 23, and 38).

Two distinctly different dolomitization styles have been identified in the Montney fairway: a low-temperature, unconformity-related dolomite, and a high-temperature (hydrothermal), thrust fault-related dolomite. Net porous reservoir thicknesses for the Debolt are shown on Map 5. Net porous values were assigned as follows:

- A 6% porosity cutoff was the basic parameter, as most producing pools (at least in the low temperature dolomites) have average porosities of 6% or greater. As well, our interpretation of the porosity-permeability cross-plot from core analysis data (see below) indicates that 6% porosity equates to near 1mD permeability.

- Log parameters were estimated visually, taking into account hole conditions (caliper log), and cross-checked against core and sample cutting lithologies and core analysis values where available. 6% porosity was estimated from the dolomite porosity curve or sonic log, within intervals with clean (<60 API) gamma log signatures. Net porous thicknesses within generally porous intervals (highlighted in yellow on Debolt Cross-sections C-C’ and D-D’) were summed up, but thin porous streaks significantly separated from thicker porous intervals were not included.

- Very thin porous intervals, where sharp, spiky log kicks indicate possible fracturing, were not included (as in Debolt Cross-section A-A’).

Debolt net porous thickness values and mapping for this regional project are semi-quantitative, but have been consistently derived and serve to identify areas with good porous reservoir potential. More intensive local work would be required to assess injectivity potential at specific locations.

Low Temperature Dolomite

The most important style of dolomitization from a reservoir quality standpoint has produced low-temperature, fabric-selective matrix dolomites. They formed at shallow depths beneath the unconformity separating the Belloy and Debolt, and in some areas, the Montney and Debolt. They are relatively thick, continuous and mappable, and exhibit vuggy, moldic and intercrystalline porosity intervals that are ideal candidates for both water source and injection.

Low-temperature dolomites occur in a large area surrounding the Blueberry Field (Twp 88, Rge 24-25W6, and map sheets 94-A-12, 94-A-13, 94-A-14 and 94-H-3 (Map 5), and host oil and gas production at Blueberry and adjacent pools. Note that two main zones of dolomitization were identified – upper (brown contours) and middle (magenta contours) dolomite zones are contoured separately, and log picks are illustrated on Debolt Cross-sections C-C’ and D-D’. In other areas (*e.g.*, north half of 94-B-9, west half of 94-G-7, and a portion of 94-G-2) porous dolomites appear to be much less continuous. Debolt Cross-section B-B’ links cored Debolt wells, showing core photographs of porous low-temperature dolomites. On a regional scale, Durocher and Al-Aasm (1997) mapped an area of “pervasive dolomitization” encompassing our low-temperature dolomites, and related their occurrence to the absence of thick, continuous Golata shales overlying the Debolt (Fig. 12).

This type of unconformity-related dolomitization is well documented in the literature (*e.g.*, James and Choquette, 1984; Durocher and Al-Aasm, 1997) and is typically characterized by brecciation, karsting, caliche horizons and other features; however, these are generally absent in the present study area. Instead, the predominant diagenetic features are vuggy and moldic porosity and enhanced intercrystalline porosity due to recrystallization of the matrix. Durocher and Al-Aasm (1997) outlined the diagenetic sequence:

- Stage 1 (Deposition and Compaction) – after deposition in a subtidal and intertidal ramp setting, the sediments were compacted and calcite and dolomite cements were precipitated.

