DOLOMITIZATION OF WABAMUN LIMESTONES AT TANGENT FIELD, NORTHWESTERN ALBERTA.

by

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Abstract

Tangent oil field in northwestern Alberta has been formed by a structural trap, created by the downthrown block of a Graben, combined with porosity created by the dolomitization of Wabamun limestone.

The dolomitization fluids have migrated from the underlying Winterburn formation, via fractures, up into the Wabamun. Well 6-32-80-23W5 is the focus of this study as it contains a complete sequence from dolomite at the base of the Wabamun up through a transition to limestones at the top of the Wabamun. Cathodoluminescence and petrographic analyses of the dolomites and the transition from dolomite to limestone has revealed 5 dolomite types; diffuse microcrystalline dolomite, mosaic dolomite with associated porosity, and without associated porosity, dolomite which replaces calcite fracture fill and dolomite related to pressure solution. These analyses have also revealed the following paragentic sequence for the five dolomite types 1) microcrystalline dolomite 2) dolomite related to pressure solution 3) dolomite replacement of calcite fracture fill 4) mosaic dolomite with and without associated porosity.

Acknowledgements

I would like to express thanks to Dr. R. G. Walker for supervision of this thesis.

The support of Amoco Canada is gratefully acknowledged, in particular to Sandy Laing who provided me with my first look at these rocks.

I would also like to thank Craig Rice, who taught me the ins and outs of cathodoluminescence, and Dave, Dan, Mark, Mike and Paul for making life interesting for the last four years.

Finally I would like to thank my parents for always encouraging me to do the best I can.

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Chapter One: Introduction

1.1 Introduction and Aim

Oil was first produced from the Wabamun Formation at Tangent Field in northwestern Alberta on Oct 17, 1981. The field had already been producing gas from shallower horizons since 1951. The production of oil at Tangent is from porous dolomites and fractured limestones of the Wabamun Formation. The purpose of this study is to determine the diagenetic history of the porous dolomites , why the dolomite is present, and to suggest a method of dolomitization.

Research into dolomitization has created many models in an attempt to catagorize dolomitization methods. These include in approximate historical order of appearance; the Hypersaline Lagoon and Reflux model (Adams and Rhodes,1960; Sears and Lucia, 1980), the Burial Compaction model (Illing, 1959; Mattes and Mountjoy,1980), the Coorong model (Alderman and Skinner, 1957; VanDerBorch,1964), the Sabkha model (Illing et al,1965; Hsu et al,1980), and the Dorag model (Bodiozamani,1973; Steiner and Choquette, 1980).
It is clear that, owing to the variety of dolomite types that exist in nature, a single process for dolomitization does not exist, and that there is no unique model to explain all dolomite. Within all of these models, sediment or rock selectivity can be a significant factor in dolomitization, but can not provide a general overall explanation.
Furthermore, limestones may retain their identity simply

because they are not reached by dolomitizing fluids. All of these models do however contain three common requirements for dolomitization:

1) the amount of Mg available for dolomitization must adequate
2) a transportation mechanism is required to deliver the Mg and remove the excess Ca
3) composition of a proposed solution must be conducive to dolomitization

Over the entire history of dolomite investigation only two basic types have been revealed; Primary Dolomite, which is penecontemporaneous and mostly associated with supratidal sediments; and Secondary Dolomite, which is the replacement of a pre-existing host with dolomite. It is generally agreed that most ancient dolomite is a replacement product and that a relatively insignificant amount of ancient dolomite is truly primary (ie. precipitated at or above the sediment-water interface).

Dolomites have also been grouped according to time of formation and these include:

1) Syngenetic: dolomite formed penecontemporaneouly in its environment of deposition
2) Diagenetic: replacement of limestone following consolidation of the sediment or coincident with consolidation
3) Epigenetic: replacement of limestone being localized by post-depositional structural elements, such as faults and fractures.

Figure 1: Upper Devonian stratigraphic section.

(from Andrichuk, 1961)

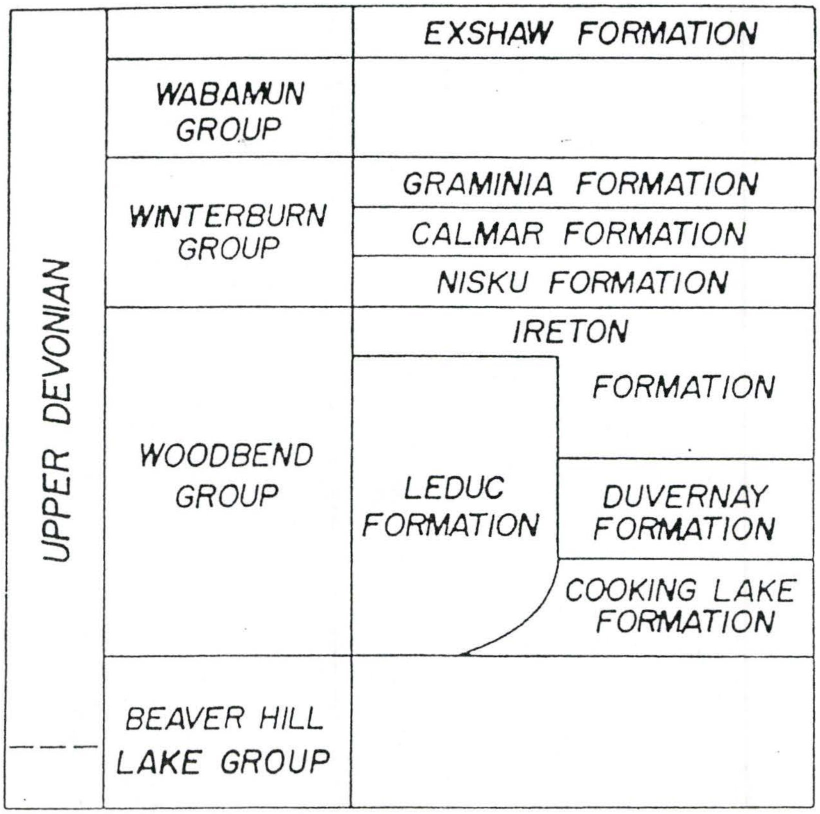

UPPER DEVONIAN
EXSHAW FORMATION
WABAMUN GROUP
WINTERBURN GROUP
GRAMINIA FORMATION
CALMAR FORMATION
NISKU FORMATION
WOODBEND GROUP
IRETON FORMATION
LEDUC FORMATION
DUVERNAY FORMATION
COOKING LAKE FORMATION
BEAVER HILL LAKE GROUP

Figure 2: Lithofacies map of the Wabamun Group.

(after Belyea, 1964)

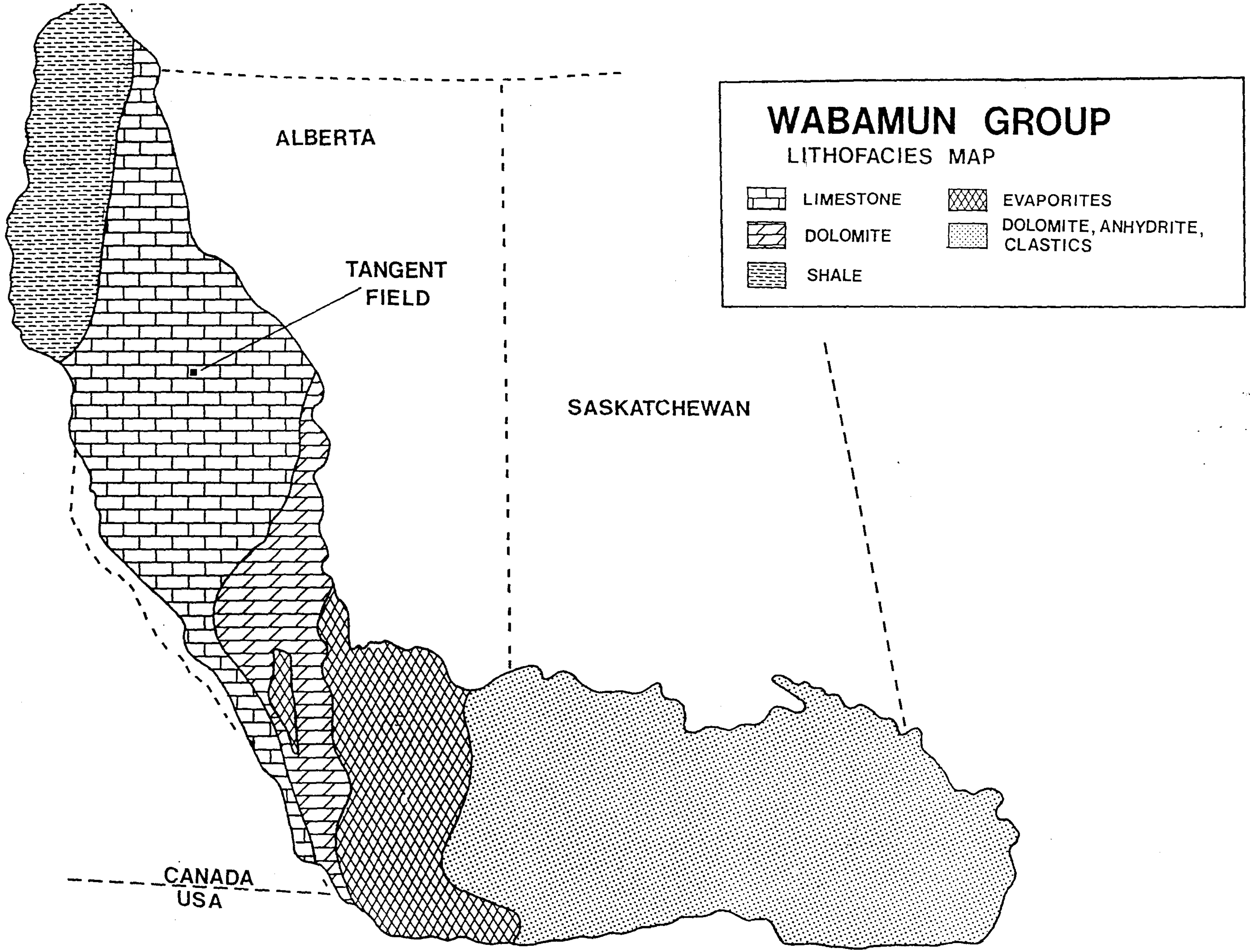
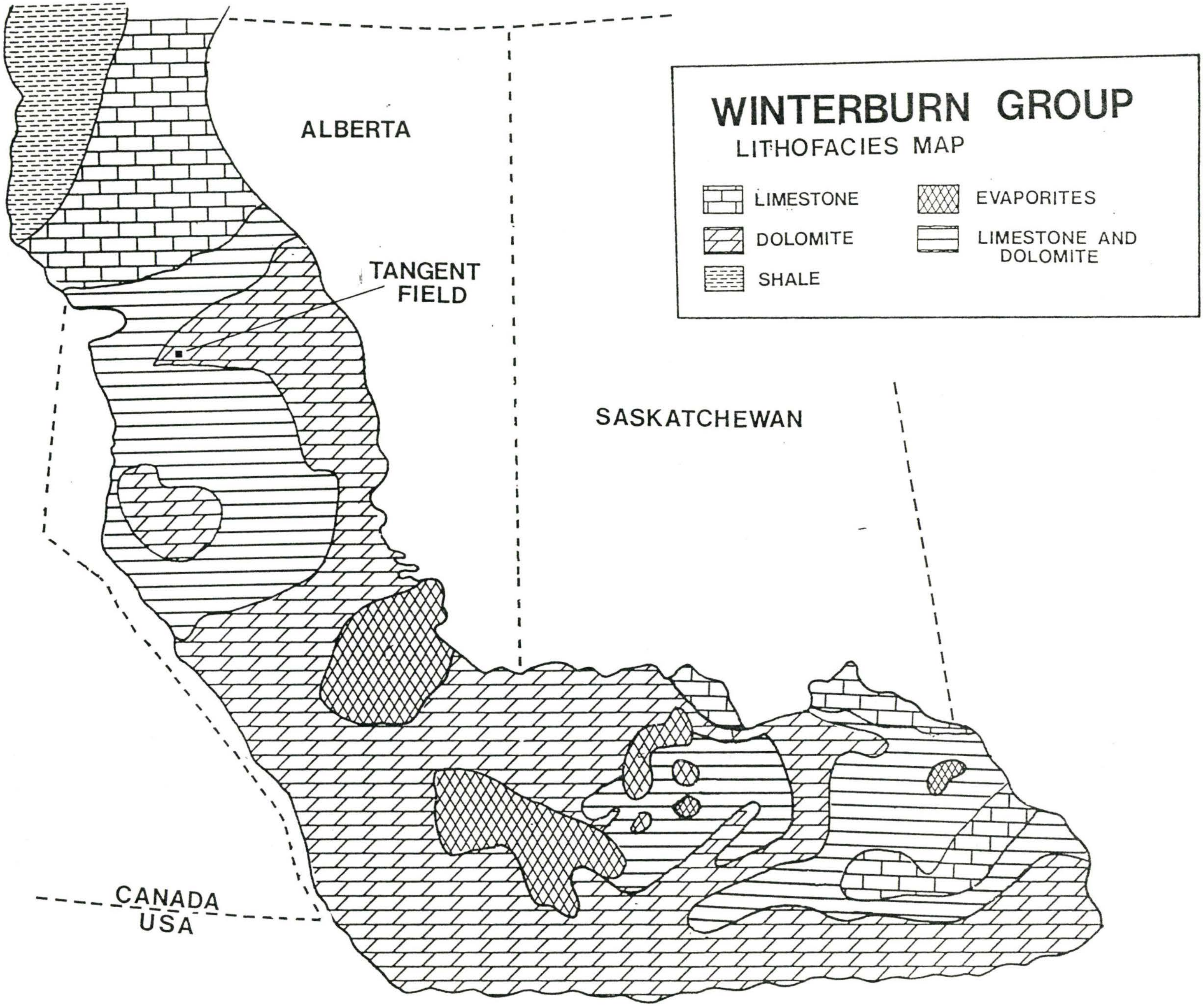

WABAMUN GROUP
LITHOFACIES MAP
LIMESTONE
DOLOMITE
SHALE
EVAPORITES
DOLOMITE, ANHYDRITE, CLASTICS
ALBERTA
TANGENT FIELD
SASKATCHEWAN
CANADA
USA

Figure 3: Lithofacies map of the Winterburn Group.

