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FLUID INCLUSION EVIDENCE ON THE DIAGENEIS OF THE MANETOE FACIES YUKON AND NORTHWEST TERRITORIES

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Abstract

Fluid inclusions from dolomite, quartz, calcite and fluorite cements in the Manetoe facies, southern Yukon and Northwest Territories, were examined. Data from the fluid inclusions reveal that the white dolomite cements formed from relatively hot, hypersaline brines. This is in good agreement with oxygen isotope data. Other associated diagenetic mineral phases formed from relatively hot waters of normal marine to higher salinities. The presence of hydrocarbons in inclusions and different water compositions imply at least two separate fluid migrations through the region.

INTRODUCTION

The purpose of this project was to study the diagenesis of the Manetoe facies dolomite and associated mineral phases. This project was completed under the supervision of Dr. R.J. Spencer, University of Calgary, and was submitted to Dr. D. Morrow at the Institute of Sedimentary and Petroleum Geology. Cores from 27 wells in the Yukon and Northwest Territories were examined, described and sampled for fluid inclusion studies (Appendix A). A literature search was conducted for articles on the geology of the area, staining techniques for carbonates, and stable isotopes (Appendix B). The fluid inclusion tests will help determine paleotemperature, paleosalinity and fluid composition at the time of cement growth. This information may place constraints on the timing of diagenesis and hydrocarbon migration, sources of diagenetic fluids and the thermal history of the basin. Fluid inclusion samples from the following wells were examined: Amoco A-4 Pointed Mountain A-55, Columbia *et al.* Kotaneelee YT H-38, Mobil Fort Simpson M-70, Imperial Sun Netla Raven F-73 and Fina *et al.* Willowlake L-59

CORE DESCRIPTION

Detailed core descriptions are provided in Appendix A. The core examined in Nahanni, Headless and Arnica Formations consisted of dark to medium gray, micro- to coarsely-crystalline dolomite, in places argillaceous or calcareous. Light gray microcrystalline dolomite has replaced some of the fossil material such as stromatoporoids and corals. Often

the darker gray dolomite is more coarsely crystalline near the later, coarse, white dolomite cement. Petrographic examination reveals clear rhombic overgrowths on inclusion-rich crystal cores.

Coarsely crystalline white dolomite occurs in fractures and veins up to 10 cm in diameter, brecciating the gray dolomite (Figure 1). The white dolomite is often mottled with the gray dolomite (Figure 2). Small (< 5 mm) to large (8 cm) vugs are found in the white dolomite. Saddle dolomite, as part of the white dolomite, occurs in some open vugs as crystals up to 5 mm, with the last growth stage as a clear rim on the milky white crystal core. White dolomite is found lining or filling moldic porosity. Polished slabs of white dolomite from several wells were found to have insufficient iron content to stain using potassium ferricyanide.

Bitumen lines some vugs and fills porosity in some veins after the white dolomite (Figure 3,4). Quartz crystals (few mm to several cm) are found partly or totally filling vugs and moldic porosity. Calcite cement occurs as coarsely-crystalline vein and vug fill (Figure 4). Fluorite, sphalerite, galena and possibly anhydrite are present in minor amounts.

PARAGENESIS

On the basis of core and petrographic examination, the paragenetic sequence appears to be:

1,2. Dolomitization of host limestone and replacement of some fossil material by a different light gray

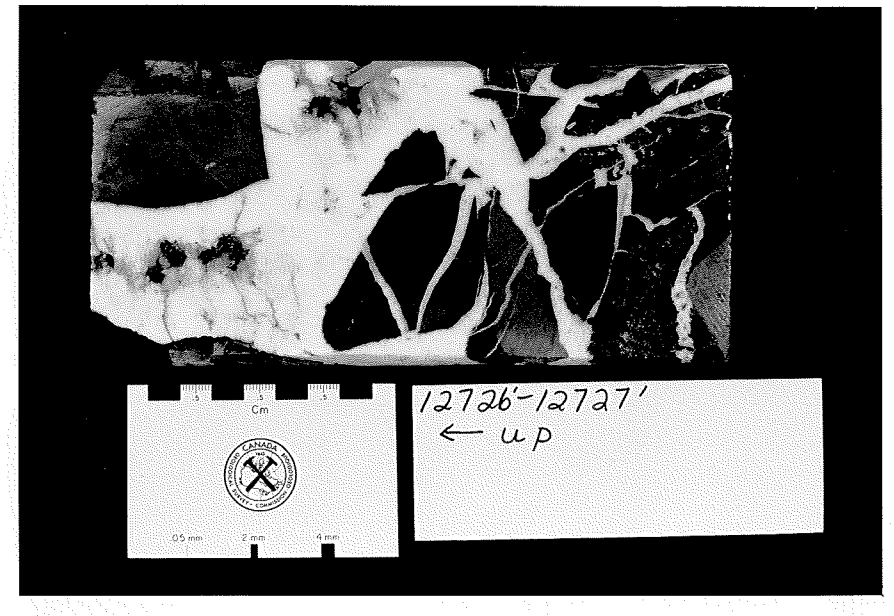

Figure 1. Dark gray dolomite brecciated by coarsely crystalline white dolomite cement. Note coarse quartz crystals in open vug and fine to medium crystalline angular breccia fragments. Sample from Columbia et al. Kotaneelee YT H-38.

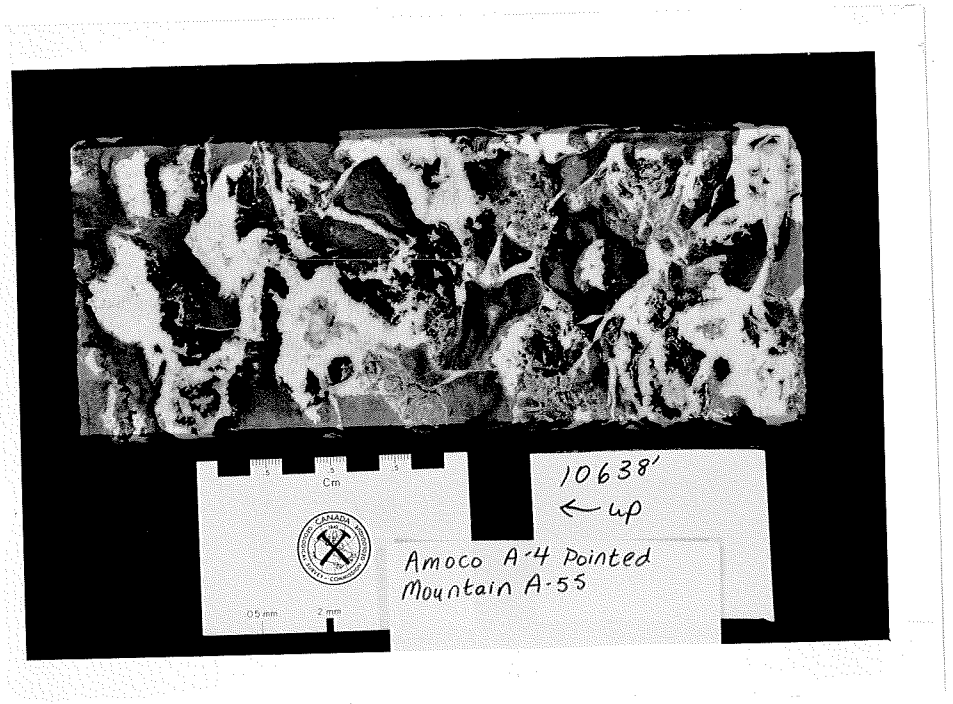

Figure 2. Dark gray dolomite mottled with white dolomite cement in irregular veins.

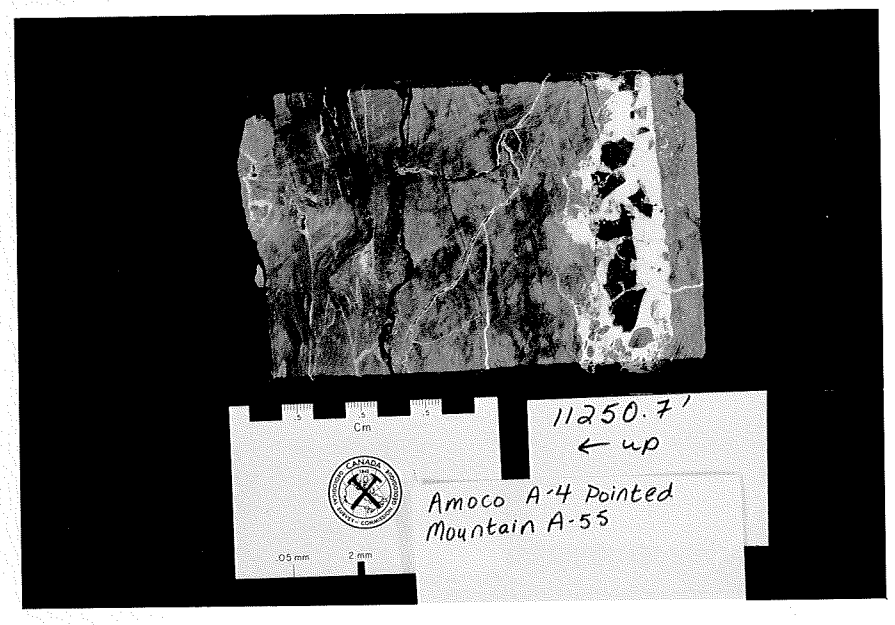

Figure 3. Dark gray dolomite with white dolomite vein containing bitumen which fills vuggy porosity in the centre of the vein.

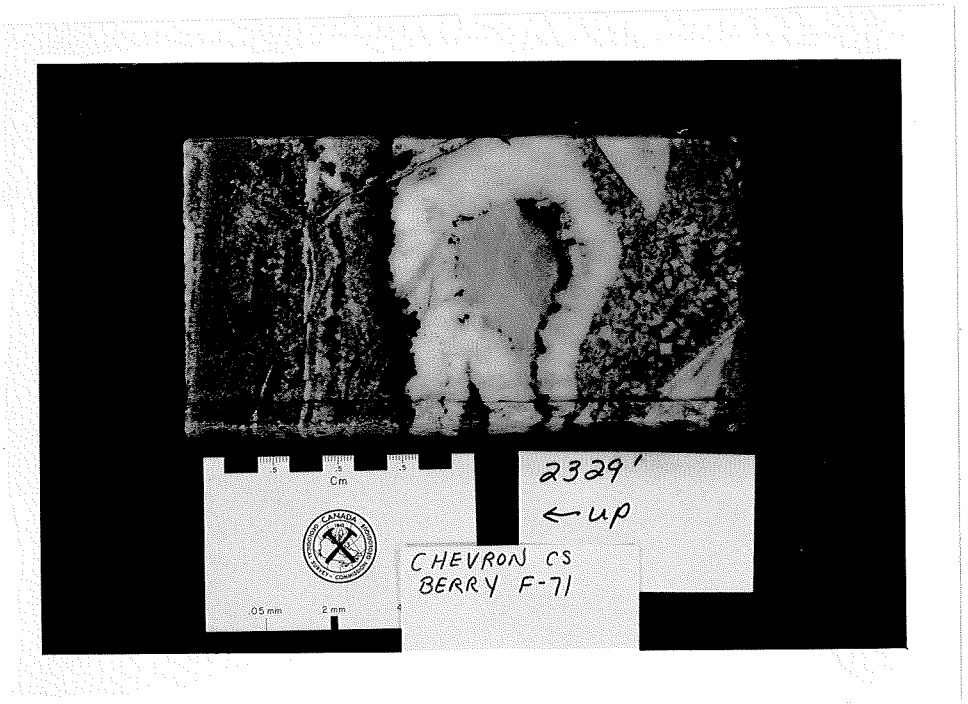

Figure 4. Medium to coarsely crystalline medium gray dolomite cut by large white dolomite vein. The intercrystalline porosity in the gray dolomite is filled with bitumen. The white dolomite vein has a large vug lined with bitumen and then filled with calcite cement.

dolomite

3. Leaching of fossil material to form moldic porosity

4. Precipitation of coarsely crystalline white dolomite cement in fractures, veins and moldic porosity

5. Migration of bitumen into the dolomite

6,7,8. Precipitation of quartz, fluorite, barite and anhydrite cements. The relationship among these cements is ambiguous.

9. Precipitaion of calcite cement and second migration of hydrocarbons

10. Stylolitization, which may have been occurring since precipitation of white dolomite (Figure 5)

11. Precipitation of another calcite ~~event~~ cement which cuts stylolites

12.? Precipitation of sphalerite and galena

13.? Stylolitization

FLUID INCLUSION DATA

For a brief review of the theory behind fluid inclusion microthermometry, see Aulstead and Spencer (1985). The homogenization temperature (T_h), which gives an indication of the temperature of formation of the cement, for over 180 fluid inclusions in dolomite, quartz, calcite and fluorite cements are given in Table 1. Each inclusion was subjected to two heating runs on a Fluid Inc.-modified USGS heating-cooling stage. No pressure correction has been applied. The eutectic (T_E) and final (T_f) melting

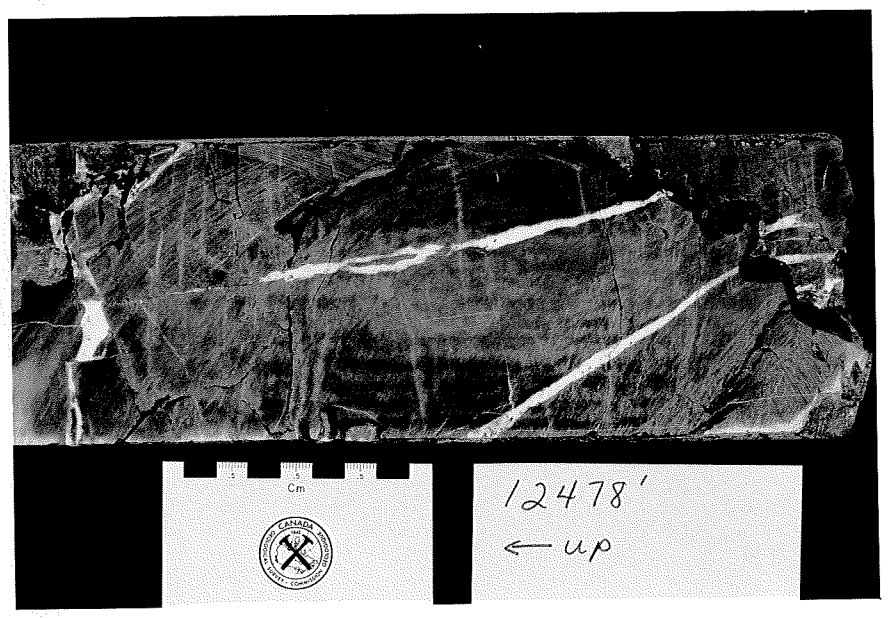

Figure 5. Large carbonaceous stylolite cuts white dolomite veins in sample from Columbia et al. Kotaneelee YT H-38.

TABLE 1 - Homogenization Temperatures (^{O}C)

Columbia et al. Kotaneelee YT H-38

DOLOMITE

11709 ft.

159.3	161.1
172.7	173.6
183.9	182.1
186.9	186.2
164.2	166.3
189.6	186.4
163.9	166.7
168.8	170.1
164.6	166.2
166.6	167.8
154.8	155.5
160.6	160.4
170.0	171.3
175.1	174.7
154.0	155.6
155.0	156.7
161.7	164.7
171.6	172.1
187.7	185.2
172.3	172.2
178.1	176.5
179.4	178.4
161.6	163.2
165.4	167.6
159.6	162.6
168.3	171.5

Average=163.4

12267 ft.

171.5	175.9
168.1	169.4
176.9	180.6
183.4	182.5
194.5	196.6
163.7	164.6
164.5	165.9
190.1	191.4
179.9	181.7
189.1	186.3
181.1	184.0

Average=179.2

12315 ft.

185.2	186.6
170.4	174.9
169.6	168.8
170.3	169.8

QUARTZ

Primary

209.7	208.7
212.3	212.9
208.6	208.9
203.2	202.2
208.0	207.4
188.8	189.2
210.0	210.9
191.7	189.6
210.3	210.1
210.5	210.4
206.3	204.4
212.0	212.1
173.2	175.6
173.9	175.2

Average=201.3

Secondary

220.8	224.0
229.6	227.2
222.1	222.4

Average=224.4

Primary

199.8	200.1
197.6	198.7
194.9	193.6
196.9	198.7

166.8	167.8
168.0	169.3
175.9	173.2
176.9	174.8
189.0	188.7
175.6	177.9
168.4	170.5
172.9	174.2
180.4	179.2
168.8	166.8
173.9	172.1
169.6	167.9
180.6	180.5
190.3	187.3
180.1	182.3

Average=175.4

199.9	201.2

Average=198.1

Secondary

231.6	230.9
225.1	225.2
225.8	224.4
228.9	226.2
230.0	228.7
216.4	219.2
222.4	221.9
221.6	223.7
225.6	225.5
226.6	226.5
223.1	225.2
229.4	227.9

Average=225.5

Amoco A-4 Pointed Mountain A-55
DOLOMITE
10218 ft.

