**A SEDIMENTARY BASIN ANALYSIS OF THE
ABITIBI GREENSTONE BELT
IN THE TIMMINS AREA,
NORTHERN ONTARIO,
CANADA**

by
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A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirement for the degree of
Doctor of Philosophy

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and
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Cell	0379
Ecology	0329
Entomology	0353
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Limnology	0793
Microbiology	0410
Molecular	0307
Neuroscience	0317
Oceanography	0416
Physiology	0433
Radiation	0821
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Paleozoology	0985
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Physical Therapy	0382
Public Health	0573
Radiology	0574
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Toxicology	0383
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Solid State	0611
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Applied Sciences	
Applied Mechanics	0346
Computer Science	0984

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Materials Science	0794
Mechanical	0548
Metallurgy	0743
Mining	0551
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Packaging	0549
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Sanitary and Municipal System Science	0554
Geotechnology	0790
Operations Research	0428
Plastics Technology	0796
Textile Technology	0795

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Behavioral	0384
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Philosophie de l'éducation	0998
Physique	0523
Programmes d'études et enseignement	0727
Psychologie	0525
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Sciences sociales	0534
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Gérontologie	0351
Gestion des affaires	
Généralités	0310
Administration	0454
Banques	0770
Comptabilité	0272
Marketing	0338
Histoire	
Histoire générale	0578

Ancienne	0579
Médiévale	0581
Moderne	0582
Histoire des noirs	0328
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Paléocéologie	0426
Paléontologie	0418
Paléozoologie	0985
Palynologie	0427

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Loisirs	0575
Médecine du travail et thérapie	0354
Médecine et chirurgie	0564
Obstétrique et gynécologie	0380
Ophtalmologie	0381
Orthophonie	0460
Pathologie	0571
Pharmacie	0572
Pharmacologie	0419
Physiothérapie	0382
Radiologie	0574
Santé mentale	0347
Santé publique	0573
Soins infirmiers	0569
Toxicologie	0383

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Biochimie	0487
Chimie agricole	0749
Chimie analytique	0486
Chimie minérale	0488
Chimie nucléaire	0738
Chimie organique	0490
Chimie pharmaceutique	0491
Physique	0494
Polymères	0495
Radiation	0754
Mathématiques	0405
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Généralités	0605
Acoustique	0986
Astronomie et astrophysique	0606
Électronique et électricité	0607
Fluides et plasma	0759
Météorologie	0608
Optique	0752
Particules (Physique nucléaire)	0798
Physique atomique	0748
Physique de l'état solide	0611
Physique moléculaire	0609
Physique nucléaire	0610
Radiation	0756
Statistiques	0463

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Agricole	0539
Automobile	0540

Biomédicale	0541
Chaleur et thermodynamique	0348
Conditionnement (Emballage)	0549
Génie aérospatial	0538
Génie chimique	0542
Génie civil	0543
Génie électronique et électrique	0544
Génie industriel	0546
Génie mécanique	0548
Génie nucléaire	0552
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Personnalité	0625
Psychobiologie	0349
Psychologie clinique	0622
Psychologie du comportement	0384
Psychologie du développement	0620
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ABSTRACT

In the Timmins area, the uppermost part of the Abitibi Greenstone belt consists of deep-water, alluvial-fluvial, and minor shelf deposits within a small (1000 km²), poorly exposed sedimentary basin. A stratigraphic framework for the >3000m of strata is provided by the Tisdale, Porcupine, and Pamour Groups (in order of decreasing age), comprising 5 formations/12 members that represent deposition within the interval 2710-2670 Ma ago. Most sediments, which consist of deep-water turbidites, were deposited on multiple source ramps or in a fan system with a single continental source to the south.

Point-count data for sandstones of all formations have yielded several key grain types that are useful for interpreting provenance and tectonic setting for each of ten depositional environments. QFL, QmFLt and QmFLq diagrams for the Timmins data indicate the predominant source area to be a complex basement uplift with minor contribution from deeply eroded volcanic arcs. In general, sediments from the various formations can be separated on the basis of characteristic ratios for the key grain types.

Data from polycrystalline quartz (Qp) diagrams show a large diversity of polycrystalline quartz, including up to 5 types in the Pamour Group reflecting a complex source region.

In conjunction with sedimentology, REE (Rare Earth Element) geochemistry is a powerful tool for solving geological problems related to provenance. The average calculated value for all ten depositional environments is 95% felsic volcanic and 5% mafic volcanic, but one data sub-set shows that the deep-water deposits contain 30% mafic volcanic and 70% felsic volcanic, and another data subset shows that the shallow-water and fluvial sediments (Pamour Group) have REE values near 100% felsic volcanic, because they were derived from a highly fractionated felsic volcanic (or tonalitic) source.

ABSTRACT (continued)

Similarities in slopes and shapes of the REE curves for all environments suggest that a large source area must have been exposed for 30-40 million years. It also implies that erosion and deposition occurred in a typical continental setting such as a pull-apart basin adjacent to a major structural intraplate boundary such as the Porcupine-Destor Deformation Zone, rather than in an accretionary sedimentary basin such as an island arc or a forearc basin.

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While in Timmins, extensive help was provided by Lorne Luhta, Resident Geologist (Ontario Geological Survey) and his staff: Pam Sangster, Chris Hamlin, and Marc Leroux. Acknowledgments also go to the geologists of several mineral exploration companies; this research could not have been completed without their exceptional co-operation, assistance and advice. I especially thank Damien Duff, Dean MacEachern, Richard Labine, and Leo Burns of Falconbridge Exploration Ltd; Ed van Hees and Kim Tyler of Royal Oak Mines Inc., and Eric Kallio and Matt Gray of Placer Dome Inc. Access to the properties of these companies was essential for collection of sedimentological and stratigraphic data.

Thanks also go to the Kidd Creek project of the GSC, especially Dr. Harold Gibson from Laurentian University and Dr. Mark Hannington of the Geological Survey of Canada, for funding geochemical analyses (Rare Earth Elements).

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Thanks also go to the National Sciences and Research Council (NSERC) for providing three years of scholarship support.

Finally, I thank my dear wife Alice for incredible patience during this project, and I thank my children, Nicholas and Alexandra, for putting up with a lot of excuses including the following phrase: " No, because I have to work on my thesis!"

TABLE OF CONTENTS

Acceptance Sheet	ii
Abstract	iii
Acknowledgements	v
Table of Contents	vii
List of Tables	xii
List of Figures	xv
List of Plates	xxiii
List of Appendices	xxiv
 CHAPTER 1: OVERVIEW AND INTRODUCTION	 1
Basin analysis of Archean sedimentary terraines	1
Geologic setting of the Abitibi greenstone belt	7
Previous work in the Timmins area	14
Earliest work (1896-1974)	14
Unconformity at the base of the Timiskaming	15
More recent work (1975-1993)	16
Stratigraphic changes as a result of the present study	21
Objectives of the present study (Born, 1995)	24
 CHAPTER 2: SEDIMENTARY FILL WITHIN THE BASIN	 28
INTRODUCTION	28
Tisdale Group	36
Whitney Formation	36
Introduction	36
Description and Interpretation	36
Member A of the Whitney Formation	36
Member B of the Whitney Formation	44
Member C of the Whitney Formation	48
Discussion	49
Porcupine Group	51
Beatty Formation	51
Introduction	51
Description and Interpretation	51
Discussion	62

Porcupine Group	64
Hoyle Formation	64
Introduction	64
Description and Interpretation	64
Member A of the Hoyle Formation	65
Member B of the Hoyle Formation	70
Member C of the Hoyle Formation	72
Discussion	88
Base of the Hoyle Formation	90
Middle part of the Hoyle Formation	91
Middle to upper parts of the Hoyle Formation	92
 Pamour Group	 93
Dome Formation	93
Introduction	93
Member A of the Dome Formation	97
Description and Interpretation	97
Detailed spatial and bedform data	103
Member B of the Dome Formation	114
Description and Interpretation	114
Detailed spatial and bedform data	124
Member C of the Dome Formation	128
Description and Interpretation	128
Discussion	133
 Pamour Group	 137
Three Nations Formation	137
Introduction	137
Member A of the Three Nations Formation	141
Description and Interpretation	141
Member B of the Three Nations Formation	145
Description and Interpretation	145
Detailed spatial and bedform data	145
Member C of the Three Nations Formation	150
Description and Interpretation	150
Detailed spatial and bedform data	162
Discussion	173
Overview and General Discussion	175

TABLE OF CONTENTS (continued)

CHAPTER 3: PROVENANCE	185
MODAL ANALYSIS OF CONGLOMERATES IN OUTCROP	
Introduction	185
Petrographic Characteristics of Various Clasts	187
Lithologic Variations of Grouped Data	191
Introduction	191
Description	197
Interpretation	198
Size Analysis of Grouped data	199
Description and Interpretation	199
Lithologic Variations of Grouped Data-Second Method	201
Description	201
Interpretation	201
Size analysis	205
Description	205
Interpretation	205
Detailed Point Counting Data	206
Introduction	206
Conglomerates Associated With Alluvial-Fluvial Deposition	212
Conglomerates Associated With Turbidites	212
Gravelly Bar Conglomerates: Mainly In A Shelf Setting	213
Size And Shape Analysis	214
Introduction	214
Conglomerates Associated With Alluvial-Fluvial Deposition	215
Description	215
Interpretation	215
Conglomerates Associated With Turbidites	216
Description	216
Interpretation	217
Conglomerates Associated With Shelf Environments	217
Description and Interpretation	217

TABLE OF CONTENTS (continued)

Petrographic Data: Modal Analysis Of Sandstones	219
Introduction	219
Variations in Textural Data	221
Description	221
Interpretation	232
Krist	235
Compositional Variations	236
Introduction	236
Provenance Plots	237
Description	237
QFL plot	237
QmFLt plot	254
QmFLq plot	256
Interpretation	257
Other provenance discrimination plots	260
Introduction	260
Description	262
Qm/Qm+F Plot	262
Matrix Plot	262
Interpretation	264
Variations In the Percentage and Nature of	
Polycrystalline Quartz (Qp)	265
Introduction	265
Description	273
Total Qp plot	273
Plot of Variations in Grain types (Qp1-Qp5)	274
Size Analysis	276
Intrepretation	277
Discussion	280
CHAPTER 4: GEOCHEMISTRY- RARE EARTH ELEMENT	
DISTRIBUTION AS A TOOL IN PROVENANCE STUDIES	294
Introduction	294
Description	298
Interpretation	307
Discussion and Conclusions	310

TABLE OF CONTENTS (continued)

CHAPTER 5: SUMMARY AND CONCLUSIONS	322
Overview of Basin Analysis	322
Nature of the sedimentary basin fill	324
Provenance	340
Provenance interpreted from geochemical parameters	347
Synopsis	348
REFERENCES	351

LIST OF TABLES

Table 1.1	A summary of previous stratigraphic subdivision for sedimentary strata in the Timmins area and proposed (current) stratigraphic subdivisions.	17
Table 2.1	A summary of stratigraphic subdivision for sedimentary strata in sections Ti 363, MS-15A, 15B, 15C, and MS-9: Whitney Formation, Tisdale Group.	42
Table 2.2	A summary of stratigraphic subdivision for sedimentary strata in sections H 12-09, H15-12, M23-23 and Ti 3568: Member C-Hoyle Formation, Porcupine Group.	73
Table 2.3	A summary of stratigraphic subdivision for sedimentary strata in sections MS -12A, 1 and 5: Member A-Dome Formation, Pamour Group.	98
Table 2.4	A summary of stratigraphic subdivision for sedimentary strata in sections MS- 13, 3 and 6: Member B-Dome Formation, Pamour Group.	120
Table 2.5	A comparison of stratigraphic subdivision and depositional units for sedimentary strata from the Whitney, Beatty, Hoyle, Dome, and Three Nations Formations.	155
Table 2.6	A comparison of facies relationships and possible relative sea level changes for sedimentary strata from the Whitney, Beatty, Hoyle, Dome, and Three Nations Formations.	177
Table 2.7	A summary of stratigraphic subdivision for sedimentary strata in sections MS -11, and Ti 1160: Member C - Three Nations Formation, Pamour Group.	183
Table 3.1	Lithologic (megascopic modal) data of grouped point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel bar conglomerates.	192
Table 3.2	Size (megascopic modal) data of grouped point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel bar conglomerates.	194

LIST OF TABLES (continued)

Table 3.3	Size and shape (megascopic modal) data of grouped point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel bar conglomerates.	195
Table 3.4	Lithologic and size (megascopic modal) data of grouped point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel bar conglomerates.	202
Table 3.5	Lithologic (megascopic modal) data of grouped point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel bar conglomerates.	203
Table 3.6	Size (megascopic modal) data of individual point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel bar conglomerates.	207
Table 3.7	Legend and definitions of grain parameter for petrographic point counts using the Gazzi-Dickinson method.	222
Table 3.8	Textural characteristics of the Archean sedimentary suite: Abitibi Greenstone belt, Timmins, Ontario.	223
Table 3.9	abbreviations and legend for table 3.8: textural characteristics.	224
Table 3.10	Modal analysis: mean values for recalculated grain parameters (Gazzi-Dickinson method).	238
Table 3.11	Modal analysis: mean values and errors for recalculated grain parameters (Gazzi-Dickinson method).	241
Table 3.12	Modal analysis: mean values and errors for recalculated grain parameters (Gazzi-Dickinson method).	244
Table 3.13	Mean grain parameters (QFL). Data derived by visual estimates of sedimentary specimens that are either too fine-grained or too altered for modal analysis.	251
Table 3.14	Modal analysis: lithologic and size data for <u>Qp</u> (polycrystalline quartz) grains.	268

LIST OF TABLES (continued)

Table 3.15	Definitions of grain parameter and characteristics for the 5 types of <u>Qp</u> (polycrystalline quartz) grains.	271
Table 3.16	Modal analysis: relative abundance of polycrystalline quartz, monocrystalline quartz with non-undulatory extinction, and monocrystalline quartz with undulatory extinction grains.	282
Table 4.1	Rare Earth Element analyses from sedimentary rocks of the Archean Abitibi Greenstone belt, Timmins, Ontario.	299
Table 4.2	Comparison of Rare Earth Element ratios from sedimentary rocks, and standard values from a mixing model.	315

LIST OF FIGURES

Figure 1. 1 AB - General geology of the Abitibi greenstone belt, Timmins, Ont.	9
Figure 1.2 Depositional model for a point-source sand-rich submarine fan.	11
Figure 1.3 Depositional model for a multiple-source sand-rich ramp (1.3A), and Depositional model for a linear-source sand-rich slope apron (1.3B).	13
Figure 2. 1 General sedimentary geology of the Abitibi greenstone belt, Timmins, Ont.	29
Figure 2.2 Unified legend and symbols for all stratigraphic sections: in all figures and appendices.	34
Figure 2.3 Location of the grids which show all of the measured sections by formation and the relative distribution within the geographic limits of each formation.	37
Figure 2.4 Location grid for all measured sections of the Whitney Formation-Tisdale Group.	39
Figure 2.5 Detailed sedimentary features of Member A - Whitney Formation, Tisdale Group	40
Figure 2.6 Representative sections of the Whitney Formation, Tisdale Group.	41
Figure 2.7 Detailed sedimentary features of Member B (Ti 3235) - Whitney Formation, Tisdale Group.	47
Figure 2.8 Location grid for all measured sections of the Beatty Formation-Porcupine Group.	52
Figure 2.9 Representative sections of the Beatty Formation, Porcupine Group.	53
Figure 2.10 Detailed sedimentary features of the Beatty Formation (MS-12C) , Porcupine Group.	54

LIST OF FIGURES (continued)

Figure 2.11	Representative sections of Beatty Formation (Ti 1368, 1369 and 1370), Porcupine Group.....	57
Figure 2.12	Detailed sedimentary features of section MS-1- Beatty Formation, Porcupine Group.....	59
Figure 2.13	Location grid for measured sections of the Hoyle Formation- Porcupine Group in the Timmins area.....	66
Figure 2.14	Detailed sedimentary features of Member A- Hoyle Formation, Porcupine Group.....	68
Figure 2.15	Detailed sedimentary features of the upper part of Member A- Hoyle Formation, Porcupine Group.....	69
Figure 2.16	Detailed sedimentary features of Member B (PS-19)- Hoyle Formation, Porcupine Group.....	71
Figure 2.17	Representative sections from the Bell Creek Area: Member C of the Hoyle Formation, Porcupine Group.....	74
Figure 2.18	Representative sections from the Hoyle Pond area: Member C of the Hoyle Formation, Porcupine Group.....	75
Figure 2.19	Detailed sedimentary features from the Hoyle Pond area (sections HP 2185 and Ti 3561): lower part of Member C- Hoyle Formation, Porcupine Group.....	76
Figure 2.20	Representative sections from an area to the east of Hoyle Pond: Member C of the Hoyle Formation, Porcupine Group.....	78
Figure 2.21 ABC	Detailed sedimentary features from the Hoyle Pond area (section M21-10 and M51-1): middle part of Member C- Hoyle Formation, Porcupine Group.....	79
Figure 2.22	Detailed sedimentary features from the Hoyle Pond area: a composite of the lower and middle part of Member C- Hoyle Formation, Porcupine Group.....	82
Figure 2.23	Representative sections from the northern Evelyn area: Member C of the Hoyle Formation, Porcupine Group.....	83

LIST OF FIGURES (continued)

Figure 2.24	Representative sections from the southern Evelyn area: Member C of the Hoyle Formation, Porcupine Group.....	84
Figure 2.25	Representative sections from the Esker Lake area: Member C of the Hoyle Formation, Porcupine Group.....	85
Figure 2.26AB	Detailed sedimentary features from the Esker Lake area: a composite of the upper part of Member C- Hoyle Formation, Porcupine Group.....	86
Figure 2.27	Location grid for measured sections of the Dome Formation-Pamour Group.....	94
Figure 2.28	Relative stratigraphic position above the substrate for measured sections of the Dome Formation-Pamour Group.....	96
Figure 2.29	Representative sections from Member A- Dome Formation, Pamour Group.....	99
Figure 2.30	Detailed sedimentary features in section MS-1: Member A- Dome Formation, Pamour Group.....	100
Figure 2.31 AB	Detailed sedimentary features in sections MS 8: Member A- Dome Formation, Pamour Group.....	101
Figure 2.32 A	Plan view showing distribution and lateral continuity of beds in section MS-1: Member A- Dome Formation, Pamour Group.....	104
Figure 2.32 B	Legend for all sketches (Plan view) of detailed spatial and bedform data for Figures 2. 32-43, 2.54 to 59, and 2.51: Dome Formation and Three Nations Formation, Pamour Group.....	105
Figure 2.33	Plan view (eastern part) showing detailed sedimentary features and lateral continuity in section MS-1: Member A- Dome Formation, Pamour Group.....	106
Figure 2.34	Plan view (western part) showing detailed sedimentary features and lateral continuity in section MS-1: Member A- Dome Formation, Pamour Group.....	107

