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Fluid compartmentalization of Devonian and Mississippian dolostones, Western
Canada Sedimentary Basin: petrologic and geochemical evidence from fracture
mineralization

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Abstract

Integrated petrographic, geochemical and fluid inclusion study of fracture mineralization and associated host rock in selected Mississippian and Devonian carbonates extending from southeast Alberta to northwest British Columbia, Canada, aims at quantifying the type and nature of fluids precipitated saddle dolomite and late calcite cement and their origin.

Petrographic and isotopic evidence from both the Devonian and Mississippian fracture-filling carbonates indicate the presence of a hydrothermal fluid source. The $\delta^{18}\text{O}$ isotopic values for the Devonian saddle dolomite (-14.62 to -3.75‰ VPDB; average -11.12 ‰) combined with enriched $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios (0.70827 to 0.71599; average 0.71006) and higher homogenization temperatures (T_h =74-194.6°C; average 126.8°C) and salinity values (7.7 to 26.6, average 16.2wt% NaCl eq.) show significant differences from the Mississippian saddle dolomite, which is characterized by less negative $\delta^{18}\text{O}$ isotopic values (-12.53 to -7.82‰ VPDB; average -9.14‰), less radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios (0.70859 to 0.70943; average 0.70887) and lower homogenization temperatures (T_h) and salinity values of fluid inclusions (87.6-214.2°C; average 136.3°C; 2.0 to 13.2, average 9.6wt% NaCl eq.). Later fracture- and vug-rimming blocky calcite cement records comparable or slightly lower values of oxygen (-16.31 to -4.08 ‰ VPDB; average -9.76 ‰) and Sr isotopes (0.70784 to 0.709743; average 0.70868) and much lower salinity values (0 to 22.5 wt. % NaCl; average: 2.86 wt. % NaCl) for samples mostly from the Mississippian age group. These results suggest possibly two different hydrothermal episodes related to

early (Antler) and late (Laramide) tectonic events that affected the Western Canada Sedimentary Basin with possible compartmentalization of hydrothermal systems and their associated brines in the basin.

Draft

Key words: Fluid compartmentalization, dolomitization, Devonian, Mississippian, Western Canada

1. Introduction

Diagenetic fluids in sedimentary basins form under diverse tectonic (e.g. foreland vs. intracratonic) and sedimentologic settings. These fluids impose a major control on reservoir-quality evolution of carbonate successions. Sediment diagenesis occurs in several geochemical zones encountered during progressive burial and uplift. Specific diagenetic mineral assemblages with largely well-defined isotopic and trace elemental compositions characterize each of these zones (e.g. Sirat et al. 2016; Fontana et al. 2014; Haeri-Ardakani et al. 2013; Morad et al. 2010, Wendte et. al. 2009; Al-Aasm, et al. 2009). Therefore, the distribution pattern of these mineral assemblages, as well as their specific chemical and isotopic compositions, may be used to understand the geochemical evolution and origin of the diagenetic fluids, and the likely temperature of mineral formation. This information will ultimately aid in unravelling reservoir evolution in time and space.

Following the lithification of carbonate sediments, the prime control on flux of basinal fluids will include the rate and absolute magnitude of sediment loading and tectonic deformation, in turn determining the distribution and timing of fractures. These fluxing fluids can have an intrastratal origin or be derived from other parts of the basin. Hence, the patterns of diagenetic alterations and of their impact on reservoir quality are linked to burial and deformation of carbonate successions.

In the Western Canadian Sedimentary Basin (WCSB), which is an excellent example of complicated passive margin, intracratonic and successor foreland basin, laterally extensive dolomitization has affected the majority of Devonian and Mississippian

carbonate reservoirs. Debate continues on the mechanism and timing of dolomitization and its inherent fluid flow, and several models have been suggested.

Dolomitization models applicable to WCSB include the “topographic or gravity-driven flow” (Garven and Freeze 1984) and “tectonically-driven squeegee” model (Oliver, 1986) which have attracted wide attention. Machel and Cavell (1999) has suggested that a squeegee-type flow is responsible for much of the interpreted deep burial dolomitization of Devonian rocks in the WCSB. Machel et al., (2001) has also concluded that a squeegee-type flow was responsible for the formation of late diagenetic calcite cement in Alberta basin. Shields and Brady (1995), Potma et al. (2001) and Al-Aasm and Raymus (2018) have been strong proponents of brine reflux dolomitization to account for most of the Devonian dolostone seen in central Alberta and the Front Ranges, and Packard and Al-Aasm (2004) have advocated a similar mechanism for the pervasive dolostones seen in the Mississippian Upper Debolt Formation of northwestern Alberta.

Morrow (1998) advocated a convection flow model as a viable alternative to the previous models. A variant on the convective flow model, structurally-controlled hydrothermal dolomitization, whereby fracture/fault-focused hydrothermal fluids are held responsible for localized dolomite formation and limestone leaching, has more recently been advocated by a number of authors, (e.g. Packard et al. 2001; Al-Aasm 2003; Smith and Davies 2006). Machel and Cavell (1999) suggested that large-scale hydrothermal dolomitization is only possible if the fluids are focused into, and funnelled through, relatively narrow aquifers.

As with the flow models, the timing of dolomitization in the WCSB remains controversial. Pre-, syn-, and post-tectonic events have been suggested based on a

differing lines of evidence including paleomagnetism, petrography/paragenesis, field relationships, geochemistry, and biostratigraphy (Al-Aasm et al. 2000, Al-Aasm 2003; Nesbitt and Muehlenbachs 1994, Mountjoy and Amthor 1994; Qing and Mountjoy 1994; Symons et al., 1998, Machel and Cavell, 1999; Cioppa et al., 2004; Davies and Smith, 2006; Lonnee and Machel 2006, Packard and Workum 2004). Previous studies from different parts of the WCSB have attributed the origin of dolomitized carbonates in the basin to a variety of early and late diagenetic events within a range of diagenetic environments, such as shallow to deep burial (e.g. Aulstead and Spencer 1985; Machel and Mountjoy 1987; Machel and Anderson 1989; Kaufman et al. 1990; Mountjoy et al. 1992; Packard et al. 1990; Qing and Mountjoy 1992; Al-Aasm and Clarke 2004; Mountjoy and Amthor 1994; Vandeginste et al. 2009, Wendte et al. 2009; Al-Aasm 2001; 2003; Al-Aasm and Clarke 2004; Ma et al. 2006). Shields and Brady (1995), for example, attributed the dolomitization of Upper Devonian carbonates of WCSB to regional-scale reflux of early brines. Machel et al., (1996) discounted the ability of this model to apply on a regional scale. In the Wabamun Group of the Peace River Arch structurally controlled zones of fractured and porous dolomite exist within medial ramp limestones (Packard et al. 1990). The fractures are interpreted to have formed during the late Devonian to early Mississippian. Packard et al. (1990) and Packard and Jansonius (1992) suggested that dolomite formed in a shallow burial environment from hydrothermal fluids during the Tournaisian or Viséan, based on palynomorphs and meso- and micro-scaled relationships between saddle dolomite and internal sediments. They also inferred that this hydrothermal event was synchronous with the emplacement of alkaline intrusives and extensional tectonics temporally associated with the evolution of the Fort St. John graben

system. Our research group (Packard et al. 2001) later investigated a unique chert reservoir in NE B.C. and attributed its origin, as well as the associated saddle dolomite, to hydrothermal activity in a shallow burial setting associated with the formation of the graben. In addition, Davies (2004) argued for a shallow burial hydrothermal fluid flux in the formation of saddle dolomite from NE British Columbia (B.C.). In contrast, Mountjoy and Amthor (1994) attributed dolomite to deep and late, hot basinal fluids that moved updip along sedimentary and fault systems during late Cretaceous and early Tertiary. Lonnee and Al-Aasm (2000) and Al-Aasm (2003) also provided good examples of the influence of hydrothermal fluids in the formation of Devonian dolomites and their relationships to a tectonic framework. Petrographic and geochemical data were presented to support both pre- and post-Laramide fluid flow events for the formation of saddle dolomite from two Middle Devonian carbonates in NW Alberta. Al-Aasm and White (1997) attributed the formation of fracture and breccia-related saddle dolomite of the Upper Debolt of the Sikanni Field in NE B.C. to hot (, basinal fluids that migrated upward through faults formed during the Laramide Orogeny. Wendte et al. (2009) provided a unique example of the effect of fracture diagenesis on the evolution of reservoir porosity in the Devonian Jean Marie carbonates from B.C., whereby dolomitizing and other mineralizing fluids flowed through vertical or near-vertical conduit systems during late Devonian early Mississippian time.

In summary, those previous studies collectively portray divergent natures and sources of dolomitizing fluids and their relationships to tectonic episodes.

The purpose of the present work is to characterize dolomite and calcite fracture mineralization in Devonian and Mississippian subsurface carbonates of western Canada,

in order to evaluate the relative timing and evolution of the diagenetic or mineralizing fluid(s). Our aim was to determine whether the diagenetic fluids that precipitated the minerals originated during Antler-age orogenesis (late Devonian to early Pennsylvanian), later during the Laramide Orogeny (late Cretaceous to Paleogene), or during both tectonic episodes, all hypotheses that have been advanced by previously published studies. Additional questions to be addressed were: (1) whether the fluids that precipitated diagenetic minerals in these fractures appeared to be either spatially or stratigraphically-limited, and (2) whether the diagenetic fluids evolved substantially over time within a given area. The above questions were to be addressed by using detailed integrated petrography, stable oxygen and carbon isotopes and strontium isotope analysis and fluid inclusion studies.

2. Geological and stratigraphic setting

In WCSB the variables associated with fracture mineralization are many and embrace diverse processes that affected the host strata at various times over a lengthy burial history. Taken collectively these events range, at a minimum, from Givetian (Middle Devonian) to Eocene. The following attempts to summarize the interpreted salient features of this long and complex basin history.

A northwest-trending trough in front of the Cordilleran Fold and Thrust Belt termed the Alberta Basin and the cratonic Williston Basin, along with the eastern Canadian Cordillera, constitute the Western Canada Sedimentary Basin (WCSB) (Fig. 1). The Alberta Basin is further distinguished by a major east-northeast trending basement structure called the Peace River Arch (Fig. 1) that represented an emergent

topographic high from the Cambrian to the Late Devonian (Cant 1988). The Peace River Arch in the Mississippian to Permian time became the site of a fault-bounded basin termed the Peace River Embayment. The Foreland Fold and Thrust Belt and the Omineca Belt are the Cordilleran structural elements formed during Middle Jurassic to Eocene compressive deformation of the western edge of the WCSB initially due to microplate collision and obduction, and ultimately the subduction of the Pacific Plate. This compressive deformation affected strata of Middle Proterozoic to Eocene age within the WCSB (Wright 1984), and affected rocks well east of the easternmost thrust sheet with subtle structural implications (fault readjustments) and more profound diagenetic consequences. Monger et al (1982) argued that the most extensive deformation occurred during the Columbian Orogeny (late Jurassic to early Cretaceous) and the Laramide Orogeny (late Cretaceous to Paleocene). Deposition of Oligocene strata in the Flathead Valley Graben (southeastern British Columbia) resulted from the regional extension following this compressive deformation.

The Mesozoic and Cenozoic evolution of the entire WCSB was significantly affected by the loading of the North American craton and the creation of western source areas during formation of the Cordilleran Foreland Fold and Thrust Belt (Wright, 1984). These events in turn lead to the rapid and deep burial, and deformation of, the Devonian and Mississippian host strata of concern in this study.

A thickness of above 6 km east of the deformed belt in the Liard Basin, and southward to over 3 km in the Canadian portion of the Williston Basin characterize the Phanerozoic sedimentary wedge that thickens westward from a zero edge on the

Canadian Shield. Due to westward thickening and thrust sheet repetition, Paleozoic strata in the Canadian Rockies can exceed 8 km in thickness.

Prior to the mid-Devonian the western edge of the North American craton during the Lower Paleozoic was a passive margin. Starting in the Late Devonian in Canada (somewhat earlier in the southwestern USA) and lasting into the Mississippian, an oblique collision event (Antler Orogeny) resulted in the development of a north-south oriented foreland basin referred to as the Prophet Trough (Richards 1989, 1994). Coincident with and likely genetically allied to, the non-orthogonal compression, were wrench and extensional structures that produced the Liard Basin and the Peace River Embayment.

The Prophet Trough of Western Canada, which developed during the late Devonian to early Carboniferous and persisted into late Cretaceous, contained the thickest Carboniferous sections (Wright 1984).

