The Origin of the Gold Creek Collapse Structure and Associated Dolomitization, West Central Alberta

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ABSTRACT

Introduction

The Gold Creek Field was discovered in 1964 by Pan Am A-1 Gold Creek 4-34-67-4W6 which was drilled to a total depth of 3913m into the Middle Devonian Watt Mountain Formation. The primary target of this well was an Upper Devonian Leduc reef seismic anomaly. The Leduc proved to be porous and water saturated but the overlying Devonian Wabamun Formation was found to be dolomitized and gas bearing. Since this time the Gold Creek Field has produced over 100 Bcf of gas and continues to be productive, mostly from the Wabamun Formation.

Location

The Gold Creek Field is located in West Central Alberta, on the south flank of the Peace River Arch. Wabamun gas production is centred on an underlying reef, the Gold Creek Leduc Reef which is a NE-SW trending elongate feature that is approximately 10 km by 5 km in size. It is situated 7 km east of the much larger Steep Creek Leduc reef which also trends to the NE-SW.

Seismic Expression of the Gold Creek Field

Figure 1 is a Wabamun time structure map from a 3D seismic survey of the Gold Creek area. The survey is dominated by two main structural features:
1. Drape over the eastern margin of the Gold Creek Leduc Reef is clearly visible as a 30-45 millisecond structural high. This is due to differential compaction of basinal Ireton shale over the windward margin of the reef.
2. The Gold Creek Collapse Structure lies immediately west of the raised eastern rim of the Gold Creek Leduc Reef. The collapse structure is a 65 millisecond, NE-SW trending, 3.8 km by 1.6 km, ovoid depression overlying the western margin of the Leduc reef. The origin of this feature is the subject of this paper.

Figure 2 is a Debolt to Wabamun isochron map from the same seismic survey. The two dramatic features that appear in the Wabamun time structure map are also clearly visible with the isochron map. The raised eastern rim of the Gold Creek Leduc Reef has 10-15 milliseconds of thinning of the Debolt to Wabamun interval. There is 20-25 milliseconds of isochron thickening overlying the the Gold Creek Collapse Structure.

Wabamun Structure and Isopach

Data from Gold Creek Field well control were examined in order to quantify the magnitude and timing of the collapse feature. The Wabamun regional dip is