LIST OF FIGURES (continued)

Figure 2.35 AB	Plan view (southern part) showing detailed sedimentary features and lateral continuity in section MS-1: Member A- Dome Formation, Pamour Group.....	108
Figure 2.36	Plan view showing detailed sedimentary features and lateral continuity in section MS-5: Member A- Dome Formation, Pamour Group.....	111
Figure 2.37	Plan view showing detailed sedimentary features and lateral continuity in section MS-D (Dome): Member A- Dome Formation, Pamour Group.....	112
Figure 2.38	A comparison of paleocurrents from Members A (alluvial) and B (turbidites), Dome Formation, Pamour Group with those from the Whitney Formation (Member C-fluvial) and the Three Nations Formation (Members A and B-fluvial).....	113
Figure 2.39	Representative sections from Member B- Dome Formation, Pamour Group.....	115
Figure 2.40	Detailed sedimentary features from section MS-2: Member B- Dome Formation, Pamour Group.....	116
Figure 2.41	Detailed sedimentary features from section MS-10: Member B- Dome Formation, Pamour Group.....	123
Figure 2.42	Plan view showing detailed sedimentary features and lateral continuity in section MS-2 (shovel outcrop): Member B - Dome Formation, Pamour Group.....	125
Figure 2.43	Plan view showing detailed sedimentary features of conglomerates in section MS-2 (shovel outcrop): Member B - Dome Formation, Pamour Group.....	126
Figure 2.44	Plan view showing detailed sedimentary features, lateral continuity, and vertical changes in section MS-2 (east end): Member B - Dome Formation, Pamour Group.....	127
Figure 2.45	Representative sections from Member C- Dome Formation, Pamour Group.....	130

LIST OF FIGURES (continued)

Figure 2.46 AB	Detailed sedimentary features from section MS-12B: Member C- Dome Formation, Pamour Group.....	131
Figure 2.47	Location grid for measured sections of the Three Nations Formation -Pamour Group.....	138
Figure 2.48	Relative stratigraphic position above the substrate for measured sections of the Three Nations Formation -Pamour Group.....	140
Figure 2.49	Representative sections from Member A- Three Nations Formation, Pamour Group.....	142
Figure 2.50	Detailed sedimentary features from sections MS-17, Ti 3590, Ti 3591: Member A- Three Nations Formation, Pamour Group.....	143
Figure 2.51	Detailed sedimentary features from section MS-16: Member B- Three Nations Formation, Pamour Group.....	146
Figure 2.52	Plan view showing detailed sedimentary features of conglomerates in section MS-16: Member B - Three Nations Formation, Pamour Group.....	147
Figure 2.53	A comparison of paleocurrents from Members A (alluvial) and B (turbidites) and C(shelf sediments), Three Nations Formation, Pamour Group with those from the Dome Formation (Member A-alluvial).....	149
Figure 2.54	Representative sections from Member C- Three Nations Formation, Pamour Group.....	154
Figure 2.55ABC	Detailed sedimentary features from section MS-4: Member C- Three Nations Formation, Pamour Group.....	157
Figure 2.56	Plan view showing detailed sedimentary features and lateral continuity of the upper part of section MS-2: Member C- Three Nations Formation, Pamour Group.....	163

LIST OF FIGURES (continued)

Figure 2.57	Plan view showing detailed sedimentary features and lateral continuity of the lower part of section MS-4: Member C-Three Nations Formation, Pamour Group.....	164
Figure 2.58	Plan view showing detailed sedimentary features and lateral continuity of conglomerates, sandstones and sandstones with HCS bedforms in the middle of section MS-4: Member C-Three Nations Formation, Pamour Group.....	165
Figure 2.59	Plan view showing detailed sedimentary features and lateral continuity of the middle part of section MS-4: Member C-Three Nations Formation, Pamour Group.....	166
Figure 2.60	Plan view showing detailed sedimentary features and lateral continuity of the upper part of section MS-4: Member C-Three Nations Formation, Pamour Group.....	170
Figure 2.61	Plan view showing detailed sedimentary features and lateral continuity of the middle part of section MS-11: Member C-Three Nations Formation, Pamour Group.....	172
Figure 3.1	Location of conglomerate point counting stations and associated measured sections in Tisdale and Whitney townships.....	192
Figure 3.2	Pie diagrams of grouped point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel bar conglomerates.....	202
Figure 3.3	Pie diagrams of grouped point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel bar conglomerates.....	204
Figure 3.4	Pie diagrams of individual point counting stations for alluvial fan conglomerates from measured section (MS) D,12 and 1.....	209
Figure 3.5	Pie diagrams of individual point counting stations for alluvial fan conglomerates from measured section (MS) 5 and 17.....	210

LIST OF FIGURES (continued)

Figure 3.6	Pie diagrams of individual point counting stations for turbidite fan conglomerates from measured section (MS) 13, 2 and 3, and gravel bar conglomerates from measured section (MS) 4, 11 and 16.	211
Figure 3.7	QFL provenance discrimination diagrams. Data derived from modal analyses (>300 points) and some comparative Phanerozoic provenance data.	247
Figure 3.8	QmFLt provenance discrimination diagrams. Data derived from modal analyses (>300 points) and compared to Phanerozoic provenance data.	248
Figure 3.9	QmFLq provenance discrimination diagrams. Data derived from modal analyses (>300 points) and compared to Phanerozoic provenance data.	249
Figure 3.10	Matrix and Q/Q+PF provenance discrimination diagrams. Data derived from modal analyses (>300 points).	261
Figure 3.11	Provenance discrimination diagram: Total Qp plot for specimens . Data derived from modal analyses (>300 points).	272
Figure 3.12	Modal analysis: relative abundance of the 5 types of Qp (polycrystalline quartz) grains.	275
Figure 3.13	Modal analysis: relative abundance of polycrystalline quartz compared to, monocrystalline quartz with non-undulatory extinction, and monocrystalline quartz with undulatory extinction grain for sedimentary specimens.	285
Figure 3.14	QFL and QmFLq provenance discrimination diagrams . Data derived from modal analyses (>300 points) and compared to Phanerozoic provenance data.	288
Figure 3.15	QmFLt provenance discrimination diagrams. Data derived from modal analyses (>300 points) and compared to Phanerozoic provenance data.	289

LIST OF FIGURES (continued)

Figure 3.16	QpLvLs provenance discrimination diagrams. Data derived from modal analyses (>300 points) and compared to Phanerozoic provenance data.	291
Figure 4.1	Location of samples: REE analyses for the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.	303
Figure 4.2	Comparison of Rare Earth Element analyses from sedimentary rocks.	304
Figure 4.3	Comparison of Rare Earth Element Analyses for sedimentary rocks of the Archean Abitibi Greenstone belt, Timmins, Ontario.	306
Figure 4.4	Comparison of Rare Earth Element Analyses, and standard values from post-Archean Australian Shale (PAAS).	308
Figure 4.5	Comparison of Rare Earth Element Analyses, and standard values from North American Shale Composite (NASC).	309
Figure 4.6	Comparison of Rare Earth Element Analyses, and values from Feng and Kerrich (1990).	311
Figure 4.7	Comparison of Rare Earth Element Analyses, using standard values from a mixing model.	313
Figure 4.8	Comparison of Rare Earth Element ratios.	314
Figure 5.1	General geology and synopsis for the sedimentary strata of the Abitibi Greenstone belt, Timmins Ontario.	325
Figure 5.2	Depositional model for a pull-apart basin or a modified rift basin.	346

LIST OF PLATES

PLATE 1:	Outcrops of turbidites from the Tisdale Group (Whitney Formation), and from the Porcupine Group (Beatty and Hoyle Formations).....	46
PLATE 2:	Outcrops from the Dome Formation of the Pamour Group showing several key sedimentary features related to the deposition of turbidites.....	119
PLATE 3:	Outcrops from the Three Nations Formation (Pamour Group) showing several key sedimentary features highlighting many of the bedform characteristics of the shelf sediments.....	152
PLATE 4:	Outcrops from the Three Nations Formation (Pamour Group) showing several key sedimentary features highlighting characteristics of HCS and tidal bed forms of the shelf sediments.....	168
PLATE 5:	Outcrops from the Pamour Group (Dome Formation and Three Nations Formation) showing clast type and bed forms.....	189
PLATE 6:	Thin sections of rocks from the Tisdale Group (Whitney Formation) and Porcupine Group (Beatty and Hoyle Formations) showing textures, fabrics, alteration and detrital compositions.....	226
PLATE 7:	Thin sections of rocks from the Pamour Group (Dome and Three Nations Formations) and the Tisdale Group (Krist Formation) showing textures, fabrics, alteration and detrital compositions.....	229
PLATE 8:	Thin sections of rocks from the Pamour Group (Dome and Three Nations Formations) showing the variety of textures and detrital compositions in polycrystalline quartz grains.....	267

LIST OF APPENDICIES

Appendix 1	Detailed sedimentary data (graphic logs) from strata of the Whitney Formation -Tisdale Group.....	360
Appendix 2	Detailed sedimentary data (graphic logs) from strata of the Beatty Formation -Porcupine Group.....	377
Appendix 3	Detailed sedimentary data (graphic logs) from strata of the Hoyle Formation -Porcupine Group.....	386
Appendix 4	Detailed sedimentary data (graphic logs) from strata of the Dome Formation -Pamour Group.....	423
Appendix 5	Detailed sedimentary data (graphic logs) from strata of the Three Nations Formation -Pamour Group.....	443
Appendix 6	Locations for drill holes (ddh), measured sections (MS), outcrops and individual point counting stations for conglomerates.....	464
Appendix 7	Descriptions of point counting data from conglomerates of the Pamour Group: Dome and Three Nations Formations	468
Appendix 8	Original counting data: grain parameters (Gazzi-Dickinson) for samples.....	475
Appendix 9	Locations of samples for REE analyses, the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.....	488

CHAPTER 1: OVERVIEW AND INTRODUCTION

Basin analysis of Archean sedimentary terranes

Comparisons between Precambrian sedimentary basins and younger Phanerozoic basins are possible when they are viewed within similar frameworks. Important parameters to be considered are: nature of the basin fill, sedimentation style, volcanic activity, unconformities, subsidence and tectonic evolution. These factors, together with other important features (mainly in Phanerozoic basins) such as time-stratigraphic correlations, heat flow, and seismic profiles provide the basis for a successful basin analysis. Basins must be evaluated within a multiscale framework where data from one scale of observation may support or enhance interpretations of processes at another scale (Burchfiel and Royden, 1988). This means that every aspect of basin analysis is dependent on many different data sets. By changing one parameter, other parameters will likely change.

In Phanerozoic sequences, basin analysis in conjunction with plate tectonics has resulted in numerous actualistic depositional models (Ingersoll, 1988). In a simplified classification scheme, there are three main plate tectonic settings: divergent margins, convergent margins and transform margins. Within this framework, it is convenient to characterize certain basin types and their depositional environments. Precambrian sedimentary sequences should also be classified in a similar manner to provide a meaningful comparison. In a later section, a comparison of Precambrian sequences to their probable Phanerozoic analogs highlights some of the basic similarities and differences.

Basin analysis of Precambrian sedimentary sequences, especially Archean sediments, is more difficult than for Phanerozoic sequences. A lack of fossils means that interpretations of paleoenvironments are based solely on the physical aspects of sedimentary facies modeling. Furthermore, the lack of biostratigraphic control results in poor stratigraphic correlations as well as poorly constrained time intervals for stratigraphic sequence deposition. In most Precambrian sequences, the only alternative correlation method is the recognition of an easily identifiable marker bed such as an amygdaloidal flow or tuff horizon. These beds may yield zircons that can be used for age determinations. In provenance studies, the lack of time constraints also makes it difficult to correlate source areas to stratigraphic intervals within the basins. This has resulted in the respective use of REE curves and U/Pb age dates of detrital zircons (Eriksson et al, 1988) to determine the composition and age of source areas.

In addition, it is difficult to determine the sediment dispersal path within deformed Archean terranes. If the deformation is significant, then the rotations of primary features based on paleocurrent directions cannot be accurately determined. Because it is difficult to carry out a basin analysis without paleocurrent data, reconstruction of the original basin configuration can only be tentative, because interpretations must hinge on the validity of the other components of basin analysis. Identification of analogous Phanerozoic basins, basin forming mechanisms and plate tectonic settings are difficult without an established basin shape.

Other parameters such as tectonic uplift and subsidence, climate, eustatic sea-level changes and paleowater depth primarily affect the nature of the sedimentary fill within the basin. These controlling parameters apply equally to Precambrian as well as younger sequences. Similarities between the older and younger basins may illustrate similar processes, whereas differences may

indicate an overall evolution, with time, from the Archean to the beginning of the Phanerozoic.

Some of the factors that affect sedimentary processes include: evolutionary changes, atmosphere and climate, eustacy (or relative sea level changes including tectonics), and crustal development:

The interaction of mantle convection processes with the atmosphere, hydrosphere, biosphere and the sedimentary layer of the lithosphere was important during the early stages of Archean evolution. Thus, it is necessary to evaluate the role of recycling in the preferential destruction of older crustal segments. Isotopic data indicate that the early evolution of the Archean was characterized by multi-stage generation of new continental crust from the mantle. There was little intracrustal recycling or intermixing with the mantle. Thus, the absence of Archean continental crust was not caused by large-scale, intracrustal recycling (Veizer, 1983). According to Viezer and Jansen (1979, 1985, 1989), the recycling and evolutionary concepts are not mutually exclusive, but complementary. Archean greenstone belts were products of the oceanic domain that have been recycled at oceanic rates prior to incorporation into stable continental crust, and at the continental rate for the subsequent 2.2 Ga. The present high volumes of greenstone belts, despite this recycling, suggests that an oceanic domain was the dominant tectonic regime in the Archean. With advancing growth and cratonization of the continental crust, the role of intracrustal recycling became progressively more prominent. Accelerated production of continental crust in the Late Archean and Early Proterozoic (2.5 Ga), was followed by an increasing level of tectonic stabilization (i.e. cratonization), chemical differentiation and stratification, and termination of greenstone production.

Archean crustal models suggest that the lithosphere was comparable in thickness with that of the present day. According to Bickle and Eriksson (1982), thickness estimates of 75 km, 110 km and 130 km correspond to greenstone terranes (2.6 Ga), cratonic shelves (2.6 Ga), and younger, cratonic shelves (2.2 Ga), respectively.

Greenstone belts represent the volume of volcanics extruded during the Archean Eon. The composition of these volcanics is a direct reflection of mantle processes, heat flow and tectonic evolution. The predominant Archean volcanic rocks are: basalts (tholeiites), ultramafic flows (komatiites) and felsic flows (ryholites) in that order of abundance. In the younger, Phanerozoic sequences, basalts are associated with ocean ridge spreading, whereas andesites (calc-alkaline volcanics) are related to convergent plate margins and magmatic arcs, and ultramafic flows are rare or absent. These differences suggest that an overall volcanic evolutionary trend occurred between Archean and Phanerozoic volcanic sequences; with time, the volume of basalt decreased, whereas andesites increased and komatiites disappeared. Another important volcanic feature also relates to the production of oceanic crust. Typical ophiolites in Phanerozoic strata consist of pillowed basalts, sheeted dyke complexes and associated mafic plutonic rocks. An exact analogy of such ocean crust has not been recognized within Archean greenstone terranes. This has led some researchers to rule out plate tectonics as a viable option to explain the formation of Archean supracrustal sequences. However, the predominance of pillowed mafic volcanic rocks indicates that the formation of greenstone belts must have occurred in a predominantly oceanic environment. Ultramafic flows were probably produced at spreading ridges or as part of the oceanic plain deposits of Jackson and Fyon (1991); flows which are both thick and differentiated are a product of lava ponding, whereas thinner flows are a result of unrestricted flow over a subaqueous surface. Examples of both types occur in one of the measured

sections in the Timmins area (Ti 1398), where ultramafic lavas apparently overlie sandstones belonging to the Whitney Formation of the Tisdale Group.

Atmospheric composition and climate represent other important factors that can affect both erosional and sedimentary processes, and therefore must be considered in comparisons between Precambrian and Phanerozoic sequences. The distribution of certain key metallic minerals, such as uraninite, and pyrite-rich gold placers within Archean and Early Proterozoic strata (Witwatersrand of South Africa) indicates that the Archean atmosphere was low in oxygen. In the Precambrian and the early part of the Phanerozoic, the land surface was essentially barren and susceptible to rapid erosion. In most continental margin coastal settings, this factor probably increased the sedimentation rates of fluvial and marine siliciclastics, but conversely masked the deposition of carbonates in all tropical and subtropical regions.

In spite of some apparent differences, there also are numerous similarities between present-day sedimentary processes and those in the Archean: some obvious similarities include sedimentary structures and bed forms. Sedimentary depositional models such as turbidite fan models and fluvial models such as the Donjek and Scott braided streams appear to be applicable to sedimentary successions in the Archean (e.g. Hyde, 1980) .

Eustasy, another major depositional factor, controls the geometry and distribution of siliciclastic lithofacies in both Precambrian and Phanerozoic sequences. Eustatic sea-level changes can be attributed to large-scale changes in the volume of ocean basins or to the volume of water within these basins. The formation of glaciers provides one of the main mechanisms for the reduction of water volume in ocean basins. Thus, large eustatic sea-level changes can be indicators of large-scale glaciation in the polar regions. In both the Precambrian and Phanerozoic Eons, glacial sedimentary sequences probably match major eustatic sea level changes. Precambrian examples, which may include additional

unrecognized Archean glacial deposits, occur in Proterozoic strata such as the Gowganda Formation in Northern Ontario (Mustard and Donaldson, 1987); there are numerous Phanerozoic and present-day examples. The occurrence of Precambrian glacial sediments suggests that similar global weather systems must have existed to produce cold, glacial, polar regions, and warm tropical equatorial regions in which tropical storms resulted in storm deposits containing diagnostic internal features such as hummocky cross stratification (HCS).