Further compactional deformation of the underlying sediments was caused by progressive tectonic and sedimentary loading (with concomitant increase in temperature) due to the extensive onlapping of thrust sheets (White 1995). However Majorowicz et al. (1985, 1986) has demonstrated that with depth in the NE section of the Rockies there exists a decrease in heat flow, and the authors implicate large scale fluid migration from recharge areas of the Rocky Mountains through deep aquifers to lowland discharge areas. White (1995) argues that a period of uplift and erosion existed in the Sikanni Field in NE B.C. during the Pennsylvanian to the start of the Permian as indicated by the presence of the Belloy Formation overlying the Stoddart Group.

Richards (1989) reported that the main tectonic elements of the WCSB in the late Devonian period were the Prophet Trough, which he described as the “downwarped and downfaulted western margin of the North American Plate of the late Devonian and Carboniferous time”, and the Peace River Embayment. During the Antler and Ellesmerian Orogenies and between latest Devonian and early Carboniferous period the Prophet Trough subsided by loading and contraction, whereas during the Cariboo Orogeny in British Columbia contraction caused its subsidence (Richards 1989; White 1959; Sutherland Brown 1963; Leithiers et al. 1986). In the early stages of the Peace River Embayment (formed by subsidence or inversion of the Peace River Arch), it was a part of the Prophet trough but during late Tournasian it became a “distinct element” (Richards 1989). Block faulting of the Arch occurred due to crustal extension during the Antler Orogeny and was followed by block subsidence. Conduits for the movement of diagenetic fluids were provided by these fault movements which also formed structural hydrocarbon traps in the Peace River area (Cant 1988; Halberstma 1996).

The major Devonian and Mississippian stratigraphic units in the WCSB relevant to this study are shown in Figure 2.

3. Material and methods

The database used in this study represents fracture-filling saddle dolomite and calcite cement samples collected from the Devonian and Mississippian carbonates from various fields (Fig. 1, Table 1). These data represent published and unpublished material collected over the years by the authors and their students and collaborators. Many cored wells from these fields were examined in detail. Determination of fracture

apertures and orientations were not conducted. The main emphasis was on examining and collecting samples from fracture fills. Petrographic examination of hundreds of thin sections was performed using petrographic microscope and by cathodoluminescence microscopy (CL) using a Technyson cold cathodoluminescence stage with a 12-15 kV beam and a current intensity of 420-430 mA on the non-stained halves of thin sections. In addition, fluorescence characteristics were studied with a Nikon EPI Ultraviolet Fluorescence stage connected to a petrographic microscope. Saddle dolomites were sampled for oxygen- and carbon-isotopic analysis and minor and trace element analysis using a microscope-mounted drill assembly to extract the desired quantity (0.5-4 mg for isotope analysis and 100-250 mg for element analysis) of powdered dolomite and calcite from polished slabs. The samples for isotope analysis were reacted in vacuo with 100% pure phosphoric acid for at least 4 hours at 50 °C for dolomite and 25°C for calcite. Samples containing both calcite and dolomite were subjected to chemical separation techniques described by Al-Aasm et al. (1990). The evolved CO₂ gas was analysed for isotopic ratios on a Delta-Plus mass spectrometer. Values of O and C isotopes are reported in per mil (‰) relative to the PeeDee Belemnite (VPDB) standard. Precision was better than 0.05 ‰ for both $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$. Strontium isotopes were analysed for selected dolomite samples. Strontium isotopic ratios were measured on a Finnigan MAT 261 mass spectrometer. All analyses were performed in the static multicollector mode using Re filaments. NBS and ocean water were used as standard references and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were normalized to $^{88}\text{Sr}/^{86}\text{Sr} = 8.375209$. The mean standard error was 0.00003 for NBS-987.

The fluid inclusion analyses were carried out on double-polished thin sections on a Linkam THM600 heating-freezing stage that was calibrated using Fluid synthetic standards. Homogenization temperatures (T_h), halite-melting temperatures ($T_{m\text{-halite}}$) and ice-melting temperatures ($T_{m\text{-ice}}$) using the equation of Bodnar (1993) in terms of the H_2O -NaCl system were measured with a precision (reproducibility) of $\pm 1^\circ C$, $\pm 1^\circ C$ and $\pm 0.1^\circ C$, respectively. Deformation of inclusion walls, necking-down of single inclusions into smaller inclusions, or leakage of fluid can all lead to changes in homogenization temperature. To limit the possibility of measuring deformed aqueous inclusions, only primary inclusions from the same field of view were measured during a single heating or freezing run. By restricting measurements to inclusions within the same field of view, any sudden changes in liquid/vapour ratios due to inclusion deformation could be observed, and removed from consideration. This does not exclude the possibility of subtle deformation in the z-axis, which is difficult to detect. Heating runs were conducted before freezing runs to reduce the possibility of inclusion stretching by freezing (Lawler and Crawford 1983). Florescence microscopy used to identify HC-bearing fluid inclusions.

Spatial variability maps were performed using the ArcGIS software. The spatial analyst tool and the Kriging interpolation method were used to create prediction surface maps to display the spatial variability of isotopic signatures, fluid inclusion homogenizations temperatures and fluid salinities of saddle dolomite and calcite cement in the studied formations. **Results**

4.1 Petrography of Devonian formations

The main diagenetic processes observed include compaction, fracturing, calcite cementation, dolomitization, anhydrite cementation and silicification. Figure 3 shows the generalized paragenetic sequence of these events. These diagenetic events occurred during early shallow burial and intermediate to deep burial, pre- and post-Laramide deformation. The generalized paragenetic sequence shown in Figure (3) is based on petrographic relationships, spatial distribution, and geochemical evidence. The focus in this paper is on dolomitization. Hence, the discussion will be on the most significant and relevant diagenetic events to evaluate the occurrence, distribution and timing of the different dolomite phases, particularly as cements in fractures, and the source(s) and chemistry of the diagenetic fluids that precipitated these diagenetic components.

Dolomitization

Four main types of dolomite are documented in the Devonian carbonates (Fig. 4): (1) fine crystalline subhedral and anhedral matrix dolomite (FCMD) ranged in size from 4 to 10 μm occurring as a host rock and is characterized by dull red color under CL; (2) medium crystalline matrix dolomite (MCMD) ranges in size from 30 to 100 μm occurring as a host rock and consisted of euhedral to subhedral and anhedral crystals. FCMD and MCMD dolomite replaced fossil fragments as well as matrix /cement and represents an early diagenetic event. Based on petrographic observations including the deflection of dissolution seams around dolomite crystals and truncation of MD by low amplitude stylolite, indicate precipitation of MD occurred prior to intensive mechanical and early chemical compaction (Clarke 1998), hence confirming that MD (FCMD-MCMD) is an early diagenetic phase; (3) pervasive dolomite (PD) is fabric

destructive, ranges in size from 50 to 250 μm , displays a dull brownish red color with bright red rims under CL and replaces mud and fossil components. PD is predated by early calcite cement and fine crystalline matrix dolomite and postdated by saddle dolomite and late blocky calcite cement; and (4) SD, which is represented by two principal occurrences: A pore-filling ranges in crystal size from 20 to 150 μm and a fracture-filling ranges in size from 50 to 300 μm . Large crystal size, iron-rich (ferroan), sweeping extinction, and curved crystal faces are the main characteristics of saddle dolomite (e.g. Radke & Mathis 1980). SD cement postdates early calcite cement and medium crystalline matrix dolomite (Figs. 5A, 5B), predates late calcite cement and anhydrite (Figs. 4D, 5F), is occasionally succeeded by quartz in Jedney (Devonian), and is crosscut by stylolites (Fig. 4E). SD exhibits oscillatory zonation of dull to bright red colors with dark red rims under CL (Fig. 4C).

Fractures

In general, there are several generations of fractures observed in the studied Devonian formations. Thin, anastomosing, randomly oriented fractures (0.5-1 cm) filled with early calcite cement represent the first generation of fractures (Fig. 6; Lonnee and Al-Aasm 2000; Mrad 2016). Larger sub-vertical fractures (1-3 cm) occluded by saddle dolomite represent the second generation (Fig. 6A, 6B, 6C). The last generation of fractures (1-5cm) are vertically oriented fractures filled with late blocky calcite cement and crosscutting saddle dolomite (Figs. 4E; 6B). Anhydrite, pyrite, sphalerite and pyrobitumen occlude pores and fractures postdating saddle dolomite and fracture/pore filling blocky calcite (e.g. Packard et al. 2001; Wendte et al. 2009).

Calcite cementation

Two types of calcite cements were observed in the Devonian samples: pore-filling and fracture-filling (Figs. 7, 8). Pore-filling calcite cement occurs in two types: blocky and equant calcite spar cement. Pore-filling equant calcite cement filled pores in brachiopods and gastropods along with occluding matrix and intraparticle porosity in corals and stromatoporoids, ranged in size from 20 to 150 μm and displays a homogenous dull red color under CL (Fig. 7F). Blocky calcite (50 to 500 μm) cement is present in dolomitized wackestones filling pores left by dissolution of grains including corals, foraminifera and ooids where they have entirely filled the interparticle porosity. Blocky calcite represents a late stage diagenetic event in the Devonian formations..

Fracture-filling equant and blocky calcite (FFC) cement ranges in size from 50 to 200 μm and it is euhedral to subhedral in shape (Fig. 8A, 8B, 8D), occurred only in the Duvernay Formation from the studied fields in the Devonian and is not luminescent under CL (Fig. 8C). FFC postdates fine and medium crystalline matrix dolomites (MCMD). Pore-filling blocky calcite cement precludes fracture-filling calcite and formed after the pore-filling SD.

4.2 Petrography of Mississippian Formations

The main diagenetic processes observed include compaction, fracturing, calcite cementation, dolomitization, anhydrite cementation and silicification (Fig.3).

Dolomitization

Five main types of dolomite are documented in the Mississippian formations (Fig. 9): (1) fine crystalline matrix dolomite (FCMD) consists of euhedral to subhedral and anhedral crystals ranging in size from 4 to 15 μm , occurring as a host rock and is

characterized by dark red color under CL (Fig. 9C, 9E).; (2) medium crystalline matrix dolomite (MCMD) consists of euhedral to subhedral and anhedral crystals, ranges in size from 20 to 150 μm occurring as a host rock (Fig. 9B). Matrix dolomite replaces fossil fragments as well as matrix /cement and represents an early diagenetic event. Based on petrographic observations, precipitation of matrix dolomite occurred prior to mechanical and early chemical compaction; (3) coarse crystalline dolomite (CCD) range in size from 200 to 500 μm , consisted of subhedral to anhedral crystals and display a dull red luminescent cores and bright red rims under CL. CCD completely replaces the limestone host rock as was indicated by the presence of allochem ghosts (e.g. Folk 1987; White 1995) ; (4) pervasive dolomite (PD) is fabric destructive (dolomitized skeletal grains), ranges in size from 50 to 250 μm , displays a dull brownish red color with bright red rims under CL and replaces mud and fossil components. PD postdates early calcite cement and FCMD and MCMD whereas it predates SD and late calcite cement. PD is concentrated in the Turner Valley Formation (Quirk Creek), whereas CCD is concentrated in the Upper Debolt Formation (Sikanni) and is characterized by larger grain size (200 to 500 μm) and (5) SD cement which occurs as pore filling with crystal sizes ranging from 20 to 100 μm and as fracture filling ranges in size from 50 to 500 μm . Large crystal size, sweeping extinction, curved crystal faces and ferroan-rich chemistry are the main characteristics of saddle dolomite. SD cement postdates early calcite cement and medium crystalline dolomite and is succeeded by late calcite cement (Fig. 9A, 9D). Microscopic examination shows that SD exhibits oscillatory zonation of dull to bright red colors with dark red rims under CL. SD is crosscut by stylolites in Sikanni and Quirk Creek.

Fractures

Two generations of fractures are observed in the Mississippian Formations. The first generation represents sub-vertical fractures (0.5-2cm) partially filled with early calcite cement and subsequently occluded by saddle dolomite (Fig. 6D). The second generation represents horizontal to sub-vertical fractures (0.5-3cm) occluded by late calcite cement (Fig. 6E). This generation of calcite cement is followed sometimes by anhydrite cement.

Calcite cementation

Two occurrences of calcite cements are observed in the Mississippian samples: pore-filling and fracturefilling ranging in size from 30 to 1000 μm (Fig. 7A, 7B, 7C, 9A). Pore filling calcite cement occurs in 3 crystal habits: bladed-prismatic, blocky, and equant calcite spar cement. Bladed-prismatic calcite occurs in fossil cavities such as in corals and stromatoporoids, ranging in size from 50 to 300 μm , and is characterized by elongate crystals. Blocky calcite (50 to 500 μm) cement is present in dolomitized wackestones filling pores left by dissolution of grains including corals, foraminifera and ooids where they have entirely filled the interparticle porosity. Equant calcite spar cement (30 to 1000 μm) fills pores in brachiopods and gastropods along with occluding matrix and intraparticle porosity in corals and stromatoporoids. Pore-filling calcite cement displayed a homogenous dull red color under CL (Fig. 7B).

