Porosity Modification During Progressive Burial in Upper Devonian Leduc Reservoirs, Rimbey-Meadowbrook Reef Trend, Alberta

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ABSTRACT
Porosity (and to some extent permeability) modifications during burial diagenesis of the Rimbey-Meadowbrook reef trend are summarized in a regional context, drawing together data from a number of publications and theses. The present depths of this reef trend vary from 1 km to over 4 km and provide a natural laboratory for studying the effects of progressive burial on carbonates. The effect of diagenesis, particularly dolomitization, on porosity modification is assessed by contrasting undolomitized buildups (e.g. Golden Spike, Strachan D3B) with dolomitized equivalents (e.g. Homeglen, Strachan D3A, Ricinus). This information is compared with parts of the deep basin of west-central Alberta between the Obed and Simonette buildups, whose diagenesis appears to be partly fault controlled.

Porosity and permeability data when compared regionally and plotted versus depth show that:

1. During shallow (<600 – 1000m) to intermediate burial replacement dolomitization decreased porosity and slightly increased permeability compared to limestone buildups at the same depths. At deeper burial depths (>2000 - 3000 m), dolostones are significantly more porous and permeable than limestones. Dolostones are more resistant to pressure solution and thus retain their porosity and permeability much better than limestones.

2. At least four dissolution and fracturing phases are identified. The early phases overlapped with replacement dolomitization and resulted in enhanced effective secondary moldic and vuggy porosity. A brecciation phase postdates the replacement dolomites and predates dolomite and anhydrite cements reflecting solution and collapse of these dolomites during intermediate to deep burial.

3. Microfracturing and deasphalting further complicate the reservoir character in deeply buried limestone buildups that appear to be
unconnected to regional dolomitization conduits, such as parts of the Strachan Leduc field.

4. Cementation, particularly by anhydrite, and to a lesser extent dolomite and calcite, gradually decreased porosity especially at depths greater than 3000 m. Two or more phases of late calcite cements precipitated during deep burial, just before or during hydrocarbon maturation and thermochemical sulfate reduction (TSR) reactions. Milky-white secondary anhydrite can significantly reduce porosity, particularly downdip from the Homeglen-Rimbey field where it is observed preferentially in the water column of the Leduc reservoir.

5. In the Obed, Kaybob South and Karr-Simonette and adjacent Devonian carbonate reservoirs of west-central Alberta, similar diagenetic textures are observed. The main difference is in the greater abundance and coarser crystal sizes of late stage calcite and saddle dolomite cements near normal faults. This region also differs in its lighter oxygen isotopes, and higher radiogenic strontium and fluid inclusion temperatures when compared to the Rimbey trend. These differences appear to be related to basement fault systems that may be linked to faults of the southern Peace River Arch. Thus, without as many faults that intersect basement there is little, if any, late-stage radiogenic pore occluding cements present, as observed in the Rimbey-Meadowbrook reef trend.

INTRODUCTION

The importance of diagenesis and dolomitization in the formation and modification of hydrocarbon carbonate reservoirs is well established in the Western Canada Sedimentary Basin. Of all the diagenetic processes dolomitization plays a major role in modifying porosity and is therefore stressed in this paper. The manner in which dolomitization took place has a significant impact on predicting the distribution of porous reservoir in a carbonate rock. All dolomitizing models require adequate sources of Mg, a hydraulic pump and suitable porosity and permeability for long distance flow of the dolomitizing fluids. One volume of limestone with about 40% porosity requires about 600 volumes of seawater (at 100% efficiency) to form a dolomite with similar porosity. Clearly, dolomitization requires the flow of enormous amounts of Mg-bearing fluids (Machel and Mountjoy, 1986; Morrow, 1990; Shields and Brady, 1995). Thus to dolomitize a limestone the precursor carbonates must have sufficient porosity and permeability at the time of dolomitization for fluids to move through the rock, whether the reaction takes place near the surface or deeper in a burial environment.