In general, basin analyses of Precambrian sedimentary sequences, especially Archean sediments, are more difficult to execute than analyses of Phanerozoic sequences, because of poorly constrained time intervals. Also, primary sedimentary flow indicators commonly are obliterated or rendered suspect within highly deformed Archean terranes. The models therefore must be more cautiously applied when dealing with Archean strata than with Proterozoic strata. Previous comparisons show that many similarities, but only a few differences, exist between sedimentary sequences, basin-forming processes and plate tectonics in the Precambrian and those in the Phanerozoic. Most differences can be explained by evolutionary processes during the Archean era. Accordingly, Precambrian basins can be grouped into one of three plate-tectonic settings, namely, divergent margins, convergent margins and transform margins (strike-slip motion).

To select the most likely plate tectonic setting, it is important to identify the depositional environments, lithofacies, facies associations, architectural elements, unconformities and spatial relationships (Mueller et al, 1992). The provenance for the successive lithological packages in the basin-fill must also be determined for the Abitibi greenstone belt in the Timmins area (Figure 1.1). These are described, discussed and interpreted in the following chapters, and represent the main component of a basin analysis for this supracrustal sequence of Archean strata.

A key component of such a basin analysis identifies and interprets the deep-water portions of the basin using a variety of depositional models. Consequently, the interpretation of turbiditic sandstones of Archean age can be strengthened by application of models based on studies of Phanerozoic and modern deep-sea fan deposits. For this thesis the model of Mutti and Ricci Lucchi (1972) has been selected, because it is a relatively simple model. Mutti and Ricci Lucchi's model, in which facies A to G represent specific areas on the deep sea fan (Figure 1.2), has been modified by the addition of sub-facies D_a (abyssal plain) and D_o (outer fan), which subdivide Facies D. This simplified model is preferable to more recent and refined models, because more recent models require detail which is not readily determined from most highly deformed Archean terranes. The fan model of Mutti and Ricci Lucchi was specifically developed for ancient active margin fans (convergent margins) that may be analogous to the local geology in the Timmins area. The exact interpretation for the facies shifts of the inner fan varies depending on the depositional model (Walker 1985b and Walker, 1992). If the model is a submarine fan with a point source, then a series of facies shifts can be attributed to the same fan throughout the basin.

The key features of such a model are the inner fan, outer fan, basin plain, and mid-fan channelized (supra fan) lobes, as well as slope apron, shelf and a coastal plain. One of the requirements is a sand-rich shelf, and according to Reading and Richards (1994), the derived sand-rich fans are moderate in size (radii of 5-10 km) and are lobate in shape.

Interpretations stemming from facies shifts within either a multiple source (Figure 1.3A) ramp (Barrett and Fralick, 1989), or a slope apron (Figure 1.3B) from a linear-source (Reading and Richards, 1994), differ from that of a point source fan. In a multiple-source ramp within a sand-rich system, the key elements are the proximal, medial and distal portions of the ramp, which merge with the hinterland region. Another key element is a narrow shelf and multiple rivers with sandy deltas. Also, the coastal relief is greater than in the case of either a point source or a linear source. A sand-rich slope apron consists of coalescing turbidite sands with a narrow sandy shelf and a broad braid plain, which is adjacent to an area of high relief, such as along a mountain belt. Note that the facies nomenclature of Mutti and Ricci Lucchi (1972) has been superimposed on these diagrams (Figure 5.2A and B). These are not completely

Figure 1.01A General geology of the Abitibi greenstone belt, Timmins, Ont.

(modified from Feng and Kerrich, 1990)

Figure 1. 01B General geology of the Abitibi greenstone belt, Timmins, Ont.

Figure 1.2 Depositional model for a point-source sand-rich submarine fan.
Archean sedimentary suite of the Abitibi Greenstone belt, Timmins Ontario

appropriate, but they do show the equivalent sedimentary strata among the three depositional models for turbidites.

A poor correlation of strata, together with a poor understanding of the three-dimensional characteristics of these turbidite systems, means that as a first estimation, the simplest model, namely the submarine fan from a point source, is probably the most appropriate. The other models could be valid, but data to support them are either scarce or ambiguous. However, inferred rapid and extremely frequent progradations of inner fan deposits in the Timmins area support a multiple source ramp (Figure 5.2) as a more realistic model for many of the turbidite deposits within all of the formations, except perhaps the Beatty Formation.

Each sedimentary section commonly shows thinning- and fining-up patterns on a local scale as well as on a larger scale. The scarcity of coarsening- and thickening-up cycles indicates that "distinct positive megasequences" shown by fining and thinning trends, predominate over "distinct negative megasequences". Both terms were defined by Mutti and Ricci Lucchi (1972), with the former term indicating the infilling of a submarine channel typical of the inner fan zone, and the latter indicating progradation of proximal facies over more distal facies, which is typical of the outer fan environment. Both types of megasequences also occur in other depositional environments, and generally indicate channel progradation for negative megasequences or channel abandonment in the case of positive megasequences.

(Facies Nomenclature from Mutti and Ricci Lucchi, 1972)

(Facies Nomenclature from Mutti and Ricci Lucchi, 1972)

Figure 1.3 Depositional model for a multiple-source sand-rich ramp (5.2A), and Depositional model for a linear-source sand-rich slope apron (5.2B). Archean sedimentary suite of the Abitibi Greenstone belt, Timmins Ontario.

GEOLOGIC SETTING OF THE ABITIBI GREENSTONE BELT

The Archean-aged Abitibi greenstone belt consists of ten lithologic and structural "assemblages" that formed between 2.75 and 2.67 Ga along the southern edge of Superior craton (Jackson and Fyon, 1991). The Timmins area, which represents the southern part of the Abitibi greenstone belt, is approximately 700 km north of Toronto. The oldest and most volumetric components of the greenstone belt comprise komatiitic, tholeiitic and calc-alkalic metavolcanic rocks with minor interflow sediments (Figure 1.1). The two youngest assemblages (namely the Hoyle and Three Nations), identified by Jackson and Fyon (1991) as part of a 30-40 MY period from 2.7 to 2.67 Ga, are the focus of this study. These "assemblages" mainly represent epiclastic rocks that define the evolution of post-volcanic, as well as late syn-volcanic basins, containing epiclastic deposits. The latter represent a period which corresponds to the cessation of volcanism and initial formation of the major sedimentary basins. The other (older) assemblages represent potential source rocks for the basin fill. Other sources may not be exposed, or may have been entirely removed by erosion, either before or after formation of the depositional basins. All of the rocks are of low greenschist metamorphic grade.

PREVIOUS WORK IN THE TIMMINS AREA

Earliest work (1896-1974)

Gold was first reported in the Porcupine area by Burwash (1896) and Parks (1899). In 1909, prospectors such as Bannerman, Gillies, Hollinger, McIntyre and Middleton discovered economic concentrations of gold in the Timmins area (Pyke, 1982).

Subsequent geological investigations by Burrows (1919), Hurst (1939), Dunbar (1948), Hogg (1950), and Leahy (1971), revised and reinterpreted most of

the geology of the Timmins Mining Camp. Some of their key observations and interpretations with respect to the sedimentary rocks are outlined below.

Hurst (1936), followed by Bass (1961), recognized an apparent age difference between the older Keewatin sedimentary rocks and sedimentary rocks of the younger Timiskaming suite which occur parallel to the Porcupine-Destor Fault. The older sedimentary rocks consist of greywackes (turbidites) that attain a maximum thickness of about 900 m in the centre of the Porcupine syncline (Ferguson, 1968). The greywackes commonly overlie felsic, intermediate, and mafic Keewatin volcanic rocks. The absence of an angular discordance as well as a lack of fragments derived from the underlying (older) volcanic rocks suggested that the contact is not an angular unconformity.

A younger sedimentary sequence that unconformably overlies both Keewatin sedimentary and volcanic rocks was referred to as Timiskaming sediments. These consist of conglomerates, turbidites and crossbedded sandstones that attain a total thickness of 1000m in Tisdale Township. Conglomerates occur mainly as a single basal unit up to 50 m thick, but they also occur as five separate thinner units that make up part of the sedimentary trough near the Dome Mine (Holmes, 1949). The Pamour and Broulan conglomerates, which represent sedimentary units of this type, consist of cobbles, pebbles and a few boulders that occur not at the base but at higher stratigraphic intervals within the Timiskaming sequence.

Unconformity at the base of the Timiskaming

The nature of the angular unconformity between the Keewatin and overlying Timiskaming sedimentary rocks in both Whitney and Tisdale townships was described and sketched by Burrows (1924), Evans (1944), McLaughlin (1956) and Ferguson, (1968). Timiskaming sedimentary rocks, which wrap around the nose of a fold in older volcanic rocks at the Dome mine,

have bedding directions that are at right angles to the trend of the volcanic rocks. Criteria for determining tops indicate that all sediments are south-facing, opposite to the underlying north-facing volcanics (Greenstone Nose). Locally, intense deformation produced clasts that are stretched to ratios of 6:1, and lineations that plunge both northeast and southwest at about 45°.

At the Dome mine, an ambiguous relationship between the various porphyry bodies and the conglomeratic strata was recognized, because the polymictic nature indicates that several types of porphyry (QFP) have been eroded, whereas the strata are also cut by younger porphyry dykes such as the Preston porphyry, which consists mainly of albite and small amounts of quartz, sericite and chlorite. Although the dyke lacks chilled margins, sedimentary inclusions in the porphyry clearly indicates that the Preston porphyry is younger than the conglomerates.

More recent work (1975-1993)

Although there have been many recent geological investigations in the Timmins Mining Camp, those by Hodgson (1983), Piroshco and Kettles (1990), Aitken (1990), Jackson and Fyon (1991), Berger (1992), Gray (1994), and especially Pyke (1982) have directly contributed to solving some of the sedimentary problems (Table 1.1). The work by Jackson and Fyon (1991) attempted to place the geological data within a tectonic-structural framework rather than in a stratigraphic framework by grouping many of the formations into Assemblages (e.g. Porcupine Assemblage rather than Porcupine Group) based on geodynamic and stratigraphic considerations. The author has attempted to maintain this nomenclature where possible, but in light of the predominant sedimentary and stratigraphic nature of this study, it is also necessary to discuss smaller subdivisions which are more easily referred to as formations rather than sub-Assemblages. The original formation names have been used where possible, in an attempt to reduce the confusion that can be caused by the use of new names.

FORMALIZED NAMES		Intermediate		type	
Formations	###	Stratigraphic			
Members	#	Divisions			
		(GROUPS)			
(note: follows informal formation names if possible)					
Born (1995)					
STRATIGRAPHY					
youngest	THREE NATIONS Fm	###	PAMOUR	sedimentary	
	Members A and B	#			
	DOVE Fm	###	PAMOUR	sedimentary	
	Members A, B, and C	#			
	ANGULAR				
	UNCONFORMITY				
	BEATTY Fm	###	PORCUPINE	sedimentary	
	DISCONFORMITY ??				
	KRIST Fm	###	TISDALE	volcanic	
	DISCONFORMITY ??				
	Formation V		TISDALE	volcanic	
	DISCONFORMITY ??				
	WHITNEY Fm*	###	TISDALE	sedimentary	
	Members A, B, and C	#			
	HOYLE Fm**	###	PORCUPINE	sedimentary	
	Members A, B, and C	#	AGE: HOYLE=		
	DISCONFORMITY ??		BEATTY		
	** indicates same age and contemporaneous with Beatty Fm of the Porcupine Group		* indicates that sediments are also interbedded and contemporaneous with pillowed mafic flows		
oldest					

Table 1.1 A summary of previous stratigraphic subdivision for sedimentary strata in the Timmins area and proposed (current) stratigraphic subdivisions. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

Table 1.1 A summary of previous stratigraphic subdivision for sedimentary strata in the Timmins area and proposed (current) stratigraphic subdivisions. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

The proposed nomenclature and stratigraphic changes that accommodate all of these conflicting circumstances are summarized in Table 1.1, and are discussed in this section.

Pyke (1982) defined the entire sedimentary sequence as the Porcupine Group, which consists of four formations that are listed by decreasing age as the Whitney, Beatty, Dome and Three Nations Lake formations (all informal formational names). Most of this stratigraphic work was done by J. Lorscheider, an assistant of Pyke; the only publication that contains the results of their work is Pyke (1982)(personal communication, J. Lorscheider). In other words, references by previous authors to Lorscheider (1975) are incorrect and misleading.

Field relationships, physical attributes of the different depositional environments, and gross lithologic characteristics were the only criteria that were used by Pyke to correlate the sedimentary strata. Unfortunately, Pyke did not have the benefit of detrital zircon ages by Corfu et al, (1990) that show a large time gap between the youngest sediments of the Porcupine Group (2679 Ma) and volcanic rocks of the Krist Formation (2700 Ma). Although no age determinations have been made for detrital zircons from the Porcupine Group, the available geochronological data suggest that a 20 Ma year gap exists between the Porcupine Group and the Timiskaming Group (sediments). Additional detrital zircon work by Bleeker and Parrish (1994) on sedimentary rocks near Kidd Creek Mine indicates that the Hoyle Assemblage is at least 2700 Ma old and probably is similar in age to sedimentary rocks of the Beatty Formation.

Pyke's subdivision basically redefined earlier work that had grouped the clastic metasedimentary sequence in the Timmins area into older Keewatin and younger Timiskaming units. These relationships, which are summarized in Table 1.1, show how Pyke's formational names roughly correspond to the Assemblage concept of Jackson and Fyon (1991). The Porcupine-Destor Fault, a major deformational zone of regional significance, forms a major bounding

surface that separates several of the Assemblages. The original descriptions and criteria for recognition as defined by Pyke (1982) are briefly summarized below; the location of these formations is shown in Figure 1.1.

The Whitney Formation (>1000 m thick), which represents the oldest sedimentary unit in the area, is composed of siltstone, feldspathic wackes and minor conglomerates at the base and intermediate to mafic tuffs interlayered with siltstones throughout the rest of the unit. The entire unit is folded and faulted and is more structurally complex than other formations consisting of sedimentary rocks.

Conglomerates occur in outcrop and drill holes just west of Nighthawk Lake (Cody Township), and along the south shore of Goose Creek (Leahy, 1971). Many of the clasts consist of QFP and siltstone. Cross-cutting scour-and fill-structures indicate tops to the east.

Pyke correlated the Whitney Formation with similar sedimentary rocks in Thornloe, Bristol, and Mountjoy townships, and concluded that the Whitney formation, which is largely time equivalent to the Tisdale Group, represents synvolcanic deposition of sedimentary rocks.

The Beatty Formation is a 1050 m thick turbidite sequence consisting of wackes and siltstones, which conformably overlies the Tisdale Group (Assemblage). An angular unconformity, which separates the Beatty from the overlying Dome formation, is exposed in the northern part of Tisdale Township. At this location, conglomerates of the Dome formation truncate the underlying turbidites of the Beatty formation at an angle of 30°. This was interpreted by Pyke to indicate a local unconformity, with a series of channel fill conglomerates, rather than a major unconformity.

The Dome Formation, which has a maximum thickness of 400 m, largely consists of a turbidite sequence containing a basal conglomeratic unit and several other conglomerate beds at higher stratigraphic levels. Pyke (1982) also

recognized a range in bedding thickness between thinly and thickly bedded turbidites, as well as a few complete Bouma cycles in the turbidites.

The Dome and Beatty Formations in Tisdale and Whitney townships were interpreted by Pyke (1982) as time equivalent to the volcanic rocks of the Tisdale Group (Tisdale Assemblage), because, according to Pyke (1982), the Dome formation merges into, and is intercalated with, pyroclastic breccias of formation VI (Krist fragmental) at the Dome mine. Thus by implication, the Beatty formation, which underlies the Dome formation, is at least in part equivalent to formation V (mafic volcanics) of the Tisdale Group, which underlies the Krist fragmental.

The Three Nations Lake Formation, which is about 400 m thick, consists of crossbedded sandstone and minor conglomerates. At least three beds consisting of pebble conglomerate were identified by Pyke.

The following interpretation of The Three Nations Lake Formation by Pyke (1982) suggests that it represents a proximal submarine alluvial fan sequence derived from a quartz-rich source area, likely from granitic terrane: the high concentration of quartz was produced by excessive weathering in tropical climates (first-cycle sediments) rather than being caused by extensive reworking or recycling of older sediments.

Stratigraphic changes as a result of the present study

Most sedimentary units within the study area were previously given informal formational names, and this original stratigraphic framework has been largely retained, with only slight modification based on new geochronological and geological data. The formational names "Beatty" and "Dome" have been retained and are herein formalized to Beatty Formation and Dome Formation. Some names such as Whitney, Krist, Hoyle, and Three Nations, which have been applied to both formations and Assemblages, are also retained with a slight modification, and are herein formalized as formation names. All of these

formations, which have a close genetic and geochronological link, are herein redistributed into the following Groups:

<u>name</u>	<u>thickness</u>	<u>age</u>	<u>type</u>
Pamour	1000m thick(minimum)	(<2680 Ma)	sedimentary
Porcupine	1000m thick(minimum)	(<2700 Ma)	sedimentary
Tisdale	1000m thick-(minimum)	(> 2700 Ma)	volcanic with minor sediments near the top of the unit
Kidd-Munro		(>2715 Ma)	volcanic

The sedimentary sequence of the Abitibi Greenstone Belt in the Timmins area appears to be at least 3000 m thick.

The following revisions of Pyke's stratigraphic nomenclature are proposed:

The name Pamour Group (new name) identifies the Group that contains the youngest rocks in the area, namely the Dome Formation and overlying Three Nations Formation. Both of these formations have been subdivided into three members, namely A, B, and C.

The previously named Porcupine Group is herein redefined as consisting of the Beatty Formation and the Hoyle Formation. The latter formation underlies much of the sedimentary basin to the north of the Porcupine-Destor Fault, whereas the former occurs only in the Porcupine syncline. The Hoyle Formation has been subdivided into three members, namely A, B, and C, whereas the Beatty Formation remains unsubdivided.

