ALLUVIAL FAN DEPOSITS OF THE CARBONIFEROUS GRANTMIRE FORMATION IN DRILL HOLE PE 83-1, SYDNEY BASIN, NOVA SCOTIA

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DATE April 29, 1999

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TITLE Alluvial fan deposits of the Carboniferous Grantmire Formation in drill hole PE83-1, Sydney Basin, Nova Scotia

Degree BSc (honours) Convocation May Year 1999

Alluvial Fan Deposits of the Carboniferous Grantmire Formation in Drill Hole PE 83-1, Sydney Basin, Nova Scotia

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The Early Carboniferous (Tournaisian) Grantmire Formation belongs to the Horton Group and is ~800 m thick, based on exposures and drill core in the northern part of the Sydney Basin onshore. The 503 m measured section of the Grantmire Formation in drillcore PE 83-1 is dominantly pebble conglomerate with interbeds of siltstone and minor beds of sandstone. The conglomerate (facies 1) is light to medium red, polymictic, poorly sorted, and clast supported with subangular to subrounded clasts. Conglomerate beds reach 15 m thickness with a maximum recorded clast size of 22 cm. They are divided into three subfacies: interbedded pebble conglomerate/sandstone, pebble to cobble conglomerate, and small boulder conglomerate. The other facies are sandstone (facies 2), siltstone with multiple sandy layers (facies 3), coarse siltstone (facies 4), and fine siltstone (facies 5). Siltstones are medium reddish brown and in two facies have calcareous nodules with green reduction patches and/or envelopes suggesting paleosol or shallow groundwater origin. Macroscale patterns suggest coarsening upward sequences on the 10-50 m scale and a rare 100 m scale are the result of fan progradation as indicated by thickening upward trends and increasing clast size. Siltstone-rich intervals suggest distal fan or interfan conditions. Mesoscale (<5m) coarsening upward sequences may represent small lobe or levee progradation whereas large-scale fining upward sequences (5-10 m) are channel fills.

The Grantmire Formation has been interpreted as the clastic fill of fault-bounded basins within the region of the Sydney Basin. Currently, the Grantmire Formation is the only mapped unit of the Horton Group in the Sydney Basin. The presence of black shales in the Horton Group is important for hydrocarbon potential regionally; they are not presently identified in the Sydney Basin. The main clast types in the Grantmire Formation are chert, sedimentary lithoclasts, quartzite, volcanic clasts, and granitic clasts. Chert is derived from an older sedimentary source than the siltstone and sandstone clasts. Volcanic clasts are dominantly rhyolite with minor basalt that could have primary or reworked origins. Acidic plutons are the origin of granitic clasts and likely provide a significant proportion of sand-sized quartz, feldspar, and mica.

Grantmire paragenesis begins with deposition of sand- and gravel-sized clasts with iron-rich clay. The clays were oxidized at the surface or in the shallow subsurface early in the depositional history forming hematite grain rims. Calcite nodules with fine mosaic textures in siltstone, are linked to shallow groundwaters. A locally pervasive poikilotopic calcite cement was emplaced prior to significant burial. Calcite commonly partially replaces potassium feldspar grains, possibly around the same time interval or subsequently. Dissolution of some grains, clays and calcite cement post-dates consolidation and has generated secondary porosity.

Porosity of sandstones and conglomerates averages 9.6% and ranges from 4.2 to 15.7 % and permeability averages 2.26 md and ranges from 0.06 to 7.72 md. Reservoir quality ranging from poor to good is likely controlled by variable amount of detrital clay, authigenic minerals, carbonate cement, paleosol development, and irregular laminae of finer material.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

Acknowledgments

Many thanks to the following people for their time and consideration for the duration of my thesis:

The Nova Scotia Department of Natural Resources Core Library Staff, their assistance and guidance in August 1998 was greatly appreciated.

George O'Reilly (Nova Scotia Department of Natural Resources), for arranging a two week work period at the Stellarton Core Library in August 1999.

Chris White (Nova Scotia Department of Natural Resources) for granting me access to the plotter printer when unable to print my stratigraphic column at Dalhousie University.

Mike Murphy and staff (CBCL Engineering) for allowing me to use the firm's AutoCAD technical staff and printer.

Dr. Barrie Clarke (Dalhousie University) for helping me review some of my more interesting thin sections for a more comprehensive analysis on the igneous clasts.

Tom Duffett and Charlie Walls (Dalhousie University) for their technical assistance and patience as I frantically tried to print my stratigraphic column before every deadline.

Gordon Brown (Dalhousie University) for the excellent quality thin sections he prepared so quickly before Christmas.

Steve Nagy (CoreLab, Calgary) for microview and macroview photographs to accompany the thin section descriptions, and conduct a porosity and permeability analysis on several Grantmire samples.

Doug Hostad (Hunt Oil), an industrial link that was interested in the possibility of the Grantmire Formation as a reservoir rock for the onshore part of the Sydney Basin, and funded the porosity and permeability analysis conducted at CoreLab, Calgary.

Dr. Martin Gibling (Dalhousie University), without his patience, persistence and enthusiasm I may never have found such a highly 'topical' subject that provided such utilization of my academic background. Above all, I would like to sincerely thank him for his positive reinforcement throughout my past three years at Dalhousie, and encouraging me to pursue goals that I never thought were possible to attain.

I would like to thank my friends and family for their smiles and encouragement throughout the year.

I would like to make a special dedication to two guys that saved me in my frantic last hours!

My cousin, Randy Croft, for keeping the house from burning down.......

AND

My brother, Jeff(ie) Oakes, for being my knight with a gas-filled jerrican!

CHAPTER 1: INTRODUCTION

1.1 Geological Background

1.1.1 Introduction to the Grantmire Formation

The Early Carboniferous (Tournaisian) Grantmire Formation belongs to the Horton Group and is ~800 m thick, based on exposures and drill core in the northern part of the Sydney Basin onshore (Fig.1.1). Paleontological dating from recovered spore assemblages from gray shale in the upper parts of the Grantmire Formation were correlated with similar spore assemblages found in the Cheverie Formation of mainland Nova Scotia (Utting et al., 1989).

The Grantmire Formation has been interpreted as alluvial fan to braided stream depositional suites (Boehner & Giles, *in review*) of fault-bounded basins within the region of the Sydney Basin where it is currently the only mapped unit in the Horton Group. The coarse polymictic conglomerate is associated with upper fan proximal deposition to the highlands and mid to lower fan deposition grading into finer distal facies (Boehner & Giles, *in review*). The 503 m measured section of the Grantmire Formation in the vertical drillcore PE 83-1 is dominantly pebble conglomerate with interbeds of siltstone and minor beds of sandstone. The lithology and stratigraphy of the Grantmire Formation from PE 83-1 is recorded in a detailed stratigraphic chart (Appendix A).

The Sydney basin fill is divided into six basic lithologic packages (Fig. 1.2) and is dominated by a heterogeneous sequence of continental siliciclastics consisting of coarse boulder-pebble conglomerates, sandstones, minor siltstones. A major section of coal-bearing strata and finer grained facies including siltstones and sandstones are present near

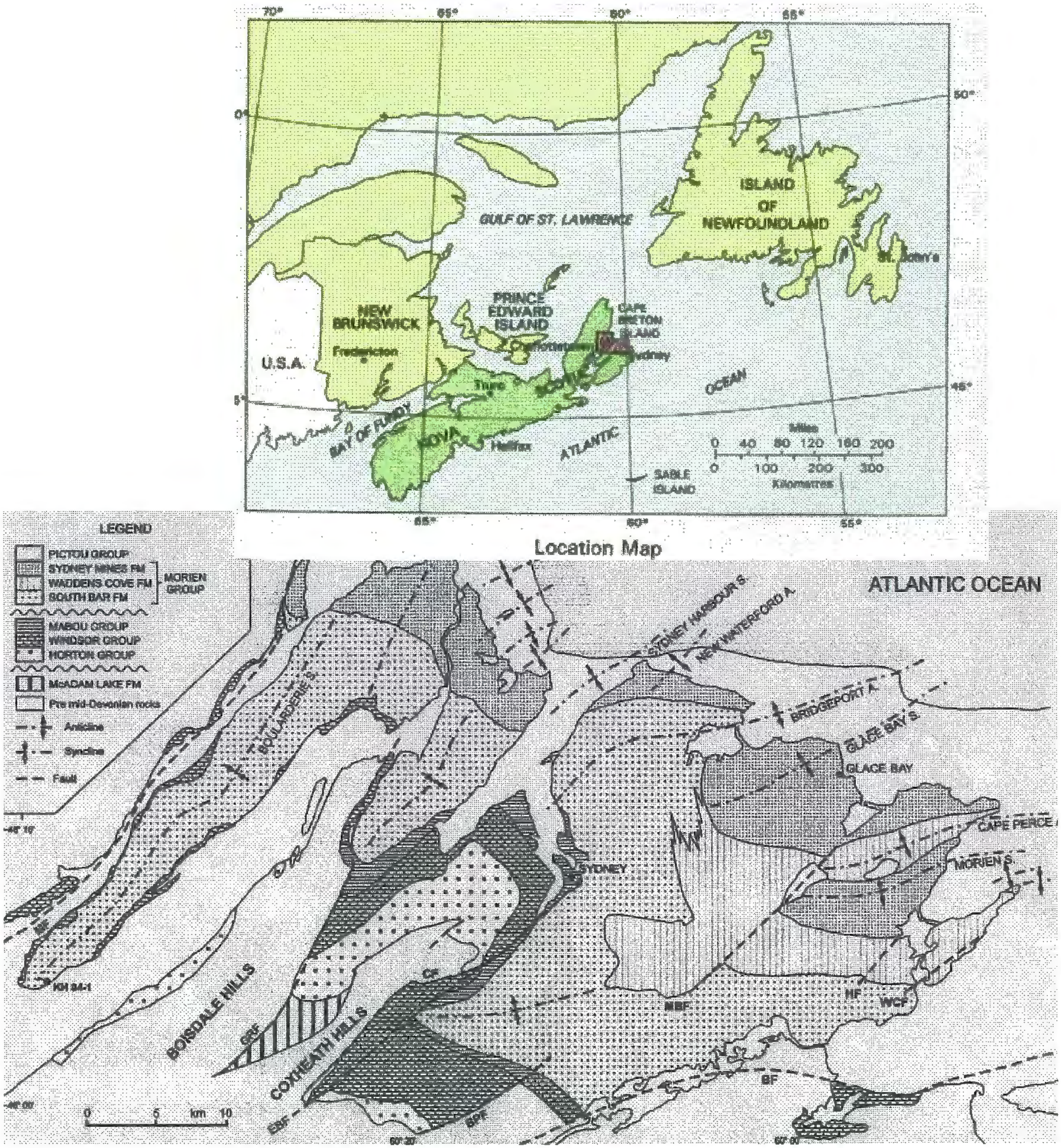


Figure 1.1 Sydney area geological map with the main lithological units and structural information (modified from Boehner and Giles, *in review*). Location map of Atlantic Canada identifying the Sydney area, highlighted in pink (inset map) (Boehner and Giles, 1996).

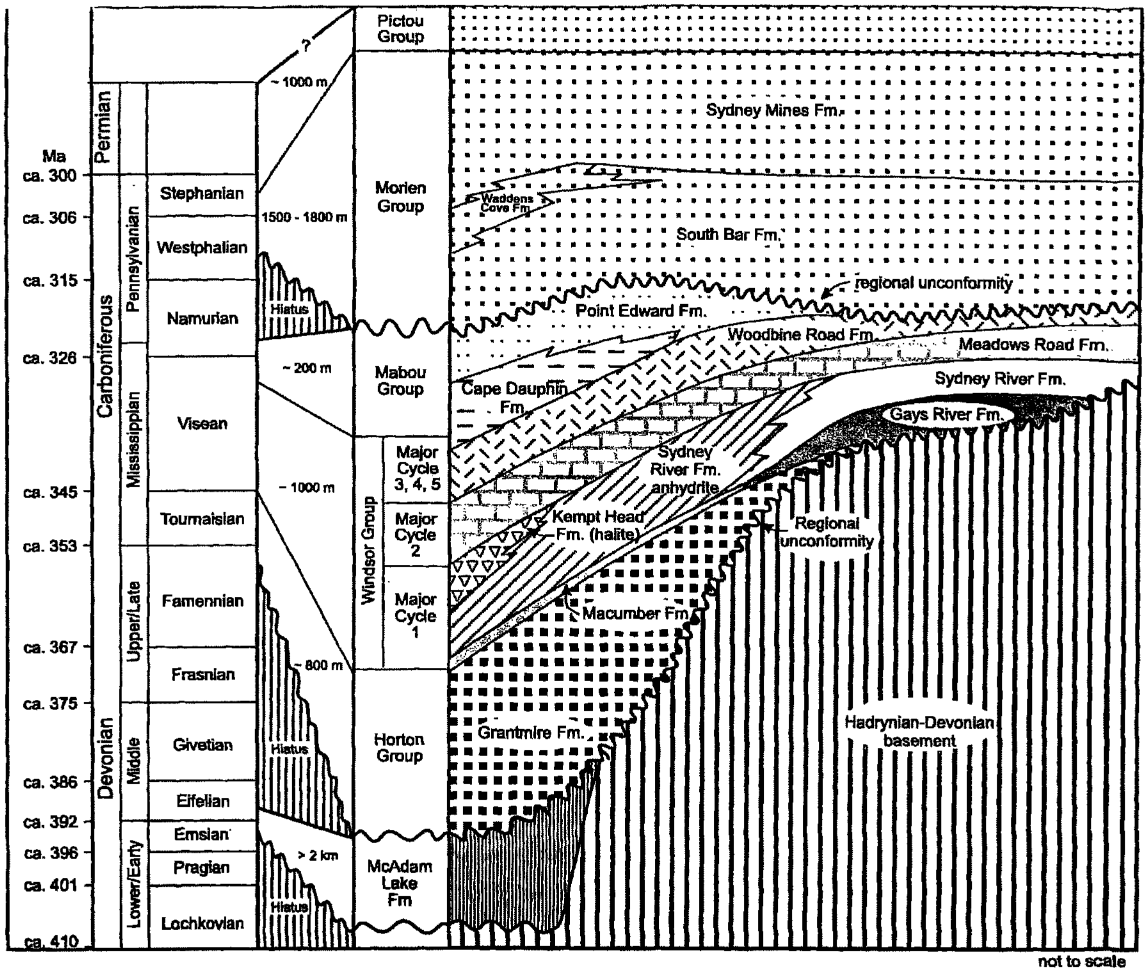


Figure 1.2 The stratigraphic column for the Sydney Basin is divided into six major lithological units: (1) pre-Carboniferous basement and McAdam Lake Formation, (2) Horton Group, (3) Windsor Group, (4) Mabou Group, (5) Morien Group, (6) undivided Permo- Carboniferous redbeds of the Pictou Group (modified from Boehner and Giles, *in review*)

the top (Boehner & Giles, *in review*).

The presence of black shales in the Atlantic Canadian Horton Group is important for hydrocarbon potential regionally, although they are not presently identified in the Sydney Basin. The current exploration in the Maritimes Basin for hydrocarbons by oil companies (Hunt Oil and Mobil Oil are two major participants) initiated the main focus for this thesis on the assessment of the hydrocarbon potential for the Grantmire Formation, rather than base metal resources.

1.1.2 Structure of the Sydney Basin

The Sydney Basin is a large Carboniferous structural basin (Boehner & Giles, *in review*) defined by a fault-truncated synclinorium consisting of a series of open folds extending north easterly into wide synclinal offshore basins. Together with strata onshore across Atlantic Canada and under the Gulf of St. Lawrence, these rocks constitute the Maritimes Basin fill (Hamblin & Rust, 1989). The Maritimes Basin (Fig.1.3) is a non-genetic term referring to a complex intermontane successor basin approximately 150,000 km^2 in area, with a suite of intracontinental depocentres that received sediments during the latest Devonian to the early Permian (Williams, 1973; Poole, 1967).

A prominent northeast-southwest structural trend in Namurian and older rocks is characteristic of the Sydney Basin (Boehner & Giles, *in review*) and adjacent Glengarry Half Graben (Hamblin & Rust, 1989) in addition to other Carboniferous basins in Atlantic Canada. This trend reflects the regional Appalachian structural fabric and is manifested by basement highland blocks, fault suites and major basin-bounding faults (Hamblin & Rust, 1989).

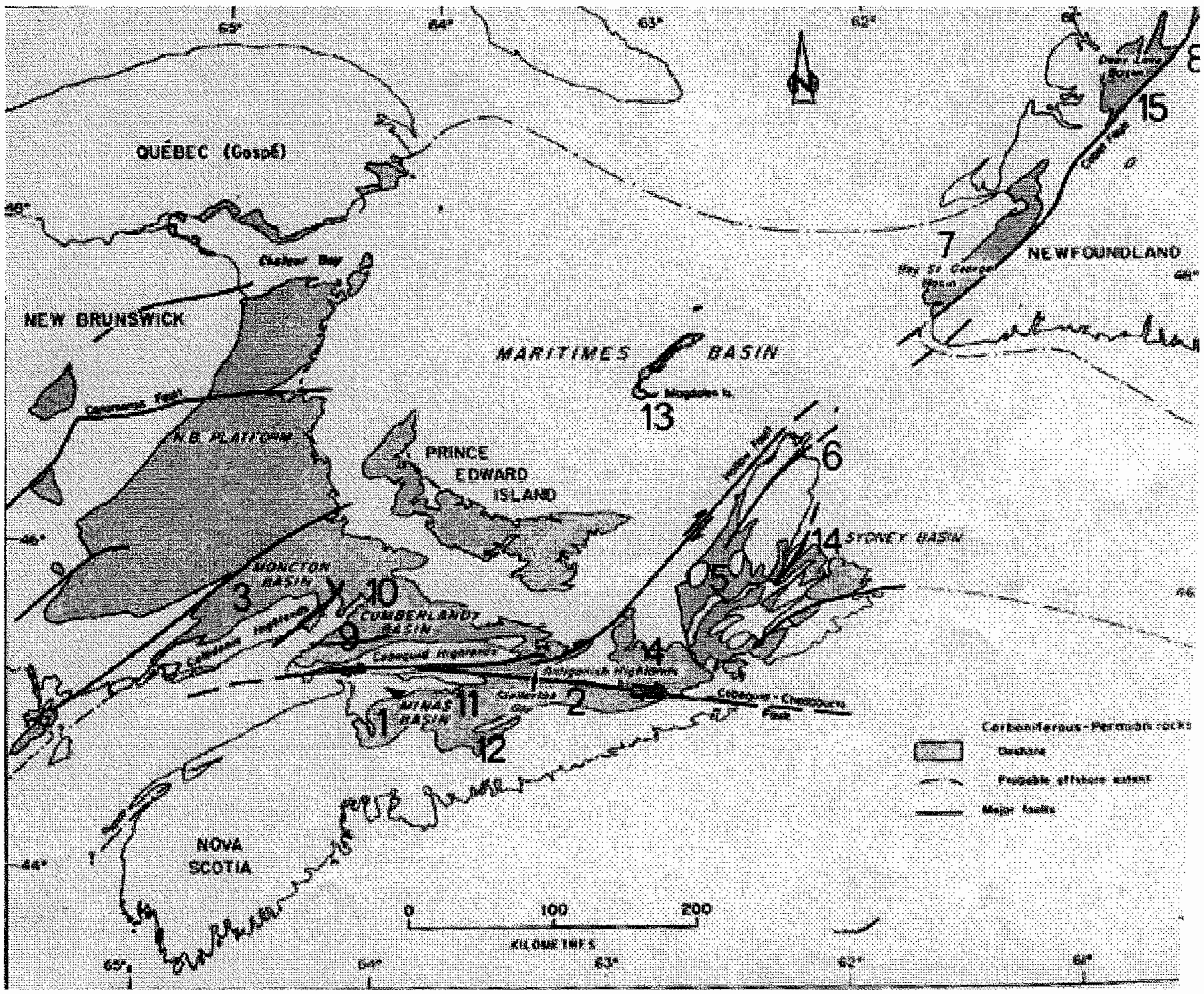


Figure 1.3 Map of the Maritimes Basin of Atlantic Canada to show onshore Carboniferous-Permian rocks (shaded). Sub basins are numbered: (1) Windsor, (2) St. Mary's, (3) Moncton, (4) Antigonish, (5) Cape Breton South, (6) Cape St. Lawrence, (7) Bay St. George, (8) White Bay, (9) Cumberland, (10) Sackville, (11) Shubenacadie, (12) Musquodoboit, (13) Magdalen, (14) Sydney, and (15) Deer Lake (from Martel & Gibling, 1996)

An east-west trend is observed in the late Westphalian strata in the eastern part of the Sydney Basin, as shown by the Cape Percé Anticline, the Morien Syncline, and the major basin-bounding fault – the Bateston Fault (Boehner & Giles, *in review*). Late stage Alleghanian transpression resulted in linear folds, normal faults, thrust faults, strike slip faults and numerous basement blocks bounded by high-angle faults that locally overprint any record of Early Carboniferous tectonic events, as noted elsewhere in Cape Breton by Hamblin & Rust (1989).

1.1.3 Geology of the Sydney Basin

The Sydney basin fill (Fig.1.4) is divided into three main tectono-stratigraphic units (1-3) separated by three prominent bounding surfaces (A, B, and C). The shaded area underlying the Sydney Basin fill is Hadrynian-Devonian basement rock consisting of stratified metasedimentary and volcanic rocks with small intrusions of granitoid plutons and porphyry (Boehner & Giles, *in review*). Contact A is a regional unconformity with areas of complex faulting in the basement rock. The coarse grained, alluvial fan-dominated sequence of redbeds of the Horton Group (Unit 1) is dated as Carboniferous, from the middle Tournaisian to early Visean. Maximum known thickness of the Horton is approximately 750-800 m in offshore areas and the strata are part of a locally extensive alluvial fan complex (Boehner & Giles, *in review*).

A rapid marine incursion represented by Windsor Group carbonates resulted in local onlap onto exposed basement highs not covered by alluvial fan deposits. The Visean Windsor Group (unit 2, lower part) concordantly and conformably (contact B) overlies the Grantmire Formation with a complex succession of interstratified evaporites (gypsum, anhydrite, salt, and potash), fine to coarse-grained redbeds and fossiliferous marine carbonates that reach a maximum thickness of 1000 m (Boehner and Giles, *in review*).

As the basin stability increased and the climate continued to be relatively arid in the Visean to early Namurian, the fluvial and lacustrine strata of the Mabou Group (unit 2, upper part) were dominated by gray mudrocks, and red sandstones and mudrocks (Boehner and Giles, *in review*). A basal unconformity (contact C) separates the coal measures of the Morien Group and overlying Pictou Group redbeds (unit 3) from the underlying Windsor/Mabou (unit 2) strata.

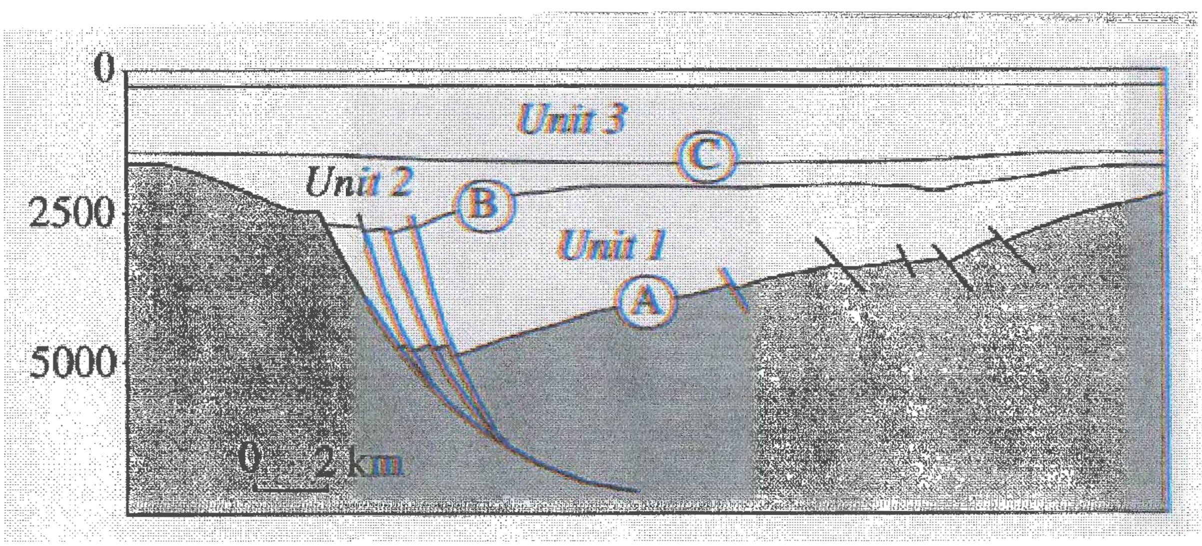


Figure 1.4 Generalized cross-section of the lower units of Sydney Basin fill with major contacts, based on seismic profiles tied to wells offshore Sydney. *Units:* pre- Carboniferous basement (shaded), Horton Group (unit 1), Windsor and Mabou Groups (unit 2), Morien and Pictou Group including the coal measures (unit 3). *Contacts:* (A) angular unconformity, (B) marine transgression, conformable, (C) unconformity (Pascucci, unpublished).

1.2 Previous work

The Grantmire Formation is currently assigned to the Horton Group in the Sydney Basin as the only recognized unit (Boehner & Giles, *in review*), although other units (Hamblin & Rust, 1989) possibly exist in subsurface extensions. Exposure of the Grantmire Formation is generally poor, with modest outcrops (Boehner & Giles, *in review*).

The term Grantmire Member was first introduced by Bell (1938) as the lowest rock unit of thick successive red conglomerate deposits underlying marine limestone and sandstone that comprise the basal section of the Windsor Group. Weeks (1954) formally raised the conglomerate unit to the Grantmire Formation, comprising "all conglomerate members that form the base of the group, regardless of whether they are Lower to Upper Windsor in age". Kelley (1967) discovered in the Baddeck and Whycocomagh map areas that strata previously assigned to the Grantmire Formation (Bell, 1938; Weeks, 1954) were erroneously allocated to the Windsor Group, and clarified that they were typical of the Horton Group.

Boehner (1981, 1983, 1985) and Prime & Boehner (1983) showed that coarse-grained conglomerate units of the Grantmire lithology commonly occur as tongues and wedges in the Windsor Group, dominantly as local interbeds in the lowermost units of the Windsor Group. Smith and Collins (1984) interpreted local conglomerate units (Coxheath, Glen Morrison etc.) to be overthrusts of Horton Group. Currently, most authors follow Giles (1983) restricted definition of the Grantmire Formation as "the succession of brick red to maroon conglomerate, sandstone and shale extending from the pre-Carboniferous unconformity to the base of the Macumber or Gays River Formation of the Windsor Group".

The Point Edward vertical drillcores (PE 83-1 and PE 84-1) were drilled by the Nova Scotia Department of Natural Resources (NSDNR) from November 1983 to February 1984 using core size HQ from 22.45-214.3 m, NQ from 214.3-464.9 m, and 464.9-761.3 m in PE 83-1, and core size HQ from 7.5-412.5 m and NQ from 412.5-448.5 m in PE 84-1. Boehner and Giles (*in review*) first logged both cores, focusing on the Windsor Group and published this research in the NSDNR open file report 93-005. In the summer and autumn of 1998, the author logged PE 83-1 in a detailed bed-by-bed analysis, focusing on the Grantmire Formation. The Point Edward drillcores (PE 83-1 and PE 84-1) are presently stored at the Drill Core Library in Stellarton, Pictou County, Nova Scotia.

1.3 Objectives

The purpose of this thesis is to examine in detail the sedimentological and stratigraphic features of the Grantmire Formation using drillcore PE 83-1 to provide the first in-depth description of this conglomerate unit. Based on these observations and thin section work involving major clast type descriptions, textures and diagenetic features, a detailed facies model is presented describing the facies successions, cyclicity, and depositional environment. Porosity and permeability analysis on core sections provides insight into the hydrocarbon reservoir potential of the Grantmire Formation.

The sedimentological evidence is used to interpret more fully the alluvial fan depositional environment previously inferred by Boehner (1981), and Boehner and Giles (*in review*). Unfortunately, the spatial variation of Horton Group strata is poorly understood (Boehner and Giles, *in review*), so a basinal analysis based on drillcore PE

83-1 and PE 84-1 is currently not possible. The lack of detail also hinders any further interpretation on possible fan shape without reviewing drill core 84-1 (located < 4 km northeast of PE 83-1; Fig.1.5) and other cores and outcrops in the same detailed bed-by-bed analysis conducted on drillcore 83-1. The facies model is based on the data collected during this project (core PE 83-1), previous work on core logs PE 83-1 and PE 84-1 by Boehner, previous work on the Horton Group elsewhere, and evidence from authors studying similar modern depositional environments and their ancient analogues elsewhere.

1.4 Scope

This thesis will closely examine the strata of the Grantmire Formation. Two drillcores, PE 83-1 and PE 84-1 (Fig.1.5) are available for study of the Grantmire, but PE 83-1 was chosen because it contained a distinct portion of the unit measuring 502.59 m out of a total 761.3 m without penetrating the underlying basement rock, and had a sharp contact with the overlying Windsor Group. Boehner and Giles (*in review*) noted that the boundary between the Windsor Group and Grantmire Formation of the Horton Group is problematic because the typical basal carbonate – Macumber or Gays River Formation - is generally not identifiable, thus making definition of the Grantmire Formation difficult. Drillcore PE 83-1 was also selected in part to add a detailed bed-by-bed description of the entire section to expand upon the initial drillcore description recorded by Boehner & Giles (*in review*).

This thesis presents descriptive accounts of the sedimentology, stratigraphy, and petrographic observations and will not present any paleontological analysis, geochemical properties or mineral chemistry. The goal is to present the first detailed analysis of the

Grantmire Formation and determine if it has suitable porosity and permeability to act as a potential reservoir, especially in view of the black shales known in other parts of Atlantic Canada and current economic interest in the reservoir potential of the formation offshore Sydney.

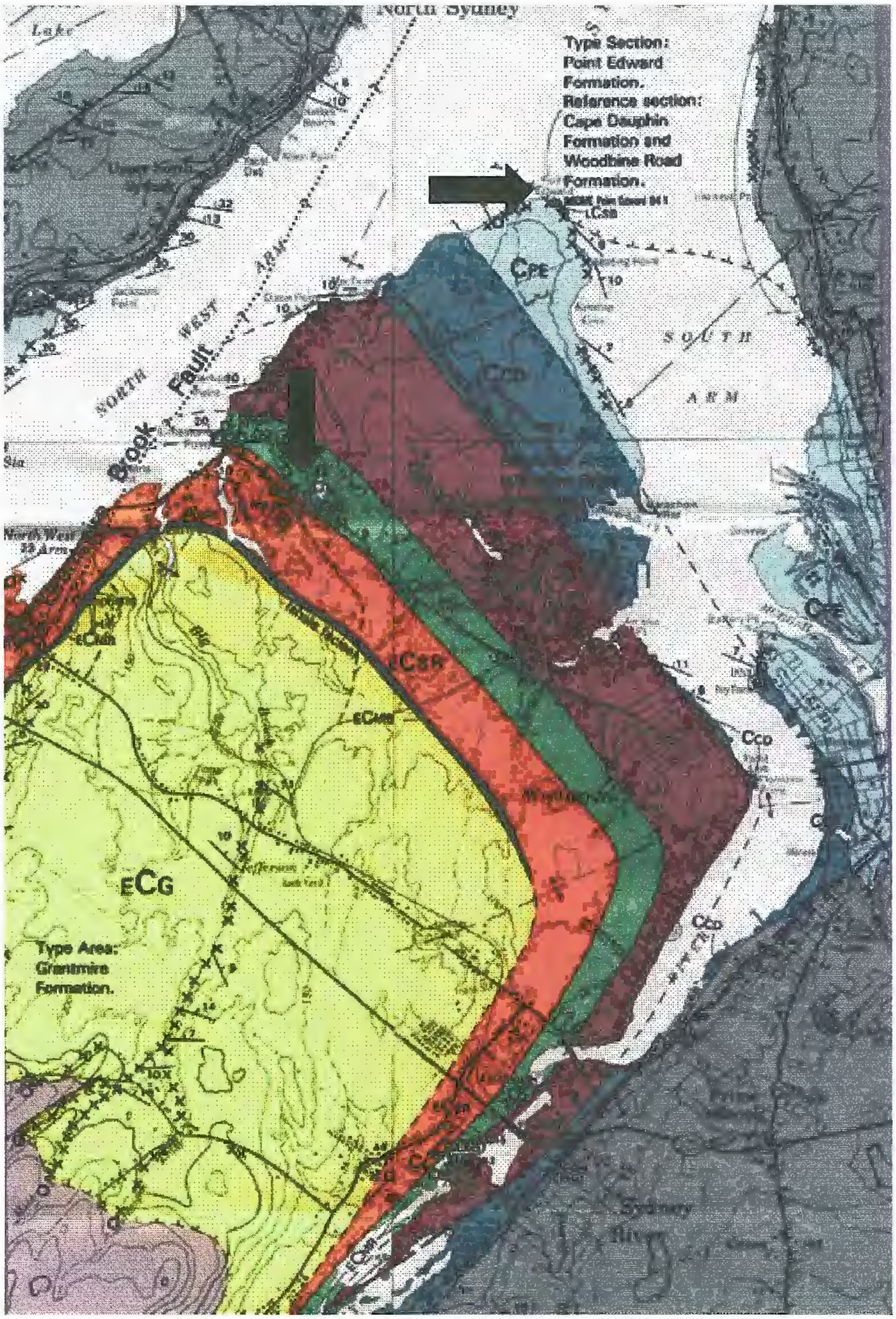


Figure 1.5 Location of drill cores PE 83-1 and PE 84-1 in the Sydney Basin. ECG = Grantmire Formation; ECMB up to ECWR = Windsor Group; CCD + CPE = Mabou Group (Boehner and Giles, 1986).

CHAPTER 2: SEDIMENTOLOGY AND FACIES INTERPRETATION

2.1 Introduction

The drillcore DDH PE 83-1 measured for the present study penetrated 761.3 m of strata, with the lower 501.59 m belonging to the Grantmire Formation (Horton Group) and the upper 259.71 m belonging to the Windsor Group. Boehner and Giles (*in review*) suggested that conglomeratic units of the Grantmire Formation record early stages of a continental basin with piedmont alluvial fans and fluvial deposition. Similar conglomerates are present as marginal facies of the lower and locally parts of the upper Windsor Group. The basin was rapidly inundated by the Windsor sea in the early Visean (Boehner and Giles, *in review*). The author agrees with Boehner and Giles (*in review*) in their placement of the Windsor/Horton boundary at ~260 m depth where finely laminated, gray and locally dolomitized limestone and laminated shale first appear. The Grantmire Formation in lower parts of the core had no interbedded dark shale or limestone. This drastic shift in rock type correlates with the Windsor marine transgression and corresponds lithologically with the Macumber Formation (Boehner and Giles, *in review*).

A detailed stratigraphic column of drill core 83-1 was produced (Appendix D) to represent the different facies proportions and to define cyclic mesoscale and macroscale patterns. The Grantmire section of core consists primarily of red conglomerate with interbedded red sandstone and medium reddish brown siltstone.