In many regions dolomitization has played a major control on the origin and quality of carbonate reservoirs, but the role of dolomitization with respect to the enhancement or reduction of porosity in dolostones is still poorly understood. The distribution of porous and permeable dolostone reservoirs is therefore difficult to predict. The reasons for this poor understanding appear to be the many different ways in which dolomite may form and/or can be later modified during diagenesis and burial. Important with respect to porosity are what chemical reactions were involved (Morrow, 1980b; Machel and Mountjoy, 1986), which governs whether or not porosity increases, remains about the same, or decreases (Machel and Mountjoy, 1986, 1987). In some modern environments dolomite precipitates in pore spaces (Hardie, 1987) and only locally replaces some skeletal fragments. In many ancient examples secondary porosity appears to have developed either during dolomitization, or later by a separate dissolution event, or events, that dissolved some or all of the remaining calcite (Amthor et al., 1993). In addition, there is
increasing evidence that locally extensive burial dissolution of earlier dolomites has taken place (Dravis and Muir, 1992; Mazzullo and Harris, 1992; Qing and Mountjoy, 1990; 1994). Late-stage burial dolomites, along with calcite, anhydrite and sulphides, occlude pores, further reducing porosity (Drivet, 1993; Drivet and Mountjoy, 1997).

The Upper Devonian Rimbey-Meadowbrook reef trend has been well studied (Figs. 1 and 2). Andrichuk (1958) provided the first overview of reef facies and diagenesis. Subsequent studies concentrated on more detailed facies analysis (Andrichuk, 1958; McNamara and Wardlaw, 1991; Drivet, 1993; Weissenberger, 1994; Wendte, 1994), reef growth (Andrichuk, 1958; Wendte 1994), diagenesis (Illing, 1959), geochemistry and porosity and permeability development (Andrichuk, 1958; McNamara and Wardlaw, 1991; Drivet, 1993; Drivet and Mountjoy, 1997; Amthor et al., 1993, 1994; Marquez, 1994; Mountjoy and Amthor, 1994; Mountjoy and Marquez, 1997), fluid inclusions (Mountjoy et al., 1997; Mountjoy et al., 1999), oil migration and entrapment (Gussow, 1968; Stoakes and Creaney, 1984; Allan and Creaney, 1991; Marquez, 1994), and fluid flow (Rostron et al., 1997). The effects of diagenesis, particularly dolomitization, on porosity modification during burial along the Rimbey-Meadowbrook reef trend are discussed in this paper following the order in which the diagenetic phases occurred in the paragenetic sequence.

Porosity development in Leduc replacement dolomites
In completely dolomitized Upper Devonian Leduc reefs, molds and vugs with some intercrystalline porosity are the most prevalent pore types, accounting for 50% to 100% of the porosity in the cores studied. Moldic porosity is commonly after Amphipora and stromatoporoids. Vuggy porosity is more common, simply because there is every gradation from fabric selective moldic to non-fabric selective vuggy porosity. Most vuggy porosity is probably solution-enlarged moldic porosity. The shape of the vugs can commonly be related to the shape of the original skeletal components, e.g. bulbous or tabular stromatoporoids, Amphipora. In many instances irregular vugs are present that are very large (>6 cm), which do not give any indication as to their precursor fabric. Size and shape of moldic and vuggy porosity is highly variable. They range from 1 mm to more than 6 cm in diameter. The most common size range is about 2 to 30 mm (Amthor et al., 1994). Matrix porosity is either intercrystalline or solution-enlarged intercrystalline porosity (pinpoint of McNamara and Wardlaw, 1991), and rarely accounts for more than 10% of the pore types. For most of the Leduc a dense, low porosity matrix is the dominant rock type comprising mosaics of medium- to coarse-crystalline, planar-subhedral dolomite. Intervals with effective intercrystalline porosity are confined to relatively narrow bands and patches, commonly associated with vuggy porosity (Drivet, 1993; Marquez, 1994; Mountjoy and Marquez, 1997). What controls these porous zones is uncertain, but they appear to represent areas of higher primary porosity in the precursor limestones.