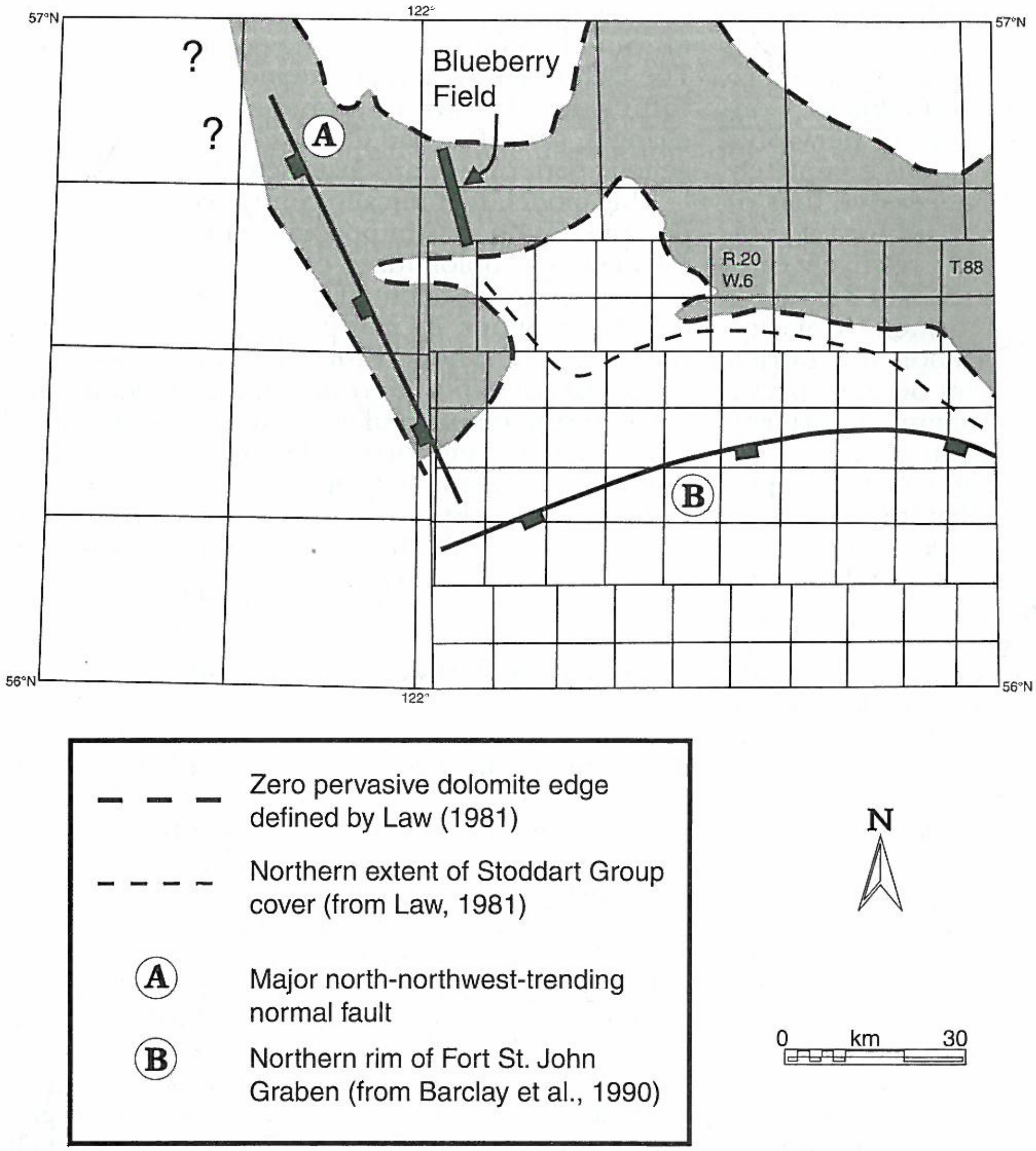


Figure 12. Distribution of dolomites in Carboniferous strata (from Durocher and Al-Aasm, 1997).

- Stage 2 (Block faulting phase) – graben formation during the Late Mississippian resulted in uplift and subaerial exposure of the upper Debolt. Pervasive, massive dolomitization occurred in the mixture zone between marine and meteoric fluids, concurrent with the formation of vuggy and moldic porosity from leaching by meteoric water. Continued uplift and erosion brought the dolomitized section to a position directly below the unconformity surface.

- Stage 3 (Deeper Burial phase) – post-Permian, the Debolt was buried to depths of up to a few kilometres and chemical compaction features formed (*e.g.*, stylolites) and calcite cements precipitated in the vugs, biomolds and interstitial space (Plate 7).

- Stage 4 (Folding and Thrust Faulting phase) – during the Laramide Orogeny, thrust faulting and folding resulted in the introduction, along fault and fracture planes, of highly saline hydrothermal fluids, resulting in the replacement of the matrix dolomites and emplacement of both coarse crystalline and saddle dolomite in the vugs and along fracture planes.

Figure 13 illustrates the progressive nature of the dolomitization and leaching, as well as the role of primary facies. Figure 13(a) shows a clean, well-cemented, unaltered skeletal pellet-coated grain grainstone. In 13(b), a similar lithology illustrates the extensive development of microcrystalline euhedral dolomite within the peloidal grains and in a small percentage of the mudstone. Dissolution of the cements has occurred along grain boundaries and in the cores of the coated grains. Figure 13(c) shows a similar lithology, but in a muddier packstone, illustrating the importance of the primary facies, particularly the degree of muddiness, in reservoir development. The dolomite developed as individual rhombs and in cryptocrystalline to microcrystalline mosaics, resulting in a chalky matrix which may have reasonable porosity but poor permeability. Figure 13(d) represents the end product in the process – the matrix is fully dolomitized, and dissolution of the undolomitized skeletal grains, particularly crinoids, results in a vuggy, highly porous dolomite.

The fabric-specific nature of this dolomitization process is illustrated by extensive porosity enhancement where the facies just under the unconformity was deposited in a proximal ramp or shoal setting, as dolomitizing fluids were able penetrate to a significant depth. By contrast, in areas where the top of the Debolt is a low-porosity depositional facies, dolomitizing fluids penetrated a minimal distance, and porosity enhancement by leaching and recrystallization occurred only to a very shallow depth – or didn’t occur at all. Even where muds were leached and recrystallized, the permeability remained poor in areas where the primary porosity was poor. The patchy distribution of porous dolomite (Map 5), both stratigraphically and laterally, reflects in part depositional facies control on dolomitization and reservoir development.