(after Belyea, 1964)


WINTERBURN GROUP
LITHOFACIES MAP
LIMESTONE
DOLOMITE
SHALE
EVAPORITES
LIMESTONE AND DOLOMITE
ALBERTA
TANGENT FIELD
SASKATCHEWAN
CANADA
USA

1.3 Tangent Field

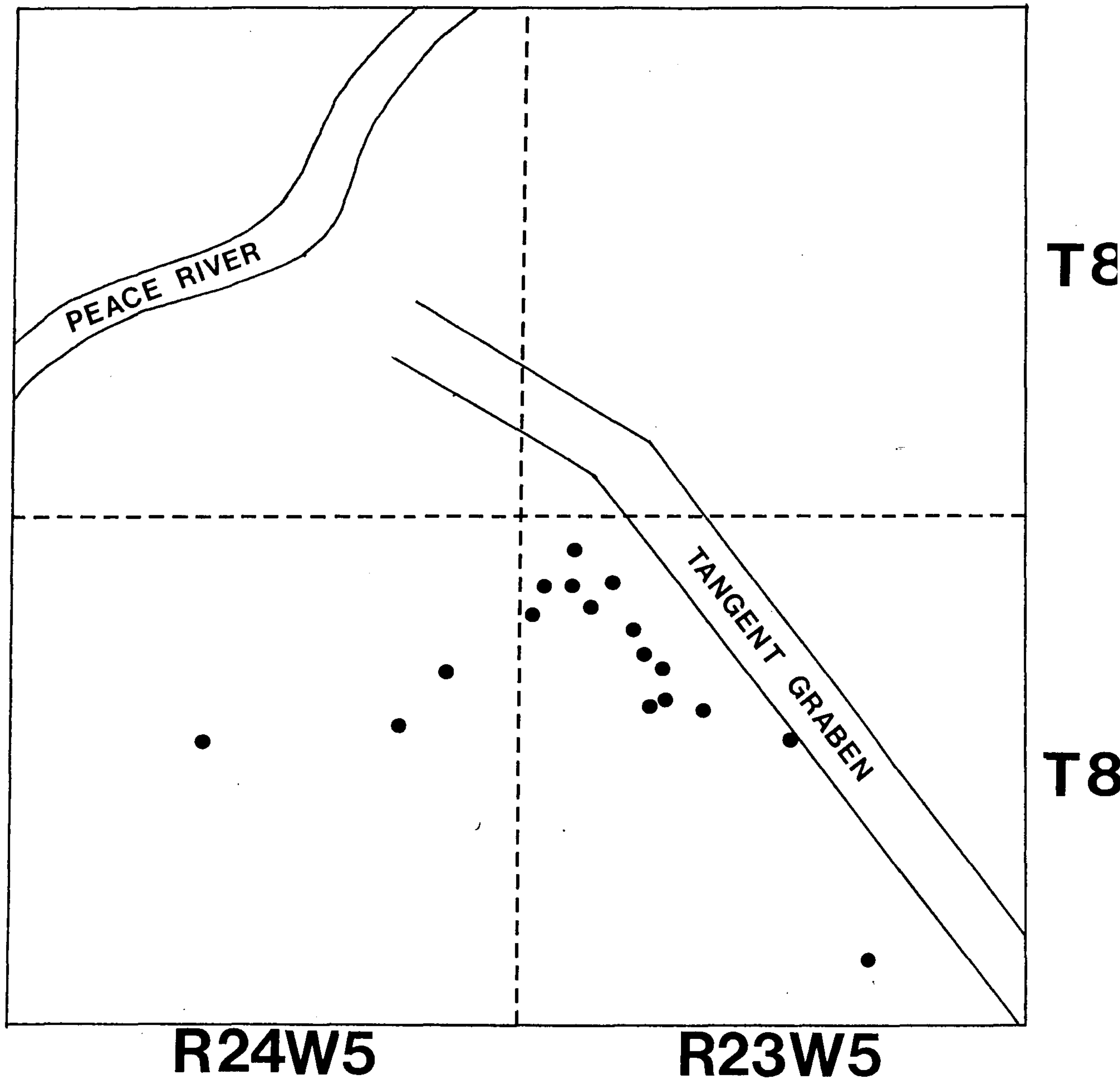
Tangent Field is located in Townships 80,81 and Ranges 23,24 west of the Fifth Meridian. The field is a structural trap, created by the downthrown block of a Graben. (Fig. 4) Reservoir porosity requirements are satisfied by fracture porosity within unaltered limestones and by intercrystalline porosity created by the dolomitization of the Wabamun limestones. The field is surrounded by non-porous limestones of the Wabamun Formation. It is overlain by the tight shales of the Exshaw Formation and underlain by the Winterburn Formation (which is mainly dolomite in the Tangent area). The field contains 17 producing oil wells (Wabamun), 16 producing gas wells (Cadotte, Gething, Montney) and 20 wells which are either shut-in or suspended.

1.4 The Wabamun at Tangent

The limestone described by Andrichuk(1951) occurs 1) outside the main field and 2) inside the field when not dolomitized. There are two end members, micrite and poorly washed biomicrites (Folk,1962), with gradational compositions between the two also present. Pelletstones are also present and are commonly capped by hardgrounds, signifying a pause in deposition or an erosive event. The most common constituent of the limestone is micrite, but the poorly washed biosparites contain abundant intraclasts and fossil fragments. Identifiable bioclasts include; brachiopod shells, crinoids, algae, forams (Tournayella), gastropods, bryozoans, echinoid spines and ostracods.

Figure 4: Map of Tangent oil field.

Black dots represent oil wells.



PEACE RIVER
TANGENT GRABEN
T8
T8
R24W5
R23W5

Various types of limestone porosity are also distinguishable. Shelter porosity is seen below curved shell fragments, fenestral porosity is seen and is filled with sparite cement, intragranular porosity is also seen and is characterized by geopetal texture. Dolomitic mottling as described by Beales (1953) is present with the mottling closely resembling burrow traces. Fractures filled with sparry calcite cut the limestone, as do fractures which are open or only partially filled. The open fractures are much smaller, usually about 25um across. The concentration of this study is centered on one well, 6-32-80-23W5, because of the complete upwards transition from dolomite through to limestone.

1.5 Previous Work

There is no published data on the dolomitization at Tangent field in north western Alberta. A regional study of the lithologies of the Wabamun was done by Andrichuck in 1960. There is however a large amount of literature on dolomitization, of which a few key papers were very useful to this study. These papers include a study of burial dolomitization by Mattes and Mountjoy (1980), dolomitization by seepage refluxion by Adams and Rhodes (1960) and finally a book by Longman (1981) on carbonate diagenesis.

1.6 Methods

1.6.1 Thin Sections

Thin sections for petrographic and cathodoluminescence were cut from samples taken from the 6-32-80-23W5 core stored at the E.R.C.B. The cored interval of 6-32 is from 1750.0m to 1805.2m below KB (equivalent to 1178.2m to 1233.3 BMSL)

Thin sections for petrographic work were cut to a thickness of 30um and then stained with Alizarin Red-S and K-ferricyanide to distinguish calcite from dolomite. The samples were then impregnated with a blue porosity indicator followed by the application of cover slips.

Samples prepared for cathodoluminescence were cut extra thick and were not stained. They were left uncovered until after use with the CL at which time the cover-slips were applied and the sections were viewed under plane light.

1.6.2 Cathodoluminescence (CL)

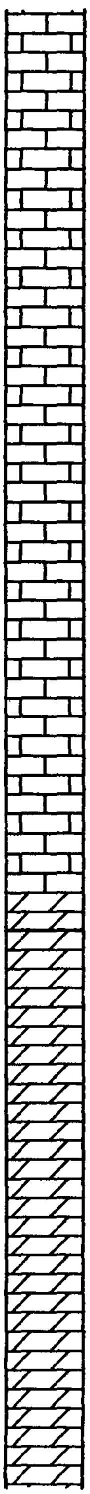
In its most basic definition CL is the visible light emitted by a mineral when subjected to electron bombardment. Luminescent intensity in carbonates is governed by a number of components which are classified into three groups; activators, sensitizers and quenchers. The main activators in calcite and dolomite are Mn, Pb and several REE. The main quenchers are Fe, Ni and Co. The process of CL involves the generation of an electron beam by applying a potential across a cold cathode in a partial vacuum. The electron beam is then deflected onto the sample via a magnetic field to produce CL colours and intensities diagnostic of certain minerals. The two main uses of CL in this study were 1) making fabrics and textures visible that are not visible under plane polarized light and 2) the identification and correlation of cementation events.

The variety of dolomitic types resulted in a variety of luminescent intensities which made photography difficult. Exposure times were 1-2 seconds under plane light and 2-4 minutes for luminescent light. Kodachrome VR400 film was used for CL and VR100 was used for thin section photomicrographs. During CL photography the beam energy was 12KV, the beam current was .8mA and the focus was set at 27.

1.7 Core Description

Numac PCP Tangent

102-6-32-80-23W5



1750.26 Top of cored interval.

1751.26 Brown mudstone-characterized by mottled appearance,numerous stylolites and hardgrounds.

1763.0 Zone of calcite fracture filling. Fractures are mainly vertical and range in size from 1-3cm wide and up to 15cm in length.

1786.0 Large fracture and rubble zone. Fractures filled with anhydrite.

1794.0 limestone

dolomite

1796.0 Large anhydrite filled fracture. Many open fractures and partially filled with calcite.

Fractures are vertical, horizontal, and angled.

Fractures are 1-3mm across and up to 15cm in length.

1805.25 Rubble zone at base of core.

Chapter 2: Petrography

2.1 Description of Dolomite Types

2.1.1 Type 1 Diffuse Microcrystalline Dolomite

Crystals of diffuse microcrystalline dolomite are usually isolated, single crystals randomly scattered throughout a matrix of otherwise unaltered limestone. Individual crystals are euhedral to subhedral, show no distinct zonation and range is size from 10um to 60um in diameter (Figs. 5,6). Microcrystalline dolomite also occurs within pellets and as single crystals replacing the cores of crinoid fragments. Occasionally these small crystals are visible in clusters of 5 or 6 and seem to be related to microfractures which are less than 5um in width.

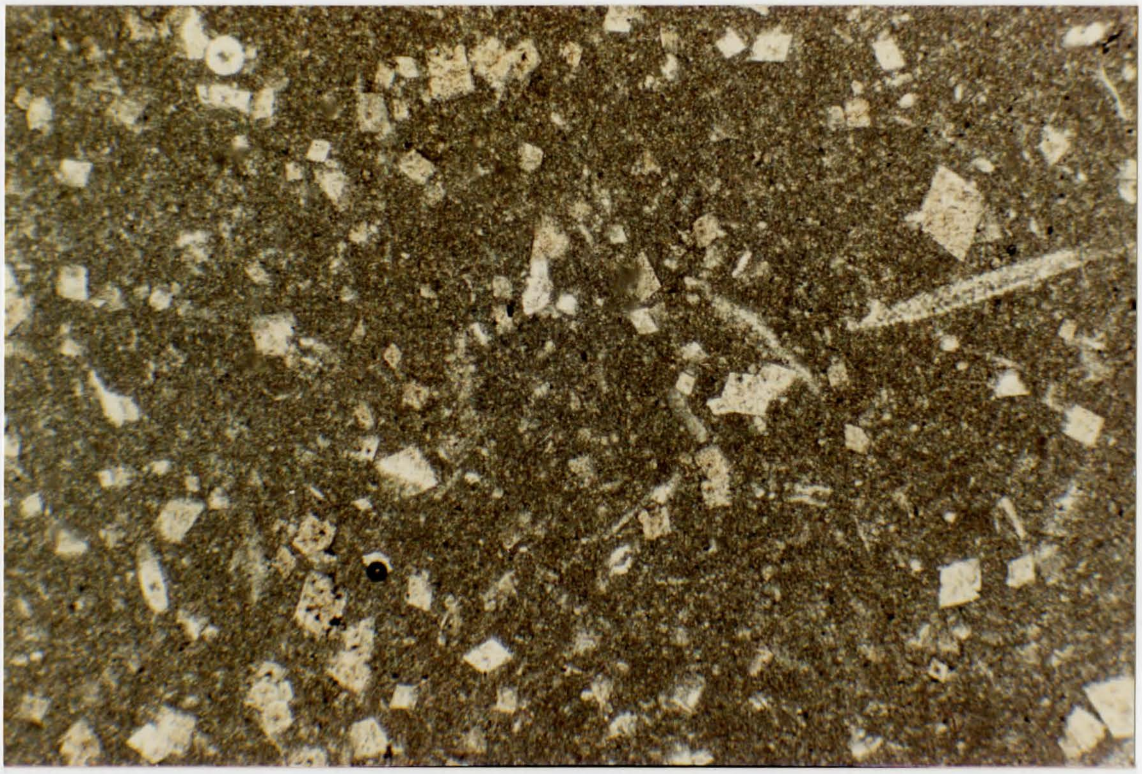
2.1.2 Type 2 Mosaic Dolomite

Mosaic dolomite is very similar to the dolomite described by Mattes and Mountjoy (1980). There is a large variation in size, shape, related fabric and amount of associated porosity. In general mosaic dolomite contains three basic crystallographic styles. The first, Type 2a, consists of euhedral crystals with associated intercrystalline porosity (Fig. 7), the second, Type 2b, consists of patches of interlocking crystals with no associated porosity of any kind (Fig. 8), and the third, Type 2c, consists of large euhedral crystals that have replaced calcite fracture fill (Figs. 9,10) and have an extremely high proportion of intercrystalline porosity.

Figure 5: a) Type 1 dolomite in a micrite matrix.

Depth 1786.2m, mag. 35X.

b) Same as above except magnification is 200X.