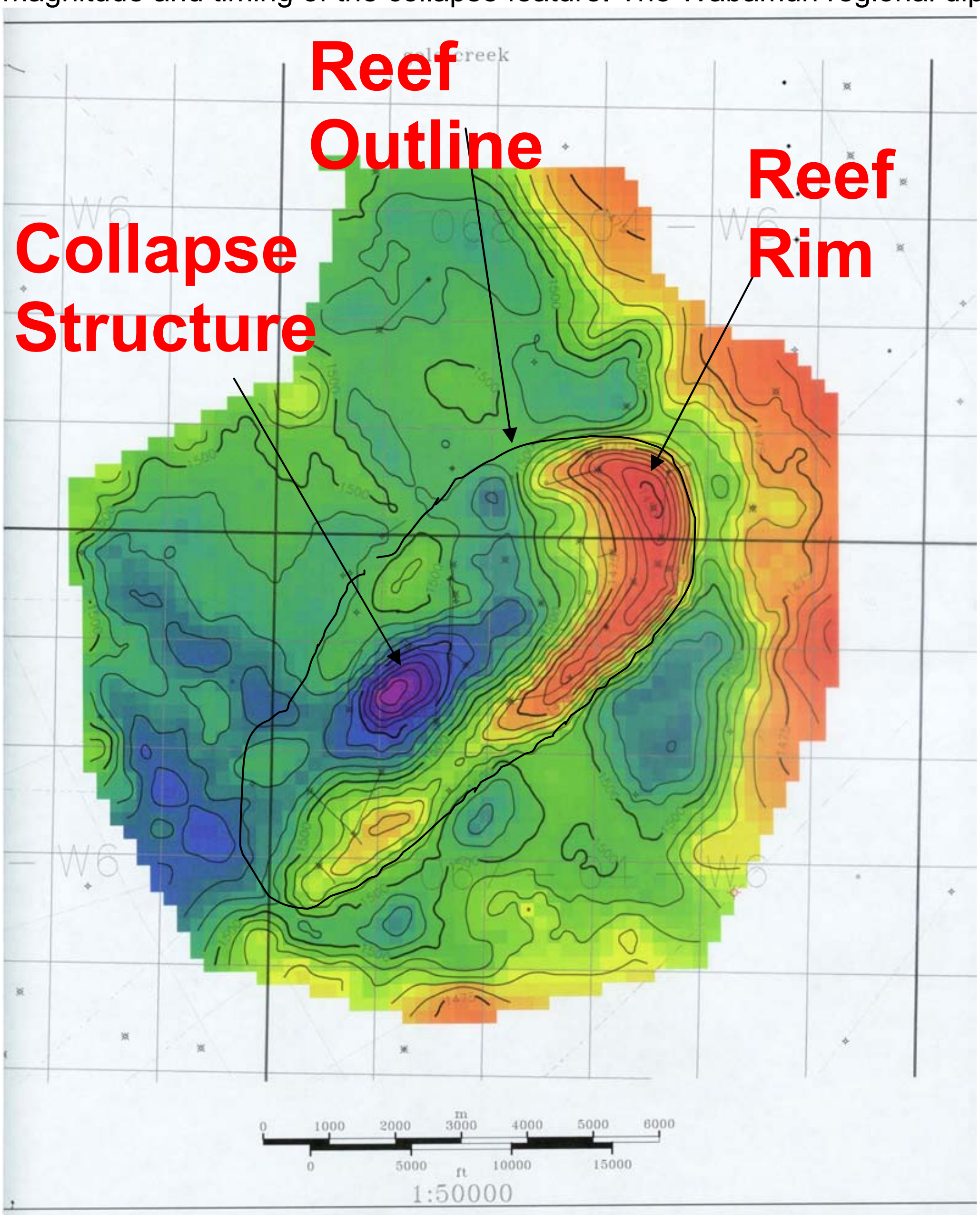

Fig. 1 is the Wabamun time structure map of the Gold Creek area. Drape over the eastern margin of the underlying Gold Creek Leduc Reef corresponds to a structural high. The Gold Creek Collapse Structure is a NE-SW trending structural low that is west of the reef rim. The contour interval is 5 milliseconds and the spectral variation in colour from orange to purple corresponds to increasing time structure values. Figure courtesy of Devon Canada.