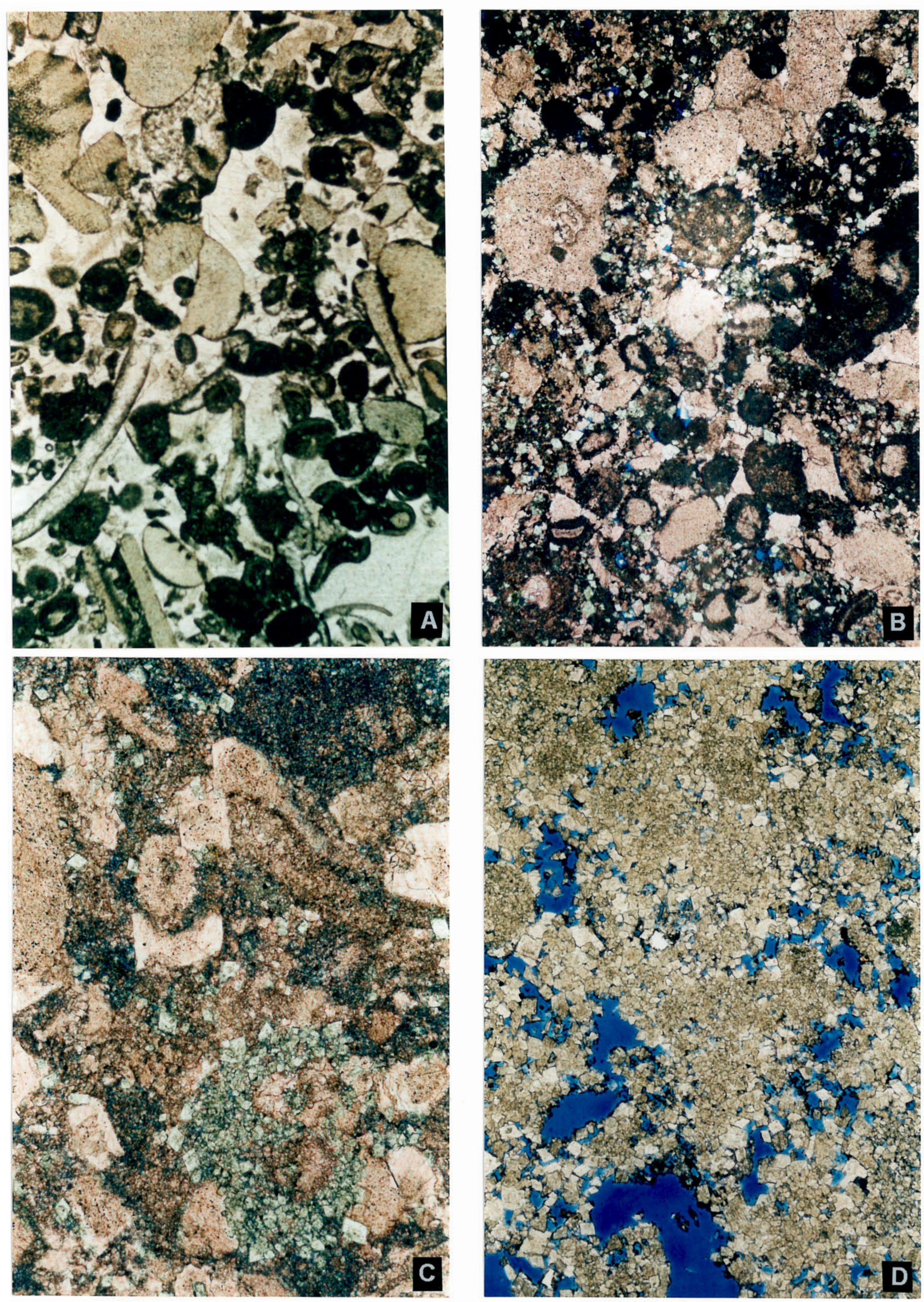


Figure 13. (a) clean, well-cemented, unaltered skeletal pellet-coated grain grainstone; (b) a similar lithology illustrates the extensive development of microcrystalline euhedral dolomite within the peloidal grains and in a small percentage of the mudstone; (c) again showing a similar lithology, but in a muddier packstone; (d) matrix is fully dolomitized, and dissolution of the undolomitized skeletal grains, particularly crinoids, results in a vuggy, highly porous dolomite.

Hydrothermal Dolomite

Hydrothermal dolomitization occurs at moderate to deep burial depths, and is a complex multiphase process that results in a predictable suite of diagenetic facies as pressure and fluid temperature increase. Fracturing and brecciation are intense, and porosity styles include intercrystalline, vuggy, moldic and fractures. A range of dolomite forms are produced in the following sequence (White and Al-Aasm, 1997):

1) Deposition and early burial phases are the same as in the unconformity-related dolomitization (Stages 1 and 3 described above) in that dolomite replaces calcite and micrite, and pseudomorphic dolomite replaces fossils in wackestones and packstones along dissolution seams;

2) With increasing pressure and interaction with progressively hotter fluids, coarse crystalline dolomite forms (crystal size is 500-2000 microns) in packstone and grainstone facies. This produces secondary porosity that may be partially occluded by pyrobitumen;

3) In the final stage, porosity is destroyed by the infilling of fractures and vugs in breccias with opaque saddle dolomite (Plates 19, 20, and 21).

Whereas many of the early stage dolomite types are similar to both models, coarse crystalline and saddle dolomites are unique to the hydrothermal dolomite model, as they are precipitated from highly saline hydrothermal fluids that travelled along thrusts and fractures formed during the Laramide Orogeny (Late Cretaceous to Early Tertiary).