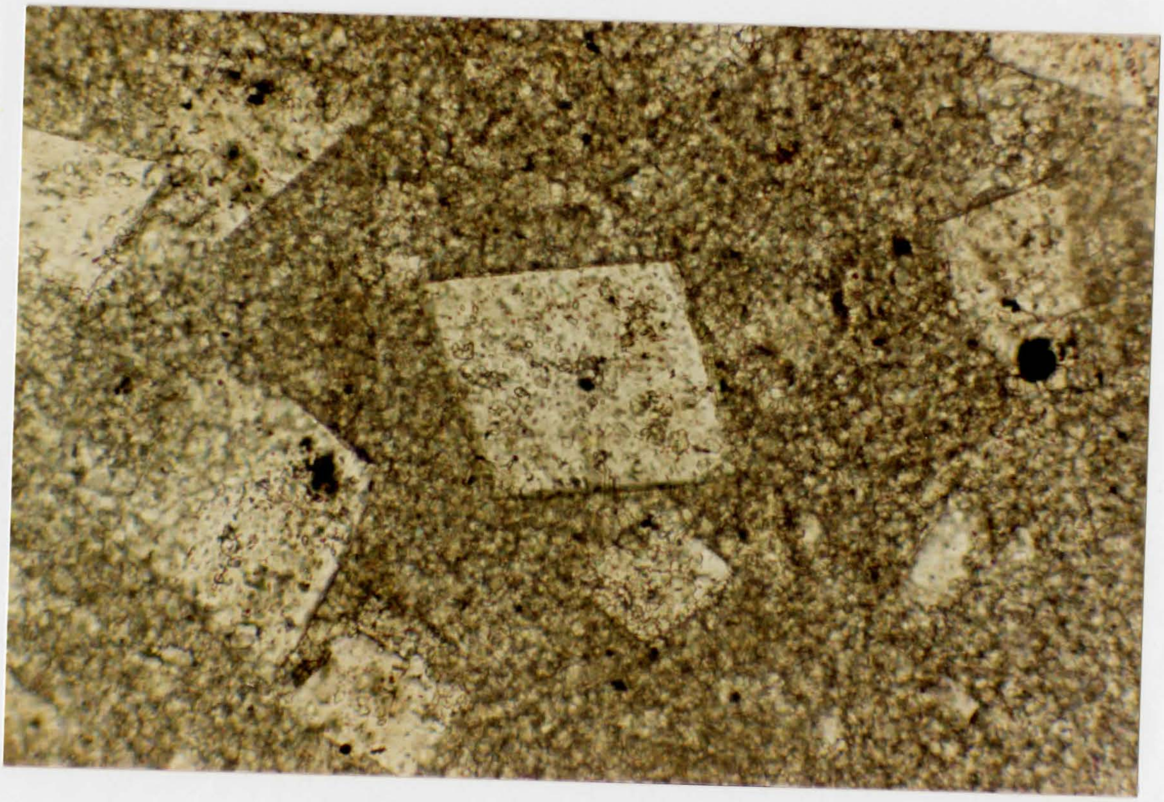
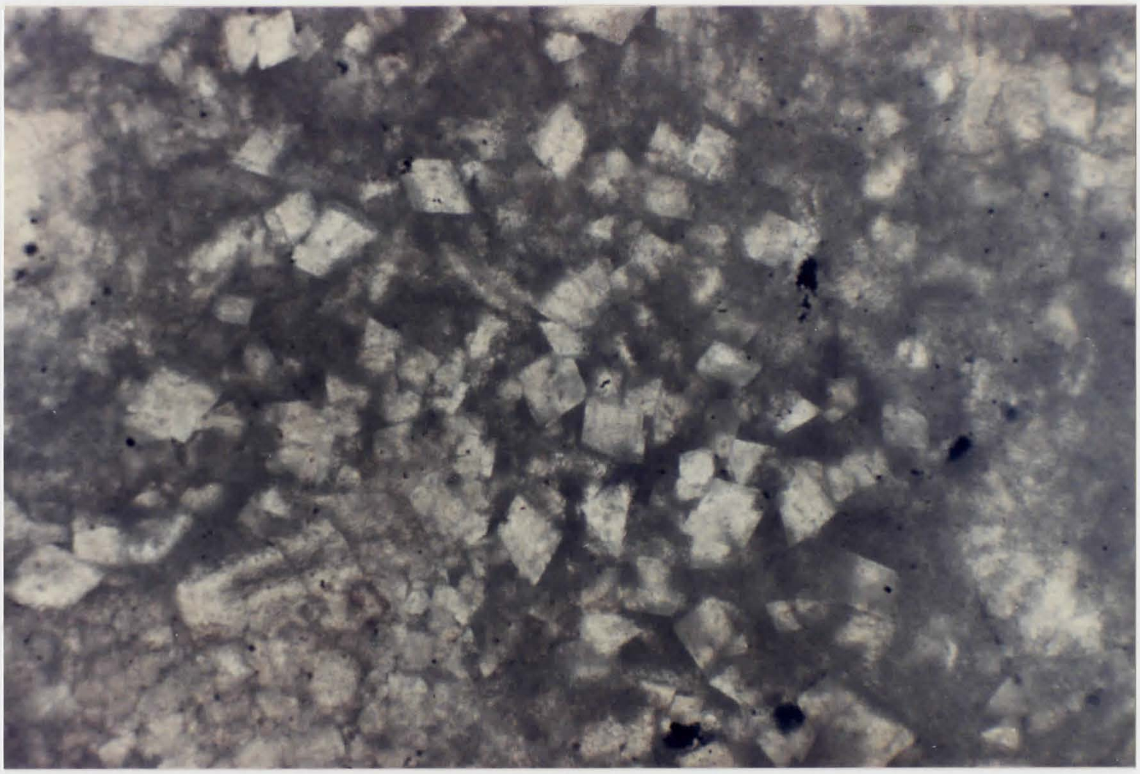
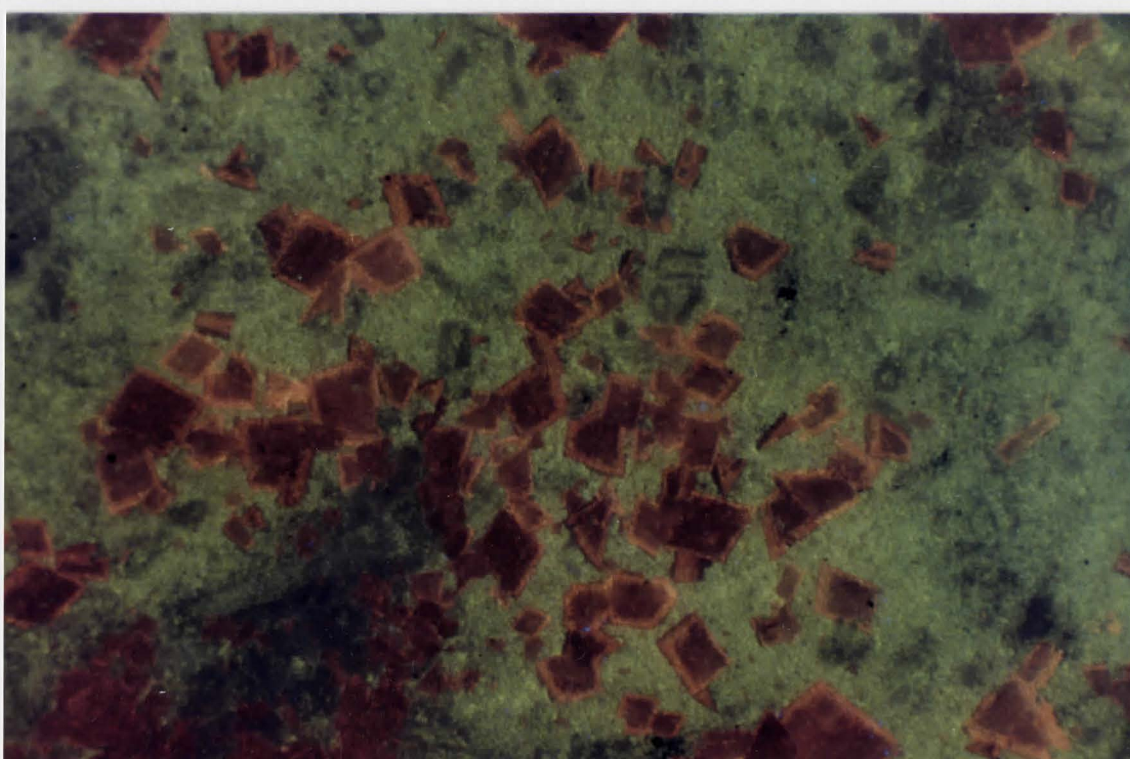


Figure 6: a) Type 1 dolomite in a micrite matrix. (the cloudy appearance is due to the lack of a cover slip) Depth 1791.3m, mag. 35X

b) CL photo of a). Note dolomite rhombs have a dark red core and a light orange rim.



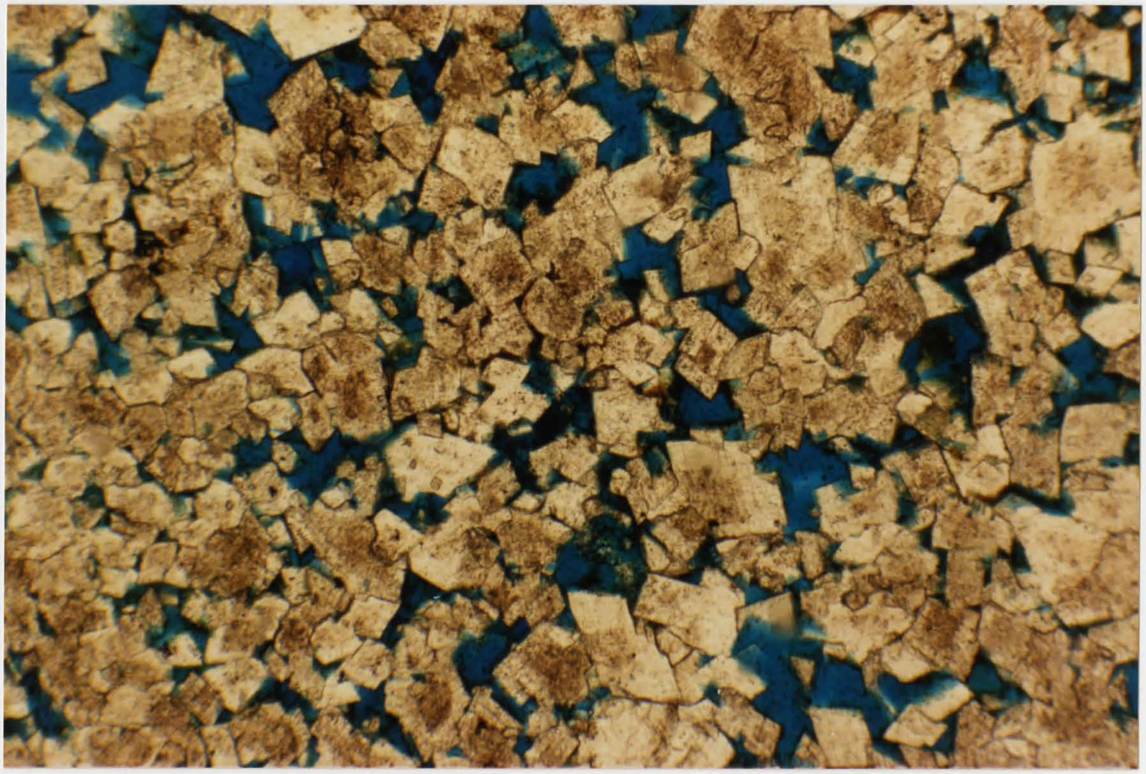


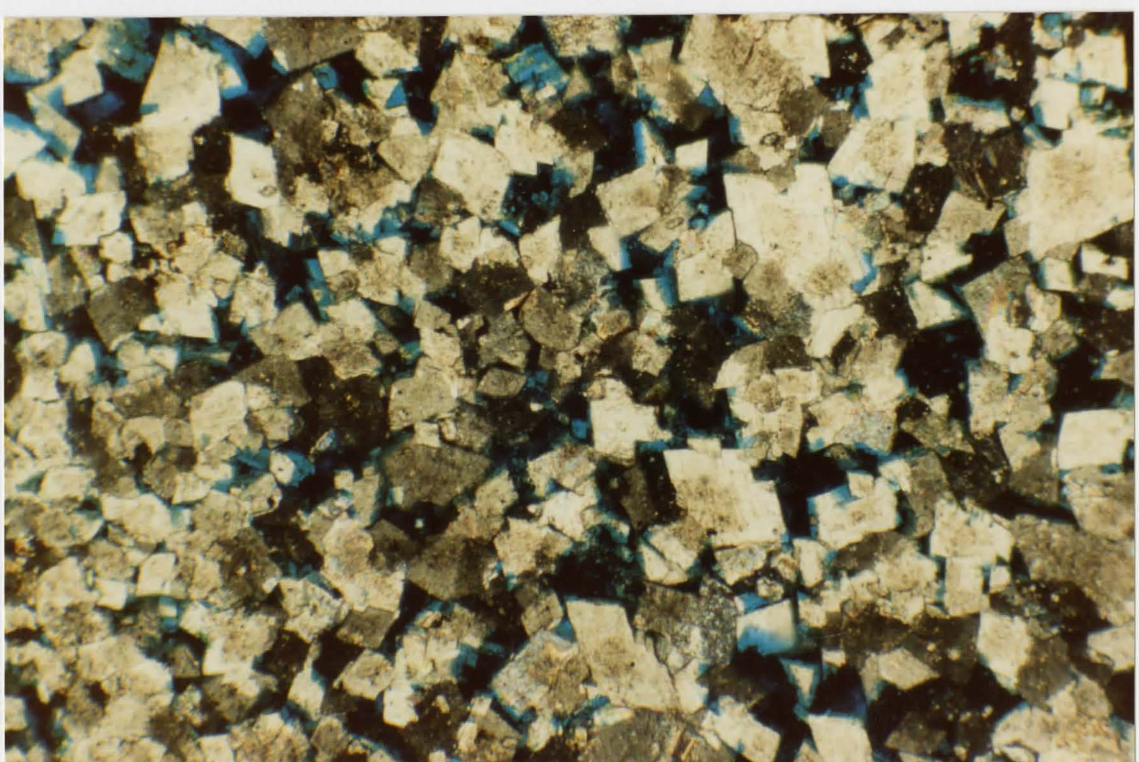
Type 2a

The first crystallographic style (Type 2a) makes up approximately 50% of the mosaic dolomite. These crystals are mostly euhedral and are often spectacularly zoned. The zonation is characterized by a dark core and a clear rim. The shape of the dark core is not always euhedral, but the form completed by the epitaxial rim is euhedral. This zonation is described by Sibley (1980) as a concentration of inclusions and voids in the core and the absence of these in the rim thus giving the cloudy core -- clear rim morphology. Most crystals show only two zones, dark core and clear rim, but there are some that seem to repeat this cycle. The size range for unzoned crystals is 80um to 120um in diameter, while the zoned crystals are larger and range in size from 80um to 160um in diameter. Small amounts of calcite are often found associated with the euhedral crystals and partially fill the intersticies between the dolomite rhombs. The calcite has rounded edges and porous spots within the crystals. It is also visible within the cores of some dolomite crystals and as inclusions throughout other crystals (this is most easily seen under cathodoluminesence). There are also dolomite crystals with porous cores and porous spots within the outer portion of the crystal. The replacement of the limestone by this style of Type 2 dolomite leaves no evidence of any primary textures and has overprinted any pre-existing dolomite and stylolites.