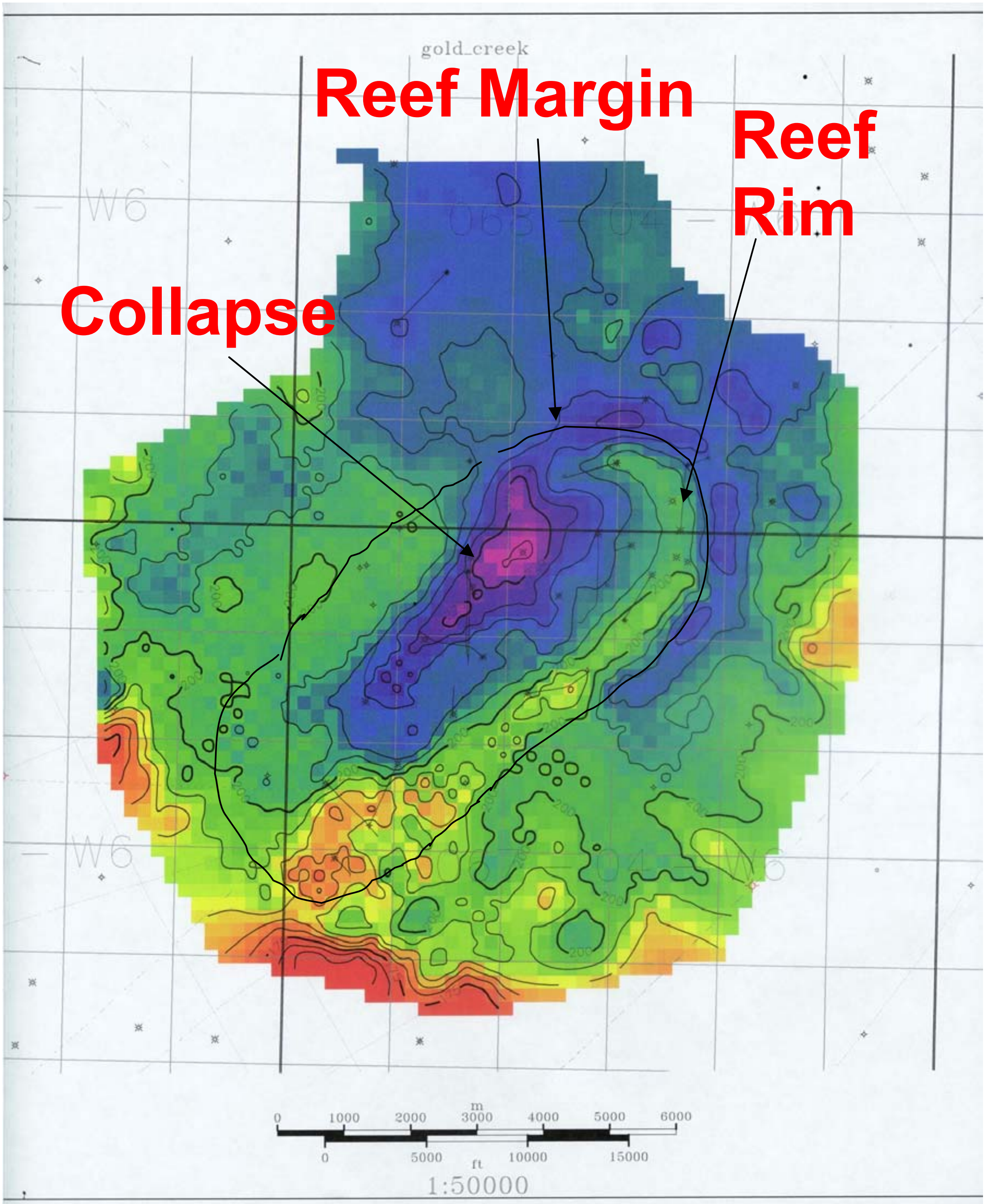

Fig. 2 is a Debolt to Wabamun isochron map. The eastern rim of the underlying Leduc reef appears as an isochron thin. The Gold Creek Collapse Structure immediately to the west of this rim is a NE-SW trending isochron thick. The contour interval is 5 milliseconds and the spectral variation in colour from orange to purple corresponds to increasing isochron values. Figure courtesy of Devon Canada.

approximately 11.8m/km to the southwest. Where the Wabamun drapes over the Gold Creek Leduc Reef rim, there is up to 50m of positive relief. Within the deepest part of the Gold Creek Collapse Structure, the Wabamun has subsided up to 110m. This is 60m lower than areas not underlain by a Leduc reef.

Mississippian Isopach Data

The Debolt to Wabamun isochron map (Fig.2) shows a substantial thickening of the Mississippian interval corresponding to the Gold Creek Collapse Structure. A series of isopach maps of the various Mississippian formations was prepared in an attempt to identify the timing of the collapse process. The Mississippian succession from Banff-Exshaw to Debolt is a 560-675m thick shallowing upwards sequence without major unconformities. Isopach maps of the various Mississippian formations show regional thickening northward related to coeval collapse of the Peace River Arch.

Isopach maps of the Banff-Exshaw and Shunda intervals have up to 5 to 10m of thinning at Gold Creek related to differential compaction of Ireton shales over the Leduc reef. These formations each show 10-15m of thickening in the area of the Gold Creek Collapse Structure, suggesting that collapse related subsidence was underway at this time.