Debolt Cross-section A-A' illustrates the discontinuous development of hydrothermal dolomites in the far northwest part of the study area; core photos on the section demonstrate poor porosity, fracturing, and hydrothermal dolomites. Porous zones are thin and log signatures spiky, indicating probable association with fractures; porous zones cannot generally be correlated from well to well. Gas production from fields in this area (Pocketknife, Sikanni) originates primarily in these fractured zones.

We have not attempted to map thin, discontinuous zones of hydrothermal dolomitization. They are difficult to quantify on logs, and contouring net porous thickness from well to well would be misleading, as we have no certainty regarding the lateral continuity of hydrothermally-generated porosity.

Porosity – Permeability Relationships

A porosity-permeability cross-plot using all Debolt core analysis data shows a "triangular distribution", as characterized by Carlson *et al*. (1999) (Debolt cross-plot, Appendix 5). There is a tremendous scatter of data that defies mathematical characterization of the entire data set. We have chosen to impose a semi-quantitative interpretation instead, attributing some of the values to conventional matrix-controlled permeability (corresponding to the low-temperature dolomites), and some to fracture-controlled permeability (corresponding primarily to fractured, hydrothermal dolomites). Looking at the data points surrounding the “matrix-controlled porosity” line, our 6% porosity cutoff would equate to permeability values between 0.5 and 1mD. While these are low values from a water production viewpoint, recall that the 6% porosity cutoff does, in general, equate to economic values for hydrocarbon production.

KISKATINAW FORMATION

Mapping

The Kiskatinaw Base Map (Map 6) illustrates well control, oil and gas production, injector wells, distribution of cores and sample logs, and lines of cross-section drawn to illustrate Kiskatinaw stratigraphy and reservoir development across the Montney play fairway. The “area of detailed mapping” outlines a smaller map area, where we have sufficient data to characterize Kiskatinaw reservoir quality and distribution. Kiskatinaw oil and gas pools are generally small and controlled by both structural and stratigraphic elements (Barclay *et al*., 1997).

Kiskatinaw well control is limited to Twp 86 and southward, where Kiskatinaw facies are preserved within the Fort St. John Graben. Highlighted well symbols to the northwest on Map 6 indicate scattered locations where Kiskatinaw tops were picked; however, we were unable to pick and map the formation consistently in the westerly distal marine facies, and particularly where structural deformation is extreme (see Belloy-Debolt Cross-sections A-A’ and F-F’). There are very few Kiskatinaw penetrations south of Twp 79, as it is very deep, and porous reservoir facies appear to be limited.

Map 7, a total isopach map of the Kiskatinaw (top Kiskatinaw to top Golata, or to top Debolt where the Golata was not picked), illustrates the influence of pre- and syn-depositional faulting on Kiskatinaw deposition. Substantial thickening occurs through the central axis of the Fort St. John Graben (Twp 81-83). The northerly zero edge of the Kiskatinaw is controlled by faults on the northern side of the complex, some of which show throws up to 600 metres. To the south of Twp 80, limited well control shows thinner but still substantial Kiskatinaw deposition. Belloy-Debolt Cross-sections B-B’, C-C’, D-D’, and E-E’ illustrate these patterns regionally. More locally, abrupt changes in Kiskatinaw thickness reflect syn-depositional movement along individual faults within the Fort St. John Graben, as illustrated schematically in Figure 14. We have interpreted the presence of short fault segments in several locations to explain such thickness variations, particularly in the Monias (Twp 81-82, Rge 20-22W6) and Parkland (Twp 81, Rge 15-16W6) areas.

Map 8 shows structure on the base of the Kiskatinaw; the base was chosen (as opposed to the top) because most quality reservoir rock occurs near the base. The map is hand-contoured throughout, taking fault offsets into consideration, and based on well control alone. We expect that additional and more intricate fault relationships could be mapped by adding seismic interpretations. Some fault traces brought in from literature sources were shifted or extended to conform with well data points at base