The core section can be divided into three lithofacies groups: (1) *conglomerate*, (2) *sandstone*, and (3) *siltstone* (Table 2.1; Fig.2.1). The conglomerate lithofacies group contains interbedded pebble conglomerate and sandstone (facies 1A), pebble to cobble

Name			Description
Siltstone facies	Facies 5 **Fine siltstone**		Fine grained siltstone, medium reddish brown, unstratified, ± calcareous matrix, ± green reduction patches
	Facies 4 **Coarse siltstone**		Fine-grained to coarse siltstone, medium reddish brown, unstratified, ± green reduction envelopes/patches, ± calcite concretions, ± calcareous matrix, ± laminations
	Facies 3 **Sandy siltstone**		Fine-grained to sandy siltstone, medium reddish brown, interstratified fine-grained to medium sandstone, ± green reduction envelopes/horizons, ± calcite concretions, ± calcareous matrix, ± laminations
Sandstone facies	Facies 2 **Medium to coarse sandstone**		Interstratified fine/medium/coarse sandstone, light/medium red, ± crossbedding, ± laminations, ± calcareous matrix
Conglomerate facies	Facies 1	Sub facies A **Inter-bedded sandstone & pebble congl.**	Clasts <0.5 cm, light/medium red, poorly sorted, polymictic, subangular/subrounded clasts, ± green reduction envelopes/ horizons, ± calcareous matrix, ± localized white calcite cement
		Sub facies B **Pebble to cobble congl.**	Clasts 0.5 cm - < 2 cm, light/medium red, poorly sorted, polymictic, subangular/subrounded clasts, ± calcareous matrix, ± localized white calcite cement
		Sub facies C **Small boulder congl.**	Clasts ≥ 2 cm, light/medium red, poorly sorted, polymictic, subangular/subrounded clasts, ± calcareous matrix, ± localized white calcite cement

Table 2.1 Lithofacies table identifying general characteristics that define the facies and sub-facies

conglomerate (facies 1B), and small boulder conglomerate (facies 1C). The sandstone lithofacies group (facies 2) is the least abundant lithology present, and is generally laminated. The siltstone lithofacies group contains interlaminated siltstone and sandstone with calcareous concretions (facies 3), fine-grained to coarse siltstone with calcareous

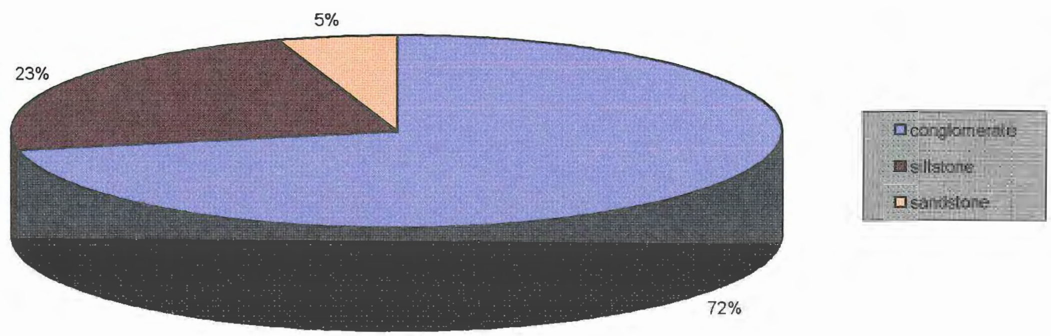


Figure 2.1 Pie chart representing different Grantmire Formation lithofacies proportions represented in drillcore PE 83-1

concretions (facies 4), and fine-grained siltstone (facies 5). This chapter describes the sedimentology of each lithofacies types, and provides a basic hydrodynamic interpretation for sediment transport based on the Hjulström diagram in figure 2.2.

2.2 Conglomerate Lithofacies (facies 1)

The Grantmire section of core is dominantly a sequence of clast-supported, polymictic, poorly sorted conglomerates with inequigranular subangular to subrounded clasts (Table 2.1). Approximately 20 m of matrix-supported conglomerates exist, comprising 4 % of the Grantmire section in comparison with 341 m of clast-supported conglomerates (68% of the drillcore). Clast composition encompasses gravel-sized quartz, chert, volcanic lithoclasts (primarily rhyolite), sedimentary lithoclasts and rare granitic clasts. Sand-sized clasts in the matrix include all these types plus feldspars (primarily orthoclase, microcline and plagioclase), muscovite, biotite, chlorite, heavy minerals, detrital clay, authigenic quartz, calcite, and hematite.

Table 2 .2: Conglomerate lithofacies

#	Facies Type	Range of Bed Thickness	Predominant Clast Size	Bed Style	Sedimentary Structures	Hydrodynamic Interpretation
A	**Interbedded pebble conglomerate /sandstone**	0.15 m to 8.72 m	<0.5 cm	Numerous clast-supported conglomerate units with sandy to silty interbeds, interbedded pebble to cobble conglomerate common, localized white calcite cement, commonly part of fining upward sequence (FUS) or coarsening upward sequence (CUS)	Minor lamination, imbrication	High energy flow regime Critical current velocity required: ~20-170 cm/sec
B	**Pebble to cobble conglomerate**	0.12 m to 3.35 m	0.5cm -2.0cm	Dominantly clast supported pebble to cobble conglomerate, localized white calcite cement, commonly part of fining upward sequence (FUS) or coarsening upward sequence (CUS), localized matrix supported conglomerate with silty matrix	Imbrication	High energy flow regime Critical current velocity required: ~50-350 cm/sec, localized debris flows (strength of flow depends on viscosity and thickness of flow)
C	**Small boulder conglomerate**	0.10 m to 1.64 m	>2.0cm	Clast or matrix supported small boulder conglomerate, commonly part of fining upward sequence (FUS) or coarsening upward sequence (CUS)		High energy flow regime, Critical current velocity required: ~130-1000 cm/sec

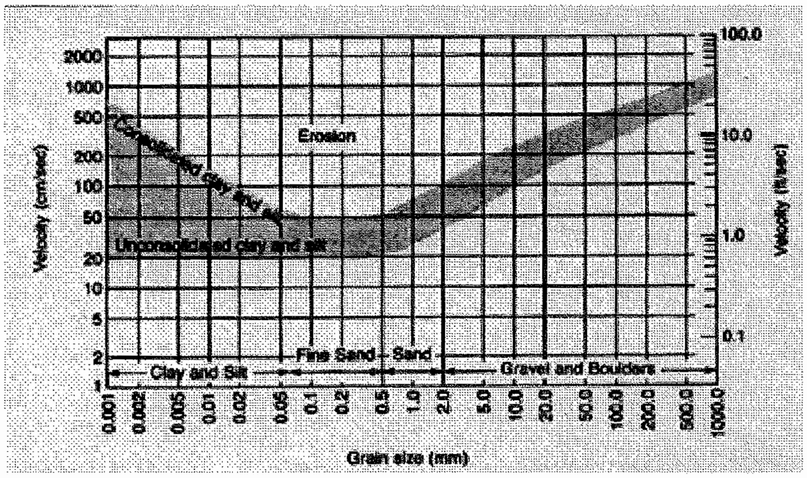


Figure 2.2 The Hjulström diagram, as modified by Sundborg, showing the critical current velocity required to move quartz grains on a plane bed at a water depth of 1 m (Boggs, 1995). Used as a guide to approximate critical velocity of currents required in the hydrodynamic interpretation for the different lithologies represented in the Grantmire Formation.

The conglomerate lithofacies is represented by thin (0.12 m) to thick (14.75 m) beds that are light to medium red depending on the abundance of calcite, quartz and matrix. The greater abundance of quartz and/or calcite lightens core colour, whereas a higher content of reddish brown matrix results in a medium red core colour.

The three subfacies reflect the average clast size, and the clast sizes were selected for convenience to reflect the general range of sizes encountered (Figure 2.3). Generally, conglomerate clasts in facies 1A are less than 0.5 cm in apparent diameter, as seen in core (Fig 2.4). Conglomerate clasts in facies 1B range from 0.5 cm to 2 cm (Fig. 2.5). Conglomerate clasts in facies 1C are greater than 2 cm (Fig. 2.6). These size ranges represent the predominant clast size, but clasts up to cobble and small boulder size are also present (in subfacies 1B and 1C respectively).

In some cases, discrete beds contained mainly one clast size grade. Where the conglomerates are poorly sorted and the clast size is too diverse to categorize, measured units were assigned clast-grade percents. For example in Figure 2.7, bedsets of interbedded sandstone, pebble conglomerate, and pebble to cobble conglomerate could be assigned proportions of 15% sandstone, 45% interbedded sandstone and pebble conglomerate (facies 1A), and 40% pebble to cobble conglomerate (facies 1B). The matrix comprises less than thirty percent of any conglomerate bed and is silty to sandy. Localized patches of white calcite cement exist within matrix-dominated areas, but the matrix is predominantly medium reddish brown calcareous siltstone.

Fine conglomerate beds (facies 1A) vary from 0.15 m to 8.72 m in thickness. Medium conglomerate beds (facies 1B) vary from 0.12 m to 3.35 m in thickness. Coarse conglomerate beds (facies 1C) vary from 0.10 m to 1.64 m in thickness. The conglomerate units appear massive and have few sedimentological features. Rare conglomerate/ siltstone contacts show imbrication (Appendix D). The restricted surface area of core makes observations of larger scale features such as bedding, cross-bedding, and slumps difficult. Bed surfaces were divided as boundaries between two different lithofacies and generally show similar orientation to the drill core axis as the local dip (0 to 16 degrees) in the Point Edward area (Fig. 1.6). Maximum apparent clast size is limited to the size of the core barrel used. In numerous cases, a single boulder formed up to 20 cm of core, yielding only a minimum size estimate. The importance of noting the maximum clast size is to infer the minimum energy required to transport a bedload of sediment with boulder-sized clasts. The average current critical velocity required to transport clasts greater than 20 cm is 400-1000 cm/sec (4/10 m/sec).

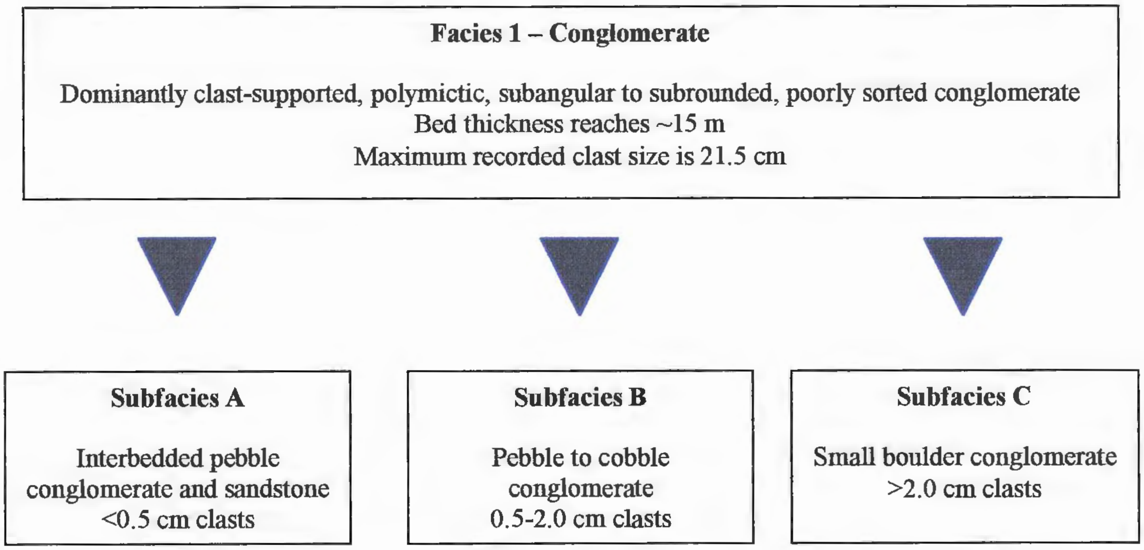


Figure 2.3 Flow chart representing conglomerate facies classification

Figure 2.4 Example of facies 1A – interbedded pebble conglomerate and sandstone (scale in cm)

Figure 2.5 Example of facies 1B – pebble to cobble conglomerate (scale in cm)

Figure 2.6 Example of facies 1C – Small boulder conglomerate (scale in cm)

Figure 2.7 Poorly sorted, interbedded conglomerate (subfacies 1A/1B) (scale in cm)

Conglomerate/conglomerate bed contacts are generally gradual. Shifts in matrix abundance or cement content indicate sharp contacts with no indication of scours or reworked material. Mesoscale fining upward sequences have both coarse tail grading where only the coarsest faction fines upward and more commonly whole bed grading. Large scale (meters to tens of meters) coarsening upward sequences have smaller packages of whole bed grading, but a general coarse tail grading trend as identified by increasing clast size.

2.3 Sandstone Lithofacies (facies 2)

Beds of the sandstone lithofacies are medium to coarse grained, moderately to well sorted, commonly laminated with moderately developed laminae (Fig.2.8). The light to medium red sandstone is predominantly quartz rich with moderate to minor proportions of lithoclasts, including volcaniclastics (see Ch.4). The sandstone lithofacies is uncommon and rarely occurs as a discrete bed, but is commonly part of a fining upward or coarsening upward conglomerate to siltstone sequence. The sandstone facies comprises approximately 5 % of the Grantmire section – an aggregate total of 25 m. Maximum sandstone bed thickness is 1.41 meters. Grain sizes within discrete sandstone beds are generally near-uniform throughout but local beds may fine upward. The matrix is calcareous with localized sections of visible white calcite cement. Lamination and cross stratification are common in the sandstone lithofacies.

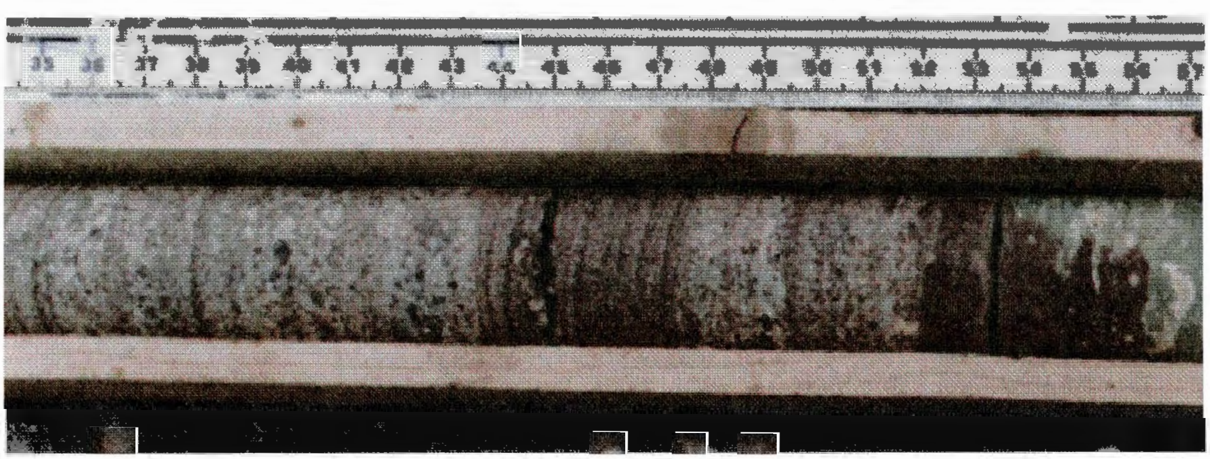


Figure 2.8 Example of sandstone (facies 2) with well developed laminae, and localized calcite cement (scale in cm)

2.4 Siltstone Lithofacies (facies 3-5)

The three siltstone lithofacies share many common characteristics (Table 2.2), they are all reddish brown with localized calcareous patches. They are mainly distinguished by differences in grain size, the presence or absence of reduced horizons and calcareous concretions, and the type of stratification.

The sandy siltstone (facies 3; Fig.2.9) is a coarse reddish brown siltstone with interstratified sandstone beds and localized calcareous patches. Bed thickness ranges from 0.09 m to 3.34 m. Facies four is a coarse reddish brown unstratified siltstone that lacks sand-sized material; bed thickness range from 0.07 m to 2.40 m. The sandy siltstone (facies 3) has moderately developed laminae and stratification whereas the coarse siltstone (facies 4) has poorly developed laminae and is weakly stratified. Both siltstones may have green reduction patches and/or calcareous concretions with green reduction envelopes and localized calcareous matrix. Calcareous concretions and reduction envelopes are better developed in the coarse siltstone facies (facies 4; Fig.2.10). Calcareous nodules/concretions with or without green reduction envelopes were developed *in situ,* rather than being transported clasts, as indicated by the lack of other coarse material in the siltstone facies. Minor sections in both siltstone subfacies have floating clasts up to 0.5 cm in diameter.

The fifth facies is a medium reddish brown fine-grained siltstone with bed thickness ranging from 0.10 m to 1.25 m. Occurrences are massive with localized calcareous patches and may have minor reduction patches (Fig.2.11). The fine siltstone appears to be relatively unmodified by later pedogenic or groundwater cementation, whereas the sandy siltstone (facies 3) and coarse siltstone (facies 4) have (facies 5) been somewhat modified.

Table 2.3: Siltstone Lithofacies						
#	**Facies Type**	**Range of Bed Thickness**	**Grain Size**	**Bed Style**	**Sedimentary Structures**	**Hydrodynamic Interpretation**
3	**Sandy siltstone**	0.09 m to 3.34 m	Coarse silt to medium sand	Localized calcareous rich matrix, interbedded siltstone and sandstone units, discontinuous bands of conglomerate A/B, minor floating clasts	Minor lamination, cross lamination, green reduction patches and envelopes, calcareous concretions	Low energy flow regime, flows dissipating, critical current velocity required: ~20-50 cm/sec
4	**Coarse siltstone**	0.07 m to 2.40 m	Fine to medium silt	Localized calcareous matrix, interbedded fine to coarse siltstone, minor discontinuous bands of conglomerate A/B, minor floating clasts	Minor lamination, cross lamination, green reduction patches and envelopes, calcareous concretions	Low energy flow regime, flows dissipating, critical current velocity required: ~20 cm/sec
5	**Fine siltstone**	0.10 m to 1.25 m	Fine silt	Localized calcareous matrix	Unstratified, green reduction patches	Low energy flow regime, flows dissipating, critical current velocity required: ~20 cm/sec

Figure 2.9 Example of sandy siltstone (facies 3) (scale in cm)

Figure 2.10 Example of coarse siltstone (facies 4) with well developed calcareous concretions and green reduction envelopes (scale in cm)

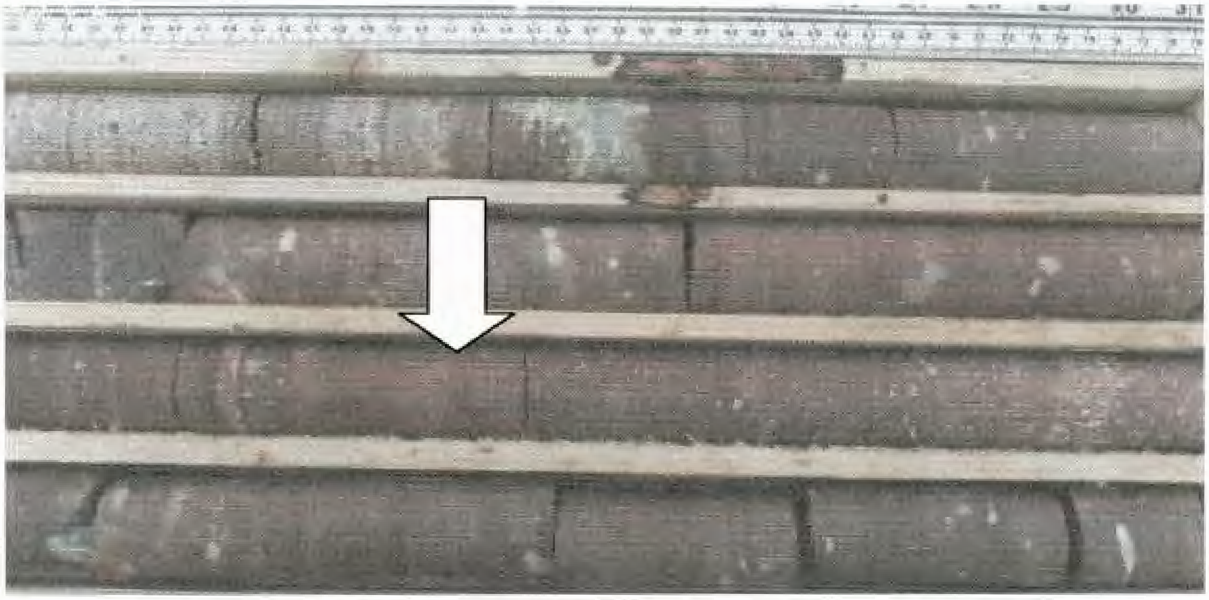


Figure 2.11 Example of fine siltstone (facies 5) (scale in cm)

2.5 Process Interpretation

Lithofacies outlined by Miall (1996) commonly correspond with lithofacies identified in the Grantmire Formation, and are indicative of certain depositional conditions. The dominant conglomerate facies (1) correlates with Miall's (1996) *Gh* lithofacies of clast-supported pebble to cobble gravel with crudely developed horizontal stratification and imbrication. Bed thickness is similar with individual beds a few decimeters and stacked beds several meters thick (Miall, 1996). Bed contacts are commonly obscured because of the absence of well-defined bedding (Miall, 1996). These sedimentary structures are indicative of longitudinal bars, lag deposits and sieve deposits (Miall, 992). Nilsen (1982) commented that long narrow bodies consisting of the coarsest and most poorly sorted sediments are stream flow deposits that accumulate within channels of streams that debouch onto and flow upon alluvial fans.

Sandstone facies (2) resembles Miall's (1996) *Sh*: horizontally bedded fine to coarse sand with horizontal laminations. Rare pebbles emplaced by sand traction currents may correlate with minor sandy matrix-supported conglomerate beds within the Grantmire (Fig.2.11). The sedimentary structures are interpreted as plane beds of the upper flow regime (Miall,1992) at the transition from subcritical to supercritical flow, and the sandstones may be deposited during single dynamic events, such as flash floods where flow conditions remain critical for a period of time (Miall, 1996). The inability to distinguish between low-dipping laminations and low-angle cross-bedding in core makes Miall's (1996) *Sl* lithofacies another possibility. It represents similar hydrodynamic settings where current conditions are unidirectional and transitional to upper flow regime. The interpretation for low angle cross beds are commonly scour fills, washed-out dunes and antidunes (Miall, 1992). High-angle crossbeds identified in sandstones (facies 2) may be attributed to local dunes (facies *St* of Miall, 1996).

The three siltstone lithofacies – sandy siltstone, coarse siltstone, and fine siltstone fall under Miall's (1996) *Fl* lithofacies of laminated sand, silt, and mud with scattered pedogenic nodules. The interlamination of three siltstone facies is common in overbank areas, and represents deposition from suspension and from weak traction currents (Miall, 1996). Siltstone facies, dominantly 3 and 4, have green reduction patches and reduction envelopes in addition to calcareous concretions. These features suggest paleosol development or shallow groundwater effects. Reduction probably took place mostly in the sub-surface, and calcareous nodules or concretions might have developed around roots, although no root traces were observed in the concretions.

Figure 2.11 Example of matrix-supported conglomerate (scale in cm)

CHAPTER 3: FACIES SUCCESSIONS AND CYCLES

3.1 Introduction

The Grantmire Formation has been interpreted as the coarse clastic sediments of alluvial fans and braided streams deposited in a fault bounded extensional basin (Boehner & Giles, *in review*). The pebble to small boulder, polymictic conglomerates are lithologically similar to the coeval Ainslie facies of the Horton Group elsewhere in Cape Breton (Hamblin, 1989b) and suggests similar depositional conditions near fault margins, extending a short distance towards basin centers. Compilation of data from drillcore PE 83-1 is summarized in Appendix D as a detailed stratigraphic column. Mesoscale and macroscale patterns are identified in the Grantmire section of drillcore PE 83-1, and indicate fan and lobe progradation, channel and/or flooding events.

3.2 Facies Successions and Cycles

3.2.1 Mesoscale Patterns

3.2.1.1 Fining Upward Sequences

The Grantmire Formation has stacked fining upward sequences (FUS) that are divided into two categories: (1) <2 m thick and (2) 5-10 m thick. Category 1 FUS are <2 m thick, moderately to poorly developed cycles (Fig. 3.1). Rarely are FUS sequences well developed with a conglomerate base that gradually progrades into finer material (facies 2 sandstone and facies 3-5 siltstone). Abrupt contacts between facies are more common. The small-scale fining upward cycles are interpreted as the fills of small channels or as flood events within channels or on overbank areas.

Category 2 FUS are 5-10 m thick with moderately to well developed cycles (Fig.3.2). All three subfacies of conglomerate are normally represented, but the

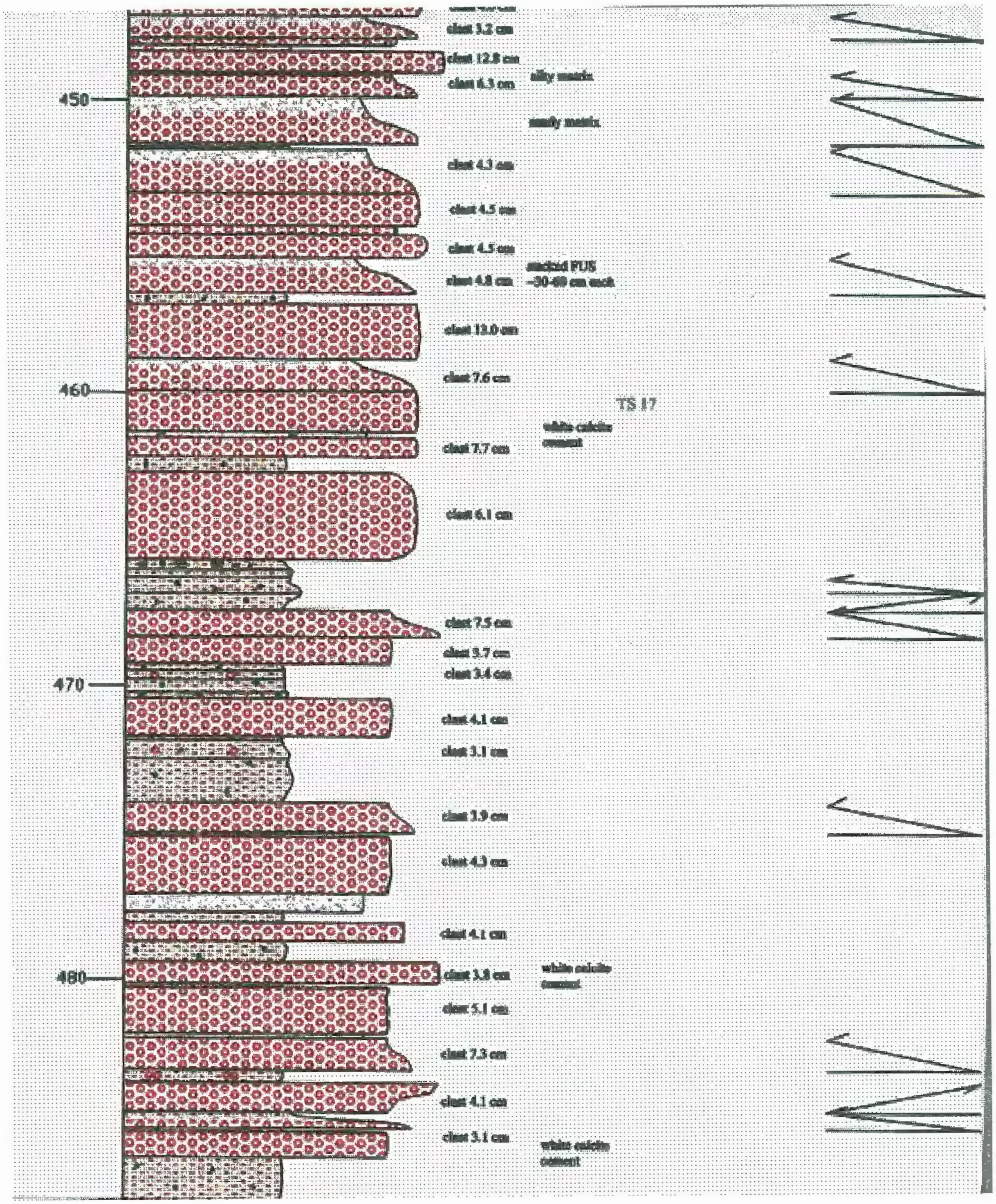


Figure 3.1 Local section from stratigraphic column in appendix D showing <2 m thick small-scale fining upward cycles. Grain size increases from left to right. Maximum clast size shown for each bed. Fining upward cycles are shown to the right. Scale in meters.

sequences may completely lack the sandstone facies before proceeding into the siltstone facies (3-5). Contacts are commonly abrupt between conglomerate, sandstone and siltstone facies, but are normally gradational between conglomerate subfacies. Where sandstone (facies 2) is present, it commonly grades upward into sandy siltstone (facies 3); contacts between the siltstone facies (3-5) are gradational. These thick cycles can contain small-scale fining upward sequences, as part of an overall upward progression. Larger scale FUS are interpreted as the fills of large channels because they show, on aggregate, progressively finer sediment laid down as flows wane and flow competence decreases. These larger channels are suggested to be proximal because they contain the largest clasts, including the largest recorded clast size (21.5 cm).

Facies 3-5 (siltstone) generally follow each other vertically with the coarse siltstone at the base and grades into sandy siltstone and fine siltstone. The stratification in the coarse siltstone (facies 4) indicates that bed sediment transportation was occurring, whereas the lack of stratification and finer material in facies 5 suggests gentle settling of particulate matter, or the breakdown of stratification due to bioturbation.

3.2.1.2 Coarsening Upward Sequences

Coarsening upward (CUS) mesoscale sequences can be divided into main two categories: (1) 10-50 m, and (2) <5m; rarely a third poorly defined mesoscale sequence of 200 m occurs, representing a siltstone-rich member. Facies contacts in category 1 are abrupt and commonly have interstratified coarse and fine material, but the overall sequence is evident from thickening upward beds and/or increasing clast size (Fig. 3.3). The depositional setting is interpreted as fan progradation, as coarser material progrades over finer grained sediments due to lobe advance through channels and sheet floods,

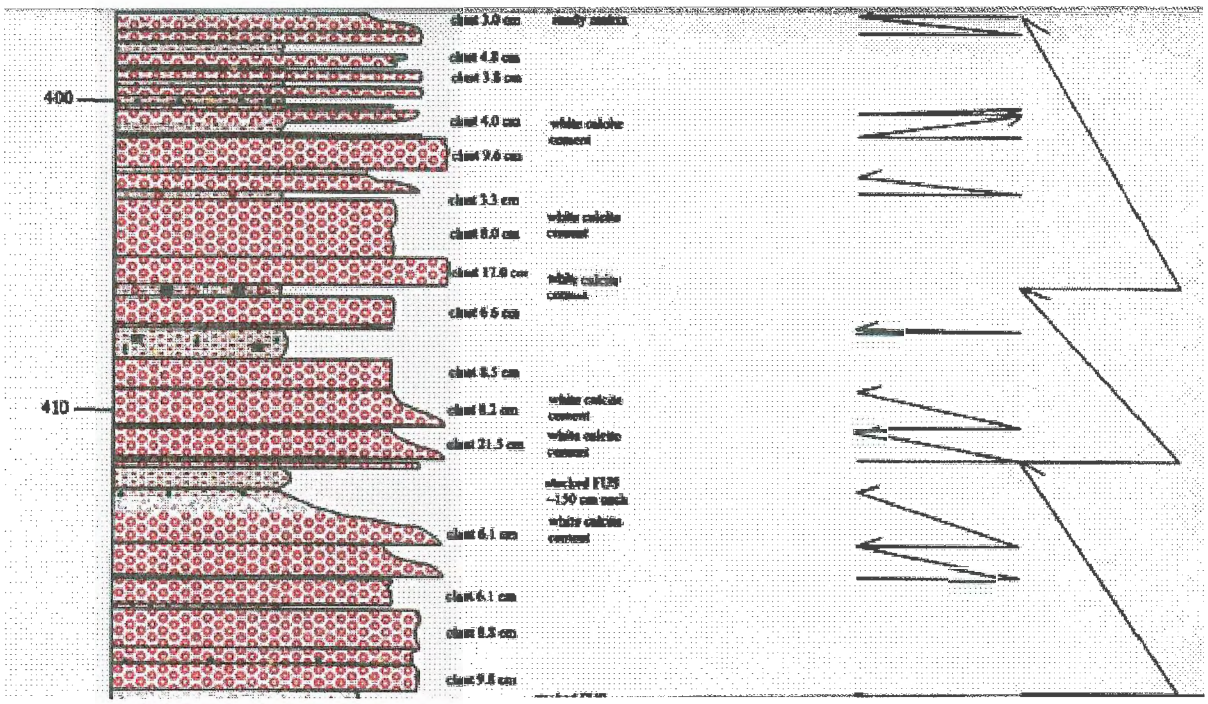


Figure 3.2 An example from Appendix D, demonstrating multiple fining upward Sequences 5-10 m thick. Grain size increases from left to right. Maximum clast size shown or each bed. Larger fining upward cycles are shown to the far right. Scale in meters.

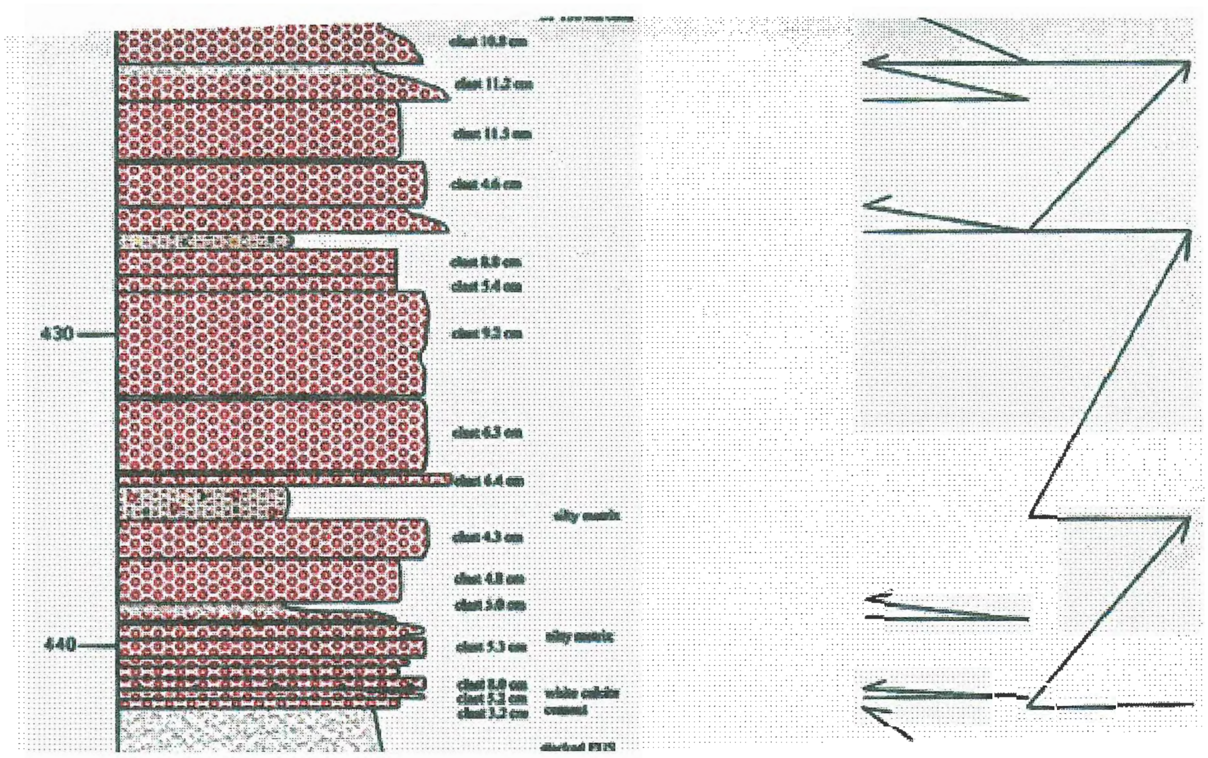


Figure 3.3 An example from Appendix D demonstrating multiple 5-10 m coarsening upward sequences. Grain size increases from left to right. Maximum clast size shown for each bed. 5-10 m coarsening upward cycles are shown to the right. Scale in meters.

forming coarsening upward sequences. Proximal deposits commonly contain large coarsening upward sequences tens to hundreds of meters thick, recording increasing source-area relief and depositional slope during active tectonism (Miall, 1992).