Fracture-filling calcite cement ranges in shape from euhedral to subhedral crystals with 50 to 300 μm size and is non luminescent under CL. The first generation of sub-vertical fractures crosscut the undolomitized limestone and are occluded by

early calcite cement. The second generation of horizontal to sub-vertical fractures crosscut early calcite cement and saddle dolomite and are crosscut by stylolites and occluded by late calcite cement. Pore filling blocky late calcite cement postdated fracture-filling calcite and formed after the pore filling saddle dolomite cement.

5. Geochemistry of the Devonian and Mississippian fracture-filling

Oxygen and Carbon Isotopes

The $\delta^{18}\text{O}$ isotopic values for the Devonian and Mississippian fracture and pore-filling SD range from -14.62 to -3.75 ‰ (average -11.12 ‰) and -12.53 to -7.82 ‰ (average -9.14 ‰) VPDB, respectively. $\delta^{13}\text{C}$ values range from -5.89 to 3.16‰ (average 0.36 ‰) and -1.99 to 3.75 ‰ (average 2.33 ‰) VPDB for the Devonian and Mississippian SD, respectively (Fig. 10 and Table 2). Figure 10 also shows the variations of these isotopes according to their corresponding fields. Figure 11 shows the isotopic values of fracture and pore-filling calcite cement grouped according to age. There is a distinct statistical difference in both carbon and oxygen isotopes with respect to their age; more negative values for Devonian samples vs Mississippian counterparts (t-test values of 0.019 for carbon in calcite and 0.000 for carbon and oxygen from saddle dolomite at 95% confidence level).

$\delta^{18}\text{O}$ values of late, blocky pore- and fracture-filling calcite cement ranging from -15.16 to -5.52 (average -10.65 ‰) and -16.31 to -4.08 ‰ VPDB (average -9.76 ‰) for the Devonian and Mississippian calcite cement, respectively. As for the $\delta^{13}\text{C}$ values, they range from -6.47 to 3.03‰ VPDB (average -0.15‰) and -19.22 to 9.36‰

VPDB (average -2.27 ‰) for the above age groups, respectively. The summary of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ results for dolomite types and calcite are presented in Figures 10 and 11 and Table 2.

Strontium Isotopes

The Sr isotopic ratios for Devonian and Mississippian-hosted saddle dolomite range from 0.70827 to 0.71599 (average 0.71006) and 0.70859 to 0.70943 (average 0.70887), respectively. Devonian saddle dolomite is more enriched in $^{87}\text{Sr}/^{86}\text{Sr}$ than the Mississippian counterpart but both show deviation from the postulated values for Devonian and Mississippian seawater composition (cf. Veizer et al. 1999). $^{87}\text{Sr}/^{86}\text{Sr}$ values of fracture/pore-filling calcite cement vary from 0.70810 to 0.71300 (average 0.71016) and 0.70784 to 0.709743 (average 0.70868) for the Devonian and Mississippian carbonates, respectively (Fig. 12 A, 12 B).

Fluid Inclusion results of the Devonian and Mississippian Formations

Microthermometric measurements were performed on primary fluid inclusions in selected carbonate samples from the Devonian and Mississippian carbonates encompassing vug and fracture-fill saddle dolomite and blocky calcite. The inclusions are one phase and two phase (liquid rich with vapor bubble) and ranging in shape from circular to irregular and in size from less than 1 μm to 5 μm in diameter (Fig. 13). The reported measurements of melting (T_m) and homogenization temperatures (T_h) are from two phase liquid-vapor inclusions from saddle dolomite and calcite. Hydrocarbon fluid inclusions were not identified in the selected samples from the studied formations. A summary of the fluid inclusion results is presented in Table 3.

Fluid inclusion data of saddle dolomites varied from T_h : 74-194.6°C (average 126.8°C), 7.7 to 26.7 wt. % NaCl (average: 16.25 wt. % NaCl) and T_h : 87.6-214.2 °C (average 136.3°C), 2.0 to 13.2 wt% NaCl (average: 9.6 wt. % NaCl) for the Devonian and Mississippian samples, respectively (Figs. 14, 15). As for blocky calcite it ranges from T_h : 61-168°C (average 112.6°C), 7.7 to 25.8 wt. % NaCl (average: 14.1 wt. % NaCl) and T_h : 117.3-196.4 °C (average 145.6°C), 0 to 22.5 wt. % NaCl (average: 2.86 wt. % NaCl) for the above age groups, respectively (Figs. 16, 17). There is a distinct statistical difference in salinity for both saddle dolomite and calcite cement with respect their age (t-test values of less than 0.000 at 95% confidence level). There is also a significant statistical difference in T_h for calcite cement for both age groups.

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6. And spatial variability of isotopic signatures, salinities and homogenization temperatures of saddle dolomite and blocky calcite in the Devonian and Mississippian Formations

sotopic and fluid inclusion data for both saddle dolomite and blocky calcite cement in the Devonian and Mississippian formations show a distinctive spatial and stratigraphic variations within the WCSB (Figs. 18-25). In general, very negative $\delta^{18}\text{O}$ values (Fig. 18), highly radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (Fig. 19), and high Th and high salinity values of saddle dolomite (Figs. 20-21) are observed in NW part of the basin in comparison to SE part of Alberta. However, there are some exceptions, such as saddle dolomite from the Middle Devonian Slave Point Formation from Jedney field (Fig. 1), which would appear to have precipitated from less saline brines than other areas. However, these observations may reflect spatial sampling bias whereby more Devonian saddle dolomite were analyzed in the NW part of the basin.

Post-saddle dolomite blocky calcite cement show comparable spatial trends with respect to $\delta^{18}\text{O}$ (Fig. 22) and $^{87}\text{Sr}/^{86}\text{Sr}$ values (Fig. 23). As for Th and salinity values, higher temperatures are concentrated in the Devonian calcites in the central part of the basin (e.g. Devonian Wabamun Group of Gold Creek, Monias, Teepee fields; Fig. 24) but lower salinity in NW part of the basin (Fig. 25; e.g. Devonian and Mississippian dolostones; Jedney, Sikanni).

7. Discussion and interpretation

The integrated petrographic, stable and radiogenic Sr isotopes and fluid-inclusion microthermometry studies provide an understanding of the geochemical

conditions during the formation of diagenetic phases hosted in a broad sampling of Devonian and Mississippian carbonates in the WCSB.

The studies provide a fingerprint to characterize and distinguish those basinal brines, that accessed the Devonian and Mississippian strata both by diffuse aquifer flow and fractures, and that were responsible for matrix replacive dolomitization as well as dolomite and calcite cementation in pore spaces and fractures.

7.1. Constraints from petrography

A summary displaying the generalized paragenetic sequence of identified diagenetic events is shown in Figure 3. Based on the petrographic observations and cross cutting relationships, both early (marine to shallow burial) and deeper burial diagenetic processes are recognized.

In the Devonian formations, calcite cementation occurred during early and late diagenetic stages where it commenced in shallow marine environments and continued through to deep burial environments (Fig. 3). Earlier equant calcite spar cement filled pores in brachiopods and gastropods and in intraparticle porosity in corals and stromatoporoids. Blocky calcite spar occurred as a void- and fracture-filling and represents a late (post saddle dolomite) diagenetic event (Fig. 7, 8).

The formation of fine and medium crystalline dolomites in the Devonian formations occurred prior to chemical compaction (Figs. 4-5). Evidence such as the deflection of dissolution seams around dolomite crystals (Fig. 4F) and its occurrence prior to higher amplitude stylolitization indicate precipitation that predates chemical compaction, consistent with a shallow burial diagenetic environment.

Pervasive dolomite (PD) postdates early calcite cement and matrix dolomite (MD), replaces mud and fossil components, and occurs within pressure solution seams; therefore, it also likely formed in a shallow to intermediate burial setting. Qing and Mountjoy (1994) suggested that dissolution of high magnesium calcite and magnesium remobilized by pressure solution of older dolomite could represent the sources of magnesium, where stylolites would act as conduits for the diagenetic fluids (e.g. Paganoni et al. 2016).

The occlusion of the second generation of fractures combined with its formation after pervasive dolomite and fine and medium crystalline matrix dolomite (Fig. 3) suggest that SD represents a later diagenetic event and is possibly of a shallow to intermediate burial origin.

Calcite cementation in the Mississippian formations represents an early and late stage diagenetic event where it commenced in a shallow marine environment and continued through to deep burial realm. Evidence such as the occurrence of bladed calcite cement in cavities and as pore filling cement in corals and stromatoporoids, which was succeeded by calcite spar cement healing of broken fossil fragments subjected to mechanical compaction indicate that calcite spar cement precipitated in a shallow burial environment (Foreman 1989; Durocher and Al-Aasm 1997). The non-luminescent CL characteristics and occlusion of early fractures and stylolites suggest that this type of cement formed in a shallow burial environment (Al-Aasm and Vernon 2007). Very low Mn^{2+} (< 25 ppm) and Fe^{2+} contents in an oxidized solution is also indicative of non-luminescence (Budd et al. 2000). Late fracture- and pore-filling calcite postdating saddle dolomite suggest formation in a burial environment.

Fine crystalline matrix dolomite in the Mississippian formations formed prior to mechanical compaction and therefore represents an early diagenetic event. Saller (1984) suggested that a possible mechanism for dolomite formation is through tidal pumping of large volumes of seawater into sediments. Durocher and Al-Aasm (1997) suggested a pre-compaction origin of early matrix dolomite in the Upper Debolt Formation (Blueberry Field) possibly from marine fluids. A shallow burial setting prior to significant compaction is also suggested for the Lower Ordovician fine crystalline dolomite in eastern Laurentia (Azomani et al. 2013). Al-Aasm and Packard (2000) proposed a very shallow (tens of metres) burial environment for the early formed matrix dolomite in the Upper Debolt Formation of the Dunvegan Field (NW Alberta) possibly from refluxing dolomitizing fluids associated with dense modified (evaporated) Mississippian seawater. Therefore, the most relevant model to explain the formation of this dolomite is the shallow burial model by marine or modified marine fluids.

Medium crystalline matrix dolomite formed after mechanical and during early chemical compaction in the Mississippian formations and hence formed during shallow to intermediate burial depths. Al-Aasm and Raymus (2007; 2018) suggested the reflux brine model for the formation of fine to medium crystalline matrix dolomite in the Devonian Crossfield reservoir in Alberta. The petrographic evidence that supported their conclusion includes non-luminescent to very dull luminescent matrix dolomite and that the dolomite is crosscut by dissolution seams combined with the significant preservation of the origin fabrics.

Coarse crystalline dolomite formed during intermediate burial depths possibly by hydrothermal fluids as evidenced by the presence of brecciated fragments of this

dolomite and the abrupt transition between limestone and dolomite beds due to porosity and permeability changes along with the proximity to crosscutting faults and fractures (Stoakes 1987). The above features are also observed in the Upper Wabamun Formation (Packard et al. 1990), Black River and Trenton Formations of the Michigan Basin (Coniglio et al. 1994) and Presqu'ille Barrier, NWT (Qing and Mountjoy 1994).

Pervasive dolomite postdated early calcite cement and matrix dolomite. Lu (1993) suggested that pervasive dolomite in Upper Mississippian Turner Valley Carbonates, Quirk Creek, Alberta formed at shallow to intermediate burial environments (e.g. Machel 2004). Pervasive dolomite is present in many Mississippian fields from Western Canada Sedimentary Basin including Sikanni, Dunvegan and Blueberry (Upper Debolt Formation), Quirk Creek and Moose Mountain (Turner Valley Formation), and the Sylvan Lake (Pekisko Formation). Al-Aasm (2000) suggested that pervasive dolomite in the Sylvan Lake, Quirk Creek and Blueberry fields formed during shallow burial whereas it formed during intermediate burial in Sikanni and Moose Mountain. Petrographic and isotopic evidence pointed towards recrystallization of matrix dolomite commencing early in the diagenetic history of the Mississippian carbonate and continuing through burial. Changes in burial conditions and fluid chemistry are reflected due to variations in geochemical, isotopic and crystallographic signatures. No evidence of meteoric exposure exist in Sikanni probably since it was deposited in the deeper parts of the basin in a platform setting (cf. White and Al-Aasm 1997). Al-Aasm (2000) concluded that in some carbonate reservoirs (e.g., Upper Debolt Formation from the Dunvegan Field), recrystallization of microcrystalline

dolomites initiated in marine pore fluid contrary to others (e.g., Pekisko dolomites; Adam and Al-Aasm 2017) where it commenced in a meteoric-dominated system. Recrystallization of dolomite occurred during burial conditions from ambient temperature and hydrothermal basinal fluids. Therefore, a shallow to intermediate burial model is proposed here for the formation of pervasive dolomite.