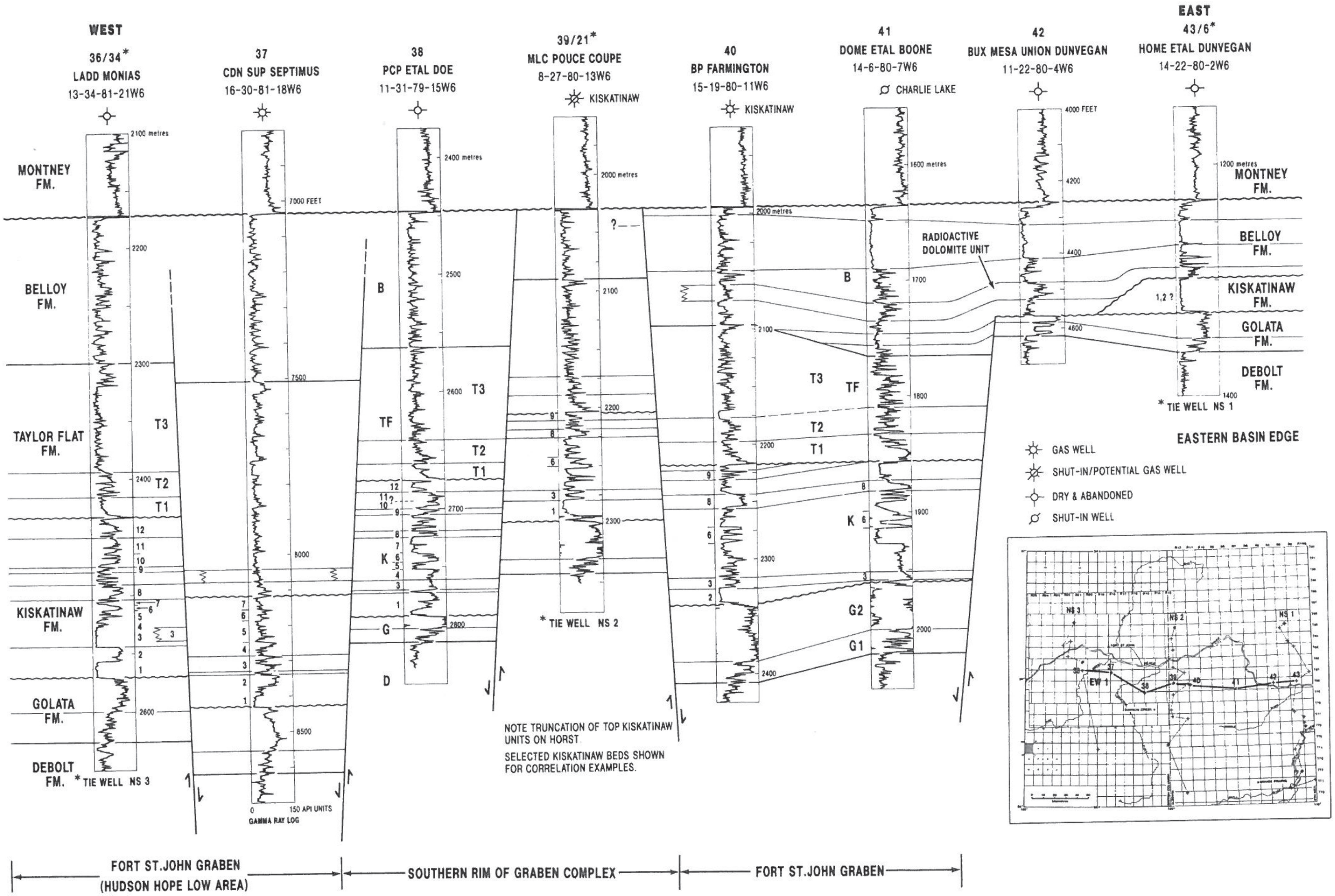


Figure 12. Belloy-Debolt cross-section in Fort St. John Graben, showing syndepositional faulting that profoundly influenced depositional thicknesses (from Barclay et al., 1990).

Kiskatinaw level. Structure plays an important role in hydrocarbon trapping in the east, and so must be considered carefully in assessing suitability of injection zones.

Map 9 illustrates drill depth to the base of the Kiskatinaw – and so is influenced both by base Kiskatinaw structural elevation and by surface topography. Well density is inadequate to accurately reflect surface topography, and so the map serves only as a general guideline. With this in mind, it is computer contoured using a 100m contour interval. Fault lines were used to constrain the contouring. While drill depths to the Kiskatinaw are 2500m or less over much of the Montney play fairway, they are generally >3000m south of Twp 79.

Reservoir Characterization

Map 10 illustrates distribution of net porous Kiskatinaw sandstones. A porosity cut-off of 6% (sandstone density log) was used in combination with a soft gamma log cut-off of 75 API units. Almost all net porous reservoir sandstone was found within thick basal sandstones; thinner sandstones higher in the section tend to be more cemented and less continuous. Even in the basal sandstones, which are >20m thick in many places, silica and carbonate cementation has occluded most porosity, as demonstrated by core analysis grain density values (see below), well logs, and sample cuttings descriptions. Note that the contours are open to the north in Twp 83-84, Rge 14-15W6; we recognized additional Kiskatinaw reservoir and production to the north, but we elected to discontinue net porous sandstone picks more than two townships northeast of the Montney play fairway boundary.

We have not encountered a systematic study of Kiskatinaw reservoir quality and diagenesis, but we note that most of the porous sands occur in the south and east, suggesting that the major graben-bounding faults in the north may have had a negative influence on reservoir quality.

Porosity – Permeability Relationships

Appendix 5 contains three porosity-permeability cross-plots for the Kiskatinaw. Data have been binned according to grain density as sandstone (grain density <2690 kg/m^3), mixed lithology (primarily carbonate-cemented sandstones) (grain density 2690 to 2770 kg/m^3), and dolomite (either thin dolomite beds or heavily-cemented sandstones (grain density >2770 kg/m^3). All three plots are dominated by a fairly good linear poro-perm relationship, with a scattering of low-porosity, high-permeability values that can be attributed primarily to fractures. The fracture values skew the mathematically-derived best-fit line, and make it difficult to achieve a high correlation coefficient.

A secondary “best fit” line was hand-drawn for the Kiskatinaw sandstone, to fit a subset of the data at low porosities. This and the mathematical best fit line, which fits higher-porosity samples better, suggest there may be a bimodal population of rock types within the sandstones, possibly related to grain size or the degree of silica cementation. In the clean sandstones, the 6% porosity cutoff equates to a broad range of permeabilities, centering around 2-3 mD.