Category 2 mesoscale CUS are generally <5m (Fig.3.4), and commonly do not contain all facies (from conglomerate to siltstone). Basal contacts are sharp and coarsening up beds are moderately to well developed. CUS beds normally grade from a sandy siltstone to sandstone or interbedded pebble conglomerate and sandstone. Progression from finer material into slightly coarser material on a scale of a few meters is common in small lobes and levees that are undergoing progradation (Miall, 1992, Reading, 1986).

3.3 Cyclicity of Facies Successions

3.3.1 Macroscale Patterns

Figure 3.5 is a schematic representation of the detailed stratigraphic column in Appendix D to identify macroscale patterns in drill core PE 83-1. The macroscale patterns are interpreted in terms of fan morphology, for which justification is provided later in this chapter. From 760-592 m, large-scale (category 1) coarsening upward cycles are clear and commonly have interspersed smaller scale fining upward and coarsening upward sequences. The conglomerate/siltstone ratio is 6:1 verifying that facies 1 (conglomerate) is dominant. The abundance of conglomerate and modest abundance of finer fractions is indicative of a medial to distal fan.

An abrupt contact separates these beds from the overlying siltstone-rich interval, from 592-488 m. In contrast to the previous interval, this clear ~100 m unit is approximately 50% siltstone and 50% conglomerate (Fig.3.6). The greater representation of siltstone facies is evident and, carbonate nodule (calcareous concretion) beds and reduction zones occur. The lesser abundance of conglomerates, the decreased clast size and greater abundance of silty material suggests a lower fluid competence. A depositional interpretation of interfan to distal fan is suggested where these finer sediments are predominant.

The siltstone interval grades into a poorly defined coarsening upward sequence from 488-288 m. This 200 m interval has large fining upward (category 2) bodies and rare siltstone facies (~5%). The larger fining upward sequences are interpreted as the fills of large mesoscale channels on a proximal fan where the lack of finer material indicates that sand and silt are readily transported in the high-energy regime leaving the coarser

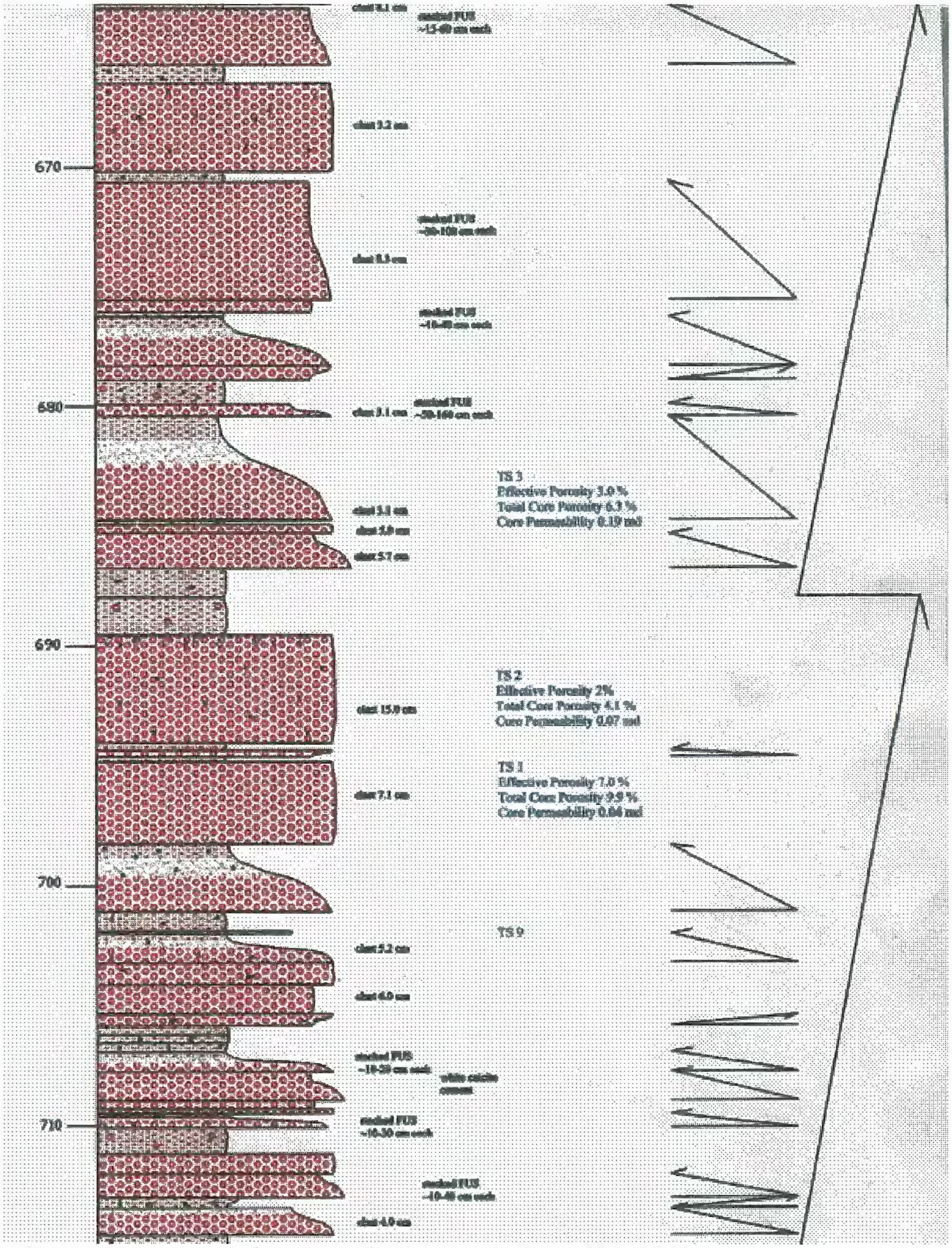


Figure 3.4 An example from Appendix D demonstrating multiple 10-50 m coarsening upward sequences with multiple smaller-scale fining and coarsening upward sequences. Coarsening upward sequences defined by increasing clast and/or bed. Grain size increases from left to right. Maximum clast size shown for each bed. 10-50 m coarsening upward cycles are shown to the far right. Scale in meters.

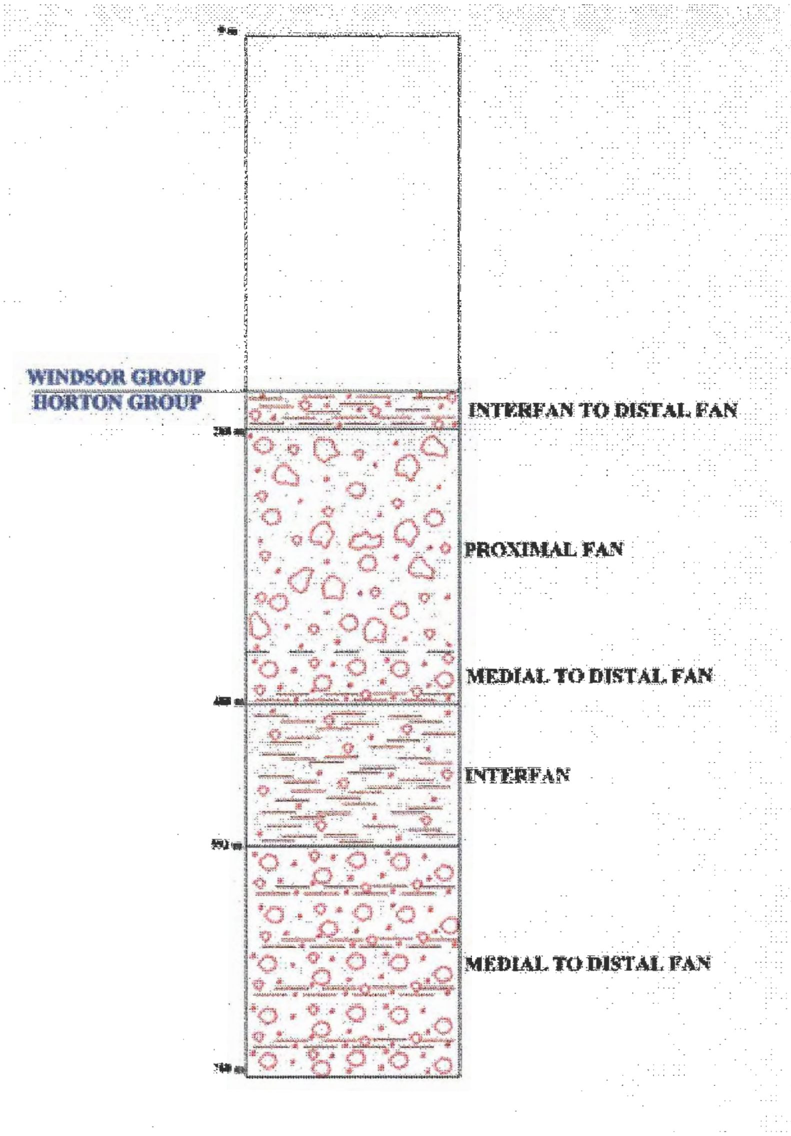


Figure 3.5 Schematic representation of macroscale patterns from Appendix D. Conglomerates are dominantly clast-supported. Scale in meters.

conglomerate facies.

An abrupt contact separates the third and fourth interval, from 288-260 m. This ~30 m interval is similar to the siltstone-rich interval, with comparable conglomerate/ siltstone proportions and nodules indicating an interfan to distal fan environment. At 260 m an abrupt contact occurs between the red Grantmire conglomerates (Horton Group) and the overlying dark gray limestone and shale of the Windsor Group.

3.4 Facies Model (Depositional Environment)

The Grantmire Formation has been interpreted as the coarse clastic fill of extensional fault bounded basins (Boehner & Giles, *in review*; Hamblin, 1989). Such coarse successions are commonly attributed to alluvial fans. An alluvial fan is part of a distributary fluvial system, and much of the Grantmire Formation could have formed where rivers emerged from confined, mountain valleys onto the Sydney Basin floor and deposited sediments in channels and sheetfloods (Miall, 1992). Most alluvial fans are dominated by water laid deposits, predominantly horizontally stratified gravel facies (*Gh*) in the proximal reaches (Miall, 1984, 1996).

An alluvial fan environment for the Grantmire Formation is supported by the presence of fault-bounded basins (Gibling *et al.*, 1999), where flow from adjacent uplands is confined until the apex or intersection point where sediments are rapidly deposited due to swift lowering of shear stress and the sudden drop in velocity, capacity, and competency (Bull, 1972; Blair, 1987). The great thickness (>500 m) of the Grantmire Formation conglomerates indicates that sediments were not simple axial river deposits, but implies a fan system where great wedge thickness is common (Blair and McPherson, 1994). A river delta system is unlikely because the typical sediment mode transports smaller sediments because of low fluid competency and moderate capacity.

Full justification for an alluvial fan system requires a regional analysis of the Grantmire Formation by mapping facies trends, grain-size trends, and conducting a paleoflow analysis. Not all required information can possibly be derived from one core for a regional analysis. Hamblin (1989a) confirmed alluvial fans in the Ainslie and Cabot Sub-basins through regional mapping and paleoflow analysis thus providing fan models

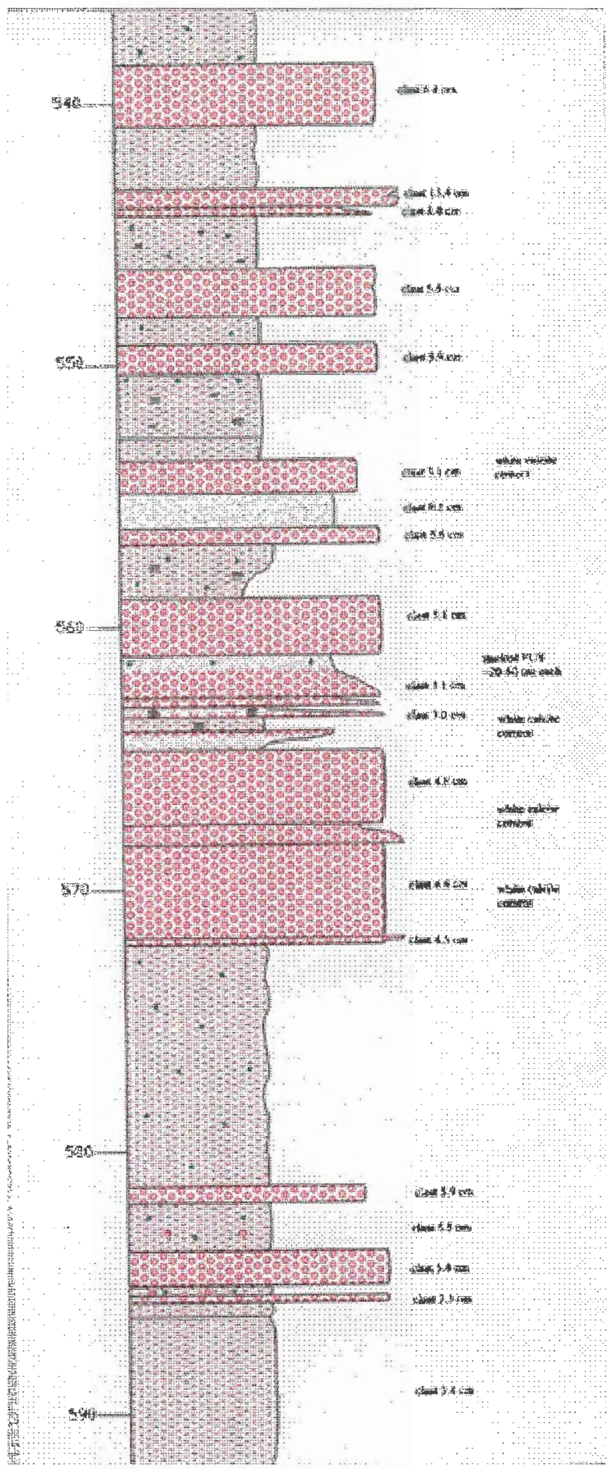


Figure 3.6 An example from Appendix D of a siltstone-rich member in the Grantmire Formation representing an interfan to distal fan environment

for other Horton areas in Cape Breton sharing similar lithology, sedimentary features, and structural history.

The morphology of an alluvial fan (Fig.3.7) would promote supercritical water flow conditions to entrain pebble- to boulder-sized clasts which would be deposited rapidly basinward as slope decreases, flow competency decreases, flow depth decreases and flow width increases (Blair and McPherson, 1994). The angularity and immaturity of gravel clasts argue for a nearby source, consistent with an alluvial fan environment (Fig.3.8). The competence of the flow is indicated by the grain size of sediment that was transported. The largest measured recorded boulder clast diameter of 22 cm suggests that proximal energy flow would have to be a minimum of 400 cm/sec (Fig.2.2). Mesoscale patterns with coarsening upward sequences on the 10-50 m scale are interpreted as the result of fan progradation, as indicated by thickening upward trends and generally increasing clast size. Smaller scale (<5m) coarsening upward sequences are probably due to small lobe or levee progradation. The rapidity and magnitude of flow attenuation on all fans and resultant drop in competency and capacity is a fundamental difference distinguishing a fan system from a river system (Blair and McPherson, 1994; Fig.3.9).

The Grantmire Formation is a coarse clast-supported conglomerate or fanglomerate that is part of an ancient basin margin where stream flow deposition resulted from channels that may have been braided. Large-scale coarsening upward sequences commonly reflect prograding fans as sheets or lobes. Minor occurrences of pebble to cobble sized clasts in a siltstone matrix could have been the product of a debris flow, or a high-energy flow that had greater competence than initially indicated by the

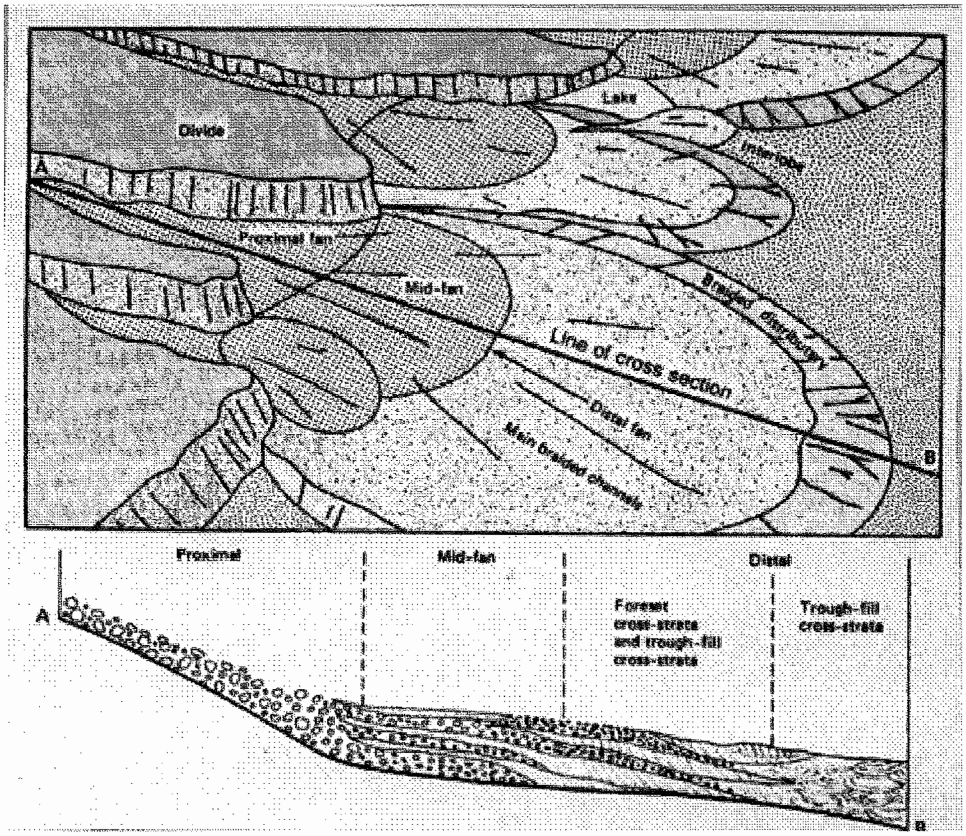


Figure 3.7 A schematic alluvial fan model representing the progression from coarse to finer sediments with distance from the source (McGowen & Groat, 1971).

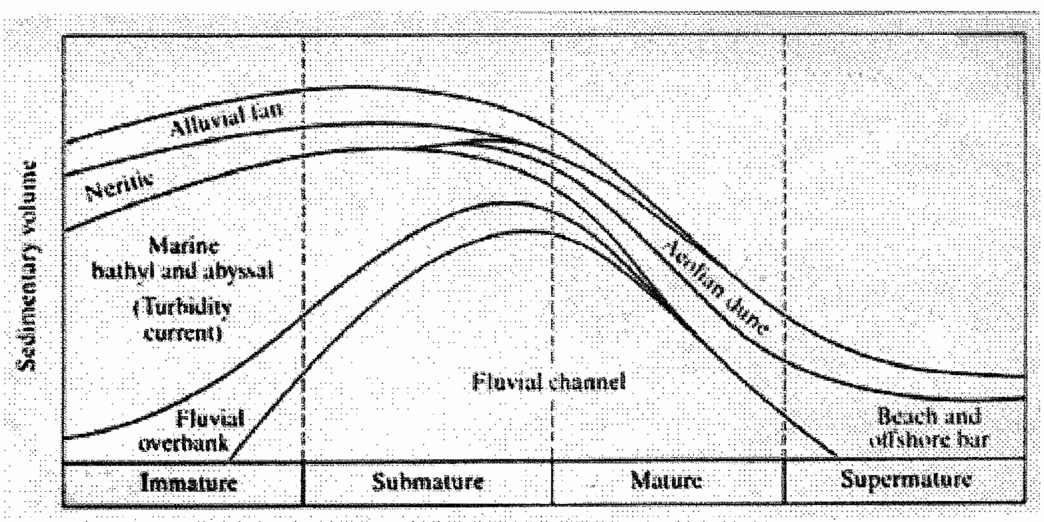


Figure 3.8 A qualitative diagram representing the relationship between textural maturity, sedimentary environment, and sedimentary volume. Note that alluvial fans are high volume, immature sediments (Ehlers and Blatt, 1982).

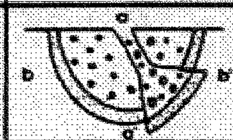
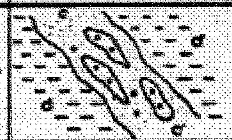
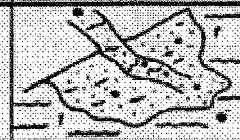
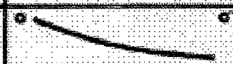
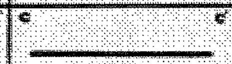
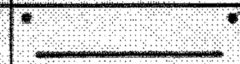
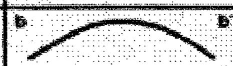
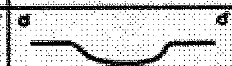
Geological Feature	Alluvial Fans	Rivers	River Deltas
Planview Shape			
Flow Expansion Angle	180°	Negligible	180°
Radial Profile			
Radial Length	<10 to 15 km	10 to 1,000 kms	1 to 100s kms
Radial Relief Over 10 Km	300 to >2,000 m	1 to 70 m	1 to 70 m
Cross-Profile			
Cross-Profile Relief	300 to >2,000 m	1 to 15 m	0.1 to 20 m
Geomorphic Setting	Piedmont	Most Continental Settings	Most Continental Settings
Propensity for Unconfined Flows	Very High	Very Low	High
Floodplains Present?	No	Yes	Yes
Radial Slope Values	1.5° to 25°	<0.5°	<0.5°
Typical Sediment Mode	Pebbles to Boulders	Sand to Cobbles	Mud to Pebbles
Rate of Slope Gain Relative to Grain Size	Very High	Low	Low
Effect of Vegetation	Very Minor	Major	Major
Relative Drainage-Basin Size	Very Small to Small	Moderate to Large	Moderate to Large
Relief Ratio of Drainage Basin	Very High	Low	Low
Propensity for Generating Flashfloods	Very High	Low to Moderate	Low to Moderate
Sediment-Gravity-Flow Activity	Very Common	Rare	Rare (except at front)
Typical Water Flow Conditions	Supercritical	Subcritical	Subcritical
Magnitude of Tractive Forces	Very High	Moderate	Low to Moderate
Flow Competency	Very High	Low to Moderate	Low to Moderate
Effect of Slope Failures on Sedimentation	Very High	Low to Moderate	Low (except at front)
Clasts Entrainable by Flow 1 m Deep	Med Boulders to Pebbles	Med Pebbles to Crs Sand	Granules to Med Sand
Flow Capacity	Very High	Moderate	Moderate
Δ Flow Depth Downslope	Greatly Decreases	Slightly Increases	Slightly Decreases
Δ Flow Width Downslope	Greatly Increases	Slightly Increases	Moderately Increases
Δ Flow Competency Downslope	Greatly Decreases	Slightly Increases	Slightly Decreases
Δ Flow Capacity Downslope	Greatly Decreases	Slightly Increases	Slightly Decreases
Δ Water Discharge Downslope	Greatly Decreases	Greatly Increases	Consistent
Frequency of Aggradational Events	Very Rare	Common to Rare	Common to Rare

Figure 3.9 Comparison of typical morphological, hydraulic, and sedimentological properties of alluvial fans, rivers and river deltas in sedimentary basins (Blair and McPherson, 1994). The properties in the Grantmire Formation generally support an alluvial fan system.

siltstone matrix. The availability of gravel-sized clasts may have been restricted locally. However, debris-flow deposits do not appear to have been dominant in the succession. Decreasing flow capacity and competency results from fan morphology where slope decreases, channels are wider and shallower and unable to confine sediment loads, contributing to an increase in sheetflooding and deposition of finer material downfan (Bull, 1972; Blair and McPherson, 1994). The distal fan has the gentlest slope, and silt accumulation is common where flow attenuation is too low to transport coarser material.

The red colour potentially identifies the climate conditions under which sediments were deposited. Walker (1967) suggested that the red pigment in alluvial fans forms *in situ* where oxygen-rich moisture alters iron-bearing minerals within the sediments (predominantly hornblende and biotite) to hematite, thus staining the fan sediments throughout. Walker further states that clay minerals and calcium carbonate are other products of such a chemical attack. Hand samples and thin sections (Chapter 4) in the Grantmire Formation show variable amounts of calcite cement and clay minerals, which could be in part by-products of altering iron-rich silicates. Redbeds are commonly associated with evaporites, and the generally accepted association indicates that sediments were deposited in a semi-arid to arid environment (Walker, 1967). The development of calcareous concretions in reddish brown siltstone is another indication of a semi-arid to arid climate experiencing seasonal precipitation (Boehner & Giles, *in review*).

CHAPTER 4: PETROGRAPHY AND TECHNICAL PROPERTIES

4.1 Methods

The objective of this chapter is to evaluate the mineralogy and texture of the sediments on a microscopic scale and conduct a limited study on the reservoir quality of the Grantmire Formation in DDH PE 83-1. The current hydrocarbon exploration by Hunt Oil in the region of the Sydney Basin initiated the author's contact with Doug Hostad (Hunt Oil, senior exploration geologist). An agreement was reached, and Hunt Oil funded a porosity and permeability analysis and thin section description on several samples from the Grantmire Section and would provide the author with an unpublished report. The author was permitted to use the data from the report and incorporate the information into her thesis.

Steve Nagy from CoreLab Calgary completed the Hunt Oil report (unpublished report, 1998) on the reservoir quality of Grantmire Formation rocks at Point Edward, Cape Breton divided thin sections 1-8 by gravel size, matrix size and authigenic minerals to calculate clast percentages. The methodology for clast percentage calculations was not outlined in the report. The Hunt Oil report (1998) was supplemented with an additional analysis by the author on the same pre-described thin sections, in addition to eleven more thin sections. The same clast type and size categorization was used to estimate mineral abundances by qualitative observation and recorded in chart 4.2.

A porosity and permeability analysis was conducted by CoreLab (Calgary) on eight core samples from the Grantmire Formation portion of PE 83-1 using methods listed in Appendix B, and results recorded in Appendix C. Seven of these samples were conglomerates and the eighth was sandstone. Sampling was not reflective of the full succession because only the lower 100 m (Appendix D shows location on stratigraphic column) of the core was chosen for testing. Samples were selected based on facies type and visible porosity (evident only in lower 100m, and not evident). More conglomerate samples were chosen (7 in total) because facies 1 predominates in the Grantmire drill core 83-1. The conglomerate samples were selected according to differences in clast size, matrix material, presence of calcite cement, and pore space. One well sorted sandstone sample without laminae or pervasive calcite cement was chosen because sandstones are generally ideal reservoirs if they have a caprock (North, 1985).

Thin sections 1-8 were prepared at CoreLab, and thin sections 9-19 were prepared at Dalhousie University. Thin sections 1-8 were prepared by first impregnating the samples with blue epoxy to identify porosity. One half of each sample was stained with Alizarin Red and potassium ferricyanide to distinguish calcite (pink) from dolomite (non-stained) and ferroan (iron-bearing) carbonates (blue), and the other half was stained with sodium cobaltinitrite to identify alkali feldspar (yellow). None of the thin sections prepared at Dalhousie were stained.

4.2 Petrography

4.2.1 Conglomerate Lithofacies

Thin sections 8-12, 14, 18, and 19 are immature, very poorly sorted conglomerates consisting of mineralogically diverse granules to pebbles that are clast-supported and polymictic with minor silty to sandy matrices (Fig 4.1, 4.2). These samples represent the conglomerate facies (facies 1) and belong to the interbedded pebble conglomerate and sandstone subfacies.

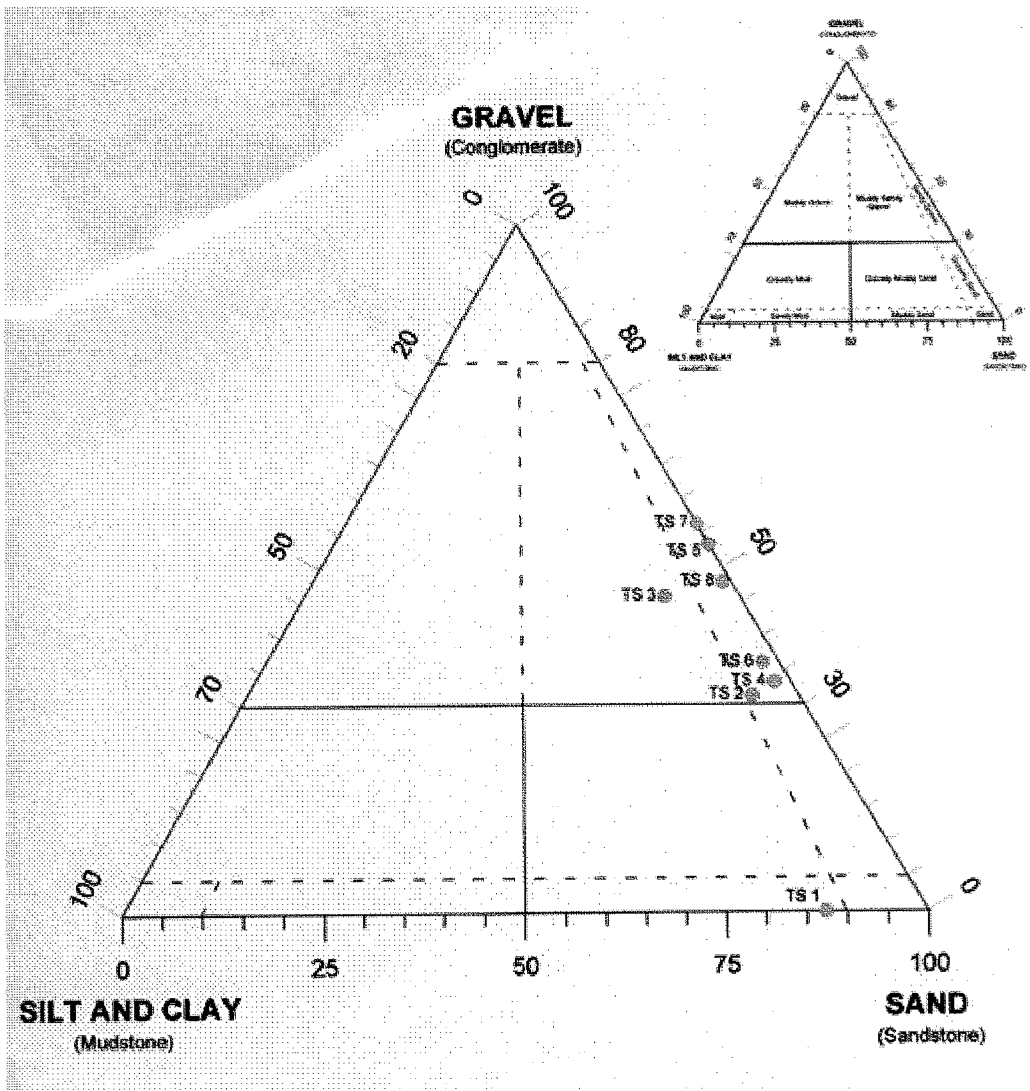


Figure 4.1 Clastic textural classification for PE 83-1 thin sections 1-8 (based on Folk, 1968; diagram from Hunt Oil, 1998).

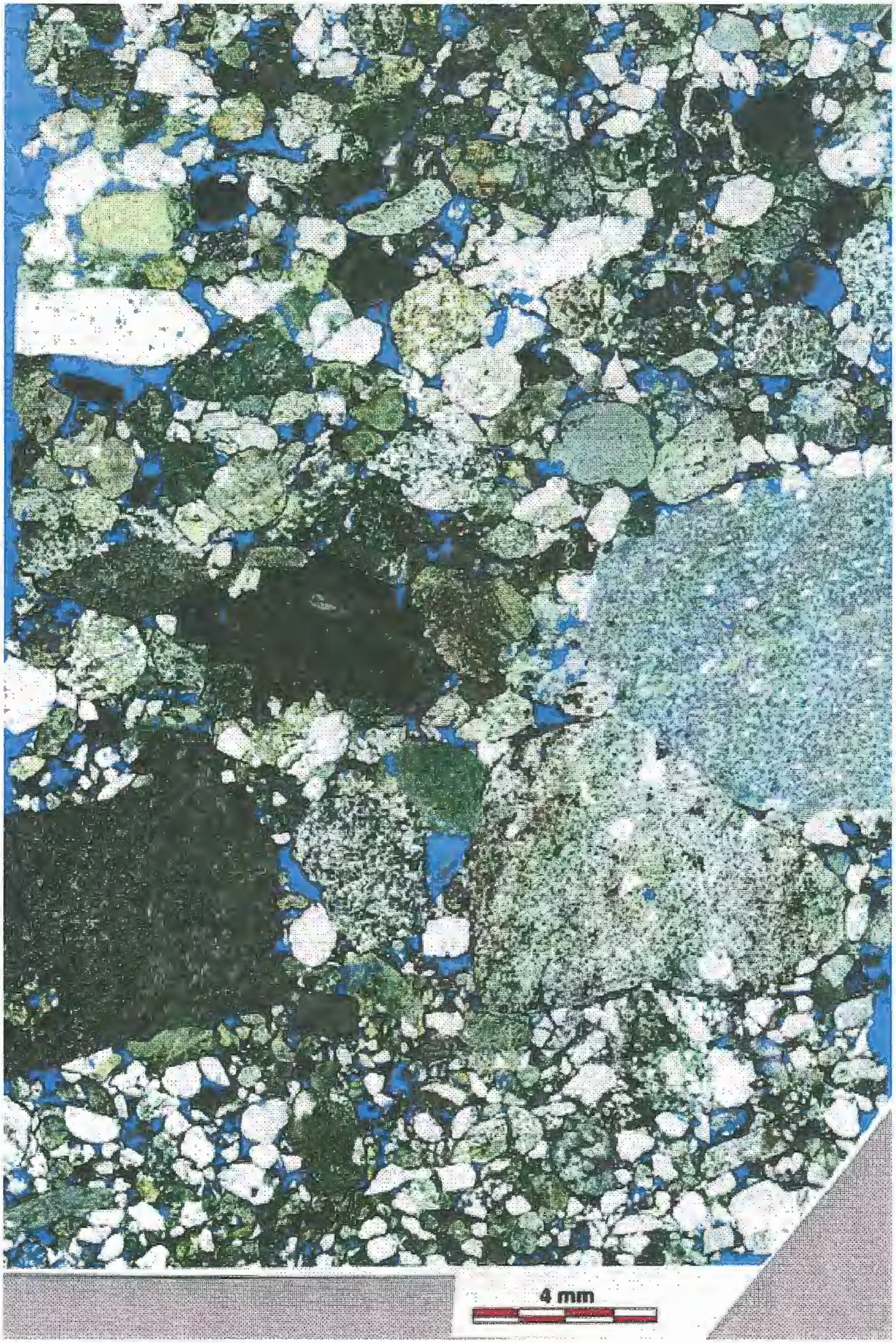


Figure 4.2 Macroview of a sandy conglomerate containing gravel-sized clasts of chert, polycrystalline quartz, rhyolite, and siltstone (Hunt Oil, 1998)

Framework mineralogy of the gravel portion (>2 mm) is predominantly chert (5-31%), followed by sedimentary and metasedimentary lithoclasts (0-23%) that consists of sandstone, siltstone and quartzite (0-15%). Rhyolite (0-12%) and other volcanic (basalt) (0-2%) lithoclasts are present in most thin sections. The presence of relatively unstable pebbles such as sandstone and volcanic clasts suggests that these clasts represent a first-generation deposit. The unstable sutured quartz grains in quartzite from thin sections 2 & 7 and presence of chalcedony indicates metamorphism in the source area.

The mineralogy of the muddy to sandy matrix includes primarily monocrystalline quartz (9-30%), chert (7-25%), polycrystalline quartz (4-15%), and lesser sedimentary (0-8%), plutonic (trace-10%), and volcanic (trace-6%) lithoclasts. Accessory alkali feldspar (trace-4%) and trace plagioclase feldspar, mica, and heavy minerals are present. Detrital

Authigenic minerals are predominantly calcite (0-25%) and hematite (trace-6%). Matrix clay (trace-9%) is unevenly distributed and likely consists of illite and kaolinite (Hunt Oil, 1998). with trace overgrowths of quartz and kaolinite occur on hematite rimmed clasts (Hunt Oil, 1998). The abundance of hematite varies slightly with the matrix type. A muddier matrix generally has slightly higher proportions of hematite than a sandy matrix. Calcite abundance varies considerably and calcite is present as both a cement (particularly TS 5 & 19, Fig.4.3) and as a grain-replacing mineral. In thin sections 13 and 17, calcite has twin lamellae. Hematite cement rims grains, but also occurs as a pervasive filling within grains. Trace authigenic euhedral quartz occurs in large open pore spaces and on hematite rims surrounding framework grains.