The Tisdale Group, which formerly consisted only of volcanic rocks, has been redefined to include the Krist Formation as its youngest unit, underlain by pillowed mafic volcanic flows which are in part intercalated with, and underlain

by, sedimentary rocks of the Whitney Formation. Previously, Pyke referred to the Krist fragmental unit as formation VI. The redefined Tisdale Group now represents a predominantly volcanic package with a minor sedimentary component (Whitney Formation) in its upper part, and a fragmental, intermediate to felsic volcanic unit at the top (Krist). The Whitney Formation, which consists of Members A, B, and C, represents pre- and syn-volcanic sedimentation before deposition of the Krist Formation, which in turn represents the final volcanic activity of the Abitibi Greenstone Belt in the Timmins area. Therefore, the stratigraphic section from the base of the Whitney Formation to the top of the Krist Formation probably contains evidence which documents the termination of volcanism in the Timmins area: This important characteristic may in fact signal a terminal collision or docking of two or more plate-tectonic regimes, and represents a significant event in the tectonic history of the Abitibi Greenstone Belt in the Timmins area.

Thus, the stratigraphic nomenclature discussed above and the Assemblage concept proposed by Jackson and Fyon (1991) represent two parallel systems which are at times difficult to reconcile due to a conflicting and confusing nomenclature. The latter is largely based on structural considerations, whereas the former is based on a stratigraphic framework as well as the scale and mappability of the sedimentary units. The Formation and Group names are therefore preferred, and the Assemblage nomenclature will only be referenced when absolutely necessary.

OBJECTIVES OF THE PRESENT STUDY (Born, 1995)

The principal objective of the present study was to complete a basin analysis of the sedimentary sequence of the Abitibi Greenstone belt in the Timmins, Ontario area, based on the following research components:

- 1) Six months of field work in the Timmins area (summer of 1991 and 1992) covering an area of approximately 1000 km², the equivalent of 10 complete townships. The following townships, which are listed from east to west, were part of this investigation: German, Macklem, Matheson, Evelyn, Cody, Whitney, Hoyle, Tisdale, Mountjoy, Jessop, Kidd, Ogden, Thornloe, and Denton.
- 2) Approximately 14 km of sedimentary section was measured and described in detail to provide data for paleogeographic and depositional reconstruction of the basin. Of this, approximately 4 km represents outcrop sections, whereas another 10 km of measured section (MS) comes from diamond drill cores. Most measured sections representing outcrops are in close proximity to Whitney and Tisdale townships: In total there are approximately 30 measured sections of this type. Elsewhere, the paucity of outcrop meant that drill core was the primary method for studying the basin evolution.

The distribution of stratigraphic data, derived from a study of about 40 drill holes (average 200 m true thickness) in a widespread region, covers an east to west distance of 80 km and a north to south distance of 50 km. The spacing and locations of selected drill holes was not arbitrary, because wherever possible, several holes clustered together were chosen in an attempt to establish local correlations prior to attempting larger, basin-wide correlations. A lack of data in areas away from the margins of the basin reflects the paucity of drill holes in these areas; every attempt was made to examine all available and pertinent data. Most of the drill core is stored at the Drill Core Library of the Ontario Ministry of Northern Development and Mines in Timmins. Other cores, particularly from

the Kidd Creek and Hoyle Pond areas, were provided courtesy of Falconbridge Exploration Inc.

The purpose of stratigraphic mapping and drill core logging is to identify the various lithofacies, which collectively determine the facies associations for each formation. This methodology is needed to unravel the tectonic history of the sedimentary basin, as well as to constrain previously proposed tectonic models that are mainly based on the local volcanic rocks, while ignoring the sedimentary record. Comparisons are also made with better understood examples of deep-water basins which represent Proterozoic to Paleozoic island-arc basins, fore-arc basins, back-arc basins and continental rift basins.

3) Modal analyses of conglomerates (point-counting of clasts) in outcrop were completed in all 11 measured sections that contain some sedimentary rocks of the Pamour Group. A total of 43 counting stations, which each represent at least 100 points, were completed in order to infer provenance for the conglomerates.

From an economic standpoint, these sedimentary strata are important because a substantial percentage of lode gold mineralization within the Timmins Mining Camp (at both Pamour and Dome Mines) is either hosted within the basal strata or associated with the basal unconformity. Therefore, the primary lithologic facies distribution and geometry of the conglomerate lenses relative to other sedimentary facies (as determined by detailed mapping) are important factors controlling continuity, distribution and size of the gold-bearing quartz veins. Furthermore, provenance and alteration studies of different conglomerates provide powerful tools for unraveling the complex geological history of late structurally controlled mineralization. Within the conglomerate, the occurrence of numerous porphyry, vein-quartz and fuchsitic clasts suggests that intrusion of at least some porphyries, quartz veins and associated

hydrothermal alteration predate the main mineralization event (younger than 2.68 Ga).

4) Modal analyses of sandstones @ 300 grains (points)/slide provided an investigative tool for inferring provenance of sandstones from the Porcupine Group, Pamour Group and the upper part of the Tisdale Group. Approximately 130 thin sections of rocks were initially selected as representative of the various formations and possible depositional environments. Of these, only 60 displayed an appropriate state of preservation and grain size for petrographic modal analysis.

5) Twenty-six samples of sandstone, mudstone and volcanoclastic rocks, which are representative of the various formations, were analyzed for REE content at XRAL Laboratories, Toronto. This lab work, which was funded by the Kidd Creek project of the GSC, provided geochemical data that supplements petrographic data for the same samples. The two data sets allow for a detailed interpretation of sedimentary provenance as well as for evaluation of geochemical differences between mudstones and sandstones from the same depositional environment. Thus, the geochemical REE characteristics of the eroded material can provide an independent method for determining the provenance of the sediments, which either supports or contradicts the petrologic evidence.

6) Detailed 1:100-scale mapping, which was carried out at several selected localities, including the shovel outcrop (MS-2), and Dome outcrop west of the open pit (MS-D) , determined the exact spatial and lateral relationships between the various lithologies at each location. In addition, sketching at 1:50 scale provided detailed information on the vertical and lateral variations of beds and bedforms at localities MS-1, 2, 4, 5, 11, and 16. For documentation purposes, such detailed data are needed to differentiate beds forms that characterize different depositional environments. These data are particularly important for interpreting drill core sections, because only vertical changes are recorded in core, and the extent of lateral variations is otherwise unknown.

7) On the basis of previous work on the Krist fragmental unit, its origin was largely enigmatic. Therefore, REE geochemistry, modal analysis of volcanoclastic samples (300 points/slide), and megascopic point-counting of clasts at several locations have provided new information relevant to the depositional setting, degree of erosion and sedimentary reworking, and provenance of this felsic volcanic unit which consists almost entirely of felsic volcanic fragments and derived crystals of feldspar and quartz. Because this felsic fragmental unit represents the termination of volcanism in the Timmins area, its origin is especially relevant to a reconstruction of the topography and basin configuration before cessation of the volcanism that preceded development of the deep-water turbidite basins.

CHAPTER 2: SEDIMENTARY FILL WITHIN THE BASIN

INTRODUCTION

The main lithofacies associations, which represent ten distinct but interconnected depositional environments, are described below together with a brief environmental interpretation. For convenience, the terms sand, silt and mud are generally used in place of meta-sandstone, meta-siltstone, and meta-mudstone. All of the rocks are generally of a low greenschist metamorphic grade. The descriptions have been grouped into gross stratigraphic association within the Tisdale, Porcupine or Pamour Group, according to the individual formation (Figure 2.1):

TUFF($\pm$ flows)-MUDSTONE TURBIDITE Association : represents synvolcanic sedimentation, and occurs in Member A of the Whitney Formation, and Member A of the Hoyle Formation.

MUDDY LAMINATED TURBIDITE Association: probably represents abyssal plain deposits, and occurs in all five formations (i.e. Whitney, Beatty, Hoyle, Dome and Three Nations), except Member A of both the Dome and Three Nations Formations.

GRAPHITE-MUDSTONE TURBIDITE Association: probably represents abyssal plain deposits, but in a restrictive and anoxic environment. These mainly occur in the Whitney, Hoyle, and Beatty Formations.

Figure 2.01 A General sedimentary geology of the Abitibi greenstone belt, Timmins, Ont.

Figure 2.1B General geology of the Abitibi greenstone belt, Timmins, Ont.

THINLY BEDDED (THB) TURBIDITE Association: probably represents lobe fringe deposits. These occur in all formations except the Three Nations Formation (i.e. Whitney, Beatty, Hoyle and Dome).

MEDIUM BEDDED (MDB) TURBIDITE Association: probably represents mid-lobe sandstone deposits. Again, these occur in all formations except the Three Nations Formation.

THICKLY BEDDED (TKB) TURBIDITE Association: probably represents inner fan deposits . These occur in all formations except the Three Nations Formation (i.e. Whitney, Beatty, Hoyle and Dome).

TURBIDITE-CONGLOMERATE Association: probably represents channel facies, and occurs in the Dome Formation, but rarely in the Beatty and Hoyle Formations.

ALLUVIAL -FLUVIAL CONGLOMERATE Association: These facies are indicative of stream flow in Member A of the Dome Formation, Members A and B of Three Nations Formation, Member C of Whitney Formation and probably in Member A of the Hoyle Formation.

SHELF SANDSTONE (ARKOSE) Association: probably represents shallow-water deposition and shows features indicative of wave reworking and periodic quiet water. These occur mainly in the Three Nations Formation (Member A), and rarely in the Whitney formation (Member C) .

GRAVELY BAR Association: matrix-supported conglomerates that are interbedded with the shelf arkose assemblage. These occur only in the Three Nations Formation.

The list shows that many of the facies associations occur within more than one formation, and thus similar depositional conditions occurred over a span of up to 40 MY. A more detailed approach is needed, however, to work out a precise depositional history and to derive some meaningful interpretations for the lithofacies that make up each facies association.

Lithofacies mapping utilizing 14 km of section, in conjunction with the recognition of any unconformable relationships, are the main methods of basin analysis for most of the sedimentary strata of the Abitibi Greenstone belt in the Timmins area. To facilitate the recognition of lithofacies and larger sedimentary cycles, detailed descriptions of some sedimentary parameters, such as bedding thickness and the percentage of mudstone beds, have each been classified into four different types. All strata, regardless of depositional environment, have been classified in this manner to maintain a consistent nomenclature. This approach, which is particularly valid for turbiditic sandstones, makes for an easier interpretation of the depositional environment within any turbidite fan model. Thus, the type of turbidite can be determined partly on the basis of bedding thickness and the percentage of mudstones (Reading and Richards, 1994):

Bedding Thickness

Type 4 (abyssal or distal type)	laminated	<1 cm
Type 3 (distal type)	very thinly bedded	1-10 cm
Type 2 (medial to distal type)	thinly bedded to medium bedded	10-50 cm
Type 1 (proximal type)	thickly bedded	50-100 cm
Type 1 (proximal type)	very thickly bedded	>100 cm

also ,Turbidite type based on the percentage of mudstone beds

Type 4 (abyssal or distal type)	mudstones	>70% mud
Type 3 (distal type)	muddy turbidite	30-69% mud
Type 2 (medial to distal type)	regular turbidite	6-29% mud
Type 1 (proximal type)	sandy turbidite	<6% mud
(sandstone facies)		

A combined nomenclature is as follows:

(1-1) TBTE signifies a very thickly bedded to thickly bedded turbidite containing <6% mudstone beds: typical of proximal turbidites (sandstone facies).

These classifications, together with other pertinent stratigraphic data such as unit thickness, tops indicators and bedding, etc., are compiled as graphic logs in Appendices 1 to 5 for all measured sections including outcrop (MS or PS) and drill core (all other prefixes): Each appendix contains all the sections for that particular formation.

The distribution of measured sections is widespread and covers an east to west distance of 80 km and a north to south distance of 50 km; a lack of exposure makes most correlations difficult. Most sections, including drill core and outcrop, display stratigraphic younging directions throughout. Fold repetition of stratigraphy on the scale of a few metres, which is represented by consistent changes in the younging direction of the sediments as shown by grading and/or loading structures, occurs in only a few sections. Variations in the stratigraphic sequence along regional strike, and to an extent across strike, thus record original differences within the basin. In total, there are about 30 measured sections from outcrop and another 40 measured sections from drill holes. Figure 2.2 shows the legend and symbols for measured sections in all subsequent figures and appendices.

Figure 2.2 A Unified legend and symbols for all stratigraphic sections: in all figures and appendices; Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

Figure 2.2 B Unified legend and symbols for all stratigraphic sections: in all figures and appendices: Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

LITHOLOGIC VARIATIONS

Classification of Turbidites based on percentage of mudstone beds

Mudstones (abysal or distal type)	Type 4	> 70% mud
Muddy Turbidites (distal type)	Type 3	> 30% mud
Regular Turbidites (medial to proximal type)	Type 2	21-30% mud
	Type 2	11-20% mud
	Type 2	6-10% mud
Sandy Turbidites (proximal type): sandstone facies	Type 1	< 6% mud

% mud

Bedding features symbols and lithologies

	split core
	mudstone beds
	breccia
	mud chips
	pebbles
	carbonatized
	Pyrite
	strained
	flow tops
	megaclasts
	rafted clasts
	coarse-tailed fining up
	fining up
	coarse-tailed coarsening up
	sheared
	fuchsite chips
	gravel bars
	agglomerate
	thickening-up cycle
	thinning-up cycle
	sheared
	imbrication
	mudcracks
	reactivation surfaces
	mud drapes
	loadcasts
	fault
	coarsening up
	fining up
	major scour at base of channel
	chaotic bedding
	low-angle tabular bedding
	convolute bedding
	high angle planar crossbeds
	hummocky cross-stratification
	planar-tabular bedding
	herringbone cross-stratification
	climbing ripples
	lenticular bedding
	oscillatory ripples
	wavy parallel bedding
	trough cross-stratification
	flaser bedding
	current ripples

BEDDING THICKNESS

Classification of Turbidite based on thickness of bedding

	amalgamated bedding contact
	erosional bedding contact
Type 4 (abysal or distal type)	α laminated (< 1 cm)
Type 3 (distal type)	β very thinly bedded (< 10 cm)
Type 2 (medial or distal type)	γ thinly bedded to medium bedded (10-50 cm)
Type 1 (proximal type)	δ thickly bedded (50-100 cm)
Type 1 (proximal type)	ϵ very thickly bedded (> 100 cm)

COMBINED NOMENCLATURE

(1-1) TBTE= very thickly bedded or thickly bedded Turbidite containing $< 6\%$ mudstones
(proximal turbidities: sandstone facies)

Tisdale Group

Whitney Formation

Introduction

These sedimentary rocks, which represent the oldest sedimentary rocks of the local sequence, are intimately associated with volcanics, and as such are a product of synvolcanic sedimentation, i.e. they either underlie or are intercalated with volcanic rocks, mainly mafic volcanic flows, mafic to felsic tuffs, and reworked tuffs. This formation, which occurs to the east of South Porcupine, extends eastward to Nighthawk Lake, and south from the Porcupine Destor Fault to the junction of Goose Creek and Nighthawk Lake (Figure 2.1). This represents an area of approximately 9 km by 5 km (Figures 2.3 and 2.4). Approximately 1100m of section were examined to prepare 12 representative sections (Figure 2.4) as a basis for inferring depositional environments for this formation (Appendix 1). The folded nature of the sedimentary strata makes correlation either very difficult or impossible, but the local environments can be identified and interpreted. A range of environments can be deduced for the Whitney Formation without actually correlating all of the sections. These differing depositional environments are designated by several new stratigraphic subdivisions, known as Member A, B, and C.

Description and Interpretation

Member A of the Whitney Formation

Sections Ti 360, and Ti 363 (Figures 2.5 and 2.6), which are located near Nighthawk Lake at the eastern edge of the formation, both show minor pyroclastic rocks intercalated with epiclastic rocks (Appendix 1). Otherwise, the sedimentary succession suggests that a mid fan sandlobe from a nearby fan prograded over deep-water mudstones (i.e. distal facies). It also shows a clear

Figure 2.3 A Location of the grids which show all of the measured sections by formation and the relative distribution within the geographic limits of each formation; Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

Figure 2.03B Location of the grids which show all of the measured sections by formation and the relative distribution within the Greenstone belt, Timmins, Ontario.

Figure 2.5
Detailed sedimentary features of Member A
- Whitney Formation, Tisdale Group

Figure 2.6

Representative sections of the Whitney Formation, Tisdale Group; Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

WHITNEY FORMATION			Bouma Divisions			
Section	type	%	Base	Top	Facies	
363	(2-3) TBTE	4	165	171	Tde	Do
	(2-3) TBTE	19	138	165	Tde	Do
	(3-2) TBTE	21	108	138	Tde	Do
	(3-4) TBTE	28	68	108	Tde	Da
	(3-2) TBTE	2	65	68	Tab	C
	(4-4) TBTE	10	50	65	Tde	Do
	MVLC	6	42	50		
	(3-2) TBTE	7	32	42	Tde	Da
	MAFIC TUFF	3	28	32	Tab	C
MS-15A	(2-2) TBTE	64	15	42		C
	(3-3) TBTE	19	7	15		Do
	(3-4) TBTE	17	0	7		Da
MS-15B	(3-1) TBTE	43	17	30	Ta, Tae	B
	(3-3) TBTE	33	7	17	Tde	Do
	(3-1) TBTE	23	0	7	Ta, Tae	B
MS-15C	(2-1) ARNT	15	62	68		
	(3-4) SLST	36	48	62		SF
	(2-1) TUFF	41	32	48		Al
	Covered		3	32		
	(1-2) CGLM	8	0	3		
MS-9	MVLC FLOWS		126	130		
	MVLC TUFF	6	124	126		
	(2-1) TBTE	8	121	124	Ta, Tae	B
	(4-3) TBTE	56	101	121	Tde	Do
	(2-1) TBTE	14	96	101	Ta, Tae	B
	(3-3) TBTE	6	94	96	Tde	Do
	(1-1) TBTE	11	90	94	Ta, Tae	B
	OVERBURDEN		80	90		
	total seds					

Table 2.1 A summary of stratigraphic subdivision for sedimentary strata in sections Ti 363, MS-15A, 15B, 15C, and Ms-9: Whitney Formation, Tisdale Group. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

affinity for tuffs overlying mudstones ($\pm$ graphite), which is indicative of either volcanic deposition either during periods of quiescence, or at a distance from the turbidite fan.