Few cemented or dolomitic sandstone samples exhibit permeabilities >1mD – almost all good reservoir quality is in clean, siliceous sandstones.

BELLOY FORMATION

Mapping

The Belloy Base Map (Map 11) illustrates well control, oil and gas production, injector wells, distribution of cores and sample logs, and lines of cross-section drawn to illustrate Belloy stratigraphy and reservoir development across the Montney play fairway. The "area of detailed mapping" outlines a smaller map area, where we have sufficient data to characterize Belloy reservoir quality and distribution. The Belloy is a major oil and gas producer in northeastern B.C.; smaller gas pools in the south are controlled primarily by structure, whereas the large oil and gas pools at Eagle and Stoddart exhibit both stratigraphic and structural elements (Barclay *et al*., 1997).

Highlighted well symbols to the northwest on Map 11 indicate scattered locations where Belloy tops were picked; however, we were unable to pick and map the formation consistently in the westerly distal marine facies, and particularly where structural deformation is extreme (see Belloy-Debolt Cross-sections A-A' and F-F').

Map 12, a total isopach map of the Belloy (top Belloy to top Kiskatinaw, or to top Golata where the Kiskatinaw was not picked), includes undifferentiated Taylor Flat Formation strata, as discussed above under Depositional Review. Abrupt thickening of the succession south of the graben-bounding faults in Twp 83-85 reflects syn-depositional thickening, primarily within the Taylor Flat Formation. Smaller faults exert more local control, as discussed above for the Kiskatinaw Formation. North of the main Fort St. John Graben faults, where isopach values are 50m or less, the section is made up entirely of Belloy strata. While the 25m contour can be drawn with confidence, it is difficult to delineate a Belloy zero edge. Belloy-Debolt Cross-section B-B' demonstrates that Belloy strata pass northward into a heterolithic section on top of the post-Debolt unconformity, and are patchily preserved as a few metres of rocks characterized by "hot" gamma log kicks (*e.g*., wells a-55-B/94-A-13, c-32-J/94-A-12). In addition, as discussed above, some Belloy-equivalent carbonates, identified biostratigraphically in core, cannot be consistently distinguished on well logs alone, and hence have been included in the Debolt Formation in our correlations and mapping.

Map 13 shows structure on the top of the Belloy Formation. The map is hand-contoured north of Twp 79, taking fault offsets into consideration, and based on well control alone. To the south, where well data are scarcer, the map is computer contoured, all at a 50 m interval. Note that specific configurations of some faults are different on the structure map, compared to Belloy isopach map. The more extensive faulting on the isopach map reflects syndepositional fault displacements active during Taylor Flat time; few faults on the Belloy structure map indicate reduced fault activity and offset by the end of Belloy deposition. We did not extend structural contours westward into the Foothills, where reservoir-quality facies are lacking and Laramide deformation has created considerable fracturing.

Map 14 illustrates drill depth to the top of the Belloy – and so is influenced both by top Belloy structural elevation and by surface topography. Well density is inadequate to accurately reflect surface topography, so the map serves only as a general guideline. With this in mind, it is computer-contoured using a 100m contour interval. Fault lines were used to constrain the contouring, which in places has produced unrealistic values (*e.g.*, fault wedge in Twp 83-84, Rge 20-21W6). While drill depths to the Belloy are 2300m or less over much of the Montney play fairway, they are generally >3000m south of Twp 78.

Reservoir Characterization

Map 15 illustrates distribution of net porous Belloy reservoir, primarily within the upper 50-75m of the formation. Recognizing the mixed lithologies present in the Belloy, we attempted to attain a porosity cut-off of approximately 6%, in combination with a soft gamma log cut-off of 75 API units. Where clean sandstone facies are present, as at Eagle and Stoddart, the sandstone density scale was used. Elsewhere, we looked for porosity log deviations from background and the presence of SP log deflections and even filter cake on the caliper log to indicate presence of permeability. Where information was inconclusive, we tended toward an optimistic interpretation of porous reservoir thickness. We calibrated porosity values to core where available; unfortunately, wellsite sample cuttings log interpretations are generally not adequate to support porosity / permeability assessment.

Substantial thicknesses of net porous reservoir are present in the Belloy in most wells in Twp 79-85, and as far west as Rge 19 and 20W6. Faults delineating the northern flank of the Fort St. John Graben do not appear to have exerted dramatic influence on net porous thickness. At a regional mapping scale, continuity of net porous zones is difficult to determine, but the widespread presence of some porous reservoir in almost every well in the northeast implies at least some degree of continuity. Systematic thinning of net porous section to the south and west suggests that burial diagenesis has been important in degrading reservoir quality; there is little porous reservoir below a present-day burial depth of 2200m (compare Map 14).

Inspecting the thick lower Belloy (including Taylor Flat Formation) section within the Fort St. John Graben, it is apparent that net porous reservoir quality is developed, at least in some wells. This porosity was not mapped for three reasons:

- Many porous zones are relatively thin and isolated;
- Well-to-well correlations are difficult, and hence continuity of potential porous zones is difficult to establish;
- There are very few cores or tests to verify reservoir quality and fluid content.