SHALLOW TO INTERMEDIATE BURIAL DIAGENESIS

Replacement dolomitization – does it increase or decrease porosity?
There is a common misconception in text books and the literature that dolomitization is responsible for increasing porosity and permeability of the precursor limestones. In the shallow part of the basin (<2000 m), Devonian limestone buildups of western Canada have retained higher porosity than their dolomitized counterparts (Figs. 3 and 4; McGillivary and Mountjoy, 1975; Walls and Burrowes, 1985, 1990). For example, Golden Spike limestones (1630 – 1810 m) have generally higher porosity values than dolostones of the adjacent Leduc buildup at similar burial depths (1650 - 1930 m) (Fig. 4). Comparing the Upper Leduc in the Golden Spike limestone reservoir with the stratigraphically equivalent dolomites at Homeglen-Rimbey with present burial depths of 1700 and 2300 m respectively is instructive (Fig 5), especially when estimating porosity changes in terms of early burial history. The present average porosity values for the Upper Leduc in the Golden Spike buildup margin and interior are 7 and 10% respectively (Walls and Burrowes, 1990). Present average porosity values based on core analysis in the Homeglen-Rimbey buildup margin and interior are reversed and are 10 and 7% respectively. The differences observed in the interior facies may be explained by the predominantly mosaic
subhedral to anhedral dolomite crystal texture observed in the Homeglen-Rimbey dolomites, whereas the original interparticle porosity still occurs in the limestone equivalent of Golden Spike. The slightly higher porosity values for the upper Leduc in Homeglen-Rimbey margins appears to be due in part to the greater abundance of vuggy porosity, whereas the buildup margins of Golden Spike are dominated by interparticle and shelter porosity being partially to completely filled with submarine cements.

Both the Golden Spike and Homeglen-Rimbey buildups probably started out with primary porosities of 30 to 50% (Fig. 5). Conceptually, this would have been reduced to about 20 to 30% during early mechanical compaction prior to dolomitization. The mosaic subhedral and anhedral crystal texture common to replacement dolomites resulted in the destruction of the primary porosity observed in the limestone counterpart (e.g. interparticle and fenestrae) and is interpreted to have further reduced porosity to about 15 to 20% at shallow to intermediate burial depths. Porosity was further reduced during intermediate burial by chemical compaction and cementation to their present values of 7 to 10% (Fig. 5). Thus it is concluded that mean porosities decreased during early replacement dolomitization. Porosity might be increased locally by dissolution of any remaining calcites after dolomitization. Although the Homeglen-Rimbey dolostones have undergone deeper burial, they have retained, in general, similar average porosity values as the shallower buried Golden Spike buildup, because dolomites are more resistant to chemical compaction than limestones. Thus dolomites tend to lock in or "freeze" their porosity unless occluded by later cements. Based on this model, the porosities in limestone buildups for this shallower part of the reef trend were reduced during burial more slowly and progressively from between 20 to 30 % to their present values of 7 to 10% (Fig. 5). Furthermore, compared to the Golden Spike, the permeability is in general much greater in all facies from the Homeglen-Rimbey. These high permeability values may in part have resulted from the fracturing associated with the dolomitization and later diagenesis and play a major role in enhancing flow rates in the dolostone reservoirs.