Alteration of primarily alkali feldspar occurs through dissolution or partial to full replacement by calcite. Hematite inclusions within chert and sedimentary and volcanic lithoclasts are common. Varying degrees of alteration of biotite to chlorite are also evident.

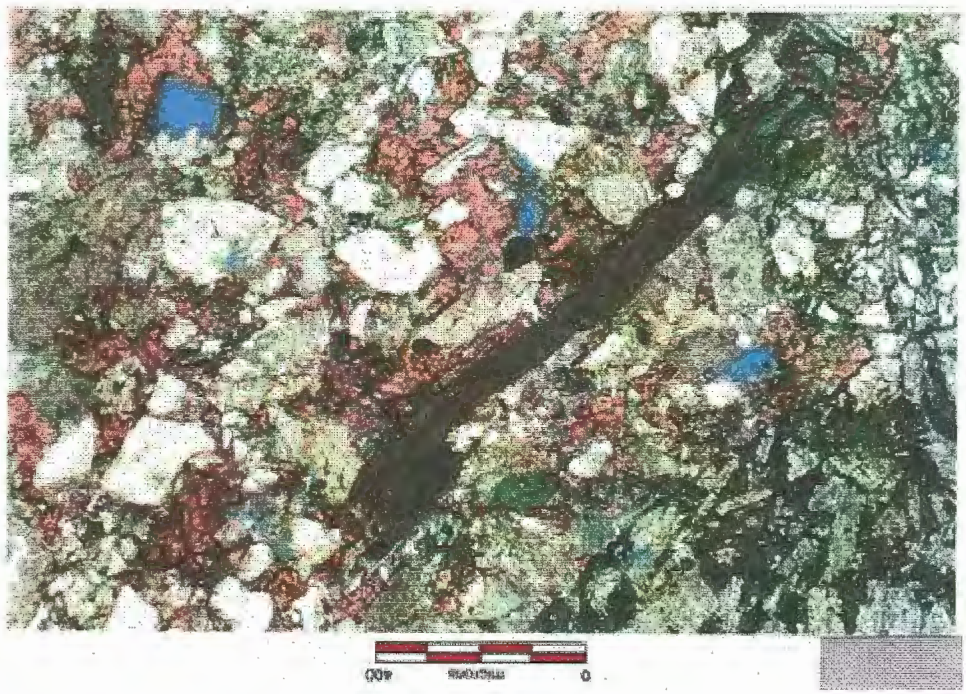


Figure 4.3 Pervasive calcite cement (stained pink) reduces the effective porosity and permeability of the sample (Hunt Oil, 1998)

4.2 Sandstone and Siltstone Lithofacies

The sandstone/siltstone lithofacies are immature, poorly to moderately sorted, and commonly have laminae. Muddy sandstones generally have laminae of moderately sorted, finer grains separating very poorly sorted, coarser grained laminae (Fig.4.4). Framework mineralogy is dominantly monocrystalline quartz (23-35%), with minor inclusions such as vacuoles and heavy minerals (sulphides – dominantly pyrite). Significant amounts of chert (16-25%), polycrystalline quartz (5-16%), and lesser amounts of igneous lithoclasts (1-18%) are present as major framework grains. Minor

Figure 4.4 Poorly sorted sandstone with irregular laminae of finer grained material (Hunt Oil, 1998)

framework grains include leached alkali feldspar (1-4%), and micas (1-10%). Heavy minerals vary in abundance within samples, but generally concentrate along contacts of laminae. Detrital clay (3-12%) is likely a combination of illite and kaolinite (Hunt Oil, 1998).

Authigenic minerals include calcite (3-10%), hematite (2-8%), and kaolinite (0-trace). Calcite occurs primarily as a grain-replacing mineral of alkali feldspar, and less commonly as a cement. Hematite occurs as rims around grains (Fig.4.5) and as cement filling intergranular and intragranular pores and is likely an alteration product of iron-rich clays because of the reddened colour.

Alteration from dissolution affects chert and alkali feldspar, resulting in partial to complete replacement of these grains by calcite. Hematite inclusions within chert are common. Varying degrees of alteration of biotite to chlorite are present in the sandstone lithofacies.

4.3 Porosity and Permeability

Recorded porosity from the samples was assessed using Table 4.1 to predict reservoir quality. Conglomerate samples that yielded fair to good reservoir quality (Table 4.2) were sandy conglomerates (litharenites) that had visible pore space in hand sample. Samples with negligible to poor reservoir quality (Table 4.2) had a combination of one or more of the following factors: pervasive calcite cement, hematite cement occluding pore space, greater abundances of detrital clay, and irregular laminae of finer material. Porosity is divided into effective porosity and total porosity. Effective porosity is a measure of the void space that is sufficiently interconnected to yield potential oil and gas recovery whereas total core pore space includes all types of pore space (effective and non-effective) (North, 1985). The total core space is always greater than the effective porosity (Table 4.2) but in some cases, there is little difference between the two (i.e. all pores are well connected). The porosity difference can be influenced by the nature of porosity, depending if porosity is primary or secondary. The shape of pores are strongly dependent upon the shapes of the grains (North, 1985), therefore the poorly sorted subangular grains and variable clast sizes can reduce the porosity. Primary porosity is the original porosity the rock possesses at the end of its depositional phase, on first burial.

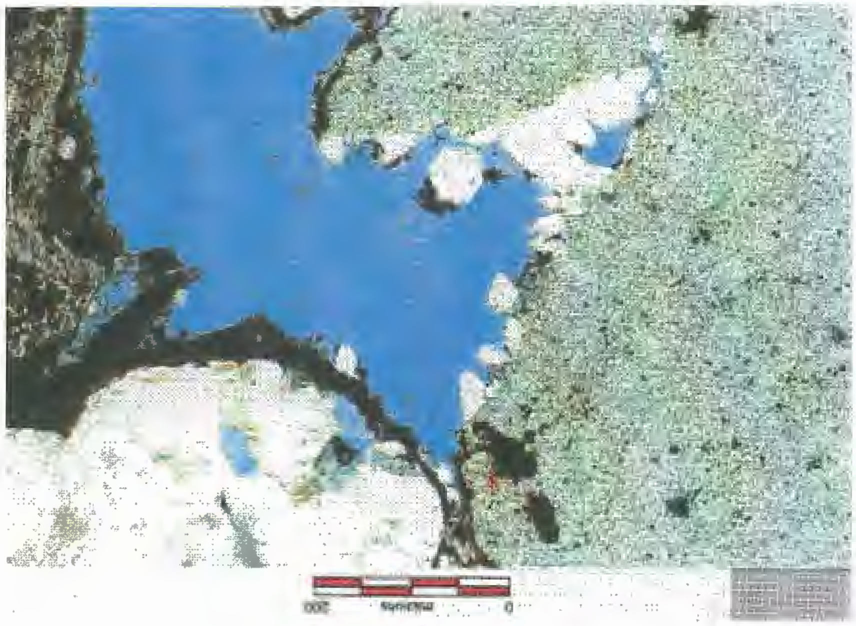


Figure 4.5 Example of hematite rims, common throughout the Grantmire Formation in addition to authigenic, euhedral quartz in open pore space identified by blue epoxy (Hunt Oil, 1998).

Table 4.1 Predicting reservoir quality based on porosity (North, 1985)

ϕ (percent)	Qualitative Evaluation
0-5	negligible
5-10	poor
10-15	fair
15-20	good
20+	very good

Table 4.2 Reservoir quality based on data in Table 4.1

	TS 1	**TS 2**	**TS 3**	**TS 4**	**TS 5**	**TS 6**	**TS 7**	**TS 8**
Total Porosity	9.9 %	4.1 %	6.3 %	15.7 %	5.5 %	12.0 %	12.1 %	11.3 %
Effective Porosity	7.0 %	2.0 %	3.0 %	13.0 %	2.0 %	10.0 %	11.0 %	9.0 %
Reservoir Quality	Poor	negligible	Negligible to fair	Fair to good	Negligible to poor	Poor to fair	Fair	Poor to fair

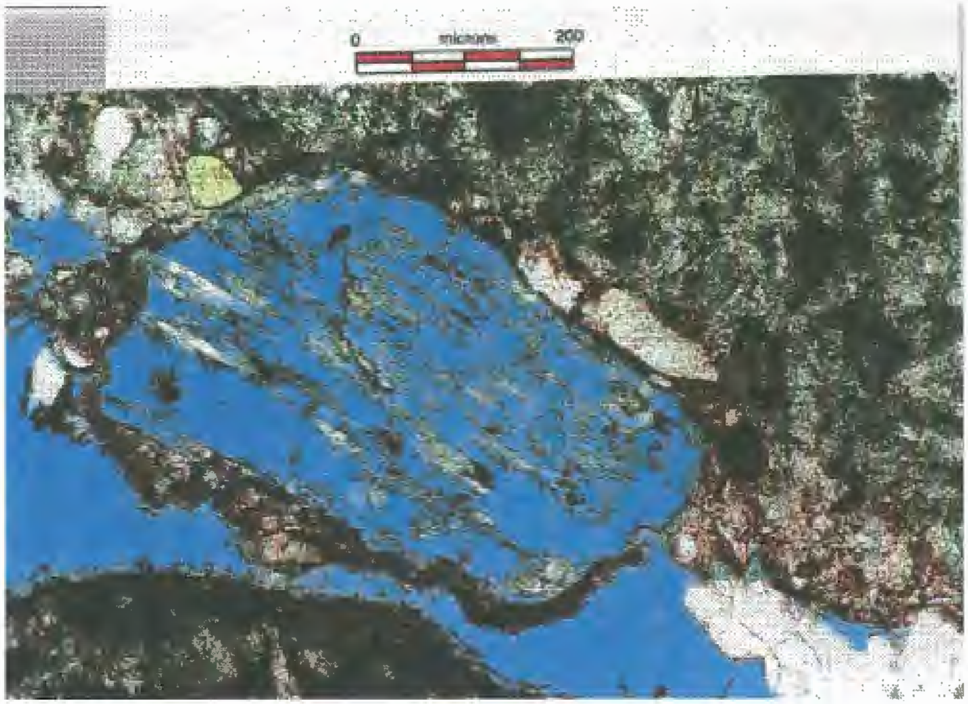
Secondary porosity is additional pore void space due to post-depositional or diagenetic processes (North, 1985).

Intergranular porosity (Fig.4.6) is present in many thin sections as the main pore type, and a close agreement occurs between the thin section (effective) porosity and core (total) porosity. Secondary porosity (Fig.4.7) occurs after dissolution of calcite, feldspars, and chert but is largely non-effective because of pervasive hematite rims that remain around pores after the grain has been dissolved. Minor microporosity (Fig.4.8) occurs in most samples with detrital clay and minor to trace kaolinite clay.

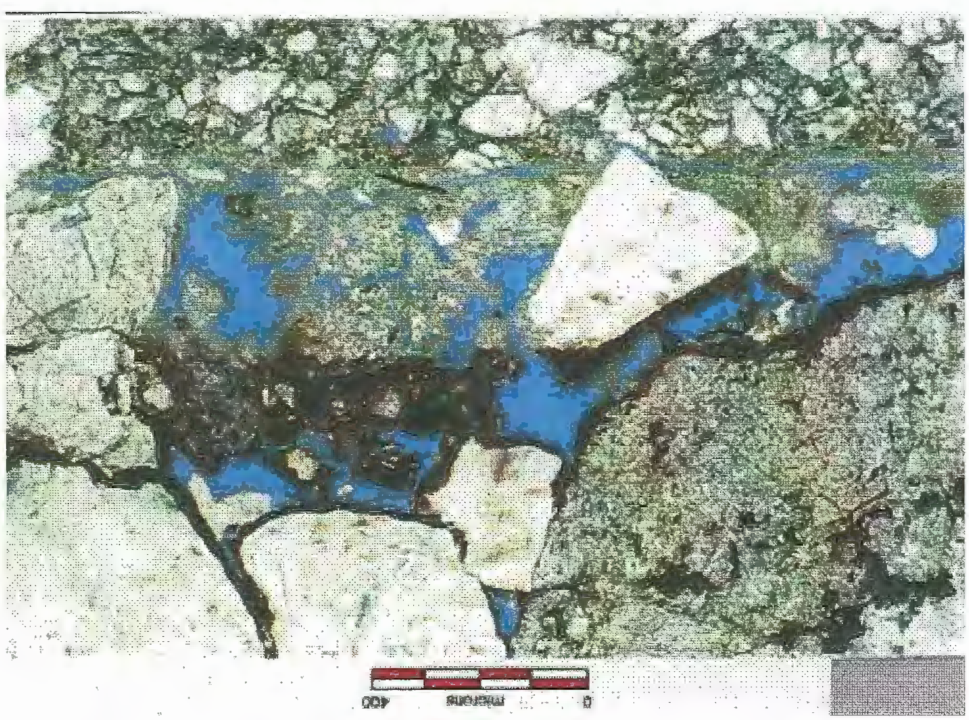
Sample MO-98-095 (TS 9, Fig.4.9) shows dissolution of alkali feldspar and calcite. The only remnants of these original minerals are small relict fragments that have not yet been leached. Hematite rims preserve the original grain shape; their uncollapsed shapes indicate late stage dissolution and lack of recent diagenesis. The abundance of non-effective secondary porosity and microporosity in detrital clay lowers the total effective porosity in many samples. Intergranular pore spaces may be original primary porosity or from dissolved minerals resulting in secondary porosity.

Permeability in the Grantmire Formation varies considerably depending on the amount of pervasive calcite cement, hematite cement occluding pore space, greater abundances of detrital clay, and irregular laminae of finer material. The calculated permeability is assessed in Table 4.3 to predict reservoir quality. The results are listed in Table 4.4 and the permeability assessment ranges from poor to fair.

Figure 4.6 Intergranular porosity (unlikely to be primary because most of the Grantmire Formation shows evidence of dissolution) (Hunt Oil, 1998)



(A)



(B)

Figure 4.7 Secondary porosity: (A) dissolution of alkali feldspar, (B) dissolution of calcite cement (Hunt Oil, 1998)

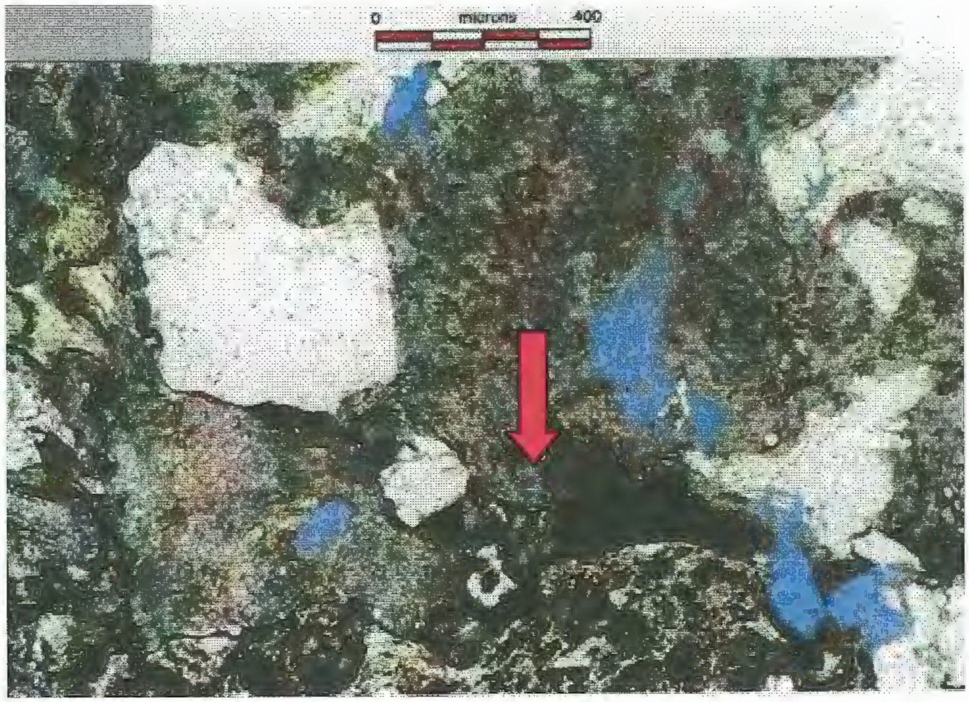


Figure 4.8 Microporosity in detrital clay (as indicated by arrow) (Hunt Oil, 1998)

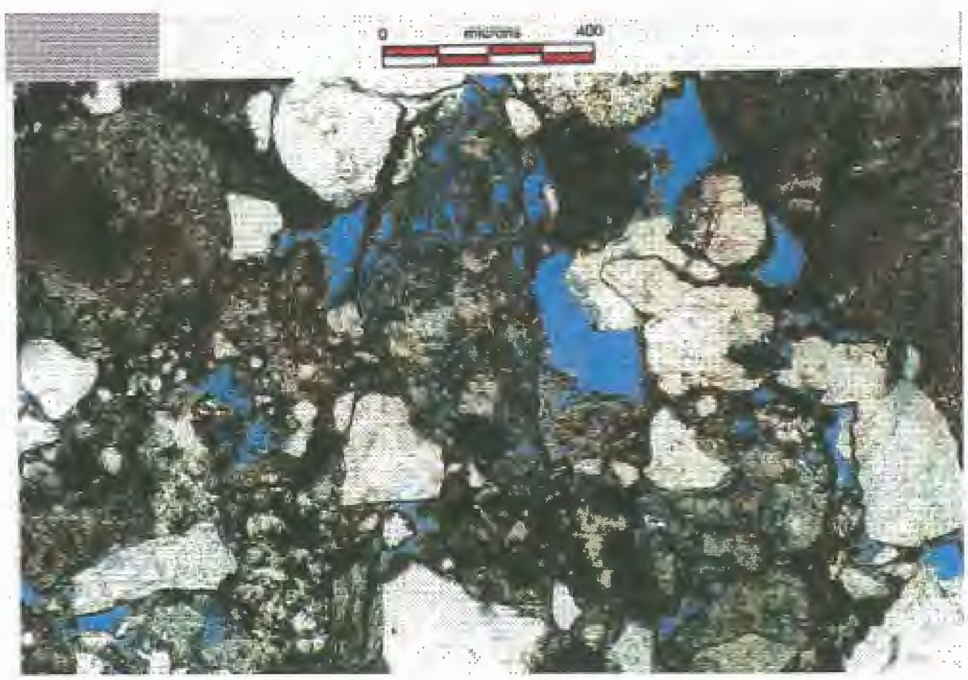


Figure 4.9 Skeletal alkali feldspars and dissolved minerals commonly results in the secondary (non-effective) porosity (Hunt Oil, 1998)

Table 4.3 Generalized reservoir quality based upon permeability (North, 1985)

Qualitative description	*K* – value (mD)
poor to fair	<1.0-15
moderate	15-50
good	50-250
very good	250-1000
excellent	>1000

Table 4.4 Permeability and reservoir analysis for the Grantmire Formation

	TS 1	**TS 2**	**TS 3**	**TS 4**	**TS 5**	**TS 6**	**TS 7**	**TS 8**
Permeability (md)	0.04	0.07	0.19	7.42	0.06	6.24	2.82	1.25
Reservoir Quality	Poor to fair	Poor to fair	Poor to fair	Poor to fair	Poor to fair	Poor to fair	Poor to fair	Poor to fair

4.4 Overall Reservoir Quality

The average porosity is 9.6% and ranges from 4.2 to 15.7 % therefore reservoir quality is poor to good.. The average permeability is 2.26 md and ranges from 0.06 – 7.72 md, and therefore the reservoir quality is poor to fair. The average permeability reveals a slightly lower prediction for reservoir quality than permeability, and emphasizes the need to base reservoir quality on more data to determine better averages and define anomalously high or low averages. Reservoir quality is controlled by variable amounts of detrital clay, authigenic minerals, irregular laminae (TS 4,7,8,11,13, & 17) of finer material, carbonate cement (TS 2, 5, 19), and paleosol development (TS 9, 11, 16, 17). Calcite cement is the greatest factor in poor reservoir quality, with detrital clay and hematite further reducing porosity and permeability. Extensive hematite cement and detrital clay in sandstone and siltstone isolate pore spaces, contributing to poor permeability. Laminae of finer material can also reduce reservoir quality to fair. The best reservoir quality occurs within samples that have well preserved intergranular porosity and limited detrital clay (TS 4 & 6) – generally sandy conglomerates. Porosity and permeability information from Table 4.2 and 4.4 are combined in Table 4.5 to predict reservoir quality, and are graphically represented in Figure 4.10, which shows reasonable linear correlation of porosity and permeability.

Table 4.5: Reservoir Quality

TS	Rock Type	Thin Section Porosity (%)	Core Porosity (%)	Kair (md)	Reservoir Quality
1	Muddy sandstone	7	9.9	0.04	Poor
2	Sandy conglomerate	2	4.1	0.07	Poor
3	Muddy sandy conglomerate	3	6.3	0.19	Poor
4	Sandy conglomerate	13	15.7	7.42	Poor - Good
5	Sandy conglomerate	2	5.5	0.06	Poor
6	Sandy conglomerate	10	12	6.24	Poor - Good
7	Sandy conglomerate	11	12.1	2.82	Poor - Fair
8	Sandy conglomerate	9	11.3	1.25	Poor - Fair

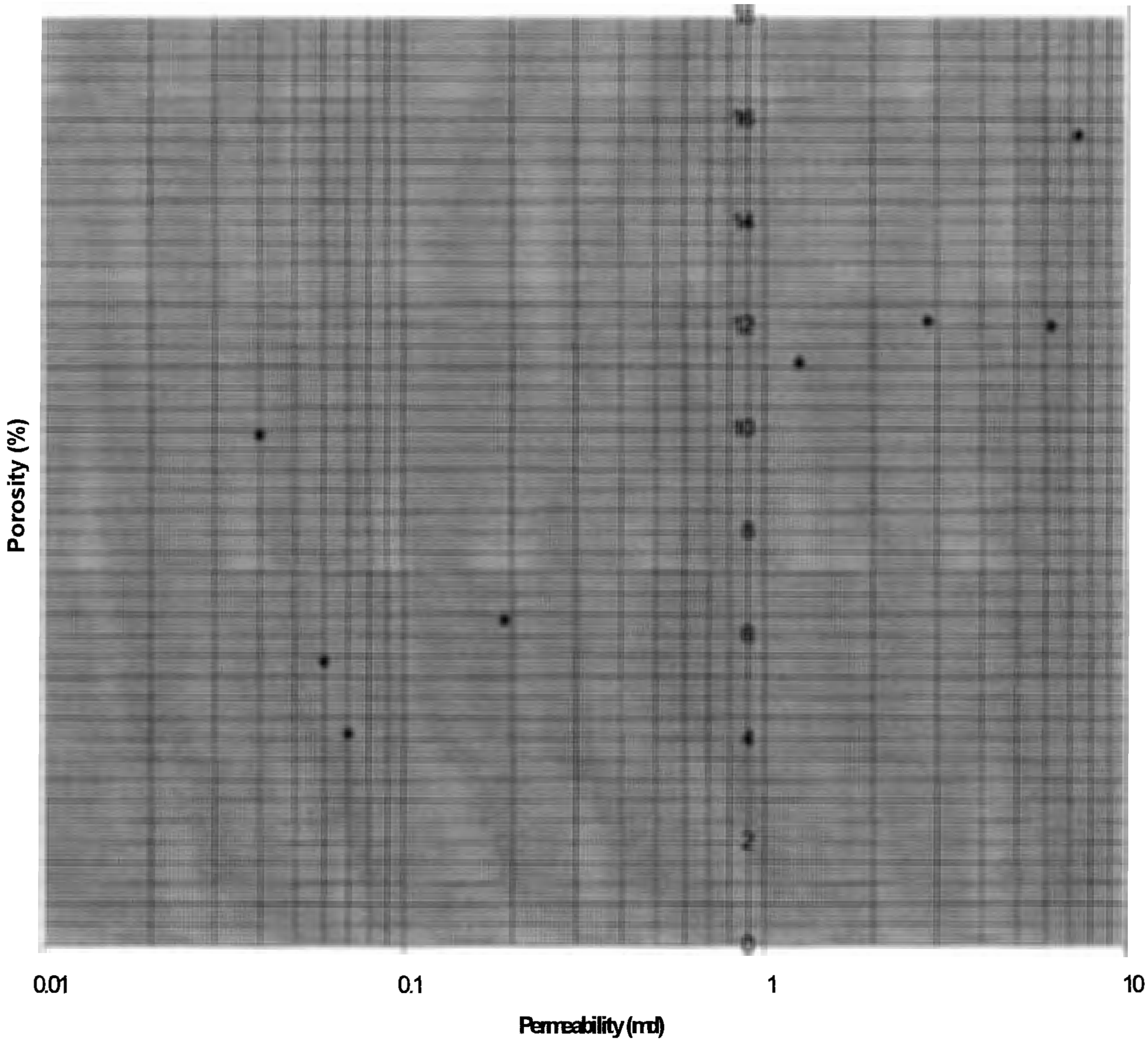


Figure 4.10 Eight samples from drill core PE 83-1 showing a general linear correlation of porosity and permeability

4.5 Discussion

4.5.1 Source Rocks

Clast type abundance is listed in Appendix B and reveals a general trend in clast proportion. The following are main the gravel types listed in order of decreasing abundance: (1) chert, (2) siltstone/sandstone, (3) quartzite, (4) volcanic clasts, and (5) rare granitic clasts. Chert occurs as pale, silicified turbid grains, and as dark, altered (possibly effected by hydrothermal processes) oxide-rich volcanic clasts, and is dominant in most thin sections. Generally, an equally abundant gravel-sized clast is polycrystalline quartz (original quartzite rock). The variation in the degree of alteration is not linked with the diagenetic history, but with the metamorphism of original rock. The volcanic rocks present are dominantly rhyolite with quenching and/or devitrification textures, also present are minor amounts of trachyte and basalt. Thin section 3 has an euhedral olivine phenocryst, and its mineralogy and fine-grained texture are consistent with unaltered basalt. The only well preserved granitic clast with quartz, muscovite and minor feldspar is in thin section 9. Alkali feldspar (dominantly orthoclase and microcline), multiple twinned plagioclase, chlorite (primary and as an alteration product), biotite, muscovite and pseudomorphed amphiboles are minor gravel-sized monomineralic constituents.

A detailed petrological study was beyond the scope of this thesis, but it was important to identify major clast types, approximate proportions, and degree of sorting to suggest proximity and type of depositional environments and to assess reservoir quality. An in-depth study may be useful in identifying source rock origins for the Grantmire Formation by correlating the mineralogy to similar rock types located in the local region. Without a better analysis and comparison with local rocks with similar mineralogies, only generalized source rock origins can be proposed. Chert is likely derived from an older sedimentary source than the siltstone and sandstone clasts because the latter easily break down during extended transportation. Quartzite represents the metamorphic effects on sedimentary rocks. Volcanic clasts are dominantly rhyolite that could have young or reworked origins. Rhyolite clasts commonly have fresh quenching or micrographic textures, devitrification, and plagioclase phenocrysts in less altered samples. Acidic plutons are the origin of phaneritic granitic clasts and likely provide a significant proportion of sand-sized quartz, feldspar, and mica clasts.

4.5.2 Paragenesis of the Grantmire Formation

Textural relationships within the thin sections reveal paragenesis linked to relative time rather than depth of burial. Grain suturing, mosaic textures and strain fabrics within clasts randomly vary within the PE 83-1 core suggesting that metamorphism and deformation occurred in the source area(s) before clasts were encompassed in the Grantmire Formation.

A simplified assessment of Grantmire paragenesis (Fig.4.11, Fig.4.12) begins with the deposition of sand- and gravel-sized clasts with iron-rich clay. The iron-rich clays were oxidized at the surface or in the shallow subsurface early in the depositional history. Clay proportions vary, but low or negligible amounts of clay are correlated with the absence of hematite rims. Carbonate nodules with fine calcite mosaic textures in siltstone facies 3 and 4, are another indication of near-surface conditions of groundwater infiltration. Surficial or near surface carbonate-rich waters introduced locally pervasive poikilotopic calcite cement with coarse mosaic textures prior to significant burial. In calcite-cemented areas, clasts appear to barely touch in a two-dimensional thin section, indicating that cementation took place prior to significant compaction. Commonly around the same time interval, calcite partially replaces potassium feldspar grains.

Partial dissolution of the clay matrix and calcite cement created intergranular (secondary) porosity and promoted local grain collapse. Partially leached chert and volcanic clasts are present, with minor dissolution of alkali feldspars. The presence of uncollapsed hematite rims where grains have dissolved suggests the material was consolidated at the time of dissolution and experienced little later diagenesis. Development of intergranular porosity allowed silica-rich fluids to form euhedral authigenic quartz in open pore spaces. Minor kaolinite clay was also deposited in pore spaces. Mica pressure shadows in matrix (sand-sized) material suggests minor deformation during diagenesis and bent mica is attributed to minor compaction.

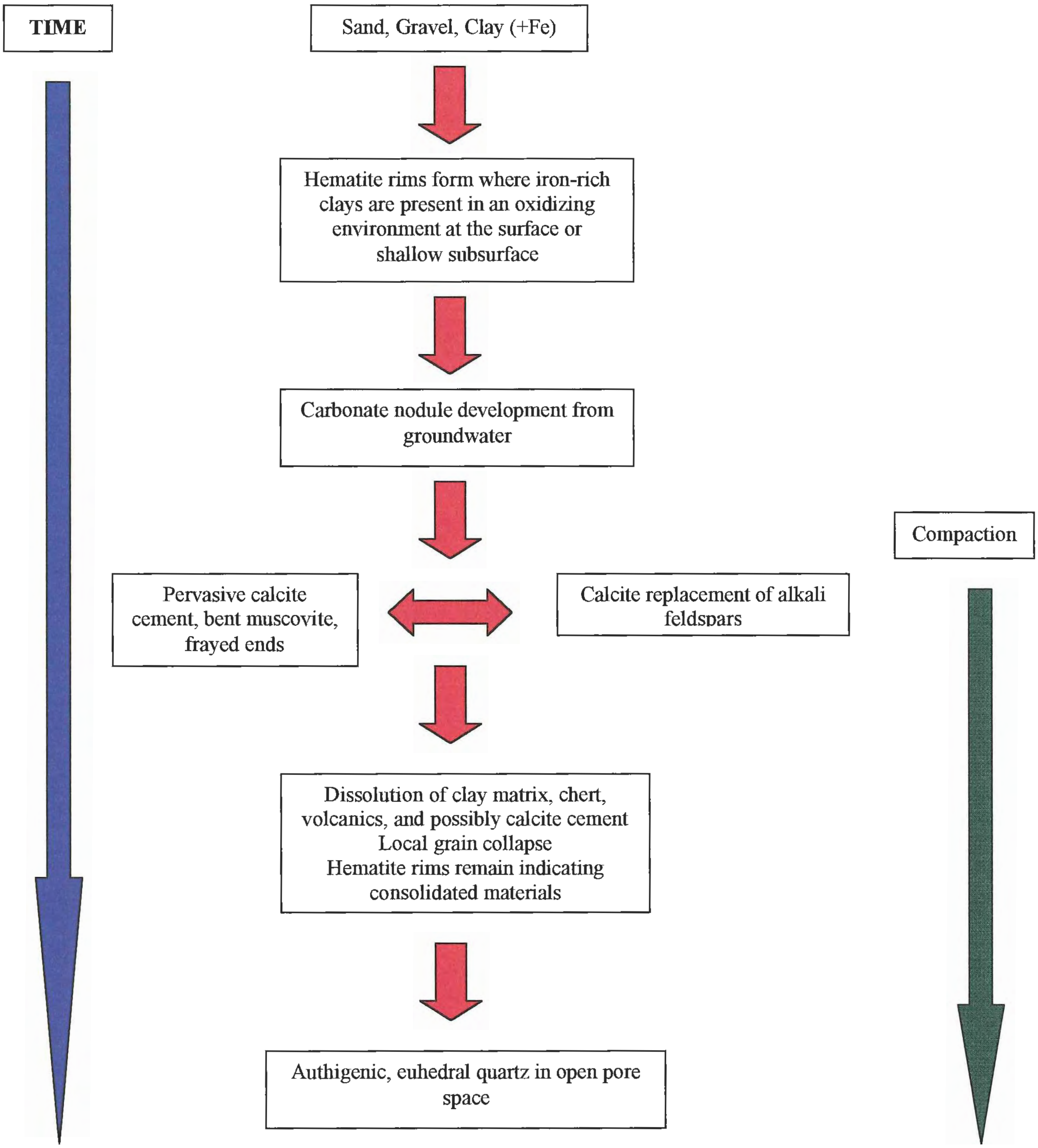


Figure 4.11 Simplified paragenesis model for the Grantmire Formation

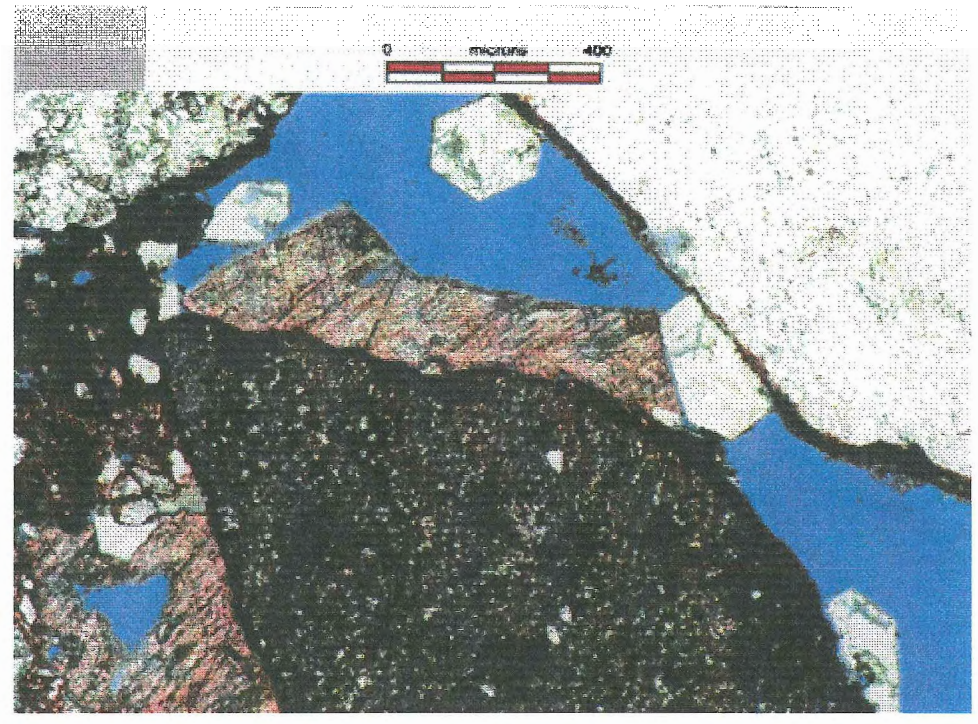


Figure 4.12 Mineral associations in thin section supporting the paragenesis model (Hunt Oil,1998). Clasts are hematite rimmed, with euhedral quartz in open pore space. Calcite developed sequentially, and in the lower left of the slide, quartz is enveloped in calcite.

CHAPTER 5: RESOURCE POTENTIAL

5.1 Introduction

Horton sedimentary rocks represent the basal nonmarine coarse clastic fill deposited in fault-bounded extensional basins in western and northern Cape Breton, following the Acadian Orogeny (Hamblin, 1989b). The alluvial fan deposits were later overlain by Windsor Group clastics, evaporites and carbonates. Base metal occurrences with minor amounts of copper, lead and zinc are widely scattered along the Windsor-Horton contact (Kirkham, 1978). The presence of major thrust repetition of parts of the Horton Group and offset of the basin margin potentially creates suitable structural traps that might have allowed petroleum migration into suitable clastic reservoir rocks along the basin margin.