The occlusion of late fractures and vugs, replacement of early calcite cement and formation after medium crystalline matrix dolomite and pervasive dolomite indicates that saddle dolomite (SD) precipitated in a shallow to intermediate burial environment.

However, Al-Aasm and Vernon (2007) interpreted the saddle dolomite from the Mississippian Pekisko Formation to be of a deeper burial settings as it postdated the pervasive dolomite (which formed during shallow burial) and chemical compaction features.

7.2. Constraints from stable and Sr isotopes

The $\delta^{18}\text{O}$ isotopic of precipitated carbonate minerals depends on the isotopic composition, salinity and temperature of fluids (e.g. Nelson and Smith 1996). Hence, the isotopic composition of diagenetic carbonates can be used to trace fluid composition and source during dolomitization (Chen et al. 2013).

The $\delta^{18}\text{O}$ isotopic composition of saddle dolomite from many fields (Fig. 10) show some overlap, suggesting formation from comparable fluid temperature and/or similar fluid isotopic chemistry. On the other hand, there can be nice separation between fields (Fig.10B). However, on average Devonian saddle dolomites have more negative $\delta^{18}\text{O}$ values in comparison to Mississippian saddle dolomites (Fig. 10A). This may suggest

precipitation of the former group by warmer hydrothermal fluids than the latter group. It may also signify a change in fluid composition involved in the formation of saddle dolomite (cf. Al-Aasm 2003.)

There is also an overlap in $\delta^{13}\text{C}$ values between fields (Fig. 10), with possible internal, buffering from host carbonates. However, there are more negative values in some fields, such as Rainbow South (Sulphur Point Formation) which can be related to a different source of negative carbon derived from the oxidation of hydrocarbons, possibly related to thermochemical sulphate reduction (e.g. Machel et al. 1987; Lonnee and Al-Aasm 2000). The spatial distribution of oxygen isotopes shown in Figure (18) shows an apparent negative shift in $\delta^{18}\text{O}$ as you go from the Peace River Arch area in the southeast (Fig. 1) to northwest Alberta and northeast British Columbia, a phenomenon discussed by Packard and Al-Aasm (2016)..

The formation of blocky calcite postdating SD has been reported by many authors for many hydrothermal systems in dolostones (e.g. Lonnee and Machel 2006; Sirat et al. 2016; Mansurbeg et al. 2016). The highly negative and variable $\delta^{18}\text{O}$ values (Fig. 13) corroborated by high homogenization temperatures and salinities of fluid inclusions suggest a hot, saline fluids with evolved water/rock ratios for the formation of blocky calcite. The wide range of $\delta^{18}\text{O}$ values can be explained in terms of a wide range of precipitating temperatures and/or fluctuations in the oxygen isotopic composition of the hydrothermal fluids.

The investigated saddle dolomite and blocky calcite cements show some overlap in their $^{87}\text{Sr}/^{86}\text{Sr}$ ratios but both deviate from the postulated values of Devonian and Mississippian seawater (Figs. 14 A, 14 B). This argues for basinal fluids that have been

interacted with basement or radiogenic clastic successions, as the major source of fluids for hydrothermal dolomitization and later calcite cementation (cf. Al-Aasm 2003). However, Devonian saddle dolomite shows more radiogenic values than Mississippian dolomite, especially apparent in the NE part of the basin (Fig. 19), which suggests two different hydrothermal pulses possibly related to early and late tectonic events that affected WCSB.

7.3. Constraints from fluid inclusions

Fluid inclusion data of saddle dolomites for the Devonian formations (Figs. 14-15) suggest precipitation from a hot, saline brines. For the Mississippian fields, the fluid inclusion data also suggest formation by relatively hot but less saline brines. These data are indicative of hydrothermal activity as well (e.g. Searl 1989; Al-Aasm 2003; Smith and Davies 2006). Al-Aasm (2003) classified the homogenization temperature for Devonian and Mississippian SD in WCSB into 3 groups: a lower range (ca. 80-120 °C), a medium range (120-160 °C), and a higher range >160 °C. Group one comprised the Devonian Wabamun Group and some samples from the Mississippian Upper Debolt Formation. In Group two are SD from the Slave Point Formation, Wabamun of Parkland field and some samples from the Upper Debolt Formation. Group three contains the Slave Point Formation from Jedney and Sulphur Point Formation from Rainbow South. Two groups were suggested for the salinity values measured from fluid inclusions in SD (Al-Aasm 2003): group one from Parkland, Tangent and Hamburg fields were characterized by high salinity values (>20 wt. % NaCl) and group two from Jedney, Sikanni and Rainbow South were characterized by lower salinity

values (<20 wt. % NaCl) (Figs. 20-21). The above data is consistent with the enlarged data set from this study.

Figure (15A) demonstrates no clear relationship between Th and salinity for the saddle dolomite from the Devonian formations but a positive relationship with respect to the Mississippian dolomite. This can be related to variable fluid sources within the Devonian successions, perhaps related to local tectonic setting within different parts of the sampled formations. Saddle dolomite from the Slave Point Formation (Hamburg Field) have higher salinity relative to the ones from Slave Point Formation (Jedney Field), indicating a highly saline brine source possibly due to spatial variability within the Devonian fields (Fig. 15B). Fluids associated with the Laramide Orogeny tend to be mixed brines and meteoric waters with a salinity range of 0-10 wt. % NaCl (Nesbitt and Muehlenbachs 1994). Hence, the highly saline values (22-25 wt. % NaCl) from Hamburg (North Western Alberta) suggest its association with the Antler Orogeny (late Devonian and early Mississippian) in contrast with Jedney (North East British Columbia) that is related to hydrothermal fluid flow that is possibly diluted with less saline fluids of local source; a hypothesis that has not been tested yet. The bimodal distribution of the salinity (Fig. 14B) of saddle dolomite from the Devonian formations may also suggest a divergent fluid source responsible for the precipitation of saddle dolomite and can be associated with hydrothermal fluids charged during the late Devonian and early Mississippian (Antler Orogeny). $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios of the Mississippian and Devonian saddle dolomites are enriched relative to the Devonian and Mississippian marine carbonates (Fig. 12), hence requiring an enriched strontium fluid source with two separate pulses of hydrothermal fluids given that the Devonian

SD and late calcite was characterized by more enriched $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios relative to the Mississippian SD and late calcite (Al-Aasm, 2003).

Variable saline and hot fluids were also instrumental in the formation of post-dated blocky calcite (Figs. 16). However, a bimodal distribution of salinity in the Devonian blocky calcite (Fig. 16B) also may signify the varying spatial distributions of fluids migrated via fractures and faults in different parts of the basin (Fig. 25).

7.4. Chemistry of pore fluid evolution

Fluid inclusions and isotope data can be used to infer changes in the oxygen isotope composition of pore fluids in the Devonian and Mississippian vug- and fracture-filling SD and blocky calcite during progressive diagenesis. The relationships among mineral $\delta^{18}\text{O}$ values, pore water $\delta^{18}\text{O}$ values and temperature for diagenetic phases from the investigated carbonates are shown in [Figures 26-27](#) and likely pathways for pore water evolution have been suggested. These pathways reflect changes in temperature and in fluid chemistry or both. Using the mean Th values and the range of $\delta^{18}\text{O}$ for saddle dolomite from both time frames, the ^{18}O composition of the precipitating fluids was determined. These fluids are characterized by enriched $\delta^{18}\text{O}$ fluids values -2 to +14 ‰ VSMOW for Devonian SD and from -2 to +12‰ VSMOW for Mississippian SD and both are forming at elevated temperatures. These fluids may have originated from the basement with contributions from Devonian brines (e. Al-Aasm, et al. 2002).

Figure 27 shows the relationship between $\delta^{18}\text{O}$ values for fluids, temperature and $\delta^{18}\text{O}$ values for late blocky calcite cement which cross cut and postdates saddle dolomite formation. It shows that the Mississippian blocky calcite cement formed at elevated temperatures and from more enriched pore fluids compared to the Devonian. Thus, indicating a divergence in the fluids origin.

7.5. Relationship between fracturing, tectonic events and fluid flow

Qing and Mountjoy (1989) along with Wong and Oldershaw (1981) proposed that fluids of burial origin precipitated the SD in the Devonian reefs of western Canada. Chemical compaction and thermochemical sulfate reduction were suggested by Machel (1987) to account for the saddle dolomite formation in the Nisku reefs. Viau and Oldershaw (1984) suggested that the same saddle dolomite cements studied by Wong and Oldershaw (1981) were in fact precipitated from hydrothermal fluids at relatively shallow burial depths. Al-Aasm (2003) and Davies and Smith (2006) suggested that the formation of saddle dolomite in both the Devonian and Mississippian formations from WCSB occurred as a result of hydrothermal fluid flow along faults and fractures associated with deformation during the late Devonian and Mississippian. The relationship between structure and hydrothermal fluid flow has been examined in detail by Davies and Smith (2006) using many examples from the WCSB. Ma et al. (2006), based on numerical modelling, proposed that hydrothermal fluid flow during the Antler Orogeny (late Devonian and early Mississippian) were responsible for saddle dolomite formation in the Upper Devonian Wabamun Group. Examples of interpreted hydrothermal dolomites include the Presqu'île dolomite (Qing and Mountjoy 1994), the Manetoe dolomite (Morrow et al. 1986), dolomites from the

Keg River Formation (Aulstead and Spencer 1985; Qing and Mountjoy 1989), Slave Point Formation (Clarke and Al-Aasm 1998), the Upper Devonian Jean Marie Member (Wendte et al., 2009) and the Wabamun dolomites (Packard et al. 1990; Packard et al, 2001). Lonnee and Al-Aasm (2000) proposed that the precipitation of saddle dolomite in the Middle Devonian Sulphur Point Formation, Rainbow South Field, Alberta, involved a hot hydrothermal fluid based on geochemical and petrographic evidence.

The timing of SD formation in the Devonian and Mississippian carbonates is discussed taking into account the relationship between fracturing and tectonic events in WCSB. Diagenetic fluids responsible for hydrothermal dolomitization in the Devonian were channeled through faults, whose transmissibility was likely temporally-limited (i.e. associated with specific tectonic events), during various stages of burial of the impacted strata.

Tectonic compression and sedimentary loading, along with regionally elevated heat flow in WCSB resulted in large scale fluid movement, and were confined to two main events since the deposition of the Devonian strata: the Antler Orogeny between late Devonian and early Mississippian (Machel and Cavell 1999; Root 2001) and the Columbian/ Laramide Orogenies between late Jurassic and early Tertiary (Symons et al. 1999). Packard et al. (1990; 2001), Kaufman et al. (1990), Nesbitt and Muehlenbachs (1995) and Ma et al. (2006) proposed that dolomitization of Devonian strata in many regions of the WCSB was caused by the upward and lateral flow of warm hydrothermal fluids. The hydrothermal dolomitization of the Wabamun Group in the Peace River Arch was suggested by Packard et al. (1990) to have occurred during

a post Devonian, pre-Laramide hydrothermal event, and evidence was presented by Packard and Jansonius (1994) that constrained that timing to early Mississippian (Tournaisian). Furthermore, Nesbitt and Muehlenbachs (1994) reported that a pre-Laramide hydrothermal event was attributed to migration of warm, saline brines (150 ± 25 °C; salinity values of 20 to 25 eq. wt%NaCl) in the western part of the WCSB into the eastern carbonate sequences and formed saddle dolomite as well as Pb-Zn deposits.

The timing of SD precipitation can be constrained using petrographic, geochemical and fluid inclusion data. Petrographic evidence, such as formation of saddle dolomite that occludes fractures and predates stylolitization (indicative of deeper burial setting), support an earlier shallow burial origin of saddle dolomite. Geochemistry and microthermometry also support an early (relatively shallow burial) setting. The Devonian formations are characterized by enriched $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios (0.708627 to 0.71599) and high salinities (7.7 to 26.7wt% NaCl), which are consistent with the pre-Laramide salinities range as suggested by Nesbitt and Muehlenbachs (1994). The burial history curves for many Devonian carbonates suggest a shallow to intermediate burial for the formation of saddle dolomite (60 to 80 °C; Packard et al. 1990; Packard et al., Al-Aasm 2001; Al-Aasm 2003; Wendte et al. 2009). Therefore it is reasonable to postulate that, SD precipitation occurred as a result of hydrothermal fluid flow along faults and fractures most likely associated with deformation during the Antler Orogeny (late Devonian and early Mississippian). Only Jedney would appear to be the exception, based on the petrographic and geochemical evidence.