Section Ti 360 (Appendix 1) shows a more complex arrangement of pyroclastic lithofacies interbedded with epiclastic sandstone, mudstone and siltstone beds (Figure 2.5): all lithologies are either very thinly bedded or rarely laminated. The percentage of tuffaceous beds ranges from 10 to 20% in sections where pyroclastics are interbedded with epiclastic lithologies. In the middle of the section, a progradation of Facies C turbidites of Mutti and Ricci Lucchi (1972) indicates that mid-fan facies overlie finer-grained outer fan deposits, which are represented by a coarsening-up cycle in the lower part of the section (70-120m). The occurrence of abundant loading and dewatering structures in the upper part of the section, however suggests that these fine-grained facies may represent slope facies, which are transitional between the fan facies (middle part) and abyssal plain deposits (not shown in this section). Pyroclastic beds are intimately interbedded with Facies D_O (outer fan) turbidites in the finer-grained portions of the section. Figure 2.5 shows a more detailed view of the measured section, with pyroclastic interbeds most common in the upper and lower parts of the section. In addition to these intercalations, there also are some interbeds of mudstone units (1-6m thick), without pyroclastic material. The depositional cycles appear to be 10-20 m thick in the lower part of the section, and 6-10m thick in the upper parts. The middle part of the section, which clearly shows a fining-up trend and increased mud content, represents a section of about 70 m of epiclastic strata with some intercalated tuffaceous beds, muddy turbidites and minor graphitic mudstone. Sedimentary cycles, which appear to range in thickness between 5 and 10m, are similar in thickness to the lower part of the section.

Pyroclastic beds are underlain by, and intercalated with, a 25 m thick section of epiclastic rocks in section Ti 3236 (Appendix 1). The general succession of epiclastic rocks is sandwiched between the underlying ultramafic flows and an overlying mafic tuff (Figure 2.6) that has a minimum thickness of 30 m. The epiclastic rocks consist mainly of sandy turbidites (sandstone facies or Facies B) overlain by a thin unit of turbidites of Facies C. These sediments were deposited in an inner fan region of the turbidite fan. Thinning-up and fining-up trends occur on a scale of a few metres.

Member B of the Whitney Formation

Section Ti 3489 is considered typical among several sections (Table 2.1) that are representative of Member B, such as MS-15 A, 15B, Ti 3489, Ti 3235, Ti 3236, Ti 1841, (Figures 2.6 and 2.7), Ti 1398, and MS-9 (Plate 1.A).

Section Ti 3489 contains several turbidite facies, namely C, B and D, in order of decreasing abundance, but no intercalated pyroclastic beds. This 100 m section, which is overlain by mafic and ultramafic flows (Appendix 1), shows an overall thinning-up trend as well as several thinning-up and fining-up trends on a local scale. For this section, a mid-fan depositional environment is postulated, within which progradation of inner fan sandstone deposits (10m thick) occurred both at the base and at the top of the sedimentary section.

A similar relationship can be seen in section Ti 1398, where sandy turbidites underlie ultramafic flows (Appendix 1). This facies arrangement may also indicate shallowing from a fine-grained to a massive sandstone facies accompanied by subaqueous volcanism in the uppermost unit.

PLATE 1:
OUTCROPS OF TURBIDITES FROM THE TISDALE GROUP (WHITNEY FORMATION), AND FROM THE
PORCUPINE GROUP (BEATTY AND HOYLE FORMATIONS)

(PLATE 1.A):

Outcrop of turbidites (sandstone facies with <6% mudstones) from the Whitney Formation-Member B. These represent inner fan deposits in MS-9 (Whitney Township). Scale card is approximately 10 cm long; stratigraphic tops are to the left.

(PLATE 1.B):

Outcrop of turbidites (sandstone facies with <6% mudstones) from the Beatty Formation. These represent inner fan deposits in MS-1 (Tisdale Township). Scale card is approximately 10 cm long; stratigraphic tops are to the left.

(PLATE 1.C):

Drill core of graphitic turbidites (muddy facies with >30% mudstones) from the Hoyle Formation-Member C. These represent distal fan deposits (Hoyle Township). Scale card is approximately 10 cm long; stratigraphic tops are to the left.

(PLATE 1.D):

Outcrop of turbidites (regular turbidite facies with 6-30% mudstones) from the Dome Formation-Member B. These represent mid fan deposits in MS-2 (Whitney Township). Scale card is approximately 10 cm long; stratigraphic tops are to the left.

Figure 2.7
Detailed sedimentary features of Member B (Ti 3235) - Whitney Formation,
Tisdale Group

Member C of the Whitney Formation

MS-15C (Appendix 1), which is unlike section 15A or 15B, contains pyroclastic and volcanic rocks and sediments that show several features suggestive of a different style of sedimentation than elsewhere in the Whitney Formation. The basal units in this 70m section (Table 2.1) (Figure 2.6) are a basal conglomerate and an overlying arenite, both with traction features and thick bedding. The clast-supported conglomerate, which consists mainly of siltstone clasts up to 8 cm size and a coarse-grained sand matrix, is cut by a porphyry dyke. Because several unusual clast types and the cross-cutting porphyry dyke at this locality have not been observed by the author in any of the younger sedimentary strata in the Timmins area, a relatively old age for these sediments is suggested.

A 20m thick section of tuffs and lapilli tuffs, which overlies the basal conglomerate unit, contains scours, cross-laminations and mud layers that suggest sedimentary reworking, possibly in a subaerial (fluvial) environment. The upper part of section MS-15C consists of trough cross-bedded sandstones that show abundant traction features typical of fluvial, stream flow environments, such as scours, grading and cross-bedding with thinly to thickly bedded cosets. Interbedded siltstones near the base of the sandstone section suggest that these represent quiet water conditions with either overbank or flood-stage deposits in a fluvial environment, or quiet water in a shallow depositional environment.

Section MS-15C (Figure 2.6) is unique for the Whitney Formation because it shows a lithofacies arrangement that supports a fluvial to very shallow-water depositional environment. The interbedded tuffs, which show characteristics of sedimentary reworking, suggest that these volcanics could also be subaerial. Siltstone conglomerate clasts at the base of the sequence indicate both uplift and the existence of an earlier (older) sedimentary sequence probably dominated by

quiet-water depositional environments. In summary, MS-15C represents subaerial deposition of both epiclastic and pyroclastic rocks in an otherwise deeper-water depositional environment within the Whitney Formation: neither these features nor this interpretation have been previously reported. The unique nature of this section warrants a new (informal) stratigraphic subdivision, here named Member C of the Whitney Formation. This unit lacks both lateral and vertical continuity to warrant the status of a formation.

Discussion

Lithologic components of the Whitney Formation include epiclastic and pyroclastic sediments and volcanic flows, and intercalations of all three deposit types (Figures 2.6). Probable depositional environments range from deep-water turbiditic to fluvial, or possibly shallow water (marine shelf). Some of the pyroclastics are intercalated with trough cross-bedded arkoses of typical fluvial facies, and may represent subaerial volcanics. The occurrence of the fluvial facies in association with volcanics and pyroclastics appears to be more common along the eastern edge of the Whitney Formation near Nighthawk Lake. This facies arrangement suggests that the deepest part of the basin is to the west. Unfortunately, the limited paleocurrent data (see Figure 2.38) for the Whitney Formation indicate that transport was to the northeast, rather than to the west, which probably represents transport towards deeper water.

Most sedimentary sections show thinning- and fining-up patterns on a local scale as well as on the scale of the stratigraphic unit. Positive megasequences, shown by fining and thinning trends, predominate over coarsening- and thickening-up that are characteristic of negative megasequences.

In summary, the Whitney Formation represents a pre- to syn-volcanic sedimentary sequence which comprises a minimum of 100m of turbidites underlying mafic volcanic flows at one location, whereas the maximum thickness of epiclastic rocks exceeds 200m in several drill holes (Figure 2.7). The

total thickness of the original and undeformed Whitney Formation is, however, difficult to estimate because of fold repetition and shallow-dipping strata near Nighthawk Lake, and may be in excess of 1000m. The upper contact of the Whitney Formation is exposed in outcrop, but the lower contact of pillowed, mafic volcanic flows of the Tisdale Group is largely inferred from drill hole data.

Distribution of various turbidite facies throughout the representative sections suggests that Facies C, D and B occur in that order of abundance: thus inner fan, mid fan, outer fan, abyssal plain and possibly slope facies have been identified. Progradation and retrogradation of inner fan facies is documented in many of the sections. The exact interpretation of the facies shifts within the inner fan varies depending on the depositional model. If the model is a submarine fan with a point source, then these data would indicate progradational and retrogradational facies shift of the same fan throughout the basin. The repeated nature of this facies shift in the vertical dimension also suggests that several channel migrations are recorded in the sedimentary sequence of the Whitney Formation. However, conglomeratic, inner fan deposits (Facies A) have not been identified within this formation. An alternative explanation for rapid and repeated inner fan progradations means that these units represent inner fan deposits from different fans (i.e. a multiple source or ramp model).

Porcupine Group

Beatty Formation

Introduction

Sedimentary rocks of the Beatty Formation, which occur only in the Porcupine syncline (Tisdale Township), directly overlie the Krist volcanoclastic-pyroclastic unit. They represent the first major sedimentary unit that was formed after the cessation of volcanism and the first sedimentary unit interpreted in a subsequent section to be deep water. Although the lower contact of the Beatty Formation is not exposed along the northern margin, pillowed, mafic volcanic flows of the Tisdale Group are in close proximity to the base of the formation. The upper contact of the formation is an angular unconformity with the overlying Dome Formation.

Approximately 1300m of section was examined from 6 representative measured sections to determine the sedimentary characteristics and depositional environments of this formation (Appendix 2). The measured sections (Figure 2.3) occur within a 4 by 2 km area of Tisdale Township (Figure 2.8). Folding of the sedimentary strata makes correlation difficult, but the depositional environments can be locally identified and interpreted for the Beatty Formation, without actually correlating all of the sections (Figure 2.9).

Description and Interpretation

The most westerly section is MS-12C (Appendix 2A and 2B). Several detailed intervals from this section are shown in Figure 2.10. Essentially all of section 12C, except the uppermost unit, consists of sandy turbidites (sandstone facies), typical of Facies B of the inner fan association, with T_a and T_{ae} type turbidites. The types of upward facies transitions range from Facies A, C, D in

Figure 2.8 Location grid for all measured sections of the Beatty Formation-Porcupine Group, Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

ms-12c (detailed)
 Beatty Fm. sediments:
 part of the porcupine syncline
 (mainly south-facing limb
 of the syncline)

TYPE	m	base	top
Ta (3-2) TBTE	10	500	510
(1-1) TBTE	25	475	500
(1-1) TBTE	25	450	475
(2-1) TBTE	10	440	450
??(2-1) TBTE	35	405	440
(2-1) TBTE	15	390	405
(1-1) TBTE	30	360	390
??(2-1) TBTE	80	280	360
(2-1) TBTE	6	274	280
?? (2-1) TBTE	14	260	274
Ta (2-1) TBTE	72	188	260
(1-1) TBTE	22	166	188
(2-1) TBTE	14	152	166
(1-1) TBTE	32	120	152
COVERED	104	16	120
(2-1) TBTE	16	0	16

Figure 2.10 C

Detailed sedimentary features of the Beatty Formation (MS-12C) , Porcupine Group

Figure 2.11
Representative sections of Beatty Formation (Ti 1368, 1369 and 1370), Porcupine Group

section Ti 1368, to Facies A,D in Ti 1370, to Facies D overlain by C in Ti 1369. These relationships indicate that inner fan facies (Figure 2.11) were displaced through time by mid-fan facies and outer fan deposits. The facies arrangement in section Ti 1370 suggests that parts of the mid-fan facies were either eroded or never deposited. This may also indicate that avulsion or migration of the channel occurred. The upper part of the local section (100-120m thick) largely shows an upward decrease in mudstones, which is probably indicative of progradation of mid-fan facies over deep-water mudstones.

In summary, the vertical arrangement of rock types indicates that a retrogradation of inner fan and mid-fan lithologies (Facies A and C), respectively, is followed by outer fan (Facies D_o) and abyssal plain deposits (Facies D_a). The last event, a progradation of the mid-fan facies, is indicated by the lithological changes in section Ti 1369.

MS-1, which is located along the northern margin of the Beatty Formation, represents a 390m thick section of the Beatty Formation (Appendix 2) and a 64m thick section of the overlying Dome Formation (figure 2.9). Preliminary interpretations of MS-1 (north of South Porcupine) indicates that it contains an angular unconformity representing a major hiatus between the older sedimentary rocks of the Beatty Formation (Porcupine Group-2.7 Ga) and those of the younger (2.68 Ga) Dome Formation (Pamour Group) (Corfu et al, 1991). Conglomerates of the Dome Formation and the underlying unconformity will be discussed in a latter section. This previously described unconformity (Pyke, 1982), separates underlying deep-water turbiditic sediments from overlying alluvial-fluvial strata. Several detailed intervals representative of the lower, middle and upper parts of the section show many similarities and a few differences (Figures 12A,B, and C).

Figure 2.12 B

Detailed sedimentary features of
section MS-1- Beatty Fm.,
Porcupine Group

The lower 300m of MS-1 is a predominant inner fan (Plate 1.B) association (Facies B), overlain by mid-fan deposits (Facies C) and containing some isolated and thin channels in the upper 90m of the turbidite section (Figure 2.12). This turbidite facies association can be interpreted as an assemblage of sandstone bodies (channel Facies B) capped by a series of trendless turbidites of Facies C that represent deposition on the slope or deep water plain. This can be attributed to a switching of distributary mouth channels that was caused by either avulsion or a gradual abandonment of the channel onto the lower slope face.

PS-20 represents a short (20m) outcrop section (Appendix 2) that is typical of the lower 300m of the Beatty Formation, and similar to lower parts of section MS-1. Facies B, the predominant facies type (sandstone facies), may characterize deposition on the inner fan portion of a turbidite fan.

Discussion

Turbidites characteristic of a deep-sea environment are the principal lithofacies of the Beatty Formation. A possible model is a submarine fan with a single point source, but the high frequency of inner fan deposits suggest that a multiple source ramp is a more likely depositional model. A variety of lithofacies have been identified, namely, inner fan, mid fan, outer fan, slope and abyssal plain.

Most lithofacies represent inner fan deposits dominated by Facies B with several, thin intervals of Facies C, which are mid-fan deposits. Along the northwest margin of the formation, an upward transition of Facies A, C, D₀ and C is suggestive of channel abandonment with time, and subsequent but minor progradation of a mid fan facies over deep-water sediments of the abyssal plain. The youngest strata of the formation were generally deposited in distal and quiet water environments representative of either the abyssal plain or the outer fan.

Conglomerates representative of Facies A are interpreted as inner fan deposits within the Beatty Formation. These inner fan facies may be largely correlative with Facies B, both in MS-12C and MS-1 (Figure 2.9), which contain inner fan deposits that represent a less proximal channel environment with characteristic sand-rich lithologies and an absence of conglomerate.

The predominance of thinning- and fining-up patterns on a local scale suggests that the turbidite sequences are mainly characterized by positive megasequences (Mutti and Lucchi Ricci, 1972), which infers either channel abandonment, or the filling of a submarine channel on a local scale.

Porcupine Group

Hoyle Formation

Introduction

Approximately 3300m of strata from 23 measured sections (Figure 2.13) were examined to determine the sedimentary characteristics and depositional environments of this formation (Appendix 3). Almost all of the sections are from drill core, because outcrop exposures of the Hoyle Formation are rare. Measured sections cover an area of 80 km in an east-west direction, and 50 km in a north-south direction (Figure 2.3); however, all but 4 sections are in an area that represents only 20% of this larger area. These 19 sections are located to the east and northeast of Timmins (Figure 2.13). The formation (Figure 2.1) covers a large area north of the Porcupine-Destor Fault zone, a deformation zone of regional significance. The western limits are the edge of the volcanic assemblage to the west of Kidd and Denton townships, whereas the eastern border, which is the eastern limit of German Township (near Highway 67), represents the arbitrary eastern limit for this study: The Hoyle Formation actually continues eastwards towards Matheson. The northern limit of the formation is similar to the western margin, namely the (southern) edge of the volcanic terrane, which continues farther to the north. Most of the sections are near the margin of the basin, just above mafic volcanic flows, or rarely above fragmental felsic volcanics, which probably represent pyroclastic lithologies.

Folding of sedimentary strata makes correlation very difficult on a local scale, and nearly impossible on a basin-wide scale, but the local environments can be identified and interpreted. A range of environments can thus be inferred for the Hoyle Formation without actually correlating all of the sections. Three Members, namely A, B and C, have been distinguished.

Description and Interpretation

Member A of the Hoyle Formation

Turbidites of the Hoyle Formation can be seen in most places to clearly overlie the adjacent mafic volcanic flows. Such spatial relationships, however, are less clear along the western margin of the basin in the vicinity of Kidd Township. These strata are tentatively considered as several separate stratigraphic units, namely Members A, B, and C, because of major differences in sedimentary characteristics and the uncertain spatial relationships of strata along the western margin in comparison to the rest of the formation. These new units are here designated Member A and B of the Hoyle Formation, rather than separate formations, because their lateral extents are largely unknown. The current data base suggests that these units lack the basin-wide mappability necessary for ranking as formations.

Several drill hole sections, namely sections K54-24, K54-25, and K54-30 (Appendix 3), are located in Kidd Township (Figure 2.3). These sections, which largely characterize the northwestern margin of the deep-water turbidite basin, are several kilometres west of the Kidd Creek Mine (Figure 2.1). Sedimentary strata from Member A are presumably correlative with some of the distal turbiditic sandstones that unconformably overlie the (VMS) volcanogenic massive sulphide deposit (Bleeker and Parrish, manuscript submitted), and which probably belong to the Hoyle Formation.

Three overlapping sections contain 600m of sedimentary strata, and represent a section with a true thickness of about 430m.

In summary, Member A of the Hoyle Formation consists of a 430m thick package of epiclastic rocks, which are intercalated with lesser volcanic rocks in the upper parts. The lower sequence, which is a 124m thick stratigraphic unit, consists of graphitic mudstones (Figure 2.14) of abyssal plain deposits

Figure 2.13 Location grid for all measured sections of the Hoyle Formation - Porcupine Group; Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

(Facies D_a), with minor incised sandy turbidite (Facies B) and conglomerate (Facies A) channels. The middle sequence mainly consists of Facies D_o and D_a, which are characteristic of abyssal plain and outer fan deposits, together with some inner fan (Facies B) and midfan deposits (Facies C) at the base and top of the 136m sequence.

Mafic volcanic flows and intercalated conglomerates, which are representative of proximal inner fan deposits, define the unique characteristics of the upper sequence within the composite section (Figure 2.15). Facies shifts in sections of the lower sequence are attributed to minor episodes of progradation of inner fan facies over abyssal plain sediments. Only mid-fan facies prograded over the predominant abyssal plain and outer fan facies in the middle sequence, whereas inner fan facies of the proximal type, dominate the upper sequence: these indicate major progradation of a submarine channel. Most conglomerate units, which probably represent debris flows, are characterized by mud matrix and large sedimentary and mafic volcanic clasts up to 8 cm. These proximal inner fan deposits, which contain such large clasts, could represent channels that are close to their source.