5.2 Oil and Natural Gas Potential

5.2.1 Regional Background

Deposition of the Horton Group in northern and western Cape Breton (adjacent to the study area) occurred in two fault-bounded extensional sub-basins (the Ainslie and Cabot Sub-basins) that have been interpreted as adjacent half-grabens in a regional linear tectonic system (Hamblin, 1989b). Within these basins, the Horton Group is divided into three main stratigraphic megafacies: (1) the lower Craignish, (2) middle Strathlorne, and (3) upper Ainslie (Murray, 1960). The Craignish Formation can be 2000 m thick and consists of red or gray alluvial fan conglomerate and sandstone and red mudflat-playa siltstone (Hamblin, 1989b) and unconformably overlies metamorphosed Acadian basement. The Strathlorne megafacies has assemblages of gray or green basin-center open lacustrine mudstone, with red and gray fine sandstone, deposited along a prograding shoreline and fault margin adjacent to sandstone and conglomerate (Hamblin, 1989b). The Strathlorne Formation is up to 300 m thick, conformably overlies the Craignish Formation, and thins towards the margins of the basin (Utting & Hamblin, 1991). Red and gray fault margin pebble conglomerate, red fluvial sandstone, and basin center fluvial sandstone and siltstone comprise the upper Ainslie megafacies (Hamblin, 1989b), and is compositionally similar to the Grantmire Formation. The Ainslie Formation gradationally overlies and intertongues with the Strathlorne Formation and reaches a maximum thickness of 700 m.

Differences exist between basin margin and basin center lithofacies; to date, no three-dimensional lithofacies analysis has been conducted on the Grantmire Formation to reveal if conglomerates pass basinward into finer facies, and basin margins and centers are unknown. Extensive lithological studies on Horton sedimentary rocks in the Ainslie and Cabot sub-basins (Hamblin, 1989a/b, and Hamblin and Rust, 1989), and seismic work (V.Pascucci, unpublished data) can be used as temporary models to assist in understanding the Grantmire Formation depositional history.

No Strathlorne or Craignish megafacies equivalents have been identified in the onshore part of the Sydney Basin. Assuming the Ainslie and Grantmire are coeval lithofacies equivalents, the base of the PE 83-1 core might be within ~300 m of the Ainslie/Strathlorne boundary, if Strathlorne-type rocks are present, based upon maximum thickness presently recorded for the Grantmire Formation (Boehner & Giles, unpublished report). Using the Ainslie lithofacies as a model for position within the basin, the Grantmire is dominantly a proximal alluvial fan facies along the basin margin (Fig.5.1). The predominant red Grantmire conglomerates correlate with Hamblin's (1992) Ainslie

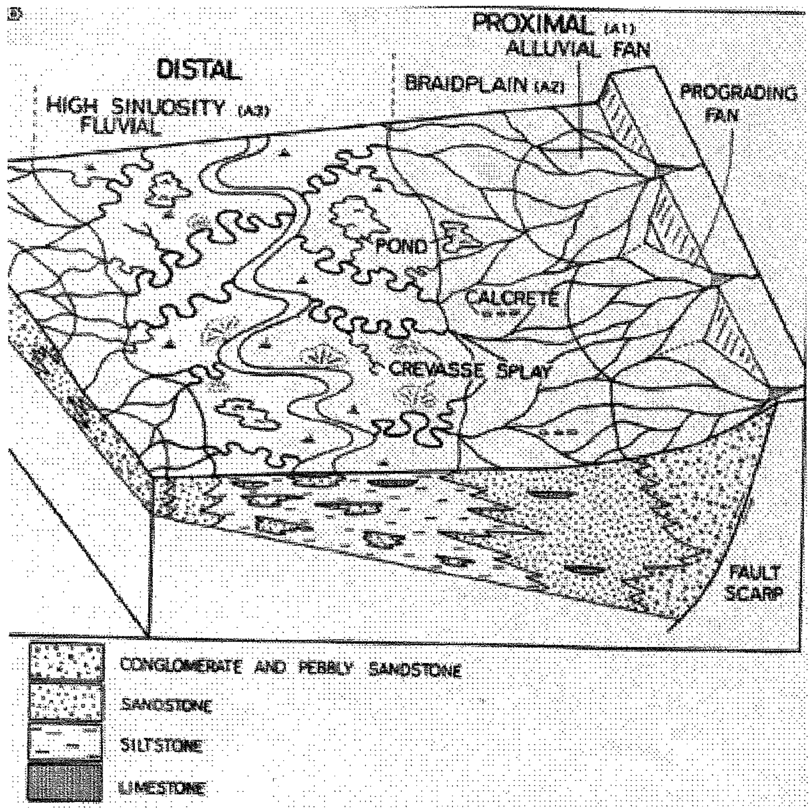


Figure 5.1 Depositional environment and facies distribution inferred for the Grantmire Formation based on a model for the Ainslie facies which is lithologically comparable (Hamblin, 1989b)

MEGAFACIES	FACIES ASSEMBLAGES	POSITION
AINSLIE	A1 red/grey pebbly css-cgl (alluvial fan/braidplain)	↑ basin margin
	A2 red fss-css & si (fluvial)	
	A3 grey/green vfss-fss & si (high sinuosity fluvial)	↓ basin centre
STRATHLORNE	S1 dark grey burrowed mudstone (open lacustrine)	↑ basin centre
	S2 grey/green vfss-fss (nearshore/shoreline)	
	S4 red si-fss (shoreline/mudflat)	
	S3 grey/green mss-bldr cgl (fan delta)	↓ basin margin
CRAIGNISH	C3 grey/green css-cgl (braidplain)	↑ basin centre
	C2 brick red si-fss (mudflat/playa)	
	C1 red/orange css-cgl (alluvial fan/braidplain)	↓ basin margin

Table 5.1 Depositional systems and facies assemblages of the Horton Group on Cape Breton Island as defined by Hamblin (1989b). Used to approximate the Grantmire Formation position in the onshore Sydney Basin.

facies of red/gray pebbly coarse sandstone to conglomerate (assemblage 1, Fig.5.1). The Grantmire siltstone fraction generally correlates with facies assemblage 2, approaching the basin center. Little to no basin center facies, as represented by assemblage 3, is represented in the drill hole of PE 83-1.

The macroscale patterns determined for the stratigraphic column of PE 83-1 suggests that two or three fans are potentially represented because medial/distal fan patterns appear twice and are separated by probable interfan sediments. A third fan is potentially represented at the top of the Grantmire, but is terminated by the inundation of the Windsor Group seas.

5.2.2 Hydrocarbon Potential of Fault-Bounded Basins

North (1985) recognized the hydrocarbon potential of fault-bounded basins because they are characterized by abundant potential source rocks(organic-rich shales), potential reservoir rocks, have short migration paths between source and reservoir rocks, and have a widespread sealing sequence. Hamblin (1989b) suggested that the juxtaposition of dark fine grained facies and red coarser grained facies, confined in a localized structural basin and overlain by a regionally continuous carbonate/evaporite unit, the Windsor Group, are all favorable characteristics for the resource potential of the Horton Group.

The identification and interpretation of two sub-basins as half grabens is important in determining areas with suitable petroleum reservoir or mineral host facies, facies pinchouts, potential source rock facies and potentially advantageous structural features (Hamblin, 1989b). In fault-bounded basins, abrupt vertical and lateral facies changes create many reservoirs (Robbins, 1983), secondary porosity is common (Ethridge & Wescott, 1984), and such basins have relatively high geothermal gradients because they represent an external environment of the formation and multiple structural trap possibilities (North, 1985).

5.2.3 Source Rock Potential

The presence of fault zones and/or major thrust repetition of parts of the Horton Group and offset of the basin margin would potentially create an environment that would allow petroleum rich sources to migrate into suitable clastic reservoir rocks along the basin margin. Periods of peak subsidence generate source rock facies in the axial zone near the main controlling fault where clastic input is limited to a narrow belt adjacent to the margin (Hamblin, 1989b). Following these events are periods of tectonic quiescence when there is rapid accumulation of reservoir facies near the margins (Quanmao & Dickinson, 1986).

Organic rich lacustrine shales of the Strathlorne megafacies are potential source rocks for petroleum generation if they occur in the area. Palynological samples of spores collected from the Strathlorne Formation (Fig. 5.2) reveal a Thermal Alteration Index (T.A.I) of 2 to 3-, which falls within the oil window (Hamblin, 1989a). Higher, more mature T.A.I values of 3 to 4- lie within the gas window, and are located close to basement blocks at sub-basin margins (Hamblin, 1989a). Samples from the Horton Group Ainslie sub-basin have vitrinite reflectance (R_0) values ranging from $\%R_0$ 0.5-2.11. These values range from within the oil window to overmature (Table 5.2).

Although no source rocks have been proven onshore in Sydney, using a locally similar tectono-stratigraphic model outlined by Hamblin and Rust (1989), the Grantmire has coeval Ainslie-type facies that are possibly underlain by Strathlorne-type organic rich lacustrine shales. Source rocks and oil showings in other areas of the Horton Group (Fig.5.3) (Utting and Hamblin, 1991; Hamblin, 1989a; Hacquebard and Donaldson, 1970; Martel and Gibling, 1996) indicate that Horton sediments commonly contained precursor kerogens, which potentially could have developed into hydrocarbons on thermal maturity (Tissot and Welte, 1984).

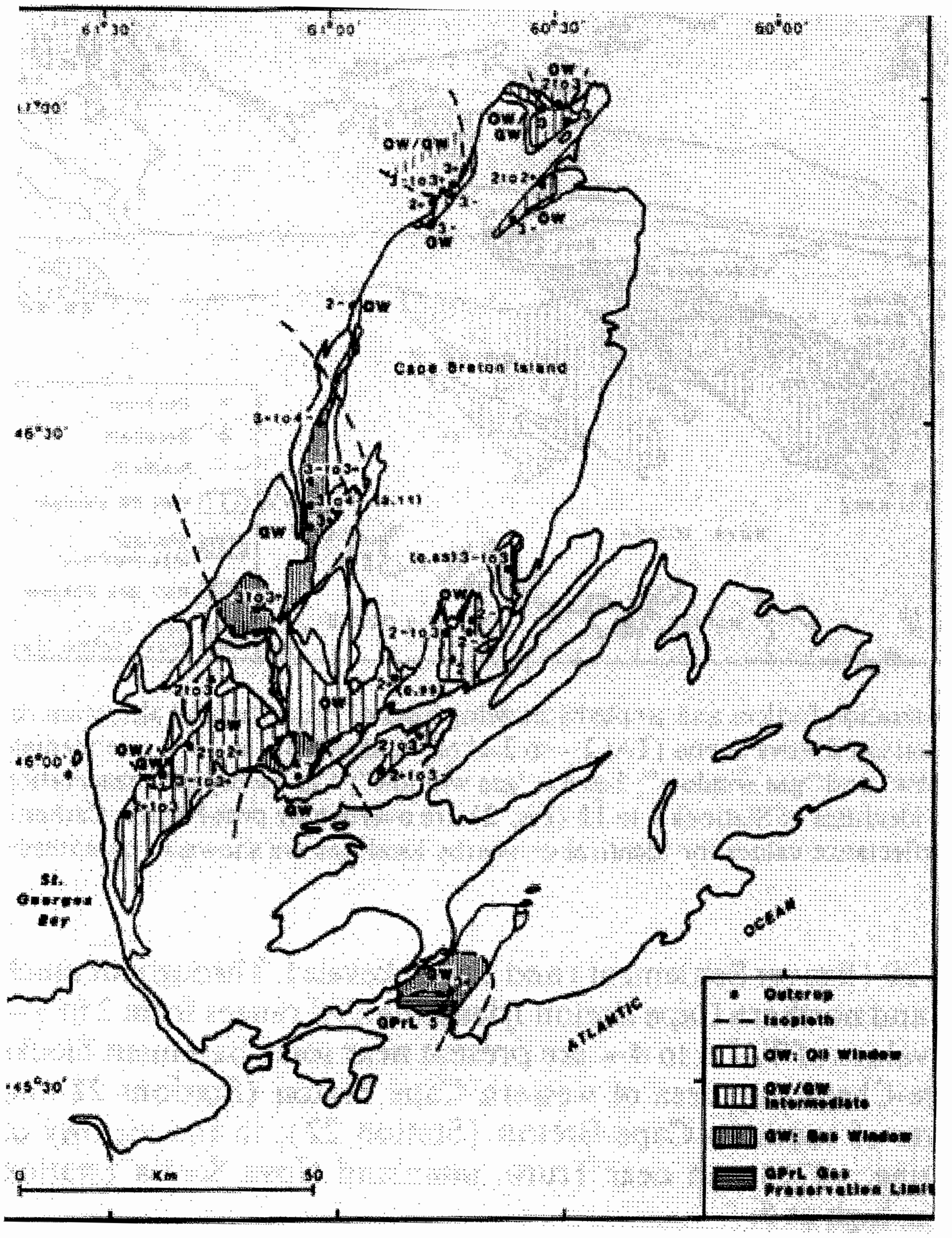


Figure 5.2 Thermal Alteration Indices and isopleth lines of equal thermal alteration for Cape Breton, Nova Scotia (Utting and Hamblin, 1991)

Thermal Alteration Index	Conodont Colour Alteration Index	Vitrinite Reflectance (Ro)%	Zones of Petroleum Generation and Destructiôn (Amorphous organic matter)
1			
	1		
1+			
		0.3	
		0.4	
2−			
		0.5	--------- Oil "Birth" Line --------
2			
		0.6	
	1.5		
2+		0.9	Peak oil generation
		1.0	Peak wet gas generation
3−	2.0	1.20	Peak dry gas generation
	2.5	1.35	-------- Oil "Death" Line --------
3	3.0		
	3.5	1.5	
3+			
	4.0		
4−	4.5	2.0	---------- Wet gas floor ----------
		2.2	
4			
		3.0	--- Dry gas preservation limit ---
		3.5	
	5		
5			
	6	4.0	
		5.0	

Table 5.2 Predicting petroleum generation and destruction by comparing thermal alteration indices and vitrinite reflectance values (Utting *et al.*, 1989; and column 4 modified from Dow, 1977 and Teichmüller, 1986)

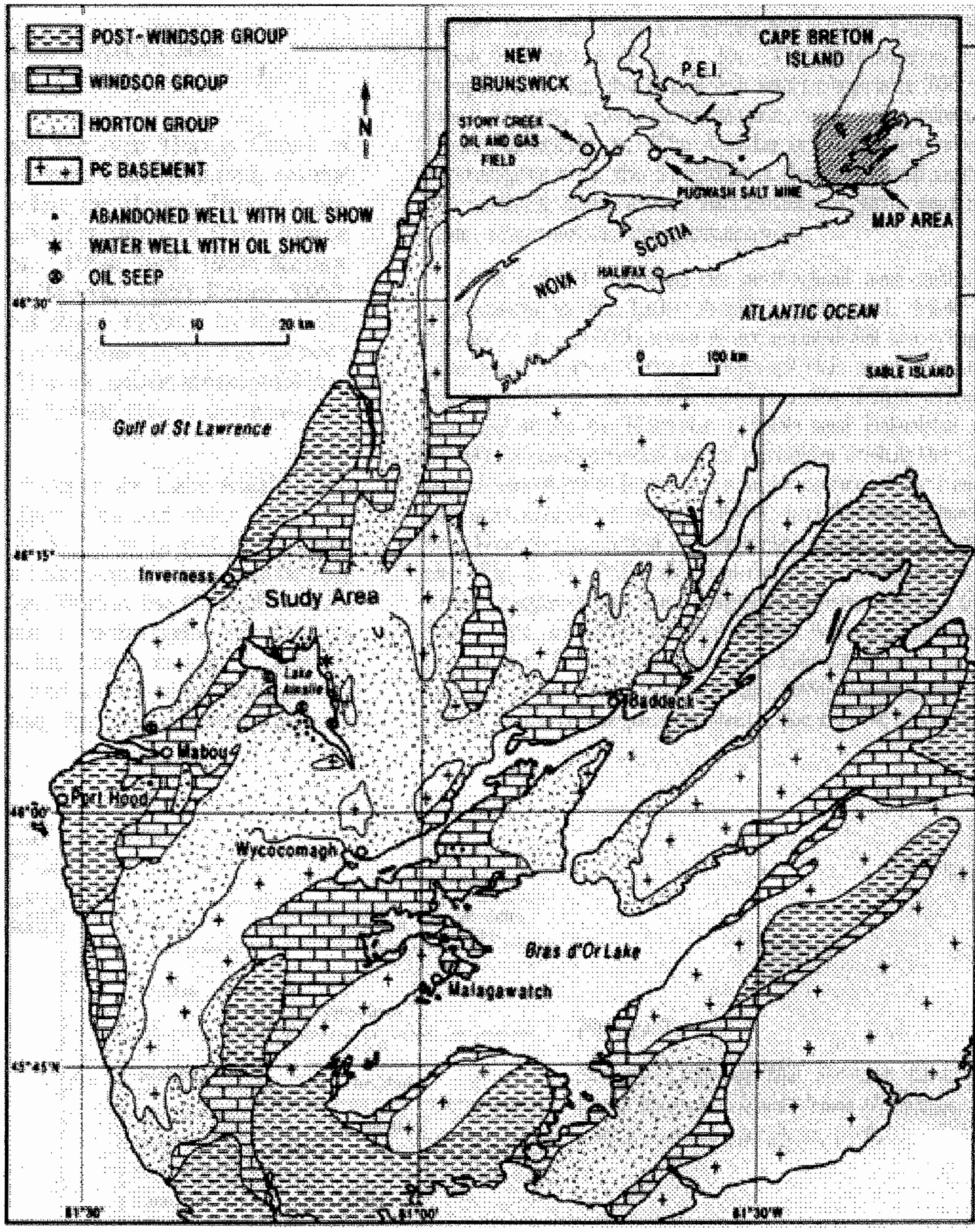


Figure 5.3 Simplified geological map of western Cape Breton Island, showing the distribution of pre-Carboniferous basement, Horton, Windsor and post-Windsor Groups, with oil shows from Horton Group rocks (from Fowler *et al.*, 1993).

5.2.4 Reservoir Rock Potential

Fault-bounded basins have thick clastic sedimentary sequences near their margins and in their upper parts (Quanmao & Dickinson). The Grantmire is a potential reservoir rock because it may be located near the margins one of the many smaller Horton basins (Gibling *et al.*, 1999) within the larger Sydney Basin. Although no source rocks have been identified within the formation, the fault-bounded basin environment was ideal to form organic rich shales and generate hydrocarbons. The reservoir rocks may overlie or be interbedded with source rocks and are commonly overlain by a regional seal of carbonates and evaporites in the Windsor Group (Hamblin, 1989a). Seeps and oil produced from Horton Group equivalents, and the presence of dark organic shales in Cape Breton (Hein *et al.*,1993; Fowler *et al.*, 1993) and the presence of oil shows in the Lake Ainslie area, indicate that suitable reservoir rocks are available in the Horton Group.

Sandstone reservoirs with uniform high porosity and permeability are usually ideal because they have excellent continuity and predictability (Candido & Wardlaw, 1985). The sandstone facies comprise less than 7% of the Grantmire Formation in DDH PE 83-1, and has localized calcite cement which has reduced permeability. The dominant conglomerate facies (facies 1) has negligible to good porosity and permeability, but may be potentially more suitable towards basin centers where sediments are likely to be better sorted. Porosity and permeability fluctuates according to pervasive calcite cement, hematite rims and cement, irregular laminae of finer grained material, and the dissolution of alkali feldspars and calcite, creating secondary porosity. No siltstone facies (facies 3-5) were analyzed for porosity and permeability, the finer laminae of material, higher percent of hematite cement and detrital clay likely make these unfavorable reservoir rocks.

5.2.5 Trap Possibilities

Fault-related and fold-related structural traps are likely found in the Horton Group and concentrated near the footwall scarp margin of half-graben segments (Hamblin, 1989a). Stratigraphic traps may also occur throughout the fault-bounded half grabens, and are closely related to the structural evolution of the sub-basins. Fault-related (Fig.5.4) and fold-related (Fig.5.5) structural traps may differ in relation to strata type. Fold-related structural traps (Fig.5.5) encompass rollovers on the hanging wall of listric normal faults and anticlinal drape over rotated basement blocks primarily in the Strathlorne and Ainslie megafacies (Hamblin, 1989a). Rollovers on thrust-reactivated listric faults near sub-basin centers are also common in the Ainslie megafacies (Hamblin, 1989a).

The greatest potential for hydrocarbon accumulations is in the pinch outs of the extensive sandy shoreline tracts, and another known trap occurs in the fluvial channels in high sinuosity fluvial facies. If the Grantmire is equivalent to Hamblin's (1989a,b; 1992) Ainslie megafacies, the Starthlorne megafacies should be underneath, and would be a potential source rock for hydrocarbon generation. The entire Ainslie depositional system (alluvial fan/braidplain to high sinuosity fluvial) overlies the Strathlorne and could form a stratigraphic trap that represents the final filling phase of the Horton sub-basins (Hamblin, 1989a,b). The final potential stratigraphic trap type occurs as an unconformity trap near sub-basin margin faults (Hamblin, 1989a).

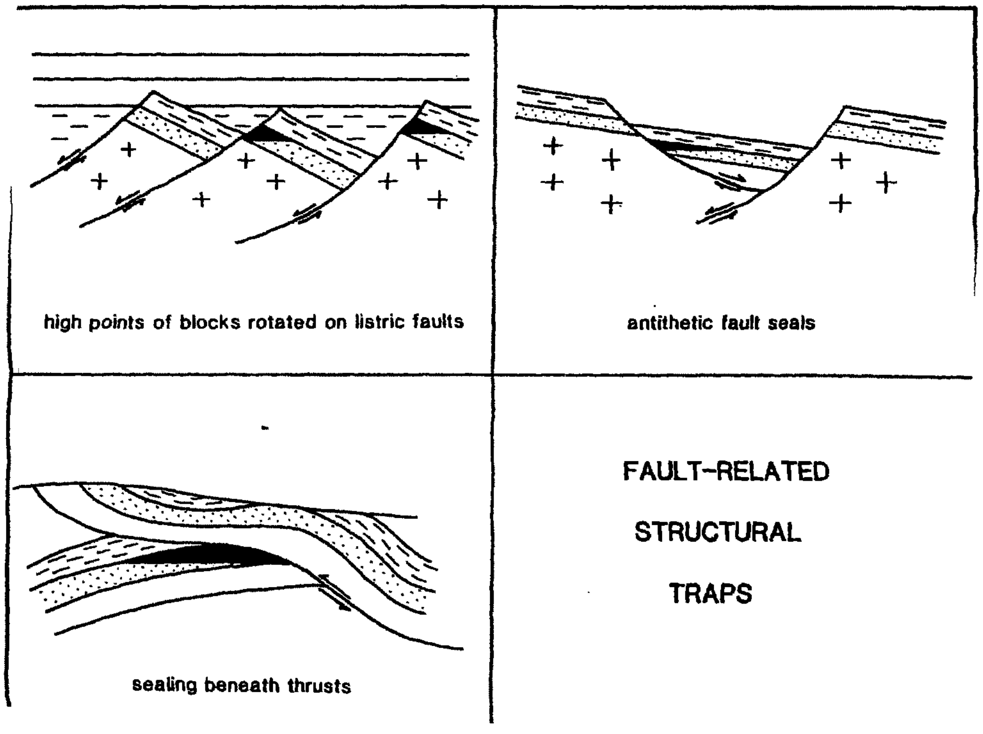


Figure 5.4 Fault-related structural traps that may be present in the Horton Group rocks on Cape Breton Island (Hamblin, 1989a)

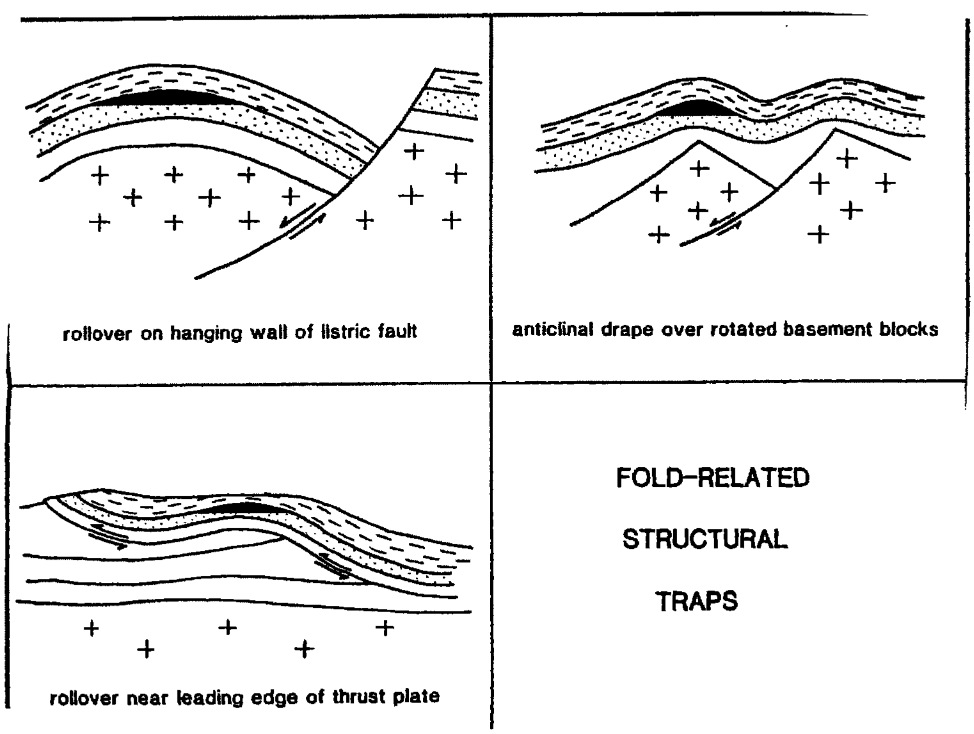


Figure 5.5 Fold-related structural traps that may be present in the Horton Group Rocks on Cape Breton Island (Hamblin, 1989a)

CHAPTER 6: CONCLUSIONS

The Grantmire Formation belongs to the Horton Group and is up to 800 m thick, based on exposures and drill core in the northern part of the Sydney Basin onshore. About 500 m of the Grantmire Formation is represented in DDH PE 83-1. Palynological evidence collected from gray shales in the upper part of the Grantmire Formation was correlated with similar spore assemblages found in the Cheverie Formation and reveals an Early Carboniferous (Tournaisian) age.

The Grantmire Formation is represented by three lithofacies groups: dominantly (1) *conglomerate* (72%), (2) *sandstone* (5%), and (3) *siltstone* (23%). The conglomerate lithofacies group is divided into three subfacies according to the dominant clast size. Facies 1 is an interbedded sandstone and pebble conglomerate with average clasts of <0.5 cm. Facies 2 is a pebble to cobble conglomerate with average clasts of 0.5 cm to 2 cm. Facies 3 is a small boulder conglomerate with clasts >2 cm. The sandstone lithofacies group (facies 2) is the least abundant lithology present, and is generally laminated. The siltstone lithofacies group contains interlaminated siltstone and sandstone with calcareous concretions (facies 3), fine-grained to coarse siltstone with calcareous concretions (facies 4), and fine-grained siltstone (facies 5).

An alluvial fan environment is supported by the known presence of fault-bounded basins confining flow until the apex or intersection point where sediments are rapidly deposited due to swift lowering of shear stress and the sudden drop in velocity, capacity, and competency (Bull, 1972; Blair 1985). The thickness (>500 m) of the Grantmire indicates sediments were not simply river deposits, but implies a fan system where great wedge thickness is common (Blair and McPherson, 1994). The angularity and immaturity of pebble to cobble sized clasts also argue for an alluvial fan environment for deposition.

Mesoscale patterns suggest coarsening upward sequences on the 10-50 m scale and a rare 100 m scale are the result of fan progradation as indicated by thickening upward trends and increasing clast size. Smaller scale (<5m) coarsening upward sequences may represent small lobe or levee progradation. Large-scale fining upward sequences (5-10 m) were formed where channels deposited finer material as flow capacity and competency decreased and flows began to wane. The Grantmire Formation of pebble to small boulder, clast-supported, polymictic conglomerates (fanglomerates) suggests deposition proximal to the Cape Breton Highlands (upper fan) that grades into finer siltstone facies (mid to lower fan), corresponding to changing flow competence and capacity as slopes decline on the alluvial fan. Proximal, distal and possible interfan successions are inferred from facies changes on tens to hundreds of meters scale.

The main gravel type clasts in the Grantmire Formation are listed in order of decreasing abundance: (1) chert, (2) siltstone/sandstone, (3) quartzite, (4) volcanics (rhyolite is commonly devitrified and has a quenched texture and is in greater abundance than basalt), (5) rare granitic clasts, in addition to minor alkali feldspar (orthoclase and microcline), plagioclase, chlorite (primary and as an alteration product), biotite, and muscovite. Chert is likely derived from an older sedimentary source than the siltstone and sandstone clasts that easily break down during extended transportation. Quartzite represents the metamorphic source area. Volcanic clasts are dominantly rhyolite that could have first generation or reworked origins. Rhyolite clasts commonly have fresh quenching or micrographic textures, devitrification, and plagioclase phenocrysts in less altered samples. Acidic plutons are the origin of granitic clasts and likely provide a significant proportion of sand-sized quartz, feldspar, and mica.

Grantmire paragenesis begins with deposition of sand- and gravel-sized clasts with iron-rich clay. The clays were oxidized at the surface or in the shallow subsurface early in the depositional history forming hematite grain rims. Calcite nodules with fine mosaic textures in siltstone, are linked to shallow groundwaters. A locally pervasive poikilotopic calcite cement was emplaced prior to significant burial. Calcite commonly partially replaces potassium feldspar grains, possibly around the same time interval or subsequently. Dissolution of some grains, clays and calcite cement post-dates consolidation and has generated secondary porosity.

The hydrocarbon potential of fault-bounded basins is characterized by abundant potential source rocks, and reservoir rocks, with short migration paths between source and reservoir rocks, and a widespread sealing sequence. The juxtaposition of dark lacustrine sediments and red coarser alluvial/fluvial sediments, confined in a localized structural basin and overlain by a regionally continuous Windsor Group with carbonates and evaporites, are all potentially favorable characteristics for the resource potential of the Horton Group.

Porosity and permeability tests from eight samples from PE 83-1 reveal poor to good reservoir quality. The average porosity is 9.6% and ranges from 4.2 to 15.7 % whereas the average permeability is 2.26 md and ranges from 0.06 – 7.72 md. Porosity is dominantly intergranular (secondary) and is largely ineffective because of variable amounts of detrital clay, authigenic minerals, carbonate cement, paleosol development, and irregular laminae of finer material..

Although no source rocks have been proven in the onshore area of Sydney, evidence of oil seeps in other parts of the Horton Group in the Maritimes Basin suggests potential hydrocarbon generation. Palynological samples of spores collected from onshore areas elsewhere in Cape Breton reveal Thermal Alteration Index (T.A.I) of 2 to 3-, which falls within the oil window (Hamblin, 1989a). Higher, more mature T.A.I values of 3 to 4- lie within the gas window, and are located close to basement blocks at sub-basin margins (Hamblin, 1989a). Vitrinite reflectance values range from 0.5-2.11%, which varies between the oil window, to overmature for oil generation but within the gas window (Hamblin, 1989a).

Sufficient trapping mechanisms are possible or have been identified in the Horton Group regionally to trap hydrocarbons. Fault-related and fold-related structural traps are concentrated near the footwall scarp margin of half-graben segments (Hamblin, 1989a). Stratigraphic traps may also occur throughout the fault-bounded half grabens, and are closely related to the structural evolution of the sub-basins.

FUTURE WORK

In the future to provide a better interpretation of the Grantmire Formation, it is important to log the second Point Edward drill core PE 84-1 to begin forming a basinal analysis. To improve facies descriptions, outcrop and a geophysical line should be studied in detail to describe sedimentary depositional features such as imbrication, dip angles, bedding, stratification, et cetera, which were obscured in core. More detail on the petrography is important to record in attempt to locate the source region(s) of the alluvial fans, and link them to older rocks in Cape Breton. It would also be interesting to extend the PE 83-1 core another few hundred meters to see if any Strathlorne-like rock types exist below. If the Grantmire has a similar depositional model as the Cabot and Ainslie Sub-basins, the potential for hydrocarbon generation greatly increases.