Extensive thrust faulting and folding resulted from the tectonic contraction of WCSB that occurred during the Laramide Orogeny (Symons et al., 1999). Conduits for hydrothermal fluids were provided through the fractures and brecciation within rocks during this deformational event. In the Upper Debolt formation (Mississippian) of the Sikanni Field, coarse crystalline dolomite (CCD) replaced the limestone during this time followed by precipitation of saddle dolomite (SD) in open fractures (White and Al-Aasm 1997). $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ isotopic values combined with the $^{87}\text{Sr}/^{86}\text{Sr}$ values for the Mississippian SD (Table 2) do not match the expected Mississippian carbonate or seawater values (Banner and Hanson 1990; Hurley and Lohmann 1989, Fig.10), indicating that saddle dolomite precipitation formed from fluids, well removed from marine parentage. The hot, saline brines, possible hydrothermal (e.g. Lewchuck et al. 2000; Lonnee and Al-Aasm 2000), were likely associated with the Laramide Orogeny. Nesbitt and Muehlenbachs (1994) have suggested that fluids associated with the Laramide Orogeny are of a mixed brine and meteoric water origin, characterized by a salinity range of 0- 10 wt. % NaCl. The Mississippian formations were characterized by an average salinity of 9.6 wt. % NaCl, consistent with these postulated Laramide-driven fluids. Thus in contrast to the Devonian, SD and late calcite in the studied Mississippian fields may have been precipitated from a much later hydrothermal pulse, likely synchronous with the Columbian or slightly younger Laramide deformations.

In Summary, $\delta^{18}\text{O}$ isotopic values combined with $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios and fluid inclusion data show some spatial variability existed within the Mississippian and Devonian fields whereby more depleted $\delta^{18}\text{O}$ values, higher salinity and higher

temperature are observed in saddle dolomite from the Devonian carbonates in the NE part of the basin compared to Mississippian dolostones in the NW part.

8. Conclusions

Core examinations, petrographic, geochemical (C-, O- and Sr-isotopes), and fluid-inclusion micro-thermometric studies of calcite and dolomite cements of the Devonian and Mississippian carbonates in Alberta and BC, lead to the following:

- 1) Petrographic evidence from the Devonian and Mississippian Formations, for saddle dolomite cements that occlude fractures and predate stylolitization, is indicative of diagenetic environments ranging from shallow to intermediate burial depths.
- 2) The negative $\delta^{18}\text{O}$ isotopic values combined with enriched $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios, high homogenization temperatures, and high to moderate salinities for the Devonian and Mississippian SD cements necessitate the presence of a hydrothermal fluid source
- 3) Isotopic evidence indicates that the Devonian SD show statistically significant differences from the Mississippian saddle dolomite, which is characterized by less depleted $\delta^{18}\text{O}$ isotopic values and less radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios. This suggests that possibly two different hydrothermal fluids were responsible, with focussed fluid flow pulses related to Antler deformation (early Mississippian) for the Devonian-hosted cements, and Laramide deformation for the saddle dolomites precipitated within the Mississippian strata.

- 4) Hydrothermal fluids were largely transmitted through faults and fracture conduits; with flow concentrated during periods of acute seismicity and deformation (peak tectonism), and/or periods of elevated local heat flow (crustal thinning and intrusive activity also associated with peak tectonism).
- 5) The Jedney Field appears to be an anomaly in this overall picture in term of lower salinity values in fluid inclusion in saddle dolomite. This can be related to local dilution of highly saline brines by fluids of less salinity, such as from meteoric water.
- 6) The effect of compartmentalization of hydrothermal fluids in Western Canada Sedimentary Basin is apparent through the geochemical and fluid inclusion data, which shows that spatial variability exists within the Mississippian and Devonian fields whereby more depleted $\delta^{18}\text{O}$ values, higher salinity and higher temperature are observed in saddle dolomite from the Devonian carbonates in the NE part of the basin compared to Mississippian dolostones in the NW part. Later fracture- and vug-rimming blocky calcite cement records comparable or slightly depleted oxygen and Sr isotopes and much lower salinity values for samples mostly from the Mississippian age group.

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Table 1

Fields	Location	Formation	Age	Latitude	Longitude
Rainbow South¹	NW Alberta	Sulphur Point	Middle Devonian	58.21	-119.92
Parkland²	NE British Columbia	Wabamun	Upper Devonian	56.00	-122.00
July Lake Area³	NE British Columbia	RedKnife	Upper Devonian	59.70	-120.50
Manir⁴	West Central Alberta	Wabamun	Upper Devonian	55.25	-118.40
Tepee⁵	West Central Alberta	Wabamun	Upper Devonian	55.40	-118.40
Tangent⁶	West Central Alberta	Wabamun	Upper Devonian	56.05	-117.60
Gold Creek⁷	West Central Alberta	Wabamun	Upper Devonian	54.90	-118.50
Shell Waterton Gas Field⁸	South Western Alberta	Mount Head	Mississippian	49.30	-113.90
Hamburg⁹	NW Alberta	Slave Point	Middle Devonian	57.42	-119.75
Sikanni¹⁰	NE British Columbia	Upper Debolt	Mississippian	57.60	-121.76
Jedney¹¹	NE British Columbia	Slave Point	Middle Devonian	57.27	-122.44
Duvernay¹²	Central Alberta	Duvernay	Upper Devonian	52.85	-116.60
Quirk Creek¹³	Alberta	Turner Valley	Mississippian	50.75	-114.36
Pekisko¹⁴	West Central Alberta	Pekisko	Mississippian	52.80	-118.00

¹ Lonnee & Al-Aasm, 2000² Packard et al., 2001³ Wendte et al., 2009⁴ Packard and Al-Aasm (Unpublished data)⁵ Packard and Al-Aasm (Unpublished data)⁶ Packard et al, 1990⁷ Rivas, 2004⁸ Lewchuk et al., 1998⁹ Al-Aasm and Clarke, 2004¹⁰ White, 1995¹¹ Al-Aasm, 1996¹² Adam, 2000¹³ Lu, 1993¹⁴ Adam & Al-Aasm, 2017

Table 2.

Field/ Formation	Sample ID	Lithology	$\delta^{18}\text{O}$ (VPDB)	$\delta^{13}\text{C}$(VPDB)	$^{87}\text{Sr}/^{86}\text{Sr}$
Rainbow South Sulphur Point	105A-SD	saddle dolomite cement	-12.86	-0.54	0.70857
	112B-SD	saddle dolomite cement	-11.95	-0.20	
	114E-SD	saddle dolomite cement	-12.53	-0.63	
	200A-SD	saddle dolomite cement	-13.68	-1.44	
	210A-SD	saddle dolomite cement	-11.05	-0.74	
	213A-SD1	saddle dolomite cement	-11.45	-1.06	
	213A-SD2	saddle dolomite cement	-11.31	-0.28	
	213B-SD	saddle dolomite cement	-11.34	-0.42	
	214A-SD1	saddle dolomite cement	-12.52	-0.26	0.70896
	214A-SD2	saddle dolomite cement	-12.39	-0.42	0.71013
	216A-SD	saddle dolomite cement	-11.44	-0.54	
	217A-SD	saddle dolomite cement	-12.92	-1.43	
	218A-SD	saddle dolomite cement	-11.19	-0.46	
	221A-SD	saddle dolomite cement	-11.94	-0.39	
	225A-SD	saddle dolomite cement	-12.46	-0.27	
	228A-SD	saddle dolomite cement	-12.54	0.05	
	230C-SD	saddle dolomite cement	-13.25	-0.20	
	402B-SD	saddle dolomite cement	-11.74	0.18	
	403A-SD1	saddle dolomite cement	-12.48	-0.09	0.70839
	403A-SD2	saddle dolomite cement	-12.66	-1.07	
	112B-rsd	replacive saddle dolomite	-12.10	-0.31	
	213A-rsd	replacive saddle dolomite	-11.78	-1.20	
	214A-rsd	replacive saddle dolomite	-11.33	-0.59	0.70924
	218A-rsd	replacive saddle dolomite	-11.12	-0.29	
	228A-rsd	replacive saddle dolomite	-12.66	-0.29	
	402B-rsd	replacive saddle dolomite	-10.71	-0.10	
	403A-rsd	replacive saddle dolomite	-11.01	-0.14	0.71024
	228A-flid	fracture lining dolomite	-12.34	-4.96	
	300A-flid	fracture lining dolomite	-14.20	-5.74	
	310A-flid	fracture lining dolomite	-13.19	-5.23	
	311A-flid	fracture lining dolomite	-13.82	-5.89	
	228A-bc	blocky calcite cement	-12.58	-4.60	0.71075
	228a-bc	blocky calcite cement	-12.96	-4.98	
	311A-bc	blocky calcite cement	-13.78	-5.37	
July Lake	1	saddle dolomite cement	-8.55	1.54	0.709882

RedKnife	2	saddle dolomite cement	-12.23	0.45	0.70985
	3	saddle dolomite cement	-10.73	1.60	0.708585
	4	saddle dolomite cement	-11.90	1.83	0.710253
	5	saddle dolomite cement	-9.72	2.70	0.708684
	6	saddle dolomite cement	-11.93	0.06	0.710046
	7	saddle dolomite cement	-12.40	0.40	
	8	saddle dolomite cement	-11.18	0.90	0.708776
	9	saddle dolomite cement	-11.71	0.62	0.712274
	10	saddle dolomite cement	-10.80	1.15	0.708643
	11	saddle dolomite cement	-11.71	0.94	0.708977
	12	saddle dolomite cement	-10.69	1.86	0.70987
	13	saddle dolomite cement	-12.07	0.32	0.709688
	14	saddle dolomite cement	-9.93	2.66	0.709085
	15	saddle dolomite cement	-11.01	2.13	0.709782
	16	saddle dolomite cement	-11.18	1.54	
	17	saddle dolomite cement	-11.77	1.04	0.709237
	18	saddle dolomite cement	-10.13	2.48	0.710493
	19	saddle dolomite cement	-12.83	0.87	0.709744
	20	saddle dolomite cement	-12.04	0.85	0.708908
Sikanni-Upper Debolt	a89I-94P10	equant calcite cement	-12.43	0.71	0.708813
	c32e-94p16	equant calcite cement	-12.69	1.47	0.710322
	c34a94p15	equant calcite cement	-11.67	3.03	0.713007
	d37i94p10	equant calcite cement	-15.16	-0.16	0.712492
	s1	saddle dolomite cement	-8.6	2.78	
	s2	saddle dolomite cement	-9.62	2.73	0.708727
	s3	saddle dolomite cement	-9.47	2.08	
	s4	saddle dolomite cement	-10.15	2.53	
	s5	saddle dolomite cement	-8.47	3.43	
	s6	saddle dolomite cement	-9.5	3	
	s7	saddle dolomite cement	-8.83	2.36	0.708788
	s8	saddle dolomite cement	-8.44	2.72	
	s9	saddle dolomite cement	-8.6	2.83	
	s10	saddle dolomite cement	-8.55	2.53	0.70862
	s11	saddle dolomite cement	-9.34	2.51	
	s12	saddle dolomite cement	-9.27	3.3	0.708591
	s13	saddle dolomite cement	-8.3	1.13	
	s14	saddle dolomite cement	-8.38	2.71	
	s15	saddle dolomite cement	-9.85	1.38	
	s16	saddle dolomite cement	-9.52	2.5	0.709025
	s17	saddle dolomite cement	-8.72	3.75	
	s18	saddle dolomite cement	-9.28	1.81	
	s19	saddle dolomite cement	-9.71	2.24	
	s20	saddle dolomite cement	-9.31	2.79	

Hamburg-Slave Point	s21	saddle dolomite cement	-8.14	2.91	0.709435
	32-1-SD	saddle dolomite cement	-9.81	1.8	
	32-1-SD	saddle dolomite cement	-10.8	1.9	
	32-2-SD	saddle dolomite cement	-8.71	2.44	
	32-2-SD	saddle dolomite cement	-8.78	2.53	
	32-10-SD	saddle dolomite cement	-9.85	1.67	
	32-10-SD	saddle dolomite cement	-9.47	2.08	
	32-6-SD	saddle dolomite cement	-9.42	2.56	
	32-6-SD	saddle dolomite cement	-9.62	2.73	0.708727
	32-5-SD	saddle dolomite cement	-9.4	2.32	
	32-3-SD	saddle dolomite cement	-8.8	2.49	
	32-3-SD	saddle dolomite cement	-8.95	2.6	
	32-9-SD	saddle dolomite cement	-9.07	2.62	
	32-9-SD	saddle dolomite cement	-9.47	1.54	
	14-3-SD	saddle dolomite cement	-8.17	1.48	
	46-19-SD	saddle dolomite cement	-7.95	3	
	46-19-SD	saddle dolomite cement	-8.88	2.8	
	46-20-SD	saddle dolomite cement	-7.82	3.07	0.709108
	46-20-SD	saddle dolomite cement	-8.27	3.05	
	46-22-LC	late fracture filling calcite	-11.99	0.58	
	14-2-LC	late fracture filling calcite	-8.5	2.04	0.709743
	14-4-LC	late fracture filling calcite	-10.01	1.05	
	14-5-LC	late fracture filling calcite	-12.6	1.23	
	14-9-LC	late fracture filling calcite	-9.19	1.79	
	03-33-SD	saddle dolomite cement	-13.78	2.26	
	06-07-SD	saddle dolomite cement	-12.71	2	
	06-20-SD	saddle dolomite cement	-11.97	2.26	
	6-20-SD	saddle dolomite cement	-12.61	2.2	0.710351
	6-20-SD	saddle dolomite cement	-12.98	2.11	
	16-25-SD	saddle dolomite cement	-12.74	2.17	
	16-25-SD	saddle dolomite cement	-13.95	2.05	
	12-08-SD	saddle dolomite cement	-12.18	2.06	
	13-35-SD	saddle dolomite cement	-12.71	3.02	
	15-12-SD	saddle dolomite cement	-12.86	2.26	0.708626
	15-12-SD	saddle dolomite cement	-13.16	1.19	
	10-10-SD	saddle dolomite cement	-12.57	2.18	
	10-10-SD	saddle dolomite cement	-12.61	2.14	
	10-10 0204	saddle dolomite cement	-12.1	2.2	0.709194
	03-06-SD	saddle dolomite cement	-13.93	1.35	
	06-07 SP	pore filling equant calcite spar cement	-6.92	1.76	