203.6	205.9
181.6	182.1
187.3	188.9
183.3	186.9
196.0	194.3
188.8	190.1
188.1	185.7

Average=190.2

10600 ft.

189.8	190.0
176.1	177.8
169.2	170.3
186.3	188.9
210.3	211.5
201.5	200.8
208.5	209.4
191.5	189.7
210.5	211.0
205.4	205.9
182.5	179.8
197.9	199.1
202.6	201.1
203.7	204.4
192.9	194.9
195.4	194.9

Average=195.1

11205.5 ft.

188.4	189.1
185.2	186.5
191.7	193.1

172.0 173.9
194.6 190.2
194.7 198.4
190.2 195.1
202.5 203.6
205.3 207.1
170.5 172.2
175.3 174.8
184.6 185.4
179.3 177.8
161.6 159.4
194.2 193.0
180.9 182.4
189.7 187.9
Average=186.2

CALCITE
10349.5´
167.3 168.8
176.3 176.6
174.4 176.1
188.1 186.1
164.4 164.8
163.0 162.9
168.8 168.5
162.5 164.4
Average=170.8

MOBIL FORT SIMPSON M-70
QUARTZ
2287´

160.1 162.5
174.6 174.3
176.7 177.5
159.6 161.7
166.7 165.4
Average=167.9

CALCITE
2295´

126.0 125.4
129.3 133.4
120.2 121.6
115.6 112.9
126.0 124.7
120.0 119.2
125.4 125.1
121.6 120.1
Average=122.9

DOLOMITE
2307.5´

168.5 164.6
171.5 168.2
172.1 173.7
168.4 171.9
176.7 178.9
163.5 165.1
Average=167.8

IMPERIAL SUN NETLA RAVEN F-73
CALCITE
7780´

113.2 108.1
119.3 117.2
125.5 124.6
129.9 126.9
Average=120.6

FINA et al WILLOWLAKE L-59
FLUORITE
1309´
a. Secondary, low salinity
105.3 103.6
106.3 104.4
105.9 106.9
107.5 106.3
106.3 107.3
106.9 106.3
Average=106.1
b. High salinity
128.4 128.8
129.9 129.4
128.9 128.7
Average=129.0
c. Moderate salinity
136.1 135.2
134.8 134.9
134.6 134.4
130.2 129.6
Average=133.7

1320´
127.5 131.8
128.8 128.9
130.1 131.1
124.8 127.9
130.1 129.6
124.5 126.1
124.9 123.8
126.8 126.0
126.6 128.1
Average=127.6

temperatures and associated homogenization temperatures for inclusions in dolomite, quartz, calcite and fluorite cements are given in Table 2. The crushing stage allows the observation of an inclusion as it is opened to atmospheric pressure. There are three different types of vapour phase behavior: (1) shrinkage, (2) expansion and (3) no change. Shrinkage of the vapour phase indicates the pressure in the vapour was less than atmospheric pressure. This implies the inclusion has not leaked since it formed. Expansion of the vapour phase on crushing indicates the presence of a noncondensible gas under pressure. This is usually the result of variable fluid immiscibility in system containing a solvus (for example, CO_2-H_2O, CH_4-H_2O). A vapour phase which shows no change on crushing indicates that either the inclusion has leaked since it formed or the inclusion trapped a two-phase liquid-vapour assemblage.

DOLOMITE

Homogenization Data

The white dolomite cement contains two-phase liquid-vapour (LV) aqueous inclusions. These isolated inclusions are assumed to be primary (ie. formed at the time of crystal growth). Secondary inclusions outline fractures through the crystals but the inclusions were too small to examine. The T_h of the primary inclusions range from approximately 155^{o}C to 210^{o}C with the majority under 195^{o} C. Inclusions in dolomite from the Mobil Fort Simpson M-70 well, northeast of the Pointed Mountain and Kotaneelee gas fields

TABLE 2 - Freezing Data

Columbia et al. Kotaneelee YT H-38

	DOLOMITE				QUARTZ	
TE		TF		TH	TF	TH
11709 ft.						
					-3.9 -3.7	173.2
TE for inclusions in quartz was					-3.7 -3.7	174.2
difficult to see accurately but					-3.4 -3.2	173.2
is less than - 40°C.					-3.8 -3.9	173.9
					-2.4 -2.4	233.1
					-2.2 -1.9	228.6
					-2.8 -2.2	223.9
					-2.0 -2.1	222.7
					Ave=-2.9	Ave=200.3
12267 ft.						
-57.4	-54.3	-20.0	-21.1		-6.7 -6.7	202.5
-56.4	-57.9	-22.2	-21.7		-6.7 -7.0	
-53.8	-55.0	-19.3	-20.9	180.6	-6.6 -6.7	197.9
-58.0	-57.5	-23.0	-22.6	169.8	Ave=-6.7	Ave=200.2
-56.2	-56.3	-28.7	-28.8	172.3		
-54.0	-54.9	-24.7	-24.2	192.3		
-56.5	-54.2	-23.2	-24.6	182.6		
-55.5	-53.4	-21.9	-22.7	176.2		
Ave=-55.7		Ave=-23.1		Ave=179.0		
12315 ft.						
-56.8	-57.8	-27.1	-27.4	171.1	-2.0 -1.6	223.1
-55.7	-56.2	-29.4	-29.1	165.4	-1.0 -1.1	
-56.3	-57.9	-28.5	-28.4		-2.6 -2.6	
-55.4	-57.5	-26.5	-27.9	175.4	-2.1 -2.5	
-56.7	-58.9	-29.0	-27.5		Ave=-2.0	
-57.3	-57.0	-27.8	-28.2			
Ave=-57.0		Ave=-28.1		Ave=170.6		
Amoco A-4 Pointed Mountain A-55						
10600 ft.						
-56.8	-54.8	-21.3	-21.2	197.9		
-57.2	-57.0	-22.4	-21.0	203.7		
-55.4	-56.9	-25.1	-25.7			
-57.4	-56.8	-15.1	-16.7	170.3		
-57.8	-54.1	-17.1	-15.2	188.9		
-53.1	-55.1	-16.3	-18.2			
Ave=-56.0		Ave=-19.6		Ave=190.2		
11205.5 ft.						
-54.6	-55.0	-22.6	-19.4	175.6		
-58.0	-56.1	-23.8	-23.8	186.4		
-56.8	-55.1	-20.0	-21.2	190.8		
-56.0	-57.1	-22.3	-21.0	182.7		
-56.2	-55.4	-19.9	-20.2	193.7		
-55.4	-54.0	-21.0	-20.5	198.0		
-53.6	-57.0	-20.6	-21.9	188.3		
Ave=-55.7		Ave=-21.3		Ave=187.9		
CALCITE						
10349.5'						

-53.0	-54.9	-15.7	-15.3	167.3
-56.0	-55.5	-14.6	-15.1	174.4
-55.4	-54.5	-12.9	-12.5	188.1
-53.9	-53.1	-15.5	-15.2	164.4
-56.1	-55.0	-13.5	-14.1	163.0
Ave=-54.7		Ave=-14.4		Ave=171.4

MOBIL FORT SIMPSON M-70
QUARTZ
2287´

-51.0	-53.3	-6.9	-5.4	160.1
-52.1		-6.7	-6.6	174.6
-54.9		-6.7	-6.8	176.7
-55.7	-54.3	-6.3		159.6
-54.8	-52.1	-6.6	-6.4	166.7
Ave=-53.5		Ave=-6.5		Ave=167.5

CALCITE

-55.9	-56.5	-17.0	-16.2	126.0
-57.5	-57.6	-13.7	-13.9	125.4
-55.4	-55.0	-14.6	-14.1	121.6
Ave=-56.3		Ave=-14.9		Ave=124.3

FINA et al WILLOWLAKE L-59
FLUORITE
1309´
a. Secondary, low salinity

-53.4	-55.2	-3.0	-4.5	105.3
-51.1	-56.7	-1.4	-1.7	106.3
-56.0	-53.9	-3.4	-5.4	105.9
-55.7	-53.0	-1.4	-4.4	107.5
Ave=-54.3		Ave=-3.2		Ave=106.3

b. High salinity

-57.6	-54.9	-23.1	-24.3	128.4
-56.1	-56.6	-23.5	-24.3	129.9
-54.6	-55.1	-23.1	-24.1	128.9
Ave=-55.8		Ave=-23.7		Ave=129.1

c. Moderate salinity

-57.9	-56.1	-6.3	-6.0	136.1
-55.9	-53.8	-6.3	-6.0	134.8
		-7.1	-7.0	134.6
Ave=-55.9		Ave=-6.5		Ave=135.2

TE=Eutectic Melting Temperature (^{o}C)
TF=Final Melting Temperature (^{o}C)
TH=Homogenization Temperature (^{o}C)

studied by Dr. D. Morrow, fall within this range but have no $T_h > 180^{o}C$.

Freezing Data

The first melting (T_E) observed within an inclusion after freezing gives an indication of the salt system of the fluid within the inclusion and thus the fluid from which the cement grew. The inclusions in dolomite have a T_E between approximately -59 and -53 ^{o}C. This implies the presence of a complex salt system (eg. $NaCl-CaCl_2-MgCl_2$). The final melting (T_f) temperature give an indication of the ionic strength or total salinity of the fluid. These temperatures range from -32 to -16 ^{o}C. The ionic strength (I) of seawater is approximately 0.6. The I of these fluids range from 5.8 to 3.9, (see Aulstead and Spencer, 1985, Figure 2). Thus the fluids range from highly to moderately saline during dolomite cementation.

Crushing Data

Inclusions in dolomite have a vapour phase which shrinks upon crushing, implying the inclusion has been isolated since it formed and the microthermometric data are accurate and reliable.

QUARTZ

Homogenization Data

The coarsely crystalline colorless quartz contained two types of inclusions:

1. primary two-phase aqueous LV and
2. secondary two-phase aqueous LV.

The primary inclusions tend to be irregularly-shaped and

occur away from fractures through the crystal. The T_h for these inclusions range from 159.6 to 211^{o}Cm with the majority between 195 and 210^{o}C. Inclusions in quartz in the Mobil Fort Simpson M-70 well had T_h ranging from 159.6 to 178 ^{o} C. They are, on average, lower than the inclusions in quartz in wells from the gas fields to the south.

The secondary inclusions tend to occur as faceted negative crystals aligned along fractures through the crystal. The T_h for these inclusions are higher than the primary inclusions, ranging from 221 to 232^{o}C.

Freezing Data

It was difficult to observe T_E in some of the quartz inclusions where melting started at temperstures less than -40^{o}C. In other inclusions, melting was first observed at temperatures between -56 and -51^{o}C, implying the presence of a complex salt system. Final melting occurred between -7 and -1^{o}C, (I=2.3 to 0.5) indicating a relatively low salinity (near seawater) fluid. The primary inclusions tend to be more saline.

No quartz inclusions were crushed due to the hardness of quartz.

CALCITE

Homogenization Data

The calcite cement contained three types of inclusions:

1. two-phase aqueous LV,

2. three-phase LLV (hydrocarbon liquid, aqueous liquid, vapour) and

3. four-phase SLLV (solid, hydrocarbon liquid, aqueous

liquid, vapour).

It is unclear which of these are primary and secondary. The two-phase inclusions have T_h ranging from 162 to 189^{o}C in the Pointed Mountain gas field, and 113 to 134^{o}C in wells to the northeast (Mobil Fort Simpson M-70 and Imperial Sun Netla Raven F-73).

The presence of hydrocarbons was detected examining the inclusions under ultraviolet (UV) illumination. Aromatic compounds fluoresce under UV excitation.

The solid present in type 3 inclusions is a daughter crystal which formed from the saline fluids in the inclusion after trapping.

Freezing Data

The two-phase inclusions from all samples had similar composition and salinity. T_E ranged from approximately -57 to -53^{o}C indicating a complex salt system. T_f ranged from -17.0 to -12.5 ^{o}C, (I=3.95 to 3.2) implying a high salinity. The presence of daughter crystals in the SLLV inclusions implies high solute content and salinity of the fluid within the inclusion.

Crushing Data

The two-phase aqueous inclusions contain a vapour phase which shrinks on opening to atmospheric pressure.

FLUORITE

Homogenization Data

There are four types of inclusions in fluorite:

a. secondary two-phase aqueous LV, T_h=105-110^{o}C and low salinity,

b. two-phase aqueous LV, T_h=128-130^{o}C and high salinity,

c. two-phase aqueous LV, T_h=124-135^{o}C and low salinity, and

d. single-phase gaseous or liquid.

It is difficult to determine which group of inclusions is primary as types b,c,d do not occur on obvious fractures as type a; but do occur on relatively regular planes. Type d are probably gaseous as they are very dark in colour, possibly due to the difference in the refractive index between the gas and the crystal host.

Freezing Data

The two-phase inclusions all have similar composition with T_E ranging from -58 to -51^{o}C, once again indicating a complex salt system. Salinities vary among the three types as follows:

Type a: T_f=-4.5 to -1.4^{o}C; I=1.95 to 0.6

Type b: T_f=-24.3 to -23.1^{o}C; I=approx. 4.9

Type c: T_f=-7.1 to -6.0^{o}C; I=approx. 2.3

Crushing Data

Types b,c,d contain a vapour under pressure. I was unable to observe Type a on crushing.

INTERPRETATION

Overall, the fluid inclusion data indicate the diagenetic mineral phases formed under relatively high temperature conditions. The variable salinity suggests changes in the source of the fluids. At least two episodes

of hydrocarbon migration occurred, on the basis of the following evidence: the presence of bitumen post-white dolomite and pre- quartz, the presence of a vapour under pressure in fluorite-hosted inclusions and fluorescent hydrocarbons found in one inclusion type in post-quartz calcite.

THERMAL HISTORY

Using the bottomhole temperature, total depth and an average surface temperature of 5°C, the present geothermal gradient for the region was calculated for the following wells:

Well	Geothermal Grad.
Pan Am Beaver YT G-01	34°C/km
Amoco A-4 Pointed Mountain A-55	38°C/km
Texaco Teck Iverson Lake M-69	39°C/km

The average of these three gradients is 37°C/km which will be used in all further calculations. For an average T_h of 205°C for quartz and 185°C for dolomite, burial required would be 5.54 km (16,888 ft.) and 5.0 km (15,240 ft.), respectively. This degree of burial is reached in the Cretaceous in the Pointed Mountain-Kotaneelee region (Figure 8, Morrow and Cummings, in press). In the Mobil Fort Simpson M-70 well to the northeast of the gas fields, the T_h for dolomite is about 170°C (current burial 757 m, 2307.5 ft.). This dolomite would require burial to a depth of 4.6 km (14.021 ft.) to form under "normal" geothermal conditions. It appears unlikely that this region was buried this deeply due

to depositional thinning and lack of loading due to orogeny as seen in the gas field region. Thus it is likely that an additional heat source is required to attain these temperatures.

The T_h of the calcite cement decreases from the gas fields in the southwest to the shallower wells in the northeast. This may indicate updip migration and cooling of the fluids from the southwest to northeast or differential burial during calcite cementation. Hydrocarbons were also being carried with the fluids which formed the calcite cements.

DIAGENETIC FLUIDS

The possible sources of the diagenetic fluids and relative timing of events may be determined by dividing the cements into similar groups on the basis of their fluid inclusion characteristics. We propose that there are three or four types of diagenetic fluids, based on homogenization temperatures and fluid salinity. They are divided as follows:

1. Hypersaline Brine

Cement Type	Well	T_f(°C)	T_h(°C)
Dolomite	H-38	-19 to -29	175
Dolomite	A-55	-20 to -25	185
Fluorite	L-59	-23 to -24	130

2. Saline Water

Fluorite	L-59	-6 to -7	106
Quartz	H-38	-6 to -7	200
Quartz	M-70	-6 to -7	160

3. ?Seawater

Fluorite	L-59	-1 to -5	135
(Secondary inclusions in fluorite)			
Quartz	H-38	-1 to -4	173 and 223

4. Brine

?Dolomite	A-55	-15 to -17	175
Calcite	A-55	-12 to -16	170
Calcite	M-70	-14 to -17	125

The first diagenetic event occurred when a hypersaline brine passed through the area precipitating dolomite and fluorite.