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APPENDIX A

Lithological Chart for DDH PE 83-1

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour (matrix)	Max. Clast Size (cm)	Degree of Sorting	Support Clast	Support Matrix	Sedimentary Structures	Other
0 – 2.28	2.28	NOT CORED, overburden								
2.28 – 4.49	2.21	Limestone	Sharp, erosional	Light grey, light brown					bedding 85°CA	
4.49 – 6.1	1.61	Sandstone	Sharp, erosional	Medium reddish brown to dark grey					Irregular laminations, bedding 85°CA	Calcareous
6.1 – 6.38	0.28	Limestone	Sharp	Light grey to white					Clay matrix at top, mottled, irregular styolitic/massive limestone	
6.38 – 7.3	0.92	Fine siltstone, coarse siltstone, sandstone	Sharp	Light/medium reddish brown, grey						Generally coarsens upward, mottled limestone at base, scattered irregular calcareous concretions, green silty reduction patches at top
7.3 – 7.52	0.22	Limestone	Sharp	Light grey brown						Dense, hard, crystalline, arenaceous
7.52 – 9.22	1.7	Coarse siltstone, sandstone	Sharp	Medium reddish brown		Moder-ate				Scattered irregular calcareous concretions, green reduction patches
9.22 – 11.08	1.86	FUS, conglomerate A fines into sandy siltstone	Sharp	Light/medium red	7.8	Moder-ate	✓		Irregular laminations, bedding 85°CA	Basal conglomerate
11.08 – 12.1	1.02	Sandy siltstone	Sharp	Medium reddish brown		Well			Bedding 85°CA	Minor calcareous concretions with green envelope
12.1 – 12.48	0.38	Limestone, minor interstratified fine siltstone	Sharp	Light grey, light reddish brown		Well			Pale red mottle and silty stringers	Large, blobular calcareous concretions, green reduction envelopes
12.48 – 16.98	4.5	Fine siltstone, interstratified coarse siltstone	Gradational	Medium reddish brown		Well				Calcareous concretions, green reduction envelopes
16.98 – 20.91	3.93	Fine siltstone	Gradational	Medium reddish brown		Well				Large, blobular, calcareous concretions, green reduction envelopes
20.91 – 24.06	3.15	Limestone (blobular), fine siltstone	Gradational	Light grey, medium reddish brown		Well				Lower bed increasingly abundant in calcareous concretions until solid, blobular limestone beds form Top red siltstone bed prominent with calcareous concretions
24.06 – 30.19	6.13	Interstratified fine siltstone, coarse siltstone B	Gradational	Medium reddish brown		Well			Dark grey, sheared shale bed @ 25.58m, bed 50cm	Calcareous concretions
30.19 - 31.85	1.66	Sandstone, minor interstratified conglomerate A	Sharp, erosional	Medium reddish brown	5.0	Moder-ate	✓			Minor calcareous concretions with green reduction envelopes
31.85 – 36.06	4.21	FUS, conglomerate A fines into fine siltstone	Gradational	Medium reddish brown	0.5	Moder-ate	✓			Calcareous concretions with reduction envelopes, dark green reduction patches
36.06 – 36.76	0.7	FUS, conglomerate B fines into conglomerate A	Sharp	Light/medium reddish brown		Moder-ate	✓			Minor green reduction patches, white calcite cement
36.76 – 38.01	1.25	Fine siltstone	Gradational	Medium reddish brown		Well				Calcareous concretions with reduction envelopes, green reduction patches

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour (matrix)	Max. Clast Size (cm)	Degree of Sorting	Support		Sedimentary Structures	Other
							Clast	Matrix		
38.01 – 41.13	3.12	FUS, conglomerate A fines into coarse siltstone	Sharp	Light/medium red	4.3	Moder-ate	✓		Laminations	Conglomerate A @ base of each cycle, minor green reduction patches, white calcite cement
41.13 – 52.3	11.17	Multiple FUS, conglomerate B @ base, fines into fine siltstone	Sharp, erosional	Medium/dark reddish brown	1.5	Moder-ate	✓		Black laminations	Calcareous concretions with and w/o reduction envelopes, green reduction patches
52.3 – 57.17	4.87	FUS, conglomerate B, sandstone, interstratified fine siltstone	Sharp	Light/medium reddish brown	8.1	Poor	✓			Local patches of white calcite cement, green reduction patches @ conglomerate A/ sandstone interface
57.17 – 60.18	3.01	Multiple FUS, sandstone fines into fine siltstone, interstratified coarse siltstone	Sharp	Medium reddish brown	0.8	Moder-ate	✓			Green reduction patches, calcareous concretions with green reduction envelopes
60.18 – 65.46	5.28	Sandstone, interstratified conglomerate A/B	Sharp	Light red	14	Very Poor	✓		Laminations, cross bedding, interstratified coarse siltstone with sandstone	15% clast conglomerate C size in conglomerate A/ sandy matrix, local patches of white calcite cement in conglomerate matrix
65.46 – 66.66	1.2	FUS, sandstone, fines into fine siltstone	Sharp	Medium reddish brown	4.0	Moder-ate	✓			Nodular limestone in green reduction envelopes
66.66 – 72.72	6.06	Multiple FUS, conglomerate C fines into sandstone	Sharp, erosional	Medium reddish brown	18	Very Poor	✓			Cycles 30-100 cm thick
72.72 – 73.76	1.04	Fine siltstone, interstratified conglomerate A	Sharp, erosional	Medium reddish brown	3.7	Poor	✓			Minor calcite cement in matrix
73.76 – 75.46	1.7	Fine siltstone, interstratified conglomerate A/B	Gradational	Dark reddish brown	5.6	Poor	✓			Dark green reduction patches, nodular limestone
75.46 – 79.34	3.88	Conglomerate A	Sharp	Dark reddish brown	3.2	Poor	✓			20% conglomerate B sized clasts
79.34 – 80.85	1.51	Fine siltstone, interstratified conglomerate A, conglomerate B	Sharp, erosional	Dark reddish brown	7.0	Poor	✓		Laminations	Dark green reduction patches, nodular limestone
80.85 – 81.79	0.94	Conglomerate A	Sharp	Medium red	2.9	Poor	✓			
81.79 – 83.43	1.64	FUS, sandstone, fines into fine siltstone	Sharp	Medium reddish brown	1.9	Moder-ate	✓			Dark green reduction patches, nodular limestone
83.43 – 87.52	4.09	Multiple FUS, conglomerate B fines into coarse siltstone	Sharp, erosional	Medium reddish brown	3.0	Poor	✓		Interstratified coarse siltstone with coarse sandstone/conglomerate A	Cycles 30-60 cm, sharp basal contacts between sequences
87.52 – 99.8	12.28	Fine siltstone, interstratified sandstone, conglomerate A	Sharp	Medium reddish brown	3.7	Poor	✓			<20% clasts, minor interbeds
99.8 – 155.25	55.45	Multiple FUS, conglomerate C fines into sandstone	Sharp	Light/medium red	10	Poor	✓		Coarse siltstone interstratified with sandstone	Cycles 30-100 cm thick, green reduction patches, nodular limestone with green envelopes
155.25 – 173.77	18.52	Multiple FUS, conglomerate B fines into sandstone	Sharp	Light/medium red	6.7	Poor	✓		Coarse siltstone interstratified with sandstone	Green reduction patches, nodular limestone with green envelopes
173.77 – 174.78	1.01	Sandstone, interstratified coarse siltstone B	Sharp	Light/medium red		Moder-ate	✓		Cross laminations	

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour (matrix)	Max. Clast Size (cm)	Degree of Sorting	Support		Sedimentary Structures	Other
							Clast	Matrix		
174.78 - 193.18	18.4	Multiple FUS, interstratified conglomerate A, conglomerate B, fines into sandstone	Sharp	Medium reddish brown	5.8	Poor	✓			Cycles 30-100 cm thick, green reduction patches, calcareous concretions with green envelopes
193.18 – 193.48	0.3	Limestone, interstratified coarse siltstone	Gradational	White/ green		Moder-ate	✓			Limestone nodules, green siltstone
193.48 – 194.15	0.67	Sandstone	Sharp	Medium reddish brown	1.2	Poor	✓			
194.15 - 194.4	0.25	Coarse siltstone, interstratified sandstone	Sharp	Medium reddish brown	0.1	Poor		✓		Green reduction envelopes, calcareous concretions
194.4 - 197.17	2.77	Conglomerate A, interstratified coarse siltstone	Gradational	Medium reddish brown	3.9	Poor	✓		Laminations, average dip 24° CA	Localised white calcite cement
197.17- 197.33	0.16	Fine siltstone, interstratified coarse siltstone	Gradational	Medium reddish brown	0.1	Poor	✓			Green reduction envelopes, calcareous concretions
197.33 - 197.69	0.36	FUS, conglomerate A, coarse siltstone	Sharp	Medium reddish brown	3.7	Poor	✓			
197.69 - 198.63	0.94	Multiple FUS, conglomerate B fines into coarse siltstone	Sharp	Medium reddish brown	4.3	Poor	✓		Parallel laminations	FUS cycles ≤20 cm
198.63 - 199.21	0.58	FUS, conglomerate A fines into sandstone	Sharp	Medium reddish brown	2.1	Poor	✓			
199.21 - 200.19	0.98	FUS, conglomerate B fines into sandstone	Sharp	Light/medium reddish brown	2.5	Poor	✓		Laminated sandstone	White calcite cement
200.19 - 200.42	0.23	Interstratified conglomerate A, fine siltstone	Sharp	Medium reddish brown	0.5	Poor	✓		Interbedded shale <0.5cm	Green reduction envelopes, calcareous concretions
200.42 - 201.22	0.8	FUS, conglomerate A fines into sandstone		Medium reddish brown	1.2	Moder-ate	✓		Laminations	
201.22 - 201.4	0.18	Interstratified sandstone, coarse siltstone, fine siltstone		Grey, medium reddish brown	0.1	Moder-ate	✓			Grey sandstone/siltstone grades into red siltstone, calcareous concretions
201.4 - 202.9	1.5	FUS, conglomerate C fines coarse siltstone	Sharp	Medium reddish brown	4.0	Poor	✓			
202.9 - 203.76	0.86	FUS, conglomerate B fines into coarse siltstone	Sharp	Medium reddish brown	5.1	Poor	✓			
203.76 - 204.41	0.65	FUS, conglomerate B fines into siltstone	Sharp	Medium reddish brown	3.2	Poor	✓			
204.41 - 205.16	0.6	FUS, conglomerate A fines into fine siltstone	Sharp	Medium reddish brown	0.8	Poor	✓			Poorly developed sequence, calcareous concretions
205.16 - 205.91	0.75	FUS, conglomerate B fines into conglomerate A	Sharp erosional	Medium reddish brown	2.8	Poor	✓			
205.91 - 206.58	0.67	FUS, conglomerate C fines into coarse siltstone	Sharp erosional	Medium reddish brown	4.2	Very poor	✓			
206.58 – 207.69	1.11	FUS, conglomerate A fines into sandstone	Sharp erosional	Medium reddish brown	0.3	Poor	✓			Cycles 20-30 cm each
207.69 - 208.04	0.35	FUS, conglomerate C fines into sandstone	Sharp erosional	Medium reddish brown	2.8	Poor	✓		Interlaminated fine sandstone and coarse siltstone	
208.04 - 208.27	0.23	FUS, conglomerate B fines into sandstone	Sharp	Medium reddish brown, light reddish brown	1.1	Poor	✓			Fines into medium grained sandstone, white calcite rich cement

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support		Sedimentary Structures	Other
							Clast	Matrix		
208.27 - 209.24	0.97	Fine siltstone	Sharp	Medium reddish brown	0.5	Poor		✓		Calcareous concretions
209.24 - 209.67	0.43	CUS, coarse siltstone coarsens into conglomerate A	Sharp	Medium reddish brown, white	3.0	Poor	✓			
209.67 - 210.56	0.89	Conglomerate A, interstratified sandstone, coarse siltstone	Gradational	Light reddish brown	1.9	Poor	✓		Well developed laminations	White calcite cement in conglomerate matrix, scattered green reduction envelopes, calcareous concretions
210.56 - 212.55	1.99	Conglomerate A, interstratified sandy siltstone	Gradational	Light reddish brown	2.0	Poor	✓			White calcite cement in conglomerate matrix, scattered green reduction envelopes, calcareous concretions
212.55 - 217.47	4.92	Multiple FUS, conglomerate A fines into coarse siltstone	Sharp	Medium reddish brown	1.0	Poor	✓			FUS sequences ~1.5 m, scattered green reduction envelopes, calcareous concretions
217.47 - 218.56	1.09	Sandy siltstone	Sharp	Medium reddish brown	2.0	Moder-ate	✓		One 5cm bed of conglomerate B	Green reduction patches
218.56 - 219.7	1.14	Conglomerate B, interstratified coarse siltstone	Sharp	Medium reddish brown	4.2	Very Poor	✓			Calcareous concretions
219.7 - 220.47	0.77	Fine siltstone, interstratified sandy siltstone	Sharp	Medium reddish brown	0.3	Poor		✓	One 8cm horizon of conglomerate A	Calcareous concretions
220.47 - 222.36	1.89	Conglomerate B	Sharp	Light reddish brown	3.2	Poor	✓			White calcite cement in matrix
222.36 - 222.76	0.4	Conglomerate A	Sharp	Light reddish brown	0.2	Poor	✓			White calcite cement in matrix
222.76 - 226.4	3.64	Multiple FUS, conglomerate A fines into coarse siltstone	Sharp	Medium reddish brown	1.0	Poor	✓			Scattered green reduction envelopes, calcareous concretions
226.4 - 227.1	0.7	Coarse siltstone, interstratified sandstone	Sharp	Medium reddish brown		Well				Calcareous concretions, white calcite cement in coarse siltstone
227.1 - 229.24	2.14	Fine siltstone, interstratified sandy siltstone	Sharp	Medium reddish brown	0.3	Moder-ate				<5% floating clasts, white calcite cement in sandstone matrix, calcareous concretions
229.24 - 230.42	1.18	Conglomerate A	Sharp	Medium reddish brown	0.5	Well		✓		Silty matrix
230.42 - 232.8	2.38	Sandy siltstone	Gradational	Medium reddish brown		Well			High angled fractures (~80°), laminations MO-98-078	Calcareous concretions
232.8 – 234.02	1.22	Sandy siltstone	Sharp	Medium reddish brown		Well			MO-98-076, medium angled fractures (40-60°)	Local green reduction layers/beds
234.02 - 235.07	1.05	Coarse siltstone	Sharp, erosional	Medium reddish brown	0.1	Well			Laminations	White calcite clasts floating in silty matrix
235.07 - 237.14	2.07	Fine siltstone	Gradational	Medium reddish brown		Well				
237.14 - 237.29	0.15	Sandstone	Sharp	Medium reddish brown		Well				Local green reduction layers/beds, reduction envelopes

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour (matrix)	Max. Clast Size (cm)	Degree of Sorting	Support		Sedimentary Structures	Other
							Clast	Matrix		
237.29 - 237.91	0.62	Fine siltstone, interstratified coarse siltstone	Sharp	Medium reddish brown		Well			Convoluted beds and laminations	Silty matrix
237.91 - 238.3	0.39	Conglomerate A	Sharp	Medium reddish brown	0.3	Poor		✓	MO-98-075	
238.3 - 238.66	0.36	Conglomerate A	Sharp	Medium/light reddish brown	5.0	Poor	✓		Interstratified red matrix and white calcite cement	
238.66 - 238.85	0.19	Sandstone	Sharp	Medium reddish brown		Well				Green reduction envelopes
238.85 - 239.1	0.25	Conglomerate A	Sharp, erosional	Medium reddish brown	4.8	Poor	✓			
239.1 - 240.17	1.07	Fine siltstone	Sharp	Medium reddish brown		Well				Green reduction envelopes
240.17 - 242.07	1.9	Fine siltstone, interstratified shale	Sharp	Medium reddish brown, dark grey		Moder-ate			Dipping beds, 16°CA, MO-98-070	
242.07 - 254.37	12.3	Shale, limestone	Sharp	Medium/dark grey		Well			Dipping beds, 14°CA, high angled shears, laminations, cross laminations,	Sulphides, calcareous nodules **Beginning of BASE OF WINDSOR**
254.37 - 255.08	0.71	Fine siltstone	Sharp	Medium reddish brown		Very Well				Calcareous concretions
255.08 - 258.71	3.63	Shale	Sharp	Medium/dark grey		Very Well			Multiple high angle shears, laminations	**Basal contact of BASE OF WINDSOR**
258.71 - 259.23	0.52	Fine siltstone	Sharp	Medium reddish brown		Very Well				Calcareous concretions **Top of the GRANTMIRE FORMATION**
259.23 - 259.29	0.07	Limestone	Sharp	Light grey		Very Well				
259.29 - 260.17	0.88	Conglomerate A	Sharp	Medium reddish brown	1.0	Well		✓	<5% clasts, floating in matrix	Green reduction beds, reduction envelopes
260.17 - 260.38	0.21	Conglomerate B	Sharp	Light reddish brown	7.2	Poor	✓			White calcite cement
260.38 - 260.61	0.23	Conglomerate A	Gradational	Medium reddish brown	0.8	Poor		✓	<10% floating clasts in silty matrix	
260.61 - 261	0.39	Fine siltstone	Sharp	Medium reddish brown		Very Well			Laminations	
261 - 261.24	0.24	Fine siltstone, interbedded sandstone	Sharp	Medium reddish brown		Moder-ate				
261.24 - 261.4	0.16	Sandstone	Sharp	Medium reddish brown		Very Well			Laminations	
261.4 - 261.96	0.56	CUS, coarse siltstone coarsens into conglomerate A	Sharp	Medium reddish brown	9.2	Poor		✓	<5% floating clasts in silty matrix	Coarsens from <0.5cm clasts into ~4cm clasts
261.96 - 262.44	0.48	FUS, conglomerate C fines into conglomerate A	Sharp	Medium reddish brown	5.8	Poor	✓			
262.44 - 263.73	1.29	Conglomerate A	Sharp	Medium reddish brown	2.1	Poor	✓			
263.73 - 264.3	0.57	FUS, conglomerate A, fine siltstone	Sharp	Medium reddish brown	1.4	Poor	✓			Green reduction envelopes

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support		Sedimentary Structures	Other
							Clast	Matrix		
264.3 - 264.44	0.14	Coarse siltstone	Sharp	Medium reddish brown	0.5	Poor				Green reduction layers
264.44 - 265.59	0.15	Conglomerate A	Sharp	Medium reddish brown	1.5	Moder-ate	✓			Green reduction envelopes
265.59 - 267.54	1.95	Multiple FUS, conglomerate B fines into coarse siltstone	Sharp	Medium reddish brown	1.9	Poor	✓			FUS sequences ~1.0m
267.54 - 267.64	0.1	Fine siltstone	Gradational	Medium reddish brown		Very Well				
267.64 - 268.3	0.66	Conglomerate A, interstratified conglomerate B	Sharp	Medium reddish brown	2.0	Poor	✓			
268.3 - 268.99	0.69	FUS, conglomerate B fines into coarse siltstone	Sharp	Medium reddish brown	1.8	Poor	✓			
268.99 - 269.92	0.93	FUS, conglomerate B fines into conglomerate A	Sharp	Medium reddish brown	2.5	Poor	✓			
269.92 - 270.97	1.05	Fine siltstone, interstratified sandstone	Sharp	Medium reddish brown		Well				Green reduction envelopes, calcareous concretions
270.97 - 271.88	0.91	Conglomerate A	Sharp	Medium reddish brown	3.1	Poor	✓			
271.88 - 273.29	1.41	Sandstone	Sharp	Medium reddish brown	0.9	Moder-ate				
273.29 - 274.84	1.55	Conglomerate A	Sharp, erosional	Medium reddish brown	0.8	Poor		✓		<2% green reduction envelopes, silty matrix
274.84 - 278.24	3.4	Multiple FUS, conglomerate B fines into coarse siltstone	Sharp	Medium reddish brown	5.2	Poor	✓		Laminations	FUS sequences ~60cm each
278.24 - 279.04	0.8	Fine siltstone, interstratified sandstone	Sharp	Medium reddish brown	0.5	Moder-ate				Green reduction envelopes, calcareous concretions
279.04 - 279.58	0.54	Conglomerate C	Sharp	Medium reddish hrown	8.3	Poor	✓			
279.58 - 279.8	0.22	Fine siltstone, interstratified conglomerate B	Sharp	Medium reddish brown	1.8	Poor	✓			Green reduction envelopes, calcareous concretions
279.8 - 280.33	0.53	Conglomerate A	Sharp	Medium reddish brown	7.0	Poor	✓			
280.33 - 281	0.67	Fine siltstone, interstratified conglomerate A	Sharp	Medium reddish brown	2.0	Poor	✓		Cross laminations	
281 - 282.65	1.65	Coarse siltstone	Erosional (gradational?)	Medium reddish brown		Well	✓		MO-98-061	Green reduction envelopes, calcareous concretions
282.65 - 283.02	0.37	Fine siltstone, interstratified conglomerate A	Sharp	Medium reddish brown	1.1	Poor	✓			
283.02 - 285	1.98	Fine siltstone, interstratified conglomerate A	Sharp	Medium reddish brown	0.4	Poor	✓			Green reduction envelopes, calcareous concretions
285 - 285.57	0.57	FUS, conglomerate B fines into conglomerate A	Sharp	Medium reddish brown	1.5	Poor	✓			
285.57-286	0.43	Conglomerate A	Sharp	Medium reddish brown	0.8	Moder-ate	✓			
286 - 286.57	0.57	Coarse siltstone, interstratified conglomerate A	Sharp	Medium reddish brown	2.1	Moder-ate	✓			
286.57 - 286.88	0.31	Coarse siltstone	Sharp	Green, medium reddish brown		Well				Red silty patches

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support		Sedimentary Structures	Other
							Clast	Matrix		
286.88 - 287.24	0.36	Conglomerate B, interstratified coarse siltstone	Sharp	Medium reddish brown	1.4	Poor	✓			
287.24 - 287.7	0.46	Conglomerate A	Sharp	Medium reddish brown	3.0	Poor		✓	<10% clasts floating in silty matrix	Green reduction envelopes, calcareous concretions
287.7 - 288.15	0.45	FUS, conglomerate B fines into sandstone	Sharp	Medium reddish brown	4.6	Poor	✓			
288.15 - 289.05	0.9	FUS, conglomerate B fines into conglomerate A	Sharp	Medium reddish brown	2.5	Poor	✓			FUS not well developed
289.05 - 291.12	2.07	Conglomerate C, interstratified coarse siltstone	Sharp	Medium reddish brown	4.7	Poor	✓			Green reduction patches, silty matrix
291.12 - 292.76	1.64	Conglomerate C	Sharp	Medium reddish brown	4.5	Poor	✓			
292.76 - 294.08	1.32	FUS, conglomerate C fines into sandstone	Sharp	Medium reddish brown	5.0	Poor	✓			
294.08 - 295.45	1.37	FUS, conglomerate C fines into sandstone	Sharp	Medium reddish brown	4.6	Poor	✓			25% siltstone matrix
295.45 - 296.31	0.86	Conglomerate C	Gradational	Medium reddish brown	17.4	Very Poor	✓			
296.31 - 297.03	0.72	Conglomerate B	Gradational	Medium reddish brown	4.2	Poor	✓			
297.03 – 297.75	0.72	Conglomerate B	Gradational	Medium reddish brown	3.0	Poor	✓			Red silty matrix
297.75 – 300.5	2.75	Conglomerate C	Gradational	Medium red	6.4	Poor	✓			Average clast size <4cm, reduction envelopes
300.5 – 302.06	1.56	Conglomerate B/C	Gradational	Medium red	13.8	Very Poor	✓			Calcareous
302.06 – 302.45	0.39	Conglomerate C	Gradational	Medium red	3.8	Very Poor	✓			White calcite cement, sub-rounded clasts
302.45 – 304.2	1.75	Conglomerate B	Gradational	Medium red	4.2	Poor	✓		MO-98-060	Green reduction patches
304.2 – 306.1	1.9	FUS, conglomerate C fines into conglomerate A	Sharp	Medium red	4.9	Poor	✓			Red siltstone matrix, green reduction patches
306.1 – 306.38	0.28	Conglomerate A	Sharp	Medium reddish brown	0.5	Poor	✓			Green reduction patches
306.38 – 307.3	0.92	Conglomerate A/B/C	Sharp	Medium red	5.2	Very Poor	✓			
307.3 – 310.2	2.9	Multiple FUS, conglomerate C fines into conglomerate A	Sharp	Medium red	12.1	Very Poor	✓			Four FUS cycles , cycles ~50-100cm each
310.2 – 315.45	5.25	FUS, conglomerate C fines into sandstone	Sharp	Medium red	17.7	Poor	✓			Well developed FUS sequence, matrix and clasts progressively fines upward
315.45 – 315.9	0.45	Conglomerate A	Sharp	Medium red	0.6	Poor	✓			
315.9 – 319.25	3.35	Conglomerate B/C	Sharp	Medium red	9.2	Very Poor	✓			
319.25 – 325.3	6.05	Multiple FUS, conglomerate C fines into conglomerate A	Sharp	Medium red	6.2	Very Poor	✓			Cycles 80-100 cm

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support		Sedimentary Structures	Other
							Clast	Matrix		
325.3 – 333.22	7.92	Conglomerate A, interstratified conglomerate C	Sharp, erosional	Medium red	10.5	Very Poor	✓			~6 beds of interstratified conglomerate, average thickness 1.8m
333.22 – 333.29	0.06	Sandstone	Sharp	Light/medium red	0.3	Poor	✓			Calcareous
333.29 – 333.38	0.09	Coarse siltstone	Sharp	Medium reddish brown	2.0	Poor				Clasts sub-rounded to sub-angular
333.38 – 333.59	0.21	Conglomerate A	Sharp	Medium red	2.2	Poor	✓			
333.59 – 335.06	1.47	FUS, conglomerate C fines into conglomerate A	Gradational	Medium red	8.1	Very Poor	✓			
335.06 – 343.78	8.72	Conglomerate A	Sharp	Medium red	7.9	Very Poor	✓		MO-98-059	
343.78 – 343.89	0.11	Coarse siltstone	Sharp	Medium reddish brown		Well				Green reduction envelopes, calcareous concretions
343.89 – 344.17	0.28	Conglomerate A	Sharp	Medium red	5.4	Poor	✓			
344.17 – 344.39	0.22	Conglomerate B	Sharp	Medium red	1.5	Poor	✓			Sub-rounded clasts
344.39 – 344.7	0.41	Conglomerate A	Sharp	Medium red	1.8	Poor	✓		One 11.5 cm bed of conglomerate C at bottom	
344.7 – 344.87	0.17	Conglomerate A	Sharp	Medium red	3.7	Poor	✓			
344.87 – 345.31	0.44	Conglomerate B	Sharp	Medium red	3.1	Poor	✓			
345.31 – 346.5	1.19	FUS, conglomerate C fines into coarse siltstone	Sharp	Medium red	4.3	Very Poor	✓			
346.5 - 348	1.5	Conglomerate A	Sharp	Medium red	4.6	Very Poor	✓			
348 – 348.66	0.66	CUS, conglomerate A coarsens into conglomerate B/C	Sharp	Medium red	3.0	Poor	✓			
348.66 – 349.04	0.38	Conglomerate A	Sharp	Light red	0.5	Poor	✓			White calcite cement
349.04 – 349.73	0.69	Conglomerate C	Sharp	Medium red	6.8	Poor	✓			~30% conglomerate clasts in very coarse sandstone matrix
349.73 – 350.95	1.22	Conglomerate B, coarse siltstone	Sharp	Medium reddish brown	1.5	Moder-ate		✓	Laminations, <20% conglomerate clasts	Green reduction envelopes, limestone nodules
350.95 – 351.92	0.97	Conglomerate B	Sharp	Medium red	5.9	Poor	✓			
351.92 – 352.85	0.93	Conglomerate A, interstratified sandstone	Sharp	Medium red	3.8	Poor	✓			
352.85 – 354.39	1.54	FUS, conglomerate B fines into sandstone	Sharp	Medium red	5.2	Poor	✓			White calcite cement
354.39 - 355	0.41	FUS, conglomerate C fines into sandstone	Sharp	Medium red	8.5	Very Poor	✓			Poorly developed sequence
355 – 355.35	0.35	Conglomerate A	Sharp	Medium red	5.0	Poor	✓			

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support Clast	Support Matrix	Sedimentary Structures	Other
355.35 – 356.16	0.81	FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	5.4	Poor	✓			
356.16 – 356.3	0.14	Conglomerate A	Sharp	Medium red	0.4	Poor		✓	MO-98-058, <10% floating clasts	Green reduction layer, calcareous, sandy to silty matrix
356.3 – 356.59	0.29	Coarse siltstone	Sharp	Medium red	0.7	Poor				
356.59 – 358.31	1.72	FUS, conglomerate A fines into sandstone	Gradational	Medium red	4.9	Poor	✓		Gradual shift into a more silty matrix	
358.31 – 358.71	0.40	Coarse siltstone	Sharp	Medium red						Green reduction envelopes, calcareous concretions <2.5 cm
358.71 - 360	1.29	Conglomerate A/B	Sharp	Medium red	4.8	Very Poor	✓			
360 – 366.27	6.27	Multiple FUS, conglomerate B fines into sandstone	Sharp, erosional	Medium red	14.7	Very Poor	✓			Poorly developed FUS, 2 cycles, bottom 1.5 m, upper 4.77 m
366.27 – 367.74	1.03	Coarse siltstone, interstratified conglomerate A/B	Sharp	Medium reddish brown	0.2	Poor	✓		Minor laminations	Interbedded conglomerate A/B, ~10 cm thick each
367.74 – 368.96	1.22	Conglomerate B	Sharp	Medium red	8.5	Very Poor	✓			
368.96 – 369.7	0.74	Conglomerate A	Sharp	Medium reddish brown	3.9	Poor		✓	Floating conglomerate clasts, MO-98-057	
369.7 – 371.5	0.18	Conglomerate A	Sharp	Medium red	8.7	Very Poor	✓			
371.5 – 376.76	5.26	Multiple FUS, conglomerate A fines into coarse siltstone	Sharp	Medium red	10.2	Very Poor	✓			Cycles ~2 m each, boulder clasts present, silty matrix
376.76 – 377.7	0.94	Coarse siltstone, interstratified conglomerate B	Sharp	Medium reddish brown	1.3	Poor	✓		2 distinct conglomerate B beds ~10 cm each	Top 15 cm green reduction patch, calcareous concretions
377.7 – 381.85	4.15	Conglomerate A/B	Sharp	Medium red	6.4	Poor	✓			
381.85 – 389.66	7.81	Conglomerate A	Sharp	Medium red	2.1	Poor	✓			
389.66 – 392.08	2.42	Multiple FUS, conglomerate B fines into sandstone	Sharp	Medium red	6.9	Very Poor	✓			Poorly defined FUS, cycles 30-80 cm each
392.08 – 393.03	0.95	Conglomerate B	Sharp	Medium red	4.7	Poor	✓		One 5cm bed of coarse siltstone	
393.03 – 394.78	0.75	Conglomerate B, interstratified conglomerate A and sandstone	Sharp	Medium red	5.5	Poor	✓			
394.78 – 395.1	0.32	Conglomerate C	Sharp	Medium red	5.4	Poor	✓			Sub-rounded clasts, ~30% silty matrix
395.1 – 395.36	0.26	Conglomerate A	Sharp	Medium red	1.5	Moder-ate	✓			
395.36 – 397.13	1.77	CUS, fine siltstone coarsens into conglomerate B	Sharp	Medium reddish brown to medium red	2.2	Poor	✓			
397.13 – 397.7	0.57	FUS, conglomerate B fines into sandstone	Sharp	Medium red	3.0	Moder-ate	✓			Poorly defined FUS, scattered <3 cm clasts in sandstone

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support		Sedimentary Structures	Other
							Clast	Matrix		
397.7 – 398.08	0.38	Conglomerate B, interstratified coarse siltstone	Sharp	Medium red/ medium reddish brown	2.5	Poor	✓		2 beds ~5cm each of conglomerate	
398.08 - 398.46	0.38	Coarse siltstone	Sharp	Medium reddish brown	05					
398.46 – 398.85	0.39	Conglomerate A/B	Sharp	Medium red	4.8	Poor	✓			Interbedded conglomerate A/B
398.85 - 399	0.15	Coarse siltstone	Sharp	Medium reddish brown	0.4				Laminations	Green reduction envelopes, calcareous concretions
399 – 399.3	0.3	Conglomerate B	Sharp, erosional	Medium red	3.5	Poor	✓			
399.3 – 399.53	0.23	Coarse siltstone	Sharp	Medium reddish brown	0.4				Laminations	Green reduction envelopes, calcareous concretions
399.53 – 399.82	0.29	Conglomerate B	Sharp, erosional	Medium red	3.8	Poor	✓			
399.82 – 400.11	0.29	Coarse siltstone	Sharp	Medium reddish brown	1.2				Laminations, MO-98-055	Green reduction envelopes, calcareous concretions
400.11 – 400.3	0.19	CUS, coarse siltstone coarsens into conglomerate A	Sharp	Medium red	0.5	Poor	✓			
400.3 – 401.04	0.7	CUS, siltstone coarsens into conglomerate B	Sharp, erosional	Medium red/ medium reddish brown	4.0	Poor	✓		Conglomerates coarsens upward by bed	2 beds of conglomerates ~3cm each
401.04 – 401.16	0.12	Conglomerate B	Sharp	Medium red	2.2	Poor	✓			White calcite cement
401.16 – 402.16	1.0	Conglomerate C	Sharp	Medium red	9.6	Very Poor	✓			
402.16 – 402.34	0.18	Sandstone	Sharp	Medium red	0.2	Moder-ate	✓			
402.34 – 402.9	0.56	FUS, conglomerate B fines into sandstone	Sharp	Medium red	1.0	Poor	✓			
402.9 – 403.17	0.27	Conglomerate A	Sharp	Medium reddish brown	3.3	Poor		✓		Average clasts size 1-3 mm, odd clasts 2-3.3 cm, sandy siltstone matrix
403.17 – 405.03	1.86	Conglomerate A	Sharp, erosional	Medium red	8.0	Poor	✓			White calcite cement
405.03 – 405.83	0.80	Conglomerate C	Sharp	Medium red	17.0	Very Poor	✓			
405.83 – 406.3	0.47	Coarse siltstone	Sharp	Medium reddish brown				✓	Floating conglomerate clasts ≤1 cm	White calcite cement
406.3 – 407.2	0.99	Conglomerate B	Sharp	Medium red	6.6	Poor	✓			
407.2 – 407.32	0.12	FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	1.8	Moder-ate	✓			
407.32 – 408.33	1.01	Sandy siltstone	Sharp, erosional	Medium reddish brown					Laminations	Green reduction envelopes, calcareous concretions
408.33 – 409.3	0.97	Conglomerate A, interstratified coarse siltstone	Sharp	Medium red/ medium reddish brown	8.5	Very Poor	✓			
409.3- 410.44	1.14	FUS, conglomerate C fines into conglomerate A	Sharp	Light/medium red	8.2	Very Poor	✓			White calcite cement

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support		Sedimentary Structures	Other
							Clast	Matrix		
410.44 – 410.54	0.10	Fine siltstone	Sharp	Medium reddish brown						
410.54 – 411.51	0.97	FUS, conglomerate C fines into conglomerate A	Sharp	Light/medium red	21.5	Very Poor	✓		MO-98-053	White calcite cement, boulder clasts
411.51 – 411.64	0.13	Fine siltstone	Sharp	Medium reddish brown						
411.64 – 411.83	0.19	Conglomerate B, interstratified fine siltstone	Sharp	Medium red/ medium reddish brown	1.2	Poor	✓			45% clasts, 55% matrix
411.83 – 412.52	0.99	Sandy siltstone	Sharp	Medium reddish brown	0.2	Well	✓		Laminated siltstone, conglomerate beds dipping @ 9°CA	
412.52 – 415.3	2.78	Multiple FUS, conglomerate C fines into conglomerate A, interstratified coarse siltstone	Sharp	Light/medium red, medium reddish brown	6.1	Poor	✓		Several interbeds of siltstone 5cm each	Poorly defined FUS, cycles ~150 cm each, green reduction patches in siltstone, white calcite cement in conglomerate
415.3 – 415.42	0.12	Conglomerate A	Sharp	Medium red	0.3	Moder-ate	✓		<5% clasts in sandy matrix	
415.42 – 416.28	0.86	Conglomerate A, interstratified sandstone	Sharp	Medium red	6.1	Poor	✓		Interbeds of sandstone have no clasts	
416.28 – 416.4	0.12	Fine siltstone	Sharp	Medium reddish brown						
416.4 – 417.63	1.23	Conglomerate B	Sharp	Medium red	8.8	Poor	✓			
417.63 – 418.16	0.53	Conglomerate B	Sharp	Medium red	0.8	Moder-ate	✓		1 bed of siltstone B with reduction patch and calcareous concretions @ bottom 5cm	Conglomerate fairly equigranular (~0.5cm clasts)
418.16 - 419	0.74	Conglomerate B, interstratified sandstone	Sharp	Medium red	9.8	Very Poor	✓			
419 – 421.3	2.3	Multiple FUS, conglomerate B fines into sandstone	Sharp	Medium red	10.8	Very Poor	✓			Poorly defined FUS, cycles 80-130 cm each
421.3 – 422.49	1.19	FUS, conglomerate C fines into conglomerate A	Sharp	Medium red	11.2	Poor	✓			
422.49 – 424.38	1.89	Conglomerate A	Gradational	Medium red	11.5	Very Poor	✓			Matrix increases upwards, clast abundance decreases
424.38 – 424.49	0.11	Fine siltstone	Sharp	Medium reddish brown						
424.49 – 425.9	1.41	Conglomerate B	Sharp	Medium red	4.6	Poor	✓			
425.9 – 426.73	0.83	FUS, conglomerate C fines into conglomerate A	Sharp	Medium red	2.8	Poor	✓			
426.73 – 427.3	0.57	Coarse siltstone	Sharp	Medium reddish brown	0.2					Green reduction envelopes, calcareous concretions
427.3 – 428.1	0.80	Conglomerate A, interstratified sandstone	Sharp	Medium red	8.8	Very Poor	✓			
428.1 – 428.63	0.53	Conglomerate A	Sharp	Medium red	5.4	Poor	✓			