The Debolt Formation thickens 10-20m over the Leduc reef and a further 95m into the deepest portion of the Gold Creek Collapse Structure. This marks the period of maximum structural collapse.

Subsidence continued, but in a less dramatic way, after Debolt deposition. The Belloy to Debolt isopach is 10-15m thinner over the Leduc reef and thickens 15 to 20m into the deepest part of the collapse structure. This implies that collapse was still ongoing at this time, but on a much reduced scale. The same could be said of post-Belloy subsidence. The Belloy structure shows up to 25m of positive relief over the Leduc reef and sags up to 10-15m over the heart of the collapse.

Origin of the Collapse Structure

The Gold Creek Collapse Structure is situated overlying a Leduc reef. It is largely confined to the area overlying the western and northern portion of the Leduc reef interior. Mossap (1973) documented a similar relationship at the Redwater Leduc Reef in eastern Alberta. Here, the Leduc reef has a raised rim and a pronounced depression in the reef interior. He was able to demonstrate, using Ireton isopach values that the reef interior grew to the same height as the reef margin. The present day reef morphology is a product of differential compaction within the Redwater reef. By measuring the amplitude of stylolites, Mossap was able to deduce that the reef interior had undergone a greater degree of chemical compaction compared to the reef margin.

Chemical compaction is a response of limestone to burial pressure. Stress at grain to grain contacts initiates dissolution of the affected grains. Stylolites are surfaces of dissolution and concentration of insoluble residue. A threshold depth of burial of approximately 300-500m is thought to be needed to initiate chemical compaction in limestone.

There is a depositional facies relationship to the susceptibility of carbonate sediment to pore pressure dissolution. Finer grained sediment undergoes stylolitization more readily than coarser grained sediment because grain to grain contacts are much more numerous. Since reef interior sediments are finer grained than sediments found along the higher energy reef margin, conditions exist for differential compaction of the Leduc reef.

Chemical compaction has been viewed as being detrimental to porosity preservation. Dissolved material is generally re-precipitated within the Leduc reef, occluding pre-existing porosity. Because the reef is a closed system to fluid flow, the amount of chemical compaction that can occur is limited by the amount of reef porosity.

At Gold Creek, it is evident that differential compaction within the Leduc reef has occurred. The well preserved rim feature on the windward east side of the reef (see Fig. 1 and 2) is proof of this. Like the Redwater example, the reef interior shows evidence of subsidence. The difference is in the magnitude of subsidence., At Redwater, only about 35m of differential compaction has taken place, whereas up to 110m has occurred at Gold Creek.

The timing of subsidence may have been similar. Mossap (1973) states that differential compaction started as early as during the Wabamun, and continued into the Cretaceous. His analysis of the timing was hampered by the fact that the entire Mississippian section in the Redwater area has been removed by Pre-Cretaceous erosion.

Leduc Isopach and Structural Evidence

Isopach and structural data from two wells that penetrated the entire Gold Creek Leduc Reef were examined for evidence of differential compaction. Well 4-34-67-4W6 was drilled along the eastern rim of the Gold Creek reef and encountered 317m of Leduc. Well 10-32-67-4W6 was drilled into the Gold Creek Collapse Structure and has a Leduc isopach of 272m. The Ireton isopach for the two wells is 9m and 7m respectively, suggesting that they grew to approximately the same height during the Upper Devonian. This implies that the difference in the isopach values (45m) is due to differential compaction within the Leduc.

A comparison of the Beaverhill Lake structure values provides evidence that basement faulting was not involved with the creation of the Gold Creek Collapse

Structure. The Beaverhill Lake Formation was the platform on which Leduc reefs grew. The difference in the elevation of the Beaverhill Lake in the two wells is only 8m, a value that can easily be accounted for by regional dip. This interpretation is supported by geophysical evidence. Seismic lines across the Gold Creek Collapse structure show no evidence of the involvement of basement in the collapse process.