	10-19 SP	pore filling equant calcite spar cement	-7.13	2	0.708166
	12-26- SP	pore filling equant calcite spar cement	-8.76	-0.7	
	13-35SP	pore filling equant calcite spar cement	-11.3	0.37	
	13-35 SP	pore filling equant calcite spar cement	-10.74	1.57	
	13-35 SP	pore filling equant calcite spar cement	-8.46	2.56	
	15-12 SP	pore filling equant calcite spar cement	-8.32	1.51	0.70963
	6-07 LSB	pore filling blocky euhedral calcite cement	-11.88	1	
	12-08 LSB	pore filling blocky euhedral calcite cement	-14.03	0.58	
	13-35 LSB	pore filling blocky euhedral calcite cement	-12.11	1.02	
	13-35 LSB	pore filling blocky euhedral calcite cement	-13.2	1.03	
	13-35 LSB	pore filling blocky euhedral calcite cement	-14.8	1.53	
	15-12 LSB	pore filling blocky euhedral calcite cement	-14.59	0.96	
	15-12 LSB	pore filling blocky euhedral calcite cement	-11.67	1.36	
	15-12 LSB	pore filling blocky euhedral calcite cement	-12.48	1.28	
	16-25 LSB	pore filling blocky euhedral calcite cement	-12.04	1.08	
	16-25 LSB	pore filling blocky euhedral calcite cement	-11.84	1.53	
	16-25 LSB	pore filling blocky euhedral calcite cement	-13.03	1.25	0.71346
Jedney- Slave Point	1	saddle dolomite cement	-12.99	0.93	
	2	saddle dolomite cement	-13.97	-0.36	
	3	saddle dolomite cement	-14.08	-0.23	
	4	saddle dolomite cement	-13.31	0.81	0.71348
	5	saddle dolomite cement	-13.17	0.81	
	6	saddle dolomite cement	-14.62	-0.12	
	J10	saddle dolomite cement	-13.16	0.62	
	J4	saddle dolomite cement	-13.68	0.67	
	J6	saddle dolomite cement	-13.42	0.7	

Duvernay	D1	saddle dolomite cement	-11.78	-2.08	0.708102
	D5	saddle dolomite cement	-6.26	1.75	
	D9	saddle dolomite cement	-6.55	2.49	
	D3	saddle dolomite cement	-9.01	1.64	
	DU6-4-1	saddle dolomite cement	-5.58	3.16	
	D1	fracture filling calcite cement	-11.4	-1.89	
	D6	fracture filling calcite cement	-7.42	-0.11	
	D9	fracture filling calcite cement	-5.52	2.37	
	D2	pore filling blocky calcite cement	-9.93	-2.17	
	D5	pore filling blocky calcite cement	-7.19	1.32	
	D8	pore filling blocky calcite cement	-7.73	0.58	
	DU3-1-1	pore filling blocky calcite cement	-5.58	0.7	
	DU4-28-4	pore filling blocky calcite cement	-10.63	-1.03	
Gold Creek Wabamun	G1	saddle dolomite cement	-7.73	0.73	0.71013
	G2	saddle dolomite cement	-7.76	-0.82	
	G3	saddle dolomite cement	-5.13	0.16	
	G4	saddle dolomite cement	-3.84	0.41	
	G5	saddle dolomite cement	-5.58	0.60	
	G6	saddle dolomite cement	-3.75	0.09	
	G7	saddle dolomite cement	-7.74	0.60	
	G8	saddle dolomite cement	-9.28	-0.37	
	G9	saddle dolomite cement	-9.99	-0.43	
	G10	blocky calcite cement	-9.57	-0.74	
	G11	blocky calcite cement	-8.03	-1.84	
	G12	blocky calcite cement	-11.61	-1.51	
	G13	blocky calcite cement	-12.03	-2.77	
	G14	blocky calcite cement	-10.33	-6.47	
	G15	blocky calcite cement	-10.40	-2.16	
	G16	blocky calcite cement	-5.98	-0.36	
	G17	blocky calcite cement	-8.54	-1.83	
Parkland Wabamun	13A	saddle dolomite cement	-12.57	-0.03	0.711
	11A	saddle dolomite cement	-10.29	0.99	
	11B	saddle dolomite cement	-10.76	0.62	
	10C	saddle dolomite cement	-10.98	0.85	
	16C	saddle dolomite cement	-11.08	1.23	
	13B	saddle dolomite cement	-9.01	0.72	
	15B	saddle dolomite cement	-10.79	0.73	

	8A	saddle dolomite cement	-11.37	0.7	
	15A	saddle dolomite cement	-11.11	1.11	
	10B	saddle dolomite cement	-11.77	1.45	
	7A	saddle dolomite cement	-11.28	0.31	
	4B	saddle dolomite cement	-10.56	0.61	0.71275
	7A	saddle dolomite cement	-9.3	0.52	0.71599
Tepee- Wabamun	1	saddle dolomite cement	-7.54	0.29	
	5	saddle dolomite cement	-12.32	-0.59	
Manir- Wabamun	7	saddle dolomite cement	-7.79	-1.28	
	9	saddle dolomite cement	-9.78	-3.03	
Tangent Wabamun	10-23-80- 24W5	saddle dolomite cement	-6.6	0.1	0.709
	10-23-80- 24W5	saddle dolomite cement	-6.35	0.1	0.70827
	10-23-80- 24W5	saddle dolomite cement	-6.97	0	0.71046
	4-21-80- 24W5	saddle dolomite cement	-7.2	0	0.7112
Pekisko	4.19.7.1.c	saddle dolomite cement	-12.53	-0.55	
	1.2.3.1.c	blocky calcite cement	-7.29	-0.02	
	2.2.3.1.a	blocky calcite cement	-10.4	9.36	
	2.2.5.1.a	blocky calcite cement	-10.9	3.64	
	2.2.5.2.a	blocky calcite cement	-10.77	8.37	0.708789
	2.2.6.1.a	blocky calcite cement	-13.45	-3.56	
	2.2.7.1.b	blocky calcite cement	-10.5	9.36	
	2.2.7.1.c	blocky calcite cement	-13.92	-2.37	
	3.1.1.1.a	blocky calcite cement	-4.79	-4.32	
	3.1.2.2.b	blocky calcite cement	-4.82	0.8	
	3.2.9.1.b	blocky calcite cement	-4.32	1.93	
	4.19.5.1.b	blocky calcite cement	-6.88	2.29	
	5.5.3.1.b	blocky calcite cement	-5.71	0.46	
	5.5.3.1.c	blocky calcite cement	-10.65	-0.83	
	5.6.4.1.a	blocky calcite cement	-5.68	1.36	
	5.6.4.1.b	blocky calcite cement	-7.36	-0.23	
	5.6.4.1.c	blocky calcite cement	-15.9	0.16	
	5.6.6.2.b	blocky calcite cement	-14.24	-0.11	
	5.6.9.1.b	blocky calcite cement	-10.62	1.92	
	6.1.1.1.a	blocky calcite cement	-5	-0.4	
	6.1.1.1.b	blocky calcite cement	-13.88	-1.58	
	6.1.2.1.b	blocky calcite cement	-13.74	-0.38	
	6.2.8.1.a	blocky calcite cement	-9.77	-0.98	
	6.2.11.1.a	blocky calcite cement	-4.15	2.04	
	6.2.15.1.b	blocky calcite cement	-15.89	0.3	
	6.3.17.1.a	blocky calcite cement	-15.49	0.39	

Quirk Creek Turner Valley	7.1.1.1.a	blocky calcite cement	-4.08	1.61
	8.2.7.2.c	blocky calcite cement	-16.31	1.51
	9.9.1.1.Bd	blocky calcite cement	-10.82	1.61
	9.9.7.1.b	blocky calcite cement	-4.34	-0.29
	9.9.9.1.b	blocky calcite cement	-4.19	-4.74
	6-7-772	megadolomite	-6.33	2.73
	12.22.16	megadolomite	-6.47	2.19
	14.12.28	megadolomite	-4.55	2.41
	14.12.22	megadolomite	-2.12	2.25
	14.12.17	megadolomite	-3.55	2.02
	14.12.13	megadolomite	-6.28	2.19
	14.12.1	megadolomite	-3.3	2.5
	12.22.16	megadolomite	-5.81	2.53
	14.12.28	megadolomite	-4.33	2.97
	14.12.17	megadolomite	-3.47	2.32
	14.12.15	megadolomite	-5.24	3.02
	14.12.1	megadolomite	-2.44	2.01
	Q2.SD	saddle dolomite cement	-9.01	-1.99
	14-12-18QC	pore filling blocky calcite cement	-9.96	-7.24
	91-100(QC)	fracture fillling calcite cement	-9.82	-3.44
	Q4	pore filling blocky calcite cement	-13.71	-4.07
	6-7-101	pore filling equant calcite spar cement	-12.48	-5.82
	6-7-100	pore filling equant calcite spar cement	-12.04	-6.46
	14-12-9	pore filling equant calcite spar cement	-12.18	-9.05
	14-12-18	pore filling equant calcite spar cement	-11.24	-9.5
	14-12-4	pore filling equant calcite spar cement	-9.33	-9.67
	.12-22-30	pore filling bladed prismatic calcite	-5.56	-0.31
	.12-22-12	pore filling bladed prismatic calcite	-6.2	-8.4
	6-7-770	pore filling blocky calcite cement	-7.19	-3.2
	.6-7-97	pore filling blocky calcite cement	-7.65	-2.07

	.12-22-20	pore filling coarse mosaic calcite spar	-11.67	-2.82	
	14-12-23	pore filling coarse mosaic calcite spar	-10.44	-9.44	
	14-12-13	pore filling coarse mosaic calcite spar	-9.31	-9.29	
	14-12-12	pore filling coarse mosaic calcite spar	-12.33	-12.69	
	14-12-23	pore filling coarse mosaic calcite spar	-10.44	-9.44	
Shell Waterton Mount Head	SW1	Calcite 2	-7.67	-3.24	0.70784
	SW2	Calcite 2	-7.54	-4.53	
	SW3	Calcite 2	-10.79	-11.21	
	SW4	Calcite 2	-10.61	-9.35	0.70838
	SW5	Calcite 2	-7.94	-5.28	
	SW6	Calcite 2	-11.96	-19.22	

Draft

Table 3.