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support Clast	Support Matrix	Sedimentary Structures	Other
428.63 – 431.98	3.35	Conglomerate B	Sharp	Medium red	9.2	Very Poor	✓			
431.98 – 432.11	0.13	Sandstone	Sharp	Medium red		Well	✓			
432.11 – 434.41	2.30	Conglomerate B	Sharp	Medium red	6.3	Poor	✓			
434.41 – 434.53	0.12	Sandstone	Sharp	Medium red		Well	✓			Clasts roughly equigranular
434.53 – 434.85	0.32	Conglomerate C	Sharp	Medium red	6.4	Poor	✓			Sub-rounded clasts
434.85 – 435.95	2.10	Conglomerate A	Sharp	Medium reddish brown	2.7	Moder-ate		✓	Clasts floating in sandy to silty matrix	Green reduction patches
435.95 – 437.19	1.24	Conglomerate B/C	Sharp	Medium red	4.3	Very Poor	✓			~25% red silty matrix, 40% conglomerate C, 35% conglomerate B
437.19 – 438.6	1.41	Conglomerate A, interstratified coarse siltstone	Sharp	Medium red/ reddish brown	4.8	Poor	✓			
438.6 – 439.2	0.60	FUS, conglomerate A fines into coarse siltstone	Sharp, erosional	Medium red/ reddish brown	5.0	Poor	✓			
439.2 – 439.3	0.10	Conglomerate A	Sharp	Medium reddish brown	0.1			✓	20% floating clasts	Green reduction patches
439.3 – 439.78	0.48	Conglomerate A/B	Gradational	Medium red	1.1	Moder-ate	✓			
439.78 – 440.35	0.57	Conglomerate B	Gradational	Medium red	5.3	Poor	✓			20% red silty matrix
440.35 – 440.67	0.32	Conglomerate A/B	Gradational	Medium red	1.2	Moder-ate	✓			
440.67 – 441.04	0.37	Conglomerate A	Gradational	Medium red	0.3	Poor	✓			
441.04 – 441.4	0.36	Conglomerate B	Gradational	Medium red	8.0	Very Poor	✓		MO-98-052	Bottom 1 cm green reduction patch
441.4 – 441.7	0.30	FUS, conglomerate B fines into sandstone	Sharp	Light/ medium red	5.2	Poor	✓			White calcite cement, <5% matrix
441.7 - 442	0.30	Conglomerate A	Sharp	Medium red	3.2	Poor	✓			
442 – 445.87	3.87	Multiple FUS, conglomerate B fines into sandstone	Sharp, erosional	Medium red	8.6	Very Poor	✓		MO-98-051	White calcite cement, cycles 20-90 cm each
445.87 – 446.02	0.15	Sandy siltstone	Sharp	Medium reddish brown	0.1					
446.02 – 446.27	0.25	Conglomerate A/B	Gradational	Medium red	8.7	Very Poor	✓			
446.27 – 447.12	0.85	Conglomerate B	Sharp	Medium red	4.0	Poor	✓		MO-98-050	
447.12 – 447.88	0.43	FUS, conglomerate B fines into sandstone	Sharp	Medium red	3.2	Poor	✓			
447.88 – 448.12	0.33	Conglomerate A/B, interstratified sandy siltstone	Sharp	Medium red/ reddish brown	1.8	Poor	✓			
448.12 – 448.34	0.22	Conglomerate A	Sharp	Medium reddish brown				✓	20% floating clasts	

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support Matrix	Support Clast	Sedimentary Structures	Other
448.34 – 449.06	0.72	Conglomerate C	Sharp	Medium red	12.8	Very Poor	✓			Silty matrix
449.06 – 449.13	0.07	Conglomerate A	Sharp	Medium reddish brown				✓	25-30% floating conglomerate clasts	
449.13 – 449.88	0.75	FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	6.3	Very Poor	✓			Silty matrix
449.88 – 451.5	1.62	FUS, conglomerate B fines into sandstone	Sharp	Medium red	2.5	Poor	✓			Very coarse sandy matrix
451.5 – 451.63	0.13	Sandy siltstone	Sharp	Medium reddish brown					Interlaminated sandstone	
451.63 – 451.7	0.07	Coarse siltstone	Sharp	Medium reddish brown						Green reduction patches, calcareous concretions
451.7 – 453.19	1.49	FUS, conglomerate B fines into sandstone	Sharp	Medium red	4.3	Very Poor	✓			
453.19 – 454.3	1.11	Conglomerate B	Sharp	Medium red	4.5	Very Poor	✓			
454.3 – 454.6	0.30	Conglomerate A	Sharp	Medium red	1.3	Poor	✓			
454.6 – 455.38	0.78	Conglomerate B	Sharp	Medium red	4.5	Very Poor	✓			
455.38 – 456.6	1.22	Multiple FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	4.8	Very Poor	✓			Cycles 30-60 cm each
456.6 - 457	0.40	Coarse siltstone	Sharp	Medium reddish brown	0.3					Green reduction patches, calcareous concretions
457 – 458.85	1.85	Conglomerate B	Sharp	Medium red	13.0	Very Poor	✓		MO-98-049	
458.85 – 459.94	1.09	FUS, conglomerate B fines into coarse siltstone	Sharp, erosional	Medium red	7.6	Very Poor	✓			
459.94 – 461.33	1.39	Conglomerate B, interstratified sandstone	Sharp	Medium red	7.8	Very Poor	✓		Boulder clasts	Minor coarse sandstone interbeds @ top 10 cm
461.33 – 461.54	0.21	Sandstone	Gradational	Light/medium red		Well	✓		Angled laminations 23°CA, MO-98-048	White calcite cement in matrix
461.54 – 462.17	0.63	Conglomerate B	Sharp	Medium red	7.7	Very Poor	✓			
462.17 – 462.71	0.54	Coarse siltstone	Sharp, erosional	Medium reddish brown	2.3					Green reduction patches, calcareous concretions
462.71 – 465.7	2.99	Conglomerate A/B	Sharp, erosional	Medium red	6.1	Very Poor	✓			
465.7 – 466.06	0.36	Coarse siltstone	Gradational	Medium reddish brown					Laminations/ cross laminations, MO-98-046	Green reduction patches, calcareous concretions
466.06 – 466.3	0.24	Sandy siltstone	Gradational	Medium reddish brown	0.5					
466.3 – 466.85	0.55	Coarse siltstone	Gradational	Medium reddish brown						Green reduction patches, calcareous concretions
466.85 – 467.42	0.57	Sandy siltstone	Sharp	Medium reddish brown	0.9					Minor green reduction envelopes, calcareous concretions
467.42 – 468.32	0.90	FUS, conglomerate C fines into conglomerate A	Sharp	Medium red	7.5	Very Poor	✓			

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support Clast	Support Matrix	Sedimentary Structures	Other
468.32 – 469.25	0.93	Conglomerate A	Sharp	Medium red	3.7	Poor	✓			
469.25 – 469.49	0.24	Coarse siltstone	Gradational	Medium reddish brown						Green reduction patches, calcareous concretions
469.49 – 469.79	0.30	Coarse siltstone	Gradational	Medium reddish brown	3.4			✓	Floating conglomerate clasts	
469.79 – 470.23	0.44	Coarse siltstone	Gradational	Green, reddish brown					Calcareous concretions ~4.8cm	Green reduction layer with minor red silty patches, calcareous concretions
470.23 – 470.42	0.19	Sandy siltstone	Sharp	Medium reddish brown					Calcareous concretions <2 cm	Green reduction patches, calcareous concretions
470.42 – 471.73	1.31	Conglomerate A	Sharp, erosional	Medium red	4.1	Very Poor	✓		Boulder clast	
471.73 – 471.86	0.13	Sandy siltstone	Gradational	Medium reddish brown					<2mm clast bed <2 cm thick	Minor green reduction patches
471.86 – 472.48	0.62	Sandy siltstone	Sharp	Medium reddish brown	3.1					Minor green reduction patches
472.48 – 473.98	1.5	Conglomerate B	Sharp	Medium red	5.2	Very Poor	✓			
473.98 – 475.01	1.03	FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	3.9	Poor	✓		Boulder clast, FUS defined by decreasing clast size and increase in matrix	Coarse sandy matrix
475.01 – 475.14	0.13	Sandy siltstone	Sharp	Medium reddish brown		Well	✓			Green reduction envelopes, calcareous concretions
475.14 – 477.08	1.94	Conglomerate A	Sharp	Medium red	4.3	Very Poor	✓			
477.08 – 477.7	0.62	Sandstone	Sharp	Medium red	5.9	Very Poor	✓			
477.7 – 478.07	0.63	Coarse siltstone	Sharp	Medium reddish brown	0.3	Moder-ate				Green reduction envelopes, calcareous concretions
478.07 – 478.68	0.61	Conglomerate B	Sharp	Medium red	4.1	Poor	✓			
478.68 – 479.4	0.72	Sandy siltstone, interstratified conglomerate A	Sharp	Medium reddish brown	4.3					Green reduction envelopes, calcareous concretions
479.4 – 480.14	0.74	Conglomerate C, interstratified sandy siltstone	Gradational	Medium red/ reddish brown	3.8	Poor	✓			Local sections of white calcite cement
480.14 – 480.28	0.14	Coarse siltstone	Sharp	Green						Green reduction layer
480.28 – 481.84	1.56	Conglomerate A	Sharp	Medium red	5.1	Very Poor	✓			
481.84 - 482	0.16	Coarse siltstone	Sharp	Medium reddish brown	1.6	Moder-ate	✓			Conglomerate bed from 480.88-480.97 m, conglomerate clasts <0.5cm average
482 – 483.07	1.07	FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	7.3	Very Poor	✓			
483.07 – 483.51	0.44	Sandy siltstone, interstratified conglomerate A	Sharp	Medium red	1.1	Moder-ate	✓			Conglomerate beds <5cm
483.51 – 484.5	0.99	CUS, conglomerate A, interstratified coarse siltstone coarsens into conglomerate C	Sharp	Medium red	4.1	Poor	✓		MO-98-045	

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support Clast	Support Matrix	Sedimentary Structures	Other
484.5 – 485.08	0.58	FUS, conglomerate B fines into fine siltstone	Sharp	Medium red/ reddish brown	3.2	Poor	✓			
485.08 – 485.19	0.11	Conglomerate A	Sharp	Medium red to green	3.1			✓	Floating conglomerate clasts	Green reduction layer
485.19 – 486.05	0.86	Conglomerate A	Sharp	Medium red	3.0	Poor	✓			Local white calcite cement, clasts roughly equigranular (0.2-0.5 cm)
486.05 – 487.52	1.47	Coarse siltstone, interstratified conglomerate A	Sharp	Medium red	1.2	Moder-ate	✓			Green reduction envelopes, calcareous concretions
487.52 - 492	4.48	Conglomerate B	Sharp	Medium red	11.3	Very Poor	✓		MO-98-044, boulder clast	Top 10 cm white calcite cement in matrix
492 – 492.59	0.59	Coarse siltstone	Sharp	Medium reddish brown						Minor green reduction envelopes, calcareous concretions (~5%)
492.59 – 492.98	0.39	Sandstone	Sharp	Medium red	2.6	Moder-ate	✓			
492.98 – 496.22	3.24	Conglomerate B	Sharp	Medium red	16.0	Very Poor	✓		MO-98-043, boulder clast	
496.22 – 497.18	0.96	FUS, conglomerate A fines into sandy siltstone	Gradational	Medium red/ reddish brown	4.6	Poor	✓			At 496.52 m, rapid gradation into sandy siltstone
497.18 – 498.05	0.87	Sandy siltstone	Sharp	Medium red to green					MO-98-042	Green reduction envelopes, calcareous concretions
498.05 – 498.13	0.08	Conglomerate A	Sharp	Medium red	6.3	Very Poor	✓			
498.13 – 498.39	0.26	FUS, conglomerate A fines into sandy siltstone	Sharp	Medium red/ reddish brown	1.5	Poor	✓			White calcite cement
498.39 – 499.14	0.75	Conglomerate B	Sharp	Medium red	2.7	Poor	✓			
499.14 – 499.55	0.25	Coarse siltstone	Sharp	Medium red	1.8	Poor	✓		One conglomerate B bed <5cm	Green reduction envelopes, limestone nodules
499.55 – 501.79	2.24	CUS, sandstone coarsens into conglomerate C	Sharp	Medium red	10.5	Poor	✓			Matrix and clasts increase in size
501.79 – 501.89	0.10	Coarse siltstone	Sharp	Green to medium reddish brown						Green reduction bed
501.89 – 502.19	0.30	FUS, sandstone fines into coarse siltstone	Sharp	Medium red	2.2	Poor	✓		Siltstone has interbedded conglomerate A	
502.19 – 502.3	0.11	Conglomerate B	Sharp	Medium red	1.3	Poor	✓			
502.3 – 502.41	0.11	Sandstone	Sharp, erosional	Medium red		Very Poor	✓			
502.41 – 502.56	0.15	Conglomerate A	Sharp, erosional	Medium red	8.4	Very Poor	✓			
502.56 – 502.63	0.07	FUS, sandstone fines into fine siltstone	Gradational	Medium red						
502.63 – 502.86	0.23	Coarse siltstone	Sharp	Green to medium reddish brown						Green reduction envelopes, calcareous concretions
502.86 – 503.56	0.80	Sandstone	Sharp	Medium red	4.0	Very Poor	✓			<25% conglomerate clasts
503.56 – 504.2	0.64	Coarse siltstone, interstratified conglomerate A	Gradational	Medium red/ reddish brown	0.6	Poor	✓		Minor floating clasts in siltstone	Green reduction patches

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support Clast	Support Matrix	Sedimentary Structures	Other
504.2 – 506.64	2.44	Conglomerate A	Sharp	Medium red	8.5	Very Poor	✓		Boulder clast	
506.64 – 506.93	0.29	FUS, sandstone fines into fine siltstone	Sharp, erosional	Medium red	2.4	Poor	✓		Conglomerate B bed <3cm thick	
506.93 – 507.38	0.45	Conglomerate A	Sharp, erosional	Medium red	4.1	Very Poor	✓			
507.38 – 507.49	0.11	Sandstone	Gradational	Medium red	3.2	Poor	✓			
507.49 – 507.64	0.15	Sandstone	Sharp	Medium red	1.6	Moder-ate	✓		Angled laminations 28°CA, MO-98-041	
507.64 – 507.72	0.08	FUS, conglomerate A fines into sandstone	Sharp	Medium red	0.8	Moder-ate	✓			
507.72 – 508	0.28	FUS, conglomerate B fines into sandstone	Sharp	Medium red	4.6	Very Poor	✓			
508 – 510.24	2.24	Coarse siltstone, interstratified conglomerate B	Sharp	Medium red/ reddish brown	4.5	Poor	✓			Green reduction patches
510.24 – 510.59	0.35	Sandstone	Sharp	Medium red		Moder-ate	✓		Cross-laminations	Green reduction envelopes, calcareous concretions
510.59 – 512.44	1.85	Coarse sandstone, interstratified conglomerate A	Sharp	Medium reddish brown to green, medium red	3.8	Poor	✓			Green reduction patches in siltstone
512.44 – 513.84	1.40	Conglomerate B	Sharp	Medium red	8.6	Very Poor	✓			Calcareous
513.84 – 515.8	1.96	Coarse siltstone, interstratified conglomerate A	Sharp	Medium reddish brown to green, medium red	1.4	Poor	✓			White calcite cement
515.8 – 515.91	0.11	Conglomerate C	Sharp	Medium red	3.2	Very Poor	✓		Boulder clast	
515.91 - 516	0.09	Conglomerate A	Sharp	Medium red	0.6	Poor	✓			
516 – 516.19	0.19	Coarse siltstone	Sharp	Medium reddish brown						Green reduction envelopes, calcareous concretions
516.19 – 516.25	0.06	Conglomerate A	Sharp	Medium red	0.5	Poor	✓			
516.25 – 516.34	0.09	Conglomerate A	Sharp	Medium reddish brown	0.5			✓	<5% floating clasts	Sandy matrix
516.34 – 516.44	0.10	Conglomerate C	Sharp	Medium red	4.3	Very Poor	✓			
516.44 – 516.64	0.20	Coarse siltstone	Sharp	Medium reddish brown						Green reduction envelopes, calcareous concretions
516.64 – 518.76	2.12	Conglomerate B	Sharp	Medium red	8.4	Very Poor	✓		Boulder clasts	
518.76 – 520.3	1.54	Coarse siltstone, interstratified conglomerate A	Gradational	Medium red/ reddish brown	0.5	Poor			Conglomerate beds <0.5cm, ~30% floating clasts in siltstone	
520.3 – 520.65	0.35	FUS, sandstone fines into coarse siltstone	Sharp, erosional	Medium red/ reddish brown	0.4	Moder-ate	✓			Green reduction envelopes, calcareous concretions
520.65 – 521.32	0.67	Conglomerate A	Sharp	Medium red	1.1	Poor	✓			

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support		Sedimentary Structures	Other
							Clast	Matrix		
521.32 – 521.8	0.48	Coarse siltstone	Sharp	Medium reddish brown						Green reduction envelopes, calcareous concretions
521.8 – 522.55	0.75	Conglomerate B	Sharp	Medium red	1.5	Poor	✓			
522.55 – 522.7	0.15	Sandstone	Sharp	Medium red	0.3	Moder-ate	✓		1-2% conglomerate A clasts	
522.7 – 523.3	0.60	Conglomerate B	Sharp	Medium red	1.5	Poor	✓			
523.3 – 524.17	0.87	FUS, conglomerate B fines into sandstone	Sharp	Medium red	1.4	Poor	✓			Coarse grained sandstone
524.17 – 525.11	0.94	Coarse siltstone, interstratified conglomerate A	Sharp	Medium red/ reddish brown	0.5	Poor	✓			Green reduction envelopes, calcareous concretions
525.11 – 525.41	0.30	FUS, sandstone fines into sandy siltstone	Sharp	Medium red/ reddish brown	0.9	Moder-ate	✓			
525.41 – 525.61	0.20	Conglomerate B	Sharp	Medium red	2.2	Poor	✓			White calcite cement
525.61 – 528.45	2.84	FUS, conglomerate B, interstratified sandstone fines into coarse siltstone	Gradational	Medium red/ reddish brown	7.5	Very Poor	✓			Green reduction patches in siltstone
528.45 – 529.03	0.58	Coarse siltstone	Sharp	Medium reddish brown to green					Laminations, fine limestone nodules floating in siltstone, calcite veins, MO-98-040	Green reduction patches
529.03 – 529.09	0.06	Sandstone	Sharp	Medium red			✓			
529.09 – 529.3	0.21	Conglomerate A/B	Gradational	Medium red	9.5	Very Poor	✓			
529.3 – 530.03	0.73	Conglomerate A	Gradational	Medium red	2.1	Poor	✓			White calcite cement
530.03 – 530.46	0.43	Conglomerate B	Sharp	Medium red	2.8	Poor	✓			
530.46 – 531.87	1.41	FUS, conglomerate A fines into sandstone	Sharp	Medium red	4.5	Poor	✓		1-2 clasts >0.3 cm	
531.87 – 532.61	0.74	FUS, coarse siltstone fines into fine siltstone	Gradational	Medium reddish brown	0.9	Moder-ate		✓	Floating conglomerate A clasts @ top	
532.61 – 533.94	1.33	Coarse siltstone	Sharp	Medium reddish brown						
533.94 – 534.47	0.53	Coarse siltstone	Gradational	Green to medium reddish brown	1.5			✓	Floating clasts <1.5 cm	Green reduction patches, size increases @ bottom
534.47 – 536.09	1.62	Coarse siltstone, interstratified sandy siltstone	Sharp	Medium reddish brown	6.2	Poor		✓	Floating conglomerate clasts ~1.0 cm	Conglomerate clasts decrease @ top
536.09 – 536.38	0.29	Conglomerate B	Sharp	Light to medium red	2.3					White calcite cement
536.38 – 538.52	2.14	Coarse siltstone	Sharp	Medium reddish brown	0.1			✓	Floating calcareous clasts	Minor green reduction envelopes, calcareous concretions
538.52 – 540.88	2.36	Conglomerate B, interstratified fine siltstone	Gradational	Medium reddish brown	6.4	Very Poor	✓			8 cm siltstone bed approximately every meter
540.88 – 543.28	2.40	Coarse siltstone	Sharp, erosional	Medium reddish brown	1.0					

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support Clast	 Matrix	Sedimentary Structures	Other
543.28 – 543.98	0.70	Conglomerate B/C	Sharp	Medium red	13.4	Very Poor	✓			
543.98 – 544.3	0.32	FUS, conglomerate B fines into sandstone	Sharp	Medium red	8.0	Very Poor	✓			
544.3 – 544.37	0.07	Coarse siltstone	Sharp	Medium reddish brown						Green reduction patches
544.37 – 546.32	1.95	Sandy siltstone	Sharp	Medium reddish brown					Laminated, angled beds 16°CA	Green reduction patches
546.32 – 548.16	1.84	Conglomerate B	Sharp	Medium red	5.6	Very Poor	✓			
548.16 – 549.22	1.56	Coarse siltstone	Sharp	Medium reddish brown to green					MO-98-038/039	Green reduction patches
549.22 – 550.34	1.12	Conglomerate B	Sharp, erosional	Medium red	5.9	Very Poor	✓		Boulder clasts	
550.34 – 552.78	2.44	Sandy siltstone	Sharp	Medium reddish brown					Cross laminations, laminations, interbeds of conglomerate A	Conglomerate bed <4.0 cm
552.78 – 553.62	0.84	Coarse siltstone	Sharp	Medium reddish brown					Laminations	Laminations increase @ top, green reduction patches
553.62 – 554.9	1.28	Conglomerate A	Sharp	Medium red	3.1	Poor	✓			White calcite cement, calcareous matrix
554.9 - 555	0.10	Coarse siltstone	Sharp	Medium reddish brown	0.2	Moder-ate				
555 – 556.25	1.25	Sandstone	Gradational	Medium red	8.5	Very Poor	✓		<1% conglomerate clasts	
556.25 – 556.86	0.61	Conglomerate B	Sharp, erosional	Light to medium red	5.6	Very Poor	✓			White calcite cement
556.86 – 558.9	2.04	CUS, coarse siltstone coarsens into sandy siltstone	Sharp	Medium reddish brown					Laminations	Green reduction envelopes, calcareous concretions (B only)
558.9 – 561.09	2.19	Conglomerate B	Sharp	Medium red	5.1	Very Poor	✓			
561.09 – 562.3	1.21	Multiple FUS, conglomerate B fines into sandstone	Sharp	Medium red	3.1	Very Poor	✓			Cycles 20-60 cm each
562.3 – 562.68	0.38	FUS, conglomerate B fines into conglomerate A	Sharp, erosional	Medium red	1.8	Poor	✓			
562.68 – 563.03	0.35	FUS, conglomerate A fines into sandy siltstone	Gradational	Medium red/ reddish brown	0.7	Poor	✓		Laminations in sandy siltstone	
563.03 - 563.44	0.41	FUS, conglomerate B fines into sandstone	Sharp	Medium red	3.0	Very Poor	✓			
563.44 – 563.96	0.52	Fine siltstone, interstratified conglomerate A	Sharp	Medium red/ reddish brown	0.6	Poor	✓		Laminations	White calcite cement
563.96 – 564.72	0.76	CUS, coarse siltstone, coarsens into sandstone, interstratified conglomerate A	Sharp	Medium red/ reddish brown	2.2	Poor	✓		Conglomerate interbeds <3cm each	Green reduction patches in coarse siltstone
564.72 – 567.54	2.82	Conglomerate B	Sharp	Medium red	4.8	Very Poor	✓			White calcite cement
567.54 – 568.3	0.76	FUS, conglomerate C fines into conglomerate A	Sharp	Medium red	2.5	Poor	✓			White calcite cement
568.3 – 571.86	3.56	Conglomerate B	Gradational	Medium red	6.6	Very Poor	✓		Boulder clast	

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support Clast	Support Matrix	Sedimentary Structures	Other
571.86 – 572.13	0.27	CUS, conglomerate B coarsens into conglomerate C	Sharp	Medium red	4.5	Very Poor	✓			CUS poorly defined
572.13 - 581.33	9.20	Coarse siltstone	Sharp	Medium reddish brown to green					Laminations	Green reduction patches, calcareous concretions
581.33 – 581.96	0.63	Conglomerate A	Sharp	Medium red	5.9	Very Poor	✓			
581.96 – 583.81	1.85	Coarse siltstone, interstratified conglomerate B	Sharp	Medium red/ reddish brown	5.5	Very Poor	✓		Odd floating conglomerate clasts	Green reduction patches MO-98-035
583.81 – 585.12	1.31	Conglomerate B	Sharp	Medium red	5.4	Very Poor	✓			
585.12 – 585.49	0.37	Conglomerate A/B	Sharp	Medium reddish brown				✓	<10% floating conglomerate clasts	
585.49 – 585.76	0.27	Conglomerate B	Sharp	Medium red	3.3	Poor	✓			
585.76 - 586.11	0.35	Coarse siltstone	Gradational	Medium reddish brown						
586.11 – 586.3	0.19	Coarse siltstone	Sharp	Medium reddish brown	0.8					Green reduction patches
586.3 – 592.1	5.80	Coarse siltstone, interstratified conglomerate B	Sharp	Medium red	3.4	Poor	✓			
592.1 – 595.18	3.08	Conglomerate B, interstratified coarse siltstone	Sharp	Medium red/ reddish brown	10.5	Very Poor	✓		Boulder clasts	
595.18 – 595.35	0.17	Conglomerate A, interstratified sandstone	Sharp	Medium red to green	2.0	Poor	✓			Green reduced sandstone
595.35 – 595.63	0.28	Conglomerate A	Sharp	Medium reddish brown				✓	White calcite/lime clasts <1mm	Sandy siltstone matrix
595.63 – 596.07	0.44	Conglomerate A	Sharp, erosional	Medium red	1.4	Poor	✓			
596.07 – 596.48	0.41	Sandy siltstone	Sharp, erosional	Medium reddish brown					Angled beds 10°CA, white calcareous clasts <1mm	Green reduction patches
596.48 – 598.25	1.77	Conglomerate A	Sharp	Medium red			✓			Minor white calcite cement
598.25 – 599.15	0.90	Coarse siltstone, interstratified conglomerate A	Sharp	Medium red/ reddish brown	3.2	Very Poor	✓			White calcite cement in conglomerate, % varies by bed
599.15 – 599.55	0.40	Coarse siltstone	Sharp, erosional	Medium reddish brown				✓	Minor calcareous clasts	
599.55 – 602.01	2.46	Conglomerate A	Gradational	Light/medium red	7.0	Very Poor	✓			Minor white calcite cement
602.01 – 602.13	0.12	Conglomerate B	Gradational	Light/medium red	1.7	Poor	✓			White calcite cement
602.13 – 603.12	0.99	Conglomerate A	Gradational	Medium red	3.0	Poor	✓		Boulder clasts	
603.12 – 603.37	0.25	Conglomerate B	Gradational	Medium red	2.8	Poor	✓			
603.37 – 604.67	1.30	CUS, conglomerate A coarsens into conglomerate B	Gradational	Medium red	0.8	Poor	✓			Poorly defined CUS
604.67 – 605.74	1.07	Conglomerate C	Sharp	Medium red	18.0	Very Poor	✓		Boulder clasts	
605.74 – 606.28	0.54	FUS, conglomerate B fines into sandstone	Sharp	Medium red	2.7	Poor	✓			

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support		Sedimentary Structures	Other
							Clast	Matrix		
606.28 – 606.41	0.13	Coarse siltstone	Sharp	Medium reddish brown to green						Green reduction layers
606.41 – 607.03	0.62	Conglomerate B	Sharp	Medium red	3.8	Very Poor	✓			
607.03 – 607.85	0.83	FUS, conglomerate B fines into sandstone	Sharp	Medium red	1.5	Poor	✓			
607.85 – 608	0.15	Coarse siltstone	Sharp	Medium reddish brown to green						Green reduction layers
608 – 609.53	1.53	Multiple FUS, conglomerate B fines into sandstone	Sharp	Medium red	2.3	Poor	✓		Boulder clasts, coarse sandstone	Cycles 15-60 cm each, local white calcite
609.53 – 609.67	0.14	Coarse siltstone	Sharp	Greyish green to medium reddish brown					Laminations, one interbed of conglomerate B (<5cm)	Primarily reduced siltstone with red silty patches
609.67 – 609.91	0.24	Conglomerate B	Sharp	Medium red	4.8	Very Poor	✓			
609.91 – 609.99	0.08	Sandstone	Gradational	Medium red						Calcareous matrix
609.99 – 610.19	0.20	Sandstone	Gradational	Light red						Calcareous matrix (greyish)
610.19 – 610.21	0.02	Sandstone	Sharp	Light greyish green						
610.21 – 610.33	0.12	Conglomerate B	Sharp	Medium red	1.8	Poor	✓			
610.33 – 610.35	0.02	Sandstone	Sharp	Light greyish green						
610.35 – 610.86	0.51	FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	7.1	Very Poor	✓		Laminations @ top	White calcite cement
610.86 – 611.15	0.29	Conglomerate A	Sharp	Medium red				✓	Floating calcareous clasts <0.8cm, average 1mm	
611.15 – 611.71	0.56	Conglomerate A, interstratified fine siltstone	Sharp	Medium red/ reddish brown	1.5	Poor	✓			
611.71 – 612.12	0.41	Sandy siltstone	Sharp	Medium red						Green reduction patches
612.12 – 612.34	0.22	Sandstone	Sharp	Medium red			✓		Coarse sandstone, laminations angled at 8°CA	Calcareous matrix
612.34 – 612.43	0.09	Coarse siltstone	Gradational	Medium reddish brown				✓	35% floating calcareous clasts	
612.43 – 612.58	0.15	Conglomerate A	Sharp	Medium reddish brown	2.0	Moder-ate		✓	25% floating conglomerate clasts	Green reduction patch (2cm)
612.58 – 613.1	0.52	Conglomerate B	Sharp	Medium red	3.7	Very Poor	✓			
613.1 – 613.69	0.59	Sandstone	Sharp	Very light red	0.9	Poor	✓		Laminations, cross laminations, MO-98-033	<3% clasts, abundant quartz in matrix
613.69 – 614.09	0.40	Sandy siltstone	Sharp, erosional	Medium red	0.1	Well	✓		Laminations, cross laminations	Green reduction patches
614.09 – 617.87	3.78	Conglomerate B, interstratified coarse siltstone and sandstone	Sharp	Medium red/ reddish brown	6.8	Very Poor	✓		Boulder clasts, one sandstone bed <5cm	Local white calcite cement, green reduction patches in siltstone
617.87 – 619.3	1.43	CUS, conglomerate A/B coarsens into conglomerate C	Sharp	Medium red	3.2	Poor	✓			Calcareous matrix

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support		Sedimentary Structures	Other
							Clast	Matrix		
619.3 – 619.67	0.37	FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	6.9	Very Poor	✓			
619.67 620.83	1.16	Conglomerate A, interstratified siltstone A	Sharp, erosional	Medium red/ reddish brown	3.5	Very Poor	✓		<10% siltstone interbeds	Minor green reduction patches
620.83 – 622.05	1.22	Fine siltstone, interstratified conglomerate A	Sharp	Medium red/ reddish brown	1.5	Poor	✓		<35% conglomerate interbeds	
622.05 – 622.52	0.47	Fine siltstone	Sharp	Medium reddish brown						Green reduction patches
622.52 – 622.9	0.38	Sandstone, interstratified fine siltstone	Sharp	Medium reddish brown	0.5	Moder-ate				
622.9 – 623.58	0.68	Fine siltstone, interstratified conglomerate A	Sharp	Medium red	0.8	Moder-ate			Cross laminations (10°CA) MO-98-033, 6 cm conglomerate bed	Minor green reduction patches (<5%)
623.58 – 624.82	1.24	Conglomerate B	Sharp	Light/medium red	8.2	Very Poor	✓		Boulder clast, MO-98-032	Calcareous matrix
624.82 – 626.07	1.25	Fine siltstone	Sharp	Medium reddish brown						Calcareous concretions
626.07 – 626.14	0.07	FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	1.8	Poor	✓			Poorly defined FUS
626.14 – 626.64	0.50	FUS, conglomerate A fines into sandy siltstone	Sharp	Medium red/ reddish brown	1.5	Poor	✓		Odd floating clast in siltstone C	Calcareous matrix
626.64 – 626.71	0.07	Sandstone	Sharp	Medium red						
626.71 – 626.86	0.15	Conglomerate A	Sharp	Medium red	4.2	Very Poor	✓			
626.86 – 627.2	0.34	Coarse siltstone	Sharp	Medium reddish brown				✓	Calcareous clasts <3 cm (defines basal contact)	
627.2 – 627.36	0.16	FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	2.7	Poor	✓			
627.36 – 631.76	4.41	CUS, coarse siltstone coarsens into conglomerate B	Sharp	Medium red/ reddish brown			✓		Calcareous clasts floating in siltstone, MO-98-031	
631.76 – 632.3	0.54	Conglomerate A	Sharp	Medium red	1.7	Poor	✓			
632.3 – 632.56	0.26	Conglomerate B	Sharp	Medium red	2.1	Poor	✓			Minor white calcite cement
632.56 – 633.57	1.01	Conglomerate A	Sharp	Medium reddish brown to green	0.8	Moder-ate		✓	30% floating conglomerate clasts <1cm, MO-98-030	Green reduction patches, calcareous concretions
633.57 – 633.86	0.29	Conglomerate B	Sharp	Medium red	3.2	Poor	✓			
633.86 – 634.6	0.74	FUS, conglomerate C fines into conglomerate A	Sharp	Medium red	7.0	Very Poor	✓			
634.6 – 635.35	0.75	Conglomerate B	Sharp	Medium red	5.7	Very Poor	✓			
635.35 – 635.58	0.23	Conglomerate B, interstratified sandstone	Sharp	Medium red	2.5	Poor	✓		Sandstone coarse to very coarse	
635.58 – 636.81	1.23	Conglomerate B, interstratified siltstone A	Sharp, erosional	Medium reddish brown to green	7.3	Very Poor	✓		Holes in sandy matrix (porous)	Green reduction patches
636.81 – 637.3	0.49	FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	0.9	Poor	✓			Minor white calcite cement

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support Clast	Support Matrix	Sedimentary Structures	Other
637.3 – 637.88	0.58	Conglomerate B	Sharp	Medium red	16.1	Very Poor	✓		Boulder clast, holes in matrix (porous), MO-98-028	
637.88 – 637.97	0.09	Coarse siltstone	Sharp	Medium reddish brown to green						
637.97 – 638.1	0.13	Conglomerate B	Sharp	Medium red	6.2	Very Poor	✓		Boulder clast	
638.1 – 641.31	3.21	FUS, conglomerate B fines into coarse siltstone	Sharp	Medium red/ reddish brown	8.7	Very Poor	✓		<5% floating conglomerate clasts, minor laminations & cross laminations in siltstone	Top 35 cm siltstone has green reduction patches, local white calcite cement in conglomerate
641.31 – 641.9	0.59	Coarse siltstone, interstratified sandy siltstone	Sharp, erosional	Medium red/ reddish brown	1.2	Poor	✓		Floating conglomerate A clasts, laminated sandy siltstone	Interbeds of sandy siltstone ~10 cm
641.9 – 642.6	0.70	FUS, conglomerate B fines into conglomerate A	Gradational	Medium red	6.0	Very Poor	✓			
642.6 – 643.15	0.55	Sandy siltstone	Sharp	Medium reddish brown					Interbeds ~5cm each	Calcareous cement in matrix
643.15 – 644.85	1.70	Sandy siltstone, interstratified conglomerate B	Sharp	Medium reddish brown			✓		Mainly parallel laminations, minor cross laminations, 2 conglomerate beds <5cm each	Calcareous matrixes
644.85 – 645.15	0.30	Conglomerate A	Sharp	Medium reddish brown				✓	<20% floating clasts	
645.15 – 645.74	0.59	Fine siltstone	Sharp	Medium reddish brown to green						Green reduction patches
645.74 – 649.18	3.44	Conglomerate A	Sharp	Medium red	4.9	Very Poor	✓			
649.18 – 652.69	3.51	Conglomerate B	Sharp	Medium red	5.2	Very Poor	✓		MO-98-024	
652.69 – 653.25	0.56	Fine siltstone	Sharp	Medium reddish brown						Green reduction layer top 19cm
653.25 – 654.03	0.78	Conglomerate B, interstratified sandy siltstone	Sharp	Medium red/ reddish brown	2.5	Poor	✓			Calcareous cement in matrix
654.03 – 654.8	0.77	Fine siltstone	Sharp	Medium reddish brown to green						Green reduction patches
654.8 - 656	1.2	Conglomerate A	Sharp	Medium red	4.0	Very Poor	✓		MO-98-023	
656 – 656.91	0.91	Conglomerate A	Sharp	Light/medium red	3.5	Very Poor		✓	<10% floating conglomerate clasts	Calcareous cement in matrix
656.91- 658.58	1.67	FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	5.9	Very Poor	✓			
658.58 – 659.41	0.83	Coarse siltstone	Sharp	Medium reddish brown to greyish green	5.0	Very Poor		✓	Minor conglomerate clast bed floating in siltstone	Green reduction patches
659.41 - 659.63	0.22	Conglomerate A	Sharp	Medium red	6.1	Very Poor	✓			
659.63 – 660.23	0.60	Sandy siltstone	Sharp	Medium reddish brown to green					Laminations @ top, MO-98-022	Green reduction patches