Figure 7: a) Type 2a dolomite with a large amount of intercrystalline porosity.
Depth 1801.3m, mag. 35X.

b) Same as above except with polars crossed.





Type 2b

The second style of Type 2 dolomite, Type 2b, accounts for approximately 40% of the total mosaic dolomite. This style is characterized by anhedral to subhedral crystals which form interlocking areas and patches. These areas and patches have no associated porosity. The anhedral shape of the crystals makes it difficult to obtain an exact measurement of diameter, but an average size is between 80um and 120um. These crystals lack any sort of zonation, extinguish diffusely and are extremely cloudy. The cloudiness of these crystals, their shape and size closely resembles the cores of the euhedral crystal portion of Type 2 dolomite. Dolomite crystals exposed to porosity around the edges of the patches and lining porous spots within the patches have the clear epitaxial rims that characterize the euhedral crystals.

Type 2c

The third crystallographic style of Type 2 dolomite, Type 2c, is characterized by large euhedral crystals that have replaced sparry cement that had previously occupied fractures. These crystals are considerably larger than any of the others so far described and average in size from 140um to 240um. Their appearence under plane light is quite dusty and not as cloudy as the cores of the Type 2a or 2b crystals. The intercrystalline porosity created by the formation of these crystals is on the order of 40 percent.

Figure 8: a) Type 2b dolomite with interlocking habit and no associated porosity. Depth 1801.3m, mag. 35X.

b) Same as above except with polars crossed.

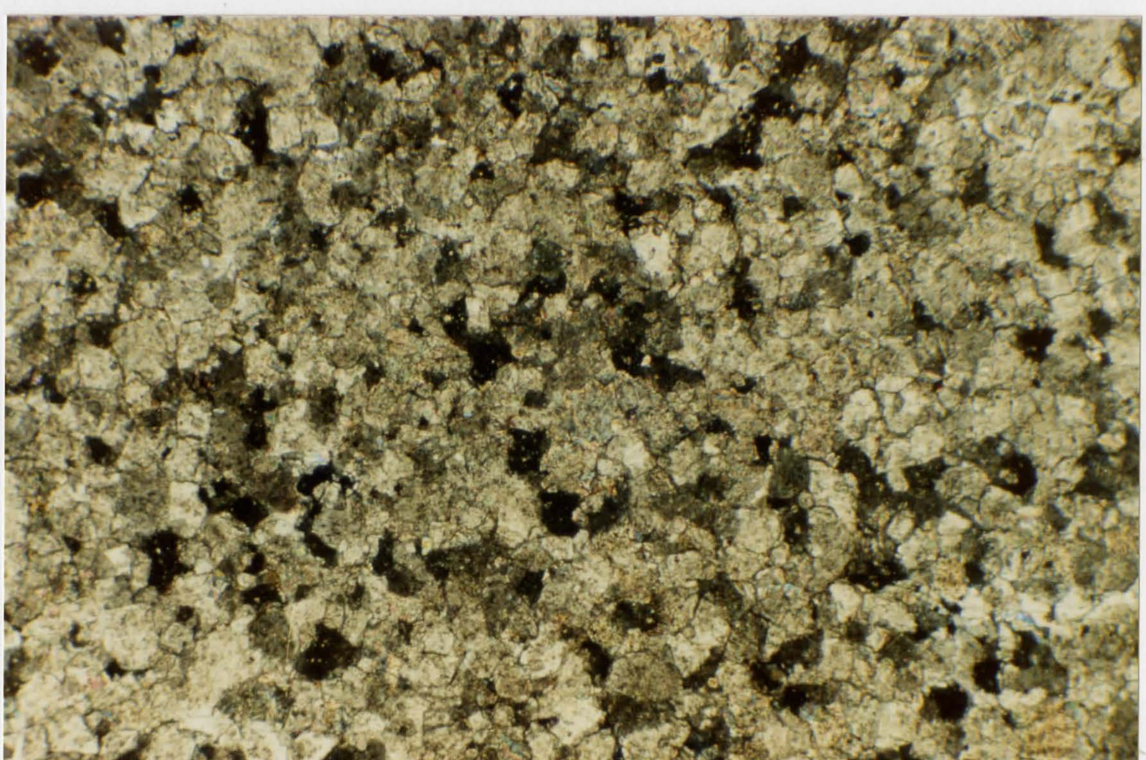
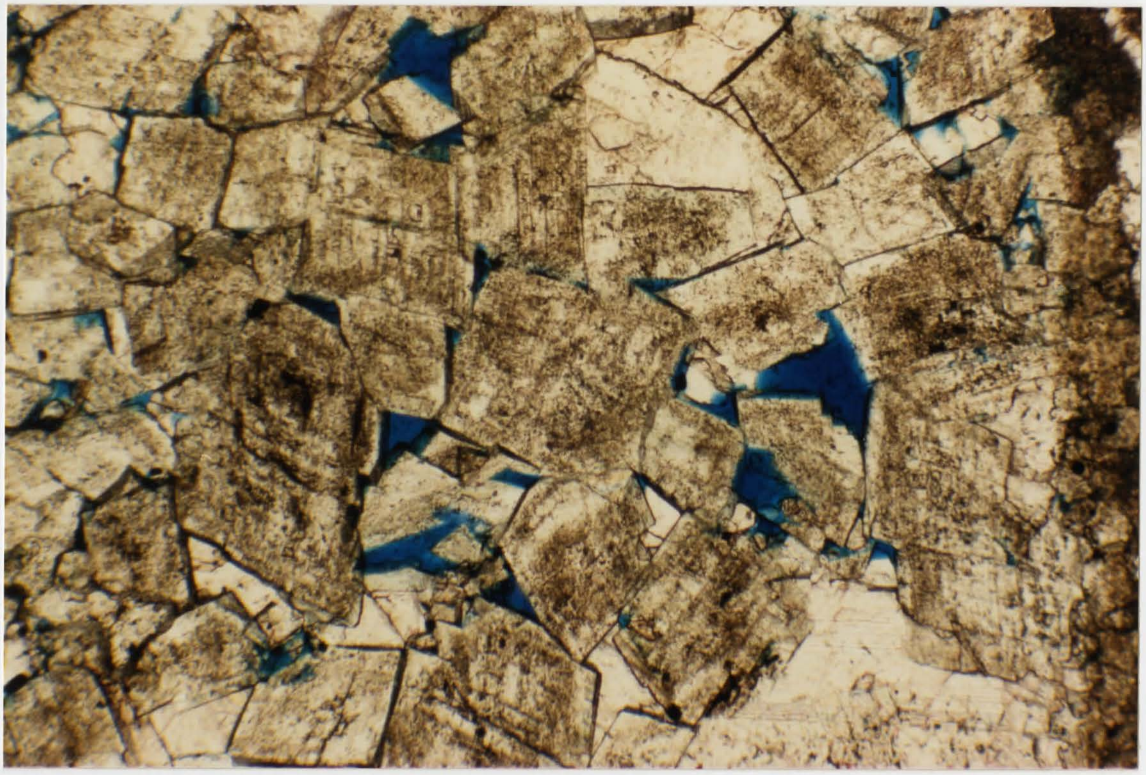


Figure 9: a) Type 2c dolomite replacing calcite fracture fill. The undolomitized micrite is visible in the left hand side of the photo.
Depth 1780m, mag. 35X.

b) Same as above except with polars crossed.



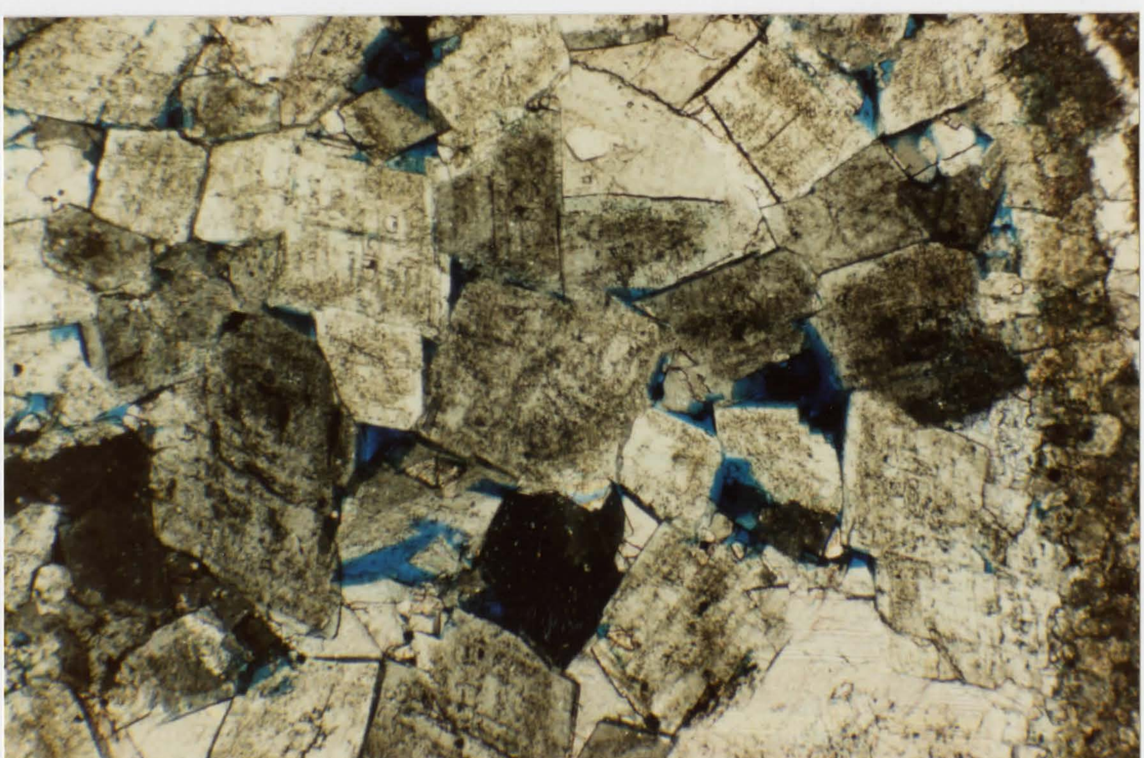
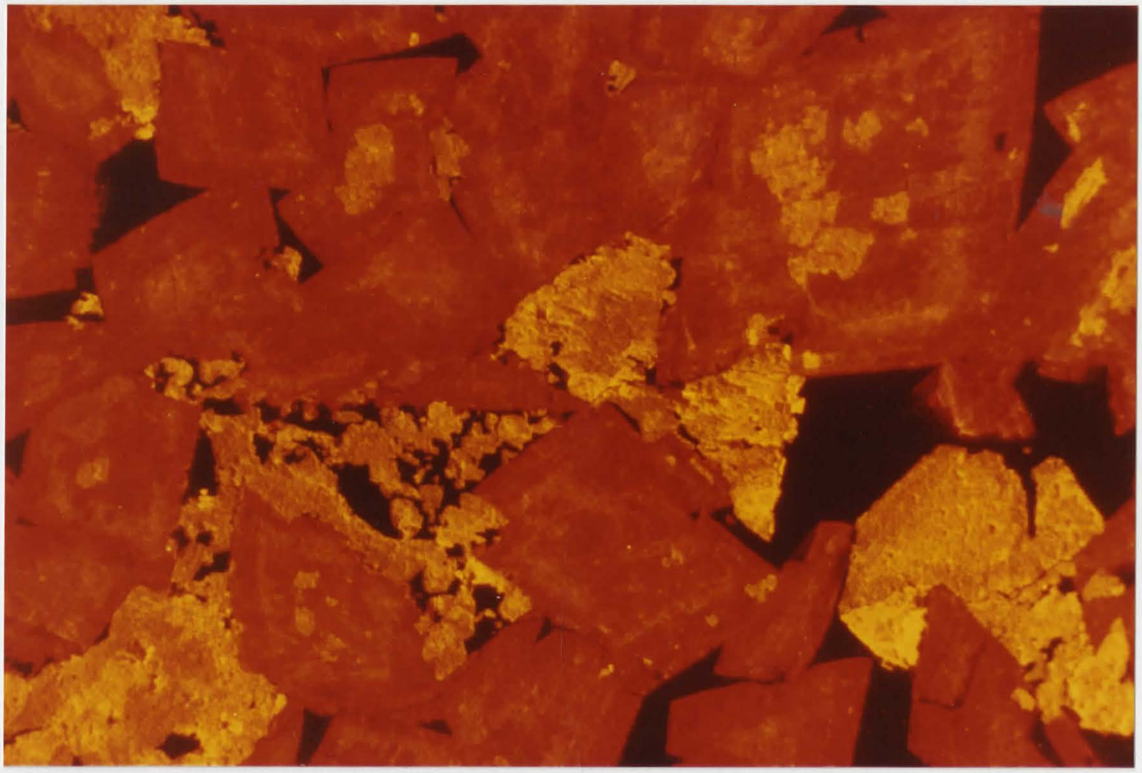
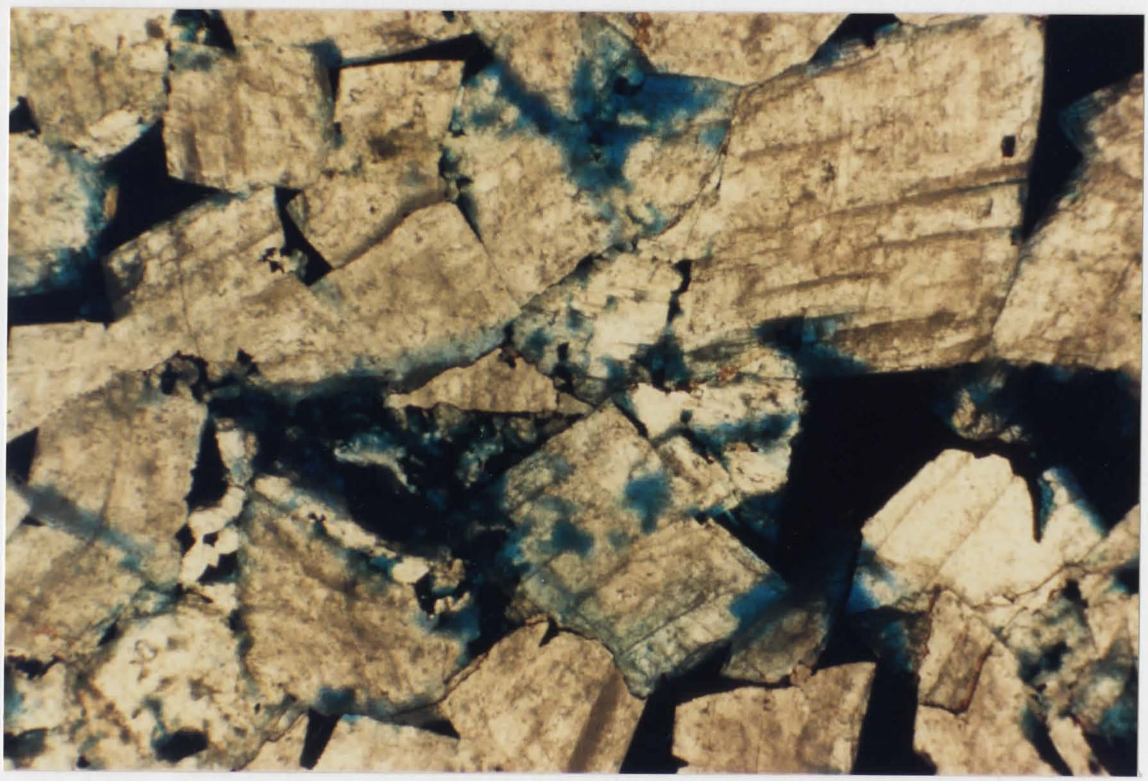


Figure 10: a) Type 2c dolomite. Depth 1796.1m, mag. 35X.

b) CL photo of the above Type 2c dolomite. Inclusions of calcite (yellow) are visible in the dolomite rhombs (orange-red).