The second event involved fluids two to three times more saline than seawater precipitating fluorite and quartz.

The third event (which may be the same as the second, but slightly less saline) may represent seawater.

The fourth event has a saline brine, approximately 6 to 8 times more saline than seawater precipitating calcite and ?dolomite. There are only three data points for dolomite in this range. These may be anomalous values as there does not appear to be a second dolomitization event. One possibility is that these are secondary inclusions containing the fluids present at the time of calcite cementation.

It is obvious that the diagenetic fluid salinity has fluctuated through time, precipitating a variety of mineral phases. These data seem to place constraints on the relative timing of the fluorite and quartz cements, with the fluorite forming prior to the quartz. There appears to be a cooling trend away from the gas fields, with calcite and quartz temperatures decreasing and fluorite (assumed to have formed

in the same event as the dolomite) having a lower homogenization temperature than the dolomite formed in the gas fields.

OXYGEN ISOTOPES

Fluid inclusion homogenization temperatures were determined for two dolomite samples from the Amoco A-4 Pointed Mountain A-55 well (10600 ft., 11205.5 ft.) for which O^{18} isotope data are available (Morrow and Cummings, in press). An attempt will be made to correlate fluid inclusion temperatures with temperatures derived from isotope data. Using a graph of temperature versus $\delta^{18}O$ dolomite (PDB) (Figure 6) from Land (1983, Figure 4-2), the $\delta^{18}O$ isotope data from these samples and fluid inclusion temperatures can be used to derive an initial water composition. All $\delta^{18}O$ for water composition are with respect to SMOW. Sample 10600 has a $\delta^{18}O$=-14.32 and average T_h=195.1°C. Using Figure 6, which has been extrapolated beyond -12 per mil (PDB), an initial water composition of approximately +5 to 6 per mil (SMOW) is obtained. Sample 11205.5 has a $\delta^{18}O$=-13.11 and an average T_h=186.2°C. This yields an initial water composition of +5 to 6 per mil.

Pierre (1982) has done research on the isotopic content of seawater on evaporation. She obtained a curve (Figure 7) for $\delta^{18}O$ (SMOW) versus density for evaporating seawater at Salin-de-Giraud, the Camargue, France. The dolomites under consideration are at halite saturation (fluid inclusion freezing data). Using a density of 1.200 g/cm^3 (Figure 12 from Pierre, 1982) for seawater evaporated to halite

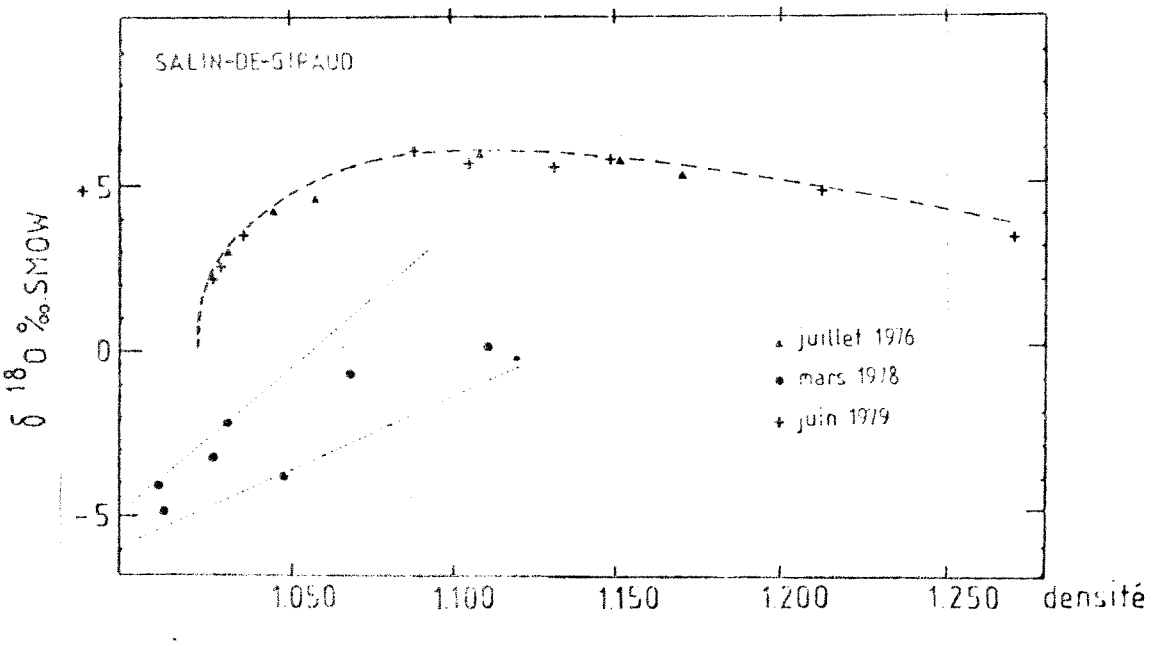

Figure 7. Evolution of the $\delta^{18}O$ (SMOW) composition of seawater in the course of evaporation at Salin-de-Giraud, France (from Pierre, 1982, Figure 11).

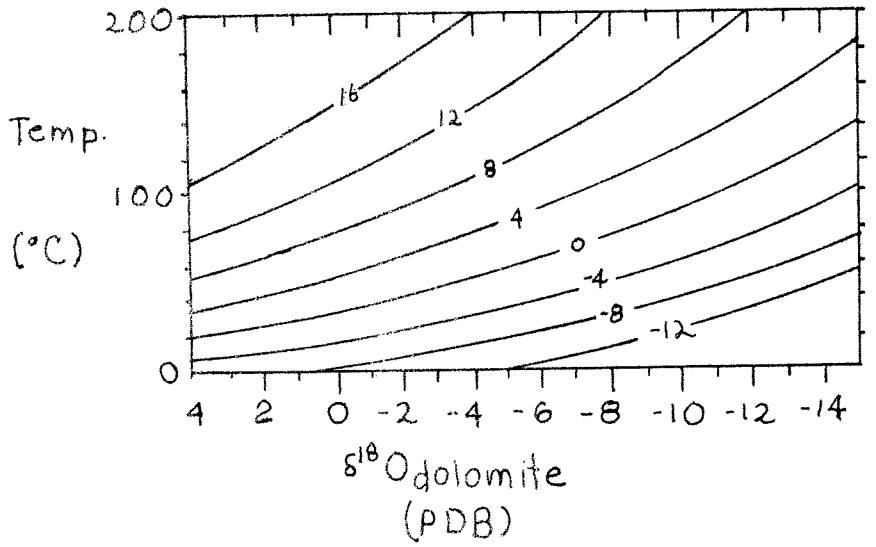

Figure 6. Modified temperature vs. $\delta^{18}O$ (PDB scale) dolomite for various $\delta^{18}O$ (SMOW scale) water compositions (from Land, 1983, Figure 4-2).

saturation, Figure 7 gives a $\delta^{18}O$ content of approximately +5 per mil (SMOW). This is in close agreement with the initial water composition derived from fluid inclusion temperature data and oxygen isotopes from the dolomite cements. Thus, it appears that the white dolomite cements formed from fluids derived from an evaporated seawater source.

CONCLUSIONS

Fluid inclusion data indicate that the white dolomite cements of the Manetoe facies formed from relatively hot, hypersaline brines. The temperatures determined from oxygen isotope values and an initial hypersaline brine are in good agreement with the fluid inclusion homogenization temperatures. Other associated mineral phases formed from relatively hot, saline to seawater salinity fluids. The changes in salinity imply changes in the source of the diagenetic fluids. It seems likely that a heat source in addition to burial is required to produce the temperatures recorded here. As well, there were two hydrocarbon migration events through the area.

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APPENDIX A

PAN AM BEAVER YT G-01

(60.00694°N 124.26333°W) lat. 60°00'25"; long.124°15'48"

Core 12 13530-13568´ rec. 35´ Nahanni Formation

Medium-dark gray dolomite, fine to microcrystalline, dark gray dolomite is brecciated, ?solution collapse,?talus; approx. 10% white dolomite as thin < 1/2 cm veins decreasing to 5% at top; gray dolomite is darker and more argillaceous at base; approx. 5% calcite as irregular blebs and veins; no porosity; minor galena at 13565, 63, and 13561´.

Core 13 13568-13591´

As above, minor shell fragments, large approx. 10 x 15 cm strom. fragment at 13572´.

Core 14 13663-13723´ rec. 60´

Dark/medium gray dolomite, brecciated, micro-finely crystalline; approx. 10% white dolomite mottled with and brecciating gray dolomite; bitumen fills some vugs and intercrystalline porosity, post white dolomite; moderately abundant calcite, post-white dolomite in some vugs and veins; minor quartz crystals in some vugs and veins, post white dolomite; minor porosity in veins containing quartz; increase in porosity in incompletely filled vugs from top to 13699´, then decrease in porosity to base of core; at 13701´, large vugs filled with calcite, 6x2 cm.

Core 15 13724-13764´ rec. 38´

Similar to core 14; large clasts dark gray finely crystalline subrounded, in sand sized dolomite fragment matrix; also brecciated by white dolomite and calcite; minor brachiopod and crinoid fragments; approx. 5-10% white dolomite and 5% calcite as vug and vein fill, also partly replacing fossil material; at 13752´ increase in white dolomite to 15% to base; sphalerite cross-cut dolomite, quartz, calcite, in vug at 13754´; ?quartz pre-calcite; at 13758´, gray dolomite is vaguely laminated, white dolomite forms dis rupted brick laminite.

Core 16 13927-13964´ rec. 37´

Dark gray, finely crystalline dolomite; 15% white dolomite as irreg blebs and veins (subhorizontal and vertical), also replacing unidentifiable skeletal material, poor vuggy porosity, not interconnected; some vugs contain quartz crystals; 13946´ vug filled with quartz crystals growing from top to base of vug, 1 crystal 1x3cm; calcite in large vein and minor vug fill at 13949-51´; also sphalerite in calcite vein at 13951´, calcite in 2 cm veins lowest 2´ of core.

Core 17 13964-13970´ rec. 4´

As above no calcite.

Core 18 13970-13973´ rec. 3´

As above, some calcite as vein fill.

Core 19 14175-14208´ rec. 33´

14175-14184.5´ medium gray dolomite;20% white dolomite veins 1/2 to 2 cm diameter, these cross-cut by thin (<2mm) spidery veins of calcite, which are cross-cut by stylolites, some are vertical.

14184.5-14199´ ?Fault zone, finely brecciated dark gray dolomite, fragments few mm; surrounded by light gray dolomite, vertical and horizontal stylolites, a vertical fault offsets white dolomite vein by 4 cm.

14199-14203´ Medium gray limestone, approx. 10% white dolomite offset by microfractures filled with calcite and white dolomite; stylolites.

14203-14208´ Medium to dark gray, micro-finely crystalline dolomite, mottled with 20-30% white dolomite.

Core 20 14410-14435´ Arnica Formation

Dark gray dolomite, as above; 20% white dolomite; 5% calcite as veins, post white dolomite to several cm thick, veins subhorizontal, most without calcite have fair porosity.

SOBC-SHELL BEAVERCROW YT K-02

(60.02889°N 125.02000°W) lat.60°01'44"; long.125°01'12"

Core 2 4786-4808´ Nahanni Formation

4786-4796´ Medium grey, mottled to brecciated dolomite; brecciated by veins lined with 1 mm white dolomite, then filled with several mm of calcite; fragments of stromatoporoids replaced by light gray dolomite.

4796-4801´ Medium to dark gray, micro-finely crystalline dolomite; white dolomite + calcite = 15%; calcite minor, some brecciation, fragments subangular, several cm.

4801-4804´ Gray dolomite, as above; white dolomite + calcite < 5% as veins <1/2 cm wide; minor brecciation; minor quartz in vug at 4803´; stylolites.

4804-4808´ Dark gray dolomite, finely crystalline to medium crystalline near 15% white dolomite; white dolomite +

calcite as irregular patches and interconnecting veins which contain few mm angular fragments of host; ?relict pellets near base.

Core 3 7630-7635´ Ronning/ Arnica Formation

Dark gray dolomitized wackestone; crinoids, brachiopods, shell fragments; 10% white dolomite as blebs and irregular veins < 1/2 cm diameter; stylolites.

BLUEMOUNT et al BEAVERCROW YT B-16

(60.08425°N 125.30131°W) lat.60°05'04"; long.125°17'48"

Core from this well containing the Manetoe facies is shattered, eaten by the drill bit. No exact measurements were taken. Core consists of argillaceous, dark gray microcrystalline dolomite with 10% white dolomite ; ? calcite in vugs post-white dolomite.

COLUMBIA et al KOTANEELEE YT E-37

(60.1750°N 124.12111°W) lat.60°06'27"; long.124°07'16"

Core 4 12799-12859´ Nahanni Formation

Dark gray - black argillaceous micro-finely crystalline host dolomite, mottled with and brecciated by 15-20% white dolomite, white dolomite occurs as irregular blebs, veins, and replacing fossil material (brachiopods, corals bryozoans, strom fragments, ?Amphipora); minor light brown/gray dolomite in strom fragments; breccia fragments are subangular, few mm to several cm; very abundant bitumen infills vugs; bitumen in some veins to 3/4 cm wide; minor quartz in some vugs post-bitumen, stylolitic; galena at 12831 as irregular blebs; decrease in white dolomite to 10% at base.

Core 5 12859-12919´

12859-12865´ Dark gray, micro-finely crystalline dolomite, cut by vein network of 15% white dolomite; minor brecciation, bitumen in centre of veins, minor fossils, replaced by white dolomite; stylolites.

12865-12897´ As above, increase of fossils to abundant; strom fragments, corals, brachiopods, Amphipora; some light gray dolomite replacing fossils, minor quartz post-white dolomite in vugs and moldic porosity from leaching of shell maeterial; minor fracture and vuggy porosity.

12897-12899´ Decrease white dolomite to 5%, minor quartz, very little skeletal debris.

12899-12909´ As 12865-12897´, minor pyrite at 99.5´.

12909-12913´ As 12897-12899´.

12913-12919´ As 12865-12897´.

Core 6 12919-12969´

12919-12926.5´ Dark gray micro-finely crystalline host dolomite; 10% white dolomite as vein network, vugs filled with bitumen; gray dolomite often coarser grained near white dolomite; minor fossils, corals, brachiopods.

12926.5-12967´ As above, with minor brecciation, increased amount of fossil material, some fossil fragments are light gray dolomite; calcite present post-white dolomite and bitumen as vug fill; vug at 12946 containing dolomite, bitumen, quartz, calcite, quartz on top of vug, euhedral crystals, calcite appears to grow from quartz; very poor vuggy porosity, occluded by bitumen, quartz, calcite.

CANADIAN SOUTHERN et al NORTH BEAVER RIVER YT I-27

(60.11155° N 124.06462°W) lat.60°06'42"; long.124°03'53"

Core 1 12591-12619´ Nahanni Formation

Dolomite, dark gray, micro-finely crystalline, approx. 20% white dolomite as irregular veins and blebs, some veins contain subangular to angular fragments of gray dolomite; some white dolomite has replaced fossil material - ? shells, stromatoporoids, corals; some strom. fragments are replaced by light gray dolomite prior to white dolomite cement; some vugs in white dolomite are filled with cream to white calcite; stylolites cut white dolomite and calcite in vug; minor quartz crystals in some vugs post-white dolomite; poor vuggy porosity, most < 1/2 cm; minor bitumen post white dolomite, pre-calcite.

COLUMBIA et al KOTANEELEE YT I-48

(60.12639°N 124.12667°W) lat.60°07'36"; long.124°07'36"
N.B. This well measured in metres.

Core 1 3660-3665.7 m Nahanni Formation

3660-3663.5m Medium/dark gray micro-finely crystalline dolomite; patchy replacement of some fossil material by light gray dolomite; brecciated by 25% white dolomite; fragments subangular to subrounded to 4 cm diameter; minor brachiopods, corals, crinoids, strom fragments; some veins white dolomite partly to completely filled with quartz; vugs contain small (few mm) to large (cms) quartz crystals; poor/fair vuggy porosity; stylolites; open vertical fractures lined with white dolomite and quartz.

3663.5-64.9 m As above, less brecciated; 15% white dolomite; poor vuggy porosity,; minor oxidized sphalerite seen in white dolomite.

Core 2 3665.7-3668.8 m rec. 1.9 m

Dark gray dolomite, finely-microcrystalline, brecciated by 15-20% white dolomite, clasts subangulsr, few mm to 6 cm, clasts contain white dolomite cut by brecciation; light gray dolomite very minor; brachiopods, corals replaced by white dolomite; minor bitumen fills some vugs post-white dolomite; decreasing amount white dolomite to 10% at base.