Role of Faulting in the Collapse Process

There is evidence that faulting was a bi-product of differential compaction of the Leduc Reef. The existence of these faults is mainly based on features within the Wabamun Formation in the vicinity of the collapse.

One piece of evidence of faulting is shale material that has been incorporated into fault breccias within the Wabamun Formation in wells such as 13-29-67-4W6. It is believed that Banff and Exshaw age debris has tumbled down fault planes and come to rest in the underlying Wabamun Formation.

More convincingly, several wells have drilled through fault zones and have encountered substantial removal of stratigraphic section. Well 13-29-67-4W6 encountered a Banff section that was approximately 67m thinner because much of the upper Banff section had been removed by normal faulting. This well, drilled through the hanging wall into the footwall of a major fault, is illustrated in Fig.3.

In areas of greatest subsidence, the margins of the Gold Creek Collapse Structure are bound by normal faults that are located along the transition from reef rim to reef interior. They ring the interior of the Leduc reef.

It is speculated that during Debolt time, reef collapse was so intense in the Gold Creek Leduc Reef, that fractures and faults were induced in the overlying Mississippian strata. These faults provided pathways for formation waters to pass out of the Leduc reef and upwards into the regional groundwater system and possibly to the surface. These faults provided an escape route for $CaCO_3$ rich brines derived form chemical compaction. This allowed stylolitization and reef collapse to proceed at an accelerated rate.

Based on the size of the collapse and the fact that a comparable amount of reef material must have been removed to create it, 0.5 cubic km of limestone must have been dissolved from the reef interior. Some of this material would have occluded reef porosity. Some of this material would have been re-precipitated in overlying strata as white sparry calcite cement. Some of the dissolved reef material may have made its way to the surface.