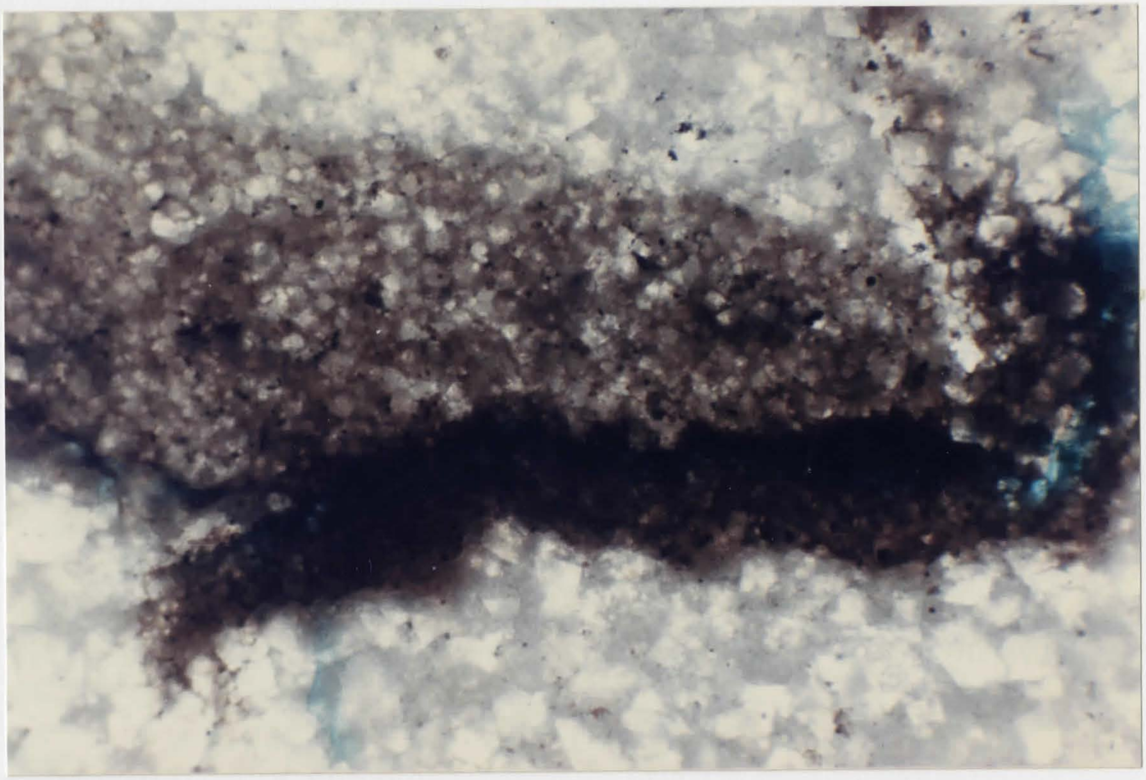
The edges of these crystals are often jagged and quite ratty, inclusions of calcite within the crystals are common. CL reveals that the cores of some of these cores are also calcite. The calcite fracture fill, when still present, is characterized by very irregular crystal boundaries and amoeboid porosity spots all through the crystals.

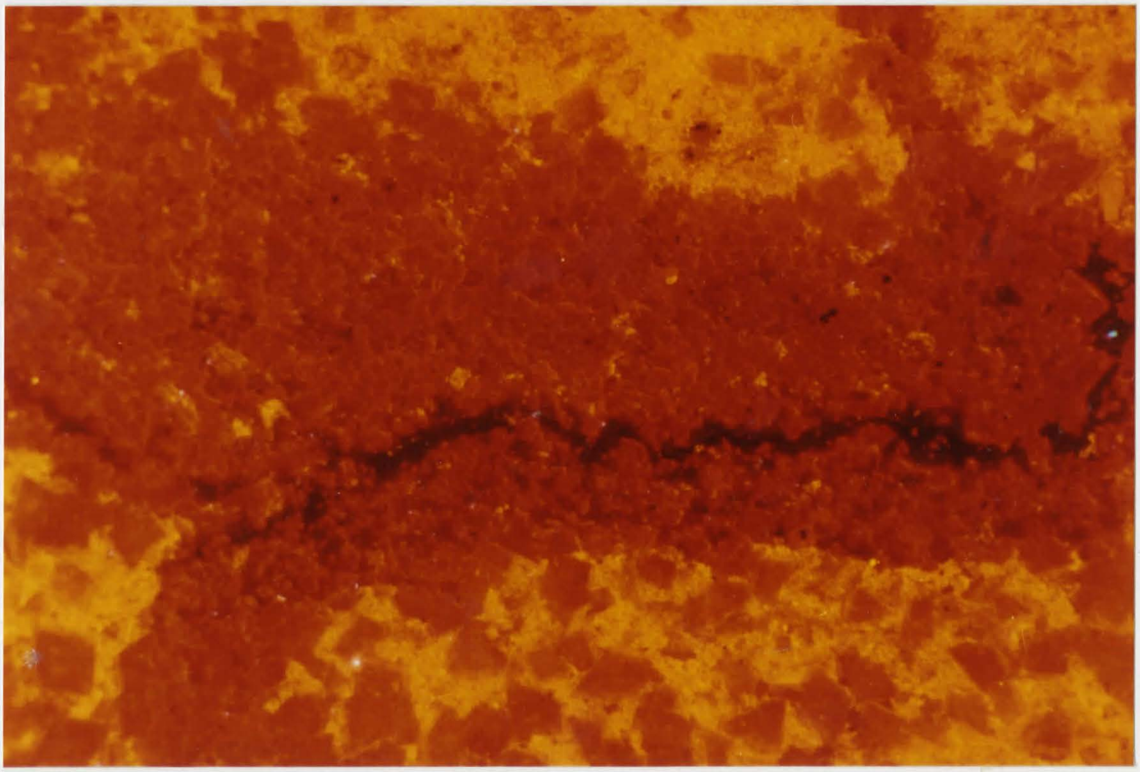
2.1.3 Type 3 Dolomite Related to Pressure Solution

This type represents a very small portion of the total dolomite and is directly related to pressure solution. This dolomite occurs in bands which mimic the stylolite topography, and the dolomite usually occurs only on one side of the pressure solution seam. Replacement does not seem to follow any preferential pattern except that the amount of dolomite decreases away from the pressure solution interface. Crystals are typified by a size range between 10um and 40um and are stained a brown tint, probably due to the organics being partially dissolved by the solution process (Fig. 11). An accurate measurement of the amount of dolomite directly related to pressure solution is not possible. This is due to the overprinting by mosaic dolomite which has obscured the earlier textures created by the stylolites and their related dolomite.

Figure 11: a) Plane light photo of a stylolite. Depth 1799m, mag. 35X.

b) CL photo of the above stylolite showing dolomite which has formed along the stylolite. Note the difference in luminescence between the Type 1 dolomite, visible at the bottom of the photo, and the dolomite formed along the stylolite.





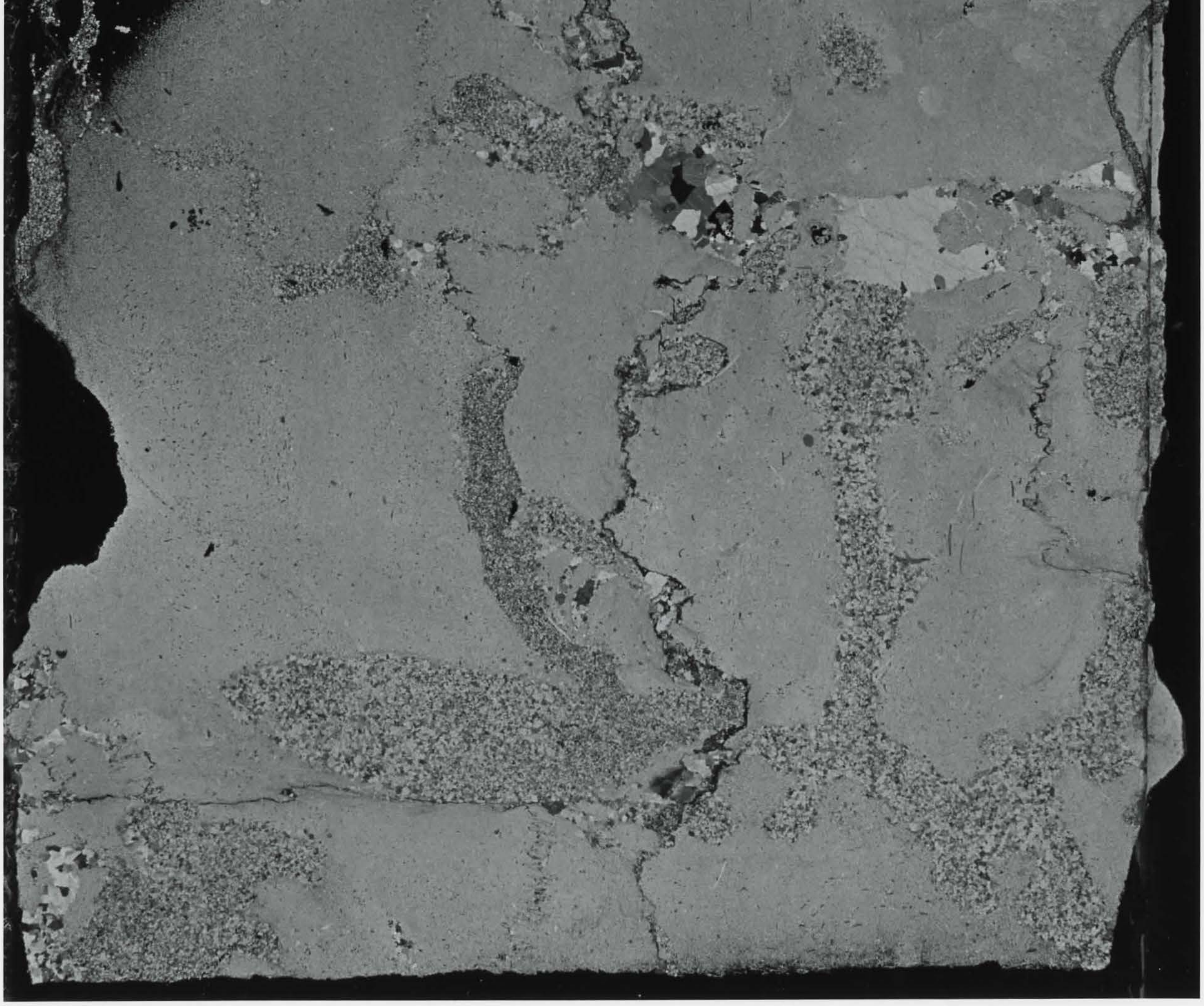
2.2 Dolomitic Mottling

Beales (1953) described mottling in the Palliser in south western Alberta. He concluded that the mottling results from a differing composition and crystallinity which has irregularly developed throughout the rock, giving rise to the development of dolomite which was more coarsely crystalline than the original limestone. The mottling described by Beales (1953) shows best on weathered surfaces as the crystalline dolomite commonly stands higher in relief than the limestone. This feature was not immediatly noticed in the Tangent core because the relief due to weathering was obviously not present. A slight colour difference was present, and after the application of HCl the mottling was readily apparant as it stood well above the limestone matrix. This mottling is clearly visible in thin section and is best seen at a depth of 1796.4m. The sharp contact between dolomite portions and the calcareous matrix are similar to those described by Beales and also to those described by Morrow (1978).

Figure 12 shows dolomitized burrows from the 6-32 well at a depth of 1794.6m. The crystals are 100um to 150um in size and are commonly interlocking but some euhedral crystals are present. The darker portions towards the centre of the burrows are similar to those described by Beales (1953). A faint bluish colour (porosity) is evident over a distance of 150um from the edge of the burrow. Recrystallization of the lime mud to microspar is also evident along the immediate fringe of the mud matrix. This

Figure 12: Dolomitic mottling as described by Beales (1953).

The actual size of this picture is 2cm x 4cm.



dolomite, when seen in a micrite matrix might warrent a seperate classification, but upon closer examination it appears to be represented by the interlocking non-porous style of Type 2b dolomite.