Further downdip in the deeper part of the basin, the Strachan and Ricinus buildups (Fig. 1) provide additional examples of the differences between limestone and dolostone reservoirs (Marquez, 1994; Mountjoy and Marquez, 1997). Dolostones are similar in texture, geochemistry and porosity types to dolomites updip along the reef trend. Replacement dolomites form about 95% of the dolomite reservoirs. In Ricinus West porosities vary between 0.6 and 19.4% and average 6.5%, and permeabilities between Kh 0.06 to 2100 md (average about 15 md depending on pore type). The Strachan gas field forms two separate pools. The eastern D3A pool is comprised mostly of dolomites, whereas the D3B pool consists predominantly of limestones. The D3A pool with more extensive early replacement dolomitization is the better reservoir, with porosities ranging from 0.5 to 12.6% (mean 7.7%), and higher permeabilities from Kh 0.1 to 396 md (mean 11 md) than in associated limestones (Fig. 6) (Mountjoy and Marquez, 1997, Table 5). The higher porosities in the D3A pool compared to the limestone D3B pool appear to be due to less chemical compaction in the dolomites than in the limestones, a characteristic noted for South Florida dolomites (Schmoker and Halley, 1982), and also due in part to more leaching of calcite in the dolomites (Amthor et al., 1994; Marquez, 1994). Most importantly, significantly higher permeabilities in the Strachan D3A pool enhanced the capacity of this dolostone reservoir to act as efficient flow units (Mountjoy and Marquez, 1997). However, overall the porosity was reduced during dolomitization from what it was in the precursor limestones (Fig. 5). This appears to be characteristic of dolomites in the Devonian of the Western Canada Sedimentary Basin, regardless of stratigraphic level.

Timing of dissolution associated with replacement dolomitization
Replacement matrix dolomitization was accompanied and/or followed by dissolution (Dissolution II, Fig. 2) Machel and Mountjoy, 1987; Machel and Anderson, 1989; Amthor et al., 1993; Drivet, 1993; Drivet and Mountjoy, 1997), which commonly led to the creation of considerable amounts of secondary moldic and vuggy porosity (about 5 to 20 vol %). Little leaching and dissolution has been observed in limestones, indicating a direct relationship between dolomitization and dissolution. Thus, the fluids responsible for dissolution must have used the same conduit systems as the dolomitizing fluids. A key problem is determining when this dissolution took place. This can only be determined
from evidence in partially dolomitized buildups and by comparing dolostones reservoirs with limestone buildups.

The partial dolomitization of the margins of the Miette reef complex, exposed in the Jasper Front Ranges, has been studied in detail by Mattes and Mountjoy (1980). The limestone sections of the outcrop display very little leaching and dissolution of calcite allochems and fossils when compared to the dolomitized equivalents. Replacement dolomites are usually fabric selective and preferentially replace the matrix in partially dolomitized intervals, leaving the calcite fossils intact for the most part. Many horizons consist of less than 60% dolomite due to the presence of unaltered or non leached allochems and fossils. Immediately along strike the calcite has been dissolved out producing vuggy porosity. This, combined with the lack of leached fossils in limestone equivalents, support a later dissolution event following early matrix dolomitization.

Similar textural evidence is present in the Strachan cores. Dolomitization is fabric selective and preferentially replaces the finer matrix, although some skeletal fragments and cements are also dolomitized. Where dolomitization is partial, the matrix is completely replaced and the majority of skeletal fragments preserved as calcite. Where fabric destructive dolomitization occurs in the interior and eastern margin of pool D3A, calcite skeletal debris is partially to completely dissolved forming vuggy and mordic porosity (Marquez, 1994) similar to the Miette buildup. Although vuggy and mordic porosity also occur in minor amounts in the limestone cores, these pore types are significantly more abundant in the dolomitized section. The increased leaching in the dolomitized cores suggests a higher degree of dissolution is associated with dolomitization, and hence contemporaneous and/or post-dating replacement dolomites. Similar later solution of calcite following replacement dolomitization has been reported by Choquette et al. (1992).