Figure 2.14 Detailed sedimentary features of Member A- Hoyle Formation, Porcupine Group

Figure 2.15 Detailed sedimentary features of the upper part of Member A- Hoyle Formation, Porcupine Group

Member B of the Hoyle Formation

The westernmost section, represented by PS-19 (Appendix 3), is an outcrop section in Denton Township with a vertical thickness of 200m (Figure 2.16). The basal part of the section consists of felsic volcanic flows overlain by conglomerates and sandstones in an 18m-thick package with sandy turbidites between an upper and lower conglomerate (Gms facies). "Regular" turbidites (with 6% to 30% mudstone) overlain by sandy turbidites (sandstone facies with <6% mudstone) make up the remaining lower half of the section. The upper 30m of the section consist of sandstones and minor conglomerates typical of Facies B with rare mudstone interbeds (<1%). An upward facies succession of A, B, A, C, and A in the lower half of the section is overlain at the top of the section by Facies B with minor conglomerates. This facies shift documents an initial progradation and subsequent retrogradation of inner channel facies (Facies A and B), followed by mid fan deposits of Facies C and a second progradation of inner fan deposits (Facies B) in the upper half of the section; inner fan facies represent greater than 80% of the entire section.

Variations in grain-size and bedding outline a general fining-and thinning-up trend in the lower half of the section, whereas the upper 30 m of the section mainly consists of thickly bedded (.5-1m) sandstones of uniform grain size. Other sedimentary features are difficult to identify due to the strained and tectonized nature of the rocks: this section is located near a prominent E-W deformation zone.

Figure 2.16 Detailed sedimentary features of
Member B (PS-19)- Hoyle Formation, Porcupine Group

Member C of the Hoyle Formation

East of Murphy Township, the Hoyle Formation consists of turbidites, which consistently overlie mafic volcanic rocks that are similar to the Tisdale Group. This makes the sequence part of a basin that formed after the cessation of volcanism, presumably less than 2.7 Ga ago.

All sections except PS-33, which is an outcrop section, represent drill core from Hoyle, Matheson, Whitney, Evelyn and German townships (Figure 2.13). Many of the holes are in the vicinity of the Hoyle Pond Mine, to the northeast of Timmins in Hoyle Township (Appendix 3).

Correlation and interpretation of local sedimentary sequences in a poorly exposed area is only possible when an area contains several drill holes in close proximity. On the basis of the spatial distribution of sections into such geographically separated clusters, several local correlations and interpretations have been made for the following areas, which are listed (Table 2.2) in a west to east direction as: Bell Creek (2 sections-Figure 2.17); Hoyle Pond (10 sections-Figure 2.18), Northern Evelyn (2 sections-Figure 2.23), Southern Evelyn (2 sections-Figure 2.24), and the Esker Lake (3 sections -Figure 2.25, 2.26A, and 2.26B) sequences, respectively. The latter sequence represents strata from the upper part of the member.

Various lithofacies, namely Facies B, C, D_a, and D_o, each define the base of the Hoyle Formation by directly overlying mafic volcanics at different localities near the Hoyle Pond Mine. Only a few thinning-and fining-up trends, which mainly occur in sections with inner fan deposits (Facies B) at the base, have been recognized within the basal unit of the Hoyle Formation. Proximal inner fan deposits defined by conglomerates (Facies A) occur only in one section

Member C: Hoyle Formation					Bouma Divisions	
Section	type	% Base Top			Facies	
12 09	(1-2) TBTE	17	44	36	Tabe	C
	(1-1) TBTE	83	84	44	Tae	B
	MVLC		90	84	flows	
15-62	(1-2) TBTE	4	313	315	Tabe	C
	(1-2) TBTE	47	289	313	Tabe	C
	(1-2) TBTE	8	285	289	Tabe	C
	(2-3) TBTE	10	280	285	Tde	Do
	(4-4) TBTE	16	272	280	Tde	Da
	MVLC		233	272	flows	
	(4-4) TBTE	16	225	233	Tde	Da
	QFP		220	225	flows?	
3568	(2-2) TBTE	4	166	170	Tbe	C
	(3-3) TBTE	13	154	166	Tde	Do
	(2-3) TBTE	20	136	154	Tde	Do
	(1-1) TBTE	4	132	136	Ta,Tae	B
	(2-3) TBTE	33	102	132	Tde	Do
	(2-3) TBTE	18	86	102	Tde	Do
	(1-1) TBTE	2	84	86	Ta,Tae	B
	(4-4) TBTE	4	80	84	Tde	Da
	MVLC		76	80	flows	
	Fault Brx		56	76	pyroclastic	
	Felsic Tuffs		38	56	pyroclastic	
23-23	(2-3) TBTE	50	66	54	Tde	Do
	(3-4) TBTE	50	78	66	Tde	Da
	MVLC		84	78		

Table 2.2 Summary of stratigraphic subdivision for sedimentary strata in sections H 12-09, H15-12, M23-23 and Ti 3568: all sections are from Member C of the Hoyle Formation, Porcupine Group. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

Figure 2.17 Representative sections from the Bell Creek Area:
Member C of the Hoyle Formation, Porcupine Group

Figure 2.18
Representative sections
from the Hoyle Pond area:
Member C of the Hoyle
Formation, Porcupine
Group

Figure 2.19 Detailed sedimentary features from the Hoyle Pond area (sections HP 2185 and TI 3561): lower part of Member C- Hoyle Formation, Porcupine Group;

near Hoyle Pond Mine, but are absent from the other 22 sections; these conglomerates are at least 16m above the mafic volcanics. Sulphide-rich clasts represent a rare lithology that does not occur in other sections of the Hoyle Formation. Thick bedding is characteristic and some reverse graded bedding occurs near the upper contact.

Mudstones, which directly overlie the volcanics, commonly form the base of coarsening-up and some thickening-up sequences (the latter is best illustrated in section Ti 3568, Figure 2.18).

Three sedimentary sections in the vicinity of the Hoyle Pond Mine lack mafic volcanics at the base. These sections, namely, M21-10, M51-1 and Ti 1841, represent strata from the Hoyle Formation (Figure 2.20), at some undetermined distance above the underlying mafic volcanics.

Correlation among these three sections show that Ti 1840 is similar to the upper part of either M21-10 or 51-1, but the latter two sections are not correlatable, and thus probably represent different stratigraphic intervals totaling at least 400-500m (Figure 2.21). This total thickness assumes no overlap nor large stratigraphic interval between the sections. The first assumption is probably correct, but the second assumption is difficult to prove because of folding and possible faulting of the sedimentary strata subsequent to deposition. The sandy turbidites that occur at the base of section M21-10 and at the top of section M51-1 possibly represent the same depositional unit, or the upper and lower parts of the same depositional unit. In either case, this facilitates stratigraphic reconstruction of a composite section with M51-1 overlain by M21-10. This epiclastic succession occurs at some distance above the basal contact, possibly within the middle part of the Hoyle Formation. An analogous reconstruction can be made with M51-1 overlying H16-12, which represents the basal unit of the

Figure 2.20
Representative sections
from an area east
of Hoyle Pond : Member C
of the Hoyle Formation,
Porcupine Group

Figure 2.21 A
Detailed sedimentary features from the Hoyle Pond area (section M21-10 and M51-1): middle part of Member C- Hoyle Formation, Porcupine Group

Figure 2.21 B
Detailed sedimentary features from the Hoyle Pond area (section M21-10 and M51-1): middle part of Member C- Hoyle Formation, Porcupine Group

Hoyle Formation (0-100m thick) in the Hoyle Pond area (Figure 2.22). Facies C represents the depositional unit that likely connects both sections in a manner similar to that described above. If these assumptions are correct, then the stratigraphic succession of H16-12, M51-1, and M21-10 represent a 500-600m sequence of the Hoyle Formation in this area. This composite section (Figure 2.22) records a minimum of five major progradations of inner fan deposits (Facies B). These mostly prograde over mid fan deposits (Facies C), or rarely over mid fan deposits intercalated with outer fan deposits (Facies D_O). Several sandy turbidite units are also intercalated near the top of the sequence with regular turbidites (Facies C) typical of mid fan deposits throughout a 100m section. The basal unit of the formation records only one major progradation of inner fan deposits (Facies B), and that is over mafic volcanic flows, whereas the overlying 400-500m of strata record another 4 major progradations, approximately one for every 100m of the sequence. These progradations probably mark deposition during major low stands of the turbidite fan system. Again, this type of frequency probably indicates the presence of a multiple source ramp, rather than a single point source for a single turbidite fan. The simplest turbidite fan model is considered here to be the one that is most appropriate for deformed terranes, especially Archean sedimentary terranes (see Chapter 1).

The composite stratigraphic section from the Esker Lakes area represents the upper part of Member C as well as the upper part of the Hoyle Formation (Figures 2.25, 2.26 A, 2.26B). The upper sequence is similar to the middle sequence, because inner fan deposits prograde over mid fan facies (i.e. Facies B over D) in the uppermost part of the section, elsewhere they prograde over outer

Figure 2.22

Detailed sedimentary features from the Hoyle Pond area:
a composite of the lower and middle part of Member C- Hoyle
Formation, Porcupine Group

Figure 2.23
Representative sections from the northern Evelyn area:
Member C of the Hoyle Formation, Porcupine Group

Figure 2.24
Representative sections from the southern Evelyn area: Member C of the Hoyle Formation, Porcupine Group

Figure 2.25

Representative sedimentary sections from the Esker Lake area: Member C of the Hoyle Formation, Porcupine Group

fan deposits (i.e. Facies B over C). In total, the lower, middle and upper sequences record 1, 5, and 8 major progradations of Facies B, respectively, in addition to 3 minor progradations of the same type in the lower sequence. This trend reflects an evolution of the depositional environment with time to inner fan deposits, which may represent periodic low stands within the deep-water turbiditic basin. In fact, such stratigraphic changes suggest that mid fan, outer fan, and inner fan deposits dominate the lower, middle and upper sections of this sequence, respectively. Alternatively, these progradations could be due to multiple fans.

Discussion

Turbidites represent the principal deposits within Member A, B and C of the Hoyle Formation. A variety of lithofacies have been identified within these deposits, namely, inner fan, mid fan, outer fan, slope and abyssal plain.

Most interpretations stem from a model based on a single point source for a single submarine fan, but the frequency of repeated progradations suggests that several point sources likely supplied the inner fan deposits, rather than repeated tectonism or repeated eustatic sea level changes. The lack of proximal inner fan deposits (conglomerates) suggests that many systems may have developed at the expense of a single, very large turbidite fan containing a well-developed inner fan. Thus, a multiple source model incorporating a turbidite ramp represents a more likely scenario than a model with a single source for a single turbidite fan.

PS-19 has been designated as a separate Member, namely Member B, because of unique sedimentary characteristics that differ from those of other lithologies in the Hoyle Formation (i.e. Member C). The close proximity of Member A and B (Figure 2.1 and 2.3) along the western margin of the basin suggests that they share a close genetic relationship, in spite of minor differences in facies. One of the distinguishing features of Member B is the predominance of

inner fan facies, rather than other parts of the turbidite fan. Most lithofacies from PS-19 and the upper sequence of Member A represent inner fan deposits dominated by Facies A and B together with several thin intervals of mid-fan deposits (Facies C). Both the middle and lower sequences of the composite section (Member A) largely consist of abyssal plain and outer fan deposits, Facies D_a and D_o, respectively. The presence of a substantial thickness of graphitic mudstones in the lower unit distinguishes it from both of the overlying sequences.

The spatial and temporal relationships suggest that the entire composite section, and by definition Member A, represents a pre- to syn-volcanic epiclastic sequence of a substantial thickness. The age of the volcanics is unknown, but is believed to be approximately 2715-2700 Ma on the basis of similarity to volcanics of the Tisdale Group. If these inferences are correct, then Member A, which underlies the package of volcanic flows, is older than any of the volcanics that occur along the western margin of the basin (2.7 Ga), but presumably correlative with turbidites at the Kidd Creek Mine (younger than 2.7 Ga: Bleeker and Parrish, manuscript submitted). These apparently contradictory relationships can be explained by the following:

- 1) Member A is diachronous, or
- 2) sedimentary strata at the mine cannot be correlated with strata of Member A because the latter represents an older sedimentary package that either predates, or is synchronous with, the Kidd-Munro volcanics, or
- 3) Member A represents an epiclastic unit that is synvolcanic and analogous in character and in age to the Whitney Formation of the Tisdale Group. This represents an interesting possibility which would make the volcanics along the western margin correlative to the volcanics in the middle of the Timmins Mining Camp some 50-60km to the southeast.

The third scenario, which is based on similar spatial and sedimentary facies relationships, probably represents the correct one; this makes strata to the west of the Kidd Creek mine correlative with all three members of the Whitney Formation including Member C, a unit that represents subaerial deposition of sedimentary and volcanic strata. Many of these questions can only be answered by determining an age for the volcanics along the western basin margin, and by examining more sedimentary sections between the Kidd Creek Mine and Member A of the Hoyle Formation (Figures 2.14 and 2.15).

Base of the Hoyle Formation

The following discussions are based on observations within strata from Member C: This represents an area that extends eastward from the Bell Creek Mine in Hoyle Township to the east of German Township.

The basal sequence of the Hoyle Formation is exposed near the Hoyle Pond Mine (Figures 2.19 and 2.22). It consists of inner fan deposits directly overlying mafic volcanics (sections H12-09 and 16-12), and mudstones and distal deposits directly overlying mafic volcanics as in 5 other sections. The latter type commonly forms the base of coarsening-up and some thickening-up cycles that are typical of negative megasequences.

Proximal inner fan facies, which are represented by conglomerates, are rare and occur in only one section. This conglomerate does not, however directly overlie mafic volcanic flows, but occurs some 20m higher in the section. Graphitic mudstones and muddy turbidites, which represent facies D_a and D_o, respectively, are common in the basal sequence of the Hoyle Formation. The occurrence of abundant graphite (Plate 1.C) suggests that deposition occurred in a restrictive, anoxic environment. In general, various portion of the turbidite fan, which represent a variety of depositional environments, directly overlie mafic volcanic flows.

Middle of the Hoyle Formation

The middle part of the formation near Hoyle Pond consists of : mid fan deposits (Facies C) at the base, inner fan deposits (Facies B) intercalated with mid fan deposits in the middle, and inner fan deposits (Facies B) at the top of a 400m thick composite section near Hoyle Pond (Figures 2.21 and 2.22). In total, four major progradations of inner fan deposits are recorded in this composite section: approximately one for every 100m of the sequence. These probably indicate deposition during major low stands of the deep-water basin.

Another section, which probably represents the middle part of the formation, occurs in the northern part of Evelyn Township. This 360m composite section (Figure 2.23) has inner fan deposits (Facies B) in the lower half, whereas mudstones representative of facies D₀ and D_a, dominate the upper half of the section, except for the upper 40m, which consists of mid fan deposits (Facies C). Several progradational events are recorded in this stratigraphic section, including 6 progradations of inner fan deposition in the lower 120m , and one progradation of mid fan depositions at the top.

A 230m composite section in southern Evelyn Township (Figure 2.24) also represents strata from the middle of the formation. Sandy turbidites of Facies B dominates the lower portions, whereas the upper 50m of the section consists of regular turbidites (Facies C). This composite section differs from the others, because the mudstones and muddy turbidites of the outer fan and abyssal plain are absent. Inner fan deposits prograded over mid fan deposits in the lower 150m of this section; in total 4 such events are recorded in this unit. The high frequency of progradations suggests that the sediment was probably from more than one feeder system, indicating the possibility of a turbidite ramp system (cf. Barrett and Fralick, 1989) that fed numerous smaller fans, rather than one large channel system .

Middle to Upper parts of the Hoyle Formation

The Esker Lakes area, which is far removed from the edge of the depositional basin, may represent the only strata from the upper parts of the Hoyle Formation. It is difficult to determine the relative stratigraphic position because all strata have undergone subsequent folding and deformation. The total composite section from this area represents about 400m of strata, and mid fan, outer fan, and inner fan deposits dominate the lower, middle and upper sequences, respectively. Inner fan deposits of Facies B, which prograde over outer fan deposits in both the middle and upper sequences and over mid fan deposits in both the lower sequence and the upper 60m of the composite section, record a total of 14 major progradations within 380m of section.

Because a predominance of inner fan deposits makes this composite section different from the sedimentary sequences that are directly attributable to the middle of the Hoyle Formation, it probably represents a younger sequence, namely, the upper part of the Hoyle Formation. This also indicates that the depositional conditions at some localities within the turbidite basin evolved with time from abyssal plain and outer fan deposits to an inner fan system. Elsewhere, this system would largely be a continuation of the sedimentary succession near Hoyle Pond, where sandy turbidites dominate the uppermost units in the middle part of the Hoyle Formation. Again, the high frequency of inner fan deposits suggests that more than one delivery system must have brought detritus from the hinterland regions into the deep-water basin. The absence of a major distributary channel, such as a delta-submarine canyon system, is suggested by the predominance of (sandy) inner fan deposits without any conglomerates from the most proximal parts of the channel.

Pamour Group

Dome Formation

Introduction

The Dome Formation (Figure 2.1 and 2.3), which underlies a narrow strip along the Porcupine-Destor Fault zone, extends from the Dome Mine in Tisdale Township (Figure 2.27) to the eastern border of Whitney Township and beyond.

Characteristic spatial relationships show that the Dome Formation unconformably overlies a variety of older lithologies, including turbiditic sandstones at MS-1 and 12A, and mafic volcanics almost everywhere else. This unconformity represents an angular discordance that has been historically documented for at least the past 70 years. Recent radiometric measurements of detrital zircons from the Dome Formation by Corfu et al. (1990) has yielded a U-Pb age of 2679 Ma for epiclastic rocks from the Dome Formation in contrast to the inferred age of 2700 Ma for the underlying strata, which consists of mafic volcanics, the Krist fragmental of the Tisdale Group, and epiclastic rocks of the Beatty Formation. Another determination for a sample from the Kidd Creek Mine area by Bleeker and Parrish, (manuscript submitted) shows the youngest detrital zircon age of the Hoyle Formation at the Kidd Creek Mine to be 2700 Ma. This age is the same as for the Beatty Formation, but is older than the detrital age of the Dome Formation. The upper contact of the Dome Formation, which is conformable with the overlying Three Nations Formation, occurs at several localities including MS-2, and 4, as well as at Ti 3590.