Field/Formation	Sample ID	Lithology	Th(pressure corrected) (°C)	Salinity wt.%NaCl
July Lake RedKnife	C92	saddle dolomite cement	115	14.7
		saddle dolomite cement	108	14.7
		saddle dolomite cement	118	15.3
		saddle dolomite cement	99	16.8
		saddle dolomite cement	129	23.5
		saddle dolomite cement	103	13.8
		saddle dolomite cement	103	21.1
		saddle dolomite cement	99	24.8
		saddle dolomite cement	133	24.3
	C92	saddle dolomite cement	111	11.2
		saddle dolomite cement	149	10.6
		saddle dolomite cement	136	22.4
		saddle dolomite cement	132	16.1
		saddle dolomite cement	106	14.8
		saddle dolomite cement	125	13.6
		saddle dolomite cement	80	14.2
		saddle dolomite cement	110	14.5
		saddle dolomite cement	110	14.5
		saddle dolomite cement	100	14.8
		saddle dolomite cement	121	13.3
		saddle dolomite cement	133	14.6
	a21	saddle dolomite cement	-	14.8
		saddle dolomite cement	117	15.1
		saddle dolomite cement	136	15
		saddle dolomite cement	140	18
		saddle dolomite cement	121	14.9
		saddle dolomite cement	114	12.4
		saddle dolomite cement	115	14
		saddle dolomite cement	112	21.9
		saddle dolomite cement	132	16.5
		saddle dolomite cement	124	16.6
		saddle dolomite cement	93	17.8
		saddle dolomite cement	96	24.1
		saddle dolomite cement	102	12.6
		saddle dolomite cement	112	24.9

c34	saddle dolomite cement	100	22.5
	saddle dolomite cement	124	12.2
	saddle dolomite cement	108	11.5
	saddle dolomite cement	127	18.2
	saddle dolomite cement	127	16.5
	saddle dolomite cement	90	18.9
	saddle dolomite cement	115	12.2
	saddle dolomite cement	137	12.4
	saddle dolomite cement	81	14.4
	saddle dolomite cement	113	14.5
	saddle dolomite cement	122	16.4
	saddle dolomite cement	85	14
	saddle dolomite cement	90	13.7
	saddle dolomite cement	101	15.3
	saddle dolomite cement	104	15
	saddle dolomite cement	100	18.4
	saddle dolomite cement	115	15.5
	saddle dolomite cement	105	24.9
	saddle dolomite cement	102	23.9
	saddle dolomite cement	106	15.5
c34	saddle dolomite cement	103	13.2
	saddle dolomite cement	99	23.4
	saddle dolomite cement	153	10.6
	saddle dolomite cement	111	-
	saddle dolomite cement	106	-
	saddle dolomite cement	105	10.4
	saddle dolomite cement	126	9.7
	saddle dolomite cement	127	12.7
	saddle dolomite cement	122	13.4
	saddle dolomite cement	140	12.7
	saddle dolomite cement	136	14.2
	saddle dolomite cement	131	13.8
B68	saddle dolomite cement	122	13.7
	saddle dolomite cement	117	14
	saddle dolomite cement	139	10.4
	saddle dolomite cement	135	15.2
	saddle dolomite cement	95	14.4
	saddle dolomite cement	142	17.5
	saddle dolomite cement	103	17.8
	saddle dolomite cement	107	18.9
	saddle dolomite cement	101	23.1
	saddle dolomite cement	140	11.1
	saddle dolomite cement	143	11.5

C32	saddle dolomite cement	109	18.2
	saddle dolomite cement	127	15.5
	saddle dolomite cement	113	15.7
	saddle dolomite cement	132	-
	saddle dolomite cement	90	-
	saddle dolomite cement	93	-
	saddle dolomite cement	82	-
	saddle dolomite cement	80	-
	saddle dolomite cement	103	-
	saddle dolomite cement	85	-
	saddle dolomite cement	112	-
	saddle dolomite cement	105	-
	saddle dolomite cement	101	-
	saddle dolomite cement	106	-
	saddle dolomite cement	93	-
	saddle dolomite cement	95	-
	saddle dolomite cement	98	-
	saddle dolomite cement	112	-
	saddle dolomite cement	121	12.5
	saddle dolomite cement	110	12.4
	saddle dolomite cement	118	-
	saddle dolomite cement	122	14.9
	saddle dolomite cement	117	-
	saddle dolomite cement	119	15.5
	saddle dolomite cement	127	-
C32	saddle dolomite cement	141	15.7
	saddle dolomite cement	114	15.1
	saddle dolomite cement	83	-
	saddle dolomite cement	85	-
	saddle dolomite cement	83	-
	saddle dolomite cement	88	-
	saddle dolomite cement	119	14.5
	saddle dolomite cement	117	14.3
	saddle dolomite cement	95	-
	saddle dolomite cement	97	-
	saddle dolomite cement	100	-
	saddle dolomite cement	96	-
	saddle dolomite cement	98	16
	saddle dolomite cement	141	11.7
	saddle dolomite cement	108	14.6
	saddle dolomite cement	151	12.4
	saddle dolomite cement	128	-
	saddle dolomite cement	102	23.5

C32	saddle dolomite cement	106	13.6
	saddle dolomite cement	122	24.2
	saddle dolomite cement	100	14.7
	saddle dolomite cement	74	-
	saddle dolomite cement	88	-
	saddle dolomite cement	109	13.7
	saddle dolomite cement	107	20.7
	saddle dolomite cement	99	20.8
	saddle dolomite cement	90	24
	saddle dolomite cement	105	18.6
	saddle dolomite cement	105	12.2
	saddle dolomite cement	105	12.4
	saddle dolomite cement	124	9.7
	saddle dolomite cement	105	-
	saddle dolomite cement	107	15.8
D37	saddle dolomite cement	92	-
	saddle dolomite cement	147	-
	saddle dolomite cement	138	17.3
	saddle dolomite cement	145	14.2
	saddle dolomite cement	138	13.7
	saddle dolomite cement	140	14
	saddle dolomite cement	137	14.6
	saddle dolomite cement	115	13.8
	saddle dolomite cement	135	14.5
	saddle dolomite cement	120	22.9
A41	saddle dolomite cement	132	24.4
	saddle dolomite cement	107	12.1
	saddle dolomite cement	115	-
	saddle dolomite cement	129	21.3
	saddle dolomite cement	143	21.7
	saddle dolomite cement	95	24.5
	saddle dolomite cement	107	24.3
	saddle dolomite cement	109	16.4
	saddle dolomite cement	110	-
	saddle dolomite cement	108	20.2
	saddle dolomite cement	131	10.2
	saddle dolomite cement	135	10.4
	saddle dolomite cement	105	12.6
	saddle dolomite cement	107	12.6
	saddle dolomite cement	110	12.7
	saddle dolomite cement	131	13.2
	saddle dolomite cement	122	23.6
	saddle dolomite cement	115	23.7

A25	saddle dolomite cement	124	19.5
	saddle dolomite cement	137	19.1
	saddle dolomite cement	118	24.5
	saddle dolomite cement	115	18.9
	saddle dolomite cement	134	18.8
	saddle dolomite cement	115	-
	saddle dolomite cement	110	-
	saddle dolomite cement	110	25.6
	saddle dolomite cement	138	12.9
	saddle dolomite cement	117	16.5
	saddle dolomite cement	137	12.3
	saddle dolomite cement	95	12.3
	saddle dolomite cement	127	15.7
	saddle dolomite cement	131	11.5
	saddle dolomite cement	113	11.8
	saddle dolomite cement	127	24.1
	saddle dolomite cement	136	24
	saddle dolomite cement	127	24.4
	saddle dolomite cement	109	12.7
	saddle dolomite cement	114	10.1
	saddle dolomite cement	138	16.2
	saddle dolomite cement	124	9.2
	saddle dolomite cement	105	11.3
	saddle dolomite cement	107	11.5
	saddle dolomite cement	100	19.3
	saddle dolomite cement	97	23.3
B86	saddle dolomite cement	115	-
	saddle dolomite cement	95	-
	saddle dolomite cement	96	-
	saddle dolomite cement	105	-
	saddle dolomite cement	127	-
	saddle dolomite cement	97	-
	saddle dolomite cement	95	-
	saddle dolomite cement	96	-
	saddle dolomite cement	92	-
	saddle dolomite cement	98	-
	saddle dolomite cement	116	-
	saddle dolomite cement	104	-
	saddle dolomite cement	102	-
	saddle dolomite cement	98	-
	saddle dolomite cement	123	15.1
	saddle dolomite cement	127	11.5
	saddle dolomite cement	144	14.4

D38	saddle dolomite cement	100	10
	saddle dolomite cement	112	14.6
	saddle dolomite cement	115	19.8
	saddle dolomite cement	125	-
	saddle dolomite cement	103	11
	saddle dolomite cement	109	11.1
	saddle dolomite cement	126	11.5
	saddle dolomite cement	116	12.8
	saddle dolomite cement	88	12.7
	saddle dolomite cement	113	13.7
	saddle dolomite cement	105	12.7
	saddle dolomite cement	125	12.5
	saddle dolomite cement	139	14.4
	saddle dolomite cement	115	12.2
	saddle dolomite cement	124	12.2
	saddle dolomite cement	102	8.8
	saddle dolomite cement	107	13
	saddle dolomite cement	113	13.3
	saddle dolomite cement	126	13.7
C74	saddle dolomite cement	98	11.9
	saddle dolomite cement	85	-
	saddle dolomite cement	83	13.7
	saddle dolomite cement	87	-
	saddle dolomite cement	122	15.2
	saddle dolomite cement	99	23.5
	saddle dolomite cement	102	23
	saddle dolomite cement	141	22.2
	saddle dolomite cement	122	24.4
	saddle dolomite cement	90	22.9
	saddle dolomite cement	127	22.8
	saddle dolomite cement	110	21.2
	saddle dolomite cement	124	21
	saddle dolomite cement	163	15.7
	saddle dolomite cement	121	24.1
	saddle dolomite cement	117	19.2
A89	saddle dolomite cement	121	21.4
	saddle dolomite cement	117	21.6
	saddle dolomite cement	107	-
	saddle dolomite cement	110	23.4
	saddle dolomite cement	93	24.5
	saddle dolomite cement	128	19.3
	saddle dolomite cement	115	22.6
	saddle dolomite cement	113	25.2

	saddle dolomite cement	119	-
	saddle dolomite cement	106	12.4
	saddle dolomite cement	108	15.3
	saddle dolomite cement	124	26.7
	saddle dolomite cement	120	23.3
	saddle dolomite cement	110	23.9
	saddle dolomite cement	108	23.9
	saddle dolomite cement	111	23.4
	saddle dolomite cement	105	23.3
	saddle dolomite cement	121	19.3
	saddle dolomite cement	143	23.8
	saddle dolomite cement	127	12.4
B50	saddle dolomite cement	117	14.4
	saddle dolomite cement	125	25.4
	saddle dolomite cement	121	23.3
B50	saddle dolomite cement	99	15.3
	saddle dolomite cement	119	11.5
	saddle dolomite cement	114	11.3
	saddle dolomite cement	123	10.7
	saddle dolomite cement	101	-
	saddle dolomite cement	127	15.5
	saddle dolomite cement	153	11
	saddle dolomite cement	153	15.8
	saddle dolomite cement	149	14.7
	saddle dolomite cement	143	14.6
	saddle dolomite cement	127	13.3
c34a-94p15	equant calcite cement	all liquid	9.9
c34a-94p15	equant calcite cement	61	-
c34a-94p15	equant calcite cement	74	11.2
c34a-94p15	equant calcite cement	118	9.8
c34a-94p15	equant calcite cement	105	9.8
b68d-94p16	equant calcite cement	110	10.2
b68d-94p16	equant calcite cement	105	17.8
b68d-94p16	equant calcite cement	118	13.1
b68d-94p16	equant calcite cement	104	22.1

b68d-94p16	equant calcite cement	109	19.8
b68d-94p16	equant calcite cement	98	22
b68d-94p16	equant calcite cement	115	11.8
b68d-94p16	equant calcite cement	96	11.1
b68d-94p16	equant calcite cement	103	14
b68d-94p16	equant calcite cement	109	22.9
b68d-94p16	equant calcite cement	116	13.4
d37i-94p10	equant calcite cement	136	11.4
d37i-94p10	equant calcite cement	132	12.3
d37i-94p10	equant calcite cement	115	12.4
d37i-94p10	equant calcite cement	110	12.4
d37i-94p10	equant calcite cement	119	12.5
d37i-94p10	equant calcite cement	130	12.4
d37i-94p10	equant calcite cement	129	12.4
d37i-94p10	equant calcite cement	102	12.1
d37i-94p10	equant calcite cement	126	11.9
d37i-94p10	equant calcite cement	128	12.3
d37i-94p10	equant calcite cement	119	12.5
d37i-94p10	equant calcite cement	125	25.7
d37i-94p10	equant calcite cement	123	25.8
d37i-94p10	equant calcite cement	118	-
d37i-94p10	equant calcite cement	119	15
d37i-94p10	equant calcite cement	107	11.7
a89i-94p10	equant calcite cement	103	11.5

Sikanni-Upper Debolt	a89i-94p10	equant calcite cement	101	-
	a89i-94p10	equant calcite cement	104	11.6
	a89i-94p10	equant calcite cement	96	10.7
	a89i-94p10	equant calcite cement	131	10.1
	a89i-94p10	equant calcite cement	103	10.1
	a89i-94p10	equant calcite cement	110	10.2
	a89i-94p10	equant calcite cement	96	10.1
	a89i-94p10	equant calcite cement	89	10.1
	a89i-94p10	equant calcite cement	85	10
	a89i-94p10	equant calcite cement	107	11.1
	a89i-94p10	equant calcite cement	101	11.1
	a89i-94p10	equant calcite cement	106	10.6
	s1	saddle dolomite cement	137.1	12
	s2	saddle dolomite cement	173.7	
	s3	saddle dolomite cement	156.9	8
	s4	saddle dolomite cement	115.3	8
	s5	saddle dolomite cement	115.3	8
	s6	saddle dolomite cement	107.4	
	32-8-SD1	saddle dolomite cement	214.25	---
	32-8-SD2	saddle dolomite cement	114.39	10.5
		saddle dolomite cement	131.19	10.5
	46-2-SD1	saddle dolomite cement	87.69	6
		saddle dolomite cement	91.65	2
		saddle dolomite cement	137.13	7
	14-9-LC1	late fracture filling calcite	117.35	0
		late fracture filling calcite	145.04	0
	14-9-LC2	late fracture filling calcite	153.94	0
		late fracture filling calcite	166.79	--
		late fracture filling calcite	130.21	0
	14-2-LC1	late fracture filling calcite	145.04	0
		late fracture filling calcite	147.01	0
		late fracture filling calcite	145.04	-
	14-2-LC2	late fracture filling calcite	196.45	0