When attempting to predict distribution of reservoir properties in dolostones, it is important to try to determine the timing of replacement matrix dolomitization in order to understand the dolomitizing mechanism and how the associated solution and porosity modification may have taken place. This is done by relating the paragenetic sequence to approximate burial depths, a difficult task that is facilitated in settings where partially dolomitized limestones occur. Several dolomitization models have been proposed, including early to intermediate burial at depths estimated to be between 500 and 1500 m (Figs. 2 and 7) during the Antler Orogeny (e.g. Amthor et al., 1993, Mountjoy and Amthor, 1994; Drivet and Mountjoy, 1997), seafloor dolomitization (e.g. dolomitic green shales in Golden Spike, McGillivray and Mountjoy, 1975), reflux (Wilson, 1975; Shields and Brady 1995) and convection (Wendte et al., 1998; Morrow, 1998). It is beyond the scope of this paper to discuss the merits of the various models. Selecting a specific dolomitizing model to address porosity modification becomes less crucial in an area of pervasive dolomitization as observed along the entire Rimbey trend. Perhaps more important is to relate the porosity modification textures to the main diageneric phases within a paragenetic framework as a means to establish relative timing and better predict reservoir character. This, combined with regional observations, such as the correlation between dolomitized Cooking Lake platform and the overlying porous dolostone Leduc, are more relevant to predicting changes in porosity.

**DEEP BURIAL DIAGENESIS**

**Burial cements**

In the Rimbey-Meadowbrook reef trend, secondary porosity in replacement dolomites contain conspicuous but relatively minor amounts (generally less than 2% of the secondary pore space) of dolomite cement (Figs. 2 and 8), which usually appears as limpid to milky crystals up to about 1 mm in diameter, increasing to 5 mm in the Strachan and Ricinus buildups. Locally in a few cases, these cements can occupy up to 50% of a rock. Planar dolomite cements occur throughout the reef trend from its deepest part up dip to Acheson, near Edmonton. Saddle dolomites occur preferentially rimming clasts of replacement dolomite in dissolution collapse breccias in buildups from Rimbey southward. The depth at which dolomite cements precipitated is uncertain but likely ranged from intermediate to deep burial (Drivet, 1993; Drivet and Mountjoy, 1997). Fluid inclusion data from the
planar dolomite cements sampled at different burial depths along the reef trend are highly saline and have relatively uniform mean homogenization temperatures (122 to 131 °C), suggesting that they formed from relatively hot fluids before significant basin tilting (Mountjoy et al., 1999). Three saddle dolomite cements analyzed have mean homogenization temperatures between 120 and 170 °C and probably precipitated during deeper burial. Maximum burial temperatures are estimated to be around 150 °C for Garrington buildup (Fig. 7).

In many parts of the basin, milky-white secondary anhydrite also fills this secondary porosity (e.g., Machel et al., 1994). Down dip from Homegen-Rimbey pool, anhydrite significantly reduces porosity, particularly in the water column (Figs. 2 and 8). Two or more phases of late calcite cements precipitated during deep burial, just before or during hydrocarbon maturation and thermochemical sulfate reduction (TSR) (Figs. 2 and 7; Drivet, 1993; Marquez, 1994; Marquez and Mountjoy, 1996). Fluid inclusions of these late calcites range from means of 100 °C to 166 °C. They fall into two groups, an early group with positive δ¹³C and that follow a 30 °C/km geothermal gradient, whereas the later calcites have negative δ¹³C suggesting they are a by-product of TSR and follow a 20 to 25 °C/km gradient (Mountjoy et al., 1999). Minor native sulphur and sulphides were precipitated and presumably also resulted from TSR reactions and overlap with bitumen emplacement. Minor pressure solution of the earlier replacement dolomites could easily account for the small amounts of dolomite cements present. These dolomitizing fluids may have been driven by sedimentary and tectonic loading of the foreland basin during the Laramide orogeny.