The various sedimentary characteristics and depositional environments of this formation (400-500m thick) (Appendices 4) were determined by examining a series of 18 sections (1500m), mainly from outcrop, but also supplemented by data on the lateral continuity for conglomeratic units in sections MS-1, 2, 5 and -D (at Dome). These data, including bed forms, scour surfaces, and paleocurrents, are critical for distinguishing between two distinct depositional environments in

Figure 2.27
Location grid for measured sections of the Dome Formation-Pamour Group; Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

the Dome Formation, namely, alluvial-fluvial conglomerates and channel conglomerates from turbidite fans (discussion to follow). Because of the spatial distribution of these distinct lithologies, the basal part of the formation, which essentially consists of alluvial-fluvial conglomerates at MS-D, 1, 5, 8, and 12A, are designated as Member A. Elsewhere, mudstones or turbidites containing conglomeratic beds at MS-2, 3, 6, 8 and 10 are designated as Member B, whereas turbidites which do not contain conglomerate interbeds are known as Member C; presumably these are from the middle and upper parts of the Dome Formation, but their relative positions are difficult to ascertain.

Stratigraphic correlations are possible because the entire sequence, which is 400-500m thick, forms a south-facing monocline: however, such correlations are more reliable on a local scale than on a basin-wide scale. Mafic volcanics, which underlie the sedimentary strata, represent the only convenient datum for basin-wide correlations (Figure 2.28). However, even if correlations can not be made, the local environments from each section can be identified and interpreted. An inventory of these represents the range of depositional environments for the Dome Formation. Most of the sections are near the margin of the basin, just above mafic volcanic flows, or rarely above epiclastic rocks of the Beatty Formation.

The stratigraphic data provide the main basis for an initial overview of the entire formation, which is subdivided into three Members, namely A, B, and C (Figure 2.28)

Figure 2.28
Relative stratigraphic position above the volcanic basement for measured sections of the Dome Formation, Pamour Group

Member A of the Dome Formation

Description and Interpretation

The strata of Member A (Table 2.3), restricted to the basal part of the Dome Formation, occur in sections MS-1, 12A, 5, 8, and D (Dome) (Figure 2.29).

Conglomerates in Member A appear to represent alluvial stream - dominated deposits which lack sandstone interbeds, but contain abundant pebbly horizons (Plate 5.C to 5.E). Within the lower part of the conglomerate section, the presence of coarse-tailed reverse graded bedding (Figure 2.30) suggests repeated surging flow, as opposed to the predominant coarse-tailed normal graded bedding, suggestive of repeated waning flow, in the upper part of the section.

A similar basal unit also occurs at MS-5, 8 (Figure 2.29), and D(Dome), where the substrate is mafic volcanic rocks, rather than turbiditic sandstone.

At MS-5 (Table 2.3), sedimentary characteristics are the same as previously mentioned, including megaclasts, amalgamated beds, and coarsening and fining trends.

Conglomerates also occur at MS-D (Dome), but these strata are deformed and folded in a regional deformation zone along as the Dome Fault. These conglomerates represent distributional data that can only be synthesized by using comparative data from other sections such as MS-1, 5, 8 and 12A.

Dome Formation: Member A			Bouma Divisions			
Section	type	%	Base Top		Facies	
MS-12A	(3-3) TBTE	10	62	67	Tde	Do
	(1-1) CGLM(C)	2	61	62	Gm	Al
	(1-1) CGLM(C)	18	52	61	Gm	Al
	(1-1) CGLM(C)	43	31	52	Gm	Al
	(1-1) CGLM(C)	14	24	31	Gm	Al
	(1-1) CGLM(C)	12	18	24	Gm	Al
MS-1	(1-1) CGLM(M)	3	440	447	Gm	Al
	(1-1) CGLM(C)	6	426	440	Gm	Al
	(1-1) CGLM(C)	5	386	398	Gm	Al
	(3-2) TBTE	2	382	386	Tbde	C
	(2-2) TBTE	11	358	382	Tbde	C
	(1-1) TBTE	8	340	358	Ta, Tae	B
	(2-2) TBTE	9	320	340	Tbde	C
	(2-2) TBTE	11	296	320	Tbde	C
	(1-1) TBTE	8	198	216	Ta, Tae	B
	(1-2) TBTE	4	190	198	Tbde	C
	(1-1) TBTE	9	170	190	Ta, Tae	B
	(1-1) TBTE	13	22	50	Ta, Tae	B
	(1-1) TBTE	10	0	22	Ta, Tae	B
MS-5	(1-1) TBTE	11	62	70	Ta, Tae	B
	(2-2) TBTE	6	58	62	Tbde	C
	(1-1) TBTE	6	54	58	Ta, Tae	B
	(2-1) CGLM(M)	4	51	54	Gm	Al
	(1-1) CGLM (C)	4	48	51	Gm	Al
	(2-1) CGLM(M)	3	46	48	Gm	Al
	(1-1) CGLM (C)	9	40	46	Gm	Al
	(1-1) CGLM (C)	36	15	40	Gm	Al
	(2-1) CGLM(M)	1	14	15	Gm	Al
	(1-1) CGLM (C)	20	0	14	Gm	Al

Table 2.3 Summary of stratigraphic subdivision of sedimentary strata in sections MS -12A, 1 and 5: Member A-Dome Formation, Pamour Group. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

Figure 2.29
Representative sections of Member A-Dome Formation, Pamour Group

Figure 2.31

Detailed sedimentary features in sections MS-5 and 8: Member A of Dome Formation, Pamour Group

Figure 2.31

Detailed sedimentary features in sections MS-5 and MS-8: Member A of Dome Formation, Pamour Group

Detailed spatial and bedform data

Mapping at outcrop scale in several sections containing Member A such as MS-1, 5 and D(Dome) has documented the lateral continuity of the sedimentary units as well as the various bedforms, and paleocurrents at these locations. Details on compositional variations of the clast types are discussed in a later section on provenance.

Detailed mapping at MS-1 shows that several distinctive conglomerate beds are traceable over a lateral distance of 30-40m, but some are less traceable (Figure 2.32): It appears that these strata have rapid facies transitions and some have sedimentary structures with a poor preservation potential. This area essentially represents a series of alluvial bars (Figures 2.33 and 2.34) containing abundant crossbedding, with festoons more abundant than planar foresets (Plate 5.C).

In terms of the hierarchy of bedforms, first order erosion surfaces representing foresets are cut by second order surfaces representing cosets, which separate beds showing opposite directions of transport. These are rarely truncated by third order surfaces that commonly separate distinctive lithological units. No major bounding surfaces representing fourth order erosional surfaces have been identified.

Details from the upper part of MS-1, which is 25m thick, however, show a similar pattern (Plate 5.E), except that the clasts are smaller, and reverse grading is absent (Figures 2.35). This unit, which contains the smallest clasts and the most matrix in the entire conglomerate section, was deposited during periods of

Figure 2.32 B: Legend for all sketches (plan views) of detailed spatial and bedform data for Figures 2. 32-43, 2.54 to 59, and 2.51: Dome Formation and Three Nations Formation, Pamour Group

Figure 2.33

Plan view (eastern part) showing

lateral continuity in section MS-1:

Member A of Dome Formation, Pamour Group

Figure 2.35 A

Plan view (south ern part) showing detailed sedimentary features and lateral continuity in section MS-1: Member A- Dome Formation, Pamour Group

Figure 2.35 B

Plan view (south ern part) showing detailed sedimentary features and lateral continuity in section MS-1: Member A- Dome Formation, Pamour Group

either reduced uplift or reduced current flow.

Detailed sketches from MS-5, (Figure 2.36) show similar depositional characteristics with high angle crossbeds and truncation surfaces, some of which are reactivation surfaces: transport is mainly from the east.

A 30-40m thick section of similar conglomerates also occur in MS-D (Dome), but unlike previously described conglomerates, these are extensively deformed as well as folded (Figure 2.37). The distribution of basal units and the variation in clast size suggests that tops are currently to the south.

Paleocurrent data for Member A of the Dome Formation (Figure 2.38) show a bimodal distribution, with most currents to the southwest, but some to the northeast. Several sections, such as MS-12A and 8, show a more diverse current pattern, rather than the strongly bimodal patterns for MS- 1 and 5. By contrast, current directions for fluvial units (Member C) in the Whitney Formation (Tisdale Group), which represents older strata, shows transport only to the northeast. However, fluvial units in the Three Nations Formation (Members A and B), which represent strata younger than the Dome Formation, show a weak bimodal distribution, with most paleocurrents mainly to the northwest. The paleocurrent patterns differ in type and in direction among the three fluvial packages. These are listed in decreasing age as: Member C- Whitney Formation, Member A- Dome Formation, Member A and Member B- Three Nations Formation.

Figure 2.36 Plan view showing detailed sedimentary features and lateral continuity in section MS-5: Member A of Dome Formation, Pamour Group

Figure 2.37
Plan view showing detailed sedimentary features and lateral continuity in section MS-D (Dome): Member A of Dome Formation, Pamour Group

Member B of the Dome Formation

Description and Interpretation

Member B represents turbidites with closely associated conglomerates that either incise the turbidite sequence or represent slope-break conglomerates: evidence to support such interpretations are outlined in the following section. Measured sections, namely MS-2, 3, 6, 10, 13, and the base of MS-4 contain examples of Member B of the Dome Formation (Appendices 4A and 4B).

The generally conformable stratigraphic relationship in MS-2 (Figure 2.39) suggests that many of the conglomerates are not fluvial deposits. Turbidites of the Dome Formation mainly consist of thinly bedded sandstone bodies containing 10-20% intercalated mudstones with only minor amounts of sandstone (<6% mudstone). These represent typical lithologies of Facies C, which are analogous to classic turbidite packages previously described here and elsewhere. Compared to older turbidites (i.e. those from the Beatty Formation), there are some similarities but also many differences that may be used to distinguish the two such as:

The younger turbidites consist predominantly of facies C or regular turbidites (see earlier definitions). They form thinner recognizable sedimentary cycles (<6 m cycles), and exhibit bedding that ranges from thinly- to very-thinly bedded, and commonly contain sequences of repeated thinning-up trends over vertical distances of 1-2 m. Only rarely do thickening-up trends occur within the turbidites (Plate 1.D). By contrast, the older turbidites show a predominance of sandstone facies lithologies (Plates 1.A, and B); they are thickly- to very thickly-bedded with characteristic massive, amalgamated sandstone beds arranged in 20-40 m thick sedimentary cycles.

All of the conglomerates in MS-2 (Figure 2.40) are thickly bedded (0.5-1 m

Figure 2.39

Representative sections of Member B- Dome Formation, Pamour Group

Figure 2.40

Detailed sedimentary features in section MS-2: Member B - Dome Formation, Pamour Group

thick) and are generally massive and clast-supported (2 m thick) at the base (Gm facies). These are overlain by matrix-supported and weakly stratified conglomerates (Gms facies) with minor sandstone interbeds in the upper 5 m (Plate 2.A). In this sequence, amalgamated bedding surfaces are common, but grain size variations, together with the arrangement of beds, indicate a general coarsening- and thickening-up trend, as well as an increase in matrix content. A pebbly sandstone unit that directly overlies the uppermost matrix-supported conglomerate bed represents a transition between the underlying conglomerates and the overlying and presumably conformable sandstones of the Three Nations Formation.

These turbidites represent typical Facies C lithologies described by Mutti and Ricci Lucchi (1972), which are typical of slope break lithologies with no distinctive thinning-up or thickening-up trends within the 70 m section. The general conformable stratigraphic relationships of conglomerates in these sections to the underlying turbidites suggests that they represent subaqueous channel-fill or channels incised into turbiditic sandstones. The abundance of amalgamated bedding contacts, together with the lack of traction structures such as trough crossbeds, extensive erosional scours of the internal and external type, and other general fluvial-like features make a fluvial origin unlikely. Overlying the conglomerates in MS-2 are the youngest strata of the Pamour Group, namely arkoses and quartz arenites of the Three Nations Formation.

Section MS-3 (Table 2.4) illustrates turbidites that unconformably overlie (Figure 2.39) Mg-tholeiitic pillowed volcanics of Formation IV (Pyke, 1982).

As in MS-2, turbidites of MS-3 represent Facies C lithologies typical of mid fan deposits that do not contain any consistent thinning-up or thickening-up trends within the 70 m section. Units of thickly bedded (0.5-1 m thick) sandstone

PLATE 2:

OUTCROPS FROM THE DOME FORMATION OF THE PAMOUR GROUP SHOWING KEY SEDIMENTARY FEATURES RELATED TO THE DEPOSITION OF TURBIDITES

(PLATE 2.A):

Outcrop of the Dome Formation-Member B showing turbidites interbedded with channel fill conglomerates. These represent proximal inner fan deposits of MS-2 (Whitney Township). Scale card is approximately 10 cm long, stratigraphic tops are shown by arrow.

(PLATE 2.B):

Outcrop of brown channel fill conglomerates showing a basal contact with black mudstones, characterized by loading rather than erosion. These represent proximal inner fan deposits from MS-3 (Whitney Township) in the Dome Formation-Member B. Scale card is approximately 10 cm long, stratigraphic tops are shown by arrow on the card.

(PLATE 2.C):

Outcrop of turbidites from the Dome Formation-Member B showing flute casts on bedding. These represent mid fan deposits in MS-10 (Whitney Township). Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. Scale card is approximately 10 cm long, current directions are from the bottom to the top of the page.

(PLATE 2.D):

Outcrop of turbidites from the Dome Formation-Member C showing wave ripple crest on bedding. These represent wave reworking of mid fan deposits in MS-14 (Tisdale Township). Scale card is approximately 10 cm long, currents were perpendicular to the bifurcating crests.

Member B-DOME FORMATION					Bouma Divisions	
Section	type	%	Base Top		Facies	
MS-13	(1-1) CGLM(M)	8	137	141	Gms	A
	(1-1) CGLM(C)	34	120	137	Gm	A
	(3-3) TBTE	covered	29	120	Tde	Do
	(3-3) TBTE	4	27	29	Tde	Do
	(1-1) CGLM(M)	4	25	27	Ta	A
	(1-1) CGLM(C)	30	10	25	Ta	A
	(3-3) TBTE	14	3	10	Tde	Do
	(2-2) TBTE	6	0	3	Tbde	C
MS-3	(2-2) TBTE	12	80	90	Tbde	C
	(2-1) TBTE	12	70	80	Ta, Tae	B
	(2-2) TBTE	24	50	70	Tbde	C
	(2-1) TBTE	2	48	50	Ta, Tae	B
	(2-2) TBTE	12	38	48	Tbde	C
	(1-1)CGLM	7	32	38	Ta, Tae	B
	(2-2) TBTE	9	24	32	Tbde	C
	(3-4) TBTE	6	19	24	Tde	Da
	(1-2) CGLM (A)	16	5	19	Tbde	C
	MVLC		0	5		
MS-6	(1-1) TBTE	22	27	34	Ta, Tae	B
	(2-2) TBTE	19	21	27	Tbde	C
	(1-1) CGLM (C)	16	16	21	Ta	A
	(1-1) CGLM(M)	28	7	16	Ta	A
	(2-2) TBTE	6	5	7	Tbde	C
	(2-1) CGLM(A)	9	2	5	Ta	A

Table 2.4 Summary of stratigraphic subdivision for sedimentary strata in sections MS- 13, 3 and 6: Member B-Dome Formation, Pamour Group.

facies represent Facies B, which may indicate mid-fan deposition of sandstones bodies or more likely as larger sandstone beds that are part of a depositional environment with a prograding lower fan. Conglomerates generally exhibit a conformable stratigraphic and non-channelized relationship with the underlying turbidites (Plate 2.B), which probably indicates deposition as subaqueous channel-fill at or near the shelf slope break.

In the overlying turbidites, there are four cycles (3-6 m thick) that each consist of a unit of basal sandstone facies turbidites (Facies B) overlain by a thin unit of regular turbidites (Facies C): the rest of the section can also be grouped into similar sedimentary cycles. The four cycles exhibit several repeated thickening-up cycles (2 examples), a unit containing several repeated thinning-up cycles, and another unit containing several repeated thinning-up cycles together with a fining-up trend, and a corresponding increase in mud-content.

MS-6 (Table 2.4), which is near MS-3, also shows a similar vertical sequence (Appendix 4) with a matrix-supported conglomerate known as the "agglomerate unit" overlying mafic volcanic flows at the base of the epiclastic sequence. A general facies arrangement of D_a , A, D_o , and B illustrated by the stratigraphic succession at MS-6, suggests that two progradations are recorded in this short, 34m section: conglomerates of the proximal inner fan facies prograded over abyssal plain deposits in the lower part, whereas inner fan sandstones prograded over outer fan deposits in the upper part. This arrangement also suggests that sea level fluctuations were an important factor during deposition of both sequences. The "Agglomerate", which probably represents subaqueous debris flows, is a monomictic sedimentary unit that was directly derived from the underlying mafic volcanics without much transport from the source.

MS-13 (Table 2.4) illustrates a stratigraphic succession similar to MS-2, with conglomeratic units (Figure 2.39) overlying a substantial thickness of turbidites. However, a second conglomerate unit also occurs at the top of the section, some 90m above the lower unit: the total section is about 150m thick. The lower conglomeratic lens, which consists of an upper matrix-supported and a lower clast-supported conglomerate with a basal scour, overlies regular turbidites of Facies C that are typical of mid fan deposits. Although the 17m thick conglomeratic unit is highly deformed, graded bedding is still recognizable in sand interbeds, and amalgamated bedding contacts are ubiquitous. The overlying mudstone unit, which occurs at the base of a thick interval of no outcrop, suggests that abyssal plain deposits succeeded the inner fan conglomerates, and possibly represent the top of a fining- and thinning-up cycle (20m thick).

The upper conglomeratic unit at MS-13, which is 20m thick, presumably overlies turbidites that are indicated by old drill records on a map by Ferguson (1968). In a depositional setting similar to the lower conglomeratic unit, the upper conglomerates also consist of clast-supported conglomerates overlain by matrix-supported conglomerates near the top. Fining- and thinning-up trends shown by conglomerates in the lower 20m of the section are interpreted as a submarine-channel infill.