Core 3 3668.8-3672.1 m rec. 1.7 m

Dolomite, medium to dark gray, fineto microcrystalline; brecciated by 15% white dolomite ; quartz infill centre most vugs and veins; in some places bitumen infills intercrystalline porosity in dark gray dolomite and vugs in white dolomite; some vugs have white dolomite and quartz but no bitumen; ? isolated prior to hydrocarbon migration; brachiopods, corals, bryozoans replaced by white dolomite; sphalerite crystals in white dolomite, quartz, and porosity; fair vuggy porosity.

Core 4 3724-3741 m

3724-3726 m Dark gray dolomite, micro-finely crystalline; brecciated and mottled with 25% white dolomite; quartz crystals in vugs; fair vuggy porosity.

3726-29.2 m 10-15% white dolomite, as mottled vein network, replacing minor shell fragments; poor vuggy porosity.

3729.2-31 m 20% white dolomite, stromatoporoids to 8 cm, corals replaced by light gray dolomite cross-cut by white dolomite; poor vuggy porosity.

3731-33.5 m 10% white dolomite as irregular veins, replacing unidentifiable skeletal material, 1 gastropod; minor vuggy porosity, porosity in centre some veins; minor bitumen in some veins; stylolite cross-cut veins.

3733.5-34.5 m 15% white dolomite as irregular blebs, veins; light gray dolomite replacing minor fossil material; quartz in some vugs and veins; stylolites.

3734.5-36 m As 31-33.5 m.

3736-39 m As 33.5-34.5 m.

3739-40.5 m Gray dolomite; float-rudstone; large stromatoporoid fragments light gray; corals, brachiopods light gray and white dolomite ; fair vuggy porosity, vugs

large to 8 cm, large quartz crystals; vug at 39.2 with quartz and calcite.

3740.5-41 m As 33.5-34.5 m.

Core 5 3741-3759.2 m

3741-42.2 m 15% white dolomite in dark gray dolomite, fine-micro crystalline; minor brecciation by irregular veins; stromatoporoids, corals, brachiopods replaced by light gray and white dolomite; bitumen in open veins; stylolite.

3742.2-2.95 m Dark gray dolomite, vague laminae, 5% white dolomite as horizontal veins, replacing brachiopods; stylolites; bitumen in centre of veins.

3742.95-5.3 m 20% white dolomite, irregular veins, fossil replacement, minor brecciation, fragments to 5 cm, subangular; galena at 44.3 m; large number brachiopods, few corals and stromatoporoids > 2 cm are light gray dolomite ; quartz infills some vugs as cloudy and clear crystals; bitumen in veins; fair vuggy porosity.

3745.3-45.7 m As 42.2-42.95 m.

3745.7-49.2 m As 42.95-45.3; galena bleb at 47.2 m; stylolite cuts vein filled with quartz.

3749.2-50.7 m 30% white dolomite, brecciating dark gray dolomite; as 42.95-45.3.

3750.7-52.2 m As above, 20% white dolomite.

3752.2-52.7 m Vague laminae in finely crystalline dolomite; 20% white dolomite follows laminae, horizontal; minor quartz in vugs and open veins.

3752.7-54.3 m As 42.95-45.3 m; 15% white dolomite.

3754.3-54.8 m As 52.2-52.7; dark gray dolomite laminated; minor pyrite post-white dolomite in small vug.

3754.8-59.2 m As 42.95-45.3 m; 15-20% white dolomite.

Core 6 3759.2-3771.6 m

Dark-medium gray dolomite, mottled to minor brecciation by 15-30% white dolomite; fair vuggy porosity connected by partly open fractures; corals, stromatoporoid fragments light gray to white dolomite ; quartz some vugs, large crystals; decrease amount white dolomite to 10% at base; bitumen in some porosity; stylolites.

Core 7 3771.6-3774.2 m

Dark gray dolomite, fine-microcrystalline; 15% white dolomite as horizontal/subhorizontal fracture/vug system; minor quartz crystals in some vugs; fair vuggy porosity; stromatoporoid fragments at top replaced by 90% light gray / 10% white dolomite; dark gray dolomite mottled.

Core 8 3774.2-3782.4 m
Dark/medium gray, mottled dolomite, fine-microcrystalline; 1 cm bands rich brachiopods, shell fragments, preferentially replaced with white dolomite; ? load structures in medium/dark gray dolomite; quartz crystals in vugs; minor stromatoporoids and corals replaced by light gray and white dolomite.

Core 9 3910.4-3912.6 m Headless Formation

Dark gray dolomite, finely crystalline,mottled, minor brecciation; fractures filled with white dolomite; mainly subhorizontal; no fossils, stylolites; minor vuggy porosity.

Core 10 3912.6-3916 m

3912.6-13.5 m Dark gray dolomite, brecciated by 25% white dolomite; veins white dolomite (several cm) contain angular fragments dark gray dolomite; ? minor brachiopods.

3913.5-14 m Dark/medium gray dolomite, wavy-lenticular laminae to nodular (medium in dark gray); horizontal veins white dolomite follow dark laminae; 10% white dolomite; bitumen infill some porosity in white dolomite.

3914-16 m Tight massive medium gray dolomite; <5% white dolomite veins; poor porosity.

Core 11 3949.2-3956.8 m
3949.2-50.2 m 10% white dolomite replacing shell fragments, gastropods and as horizontal veins and irregular blebs; host - dark gray dolomite mottled, fine-microcrystalline, more coarsely crystalline near white dolomite; minor vuggy porosity.

3950.2-51 m <5% white dolomite as irregular veinlets 1 mm diameter; dark to medium gray fine-microcrystalline dolomite.

3951-55.2 m Medium gray microcrystalline dolomite; <5% white dolomite as small (<2mm) flecks and as minor horizontal veins, minor bitumen; minor stylolites.

3955.2-56.8 m 10% white dolomite as horizontal veins and irregular blebs locally more abundant with 1-2´ intervals as 3951-55.2 m; poor vuggy porosity; minor quartz crystals in some veins.

Core 12 4035-4036.6 m Arnica Formation

4035-35.7 m Light gray/brown dolomite, microcrystalline (?micritic), micro-fractures <1 mm filled with white dolomite (<5%).

4035.7-36.6 m As above, vaguely laminated; 5% white dolomite as subvertical 4 mm veins.

Core 13 4036.6-4043.6 m

4036.6-37.6 m As 4035.7-36.6 m with minor vugs lined with white dolomite; minor skeletal material replaced by white dolomite.

4037.6-39.8 m Medium gray/brown fine-microcrystalline dolomite; subvertical veins to several mm filled with white dolomite; poor vuggy porosity;bitumen fills some veins; more fossils than above; some moldic porosity; stylolites.

4039.8-40 m Float/rudstone, dark gray dolomite, fine-microcrystalline with corals and stromatoporoids replace by light gray and white dolomite, vuggy, moldic porosity, 10% white dolomite.

4040-43.1 m 15% white dolomite; dark gray dolomite, fine-microcrystalline, poor vuggy porosity; veins horizontal and subvertical, some filled with bitumen; minor calcite as vug fill.

4043.1-43.6 m Medium gray /brown micritic microcrystalline dolomite; 5%white dolomite as 2 mm blebs- ?fenestral fabric.

Core 14 4043.6-4046 m

Light to medium gray/brown dolomite, microcrystalline, fractured, 5% white dolomite as veins and minor fossil replacement.

Core 15 4158.2-4165.2 m

Medium gray/brown dolomite, finely crystalline, a few small (< 1 cm) vugs at top, few small (<2mm) veins filled with dolomite at base; quartz as minor vug fill; 5% white dolomite.

Core 16 4424.4-4429.4 m

As above, minor calcite as vein fill.

COLUMBIA KOTANEELEE YT H-38

lat.60°07'16"; long.124°06'03"

11690-700´ Dolomitized fossiliferous wackestone, dark gray; crinoids, Amphipora, molluscs; white dolomite as irregular veins, vugs in white dolomite lined with bitumen

and quartz; sphalerite cuts dolomite and quartz; minor brecciation.

11700-703′ As above, some vugs filled with bitumen.

11730-705′ As above, more shells; some geopetal structures, sediment on base, then white dolomite around edge, quartz infill; some shells leached and filled to partly filled with white dolomite creating vuggy porosity.

11705-726′ Minor white dolomite, dark gray micro-finely crystalline dolomite; quartz crystals in vugs; numerous stylolites, coral at 711′.

11726-30′ As above, contains transported domal stromatoporoids; minor pyrite.

11730-39′ Lenses medium crystalline gray dolomite in host as above; less sphalerite than above; some vuggy porosity.

11739-40′ Gastropods, brachiopods replaced by white dolomite.

11740-744′ Dark gray dolomite with white dolomite veins, increasingly fine crystalline to base.

11744-46 As above, core broken.

11746-50 Mottled micro-finely crystalline gray dolomite, numerous stylolites; small vugs with white dolomite and quartz infill.

12040-45′ Dark gray dolomite, light gray dolomite stromatoporoids to 10 cm diameter.; brecciated fragments drak dolomite in white dolomite veins; veins to 2 cm; vugs to several cm; brachiopods, strom. fragments, minor Thamnapora; geopetal structures in some brachiopods.

12045-46′ ?cryptalgal layering dark gray and white dolomite.

12046-63′ As 12040-45′, minor stromatoporoids., minor quartz at 12063′.

12260-66′ Dark gray dolomite, microcrystalline, trace argillaceous stringers; white dolomite vein cement contains angular breccia fragments of surrounding dolomite; no fossils; minor small vugs; some fractures not totally filled.

12266-68′ Brickwork laminite, brecciated by white dolomite, gray dolomite fragments are laminated; carbonaceous stylolites.

12268-76.5′ As above, less white dolomite; a few shells; minor bitumen in vugs.

12276.5-79 Massive dark gray dolomite, microcrystalline, minor white dolomite; pyrite.

12279-83′ As above, increase white dolomite.

12283-85′ Very brecciated, angular fragments to 5 cm; quartz in vug at 83′.

12285-90′ Dark gray dolomite , microcrystalline, some laminations, some burrows, preferentially replaced by white dolomite.

12290-97.5 As above, micro-medium crystalline.

12297.5-98.5′ Fossiliferous zone; gastropods, brachiopods, some vugs resulting from leaching of shells and partial fill with white dolomite.

12298.5-315′ Mottled medium crystalline gray dolomite, veins white dolomite, minor brecciation at 305′; pyrite.

12315-18.5′ Fossil rich beds alternating with fossil poor dark gray dolomite, microcrystalline; fossils- Amphipora, corals, brachiopods.

12318.5-20′ As 12298.5-315′.

12450-53.5′ Dark gray dolomite, micro-finely crystalline; white dolomite veins to 2 cm; gray dolomite vaguely laminated; some brecciation.

12453.5-72′ As above, more brecciation, glassy bitumen infills some veins; unfossiliferous; stylolites.

12472-74′ Minor Amphipora.

12474-77′ As above, massive, minor brecciation at base; minor quartz.

12477-79′ Some fossil devris, < 2 mm; minor open microfractures; minor vuggy porosity.

12479-84′ Mainly mottled dark gray dolomite; 15% white dolomite as subhorizontal veins.

12484-86′ Finely crystalline dark gray dolomite, vaguely laminated, minor brecciation.

12486-91′ More white dolomite mottled with gray dolomite; some angular breccia fragments within veins.

12491-96′ Entire core brecciated versus breccia in veins

above; very minor vuggy porosity.

12496-97.5′ Brickwork laminite.

12497.5-505′ Dark gray dolomite, microcrystalline, minor porosity in vertical veins.

12505-508′ As 12497.5-505′.

12508-510′ As 12486-91′.

12708-718′ Dark gray dolomite, mottled to massive, very finely crystalline; stylolites, 5% white dolomite as 1 mm veins.

12718-20′ 15% white dolomite ; as veins with porosity in centre of veins; minor quartz crystals as vein fill after white dolomite.

12720-22′ As 12708-18′.

12722-22.5′ Brickwork laminite; stylolite at base.

12722.5-24.5′ As 12708-718′.

12724.5-27.5′ Angular brecciation fragments to 8 cm; vuggy porosity; large quartz in some vugs; ? altered rims lighter dolomite around fragments at 26′.

12727.5-28.5′ ?Cryptalgal- vague crinkly layering of white dolomite cement; minor porosity in white dolomite.

12728.5-31′ Dark gray dolomite , micro-finely crystalline, white dolomite veins, porosity in centre.

12731-32.5′ As 12727.5-28.5′.

12732.5-36′ As at 12708".

12736-37.5′ Very dark gray dolomite, medium crystalline, mottled horzontal and vertical veins white dolomite.

12737.5-39′ As above, some fossil debris.

12739-40′ Dark gray dolomite, with 2 cm horizontal veins white dolomite.

12740-42′ As 12708′.

12742-46.5′ As 12727.5-28.5′.

127846.5-47′ Bands (5-10 cm) fine and coarse crystalline dolomite.

12747-53′ Mottled well-mixed white dolomite/coarsely

crystalline dark gray dolomite.

12753-61.5′ Finely crystalline dark gray dolomite, very minor white dolomite veins.

12761.5-63′ ?Stromactactis porosity, outlined by white dolomite; some large veins white dolomite.

12763-66.5′ Laminated mud load structures, ripples; 10% white dolomite as open veins follows mud alminae.

12766.5-71′ Dark gray dolomite, 10% white dolomite as 1 cm open veins.

12771-72′ Brecciated, vaguely laminated gray dolomite; somewhat zebraic in patches; subparallel bedding; minor vuggy porosity; vertical vein system appears post-horizontal.

12772-75′ Dark gray dolomite, finely crystalline; 10% white dolomite as vertical fractures, some open.

12775-80.5′ 20% white dolomite, slightly brecciated; some vuggy porosity; pyrite in veins post-dolomite and bitumen at 76.5′

12780.5-82.5′ As above, more brecciated; minor quartz; vuggy porosity.

12782.5-88′ Dark gray dolomite, finely crystalline, slightly mottled; 10% white dolomite , mottled with gray; slightly vuggy.

12788-89′ Zebraic; horizontal alternating bands gray /white dolomite; open vein porosity.

PAN AM A-3 POINTED MOUNTAIN G-62

(60.35744°N 123.94633°W) lat.60°21'27"; long.123°56'47"

N.B. Core brecciated by bit, in small pieces.

Core 1 13131-13173′ Nahanni Formation

13131-41 30% white dolomite as irregular veins, patches and replacing skeletal material in in dark gray finely crystalline host dolomite (float-rudstone); stylolites; quartz crystals fill to partly fill vugs; good vuggy porosity; bitumen fills some small vugs; fossils include brachiopods, small stromatoporoids, small corals; gray dolomite appears coarser near white dolomite; few patches black argillaceous dolomite brecciated by white dolomite , also contain white dolomite as fossil replacement; sadlle dolomite in vugs.

13141-42.5′ 15% white dolomite , as above, fewer fossils,

poor vuggy porosity.

13142.5-49.5′ 20% white dolomite mottled with dark gray finely crystalline dolomite; veins white dolomite to several cm, subhorizontal; minor brecciation, fragments angular to several cm; bitumen fills some vugs; poor vuggy porosity.

13149.5-73′ 25% white dolomite , mottled with dark gray micro-finely crystalline dolomite; several cm veins subhorizontal; bitumen in centre of veins; gray dolomite coarser in general near white dolomite veins; corals, brachiopods, small stromatoporoids replaced by white dolomite; some moldic porosity filled with quartz, post-white dolomite.

Core 2 13165-13188′ rec. 11.8′

20% white dolomite as veins, irregular patches, fossil replacement, mottled with dark micro-finely crystalline gray dolomite; stromatoporoids, corals, brachiopods; fair vuggy porosity; quartz as large crystals (1x2 cm) in some vugs and replacing fossils; bitumen in some veins; stylolites.

Core 3 13188-13194′ rec. 3.9′

15% white dolomite as mottled irregular veins in dark gray dolomite; minor fossils; minor quartz; poor vuggy porosity; stylolites.

Core 4 13311-13326′ rec. 13′

As above with brecciation; porosity in centre of veins partly occluded by bitumen.

Core 5 13326-13340′ rec. 10′

As above, a few small (2 cm) stromatoporoid fragments at base replaced by white dolomite.

Core 6 13670-13697′ rec. 22′

10% white dolomite in very dark gray micro-finely crystalline dolomite, argillaceous , numerous partings; minor gastropods, brachiopods, stromatoporoids replaced by white dolomite ; gray dolomite mottled to vaguely laminated, appears coarser near white dolomite; ? relict of soft sediment deformation at 83′.

Core 7 13870-13882′ rec. 7.4′ Headless Formation

13870-72′ Medium crystalline, medium gray dolomite mottled with 10% white dolomite cement; intercrystalline porosity filled with bitumen; relict shell material.