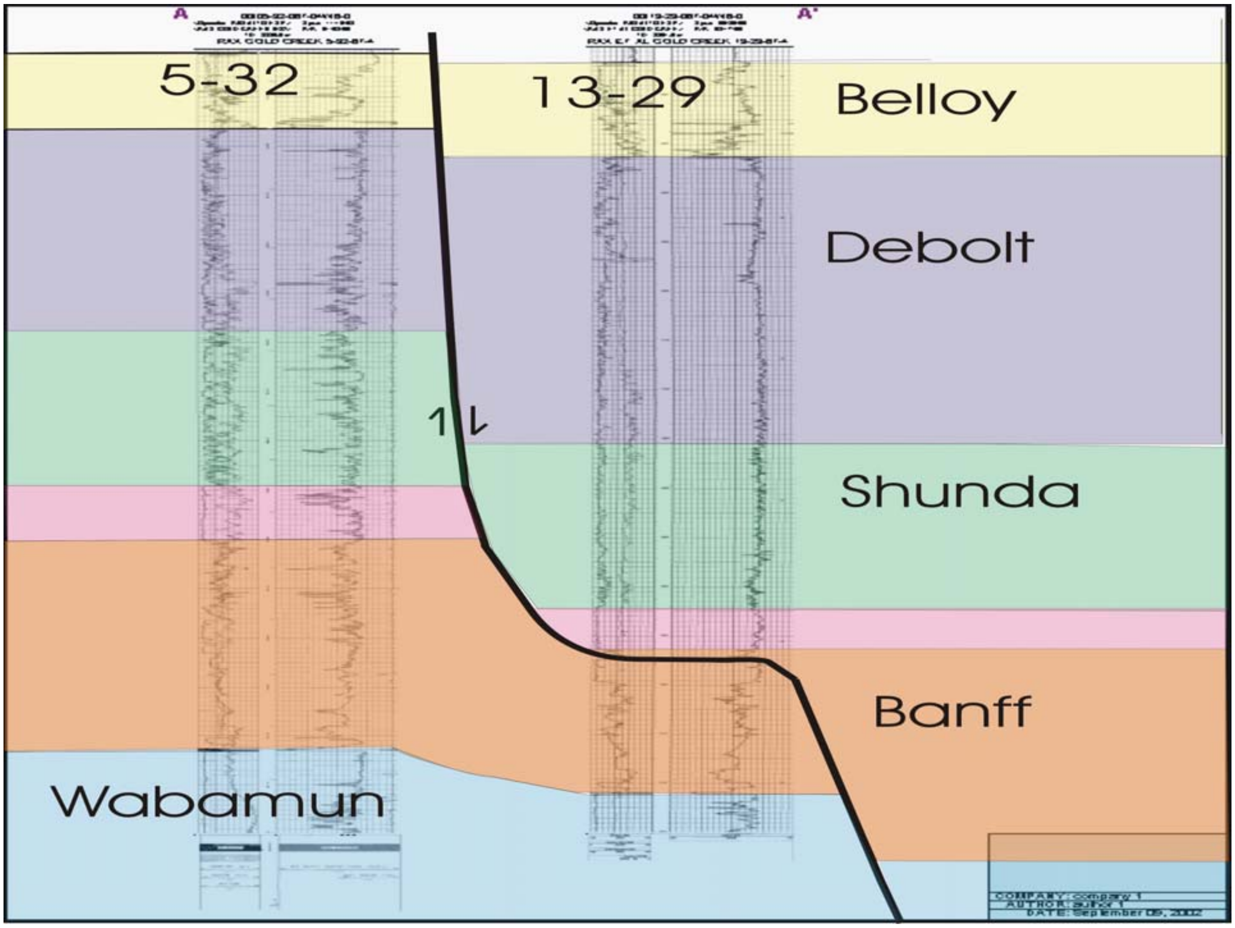

Fig. 3 illustrates an example of normal faulting along the western margin of the Gold Creek Collapse Structure. Well 13-29-67-4W6 was drilled through a normal fault related to collapse of the underlying Leduc reef. In the hanging wall of the reef, 87m of additional Debolt and 23m of additional Belloy thickness is present, compared to thicknesses at 5-32-67-4W6, only 500m away. The Banff at 13-29-67-4W6 is 67m thinner than at 5-32 because of fault removal.

Dolomitization

Faults related to the Gold Creek Collapse Structure appear to have played a major role in the dolomitization of the Wabamun in the Gold Creek Field. Dolomite is rare in the absence of faulting, whereas wells drilled near faults almost always encounter extensive Wabamun dolomitization.

It is believed that there is a connection between the dolomitization of the Leduc and Wabamun Formations. The Gold Creek and Steep Creek reefs are extensively dolomitized. It seems likely that faults provided conduits for these dolomitizing fluids to pass upwards into the Wabamun Formation. Assuming that the major episode of faulting was during Debolt deposition, dolomitization must be a post-Debolt event.

Conclusions

1. The Gold Creek Collapse Structure was caused by differential compaction within the Gold Creek Leduc Reef.
2. Differential compaction was caused by lagoonal sediments of the reef interior undergoing more intense chemical compaction than the coarser grained reef margin sediment.
3. Chemical compaction was a product of burial of the Leduc reef. Differential compaction began during Banff sedimentation but culminated during Debolt deposition.
4. Debolt age reef collapse was so rapid that it induced faulting in the overlying Devonian and Mississippian strata.
5. These faults allowed the flow of CaCO3 rich brines out of the Leduc reef, allowing further chemical compaction to proceed at an accelerated rate.
6. Differential compaction of the Gold Creek Leduc Reef continued after Debolt time, but at a reduced rate.
7. The factors that contributed to the Gold Creek Collapse Structure are the great thickness of the Leduc Reef (minimum thickness 317m), the aggredational nature of reef margin and lagoonal facies within the reef (creating conditions for variations in susceptibility to chemical compaction) and the deposition of 750m of Mississippian and Devonian age sediment on overlying the Leduc reef by Debolt time.
8. Faulting related to reef collapse provide conduits for dolomitization of the Wabamun Formation. Dolomitization must have occurred after this event.

References

Mossap, G.D.,1972, Origin of the peripheral rim, Redwater Reef, Alberta: Bull. Canadian Petroleum Geology, v.20, p.238-280.