**Brecciation and Fracturing due to subsurface solution**

Brecciation and fracturing is common but varies from isolated occurrences to several meter-thick zones (e.g. well 8-17-50-26 W4). Breccias are characterized by cm-sized angular dolomite clasts with pointed or sutured contacts, forming open framework breccia porosity. The dolomite clasts are identical to non-brecciated replacement dolomites and display truncation of stylolites and fractures at the edges of clasts. Inclined stylolites within individual dolomite clasts indicate rotation and displacement during solution. Some clasts are rimmed by minor amounts of zoned saddle dolomite cements. These breccias postdate the replacement dolomites, and therefore reflect solution, collapse and the development of caverns during intermediate to deep burial (Figs. 2 and 7; Amthor et al., 1993; Drivet, 1993; Drivet and Mountjoy, 1997). This breccia texture is observed in the Leduc dolostones but has not been reported in the Golden Spike and Redwater limestone buildups. In the Homegen Rimby field, breccias were only observed in the buildup margin facies. They cannot be correlated east-west across the buildup, and are not associated with subaerial exposure. The volume of breccia increases downdip along the Rimbey trend. When observed in core, this solution breccia texture is completely cemented by dolomite and anhydrite, and may be responsible for the lack of core recovery and rubble zones in some cores suggesting the presence of cavern porosity.

At least four stages of burial solution and fracturing have been documented in the Rimbey-Meadowbrook reef trend (Fig. 2, Drivet and Mountjoy, 1997) and in both the limestone Strachan and dolostone Ricinus buildups in the deepest part of the trend (Marquez, 1994; Mountjoy and Marquez, 1997). The second phase of dissolution seems to have resulted in the extensive vuggy dolomite porosity, as well as brecciation and cavern development (Drivet, 1993; Marquez, 1994). The last two stages overlap with dolomite, calcite, and anhydrite cementation.

**Microfracturing and deasphalting**

Deep burial microfracturing and deasphalting further complicate the porosity and permeability in some limestone reservoirs. These microfractures are restricted to buildups that appear not to be connected to the regional conduits systems, such as the Strachan Leduc field. Microfractures (hairline fractures <1mm) are very abundant in the upper part of the reservoir, but considerably decrease the reservoir quality of the carbonate rock, due to bitumen filling, thus reducing the porosity to between 2 and 4% (Marquez and Mountjoy, 1996). They extend outwards from vuggy and moldic pores and fractures and crosscut all sedimentary and diagenetic products including some late-stage anhydrite cements. Overpressuring, caused by thermal cracking of crude oil to gas during increasing burial, explains many of the characteristics of the microfractures; their association with all pore types, bitumen filling, their late timing, and their restriction to isolated limestone buildups in the deep...
POROSITY TRENDS WITH INCREASING BURIAL

Amthor et al. (1994) presents core porosity and permeability data from 31 widely spaced Leduc intervals, from 1650 m to 4650 m burial depth along the Rimby reef trend. Grouping of these data by burial depth indicate an overall decrease of porosity with increasing depth along the reef trend (Amthor et al., 1994) (Figs. 2, 8). High permeabilities (Kh, Kv) correlate with high and average porosity values. From the Rimby-Homeglen buildup southwards, anhydrite constitutes the most pervasive and volumetrically important porosity occluding phase, filling vuggy, moldic, and fracture related porosity (Figs. 2, 8). The updip northward decrease in anhydrite coincides with an increase in average porosity values from 2% to 7% (Fig. 8; data from ERCB core analyses). Calcite and dolomite cements also increase downdip further decreasing the porosity and permeability. Thus, the most porous reservoir dolomites occur in the northern part of the Rimby-Meadowbrook trend (from Township 37 northward), at burial depths shallower than about 2300 m, where anhydrite is minor (Drivet, 1993; Drivet and Mountjoy, 1993, 1997).

DIFFERENCES FROM OTHER PARTS OF THE WESTERN CANADA SEDIMENTARY BASIN

Carbonates of the Rimby-Meadowbrook reef trend are similar to Devonian carbonates in the west-central Alberta deep basin in terms of overall diagenetic phases and their characteristics. However in the deep basin of west-central Alberta (Pine, Fir, Kaybob South, Obed and Simonette), late-stage saddle dolomites and calcites are locally more abundant and exhibit somewhat higher homogenization temperatures (Duggan, 1997; Green, 1999, Smith 2001). Dolomites in Kaybob South are restricted to a 3 to 7 km wide zone along a 40 km platform reef margin in contact updip with Waterways basinal nodular, crinoidal micritic limestones. The restriction of abundant late stage cements and brecciation to pervasively dolomitized areas suggests they may have resulted from vertical fluid flow along fault systems. Seismic data from Kaybob South shows clearly stratigraphic offsets of 20 to 40 m (Green, 1999). Kaybob South lines up along a NW-SE trend with the dolomitized Rosevear marine channel about 40 km to the southeast, which Kaufman et al. (1991) interpreted to be related to deep-seated faults.