Locally, however, review of the lower Belloy / Taylor Flat section is recommended to determine whether porous intervals exist that might be correlated over areas of several km^2.

Porosity – Permeability Relationships

Appendix 5 contains three porosity-permeability cross-plots for the Belloy. There are very few cores in the Taylor Flat Formation, and so almost all these data are from the upper 50m of the Belloy Formation. Data have been binned according to grain density as sandstone (grain density <2690 kg/m^3), mixed lithology (primarily carbonate-cemented sandstones and limestones) (grain density 2690 to 2770 kg/m^3), and dolomite (either dolomites or heavily cemented/mineralized sandstones (grain density >2770 kg/m^3).

All three plots are dominated by a fairly good linear poro-perm relationship, with a scattering of low-porosity, high-permeability values that can be attributed primarily to fractures. The fracture values skew the mathematically-derived best-fit line, and make it difficult to achieve a high correlation coefficient. Unlike the Kiskatinaw, good reservoir quality occurs in all three lithological bins, consistent with the observation that there are porous / permeable carbonates in the Belloy.

FLUID INJECTION POTENTIAL

There are several important criteria in identifying and ranking areas within the Montney fairway for suitability or "favourability" for injection. These include:

- Presence of substantial net porous reservoir thicknesses in one or more of the target formations;
- Known or potential hydrocarbon pools within the target formations that may be influenced by disposal activity;
    - Disposal too close to existing producers may adversely affect production volumes;
    - Existing depleted or semi-depleted pools may offer potential for present or future disposal activity;
- Hydrocarbon exploitation potential in bounding formations that are expected to provide a seal to injected fluids, as hydraulic fracturing may compromise the integrity of this seal;
    - The primary focus here will be on the Montney – are there developments in the lower Montney close enough to the top of underlying formations (primarily the Belloy) to affect the potential seal?
- Hydrocarbon exploration and development potential in deeper strata
    - New wells penetrating a high-pressure disposal zone may experience drilling issues
        - Isolated production from the Wabamun and Slave Point in or near the Montney play fairway highlights the potential for this issue to arise
- Faults and fractures may pose seismic risks or even water containment risks when significant water volumes are injected.

To address these factors, we have integrated relevant mapping and data to develop a high / medium / low "favourability" ranking for each target disposal formation. "High" favourability indicates areas with good aquifer characteristics and capacity, with few or no risks arising from hydrocarbon prospectivity or activity, while "low" favourability indicates poor aquifer characteristics and/or significant risks from existing or prospective hydrocarbon developments within or impacting upon target aquifers.

DEBOLT FORMATION

Favourability Mapping

Map 16 shows injection favourability for the Debolt Formation. Note that there are no gas wells completed in the basal part of the overlying Montney Formation where injection favourability is mapped, and thus risk of top seal for a Debolt injection zone is deemed to be minimal.

High favourability is indicated where we have mapped relatively thick, continuous net porous reservoir, and see no negative factors such as faulting or deeper prospectivity. There are a number of Debolt gas wells within the highly favourable area, but these have all produced small amounts of gas (0.27 BCF or less), and have been abandoned or suspended for 20 years or more. Debolt injector d-A96-K/94-A-12 lies within the high favourabililty area; all other injectors lie to the west along fault / fold trends, where there appears to be significant chance of reservoirs being fractured.

Medium favourability is indicated where net porous reservoir is thinner, and envelops the high-favourability areas.

Low favourability is mapped generally where net porous reservoir is very thin (<5 m). It is also indicated along major fault trends in the west, where net porous reservoir development is associated with both thicker low-temperature dolomites and fractured hydrothermal dolomites. Most Debolt producing oil and gas wells lie along these trends, as do many of the existing injectors. It would be worthwhile to examine the behaviour of injection wells along these structural trends to determine whether there is evidence of fractures posing a risk to reservoir integrity. Finally, low favourability is also indicated in the vicinity of Slave Point gas wells in 94-A-13 and 14; however, the low-favourability areas are small, as Slave Point buildups have been delineated in detail, and further deep exploratory potential is unlikely to exist.

Existing Injection Wells

Ron Stefic of the B.C. Oil & Gas Commission supplied PRCL with a list of approved injection wells in the Belloy, Kiskatinaw and Debolt formations. Locations have been posted on the corresponding base maps, and are listed in Appendix 6. Twenty-one wells approved for injection in the Debolt are within the Montney play fairway area, essentially all of them in the western along fault / fold trends (Map 1, 16). One is approved for acid gas disposal, one for non-hazardous waste, and the rest for salt water. Injection schemes have been terminated in three of the wells, according to the OGC database.

KISKATINAW FORMATION

Favourability Mapping

Map 17 shows injection favourability for the Kiskatinaw Formation. The risk of top seal for a Kiskatinaw injection zone is deemed to be minimal everywhere, as porous Kiskatinaw sands generally occur at the base of the section, and are overlain by thinly-bedded shales and tight clastics of the upper Kiskatinaw and Taylor Flat Formation. Favourability is mapped in Twp 81-83, well east of the Montney play fairway boundary; we have chosen to cut off the mapping at an east-west trending fault in Twp 83.