13872-base Argillaceous, black dolomite, vague laminations, pyrite flecks; <2% white dolomite as <1/2 cm patches.

Core 8 Medium gray/brown dolomite becoming lighter at base, nodular to massive at base; 5-10% white dolomite as irregular veins and replacing crinoids and small brachiopods.

AMOCO A-4 POINTED MOUNTAIN A-55

(60.40139°N 123.91085°W) lat.60°24'05"; long.123°54'39"

Core 1 10296-10348' Nahanni Formation

10296-299' Medium-dark gray dolomite, micro-coarsely crystalline, mottled as a result of varying crystallinity; 25% white dolomite cement; saddle dolomite in vugs; veins of white dolomite from few mm to 2 cm; fair vuggy porosity, some vugs to 8 cm diameter; coarsely crystalline dolomite has bitumen/argillaceous material around crystals as in Berry F-71 well; brachiopods replaced by white dolomite; quartz fills to partly fills some smaller vugs (few cm), originally a lime wackestone.

10299-10303' As above with brecciation of gray dolomite by white dolomite ; breccia fragments angular to sub angular, few mm to 3 cm; white dolomite associated with brecciation also in thin veins (1-5 mm).

10303-305' As above originally a lime floatstone; large number of whole brachiopods and shell fragments.

10305-309 As above, 20% white dolomite, brecciated by veins to 1 cm; breccia fragments angular, few mm to 10 cm; vugs to 5 cm diameter; stylolites; gray dolomite mottled due to variations in crystal sizes, ? result of invasion of white dolomite; band of black microcrystalline dolomite at 10301.5', stylolitic upper contact, brecciated by white dolomite.

10309-10312' As above, more brachiopods, some with geopetal structure, sediments at base, white dolomite cement on top; white dolomite vein cut by stylolite.

10312-13' Medium to dark gray dolomite, mottled, slightly brecciated, some brachiopods replaced by light gray dolomite, then white dolomite cement; calcite as vug fill, 1 quartz crystal at top of vug, bitumen present post-white dolomite around outside of vug; band black dolomite at 12.9', upper and lower contact stylolitic.

10313-314.75' Dark gray dolomite, angular brecciation by 10% very fine (1/2 cm) veins white dolomite; white dolomite veins often contain small (1 mm) fragments of gray dolomite, minor brachiopods, geopetal as above; bitumen in veins

post-white dolomite, quartz in some vugs, poor vuggy porosity.

10314.75′-316′ Gray dolomite brecciated by 20% white dolomite, angular fragments to 7 cm, fair vuggy porosity.

10316′-318′ Gray dolomite mottled to brecciated with 40% white dolomite; breccia fragments angular; ?white dolomite replacing stromatoporoid fragments; vugs to 5 cm; good vuggy porosity; very minor brachiopods.

10318-10320′ 15% white dolomite; quite vuggy; some brachiopods.

10320-10332′ 30-35% white dolomite mottled with gray dolomite, minor brecciation; good vuggy porosity, quartz crystals in some vugs; saddle dolomite in vugs, some bitumen post-white dolomite fills veins to 2 cm diameter; minor brachiopods, corals, ?crinoids

10332-334.5′ 25% white dolomite, brecciated, subangular fragments, few mm to several cm, one fragment black dolomite; very minor brachiopods and corals; minor quartz in vugs; minor vuggy porosity.

10334.5-344′ 30-40% white dolomite, mottled with gray dolomite as above; increased fossil content of light gray dolomite being replaced by white dolomite; quartz as partial vug fill; band black dolomite, stylolitic contacts; stylolites cut white dolomite veins.

10344-344.5′ Brecciated angular fragments black dolomite in white dolomite vein system, tight.

10344.5-347′ Gray dolomite, brecciated by and mottled with 40-50% white dolomite; breccia fragments angular, white dolomite has eaten into them in places giving jagged outline in part; good vuggy porosity.

Core 2 10348-10396′

10347-10359′ As above, 30% white dolomite; calcite as vug fill post-white dolomite and bitumen; 1 large vug 4x8 cm; minor quartz in vug.

10359-360′ As above, 10% white dolomite.

10360-364.5′ As 10347-59′, quartz and calcite in vug at 61′ but calcite on one side of vug, quartz on other, quartz subhedral.

10364.5-10373′ 20% white dolomite, mottled with gray dolomite, most veins subhorizontal, minor brecciation with fragments few mm; bitumen post-white dolomite; minor quartz and calcite in different vugs; good vuggy porosity; minor

brachiopods.

10373-375´ As above, 15% white dolomite.

10375-380´ Dark gray dolomite brecciated by white dolomite veins to several cm wide; good vuggy porosity, minor quartz and calcite.

10380-386´ Mottled dark gray and white dolomite (30-35%); 1 mm subvertical veinlets connected to mottled white dolomite cut by stylolites; minor brachiopods and corals at 81.75´, ?Stachyodes at 82´; minor angular brecciation at 82´, fragments to several cm; white dolomite mixed with light gray dolomite around some vugs, ?vugs strom fragments originally replaced by light gray dolomite as seen in some brachiopods; at 85´ corals/Stachyodes? replaced by light gray quartz; minor quartz as crystals in vugs and as vein cutting white dolomite at 85´.

10386-393´ As above, 20% white dolomite, less mottled more vein network cutting gray dolomite, some angular brecciation; minor brachiopods, small 1/2 cm corals at 89´, geopetal seds in some brachiopods, seds at base, dolomite on top, quartz crystals in some open vugs, good vuggy porosity, some porosity in open veins, quartz in centre of calcite filled vug at 92.5´ but quartz is euhedral.

10393-396´ As above, gray dolomite mottled, 10-15% white dolomite .

Core 3 10600-10658´

10600-005´ Mottled dark gray and white dolomite (25%); a few large vugs; stylolites; very minor brachiopods, corals, gastropods.

10605-008´ As above, mottled to somewhat brecciated; breccia fragments subangular, few mm to 1 cm, minor quartz as vug fill at 07´.

10608-10610.5´ Mottled dark gray dolomite (?burrowed), 5-10% white dolomite as 1 mm to 1 cm veins, minor quartz.

10610.5-613´ 20% white dolomite ; fair vuggy porosity; corals, brachiopods light gray in color.

10613-620.5´ 10% white dolomite; large corals or ?Stachyodes, ?stromatoporoids partly replaced by light gray and white dolomite , usually have vugs at centre; minor small corals and brachiopods; quartz in some open vugs; little bitumen seen.

10620.5-22.75´ <5% white dolomite as <5 mm veins, stylolites.

10622.75-23′ 40% white dolomite mottled with gray dolomite, minor brachiopods and corals, stylolites.

10623-24′ 15% white dolomite as 1 mm veins and 2 cm vugs; minor vuggy porosity; stylolites, minor brachiopods.

10624-26.5′ 25% white dolomite mottled with gray dolomite, good vuggy porosity, minor brachiopods stromatoporoids, gastropods.

10626.5-30.5′ 50% white dolomite mottled to banded with dark gray dolomite, brachiopods, corals, ?Stachyodes; good vuggy porosity, some moldic porosity, stylolites.

10630.5-32.5′ 10% white dolomite as subhorizontal veins and replacing fossils; dark gray dolomite is vaguely laminated; 1 vein contains angular breccia fragments from surrounding dark gray dolomite, fragments few mm to > 2x0.5 cm; little vuggy porosity; stylolites.

10632.5-36′ 20% white dolomite, mottled with dark gray mottled dolomite; increase fossils to base, brachiopods and corals; little vuggy porosity; stylolites.

10636-639′ 30% white dolomite brecciating dark gray dolomite, fragments subangular, a few mm to 10 cm; fair vuggy porosity.

10639-641′ 10% white dolomite, subhorizontal veins, most few mm diameter, angular breccia fragments gray dolomite in veins; dark grey microcrystalline mottled dolomited, lowest 4" laminated; minor brachiopods.

10641-644.5′ 15% white dolomite, mottled with gray dolomite, veins several cm diameter with jagged edges; minor vuggy porosity; stylolites.

10644.5-650.5′ 25-30% white dolomite, as above; numerous stylolites; minor quartz and calcite in separate vugs.

10650.5-651.5′ 15% white dolomite as veins replacing fossils and mottled with micro-finely crystalline medium-dark gray dolomite; minor quartz in some moldic porosity; gastropods most abundant fossil this interval.

10651.5-658′ Mottled to vaguely laminated micro-finely crystalline gray dolomite, ?bioturbated; mottled with 15% white dolomite as jagged veins; minor calcite as vug fill; minor pyrite in gray dolomite; minor brachiopods; fair vuggy porosity; stylolite.

Core 4 10858-10877′

10858-61.75′ 25% white dolomite as mottled veins, some

containing breccia fragments of mottled to vaguely laminated dark gray dolomite; fair vuggy porosity; stylolite.

10861.75-69′ 15% white dolomite, 35% light gray dolomite in dark gray dolomite as above, relict float to rudstone; corals ?Thamnapora, stromatoporoids, ?Amphipora, replaced by light gray and white dolomite; stromatoporoids to 8 cm; white dolomite post-light gray; some moldic and vuggy porosity.

10869-873′ Dark gray dolomite brecciated by 15% white dolomite, breccia fragments angular to several cm long; 5% gray dolomite replacing fossils; minor vuggy and moldic porosity; minor brachiopods, stromatoporoids, corals.

10873-877′ Mottled with mixing of 10% white dolomite/10% light gray dolomite; fair vuggy and moldic porosity; minor brecciation, subangular fragments; quartz in some vugs; light grey also present as mottled bands, ?algal.

Core 5 11200-11260′ Arnica Formation.

11200-201′ Dark gray massive dolomite, slightly brecciated by < 5% white dolomite.

11201-208′ Mottled dark gray dolomite, slightly brecciated by 15-20% white dolomite as veins and fossil (strom) replacement; some white dolomite veins contain orange-red sphalerite; small (< 1cm x 3 mm) quartz crystals in some vugs; minor vuggy porosity; some porosity in veins.

11208-13.5′ As above, but porosity in centre of veins filled with bitumen, pores 1-4 mm diameter; minor brachiopods, geopetal structures; gray dolomite coarser near white dolomite.

11213.5-15′ Laminated dark gray dolomite (due to amount argillaceous matyerial and coarseness of dolomite; brecciated by white dolomite; minor vuggy porosity.

11215-19′ Dark gray dolomite brecciated by 15% white dolomite veins (2 mm-1 cm); breccia fragments angular to several cm; some few mm wide veins offset by micro-fractures; minor calcite as post white dolomite vug fill at 15′.

11219-32′ Mottled to vaguely laminated dark gray dolomite, cross-cut by subvertical and horizontal veinlets (few mm) of 5% white dolomite; minor pockets few cm across of white dolomite; stylolitic throughout; gray dolomite contains small shell fragments, crinoids; minor porosity in veins.

11232-33′ Dark gray dolomite brecciated by 10% white dolomite, angular fragments.

11233-45′ As 11219-32′, bitumen in large vein at 36′;

poor vuggy porosity; sphalerite crystals in vugs at 39, 42´; argillaceous partings in laminted dolomite.

11245-46´ ?Slump, beds contorted, white dolomite follows bend in strata; 25% white dolomite; bitumen in 1 x 0.5 cm pores in centre of veins of white dolomite.

11246-11250´ Dark gray dolomite, some wavy laminations, < 5% white dolomite; minor skeletal material < 1 mm.

112450-60´ Mottled dark gray dolomite, 10% white dolomite as veins, fossil replacement; several large (2-3 cm) veins white dolomite with porosity unfilled by bitumen; stylolites cut white dolomite; gastropods, corals, brachiopods at 57-58´.

Core 6 12144-12204´

12144-48´ Mottled dark/medium gray dolomite, brecciated by white dolomite veins < 1/2 cm diameter; argillaceous stringer.

12148-56´ Vague wavy laminated dark gray dolomite, laminae at 30^{o} to core, bands coarse and fine grained to 1 cm; pyrite in coarser dolomite; 5% white dolomite as vertical and subhorizontal veins, most 1/2 cm; bitumen in some porosity in centre of veins; no vuggy porosity; stylolites cut white dolomite.

12156-64´ 20-30% white dolomite veins to several cm across, one vertical vein followed for 1.5´; large veins contain breccia fragments of gray dolomite, as above; bitumen in porosity; quartz crystals in some vugs; gastropods; minor vuggy porosity; minor pyrite.

12164-71´ 15% white dolomite as few mm subhorizontal veins, a few several cm; numerous stylolites; minor unidentified shell fragments.

12171-71´ Unique feature; very light gray dolomite with fragments darl dolomite at base, stylolite, then darker dolomite containing breccia fragments with white dolomite; stylolite at top.

12172-75.5´ Dark gray mottled (coarse/fine) dolomite; some brecciation by 15% white dolomite, disrupted brickwork laminite; minor bitumen; numerous stylolites.

12175.5-80´ 30% white dolomite mottled with dark gray dolomite; oxidized sphalerite at 76.3´; band very light dolomite (as 71-72´) at 77´; uppper and lower contact stylolitic; band approx. 1 cm.

12180-83.5´ Mottled coarse medium gray/finely crystalline dark gray dolomite; coarse appears related to 10% white

dolomite as one fine grained dark gray dolomite fragment cut by coarser gray and white dolomite at 81´; some stylolites subvertical and few mm thick; pyrite flecks associated with stylolite; minor bitumen in veins white dolomite.

12183.5-88.5´ Dark gray dolomite, subhorizontal laminated to massive; 10% white dolomite as subhorizontal and subvertical veins (approx. perpendicular); stylolites with similar orientation; minor skeletal debris 84-85´.

12188.5-97´ Contorted lamninae approx. vertical in dark gray dolomite; 15% white dolomite; pyrite associated with shaley partings/stylolites, subvertical cut white dolomite; bitumen in veins; subhorizontal veins at 94.3´

12197-201´ Massive dark gray dolomite, subvertical veins 10% white dolomite; shaley partings/stylolites cut white dolomite; bitumen in veins.

12201-203´ Float-rudstone, dolomitized; ?stromatoporoids, shell fragments replaced by light gray and white dolomite, also few mm veins of white dolomite.

PAN AM POINTED MOUNTAIN P-53

(60.37933°N 123.90926°W) lat.60°22'46"; long.123°54'34"

N.B. Poor recovery of core, broken into pieces <6".
Core 1 12845-12865´ rec. 12´ Nahanni Formation

Dark gray micro-finely crystalline dolomite, mottled with 30-40% white dolomite, vugs and poroisty in veins of white dolomite contain bitumen and minor euhedral quartz crystals; white dolomite also replaces corals, shell fragments; poor vuggy porosity; stylolites, 1 vertical; minor brecciation at base.

Core 3 12924-12960´ rec. 9.3´ As above, 20% white dolomite.

Core 4 13060-13075´ rec. 5´ As above

Core 5 13175-13190´ rec. 5´ As above.

Core 6 13315-13323´ rec. 5.1´ As above, with increase in amount of quartz and minor calcite (not in same vugs).

Core 7 13386-13401´ rec. 1.5´ As in Core 5.

Core 8 13609-13624´ Headless Fromation. <5% white dolomite as thin (<4mm) veins.

AMOCO B-2 POINTED MOUNTAIN F-38

lat.60°27'19"; long.123°51'55"

(60.45533°N 123.86526°W)

Core 1 14200-14250′ rec. 46.5′ Nahanni Formation

14200-14223′ Dolomite, dark gray, micro-finely crystalline; mottled with 30% white dolomite, minor brecciation of gray dolomite by white dolomite; fair vuggy porosity, pinpoint to 2.5 cm; quartz infill some vugs, white dolomite replacing abundant fossil material (shells, corals, ?Amphipora); gray dolomite tends to be coarser near white dolomite, minor bitumen in intercrystalline porosity in medium crystalline gray dolomite, ? if coarseness related to white dolomite cementation, then why no bitumen in vugs of white dolomite?; stylolites.

14223-14228′ As above, 40% white dolomite.

Core 2 14371-14384′ rec. 9′

Dolomite, dark gray, micro-finely crystalline; 15-20% white dolomite as irregular blebs and veins; quartz as post-white dolomite vug fill; calcite as vein fill cross-cutting white dolomite; stylolites.

Core 4 14384-14431′ rec. 40′

Dolomite, dark gray, micro-finely crystalline; 20% white dolomite as irregular veins to mottled with gray dolomite, some brecciation, angular fragments of gray dolomite contained in veins of white dolomite, fragments to 0.5x1.5 cm; minor subhedral quartz crystals in some vugs,veins post-white dolomite; 1 vug containing calcite and quartz,quartz crystals subhedral along upper surface, calcite infills remainder of vugs at 407′; white dolomite also replacing shell fragments and corals (?Thamnapora), ? two-holed crinoids at 14417′, fair vuggy porosity, stylolites.