Hamburg-Slave Point		late fracture filling calcite	-----	0
		late fracture filling calcite	-----	0
		late fracture filling calcite	-----	0
	14-2-LC3	late fracture filling calcite	132.18	0
	06-20-01SD	saddle dolomite cement	125	22.2
	06-20-02SD	saddle dolomite cement	136	24.5
	06-20-03SD	saddle dolomite cement	142	24.1
	06-20-04SD	saddle dolomite cement	146	22.3
	06-20-05SD	saddle dolomite cement	151	24.7
	06-20-06SD	saddle dolomite cement	161	22.9
	13-35-01SD	saddle dolomite cement	127	22.3
	13-35-02SD	saddle dolomite cement	134	23.2
	13-35-03SD	saddle dolomite cement	135	23.6
	12-26-01SD	saddle dolomite cement	158	22.8
	12-26-02SD	saddle dolomite cement	147	24
	12-26-03SD	saddle dolomite cement	149	24.6
	12-26.	blocky euhrdal calcite cement	96	23.7
	12-26.	blocky euhrdal calcite cement	102	23.4
	12-26.	blocky euhrdal calcite cement	120	23.4
	12-26.	blocky euhrdal calcite cement	127	24
	13-35	blocky euhrdal calcite cement	107	24.6
	13-35	blocky euhrdal calcite cement	114	23.6
Jedney- Slave Point	SD 1	saddle dolomite	183.43	11.81
	SD 2	saddle dolomite	186.28	10.16
	SD 3	saddle dolomite	173.8	11.58
	SD 4	saddle dolomite	191.78	9.66
	SD 5	saddle dolomite	179.99	11.24
	SD 6	saddle dolomite	170.95	11.35

Quirk Creek Turner Valley	SD 7	saddle dolomite	162.5	10.77
	SD 8	saddle dolomite	162.99	11.24
	SD 9	saddle dolomite	189.72	10.16
	SD 10	saddle dolomite	184.12	11.35
	SD 11	saddle dolomite	185.59	9.28
	Q2-SD	saddle dolomite	121.5	12.1
	Q2-SD	saddle dolomite	200	12.1
	Q2-SD	saddle dolomite	171	12.1
	Q2-SD	saddle dolomite	110	-----
	Q2-SD	saddle dolomite	150	10.5
	Q2-SD	saddle dolomite	130	10.9
Duvernay	Q2-SD	saddle dolomite	130	11.1
	Q2-SD	saddle dolomite	132	13.2
	Q4-Ca	pore filling blocky calcite cement	138	22.5
	Q4-Ca	pore filling blocky calcite cement	132.5	10.5
	Q4-Ca	pore filling blocky calcite cement	136.5	7
	D5-SD	saddle dolomite	136.5	20.6
	D5-SD	saddle dolomite	141	23.2
	D1-Ca	fracture filling calcite cement	113	20.6
	D1-Ca	fracture filling calcite cement	102	19.8
Rainbow South Sulphur Point	200B-sd	saddle dolomite cement	190	12.5
	200B-sd	saddle dolomite cement	194.6	13.3
	200B-sd	saddle dolomite cement	184.9	11.7
	200B-sd	saddle dolomite cement	193.9	12.1
	200B-sd	saddle dolomite cement	181.8	12.1
	210A-sd	saddle dolomite cement	145.7	11.1
	210A-sd	saddle dolomite cement	142.3	10.9
	210A-sd	saddle dolomite cement	143.4	10.5
	210A-sd	saddle dolomite cement	156.9	10.7
	221A-sd	saddle dolomite cement	158.7	11.7
	221A-sd	saddle dolomite cement	157.1	11
	221A-sd	saddle dolomite cement	159.9	11.6
	228A-sd	saddle dolomite cement	173.4	11.7
	228A-sd	saddle dolomite cement	180.9	13.3
	228A-sd	saddle dolomite cement	180.1	13
	228A-sd	saddle dolomite cement	181.7	12.9
	228A-sd	saddle dolomite cement	176.1	13.1
	228A-sd	saddle dolomite cement	171.7	11.6
	228A-sd	saddle dolomite cement	177.4	11.6
	228A-sd	saddle dolomite cement	169.3	11.2

	228A-sd	saddle dolomite cement	167.6	11.2
	228A-sd	saddle dolomite cement	176.5	11.7
	228A-sd	saddle dolomite cement	168.8	10.6
	228A-sd	saddle dolomite cement	169.6	10.5
	228A-flt	fracture lining dolomite	124.8	9.5
	228A-flt	fracture lining dolomite	126.2	9.6
	228A-flt	fracture lining dolomite	123.8	8.1
	228A-flt	fracture lining dolomite	119.4	8
	228A-flt	fracture lining dolomite	129.1	10.4
	228A-flt	fracture lining dolomite	125.1	9.3
	228A-flt	fracture lining dolomite	124.3	7.9
	311A-flt	fracture lining dolomite	114.1	8
	311A-flt	fracture lining dolomite	110.1	7.7
	311A-flt	fracture lining dolomite	114.5	7.9
	311A-flt	fracture lining dolomite	114.2	8.4
	311A-bc	blocky calcite cement	122.1	9
	311A-bc	blocky calcite cement	118.4	9.5
	311A-bc	blocky calcite cement	123.1	7.7
	311A-bc	blocky calcite cement	119.1	8.7
	311A-bc	blocky calcite cement	125.8	8.3
	311A-bc	blocky calcite cement	116.7	7.9
	311A-bc	blocky calcite cement	129.7	9.8
	311A-bc	blocky calcite cement	120.4	7.9
Gold Creek Wabamun	gc-1	saddle dolomite cement	174	17.8
	gc-2	saddle dolomite cement	268.4	17.8
	gc-3	saddle dolomite cement	146	18
	gc-4	saddle dolomite cement	148	18
	gc-5	blocky calcite cement	146	18.6
	gc-6	blocky calcite cement	168	19
Parkland Wabamun	p1	saddle dolomite cement	121	
	p2	saddle dolomite cement	114.8	
	p3	saddle dolomite cement	138.3	24
	p4	saddle dolomite cement	152.3	20.6
	p5	saddle dolomite cement	122.6	24
	p6	saddle dolomite cement	124.1	
	p7	saddle dolomite cement	120.4	25.8
	p8	saddle dolomite cement	138	
	p9	saddle dolomite cement	148.2	
	p10	saddle dolomite cement	164.1	
	p11	saddle dolomite cement	144.3	
	p12	saddle dolomite cement	150.4	
	p13	saddle dolomite cement	137.1	
	p14	saddle dolomite cement	146.9	

p15	saddle dolomite cement	157.6	
p16	saddle dolomite cement	129	
p17	saddle dolomite cement	139.7	
p18	saddle dolomite cement	136.7	
p19	saddle dolomite cement	150.4	
p20	saddle dolomite cement	158.9	
p21	saddle dolomite cement	157.1	
p22	saddle dolomite cement	155.6	23.2
p23	saddle dolomite cement	148.6	
p24	saddle dolomite cement	181.2	
p25	saddle dolomite cement	164.4	
p26	saddle dolomite cement	172.6	
p27	saddle dolomite cement	144.8	
p28	saddle dolomite cement	178.9	
p29	saddle dolomite cement	178.1	
p30	saddle dolomite cement	182.5	
p31	saddle dolomite cement	160.9	
p32	saddle dolomite cement	166.6	
p33	saddle dolomite cement	172.4	
p34	saddle dolomite cement	123.5	
p35	saddle dolomite cement	144.5	
p36	saddle dolomite cement	173.5	
p37	saddle dolomite cement	128.7	23.7
p38	saddle dolomite cement	105.4	
p39	saddle dolomite cement	112.5	
p40	saddle dolomite cement	120.9	
p41	saddle dolomite cement	126.7	
p42	saddle dolomite cement	114.7	
p43	saddle dolomite cement	112.8	
p44	saddle dolomite cement	130	
p45	saddle dolomite cement	150.2	
p46	saddle dolomite cement	131.9	
p47	saddle dolomite cement	129.6	
p48	saddle dolomite cement	152.9	
p49	saddle dolomite cement	148.2	
p50	saddle dolomite cement	146.7	
p51	saddle dolomite cement	123.3	
p52	saddle dolomite cement	140.6	
p53	saddle dolomite cement	154.1	
p54	saddle dolomite cement	129.1	
p55	saddle dolomite cement	136.9	
p56	saddle dolomite cement	146.3	
p57	saddle dolomite cement	156.4	24.3

	p58	saddle dolomite cement	150.2	
	p59	saddle dolomite cement	141.1	
	p60	saddle dolomite cement	145.8	
	p61	saddle dolomite cement	173.2	
	p62	saddle dolomite cement	149.2	
	p63	saddle dolomite cement	123.2	
	p64	saddle dolomite cement	139.1	
	p65	saddle dolomite cement	146.3	
	p66	saddle dolomite cement	152.1	
	p67	saddle dolomite cement	174.1	
	p68	saddle dolomite cement	146.7	
	p69	saddle dolomite cement	170.1	
	p70	saddle dolomite cement	162.7	
	p71	saddle dolomite cement	138.2	
	p72	saddle dolomite cement	149.8	
	p73	saddle dolomite cement	187.6	
	p74	saddle dolomite cement	128.3	
	p75	saddle dolomite cement	144.3	
	p76	saddle dolomite cement	175.9	
	p77	saddle dolomite cement	115.7	
	p78	saddle dolomite cement	160.4	
	p79	saddle dolomite cement	156	
	p80	saddle dolomite cement	124.7	
	p81	saddle dolomite cement	159.1	
	p82	saddle dolomite cement	145.8	
	p83	saddle dolomite cement	162.5	
	p84	saddle dolomite cement	164.8	
	p85	saddle dolomite cement	146.5	
	p86	saddle dolomite cement	168.9	
	p87	saddle dolomite cement	109.4	
	p88	saddle dolomite cement	143.4	
	p89	saddle dolomite cement	160.6	
	p90	saddle dolomite cement	112.3	
	p91	saddle dolomite cement	130.4	
	p92	saddle dolomite cement	146.2	
	p93	saddle dolomite cement	139.9	
	p94	saddle dolomite cement	126.1	
	p95	saddle dolomite cement	144.9	
	p96	saddle dolomite cement	138.5	
Tangent Wabamun	t1	saddle dolomite cement	92	23.1
	t2	saddle dolomite cement	107	24.5
	t3	saddle dolomite cement	87	23.5
	t4	saddle dolomite cement	102	24.2

t5	saddle dolomite cement	102	24.4
t6	saddle dolomite cement	109	
t7	saddle dolomite cement	114	
t8	saddle dolomite cement	105	
t9	saddle dolomite cement	121	
t10	saddle dolomite cement	117	

Draft

Figure 1

		British Columbia		Alberta									
		Fort Nelson		South Central Mountains	Southern Plain		Central Plains		North West Plains				
Mississippian	Serpukhovian			Etherington						Kiskatinaw			
				Golata									
	Visean	Rundle Group	Debolt		Mount Head	Mount Head		Debolt					
					Turner Valley	Turner Valley							
			Shunda		Shunda		Shunda		Shunda				
			Pekisko		Pekisko		Pekisko		Pekisko				
	Tournaisian	Banff		Banff		Banff		Banff		Banff			
		Exshaw		Exshaw		Exshaw		Exshaw		Exshaw			
Devonian	Famennian	Kotcho		Palliser		Wabamun	Big Valley	Wabamun	Big Valley	Wabamun			
		Tetcho											
		Trout River											
	Frasnian	Kakisa Red Knife		Alexo		Crowfoot		Woodbend Group	Ireton	Fort Simpson			
		Fort Simpson		Southesk (White Reef)		Nisku			Leduc				
				Cairn (Black Reef)		Ireton			Duvernay			Winterburn	
						Leduc						Ireton	
						Cooking Lake							
	Givetian	Slave Point				Beaver hill Lake	Swan Hills	Beaver	Waterways		Waterways		
									Slave Point		Slave Point		

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17

Figure 18

Figure 19

Figure 20

Figure 21

Figure 22.

Figure 23

Figure 24

Figure 25

Figure 26

Figure 27