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support Clast	Support Matrix	Sedimentary Structures	Other
660.23 – 663.17	2.94	Multiple FUS, conglomerate B fines into fine siltstone	Sharp	Medium red/ reddish brown	5.7	Very Poor	✓			Six cycles ~15-80 cm each, rapid fining sequences
663.36 – 665.71	2.35	Multiple FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	2.5	Poor	✓			Poorly defined FUS, cycles 15-60 cm each
665.71 – 666.49	0.78	Fine siltstone	Sharp, erosional	Medium reddish brown						Green reduction patches
666.49 – 670.18	3.69	Conglomerate B, interstratified sandy siltstone	Sharp, erosional	Medium red/ reddish brown	3.2	Very Poor	✓		Boulder clasts	Calcareous cement in matrix, green reduction patches
670.18 – 670.61	0.43	Fine siltstone	Sharp	Green to medium reddish brown						Green reduction bed with red siltstone patches
670.61 – 675.54	4.93	Multiple FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	8.3	Very Poor	✓			5 cycles, 30-100 cm each
675.54 – 676.07	0.53	Conglomerate A/B, interstratified sandy siltstone	Sharp	Medium red/ reddish brown	1.5	Poor	✓			
676.07 – 676.26	0.19	Fine siltstone	Sharp	Medium reddish brown to green						
676.26 – 678.31	295	Multiple FUS, conglomerate B fines into sandy siltstone	Sharp	Medium red/ reddish brown	1.7	Poor	✓			6 cycles, 10-40 cm each
678.31 – 678.9	0.59	CUS, conglomerate A coarsens into conglomerate B	Sharp, erosional	Medium red	2.2	Poor	✓			
678.9 – 679.91	1.01	Conglomerate A	Sharp	Medium reddish brown	2.9			✓	<8% floating conglomerate clasts	This discontinuous green reduction lenses, calcareous cement in matrix
679.91 – 680.4	0.49	FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	3.1	Very Poor	✓			Poorly defined FUS
680.4 – 684.75	4.35	Multiple FUS, conglomerate B fines into fine siltstone	Sharp	Medium red/ reddish brown	3.0	Very Poor	✓			4 cycles, 50-160 cm each
684.75 – 684.94	0.19	Sandy siltstone	Sharp	Medium reddish brown to green						Green reduction envelopes, calcareous concretions
684.94 – 685.3	0.36	Conglomerate B, interstratified sandy siltstone	Sharp	Medium red/ reddish brown	5.0	Very Poor	✓			Top 10 cm has interbedded siltstone C
685.3 – 686.76	1.46	FUS, conglomerate C fines into conglomerate A	Sharp	Medium red	5.7	Very Poor	✓		MO-98-020	
686.76 – 687.97	1.21	Sandy siltstone, interbedded conglomerate A	Sharp	Medium red/ reddish brown	1.3	Poor	✓		Cross laminations, odd floating clasts in siltstone	
687.97 – 689.55	1.58	Conglomerate A	Sharp	Medium reddish brown	1.9	Poor		✓	<5% floating clasts	Silty matrix
689.55 – 694.04	4.49	Conglomerate B	Sharp, erosional	Medium red	15.0	Very Poor	✓			Minor calcareous cement in matrix
694.04 – 694.35	0.31	Fine siltstone	Sharp	Medium reddish brown					MO-98-019	
694.35 – 694.62	0.27	CUS, conglomerate A coarsens into conglomerate B	Sharp	Medium red	2.8	Very Poor	✓			
694.62 – 694.84	0.22	Fine siltstone	Sharp	Medium reddish brown						Green reduction patches
694.84 – 698.25	3.41	Conglomerate B, interstratified sandstone	Sharp	Medium red	7.1	Very Poor	✓			
698.25 – 701.09	3.65	FUS, conglomerate B fines into coarse siltstone	Sharp	Medium reddish brown						Green reduction patches

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support Clast	Support Matrix	Sedimentary Structures	Other
701.09 – 701.89	0.80	Coarse siltstone, interstratified conglomerate A	Sharp	Medium red/ reddish brown	1.6	Poor	✓	✓	Floating quartz/calcite clasts in siltstone	Green reduction envelopes
701.89 - 702	0.11	Sandstone	Sharp	Medium red	1.3	Poor	✓		<5% conglomerate clasts, interstratified fine and medium sandstone	
702 – 703.22	1.22	FUS, conglomerate B fines into coarse siltstone	Sharp, erosional	Medium red	5.2	Very Poor	✓			Calcareous cement in matrix, calcareous concretions
703.22 – 704.13	0.91	Conglomerate B, interstratified sandy siltstone	Sharp	Medium red/ reddish brown	1.9	Poor	✓		MO-98-018	
704.13 – 705.33	1.20	Conglomerate A, interstratified conglomerate B	Sharp	Medium red	6.0	Very Poor	✓			
705.33 – 705.83	0.50	CUS, conglomerate A coarsens into conglomerate B	Sharp	Medium red	2.1	Poor	✓			
705.83 – 706.22	0.39	Sandy siltstone	Sharp, erosional	Medium reddish brown					Angled beds ~11°CA	
706.22 – 706.53	0.31	Coarse siltstone	Sharp	Green to medium reddish brown						Calcareous concretions, minor veining, patchy red siltstone
706.53 – 706.94	0.41	Sandy siltstone	Sharp	Medium reddish brown					MO-98-017	Green reduction patches, calcareous cement in matrix
706.94 – 707.75	0.81	Multiple FUS, conglomerate B into fine siltstone, interstratified conglomerate A	Sharp	Medium red/ reddish brown	0.2	Moder-ate	✓		Conglomerate A interstratified with sandstone	~4 cycles 10-20 cm each
707.75 – 708.95	1.20	FUS, conglomerate B/C fines into conglomerate A, interstratified coarse siltstone	Sharp	Medium red	2.5	Very Poor	✓			White calcite cement
708.95 – 709.3	0.35	Conglomerate A/B	Sharp	Medium red	0.19	Very Poor	✓		MO-98-016	
709.3 – 709.5	0.20	Conglomerate B, interstratified fine siltstone	Sharp	Medium red/ reddish brown	1.4	Poor	✓			
709.5 – 710.07	0.57	Multiple FUS, conglomerate B fines into fine siltstone	Sharp, erosional	Medium red/ reddish brown	1.6	Poor	✓			Green reduction patches, 3 cycles 10-30 cm each
710.07 – 711.18	1.11	Coarse siltstone, interstratified sandy siltstone	Sharp	Medium reddish brown to green				✓	Minor floating clasts	Green reduction layers, calcareous cement in matrix
711.18 - 712	0.82	Conglomerate B, interstratified conglomerate A	Sharp	Medium red	1.9	Poor	✓			
712 – 712.98	0.98	Multiple FUS, conglomerate B fines into fine siltstone	Sharp, erosional	Medium red	1.8	Poor	✓			Cycles 10-40 cm each
712.98 – 713.43	0.45	CUS, fine siltstone coarsens into sandy siltstone	Sharp	Medium reddish brown					Cross laminations, MO-98-015	Green reduction patches
713.43 – 714.54	1.11	FUS, conglomerate B fines into sandstone	Sharp	Medium red	4.0	Very Poor	✓		Boulder clast	
714.54 – 715.8	1.26	Sandy siltstone	Sharp	Medium reddish brown						Green reduction patches
715.8 – 716.19	0.39	FUS, conglomerate B fines into sandstone	Sharp	Medium red	4.3	Very Poor	✓			Poorly defined FUS
716.19 – 718	1.81	Multiple FUS, conglomerate B/C fines into conglomerate A	Sharp	Medium red	3.8	Very Poor	✓		MO-98-014	Calcite veins, cycles 80-100 cm each
718 – 720.45	2.45	FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	3.1	Very Poor	✓			% matrix reduces upwards

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support Clast	Support Matrix	Sedimentary Structures	Other
720.45 – 722.54	2.09	CUS, conglomerate B coarsens into conglomerate C	Gradational	Medium red	4.4	Very Poor	✓			
722.54 – 723.84	2.09	FUS, conglomerate B fines into sandstone	Sharp	Medium red	1.5	Poor	✓			
723.84 – 724	0.16	Conglomerate B, interstratified fine siltstone	Sharp	Medium red/ reddish brown	3.2	Very Poor	✓			
724 – 724.13	0.13	Sandstone	Sharp	Medium red		Moder-ate	✓			
724.13 – 725.73	1.60	Conglomerate B/C	Sharp	Medium red	3.3	Very Poor	✓			
725.73 – 726	0.27	FUS, sandstone fines into fine siltstone	Sharp	Medium red/ reddish brown		Moder-ate	✓			
726 – 728.73	2.73	Multiple FUS, conglomerate B fines into coarse siltstone	Sharp	Medium red/ reddish brown	3.0	Very Poor	✓		Minor (~1%) floating conglomerate A clasts in siltstone, MO-98-013	Cycles 50-150 cm each, minor white calcite cement
728.73 – 728.87	0.14	Coarse siltstone	Sharp	Medium reddish brown to green						Green reduction envelopes, limestone nodules
728.87 – 731.89	3.02	Multiple FUS, conglomerate C fines into conglomerate A	Sharp	Medium red	4.1	Very Poor	✓			Cycles 60-120 cm each, local white calcite cement
731.89 – 732.29	0.40	Conglomerate A, interstratified conglomerate B	Sharp	Medium red	3.8	Very Poor	✓		<1% ~4cm	
732.29 – 732.68	0.39	FUS, conglomerate B fines into conglomerate A	Sharp	Medium red	4.0	Very Poor	✓		Boulder clast @ bottom	
732.68 – 733.14	0.46	Sandstone	Sharp	Medium red		Moder-ate	✓		Coarse grained sandstone	Core very broken
733.14 – 733.4	0.26	Coarse siltstone	Sharp, erosional	Medium reddish brown		Moder-ate				Green reduction envelopes, calcareous concretions
733.4 – 733.6	0.20	Sandy siltstone, interstratified conglomerate A	Gradational	Medium red/ reddish brown	0.3	Poor	✓		Minor conglomerate beds 2-3 cm, angled bedding 16°CA	
733.6 – 734.71	0.11	Sandstone	Sharp	Medium red		Well	✓		Laminations, minor low angle cross laminations	Calcareous cement in matrix
734.71 – 735.14	0.43	FUS, conglomerate B fines into sandy siltstone	Sharp	Medium red/ reddish brown	1.8	Poor	✓			Green reduction patches
735.14 – 735.57	0.43	Conglomerate A, interstratified coarse siltstone	Gradational	Medium red	0.3	Moder-ate	✓		MO-98-012	
735.57 – 736.35	0.78	Fine siltstone	Sharp, erosional	Medium reddish brown						Green reduction patches
736.35 – 736.39	0.04	Conglomerate A	Sharp erosional	Medium red	1.8	Poor	✓			
736.39 – 739.69	3.30	Sandy siltstone	Sharp	Medium reddish brown to green	0.4	Poor		✓	Minor floating clasts	Green reduction patches/ envelopes, calcareous concretions
739.69 – 744.91	5.22	Conglomerate B/C	Sharp	Medium red	3.2	Very Poor	✓		Boulder clasts, MO-98-010	
744.91 – 745.15	0.24	FUS, conglomerate B fines into coarse siltstone	Sharp	Medium red/ reddish brown	3.0	Very Poor	✓		Floating clasts in siltstone (<1mm)	Calcareous cement in matrix
745.15 – 745.24	0.09	FUS, conglomerate B fines into sandstone	Sharp	Medium red	0.8	Poor	✓			

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support		Sedimentary Structures	Other
							Clast	Matrix		
745.24 – 750.06	4.82	Conglomerate B, interstratified conglomerate C	Sharp	Medium red	5.3	Very Poor	✓			
750.06 – 751.18	1.12	Sandy siltstone	Sharp	Medium reddish brown	0.9	Poor			MO-98-009	
751.18 – 751.32	0.14	Conglomerate B	Sharp	Medium red	4.5	Very Poor	✓			
751.32 – 752.19	0.87	Coarse siltstone	Sharp	Medium reddish brown						
752.19 – 752.62	0.43	Conglomerate A	Sharp	Medium red	8.0	Very Poor	✓			
752.62 – 752.76	0.14	FUS, sandstone fines into coarse siltstone	Sharp	Medium red/ reddish brown		Moder-ate	✓			Calcareous concretions, calcareous matrix
752.76 – 752.92	0.16	Conglomerate A	Sharp	Medium red	1.0	Poor	✓			
752.92 – 753.95	1.03	Multiples FUS, conglomerate B fines into sandy siltstone	Sharp	Medium red/ reddish brown	2.1	Poor	✓			Cycles 30-80 cm each
753.95 – 754.08	0.13	FUS, conglomerate A fines into sandstone	Sharp	Medium red	3.0	Very Poor	✓			
754.08 – 754.28	0.20	Coarse siltstone	Sharp	Medium reddish brown	0.1	Moder-ate				
754.28 – 754.74	0.46	Conglomerate B/C	Sharp	Medium red	3.3	Very Poor	✓			
754.74 – 756.65	1.91	Conglomerate B/C, interstratified sandy siltstone	Sharp	Medium red/ reddish brown	7.2	Very Poor	✓		Boulder clasts, MO-98-005	
756.65 – 756.83	0.18	Conglomerate A	Sharp	Medium red	3.4	Very Poor	✓			
756.83 – 757.05	0.22	Coarse siltstone	Sharp	Medium reddish brown	1.7				Quartz floating clasts, angled orientation 48°CA	
757.05 – 757.66	0.61	FUS, conglomerate B fines into sandstone	Sharp	Medium red	6.5	Very Poor	✓			
757.66 – 758.11	0.45	Conglomerate B, interstratified sandy siltstone	Sharp	Medium red/ reddish brown	6.0	Very Poor	✓			
758.11 – 758.41	0.30	CUS, coarse siltstone coarsens into sandstone, interstratified conglomerate A	Sharp	Medium red/ reddish brown	0.4	Poor	✓		Floating conglomerate clasts in siltstone	
758.41 – 758.72	0.31	Conglomerate B	Sharp	Medium red	3.1	Very Poor	✓		MO-98-004	
758.72 – 758.82	0.10	Conglomerate A	Sharp	Medium red	2.3	Very Poor	✓			
758.82 – 759.2	0.38	Conglomerate A, interstratified sandy siltstone	Gradational	Medium red/ reddish brown	3.0	Very Poor	✓		Boulder clast, MO-98-003	
759.2 – 759.8	0.60	Conglomerate A	Sharp	Medium red	3.2	Very Poor	✓			
759.8 – 759.87	0.07	Fine siltstone	Sharp	Medium red/ silverish						Micaceous
759.87 - 760.05	0.18	Conglomerate A	Sharp	Medium red	3.0	Very Poor	✓			Small flakes of biotite

Interval (m)	Thickness (m)	Lithology	Basal Contact	Colour	Max. Clast Size (cm)	Degree of Sorting	Support		Sedimentary Structures	Other
							Clast	Matrix		
760.05 – 760.11	0.06	Sandy siltstone	Sharp	Medium reddish brown to silverish					MO-98-002	Micaceous
760.11 – 760.28	0.17	Conglomerate B	Sharp	Medium red	2.0	Very Poor	✓		MO-98-001	Calcareous cement matrix
760.28 – 760.96	0.68	CUS, coarse siltstone coarsens into sandstone	Sharp	Medium red/ reddish brown	1.8	Very Poor	✓			Green reduction patches in siltstone
760.96 – 761.3	0.34	Coarse siltstone	Sharp	Medium reddish brown						Green reduction patches

APPENDIX B

Porosity and Permeability Analysis

Authors Note:

No methods for the porosity or permeability analysis were provided by CoreLab Calgary. The technician, Steve Nagy, noted that it was standard procedure, and the copy of AGAT Laboratories methodology would be sufficient to explain techniques for the porosity and permeability analysis.

TITLE: BOYLE'S LAW OF GAS POROSIMETRY
Document #: CORE-006.001

0.0 AMENDMENT AND DISTRIBUTION

0.1 Amendment List

DATE	SECTION #	SECTION NAME	COMMENTS
Feb. 04, 1998		ALL	INITIAL VERSION

0.2 Distribution List

COPY	HOLDER
COPY # 1	CORE LAB

1.0 INTRODUCTION AND SCOPE

For the purposes of oil and gas exploration/development, porosity is used to determine a reservoir's size and production capabilities. As a petrophysical characteristic, porosity is defined as the proportional relationship of a rock's pore (and/or void) volume compared to its total (bulk) volume. This value is expressed as a percentage (e.g. 12.0%) or a decimal (e.g. 0.120). The total (Bulk) volume of a sample is the sum of two separate volumes : Pore Volume + Grain Volume.

$$\text{Porosity} = \frac{\text{Pore Volume}}{\text{Bulk Volume}}$$

$$\text{Bulk Volume} = \text{Grain Volume} + \text{Pore (and/or Void) Volume}$$

In petrophysical samples, "void" volume is generally attributed to vugs. At AGAT Laboratories, the standard operating procedure for determining an unknown porosity is the Boyle's Law Gas Porosimetry method, which is a combination of two separate processes : a bulk volume measurement and a grain volume measurement, which is done in a Boyle's Law Gas Porosimeter. From these two measurements, the pore volume is determined so that the porosity can be calculated.

The Boyle's Law Gas Porosimeter is generally used for consolidated core samples (routine core analysis) while unconsolidated core samples are treated as overburden samples (which is a different process.)

2.0 PRINCIPLE OF THE METHOD

The Boyle's Law Gas Porosimeter at AGAT Laboratories measures a sample's grain volume. The principle used in determining this measurement is, as name implies, Boyle's Law of Gases. Boyle's Law states that in a closed equilibrium system, a reference (known) volume of gas (Vi) multiplied by its initial pressure (PI) will be equal to the equilibrium pressure (Pe) of the gas multiplied by the second volume (Ve) when the temperature remains constant. The gas used in the Boyle's Law Gas Porosimeter (or "Porosimeter" for short) is Helium due to its small molecular size and inert nature, both of which allow a more rapid and complete absorption into a petrophysical sample.

$$Pi \times Vi = Pe \times Ve \quad \text{where } Ti = Te$$

The second value in the porosity equation, Bulk Volume, can be measured in one of two ways : Direct Measurement (Calipering), or Medium Displacement (Archimede's Principle). Direct Measurement, the more common of the two methods, involves calipering a sample's length and diameter dimensions to determine its bulk volume. Samples must be of a uniform, cylindrical shape for this method to be applied accurately. the principle behind this method is the geometrical equation to calculate a cylinder's volume : pi multiplied by length multiplied by the radius squared. Calipered measurements are reported in centimeters (to a tenth of a millimeter) while bulk volumes are calculated to cubic centimeters (cc).

BV = pi x l x r squared   for uniform cylinders

The second method of bulk volume determination, medium displacement, should only be used when a calipered volume would be inaccurate, usually when a sample is broken, fragmented or grossly irregular.

There are two mediums used in the displacement method : Mercury and Water, which will provide a Mercury Bulk and Water Bulk respectively. The principle behind this method is Archimede's principle.

By including a **mass** measurement into the set of equations, **density** may be calculated by dividing the sample's mass by an appropriate volume(Density = mass / volume). At AGAT Laboratories, two densities are standardly reported : Bulk Density and Grain Density. Bulk density is a sample's mass divided by its bulk volume while grain density is the mass divided by grain volume, assuming that pore mass is equal to zero. Both density values are reported in units of kilograms per cubic meter (e.g. a grain density for sandstone would be recorded as 2650 kg/cubic meter or simply 2650).

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

3.0 DETECTION LIMITS AND METHOD VALIDATION

The gauge used to read helium pressures within a Boyle's Law Gas Porosimeter at AGAT Laboratories is a Heise digital gauge which displays a reading to the hundredth of a psi (pound per square inch). All porosity values obtained by this method are reported at three significant figures. The smaller, digital calipers will measure to a hundredth of a millimeter (this value is generally rounded off to the nearest tenth of a millimeter) while the larger, manual calipers measure to a tenth of a millimeter. Porosity values determined by the Boyle's Law Gas porosimetry method are given a margin of error of plus or minus 0.005 (+/- half a percent). Because negative porosity values are impossible (at least from a petrophysical standpoint), any obtained porosity value of less than 0.005 must be rounded up to 0.005 so that the range does not include a negative value, thus **0.005 is the minimum reportable porosity value**.

Method validation is obtained once a quality control test sample is ran for the desired chamber size (1.0", 1.5", or full diameter) and results in porosity and density values which do not exceed a defined range.

AXIAL FLOW PERMEABILITY

Document #:CORE-007.001

0.0 AMENDMENT AND DISTRIBUTION

0.1 Amendment List

DATE	SECTION #	SECTION NAME	COMMENTS
FEB.04/98	ALL		FIRST COPY

0.2 Distribution List

COPY	HOLDER
COPY #1	CORE LAB

1.0 INTRODUCTION AND SCOPE

Permeability is the characteristic that allows fluid (or gas) to flow through a substrate. A single sheet of paper towel would have a high permeability while the rubber inner-tube of a tire would not (so long as there are no punctures or tears in the rubber). Permeability is measured in Darcies. A porous medium has a permeability of one Darcy when a single-phase fluid of one centipoise viscosity that completely fills the voids of the medium will flow through it under the "conditions of Stoke's flow" at a rate of one millimeter per second per square centimeter of cross-sectional area under a pressure gradient of one atmosphere per centimeter. Stokes flow conditions basically states that the rate of flow must be sufficiently low so as to be directly proportional to the pressure gradient. Darcies would be the unit of measurement to determine water flow rates across water-saturated coffee grounds in a low temperature coffee percolator. Since very few rocks will have this degree of permeability, petrophysical permeabilities are measured in milliDarcies (mD), one thousandths of a Darcy.

At AGAT Laboratories, there are a variety of permeability-measuring devices for petrophysical permeabilities. This is the standard operating procedure for routine core analysis in a steady state nitrogen permeameter in which the sample is held within a Hassler-type core holder. These permeameters measure a nitrogen pressure differential through a cross section of rock .

Permeability values obtained in the lab environment become an important index for oil and gas exploration/development in determining reservoir flow rates and feasibility.

2.0 PRINCIPLE OF THE METHOD

In principle, the determination of permeability is quite simple, involving only the measurement of a flow rate of a fluid (or gas) of known viscosity through a sample under a measured pressure differential, once a steady state of flow has been achieved. While Darcy originally intended for only liquid permeabilities to be determined this way, Klinkenburg showed that an extrapolated gas permeability is equal to the non-reactive liquid permeability (the Klinkenberg Effect). This type of permeability measurement is referred to as a "Klinkenberg Permeability" and is the type used for routine core analysis.

At AGAT Laboratories, the routine core analysis permeameters rely on a Hassler-type sample holder to allow nitrogen to enter and leave the sample only through diametrically opposed openings of a referenced area. Nitrogen is used as the gas for these permeability measurements because of its availability and simplicity. The initial nitrogen pressure entering the sample ("upstream pressure") is controlled by a Fine Nitrogen Regulator. The rate at which that nitrogen is permitted to flow across a sample and emerge on the opposite side ("downstream pressure") is a function of the sample's permeability in that direction. The difference between these two pressure values is the pressure gradient. Pressure gradients alone, even with a gas of known viscosity, are not enough to calculate permeability as a flow rate is required. Flow rates are determined by the use of orifices , (of small stainless steel tubing.) Orifices have a predetermined flow rate that limits the escape of nitrogen that has emerged from the sample. Excess downstream pressure which the orifice can not accommodate becomes "back" pressure, which is used to push water up a manometer or graduated cylinder (much like a barometer uses atmospheric pressure). It is the combination of these three values: the pressure gradient across a sample, known flow rate through an orifice, and excess pressure that are used to calculate a sample's permeability.

3.0 DETECTION LIMITS AND METHOD VALIDATION

Detection limits for the AGAT Laboratories routine core analysis permeameters have been restricted to a range of one one thousandth of a milliDarcy (0.001mD) to ten thousand milliDarcies (10,000 mD). Values that are measured outside of this range are reported as less than 0.001 mD and greater than 10,000 mD respectively. All values are reported in milliDarcies, an industry standard for the unit of permeability.

Method validation is performed by running quality control samples for each orifice of the permeameter. These values are calculated by a computer program (Calculations:Permeability (Vertical)) and entered into the appropriate quality control program chart. Each quality control sample has a referenced mean. Obtained values must fall within three standard deviations of the referenced mean (Control Limit).

4.0 INTERFERENCES

1) By-pass : The Hassler core holder utilizes a pressurized rubber seal to isolate only the desired core area for nitrogen entry and exit. An improper seal or puncture in the rubber will create a by-pass situation that will increase the permeabilty value.

2) Blocked Orifice : The orifices have been calibrated to an exact flow rate for each permeameter. Dust or other materials caught within these tiny orifices decrease the flow rate (and increase the back pressure). This results in inflated permeability values. Lines that are blocked will result in the same phenomenon.

3) Fractures : Fractures across a sample (natural or otherwise) will greatly increase a sample's permeability. In many cases, the matrix permeability (permeabilty determined by the pore configuration) is desired instead of the fracture permeability.

4) <u>Leaks</u> : If downstream nitrogen is allowed to escape from the permeameter other than through an orifice, the obtained permeability value will be decreased. Loose connections and cracked lines will result in leaks.

5) <u>Drilling Mud</u> : Full diameter core samples will often be muddy when cut. Wash the mud off of these samples after cutting them. Before running permeabilities on full diameter samples, it is also advisable to sandblast the sides to ensure a true permeability value.

5.0 REGULATORY LIMITS

There are no set regulatory limits for permeability.

6.0 SAMPLE REQUIREMENTS

The permeameters used in conventional core analysis are able to measure cylindrical, consolidated, petrophysical samples only (although these samples may be of any standard diameter, 1.0", up to 4.5"). It is also desirable for the samples to be of a uniform shape, although this is not a necessity.

7.0 TEST ORGANISM REQUIREMENTS

There are no test organisms required for this procedure.

APPENDIX C

Thin Section Descriptions

Sample #	TS 1	TS 2	TS 3	TS 4
Rock Type	Muddy Sandstone	Sandy Conglomerate	Muddy Sandy Conglomerate	Sandy Conglomerate
MINERALOGY		**GRAVEL**		
Monocrystalline Quartz				
Polycrystalline Quartz		1	5	
Chert		24	10	18
Sedimentary Lithoclasts			23	10
Igneous Lithoclasts			4	1
Volcanic Lithoclasts		2	2	3
		TEXTURE		
Grain Size		Granule – Pebble	Granule – Pebble	Granule – Pebble
Sorting		Poor	Poor	Poor
Roundness		Angular – Subround	Subround – Round	Subround – Round
Grain Contacts		Floating	Floating – Point	Floating – Curved
MINERALOGY		**MATRIX**		
Monocrystalline Quartz	33	23	12	11
Polycrystalline Quartz	12	13	11	13
Chert	23	11	9	19
Alkali Feldspar	4	1	1	2
Plagioclase Feldspar	Trace	Trace	Trace	Trace
Sedimentary Lithoclasts		3	6	7
Igneous Lithoclasts	1	1	4	7
Volcanic Lithoclasts	1	2	Trace	3
Mica	1	Trace	Trace	Trace
Heavy Minerals	1	Trace	Trace	Trace
Detrital Clay	11	5	9	2
TEXTURE				
Grain Size	Fine - Very Coarse	Fine - Very Coarse	Fine - Very Coarse	Fine - Very Coarse
Sorting	Poor	Very Poor	Very Poor	Very Poor
Roundness	Angular – Subround	Angular – Subround	Angular – Subround	Angular – Subround
Grain Contacts	Curved	Curved	Curved	Curved
		AUTHIGENIC MINERALS		
Quartz				Trace
Calcite	8	11	2	
Hematite	4	3	2	3
Kaolinite	Trace	Trace	Trace	

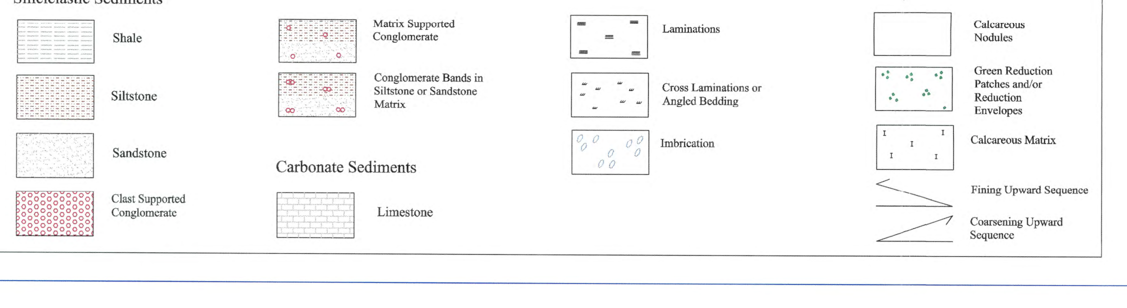
Sample #	TS 5	TS 6	TS 7	TS 8
Rock Type	Sandy Conglomerate	Sandy Conglomerate	Sandy Conglomerate	Sandy Conglomerate
GRAVEL MINERALOGY				
Monocrystalline Quartz				
Polycrystalline Quartz		8	1	
Chert	23	19	31	26
Sedimentary Lithoclasts	2	7	17	4
Igneous Lithoclasts	12			10
Volcanic Lithoclasts	3		4	6
TEXTURE				
Grain Size	Granule – Pebble	Granule – Pebble	Granule – Pebble	Granule – Pebble
Sorting	Poor	Poor	Poor	Poor
Roundness	Granule – Pebble	Granule – Pebble	Granule – Pebble	Subround - Round
Grain Contacts	Curved	Floating	Floating - Curved	Curved
MATRIX MINERALOGY				
Monocrystalline Quartz	15	10	9	9
Polycrystalline Quartz	4	11	10	12
Chert	7	25	12	14
Alkali Feldspar	2	Trace	1	Trace
Plagioclase Feldspar	Trace	Trace	Trace	Trace
Sedimentary Lithoclasts	3	7	1	3
Igneous Lithoclasts	3	3	4	7
Volcanic Lithoclasts	1	2	4	4
Mica	Trace	Trace	Trace	Trace
Heavy Minerals	Trace	Trace	Trace	Trace
Detrital Clay	Trace	2	Trace	1
TEXTURE				
Grain Size	Fine – Very Coarse	Fine – Very Coarse	Fine – Very Coarse	Fine – Very Coarse
Sorting	Very Poor	Very Poor	Very Poor	Very Poor
Roundness	Angular – Subrounded	Angular – Subrounded	Angular – Subrounded	Angular – Subrounded
Grain Contacts	Point -Curved	Curved	Curved	Curved
AUTHIGENIC MINERALS				
Quartz		Trace	Trace	Trace
Calcite	25	4	2	1
Hematite	trace	3	4	2
Kaolinite				

Sample #	TS 9	TS 10	TS 11	TS 12
Rock Type	Muddy Sandy conglomerate	Sandy conglomerate	Muddy sandy conglomerate	Sandy conglomerate
GRAVEL				
MINERALOGY				
Monocrystalline Quartz				1
Polycrystalline Quartz	2	1		2
Chert	12	5	7	16
Sedimentary Lithoclasts	3	2	2	10
Igneous Lithoclasts			1	3
Volcanic Lithoclasts	1			1
TEXTURE				
Grain Size	Granule - Pebble	Granule	Granule	Granule - Pebble
Sorting	Very Poor	Poor	Poor	Very Poor
Roundness	Angular - Subrounded	Angular - Subrounded	Angular - Subrounded	Angular – Subrounded
Grain Contacts				
MATRIX				
MINERALOGY				
Monocrystalline Quartz	30	15	18	12
Polycrystalline Quartz	4	9	8	5
Chert	23	19	15	18
Alkali Feldspar	2	3	3	2
Plagioclase Feldspar	Trace	Trace	1	1
Sedimentary Lithoclasts	1	6	8	3
Igneous Lithoclasts	Trace	3	10	3
Volcanic Lithoclasts	Trace	1	6	1
Mica	4	1	Trace	2
Heavy Minerals	Trace	Trace	2	3
Detrital Clay	2	Trace	Trace	Trace
TEXTURE				
Grain Size	Fine – Very Coarse	Fine – Very Coarse	Fine – Very Coarse	Fine – Very Coarse
Sorting	Poor	Poor	Poor	Poor
Roundness	Angular – Subround	Angular – Subround	Angular – Subround	Angular – Subround
Grain Contacts	Curved	Curved	Floating-Curved	Curved
AUTHIGENIC MINERALS				
Quartz				1
Calcite	12	11	12	9
Hematite	4	1	2	2
Kaolinite				

Sample #	**TS 13**	**TS 14**	**TS 15**	**TS 16**
Rock Type	Muddy sandstone	Muddy Sandy Conglomerate	Muddy Sandstone	Muddy Sandstone
MINERALOGY		**GRAVEL**		
Monocrystalline Quartz				
Polycrystalline Quartz		1		
Chert		15		
Sedimentary Lithoclasts		3		
Igneous Lithoclasts		5		
Volcanic Lithoclasts				
TEXTURE				
Grain Size		Granule - Pebble		
Sorting		Very Poor		
Roundness		Subround – Round		
Grain Contacts		Floating		
MINERALOGY		**MATRIX**		
Monocrystalline Quartz	35	20	23	30
Polycrystalline Quartz	5	10	12	16
Chert	25	12	16	23
Alkali Feldspar	2	3	1	1
Plagioclase Feldspar		2		
Sedimentary Lithoclasts	12	3	2	1
Igneous Lithoclasts	18	6	3	3
Volcanic Lithoclasts	5	1	1	
Mica	6	3	10	4
Heavy Minerals	1	trace	3	
Detrital Clay	3		8	10
TEXTURE				
Grain Size	Fine - medium	Fine – Very Coarse	Fine - medium	Fine - medium
Sorting	Poor – moderate	Very Poor	Poor – moderate	Poor – moderate
Roundness	Angular – subrounded	Angular - Subrounded	Angular - Subrounded	Angular - Subrounded
Grain Contacts	Curved	Floating-Curved	Curved	Curved
		AUTHIGENIC MINERALS		
Quartz			2	2
Calcite	3	6	3	10
Hematite	5	6	8	2
Kaolinite				

Sample #	TS 17	TS 18	TS 19
Rock Type	Muddy Sandstone	Sandy Conglomerate	Sandy conglomerate
GRAVEL			
MINERALOGY			
Monocrystalline Quartz			
Polycrystalline Quartz		4	15
Chert		9	25
Sedimentary Lithoclasts		3	6
Igneous Lithoclasts		11	10
Volcanic Lithoclasts		2	8
TEXTURE			
Grain Size		Granule – Pebble	Granule – Pebble
Sorting		Very Poor	Very Poor
Roundness		Subround – Round	Subround – Round
Grain Contacts	Curved	Floating-Curved	Floating-Curved
MATRIX			
MINERALOGY			
Monocrystalline Quartz	33	20	12
Polycrystalline Quartz	10	15	8
Chert	25	16	10
Alkali Feldspar	3	1	
Plagioclase Feldspar	1	Trace	
Sedimentary Lithoclasts		2	
Igneous Lithoclasts	1	5	1
Volcanic Lithoclasts	1	2	Trace
Mica	4	1	Trace
Heavy Minerals	2	1	
Detrital Clay	12	7	Trace
TEXTURE			
Grain Size	Fine – Medium	Fine – Very Coarse	Fine – Very Coarse
Sorting	Poor	Very Poor	Very Poor
Roundness	Angular – Subrounded	Angular – Subrounded	Angular – Subrounded
Grain Contacts	Curved		
AUTHIGENIC MINERALS			
Quartz			
Calcite	8	2	25
Hematite	4	1	trace
Kaolinite		trace	

Stratigraphic Column of DDH PE 83-1, Point Edward, Cape Breton, Nova Scotia



Acknowledgements:

Core Logging and stratigraphic column by Melanie Oakes, Dalhousie University

Technical and/or financial assistance provided by Hunt Oil, Core LAB, and Gordon Brown

Special thanks to Bob Boehner, Nova Scotia Department of Natural Resources, CBCL Engineering, and Martin Gibling for their support and guidance