Core 5 14650-14681′ rec. 23.3′

14650-14659.5′ 40% white dolomite as large veins to 5 cm diameter, contain subangular fragments of dark gray dolomite, little evidence of fossil material, some stylolites subvertical, other horizontal.

14659.5-14665′ 10% white dolomite as thin (<1/2 cm) veins; minor vuggy porosity in white dolomite; veins contain fragments dark gray dolomite, minor unidentifiable fossil debris replaced by white dolomite ; large (1.5cm) calcite vein at 64.5′, cut by stylolite; subhorizontal fracture system, open; stylolites very carbonaceous.

14665-14673′ 15-20% white dolomite as irregular blebs and veins to 2 cm; minor brecciation with dark gray dolomite, fine to medium crystalline, as subangular fragments in veins,

minor vuggy porosity in white dolomite.

Core 6 14877-14931´ rec. 3.3´ ?Headless Formation @ 14910´

10% white dolomite as thick 2 cm veins and replacing fossils in fine-medium crystalline, dark gray dolomite.

Core 7 14941-14954´ rec. 9.2´

10% white dolomite as irregular blebs, veins to 1 cm; replacing minor skeletal debris, minor quartz in some vugs.

PAN AM POINTED MOUNTAIN K-45

(60.40939°N 123.89771°W) lat.60°24'34"; long.123°53'52"

Core 1 10088-10146´ Nahanni Formation

10088-10108´ 20-25% white dolomite mottled with micro-finely crystalline dark gray dolomite; minor brecciation of gray dolomite by white dolomite, fragments subangular; bitumen in some vugs of white dolomite, fair vuggy porosity 1/2 x 1.5 cm; quartz crystals few mm to 1/2 cm in vugs; gray dolomite appears coarser, almost medium crystalline, closer to white dolomite; calcite post-bitumen in some white dolomite vugs; some bitumen in intercrystalline porosity in gray dolomite; stylolites, minor fossil material partly replaced by white dolomite.

10108´-10120´ As above, white dolomite 30%; increased fossil content, replaced by white dolomite, shells, strom fragments, vugs in centre some fossil material, very little bitumen in white dolomite.

10120-10127.5´ Gray dolomite as above, mottled to brecciated by 20% white dolomite, breccia fragments few mm to 1.5 cm, angular to subangular; minor quartz in some vugs, calcite in others, post white dolomite; minor bitumen in vugs, dolomite in open vugs have curved faces.

10127.5-10131.5 15% white dolomite, veins few mm to 7.5 mm, cross-cut dark gray dolomite, minor brecciation, minor shell fragments replaced by white dolomite, stylolites.

10131.5-10145´ 30% white dolomite mottled with dark gray dolomite, replacing fossil fragments - shells, corals, strom. fragments; minor brecciation.

Core 2 10145-10174´ rec. 29´

As above, 20-25% white dolomite, medium to large quartz crystals in some vugs, minor calcite as vug fill.

Core 3 10475-10513´ rec. 38´

Dark gray, mottled, micro-finely crystalline dolomite, minor wavy lamiantions; 15% white dolomite as irregular blebs and subhorizontal veins to 3/4 cm diameter, minor brecciation by white dolomite, some strom fragments light gray dolomite partly replaced by white dolomite, other fossil fragments (corals-?Thamnapora, brachiopods) replaced by white dolomite; 1 thin vein calcite cuts white dolomite; minor bitumen in some porosity.

Core 4 10720-10760´

Gray dolomite, as above, mottled with 15% white dolomite, abundant strom fragments to core width (8 cm), most appear light gray, partly replaced by white dolomite with minor quartz or calcite as vug infill, most vugs formed from dissolution of stromatoporoids; a few stylolites.

IMPERIAL SUN ARROWHEAD AURORA M-47

60.61500°N 122.

Core 8042-8097´ Manetoe 8010-8050´; Arnica Formation 8050-8450

8042-8045´ Medium brown micro-finely crystalline dolomite; 10% white dolomite as fine (,1/2 cm) veins and irregular blebs (<1/2 cm); minor calcite and quartz in some veins and vugs; quartz appears to be pre-calcite at 8042.5´; minor pyrite; minor corals, brachiopods, gastropods replaced by white dolomite.

8045-8050´ Mottled dark brown lime mudstone and medium brown dolomite; 5% white dolomite as veins connected to medium brown dolomite and replacing fossils; stylolites.

8050-base Brown limestone (mud to wackestone); minor calcite veins.

CPOG et al LABICHE F-08

(60.62230°N 124.52031°W) lat.60°37'26"; long.124°31'12"

Core 2 6706-6729´ rec. 19´ Nahanni Formation

6706-6706.6´ Limestone, dark gray, cryptocrystalline, small <1/2 cm fractures filled with calcite, stylolite at base.

6706.6-6714´ Dolomite, medium gray, fine-medium crystalline, slightly carbonaceous; finely mottled, crinkled and irregular, with 20-30% white dolomite , ?cryptalgal; calcite infills vugs post-white dolomite and bitumen, also hairline fracture filled with calcite, cut by stylolite; some vugs completely filled with bitumen, very poor vuggy

porosity.

6714-6715´ Limestone, as 6706´; very minor dolomite veins (approx. 2 mm); large crinoid fragments; hairline calcite veins.

6715-6718´ Dolomite, medium gray, finely to medium crystalline; stylolites; very carbonaceous; 15% white dolomite as irregular blebs; vugs in white dolomite filled with calcite.

6718-6725´ Dolomite, medium gray, fine-medium crystalline, crinkly laminite, ?algal; mottled with 30-40% white dolomite; minor calcite infill of vugs post-white dolomite; bitumen in intercrystalline porosity in white dolomite; stylolite.

IMPERIAL SUN NETLA RAVEN F-73

(60.70694°N 122.73611°W) lat.60°42'25"; long.122°44'10"

Core 1 7737-7787´ ?Landry/Arnica Formation

7737-7749´ Medium-light gray medium to very coarsely crystalline dolomite, bitumen in intercrystalline porosity cf. Chevron CS Berry well; 60-80% white dolomite banded with graY dolomite; minor calcite as vug and vein fill post-white dolomite; stylolites are bituminous.

7749-7754´ Mottled medium gray micro-finely crystalline dolomite, 30% white dolomite; minor light gray and light brown dolomite; upper and lower contacts stylolitic.

7754-7757´ Medium-light gray/brown cryptocrystalline (?micritic) to finely crystalline in patches, ?burrowed; 10% white dolomite as irregular blebs and patches; shell material replaced by light gray and white dolomite; stylolite.

7757-7776´ Light gray/brown to tan cryptocrystalline dolomite; wavy laminated to mottled/pelletoidal; < 5% white dolomite as thin subvertical veins; stylolite.

7776-7776.5´ Angular fragments of brown dolomite as above, brecciated by 10% white dolomite veins to 1/2 cm.

7776.5-7777.5´ Medium brown dolomite, laminated at top and base containing subangular to angular fragments of light brown dolomite; minor white dolomite vein at base containing subangular fragments of both types of dolomite.

7777.5-7787´ As above with alternatin zones of 1-2´ of angular breccia fragments of light/medium brown dolomite in white dolomite, with zones of laminated/mottled to brecciated light dolomite in medium brown dolomite (Appear to be rip-yp clasts from underlying strata; minor pyrite; stylolites cut

dolomite veins; 2 cm calcite vein at 7780´, some of calcite in centre is pink; minor calcite in vug at 7782´, post-white dolomite; ? algal, bioturbation influence.

IMPERIAL SUN ARROWHEAD I-46
Core 21 6905-6923´
lat.60°50'; long.122°15'

6916-6923´ Dolomite, mottled white and medium gray, coarse subhedral dolomite rhombs, bitumen in intercrystalline porosity in gray dolomite.

Core 22 6923-6935´
As above, approximately 20% white coarsely crystalline dolomite increasing to 60% at top, medium gray dolomite, coarsely crystalline, bitumen in intercrystalline porosity, not totally occluded; quartz crystals in some vugs, medium size (few mm by 3/4 cm); a few stylolites; minor pyrite; dolomite host finer crystalline at base, browner.

PAN AM A-2 GRAINGER N-42
(61.20000°N 123.14500°W) lat.61°12'; long.123°08'42"

Core 1 3446-3464´ ?Nahanni Formation

3446-3447.5´ 70% white dolomite alternating stringers and bands with coarsely crystalline medium gray dolomite, bitumen in intercrystalline porosity in medium gray dolomite; calcite fills most vugs in white dolomite; minor vuggy porosity.

3447.5-3448.5´ Medium gray fine-medium crystalline dolomite, 5% white dolomite as irregular blebs, no vuggy porosity, stylolites.

3448.5-3461´ Alternating bands white dolomite and medium to coarsely crystalline gray dolomite with bitumen in intercrystalline porosity; white to cream calcite fills vugs, minor pale pink calcite; stylolites, poor vuggy porosity.

3461-3462´ Fine-medium crystalline gray dolomite; 20% white dolomite, replacing corals; minor calcite in some vugs, minor pyrite, stylolites.

PAN AM A-1 MATTSON CREEK E-13
(61.04111°N 123.80833°W) lat.61°02'00"; long.123°48'30"

Core 1 2091-2141´ Nahanni Formation

2091-2096´ Dark gray dolomite, micro-finely crystalline, mottled with medium gray dolomite, calcareous; cut by calcite veins to 1/2 cm, cloudy and clear; minor corals, ?Stachyodes, brachiopods.

2096-2097´ Mottled medium/light gray dolomite, slightly

calcareous; 10% white dolomite as vug fill; calcite veins as above.

2097-2098′ As 2091-2096′.

2098-2102.5′ Mottled medium/light gray dolomite; 15% white dolomite as vug/vein fill, also mottled to approx. zebraic with gray dolomite; large (< 1 cm) veins calcite and quartz cut stylolites, quartz as euhedral crystals on edge and centre calcite veins, these veins also contain fine breccia from surrounding dolomite; minor corals, small stromatoporoids replaced by white dolomite.

2102.5-104.5′ Dark/medium gray dolomite; 10% white dolomite as veins; light gray and white dolomite replacing stromatoporoids, corals, brachiopods; minor quartz as above.

2104.5-109′ As above, 20% white dolomite; calcite post-white dolomite in vugs.

2109-109.5′ Dark gray dolomite as above, white dolomite veins cut and divided by later, calcite filled vein.

2109.5-113′ As 2098-2102.5′; large vug > width of core filled with calcite at 2110′; zebraic texture lower 1′; clean calcite vein cuts calcite vein containing breccia from surrounding rock.

2113-141′ Dark gray dolomite, calcareous; 5% white dolomite as veins, 5% calcite as vein and vug fill; approx. 20′ with light gray/brown strom. fragments, corals, brachiopods; gastropods and brachiopods replaced by light gray and white dolomite at top; at 2123′, calcite in vug is white and light brown, minor small quartz crystals; ?Amphipora in lower 10′.

Core 2 2456-2493′

2456-457′ Dark gray dolomite, micro-finely crystalline, shaley laminae to mottled; numerous stylolites, horizontal and vertical; < 5% white dolomite as vein and fossil replacement; minor quartz in some veins.

2457-462′ As above, 5% white dolomite; minor brecciation, fractured.

2462-465′ Mottled dark/medium gray dolomite micro- to medium crystalline; 10% white dolomite as vug and vein fill; minor calcite as post-white dolomite vein fill; poor vuggy porosity; fractures offset dolomite veins 1/2 cm.

2465-466.5′ Medium gray dolomite, medium crystalline; brecciated by 10% white dolomite, faintly banded; minor pyrite; minor calcite and quartz as vug fill, calcite one side vug, quartz on other.

2466.5-468.5′ Dark gray dolomite, micro-finely crystalline, vague 1 cm bands medium crystalline dolomite; 5% white dolomite as irregular blebs; calcite vein with subhedral quartz in centre.

2468.5-469′ Medium to dark gray finely crystalline dolomite, crinkly laminae followed by white dolomite, minor brecciation.

2469-479′ Dark gray dolomite, finely crystalline, variously mottled, laminated, nodular; pyrite present in dark gray dolomite as euhedral crystals, some pyrite concentrated near fossils, minor brachiopods; 5% white dolomite as vertical to subvertical veins, small vugs, replacing fossils and brecciating upper 6", fragments angular to several cm, minor quartz, calcite.

2479-481′ Light to dark gray dolomite, fine-medium crystalline, mottled dark/ fine with light medium crystalline; 20% white dolomite as veins vug fill, brecciation; minor quartz in some vugs; pyrite.

2481-481.5′ Dark gray dolomite, finely crystalline, < 1% white dolomite as veins; euhedral pyrite.

2481.5-485′ Medium gray dolomite, fine-medium crystalline; brecciated by 15% white dolomite as veins, vug fill; some quartz as vug fill; one vein with yellow mineral post-white dolomite, ?sphalerite, vein also calcite and quartz; vein cut by stylolite.

2485-488′ Dark gray dolomite, finely crystalline dolomite; minor brecciation by 10% white dolomite as subhorizontal veins, vug fill; minor pyrite.

2488-2493′ As 2479-2481′.

PAN AM A-1 GRAINGER J-15

(61.24305°N 123.04444°W) lat.61°14'35"; long.123°02'40"

Core 2 2148-2152′ ?Nahanni Formation

80-90% coarsely crystalline white dolomite alternating with stringers of 10-20% medium gray, fine-medium crystalline dolomite; minor pyrite in small vugs or in fractures in white dolomite; very minor calcite.

HORN RIVER AMERADA HESS CLI LAKE M-05

(61.91611°N 123.02972°W) lat.61°54'58"; long.123°01'47"

Core 1 4853-4891´ ?Headless/Arnica Formation

4853-4856.5´ Medium gray dolomite, fine-medium crystalline; mottled with 15% white dolomite, good vuggy porosity in gray and white dolomite; very abundant horizontal stylolites.

4856.5-4858´ 40% white dolomite as alternating stringers with gray dolomite as above; fair vuggy porosity; very stylolitic.

4858-4860´ 15% white dolomite as irregular blebs in gray dolomite as above; calcite in some vugs in white dolomite; good vuggy porosity; pyrite in vugs in gray and white dolomite ; ? vugs moldic after shell/ stromatoporoid fragments; stylolite.

4860-4861´ 80% white dolomite alternating stringers with dark gray dolomite, subhorizontal bands; stylolite; good vuggy porosity.

4861-4863.5´ As above, 60% white dolomite; pyrite crystals in some vugs to 2 mm diameter; fewer vugs than above but larger to cover entire core.

4863.5-4869´ 50% white dolomite mottled with medium to coarse crystalline gray dolomite; bitumen in intercrystalline porosity; subhedral calcite crystals in some vugs, one large crystal (1x5 cm)in vug at 4866.6´, light purple in colour.

4869-4873´ As above, gray dolomite fine-medium crystalline.

4873-4874´ As above, 80% white dolomite.

4874-4879.5´ 60% white dolomite mottled with irregular stringers of gray dolomite; bituminous stylolite.

4879.5-4881.5´ 80% white dolomite mottled with light/medium gray dolomite, fine/medium crystalline; minor calcite in fair vuggy porosity, minor pyrite crystals < 1 mm in vugs.

4881.5-4883´ 50% white dolomite alternating stringers with dark gray dolomite; fair vuggy porosity, vugs containing subhedral calcite crystals; stylolite; pyrite/chalcopyrite on fractures in some vugs.

4883-4889´ 30-40% white dolomite mottled with and brecciating medium gray finely crystalline dolomite; good vuggy porosity; calcite in vugs post-white dolomite; pyrite appears pre-calcite, as small crystals never seen on calcite, and observed between dolomite/calcite contact.

4889-4890.5´ 70% white dolomite mottled with gray dolomite as above,good vuggy porosity.

4890.5-4891′ Medium crystalline gray dolomite mottled with 20% white dolomite; very stylolitic.

Core 2 4891-4903′

4891-4893′ Light/medium gray dolomite, medium crystalline; 10% white dolomite repalcing ?fossil fragments; good vuggy porosity; 1 calcite vein cuts stylolite followed for 2′; pyrite in some vugs; argillaceous stylolite.

4893-4894′ 50% white dolomite mottled with gray dolomite as above; stylolite.

4894-4895.5′ 10% white dolomite mottled withmedium gray, medium crystalline calcareous dolomite; abundant stylolites; calcite in vugs.

4895-4898.5′ Mottled to alternating stringers of 50% white dolomite and dark to light gray finely crystalline dolomite; stringers subhorizontal; poor vuggy porosity; stylolite.