2.3 Micrite

The fauna present can be taken to describe the biological characteristics of a depositional environment. It appears that the sediment was deposited in an open marine, outer shelf environment. In this quiet depositional environment it would be expected that large amounts of fine sediment would accumulate, and the large amount of micrite in the Wabamun core at Tangent bears evidence for this environment. Micrite, by definition, consists of particles less than 5um in diameter and the particles in the Wabamun micrite range from 3um to 7um in diameter. The micrite is often interrupted by accumulations of spar-cemented pelletstones and spar-cemented fossil accumulations. Recrystallization of the micrite to microspar (7 to 10um) and pseudospar (>10um) is seen around the edges of burrows and in places randomly distributed throughout the rock. The recrystallization of micrite to either microspar or pseudospar is knowm as neomorphism (Folk,1964). The exact origin of the micrite is unobtainable due to its fine size, but possible origins include disintegration of hard parts of organisms or precipitation directly from sea water (Blatt et al.1980).

2.4 Anhydrite

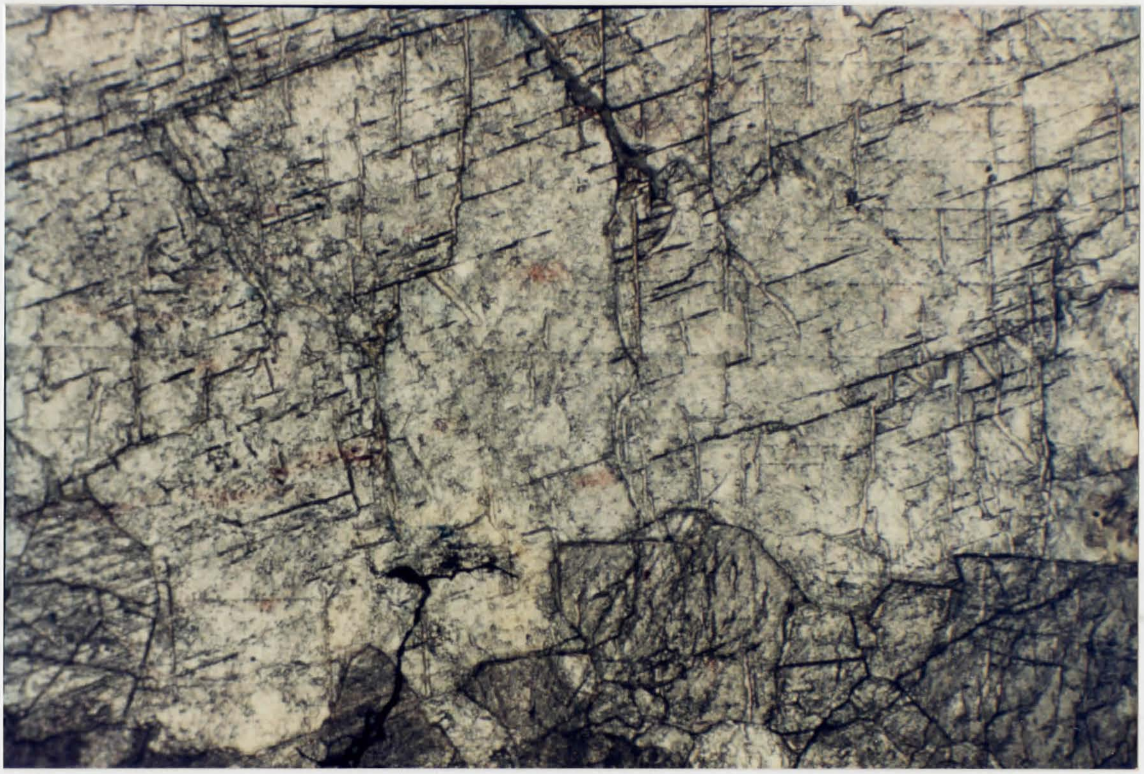
Crystals of anhydrite which are found in fractures are typically colourless in thin section, anhedral to subhedral, elongated with perfect right angle cleavage. The anhydrite shows signs of occupying a fracture once occupied by calcite. The textural evidence for this is the nature of the anhydrite and remnant calcite crystals. The anhydrite crystals are long and often curving indicating growth into free space, while there are only a few calcite crystals left they are anhedral, have ratty edges and usually appear attached to the fracture wall. Anhydrite is only found as far up in the section as the dolomite and seems to be most abundant as a cement in zones of intense fracturing. It also appears in small patches which cement dolomite rhombs of Type 2b dolomite. These crystals are smaller, poorly developed aggregates and account for only a minor portion of the total anhydrite. The anhydrite luminesces a deep blue, almost purple under CL, with no textural differences nor any cementation composition variations visible through differential luminescence. This probably indicates a single cementation event.

2.5 Calcite

Calcite occurs in two habits in the rocks at Tangent; an intergranular and intragranular cement and as a fracture fill. The crystals which fill the intragranular and intergranular primary porosity are subhedral to anhedral, equant, show excellent rhombahedral cleavage and extinguish

Figure 13: a) Calcite that has filled a fracture in the micrite. Depth 1760.3m, mag. 35X.

b) CL picture of the above calcite showing the changes in composition that occured during growth of the crystal.



sharply. The crystals which fill the fractures are similar in all respects except the equant crystal size. The crystals which fill the fractures display a gradient in size from smaller crystals (500um) near the fracture wall to larger crystals (1500um) near the centre of the fracture. CL reveals no differential luminescence in the smaller crystals that line the fractures nor in the crystals which fill the intergranular and intergranular porosity. It does however reveal an intricate growth history, through differential luminescence for the larger crystals in the centre of the fractures (Fig. 13).

2.6 Stylolites

A stylolite can be defined as a surface or contact, usually in carbonate rocks, that is marked by an irregular, interlocking penetration of the two sides: columns, pits, and teethlike projections on one side fit into their counterparts on the other. A microstylolite is a stylolite in which the relief along the surface is less than one millimeter.

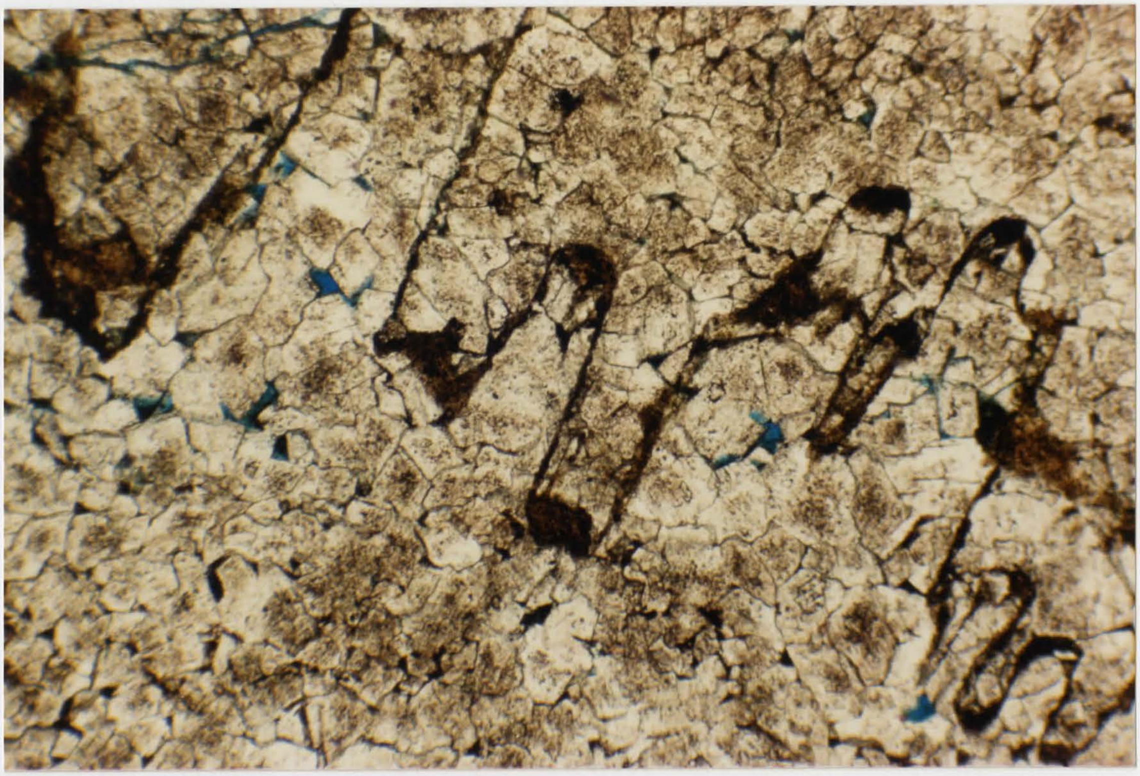
Both stylolites and microstylolites are visible in the core and thin sections. The stylolites range in amplitude from <1mm to 2mm. The control on amplitude appears to be the amount of platy material. Stylolites which are deeply sutured have a low platy mineral content and a very low accumulation of insoluble residue along the suture. Anastomosing swarms of microstylolites contain a significant amount of fine insoluble platy material (possibly clays or mica). Wanless (1978) has described 3 basic styles of pressure solution

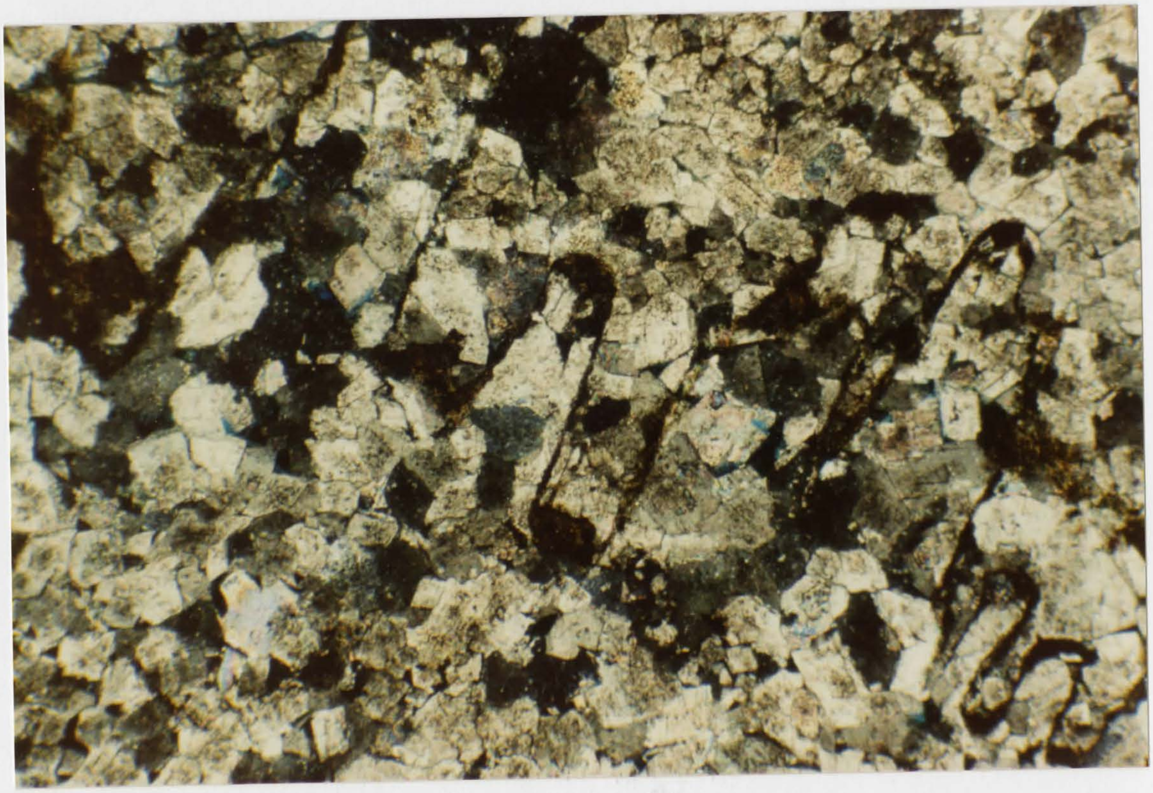
1) Sutured-seam solution: common sylolite and grain contact suture
2) Non sutured-seam solution: microstylolite, microstylolite swarm and clay seams
3) Non seam sutured dolomitization: massive or thinly laminated dolomitic limestone or dolomite.

The Wabamun limestones exhibit pressure solution fabrics typical of both 'sutured-seam solution' (Fig. 14) and 'non sutured-seam solution'. The stylolites usually have associated dolomite which normally occurs on only one side of the suture. This dolomite is characterized by small (20 to 40um) subhedral to anhedral crystals which are often stained brown and have brown material filling the intercrystalline space. This dolomite is very similar to the dolomite which fills the burrows and to Type 1 dolomite. In some there is a considerable amount of porosity (dolomite intercrystalline and fracture) associated with the solution interface. Wanless (1979) suggests that very fine grained insoluble minerals, concentrated by pressure solution, can form surfaces or zones of structural weakness, along which lateral motion can occur to relieve local stress anomolies. If this fracturing occurs, it could provide conduits for fluids to 1) leach the brown material to form intercrystalline porosity and 2) add in transporting dolomitizing fluids to form Type 2 dolomite. The formation of the dolomite along the stylolites could be a result of two processes. The first, according to Mattes and Mountjoy (1980), occurs when Mg-bearing fluid reacts with limestone across a pressure solution surface, and the strained calcite lattice yields calcium ions to the fluid. Dolomite, the stable phase at depth may be precipitated. The second process involves the accumulation of the diffuse microcrystalline dolomite along the interface simply because it is more insoluble than the calcite and thus accumulates as 'insoluble residue'. It is impossible to tell how much material has been lost due to pressure solution and the answer to where the lost material has migrated to is still being debated.

Figure 14: a) A sutured-seam solution in Type 2b dolomite. Depth 1795m, mag. 35X.

b) Same as above except with crossed polars.





Chapter Three: Porosity

3.1 Porosity

Porosity has long been classified as either primary or secondary. Primary porosity comprises that which was present in the sediment or rock immediatly after final deposition. Secondary porosity is that which was created in a sediment or rock after final deposition.

Numerous types of primary and secondary porosity exist in the limestones and dolomites at Tangent with all the primary porosity being infilled and most of the secondary porosity being open. Four types of primary porosity are evident in the undolomitized limestones at Tangent; shelter, fenestral, intragranular and intergranular. Three types of secondary porosity are present in the Wabamun dolomites; intercrystalline, fracture and vuggy.

3.2 Primary Porosity

Shelter porosity occurs below shell fragments that are preserved in a convex-up position. The convex-up position creates an 'umbrella' effect which stops infill of the space by sediment. This primary porosity was subsequently infilled by sparry cement.