High favourability is indicated where there are relatively thick, continuous net porous reservoir, and no negative factors such as faulting or deeper prospectivity. Kiskatinaw oil and gas wells are relatively isolated, and generally have not been used to influence favourability boundaries. Deeper (Wabamun) producing gaswells at Parkland (Twp 80-81, Rge 15-16W6) define an area with low or zero favourability, as additional locations may be drilled into the deep (and hydrothermally-enhanced) Wabamun reservoir.

Medium favourability is indicated where net porous reservoir is thinner, and generally envelops the high-favourability areas. Two net porous sandstone thicks in the southern part of the map are assigned medium favourability, as they are mapped on little well control, and porous reservoir boundaries are uncertain.

Low favourability is mapped generally where net porous reservoir is very thin. It is also indicated along significant faults, where possible fracturing associated with fault movements and reactivation might have compromised reservoir integrity.

Existing Injection Wells

Only one Kiskatinaw well has been approved for acid gas disposal in the Montney play fairway, at Parkland 15-17-81-15W6 (Appendix 6). The well history indicates gas production from the Kiskatinaw took place from 1993 to 2001; only a small amount of gas (262 e^3m^3) was actually injected in January 2002. It is mapped in a low-favourability area on the basis of its proximity to existing production.

BELLOY FORMATION

Favourability Mapping

Map 18 shows injection favourability for the Belloy Formation. There are broad areas of high favourability in the east, where thick net porous Belloy sections are relatively continuous. Medium favourability is indicated in flanking areas. We did not see potential for broad areas of low favourability but, instead, just narrow halos of lower favourability surrounding the medium-favourability areas – which we chose not to draw in explicitly. Note four major controls that significantly reduce Belloy favourability:

- Production from overlying basal Montney wells, which might add risk of top seal containment;
- Oil and gas production from the Belloy itself, as at Stoddart and Eagle;
- Production from deeper pools, such as from the Wabamun at Parkland (Twp 80-81, Rge 15-16W6);
- Proximity to major faults, where reservoir quality might be affected by natural fractures.

Existing Injection Wells

Three injection wells have been approved in the Belloy Formation in the Montney play fairway, two in the east (at Doe) for acid gas injection, and one at Boudreau (84-21W6) for salt water disposal (Appendix 6). All are mapped in areas with substantial Belloy thicknesses and moderate to good favourability.

SUMMARY AND CONCLUSIONS

Intensive mapping and reservoir characterization shows the Debolt, Kiskatinaw, and Belloy formations to be stratigraphically-complex units, with substantial potential to accept injected fluids in various parts of the Montney play fairway in northeastern B.C.

Our regional mapping culminates in a set of “favourability” maps, highlighting areas with reservoir capacity to accept injected fluids, constrained by several factors which may pose significant risks to long-term reservoir integrity and fluid containment.

Several key points are worthy of further thought, discussion, and study:

- Reservoir lithologies in all three formations are intricate blends of clastics and carbonates, and are very difficult to characterize from well log data. Existing core data demonstrates complex stratigraphic and lithological relationships, indicating that local analysis encompassing core and sample cuttings data will be critical in assessment and approval of a specific wellbore for injection.

- Oil and gas production performance analysis should greatly improve our understanding of potential reservoir performance. This work is to be undertaken in a subsequent study.

- Development of overlying reservoirs in the lower part of the Montney poses risks regarding top seal containment of fluids injected into underlying units. With current development patterns, this risk appears most immediate in the far southeast (Swan Lake, 93-P-9) for the Belloy, and to the northwest of Blueberry for the Debolt. Further work is required to assess these risks quantitatively.

- Faulting and associated fracturing is present throughout the study area. In the Fort St. John Graben area, intricate systems of faults have experienced movement in a dominantly extensional regime, during a number of episodes beginning prior to Kiskatinaw deposition. In the northwest, Laramide compressive forces produced a dominantly compressive regime with folding and thrust faulting, but also reactivated Devonian (Antler Orogeny) faults.

    - Oil and gas production from the Debolt and a number of younger units is focused along Laramide structural trends in the west, and many of the reservoirs are fractured to various degrees. We identified extensive fracturing in the Debolt, and believe it responsible for most productive reservoir quality in this area.

- There is a major question regarding the long-term integrity of fractured reservoirs, and whether fluid injection into them will create risks of anomalous seismicity, or even possible escape of injected fluids.

- We have completed our favourability mapping with the assumption that all faulted zones come with significant seismicity / containment risks. However, most existing Debolt injectors are located along the Laramide structures, and in areas where we see predominantly hydrothermal / fractured dolomites, as opposed to low-temperature, matrix-dominated dolomites. A detailed study of the behaviour of these injectors to date, some of which have taken substantial fluid volumes, is recommended.

Finally, we emphasize that while the Belloy, Kiskatinaw and Debolt are favoured targets for fluid disposal, they are not the only options available to operators in various areas. Substantial reservoir capacity is available locally in shallower zones, such as the Bluesky and Baldonnel. There is little information available regarding capacity of deeper zones, but PRCL has identified high-quality basal Devonian sandstone reservoirs in local areas which are very deep (>3000m), but which may offer very secure disposal potential.

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