4898.5-4901′ As above, dark gray dolomite only; stringers few mm to 1 cm; calcite in vugs; poor vuggy porosity.

4901-4903′ 30% white dolomite mottled with medium to dark gray finely crystalline dolomite; fair/poor vuggy porosity; pyrite crystals in some vugs; 1 argillaceous stylolite 1/2 cm thick.

MOBIL FORT SIMPSON M-70

(61.99930°N 122.46636°W) lat.61°59'58"; long.122°27'59"

Core 5 2286-2305′ Headless Formation

2286-2287′ Partly dolomitized calcisiltite, light gray/brown, finely crystalline; stylolites, dolomite concentrated near stylolites; pyrite at base.

2287-2291′ Light-medium gray dolomite, medium-coarsely crystalline, minor bitumen in intercrystalline porosity and in vugs in gray dolomite; 20% white dolomite as irregular veins and blebs, zebraic; good vuggy porosity; minor calcite post-white dolomite in veins; stylolites.

2291-2293′ As above, 10% white dolomite; porosity fair.

2293-2295 As 2287-91, pyrite in gray and white dolomite.

2295-2295.3′ 8 cm calcite vein containing breccia, stylolitic contact with underlying limestone.

2295.3-2303.6′ As 2286-87′, very stylolitic, dolomite contrated near stylolites, calcite veins cross-cut stylolite.

Core 5 2305-2315´

2305-2307´ Medium gray, finely to coarsely crystalline dolomite, mottled to layered with 30% white dolomite; bitumen in intercrystalline porosity in gray dolomite, none in white dolomite; calcite veins cut stylolites; pyrite post-dolomite, pre-calcite ??; calcite also as subhedral crystals in vugs; stylolitic contact at base.

2307-2312´ Limestone; pyrite concentrated near stylolites; some calcite veins cut by stylolites, minor white dolomite as vein at 2307.5´.

2312-2312.5´ Medium gray medium to coarse crystalline, 10% white dolomite mixed with gray dolomite; one vertical calcite vein.

2312.5-2315´ As 2305-2307´.

FINA et al WILLOWLAKE L-59

(62.14444°N 121.93333°W) lat.62°08'40"; long.121°56'0"

Core 1 1300-1308´ Arnica Formation

Dolomite, dark brown, microcrystalline,thin veins and large lenses (to 5 cm) coarsely crystalline white dolomite and calcite; calcite in largest lens appears to surround light green lath-like crystals (?anhydrite), 1 crystal 1x6 cm; others smaller.

Core 2 1308-1324´ Arnica Formation

Dolomite, medium to dark brown, micro-finely crystalline, mottled to pelletoid, ?bioturbated to laminated. Abundant thin veins of white dolomite, breccia fragments angular; minor amounts clear to pale purple fluorite, followed by light green anhydrite in a few veins; fluorite is post dolomite, anhydrite post-fluorite.

N.B. These rocks are underlain at 1355´ by Bear Rock Formation containing anhydrite.

CHEVRON CS EBBUTT G-72

(62.35694°N 122.47722°W) lat.62°21'25"; long.122°28'38"

Core 2 2565-2583´ Arnica Formation

2565-66.5´ Medium gray/brown fine-medium crystalline dolomite, intercrystalline porosity filled with bitumen; 25% white dolomite as veins, horizontal to 40° dip, to 5 cm diameter; minor vuggy porosity; stylolites.

2566.5-68′ Medium gray , medium-coarsely crystalline dolomite, bitumen in intercrystalline porosity, 1.5 " green shale parting at top, contains small (<1/2 cm) gray dolomite clasts-?nodules, lower dolomite contains shale clasts to 1.5 cm; 15% white dolomite as veins, some shale clasts in white dolomite.

2568-69′ Medium gray, medium to coarsely crystalline dolomite, bitumen in intercrystalline porosity; 15% white dolomite as irregular veins; stylolite.

2569-70.5′ 80% coarsely crystalline white dolomite; 20% dark gray dolomite as subhorizontal bands, finely crystalline; minor small vugs.

2570.5-71.5 As above 50% white dolomite; poor/fair vuggy porosity in white dolomite; 50% dark gray dolomite, fine-medium crystalline, bitumen in intercrystalline porosity; stylolites.

2571.5-71.6′ Green/gray shale.

2571.6-77.2′ As 2570.5-71.5, with white dolomite decreasing to 30% at base; good vuggy porosity in white dolomite.

2577.2-78.5′ Medium gray/brown dolomite, fine-medium crystalline; patches coarsely crystalline, bitumen in intercrystalline porosity; 10% white dolomite as irregular blebs; stylolite.

2578.5-79′ As 2570.5-71.5′.

2579-79.3′ 90% white dolomite, with small cream rosettes growing in dolomite and anhydrite vein; pyrite post-white dolomite and anhydrite.

2579.3-83′ 70% white dolomite, massive; fine-medium crystalline gray /brown dolomite; fair vuggy porosity; bitumen in 1 vug in gray/brown dolomite.

Core 3 2583-2599′

2583-84′ 70% white dolomite as 2579.3-83′.

2584-85′ 25% white dolomite as 1 cm veins and as few mm bands in banded fine-medium crystalline gray/brown dolomite; some coarsely crystalline patches in gray dolomite; minor vugs in gray dolomite filled with bitumen, bitumen also in intercrystalline porosity; stylolite.

2585-87′ Horizontal banded (to 1 cm) 60% white dolomite/40% brown dolomite; stylolites.

2587-89′ 30% white dolomite, patchy, vugs in white

dolomite, fair porosity; 70% brown dolomite.

2589-90´ Light-medium brown dolomite, laminated to massive, micritic at top, medium crystalline at base; 5% white dolomite as irregular blebs and veins; stylolitic upper contact, lower = ?.

2590-93´ 60-70% white dolomite as subhorizontal bands with gray/brown dolomite; fair vuggy porosity in white bands; last stage of dolomite seen in vugs have larger crystals to 5 mm and are clearer.

2593-99´ 30% white dolomite mottled with gray-brown fine-coarsely crystalline dolomite, bitumen in intercrystalline porosity; small 2x0.5 mm laths in vug at 94.3´ ? quartz.

TEXACO TECK IVERSON LAKE M-69

(62.48263°N 124.46645°W) lat.62°28'48"; long.124°27'59"

Core 1 5420-5473´ ?Landry or Arnica Formation.

5420-5421.3´ Medium -coarsely crystalline, medium gray dolomite, 25% white dolomite as irregular patches and replacing ? skeletal fragments; intercrystalline porosity filled with bitumen, stylolite at base.

5421.3-5422.5´ As above, 20% white dolomite; fair vuggy porosity; ?gastropods; minor bitumen in white dolomite vugs.

5422.5-5426´ Medium to light gray host dolomite, 20% white dolomite as irregular patches and veins, fair to good vuggy porosity; some vugs several cm in diameter; ?white dolomite replacing fossil material, tabular stromatoporoids at 24.8´, coral at 23.5´; 1 stylolite; light gray dolomite similar to that seen in other wells, here brecciated by white dolomite, minor bitumen in intercrystalline porosity and in vugs.

5426-5429.5´ Medium to light gray dolomite, 20% white dolomite as above; poor vuggy porosity, bitumen in intercrystalline porosity; several stylolites.

5429.5-5430.5´ Medium to light gray dolomite; 50-60% white dolomite repalcing gastropod? and as irregular blebs, mottled with host dolomite.

5430.5-5431.5´ 20% white dolomite replacing shell fragments; 1 large isolated vug lined with white dolomite; fine to medium crystalline dark gray host dolomite, minor bitumen in intercrystalline porosity.

5431.5-5432´ 35% white dolomite, vugs lined with white dolomite and coarsely crystalline calcite.

5432-5433.3′ 15% white dolomite as irregualr patches, gray dolomite as above; intercrystalline porosity filled with bitumen; pyrite associated with carbonaceous stylolites and bitumen filling vugs; last dolomite in vugs less cloudy.

5433.3-5435′ 60% white dolomite, as irregular veins, brecciates medium grya fine-coarsely crystalline dolomite, intercrystalline porosity and small vugs in host dolomite filled with bitumen; minor calcite in some vugs, at 33.3′, stylolite cuts white dolomite and calcite in vug.

5435-5437′ 10% white dolomite as veins and small (<1cm) irregular patches; several stylolites cut white dolomite vein.

5437-5438.5′ 30% white dolomite as above, fair vuggy porosity, Host dolomite is coarsely crystalline light gray dolomite, bitumen as above, minor ?pyrite, stylolites.

5438.5-5443.5′ Dolomite, medium gray, medium to coarsely crystalline; 40-50% white dolomite as veins, mottled to brecciated with gray dolomite, breccia fragments subangular; minor vuggy porosity, bitumen in intercrystalline porosity and filling some vugs; stylolites.

5443.5-5444′ 10% white dolomite as irregular blebs in medium-coarsely crystalline medium gray dolomite, bitumen in intercrystalline porosity.

5444-5446.5′ 30% white dolomite as veins containing pieces of surrounding medium to coarsely crystalline medium gray dolomite; white dolomite also replacing ?skeletal material, bitumen in intercrystalline and vuggy porosity; minor pyrite.

5446.5-5449′ Light to dark gray dolomite, 40% white dolomite as irregular veins and patches, fair vuggy porosity, minor bitumen in veins.

5449-5452.5′ Light to medium gray dolomite, fine to medium crystalline; 30% white dolomite as irregular stringers and veins, bitumen in intercrystalline porosity; minor vuggy and moldic porosity in light gray dolomite, white dolomite also replacing skeletal material.

5453.5-5455′ Finely crystalline medium gray dolomite, 20% white dolomite as irregular blebs and ? replacing skeletal fragments, bitumen in intercrystalline porosity.

5455- ??? 50-60% white dolomite as veins (mainly vertical with central porosity, no bitumen) and as irregular blebs brecciating light-medium gray dolomite, finely crystalline, breccia fragments angular to corroded by white dolomite; white dolomite also replacing skeletal material, ?crinoids, brachiopods.

CHEVRON CS BERRY F-71

62.50583°N 122.99083°W) lat.62°30'21"; long.122°59'27"

N.B. Saddle dolomite is seen in open vugs.

Core 1 2313-2365´ ?Headless/Arnica Formation

2313-2313.6´ Black shale, 1/4-1/8" laminae separated by light gray to white dolomite partings; flecks of pyrite in shale; one subvertical white dolomite filled fracture 1/16´ thick; increase in dolomite to base.

2313.6-15´ White coarsely crystalline dolomite in veins surrounded by medium-coarsely crystalline medium gray dolomite, intercrystalline porosity filled with bitumen; bitumen also fills small vugs in white dolomite; very minor pyrite; minor vuggy porosity.

2315-16´ Irregular indistinct crinkly laminae, 1-2 mm; outlined by white dolomite, 1-3mm, and argillaceous material; tight.

2316-19´ 50% white dolomite vaguely laminated with medium-light gray dolomite, some of this gray dolomite appears to be 1-2 mm fragments of white dolomite surrounded by bitumen, fair vuggy porosity, mainly small vugs.

2319-22.5´ 30% white dolomite as veins, vague banding as seen 2313.6-15´; coarsely crystalline calcite infills some vugs post bitumen; one vertical fracture filled with calcite, cut by stylolite, very minor pyrite in bitumen.

2322.5-23´ Coarsely crystalline gray dolomite, <5% white dolomite, minor vuggy porosity, bitumen in pores.

2323-26´ 50% white dolomite, mottled with gray dolomite, vague banding; some vertical stylolites, minor brecciation; calcite vug infill; minor quartz crystals in vug; bitumen in intercrystalline porosity and vugs.

2326-27´ Massive coarsely crystalline dark gray dolomite, 10% white dolomite , mottled, bitumen in intercrystalline porosity.

2327-29´ 60-70% white dolomite, mottled with dark gray dolomite, bitumen in intercrystalline porosity, pyrite in gray and white dolomite, also with bitumen; stylolite cuts white dolomite; minor vuggy porosity; minor brecciation.

2329-31.5´ 40% white dolomite in horizontal bands, 5 cm; interbanded with grey dolomite, crystals 0.5-4 mm diameter, bitumen in intercrystalline porosity; minor vuggy porosity.

2331.5-38´ White dolomite; mottled to banded by varying

amounts of bitumen in intercrystalline porosity; minor quartz crystals (1x2 cm) in vug at 32´; stylolites.

2338-38.5´ Light gray fine-medium crystalline dolomite, intercrystalline porosity filled with bitumen; stylolite at top and base; pyrite associated with bitumen.

2338.5-40´ Light gray to white dolomite , invaded by bitumen, minor subvertical white dolomite veins.

2340-44´ Well banded at top by gray and white dolomite; coarsely crystalline; minor calcite increasing to base as vug fill; dolomite mottled at base of unit; stylolites; small vugs.

2344-46´ Thin bands gray dolomite (few mm) with thick bands white dolomite (several cm); calcite fill to partly fill some vugs.

2346-47.5 80% medium gray dolomite, bitumen in intercrystalline porosity; 20% white dolomite; calcite fills some vugs; very minor vuggy porosity; 8 cm white dolomite vein at 47´; stylolite cuts vein.

2347.5-50´ 80% white dolomite , banded with gray dolomite as above; stylolite at base.

2350-51.25´ Banding grades down to brecciation; fragments of coarsely and microcrystalline gray dolomite in white dolomite cement; minor vuggy porosity; stylolite at base.

2351.25-55´ Mottled gray and white dolomite; stylolites; calcite partly and totally infill vugs, calcite also as subvertical veins cutting white dolomite; argillaceous at 53.75´; minor small vuggy porosity.

2355-58.5´ White dolomite mottled with dark gray dolomite; calcite infills some vugs; bitumen infills some vugs and intercrystalline porosity in gray dolomite; massive coarse calcite in vug at 55.5´.

2358.5-65´ Gray fine-medium crystalline dolomite, brecciated by white dolomite cement, breccia fragments subangular to 10 cm; medium crystalline gray dolomite has bitumen in intercrystalline porosity; increase in amount of calcite in veins and vugs to base.

HORN RIVER et al CANDEL WILLOWLAKE G-47

(62.60639°N 122.88666°W) lat.62°36'23"; long.122°53'12"

Core 1 1902-1944´ rec. 42´ ?Headless or Arnica Formation.

1902-1909´ Dark gray dolomite, fine to coarsely

crystalline, mottled with 60-70% white dolomite, intercrystalline porosity in coarse crystalline gray dolomite filled with bitumen, moderately abundant calcite as vug and vein fill; large vugs.

1909-1910′ 75% white dolomite banded with dark gray finely crystalline dolomite, dip of bands 15 degrees from horizontal; vugs in white dolomite.

1910-1912′ 15% white dolomite as vague bands with fine-medium crystalline gray/brown dolomite; calcite post white dolomite as vug fill.

1912-1915′ Banded fine-medium crystalline medium gray/brown dolomite; 5% white dolomite and calcite as irregualr thin veins (<1/2cm); stylolitic.

1915-1916.5′ Coarse to very coarse crystalline medium gray dolomite; most of intercrystalline porosity occuded by bitumen, upper contact stylolitic, 25% white dolomite overall as 10 cm vein in centre of unit.

1916.5-1920′ 40% white dolomite mottled with finely crystalline dark gray dolomite; fair vuggy porosity; calcite as partial vug fill.

1920-1923.5′ Medium gray microcrystalline to cryptocrystalline dolomite, 5% white dolomite and calcite; white dolomite in ?algal
moldic porosity, geopetal, dark
brown sediment on base, white dolomite line porosity, filled with calcite.

1923.5-1926.5′ 50% white dolomite banded with finely crystalline dark gray /brown dolomite; large calcite crystals in some vugs; fair vuggy porosity.

1926.5-1930′ 40% white dolomite mottled with gray dolomite as above; stylolites.

1930-1931.5 70% white dolomite mottled with gray dolomite, as above; large vugs partly filled with large calcite crystals (3xl cm);sphalerite post-calcite as crystals in vugs and irregular vein network; very minor galena; fractures filled with calcite cut by stylolites; some open fractures.

1931.5-1932′ As 1923.5-1926.5′, no vugs.

1932-1933.5′ 30% white dolomite mottled with medium crystalline dark gray dolomite; stylolite at base.

1933.5-1935′ 85% white dolomite, very coarsely crystalline, bitumen in intercrystalline porosity, a few vugs containing calcite; fractures unfilled; stylolite at base.

1935-1940.5′ 25% white dolomite vaguely banded with finely crystalline dark gray dolomite, becoming gray/brown at base; minor vuggy porosity, some lenses of coarse calcite.