Fenestral porosity is characterized by pores in the sediment which are larger than any grain supported pores. The exact origin of fenestral porosity is not clear, but it may be a result of entrapment of fluid during desiccation. The porosity created by this method has been infilled by sparry cement.

Intragranular porosity most commonly exists within the open chambers of shells. Normally this porosity is partially filled by micritic sediment and the cavity is finally filled by calcite cement (resulting in a geopetal fabric).

Intergranular porosity is associated with the numerous pelletstones present. This porosity existed originally as open space immediately after deposition of the pellets. It was however filled with spar cement very soon after deposition (since the pellets are not deformed it was definitly pre-compaction), reducing the porosity to near zero.

3.3 Secondary Porosity

Intercrystalline porosity is the most common form of the three secondary porosity types. It is always intimatly associated with euhedral dolomite crystals which average 150-200um in diameter and often contain the dark core -- clear rim morphology. The intercrystalline porosity is only associated with Type 2a and Type 2c dolomite.

Fracturing appears to be an ongoing event in the Tangent area. Fractures which cut the micrite are always filled with sparry calcite. Other fractures which cut the dolomite are partially filled with dolomite cement, calcite, anhydrite or nothing. Microfractures (20-40um) also cut the dolomite and are open or filled with dolomite cement. These open fractures represent a significant increase in permeability.

Vuggy porosity is only a minor portion of the total porosity in 6-32, but it is a major component in other producing wells in the field (102-16-30-80-23W5). The vugs are often filled with saddle dolomite (Radke and Mathis, 1980). The origin of the vugs is not determinable because any original shape which might have indicated the type of material that was dissolved has been altered beyond recognition.

3.4 Creation of Secondary Porosity

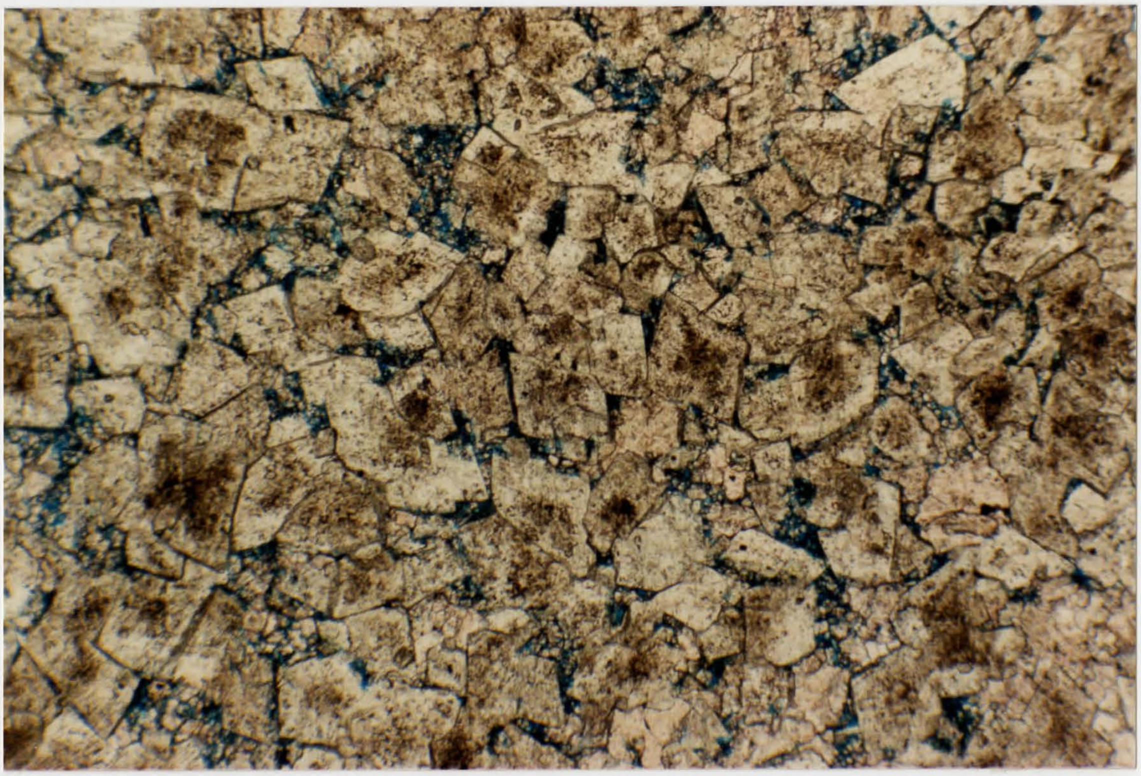
Work by Murray and Lucia (1967) has suggested two methods of forming porosity which is associated with dolomites. The first is via the volume reduction created by a mole for mole replacement of limestone by dolomite. The fact that there is no porosity associated with Type 2b dolomite implies that this method is inapplicable. The second method suggests that material between dolomite crystals is selectively dissolved by fluids (presumably unsaturated with respect to calcite). Numerous petrographic textures indicate that this dissolution is taking place.

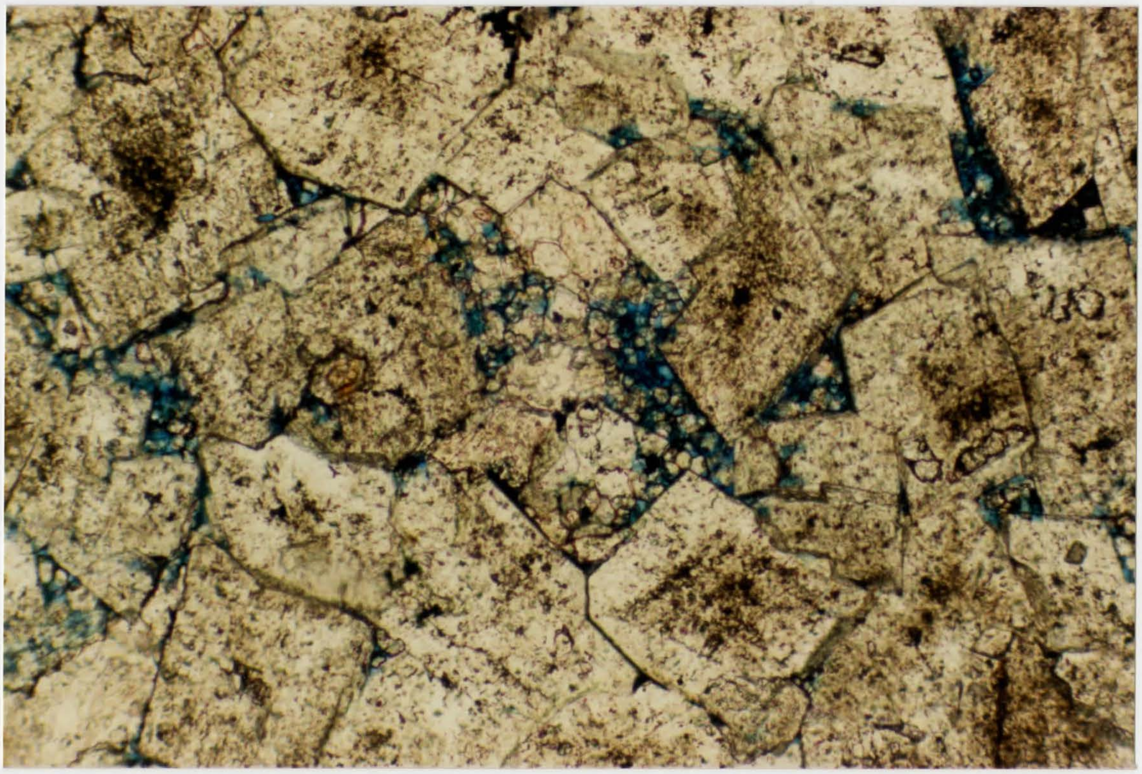
The first is shown in Figure 15. The material between the dolomite rhombs used to be micrite, but as can be seen there is considerable dissolution going on. This dissolution is evidenced by the rounded crystal boundries and by the porosity between the crystals that is not present in the undolomitized micrite.

The advanced state of this process is shown in Figure 7 and

Figure 15: a) Creation of secondary porosity caught in the act. The micrite that has not been dolomitized is being dissolved away, thus creating intercrystalline porosity. Depth 1798m, mag. 35X.

b) Same as above except magnification is 100X.





is the intercrystalline porosity associated with Type 2a dolomite. Further evidence for this fluid having properties conducive to calcite dissolution is the explanation for the clear rim zone in Type 2a dolomite. The outer zone is inclusion free because the the fluids dissolved the potentially included material prior to the rim formation.

Vuggy porosity is probably a result of the dissolution of larger $CaCO_3$ particles which, due to there size, had not yet been dolomitized. The best candidate for this would be crinoid fragments or shells which were still intact.

As mentioned before fracturing was and is an ongoing process at Tangent. Depending on the time of formation these fractures might have been filled with calcite (early), dolomite cement or anhydrite(late).

Chapter Four: Dolomitization

4.1 Dolomitization

The primary focus of this study is to answer the question of why dolomite is present in the Wabamun, and how the process proceeded through time. A number of factors, both petrographic and structural (regional and local) are inherent in the discussion of these questions.

The general morphology of the dolomite body, combined with the fact that it is surrounded laterally by undolomitized rocks and overlies dolomitized rocks (Winterburn) strongly suggests that the fluids originated from below the body and migrated upwards. The Winterburn is predominantly dolomite in the Tangent area, but for the most part the Wabamun, lying conformably on top of the Winterburn, is not dolomitized. This leads to the question of why dolomite occurs in the Wabamun at Tangent and no where else. It is obvious that the Wabamun limestones are, for the most part, impermeable, or they would have presumably been dolomitized similarly to the Winterburn. In order to crack this permeability barrier a mechanism is required that would facilitate upward migration of dolomitizing fluids.

The close proximity of the dolomite body to the Tangent Graben suggests that it is the fault plus the associated structural deformation that could meet the permeability requirements for the upward fluid migration.

The Tangent Graben is approximatly Upper Mississippianin in age, as evidenced by the thickening of the Belloy-Debolt interval over the downthrown block. The faulting is presumably related to the subsidence of the Peace River Arch in post-Devonian time. Evidence for the subsidence is the anomalous thickening of the sediments over the arch area. The downthrow of the graben block, by 700 feet, creates the updip trap for the field. Associated with this motion of 700 feet of vertical displacement must be a fairly intense and far reaching fracture system. It is this Graben, coupled with the fracture system that could provide a plumbing system for the dolomitizing fluids. The spatial distribution of the dolomite is most likely purely a function of the presence or absence of fractures.

The exact origin of the fluids responsible for the dolomitization of the Wabamun limestones at Tangent is beyond the scope of this study. However, the dolomitization sequence of the Winterburn and the Wabamun could have occured in one of two ways. The first is to dolomitize the Winterburn penecontemporaneously with deposition and to have the Wabamun dolomitized during a totally different event (after faulting). The second way is to have both the Winterburn and the Wabamun dolomitized at the same time, after faulting. In either case the fluids that are responsible for the dolomitization of the Wabamun migrated up through (or up from) the Winterburn.

4.2 Further Study.

A similar study, carried out on the Winterburn, would be very useful in determining a more exact sequence of dolomitization. Its focus should be on similarities and differences in the dolomite and dolomite paragenesis between the Wabamun and the Winterburn. Determination of the original carbonate lithologies of both formations is also required for a comparison of the controls of dolomitization.

If the dolomites in both formations were similar, it would lead to the assumption that dolomitization of both formations was during the same event, post faulting. If the dolomite differs significantly between the two formations, then the dolomitization sequence was probably; penecontemporaneous dolomitization of the Winterburn with the dolomitization of the Wabamun being a seperate event which post dates the Graben.

4.3 Dolomite -- Primary vs Secondary

The assumption has been, from the onset of this study, that the dolomite present at Tangent field is secondary. Evidence for this assumption is as follows:

1) remnant textures and particles are visible within the dolomite
2) euhedral dolomite partially replacing calcite cement and cutting boundaries of calcite crystals
3) dolomite forming and cutting stylolites
4) dolomite crystals growing across spar-micrite boundaries

5) dolomite rhombs with the cloudy core -- clear rim zonation (Chilingar, 1979)
6) coarse grain size of the dolomite crystals
7) general shape and position (relative to fault) of the dolomite body
8) Type 2 dolomite which has destroyed primary textures

4.3 Dolomite Paragenisis

The exact nature and paragenetic sequence of the replacement is not easily determinable, this is due to overprinting or destruction of previous textures by Type 2 dolomite.

The first dolomitization event was probably purely a function of escaping waters, entrapped during deposition, migrating along burrow traces. The extreme selectivity of the dolomite for the burrows and not the lime mud between them may be that early formed or penecontemperaneous dolomite in the burrows acted as nucleation seeds for further dolomite growth later in the diagenetic history, (Morrow,1978). Whether these seeds are present or not, there is a requirement that fluids capable of precipitating dolomite must somehow flow through these burrows. The burrows would probably be filled soon after abandonment, in all probability with coarser material than the lime mud that was burrowed. This would facilitate the path of least resistance (due to higher porosity and permeability) for the fluids either migrating through the rock or escaping during compaction, thus localizing dolomitization to the burrows and leaving the mud matrix untouched. The burrows were probably also filled with organic residue which would assist in the formation of dolomite. The faint bluish tint that exists around the edges of the burrow traces is thought to represent dewatering haloes resulting from burrows dug after some compaction and dewatering have taken place (Fig. 16).

Coincident with the dolomitization of the burrows was probably the formation of Type 1 dolomite. These single isolated crystals are most likely a result of small pockets of fluids of microfractures which allowed resticted fluid escape and subsequent formation of the dolomite crystals during compaction and dewatering.