The west-central deep basin differs mainly in the late-stage dolomite and calcite cements being more radiogenic and more abundant, especially along established or inferred faults as in Kaybob South, Swan Hills Simonette and Wabamun Pine Creek fields. Late calcites also contain lighter δ 13C (-3.5 to -10.0 ‰ PDB), except Simonette, and even lower values (0 to –27‰) in some high sour gas fields like Obed (Duggan, 1997; Green, 1999; Machel et al., 1999; Mountjoy et al., 1999). These differences in geochemistry and abundances of late-stage calcite and dolomite cements appear to be related to basement fault systems. The northeast linear trend of the Rimby-Meadowbrook reef has often been interpreted as being of tectonic origin (Mountjoy, 1980). Recently as part of the Alberta Basin transect of Lithoprobe, seismic profiles across the Rimby-Meadowbrook and other reef tracks were studied. Edwards and Brown (1999) found no evidence to suggest faulting (seismic resolution minimum of 20 m offset) or direct basement control on this reef tract. Thus, without significant faulting that intersects the basement there is little, if any, late-stage radiogenic cement present, as for example, in the Rimby-Meadowbrook reef trend. It is reasonable to assume that the fluids responsible for dolomitization and these late-stage radiogenic cements in settings closer to the Peace River Arch, moved vertically along porous fracture and fault conduits, probably due to readjustments during sedimentary and tectonic loading of the basin (squeegee model, Oliver, 1986) during the late Cretaceous and Paleocene.

The northwest-trending faults of west-central Alberta appear to be linked to faults of the southern Peace River Arch. A region of extensive saddle dolomites and brecciation extends northward from the Peace River Arch to the NWT (Davies, 1996; Morrow 1998), and evidence from that
area has been interpreted to support hydrothermal dolomites originating from basin brines circulated by thermal convection, driven by unknown heat sources (Morrow, 1998).

**SUMMARY**
The Rimbey-Meadowbrook reef trend provides an ideal setting to understand porosity modification in limestones and dolostones under different burial regimes. Leduc reservoirs are strongly affected by diagenesis, including replacement dolomitization and several phases of dissolution, fracturing and cementation. Porous Leduc replacement dolostones can be attributed to solution-controlled vuggy and moldic porosity. Much of this porosity appears to be related to dissolution of calcite allochems that remained after replacement dolomitization. Comparison between equivalent limestone and dolostone Leduc buildups along the reef trend indicate that dolomitization led to redistribution and a decrease in porosity during early burial. Subsequently, dolostones tend to have better retained their porosity because limestones are less resistant to pressure solution and compaction. At least four phases of fracturing and dissolution overlapped and postdated replacement dolomitization, enhancing vuggy and moldic porosity. These dissolution events were most extensive in the dolomitized portions of the reef trend pointing to an association between the two events. Porosity enhancement by dissolution was offset by several cementation events. Anhydrite, and to a lesser extent dolomite and calcite, gradually decreased the porosity especially in the deeply buried parts of the reef trend at depths greater than 3000 m. These cementation events appear to have been more extensive and abundant in the deeper west Central Alberta basin, where more faults, possibly associated with the Peace River Arch, may have further influenced diageneis and porosity modification. Relating observations on porosity to the main diagenetic phases within a paragenetic framework helps better understand and predict the origin and occurrences of porosity and permeability in carbonate reservoirs.