1940.5-1942′ Dark gray/medium brown wavy to horizontal banded, finely crystalline dolomite; 10% white dolomite tending to follow bandsin gray dolomite, 1 vug with coarse calcite crystals.

Core 2 1944-1952′ rec. 8′

Finely crystalline medium gray/brown dolomite, fractured; <1% white dolomite as irregular veins cut by stylolites.

FPC TENNECO ROOT RIVER I-60

(62.65895°N 123.40805°W) lat.62°40'; long.123°15'

Core 3 3534-3554′ Landry Formation

3534-3535′ 70% white dolomite brecciating medium gray/brown coarsely crystalline dolomite; zebraic; white dolomite in vugs is saddle dolomite; calcite in some vugs; vugs to 2x5 cm.

3535-3538′ 25% white dolomite follows relict ?cryptalgal fabric in gray/brown fine-medium crystalline dolomite; laminae crinkly to horizontal; good vuggy porosity with small vugs, stylolites.

3538-3544.5′ 20% white dolomite more patchy distribution than above; very stylolitic - 13 in 3" at 3541′; good porosity in host dolomite, porosity not appear to decrease near stylolites in host dolomite; calcite in large vug at 3543′; minor pyrite in gray/brown dolomite.

3544.5-3547.5′ 30% white dolomite mottled to vague horizontal laminated with gray/brown fine-medium crystalline dolomite; fair vuggy porosity in white dolomite, minor porosity in gry/brown dolomite; stylolite cuts pyrite at 3544′; calcite in some vugs.

3547.5-3549′ 10% white dolomite mottled with gray/brown fine-medium crystalline dolomite, minor porosity concentrated in white dolomite veins; stylolites.

3549-3552′ 30% white dolomite mottled to horizontally banded (to 3 cm) with gray dolomite as above; poor vuggy porosity; very stylolitic, offset one stylolite is 9 cm; intercrystalline porosity filled with bitumen; no bitumen seen in vugs in white dolomite; minor calcite; pyrite associated with gray dolomite; quartz and calcite in vug at 52′, quartz appears pre-calcite as quartz is against dolomite but is at top of vug.

3552-3554´ 10-15% white dolomite mottled with medium to coarsely crystalline gray/brown dolomite; coarse dolomite has bitumen in intercrystalline porosity; pyrite in gray/brown dolomite; stylolites.

APPENDIX B

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- delta O^{18}, C^{13} changes record seasonal hydrographic changes.

Clayton, R.N., Freidman, I., Graf, D.L., Mayeda, T.K., Meents, W.F. and Shimp, N.F. 1966. The origin of saline formation waters, I, Isotopic composition. Journal of Geophysical Research, 71, pp. 3869-3882.
- TDS, O18, D, values of brines from Illinois, Michigan, Alta basins and Gulf coast.
- variations in D among basins greater than within basins
- variation in O18 has large range in each basin correlating with salinity
- extensive oxygen exchange between water and reservoir rocks to give increased O18.

Davidson, D.A. and Snowdon, D.M. 1978. Beaver River Middle Devonain carbonate: performance review, fractured gas reservoir with water influx. Journal of Petroleum echnology, 30, pp. 1672-1678.
- reservoir study with data on porosity, permeability, Sw, shut in due to water influx.

de Wit, R., Gronberg, E.C., Richards, W.B. and Richmond, W.O. 1973. Tathlina area, District of Mackenzie. In: McCrossan, R.G. (ed.), The Future Petroleum Provinces of Canada, Candaian Society of Petroleum Geologists Memoir 1, pp. 187-212.
- covers most of my region
- Tath. area = plains, uplands and adjacent mountain belt to west of Grt. Slave Lk.
- strata under plains and uplands mainly Dev and remnants of Cret.
- sed wedge thickens west to mtns, Camb., Ord, Sil , Dev, Carb
- in east wedge on Can Shield
- Plains- struct controlled by faults in PC basement
- Mtns- open folds and thrusts originated in Laramide Orogeny
- good overview of stratigraphy
- maps of PC faults, X-sects

Dickson, J.A.D. 1965. A modified staining technique for carbonates in thin section. Nature, ??, p. 587.
- methods and recipe for staining cc and dol
- similar to Evamy (1963) but gives times and concentrations for staining.

Epstein, S. and Mayeda, T. 1953. Variation of O^{18} content of waters from natural sources. Geochimica et Cosmochimica

Acta, 4, pp. 213-224.
- classic reference
- marine and fresh water samples examined for relative O18/O16 ratio.
- range of salinity from 29-40 ppt., O18 content varies over range of approx. 6 permil.
- marine waters of highest salinity richest in O18.
- marine waters contaminated by melt water from ice had the lowest O18 content.
- graphs relating O18 and salinity
- equation given for temperature determination in CaCO3 using O18 values.

Evamy, B.D. 1963. The application of a chemical staining technique to a study of dedolomitization. Sedimentology, 2, pp. 164-170.
- technique using Alizarin Red-S and Potassium ferricyanide to detect variations in ferrous iron content in dolo and cc
- table = concentr. and relative amts Fe and colors obtained.

Faure, G. 1977. Principles of Isotope Geology. John Wiley and Sons, New York, 464 p.
- basic information on oxygen and hydrogen in hydrosphere and atmosphere.
- explains abbreviations and conventions.

Folk, R.L. and Land, L.S. 1975. Mg/Ca ratio and salinity: two controls over crystallization of dolomite. American Association of Petroleum Geologists Bulletin, 59, pp. 60-68.
- propose that dolomite forms most easily by decrease in salinity in a schizohaline environment (alternating hypersaline and near-fresh waters).
- flushing with fresh water decreases salinity but maintains Mg/Ca ratio.
- one of first papers to propose mixed-water model dolomitization.

Fritz, P. 1969. The oxygen and carbon isotopic composition of Pine Point lead-zinc ore deposits. Economic Geology, 64, pp.733-742.
- paragenesis- 1, dolo; 2, pb-zn;3,cc
- T never much > 100C, decreased very slowly at the end of mineralization.
- O18 composition mineralizing fluids based O18 content of hydrothermal dolo, imply stratafugic origin and comparable to formation waters in subsurface
- mineralization ended with influx isotopically lighter surface water shown in decreasing O18 of calcite.

Fritz, P. and Jackson, S.A. 1972. Geochemical and isotopic characteristics of Middle Devonian dolomites from Pine Point, northen Canada. Twentyfourth International Geological Conference, Section 6, pp.230-243.

- 3 dolomite generations: (1) supratidal, (2) diagenetic, (3) hydrothermal.
- (1) from saline brines, O^{18} rich, delta O^{18} -1 to -5 permil, >55 mol % CaCO3, high Na, S impurities.
- (2) late diagenetic, delta O^{18} -6 to -12 permil, <55 mol% CaCO3, low Na, S.
- (3) as above with <52 mol% CaCO3.

Graf, D.L. and Goldsmith, J.R. 1956. Some hydrothermal syntheses of dolomite and protodolomite. Journal of Geology, 64, pp.173-186.
- dolomite formed experimentally at T>500 C in dry state, 200-300 C wet.
- during rapid crystallization or at low temperatures, probability of cation sorting is low, disordered or metastable phase is produced.
- dolomite-like materials produced at lower temperatures are Ca-rich and do not show superstructure reflections.

Jones, R.M.P. 1980. Basinal isostatic adjustment faults and their petroleum significance. Bulletin of Canadian Petroleum Geology, 28, pp. 211-251.
- examines numerous w9idespread vertical faults, characterized by long strike lengths with examples from western Canada.
- faults penetrate asthenosphere, vertical movement maintains or restores isostatic equilibrium of lithosphere
- faults control position of stratigraphic, structural and diagenetic traps.

Kyle, J.R. 1980. Controls of lead-zinc mineralization, Pine Point district, Northwest Territories, Canada. Mining Engineering, 32, pp. 1617-1626.
- ore bodies located in paleosolution structures developed as result of post-middle Givetian subaerial exposure.
- late Devonian age (Beales, Pers. comm.) based on remnent magnetism.

Land, L.S. 1980. The isotopic and trace element geochemistry of dolomite: the state of the art. In: Zenger, D.H., Dunham, J.B., and Ethington, R.L. (Eds.), Concepts and Models of Dolomitization. Society of Economic Paleontologists and Mineralogists Special Publication 28, pp. 87-110.
- $10^3 \ln @ = 11.4$ to 11.9 for most sedimentary dolo.
- $= 10.5$ for calcite
- ancient dolomite depleted O^{18} and trace elements relative to Holocene analogs.
- Quantitative interpretation of isotope or trace element values for dolo are tenuous due to problems assigning distribution coefficients and fractionation factors, as well as multiple recrystallization in partly closed systems.
- good references.

Land, L.S. 1982. Dolomitization. American Association of Petoleum Geologists Education Course Notes #24. Denver Colorado.
- covers basics of dolomite mineralogy, aqueous solution equilibria, isotopes, trace element geochemistry and mechanisms of dolomitization.

Land, L.S. 1983. The application of stabe isotopes to studies of the origin of dolomite and to problems of diagenesis of clastic sediments. In: Society of Economic Paleontologists and Mineralogists Short Course #10, Stable Isotopes in Sedimentary Geology, pp. 4-1 to 4-22.
- gives $10^3 \ln$ @ dolo-water equations for variety of papers.
- graph of temperature vs. delta $_3O^{18}$ for various delta O^{18} water values using equation $10^3 \ln$@ dolo-water = $3.2 * 10^6 T^{-2} - 3.3$.
- proponent of multiple event dolomitization and mixed-water model.
- short section on Quartz as well.

Linholm, R.C. and Finkelman, R.B. 1972. Calcite staining: semiquantitative determination of ferrous iron. Journal of Sedimentary Petrology, 42, pp. 239-242.
- method to transfer stain from rock to acetate peels
- note that factors such as acidity and temperature of staining solution affect color (hue) of stain = use standard procedure
- amts Fe present using microprobe.

Lloyd, R.M. 1966. Oxygen isotope enrichment of sea water by evaporation. Geochimica et Cosmochimica Acta, 30, pp. 801-814.
- use of evaporation mechanism proposed by Sverdrup as model to interpret changes in isotopic composition that occur due to seawater evaporation.
- relative humidity at site of evaporation important factor in determining net isotopic enrichment, especially at high salinities.
- brines originating by evaporation of seawater in humid coastal environment attain delta O^{18} values no higher than 6 permil.
- graphs of O^{18} vs. salinity for experimental results and natural brines eg. Red Sea, salt pans.

Lovering, T.S. 1969. The origin of hydrothermal and low temperature dolomite. Economic Geology, 64, pp.743-754.
- lab data and field evidence imply composition water in equilibrium with dolomite, calcite from temperatures 20 to 400C.
- chart showing stbility fields of dolo., cc, in dilute solution as a f(T, Ca/Mg ratios)
- non-saline groundwaters have insufficient Mg to form dolo unless very hot or travel thru Mg-silicate environ
- convective circulation of waters heated by

intrusion or shallow magmas in permeable rocks will convert ls to dolo
- dolomitic alteration early.

Meijer-Drees, N.C. 1975. Geology of the Lower Paleozoic formations in the subsurface of the Fort Simpson area, District of Mackenzie, Northwest Territories. Geological Survey of Canada Paper 74-40, 65p.
- most of study area NE of mine
- descriptions of fromations very little on Dev-Carb
- Dev-Carb overlies UOrd-Sil succession unconform and onlaps granitic basement of Tathlina Uplift (Belyea, 1971)
- section on burial and geothermal gradient
- assume 2000ft min Carb seds (de Wit etal, 1973) temps at base Mt Kindle fm (UORD-SIL) Fig.7; buried 11,000 ft, 250-270 F.
- TR, JUR seds thin to absent Mackenzie Mtns assume depth burial decreased due to general uplift = hydrocarbon migration.
- renewed sedtn ECRET
- vitrinite reflectance of two UDEV coals from IOE Triad Ebbutt D-50 (1480´ - %Ro 3.09; 1505´ - %Ro 2.83) and one coal from Mt. KIndle in Shell Blackwater Lake G-52 (4808´ - %Ro 3.06) implies high degree of thermal alteration correspond to rank anthracite (a max T approx 150 C)

Meyers, W.J. 1974. Carbonate cement stratigraphy of the Lake Valley formation (Mississippian), Sacramento Mountains, New Mexico. Journal of Sedimentary Petrology, 44, pp. 837-861.
- correl of various cement zones for 10 mi. horiz and 200´ vert.
- Fe poor zone contained 4 zones found thru cathodoluminescence
- differentiates between vadose and phreatic cements.

Morrow, D.W. 1978. Dolomitization of Lower Paleozoic burrow-fillings. Journal of Sedimentary Petrology, 48, pp. 295-306.
- from Upper Ordovician of of Devon Island.
- high Mg/Ca ratio favors precipitation of more stoichiometric dolomite.
- low Mg/Ca ratio favors precipitation of Ca-rich dolomite with the exception of low salinities which will precipitate stoichiometric dolomite regardless of Mg/Ca ratios.

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- overview on:
1. crystal structure and composition variability
2. stability of dolomite in natural environments
3. kinetic effects.

Morrow, D.W. 1982. Dolomite - Part 2. Dolomitization Models and ancient dolostones. Geoscience Canada, 9, pp. 95-107.
- summary of following dolomitization models: (1) hypersaline lagoon and reflux, (2) burial compaction, (3) coorong and sabkha, (4) mixed water, (5) solution cannibalization and pressure solution, (6) tectonic/ hydrothermal.
- examples from Canada.
- mega-references.

Morrow, D.W. 1982. Interpretation of lead isotope data from zinc-lead mineralization in the northern part of the western Canadian Cordillera. Canadian Journal of Earth Sciences, 19, pp. 1070-1078.
- study of Pb isotope data from Pb-Zn deposits hosted by Devonian carbonates in northeastern B.C. and Yukon.
- samples from Kotaneelee area, Nahanni Fm. are examined.
- carbonate hosted deposits of Devonian Age based on Pb isochrons.
- vs. Macqueen and Thompson (1978) mid-Mesozoic based on geological and geochemical evidence.
- both agree dewatering of basinal shales provided fluids.

Morrow, D.W. 1984. Sedimentation in Root Basin and Prairie Creek Embayment-Siluro-Devonian, Northwest Territories. Bulletin of Canadian Petroleum Geology, 32, pp.162-189.
- Siluro-Devonian sequence from southern Mackenzie Mountains is a miogeoclinal wedge of shelf and slope sediments.
- contains map of Mackenzie shelf and table of Lower Paleozoic stratigraphy.
- study of depositional history and tectonic development.

Sommer, S. 1978. Effect of staining on microprobe determieation of iron in carbonates.

- probed samplle before and after staining- decrease in Fe in stained areas relative to unstained
- due fmtn of ppte on surface ; rxtn of $K_3Fe(CN)_6$ with Fe^{2+} = $Fe_3[Fe(CN)_6]_2$ and $KFe^{3+}[Fe(CN)_6]$

Veizer, J., Lemieux, J., Jones, B., Gibling, M.R. and Savelle, J. 1978. Paleosalintiy and dolomitization of a Lower Paleozoic carbonate sequence, Somerset and Prince of Wales Islands, Arctic Canada. Canadian Journal of Earth Sciences, 15, pp. 1448-1461.
- tests use of trace elements Na, K, Sr as indicators of paleosalinity in carbonates.
- positive results with with Na and Sr.

Walls, R.A., Mountjoy, E.W. and Fritz, P. 1979. Isotopic composition and diagenetic history of carbonate cements in

Devonian Golden Spike reef, Alberta, Canada. Geological Society of America, 90, pp. 963-982.

- calcite cements from early ot late are progressively more negative O^{18}.
- these cements have not been significantly altered by meteoric waters.
- middle and late stage cements formed in the subsurface.

Translation of ad for O.F. 1233. Please ask Louis Vincent to check.

Ce dossier public inédit décrit une étude diagénétique du faciès de dolomie de Manetoe et de ses phases minéralogiques associées. Des inclusions primaires et aqueuses de fluide à deux phases diagénétiques dans des échantillons de la dolomie et de ses phases associées de quartz, calcite, et de fluorine mineure étudiées de 5 carottes souterraines ont été examinées et leurs températures de homogénéisation, de fusion initiale, et de fusion terminale ont été déterminées. Des résultats indiquent que la dolomie de Manetoe a été précipitée des saumures hypersalines à composition saline complexe.

Ce dossier est accesssible pour la consultation aux bibliothèques de la Commission géologique, au bureau du géologue résidant à Yellowknife et à celui de Whitehorse. Des exemplaires sont en vente chez Riley's Datashare International Ltd., et au bureaux des géologues résidants à Yellowknife et à Whitehorse.