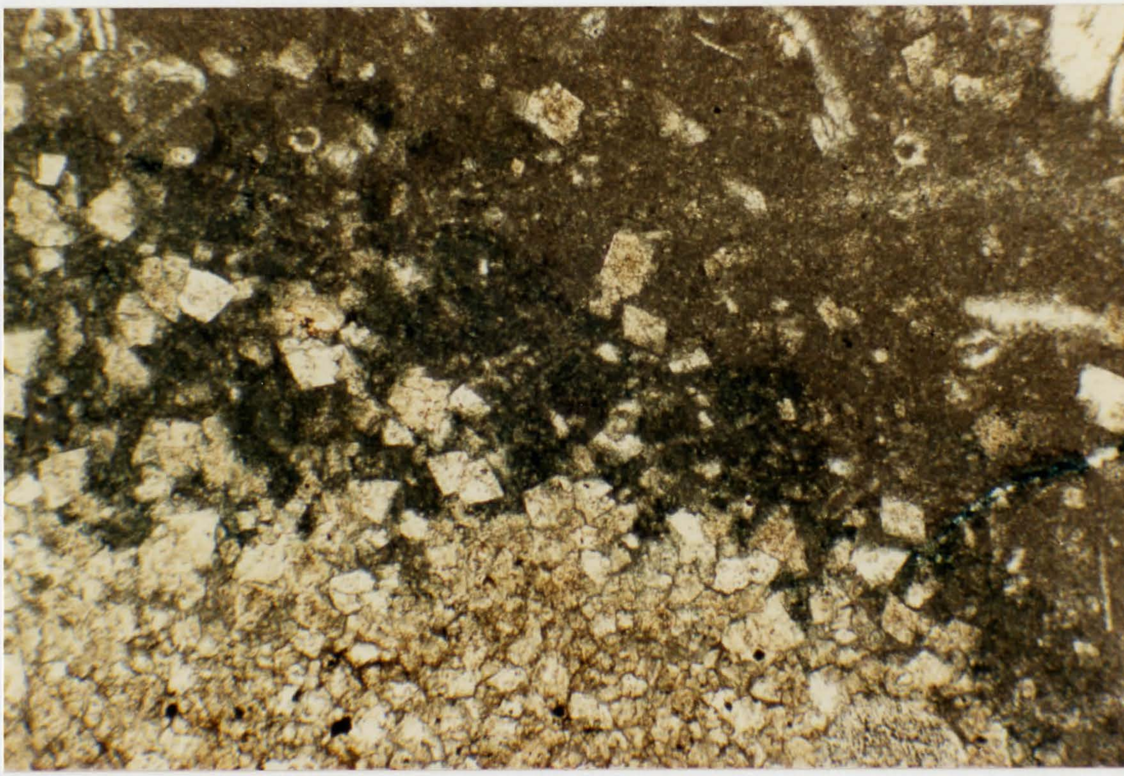
The next paragenetic event was probably the onset of stylolitization and the formation of its associated dolomite (Type 3). From the examined thin sections and core it is impossible to tell how much vertical section was lost, but it was probably a significant amount as there is a very high frequency of pressure solution interfaces visible in the core. Pressure solution would have continued until the formation of Type 2 dolomite resulted in a crystal supported matrix thus abating or in all likelihood halting the loss of material through pressure solution.

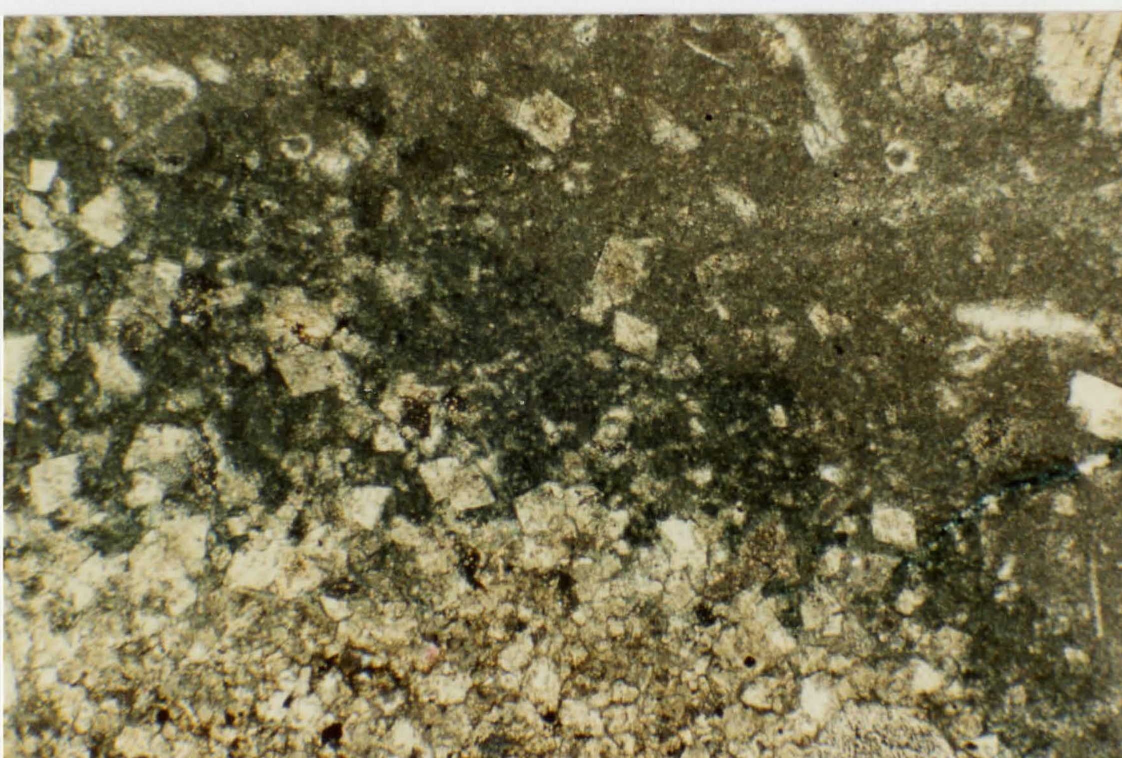
After the faulting and fracturing, selective alteration of the finer grained spar crystals that line fractures must have occured. The replacement of the calcite that fills the fractures appears to start from close to the fracture wall and progress into the fracture. This phenomenon is probably due to two things; first, the crystals that line the fracture wall are smaller in size and thus kinetics dictate that these be replaced first. Second, these smaller crystals contain small amounts of intercrystalline porosity that would allow fluid migration to bring in the dolomitizing fluids and thus replacement of the smaller crystals would have to occur before the fluids could even reach the larger spar crystals. The alteration of the calcite resulted in the formation of Type 2c dolomite. The extreme porosity created by these dolomite crystals allowed for large amounts of fluids to collect in the fractures. The action of the fault and its creation of stress was partially relieved by lateral motion along stylolites, thus creating more conduits for the dolomitizing fluids.

These fluids then began to dolomitize the formerly tight limestones of the Wabamun. The formation of Type 2a,b dolomite was probably a lengthy process and depended on capillary size pores to actually transport the fluids from the fractures into the limestones. The two Types, a and b, probably formed during the same time interval. Figure 17 shows the two types of dolomite. Note that both have similar cores but only 2a has the clear rim and trend towards euhedralism. Sibley (1980) attempts to explain the zonation (cloudy core -- clear rim) via a change in fluid composition from near calcite saturation to calcite undersaturation. It appears that in a few small pores, left open by the interlocking habit, a clear dolomite cement has formed to seal off any porosity that might have existed after the formation of the interlocking crystals. The size

Figure 16: a) Photo showing the sharp boundary between th dolomitized burrow and the surrounding lime mud. Note the porosity haloe (blue tint) that rims the burrow. Depth 1786.2m, mag. 35X.

b) Same as above except with polars crossed.





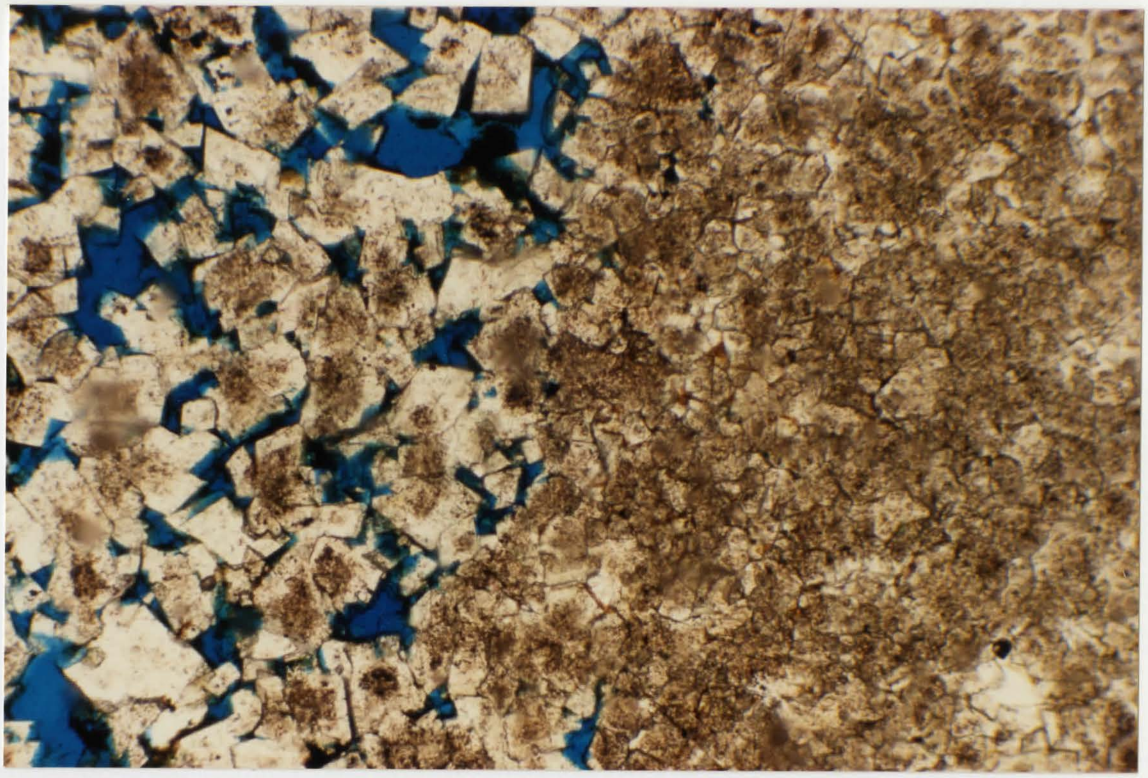
difference is also apparant with the euhedral, Type 2a crystals being larger than the Type 2b crystals.

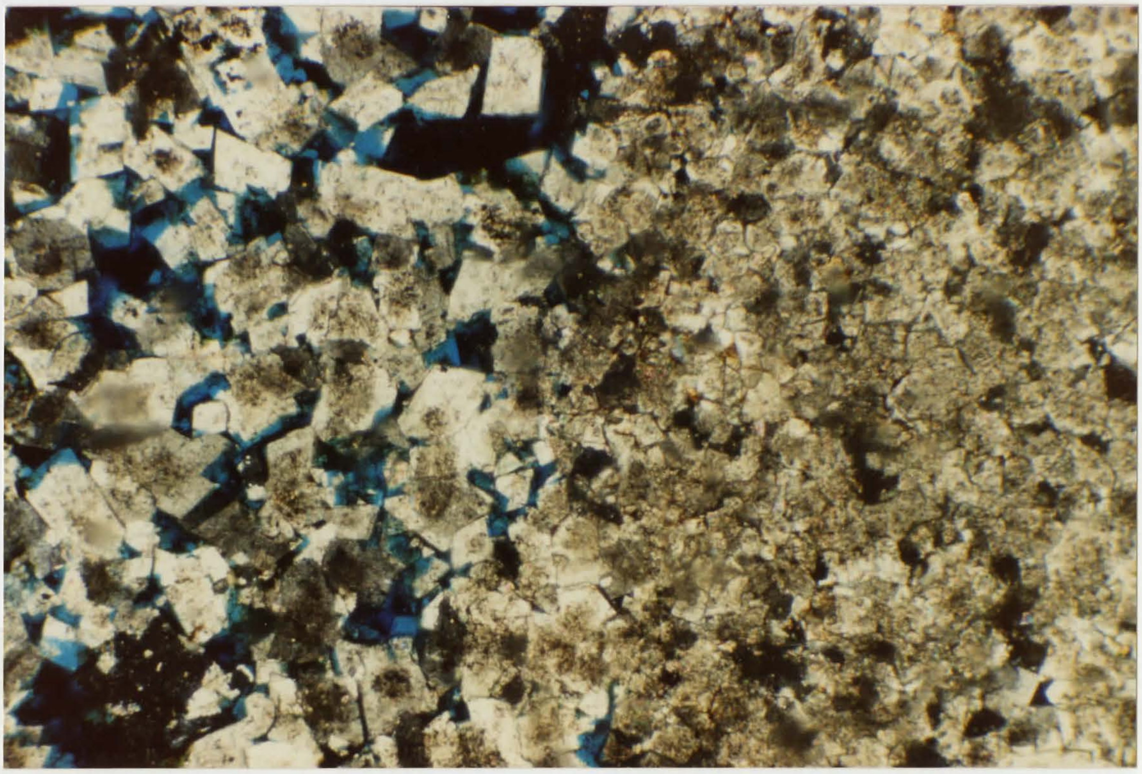
Once the formation of type two dolomite neared completion the fluids must have become unsaturated with respect to $CaCO_3$. This undersaturation resulted in the dissolution of the remaining micrite which was primarily found between the euhedral crystals of Type 2a dolomite. The result of this dissolution was the creation of intercrystalline porosity associated with Type 2a dolomite.

The question still remains as to why the two styles of dolomite, Type 2a and Type 2b, form. The answer to this lies with the control of the frequency of nucleation. Type 2b crystals form close together and this results in their interlocking habit and no associated prorosity or zonation. Type 2a crystals form farther apart allowing for the zonation and later dissolution of the material filling the interticies between them resulting in porosity creation.

Figure 17: a) An illustration of the sharp contact between Type 2a dolomite (left) and Type 2b dolomite (right). Note the similarity between the Type 2b crystals and the cores of the Type 2a crystals. Depth 1801.3m, mag. 35X.

b) Same as above except with polars crossed.





Chapter Five: Conclusions

1. Through petrographic and CL analysis 5 distinct dolomite types are present in the dolomitized limestones, three of which are epigenetic.
2. Spatial control of the dolomites at Tangent field appears to be related to faulting and the resultant fracture systems that facilitate the migration of dolomitizing fluids.
3. The dolomitizing fluids, plumbed by the faults and fractures, have migrated upwards from the Winterburn formation through the Wabamun formation.
4. The control of secondary intercrystalline porosity associated with type 2a dolomite appears to be nucleation density, with the nonporous type 2b dolomite having a higher nucleation density and thus no associated intercrystalline porosity.
5. The dissolution of micrite from between dolomite rhombs is responsible for the formation of intercrystalline porosity associated with Type 2a dolomite.

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