**Acknowledgments**
This research was supported by funds from Natural Science and Engineering Research Council (NSERC) research grants to Mountjoy, a strategic grant to Mountjoy and Machel, and LITHOPROBE grants to Mountjoy and Williams-Jones. Additional funding for parts of this research was provided by Amoco, Chevron, Crestar, Home Oil, Mobil Oil, Norcen, PanCanadian, PetroCanada, and Shell. We are grateful for unpublished data, discussions and comments from many colleagues, especially J. Amthor, J. Andrichuk, G. Burrowes, H. Chouinard, G. Davies, J. Duggan, D. Green, P. Gretener, E. Hanson, E. Horrigan, H. Huebscher, A. Laflamme, H. Machel, I. Montanez, J. Packard, L. Rock, D. Sangster, S. Smith, G. Tebbutt, J. Thiessen, J. Wendte, and A. Williams-Jones. We thank the staff at the EUB core research lab, Calgary, for their exceptionally friendly and efficient service. The paper was read critically by Mark Hearn who provided helpful suggestions that improved the manuscript.

**Selected References**
A complete reference list is available on request from Eric Mountjoy. Most references may be found in the following publications.


Fig. 1: Central and southern part of the Rimby-Meadowbrook reef trend, central Alberta Basin.

Fig. 2: Paragenetic sequence in Leduc Formation and estimated porosity changes with progressive burial (Drivet and Mountjoy, 1997).

Fig. 3: Boxplots illustrating (A) porosity distribution in limestones, dolostones and dolomitic limestones of the Leduc and Cooking Lake formations and (B) porosity distribution in the rock types of the Cooking Lake platform and Leduc buildups (Amthor et al., 1994).

Fig. 4: Boxplots showing porosity distributions in limestone (A) and dolomitized buildups (B) at different burial depths. Golden Spike has higher porosity than dolostones of the adjacent Leduc buildup at shallow burial depths (<2000 m) which is reversed at depths >4000 m (Amthor et al., 1994).
FIGURE 5

Estimated porosity at time of deposition

Golden Spike limestones
Mechanical Compaction & cementation decrease porosity.
20 to 30%

Homeglen-Rimby dolomites
Replacement Dolomitization. Porosity unplombated & decreased.
15 to 20%

Un dolomitized, Mechanical & chemical compaction & cementation decrease porosity.
20 to 30%

Chemical compaction & cementation decrease porosity progressively.
10%

Little chemical compaction. Minor cementation. Little decrease in porosity.

Fig. 5: Estimated porosity changes during burial of the limestone Golden Spike buildup and the completely dolomitized Homeglen-Rimby buildup. Note that replacement dolomitization reduces porosity in the dolomites by about 10% (Drivet, 1993).

Fig. 6: (A) Boxplot showing horizontal permeability Kh in dolomitized and limestone buildups at different burial depths. Golden Spike limestones have similar permeabilities to adjacent Leduc buildup but limestones have very low permeabilities below 4000 m compared to dolostones (Amthor et al, 1994). (B) Average porosity plotted versus north-south townships along the Rimby-Meadowbrook reef trend. Data obtained from averaging all core porosity analyses from the Leduc and Cooking Lake formations. Curve represents best fit using a statistical computer program. Township 55 represents maximum burial depths of about 2500 m and township 30 burial depths >3500 m. Data from 18 buildup wells (open circles) and 10 entire fields (filled squares). Both follow the same trend suggesting wells studied are representative of average field porosity. Formula provides equation of best fit curve. R, correlation coefficient (Amthor et al., 1994).

Fig. 7: Burial-temperature-time plot for Leduc buildups in the Homeglen-Rimby and Garrington fields assuming a geothermal gradient of 30°C/km and a surface temperature of 30°C, showing suggested time of some paragenetic events (Drivet and Mountjoy, 1997).

Fig. 8: Late-diagenetic products in southern dolomitized Rimby-Meadowbrook reef trend showing decrease in average porosity downdip from 7% at 2300 m present depth to 2% at 3500 m, mainly as a result of carbonate and anhydrite cements (Drivet and Mountjoy, 1997)