At MS-10, conglomerates constitute an 8m-thick lens that overlies mafic volcanic flows (Figure 2.41) at the base of the section. A restricted range of clast compositions is typical of conglomerates in turbidite fans (Member B). Noteworthy sedimentary features in the overlying turbidites include current ripples and flute casts in the upper part of the section (also in the upper part of MS-3), which show apparent paleocurrent directions to the southwest, but when

Figure 2.41 Detailed sedimentary features in section MS-10: Member B- Dome Formation, Pamour Group

the overturned strata are rotated to the original orientation (assuming folding about horizontal axes), these structures indicate transport (Figure 2.39) to the north (Plate 2.C).

Detailed spatial and bedform data

At MS-2, the lateral continuity of the sedimentary units has been examined in detail including the various bedforms, internal geometry, paleocurrents and spatial relations (Figures 2.41 and 2.42). On the scale of 100-200m, this unit has cut a channel into the underlying turbidites. Internal stratification consists of low to moderate angle (Figure 2.43) bedding or planar cross stratification, which is arranged as thickly bedded strata (.5-1m), with some coarse-tailed, coarsening-up of clasts near the top of the unit. Throughout most of the outcrop, the conglomerate clearly overlies the turbidites, except at the east end of the outcrop, where matrix-supported conglomerate beds (Gms) are intimately interbedded with tabular sandstone beds representative of turbidite bodies (Figure 2.44) This area shows the transition from classic turbidites, to turbidites with conglomerate interbeds, to pebbly sandstone, to arkose. The corresponding differences in bedding show changes from planar bedding in the lowest two units to trough crossbedding in the upper two units. Prominent bedforms are foresets representing erosional surfaces of the first order, together with minor second order and possibly some third order erosional surfaces.

Paleocurrents from flutes in turbidites of MS-10 and 3 (Figure 2.39) show a bimodal distribution, with the main transport direction to the north, but lesser currents to the south, as well as minor currents to the northeast and southwest. These prominent northward directions are approximately perpendicular to fluvial paleocurrent indicators in the underlying stratigraphic units of Member A - Dome Formation.

Figure 2.43

Plan view showing detailed sedimentary features of conglomerates in section MS-2 (shovel outcrop): Member B - Dome Formation, Pamour Group

Figure 2.44

Plan view showing detailed sedimentary features, lateral continuity, and vertical changes in section MS-2 (east end): Member B - Dome Formation, Pamour Group

Member C of the Dome Formation

Description and Interpretation

Member C consists of turbidites that do not contain conglomeratic interbeds. Some directly overlie mafic volcanics (sections Ti 2704, MS-14, Ti 1373, and outcrop (o/c) 342, but others such as MS-7, are in close proximity to underlying mafic volcanic flows, suggesting that they essentially represent the same setting (Figure 2.45). Some turbidites overlie conglomerates of Member A (alluvial facies) in an apparent conformable relationship at MS- 8, 5, and 12B. Only the latter section represents strata from either the middle and upper parts of the Dome Formation,. A total thickness of approximately 400m is postulated for the Dome Formation.

Turbidites at MS-14 directly overlie either mafic volcanics or a debris flow unit, and were derived from the underlying volcanics in a similar manner to the agglomerate unit of MS-3 and 6. Regular turbidites (Facies C) typical of mid fan deposits constitute the basal epiclastic unit in this thin (12m) and folded stratigraphic section.

The occurrence of wave ripples (Plate 2.D) suggests that these turbidites may represent shallow water (above fair weather wave base) turbidites, which makes this section not only unique to the Dome Formation, but also among all of the other turbidites in the Timmins area. This section thus represents mid fan deposits prograding over debris flows or directly over mafic volcanics.

In MS-7, mid fan deposits predominate, but some minor deposits of the outer fan are incised by a few sandstone channels in the lower part.

A 100m section of turbidites, which overlies alluvial conglomerates (Member A) in an apparent conformable relationship at MS-8 (Figure 2.31) , consists mainly of regular turbidites typical of mid fan deposits (Facies C). Sedimentary features include mud chips, convolute bedding and flaser bedding, suggesting that this unit was rapidly deposited, possibly as part of a channel-

levee complex (cf. Walker, 1992). Grain size variations in this and the sandy turbidites at the top of the section show distinctive fining-up trends (and some rare coarsening-up trends) typical of strata within a submarine canyon.

The stratigraphy of MS-8 (Figure 2.31) suggests that several inner fan deposits (Facies B) of a substantial thickness (20m thick) prograded over mid fan deposits (Facies C) and minor outer fan deposits (Facies D₀).

Apparent contradictions of thinning and/or fining cycles on a local scale (1-3m) compared to coarsening and thickening cycles on a larger scale (20-60m) , may be indicative of an overall vertical aggradation of the depositional system, but without a complementary progradation.

MS-12B (Figure 2.46), which is at least 300m and potentially 360m thick, represents the thickest section of the Dome Formation (Appendix 4). These turbidites, which are poorly exposed with many gaps between the outcrops, overlie alluvial-like strata of Member A in section MS-12A.

A summary of MS-12B shows that outer fan deposits, which are incised by a few sandstone channels, dominate the lower part of the sequence, whereas mid fan deposits (Facies C) are ubiquitous throughout the remainder of the sequence. Some outer fan deposits, which are interbedded with them in the upper parts of the sequence, indicate that the mid fan underwent several cycles of progradation and retrogradation cycles with time. This turbidite sequence differs from most in the Dome Formation because of an absence or near absence of inner fan

Figure 2.46 A Detailed sedimentary features in section MS-12B: Member C- Dome Formation, Pamour Group;

facies (sandy turbidites) from this turbidite sequence: a few regular turbidites, which have the same depositional features, may represent an analogous channel facies under slightly different depositional conditions.

Strata of section MS-12B may represent a unique portion of stratigraphy of the middle of the Dome Formation. Other sections are thinner and mainly represent the basal parts of the formation.

Discussion

Member A, restricted to the basal part of the Dome Formation, occurs in several sections such as MS-1, 12A, 5, 8, and D (Dome).

These conglomerates have been interpreted as alluvial strata for a number of reasons, including the general coarse nature of the detritus (commonly containing boulders), the presence of traction features indicative of stream flow (such as crossbeds and internal scours), the occurrence of coarsening and fining trends in successive beds (indicating surging and waning flow so typical of fluvial systems), the absence of sandstone interbeds, and the predominance of clast-supported conglomerates with only minor interbeds of matrix-supported conglomerates. Paleocurrents show a bimodal distribution, with the main transport direction to the southwest.

By definition, Member B represents turbidites with closely associated conglomerates that either incise the turbidite sequence or represent slope-break conglomerates. Several measured sections, namely MS-2, 3, 6, 10, 13, and the base of MS-4 contain examples of Member B of the Dome Formation.

The internal geometry and spatial elements of these conglomeratic units suggest that these are different than the conglomerates that occur in MS-1 and MS-12A (Member A). Some of these factors include: more sandstone and matrix supported conglomerate beds, a different style of bedding exemplified by low angle truncations (mainly unidirectional flow direction from the east), a

predominance of reverse-grading in many of the conglomerate beds, a lack of internal scours at the base of conglomerate beds, a lack of locally derived sedimentary clasts in the basal conglomerate, the traceability of this conglomeratic unit, the apparent conformable relationship with adjacent stratigraphic unit, particularly the overlying sandstones, and finally the overall channelized nature of this contact on a scale of 100 to 200m, which only shows minor scours (10-20 cm) on a local scale.

The transition from the conglomerates of Member B to the overlying arkoses and lithic arenites of the Three Nations Formation, is gradational: the transition shows a fining up trend with increasing matrix content in the conglomerates, whereas pebbly sandstones, which represent the basal unit of the overlying unit, grade upwards into pebble-free strata. This transition is indicative of a subaqueous facies change that can not be directly attributed to uplift, erosion, and subsequent deposition at this location. Bedding attitudes on both sides of the contact are parallel and concordant.

Member C of the Dome Formation consists of turbidites which do not contain any conglomeratic interbeds. Some of these turbidites directly overlie mafic volcanics in the case of sections Ti 2704, MS-14, Ti 1373, outcrop (o/c) 342, and MS-7. Elsewhere, turbidites of Member C directly overlie conglomerates of Member A (alluvial facies) in an apparent conformable relationship at MS- 8 (Figure 2.31), and MS-12B. The latter section probably represents either the middle or upper parts of the Dome Formation, which has a total thickness of approximately 400m.

The occurrence of wave ripples in turbidites in at least one location (MS-14), suggests that these may represent shallow water turbidites, which makes this section not only unique to the Member, but to the formation, and to all other turbidite in the various groups that constitute the epiclastic sequence of the Abitibi Greenstone belt in the Timmins area.

One of the key sections, namely MS-12B, differs from others in Member C, because of an absence or near absence of inner fan facies (sandy turbidites) from this turbidite sequence: a few regular turbidites, which have the same depositional features, may represent an analogous channel facies under slightly different depositional conditions. The extreme thickness of section MS-12B (360m) means that most of the 400-500m thick formation is included in this section.

Another key section, namely MS 12A, contains a thin unit of muddy turbidites (Facies D₀), which represents the base of the overlying turbidite sequence that continues upwards in section MS-12B. This illustrates an unusual situation of deepwater turbidites overlying alluvial deposits in an apparent conformable relationship. Obviously, this contact must represent a hiatus between the two contrasting depositional environments, but there is little physical evidence to support this, except for an erosional surface at the base of the turbidite sequence that may represent a flooding surface or disconformity.

Although there is variability in the spatial distribution of various members the following relationships generally appear to hold:

Member A, which represents alluvial-fluvial deposition, occurs only along the basal contact, and thus, constitutes the lower part of the Dome Formation in many places. Elsewhere, Member B or C appear to occupy the basal portion of the Dome Formation, and directly overlie mafic volcanic flows. This may have been caused by a transgressive or onlapping pattern for the younger members (i.e. B and C) of the Dome Formation. The absence of Member A along the basal

contact means that either it was never deposited, or it was deposited and subsequently removed by erosion before deposition of the turbidites.

Member B , which represents deposition of proximal conglomerates from the inner fan regions of a submarine channel (Facies A), generally occurs along the upper contact, and thus constitutes the upper part of the Dome Formation. It also overlies mafic volcanics at the base of the epiclastic sequence near the Pamour Mine in Whitney Township. These facts suggest that major progradation of turbidite channels occurred during deposition of both lower and upper parts of the Dome Formation.

Member C mainly consists of turbidites from mid fan deposits (Facies C), interbedded with minor intervals of inner fan (Facies C) and outer fan deposits (Facies D), in that order of abundance. This member represents greater than 300m of strata from the thickest stratigraphic sections of the Dome Formation (MS-12B), but such lithologies also occur along the basal contact and along the upper contact to the east of Nighthawk Lake. Member C probably represents the middle part of the Dome Formation throughout much of the study area.

Paleocurrents for turbidites (Member B) mainly indicate a bimodal pattern, with predominant transport directions to the north. These are perpendicular to paleocurrents from the fluvial member (Member A) and suggest that the shallow part of the basin is to the south.

Pamour Group

Three Nations Formation

Introduction

The Three Nations Formation (Figure 2.1 and 2.3), which covers a narrow strip on the south side of the Porcupine-Destor Fault zone, extends easterly from Wanwatin Falls in Thorneloe Township, to the eastern border of German Township, and continues eastward towards Matheson.

A variety of stratigraphic relationships, namely transitional, conformable, and unconformable, exists between the Three Nations Formation and the underlying turbiditic sandstones of the Dome Formation. In the few places where fluvial facies have been identified, such as in the eastern regions of the study area, the contact is unconformable, but elsewhere it is conformable.

The various sedimentary characteristics and depositional environments of this formation (Appendices 5A and 5B) were determined by examining a series of 12 sections, mainly from outcrop but also from several drill cores over a strike length of 25 km from Whitney to German townships (Figure 2.47). This represents a total stratigraphy of approximately 2000m . In addition, detailed sketches of several key outcrops (i.e. at MS- 2, 4, 11, and 16) outlined the lateral continuity of conglomeratic and sandstone units, as well as associated bed forms, scour surfaces, and paleocurrents. Such data are critical for the determination of the key differences between alluvial-fluvial conglomerates, and conglomerates interbedded with the shelf sandstones, which were likely derived by storm processes in a shallow-water environment. These represent the two divergent depositional environments of the Three Nations Formation. The basal part of the formation, which essentially consists of alluvial-fluvial conglomerates with characteristic clast-supported conglomerate beds, is designated as Member A. The conglomerates occur at several places, including east of Highhawk Lake

Figure 2.47
Location grid for measured sections of the Three Nations Formation -
Pamour Group; Archean sedimentary suite of the Abitibi Greenstone belt,
Timmins, Ontario.

at sections Ti 1390, Ti 1391, and MS-17, as well as at PS-18, which is some 40 km to the west in Thorneloe Township. Elsewhere, fluvial conglomerates, which do not contain any Gm facies, (i.e. no Gcs or clast-supported conglomerates), are designated as Member B. These occur only in the extreme eastern part of the study area at MS-16, but probably continue to the east. Presumably these are from the lower part of the Three Nations Formation, but their relative position is difficult to ascertain: they likely do not represent a stratigraphic position equivalent to the conglomerates of Member A.

Cross-bedded sandstones and arkoses interbedded with some minor pebbly sandstone and pebble conglomerates of the Gms variety represent Member C, which constitutes 90% of the strata in the formation. It presumably represents all of the middle and upper parts of the formation, but also conformably overlies turbiditic sandstones of the Dome Formation in sections MS-2 and MS-4. At these locations, Member C has an onlapping and conformable relationship, because the fluvial facies (Members A and B) were never deposited. Of all localities, sections MS-2, 4, 11, 17, 17B, 17C, 17D and Ti 1160 contain representative strata from Member C of the Three Nations Formation.

Stratigraphic correlations are possible because the entire sequence, which is at least 500m thick and possibly 1500m thick, forms a south-facing monocline. However, such correlations are more reliable on a local than on a basin-wide scale. Turbiditic sandstones of the Dome Formation, or mafic volcanic flows, both of which underlie the sedimentary strata, represent the best datum for basin-wide correlation. Figure (Figure 2.48) shows such a correlation that is based on vertical distances above this datum. However, even if correlations can not be made, the local environments from each section can be identified and

Figure 2.48
Relative stratigraphic positions above the chosen datum (top of the Dome Fm. turbidites and volcanic flows) for measured sections of the Three Nations Formation - Pamour Group

interpreted. The range of interpreted environments represents the spectrum of depositional settings for the Three Nations Formation. Most of the sections are located near the margin of the basin, just above epiclastic rocks of the Dome Formation, or rarely above mafic volcanic flows of the Tisdale Group.

The stratigraphic data are the basis for a subdivision of the formation into Members A, B, and C. Detailed spatial and bed form data derived from sketching of detailed sedimentological features constitute an important part of the stratigraphic data.

Member A of the Three Nations Formation

Description and Interpretation

Member A consists of fluvial strata characterized by abundant clast supported conglomerates (Gm or Gcs facies) at several places including east of Nighthawk Lake in sections Ti 1390, Ti 1391, and MS-17, as well as in PS-18, which is 40 km to the west in Thorneloe Township. These directly overlie turbiditic strata of the Dome Formation, except in the extreme western region (PS -18), where fluvial conglomerates overlie mafic volcanic flows. In fact, sections MS-17, Ti 1390, and Ti 1391 are located in close proximity along 100m of strike length at the base of the formation (Figure 2.49).

Section Ti 3590, which is 200m thick, shows a complete transition from the underlying turbiditic sandstones of the Dome Formation through the basal unit of the Three Nation Formation. MS-17 correlates well into between 36m and 66m of this section.

The lower part of the Three Nations Formation consists of a 120m interval of conglomerates with some interbedded arkose. the predominant lithologies include clast-supported and matrix-supported types, pebbly sandstones and

Figure 2.49

Representative sections of Members A and B - Three Nations Formation, Pamour Group

Figure 2.50

Detailed sedimentary features of section Ti 3590: Member A- Three Nations Formation, Pamour Group

arkose, in that order of abundance (Figure 2.50).

A comparison of the three sections shows that the percentage of coarse detritus decreases in a westerly direction away from a probable source region in the east. Both the detritus and currents continued in a westerly direction towards the shallow water basin. These sections also show rapid facies transitions in a lateral direction, because in the length of 100m, a predominantly conglomeratic and pebbly section changes to a mainly sandstone section with a few pebbly and conglomeratic interbeds. None of these include clast-supported conglomerates or show abundant traction features that are so characteristic of fluvial strata. The only common feature throughout is abundant trough crossbedding within arkoses in all three sections. These three sections represent about 200m at the base of the formation, designated as Member A of the Three Nations Formation.

PS-18 also represents strata from Member A (Figure 2.48), but it occurs some 40 km to the west of Nighthawk Lake, adjacent to Wanwatin Falls (Figure 2.47). One of the distinguishing features which makes this section part of Member A, is the presence of clast-supported conglomerates as a 12m unit that is about 40m above the base. The lower part of section PS-18 consists of interbedded arkose and Gms conglomerates, but the middle section (12m) contains the Gm conglomerates, whereas the upper 60m consists exclusively of Gms conglomerates.

Comparisons of this section with the "type" locality for Member A near Nighthawk Lake shows many similarities including the presence of Gm facies, the arrangement of conglomerate lithofacies, and the relative abundance of these strata. Both localities are considered to be typical of fluvial sedimentation at the base of the Three Nations Formation.

Member B of the Three Nations Formation

Description and Interpretation

Member B consists of probable fluvial strata dominated by Gms facies (matrix-supported conglomerates), but does not contain any clast-supported conglomerates (Gm facies), nor show any reverse graded bedding. This is unlike the fluvial strata of Member A, and for that matter, any fluvial deposits in the other local formations.

Only one section, namely MS-16 near the eastern edge of the study area, contains strata of Member B. It probably extends farther to the east, but also extends to the west somewhere between this section and MS-17 (Figure 2.47).

MS-16 (Figure 2.51) consists of a 70m section of matrix-supported conglomerates interbedded with pebbly sandstones (pS facies), except in the upper 10m, where several thin conglomerate beds are overlain by a 10m section of pebbly sandstone. All of the strata are thickly bedded except the uppermost pebbly sandstone, which is medium bedded. Numerous fining-up trends, graded bedding, mud chips, basal scours, and trough crossbedding occur throughout the section.

The underlying rocks are uncertain, but probably consist of sediments of either the Hoyle Formation, or the Dome Formation.

Detailed spatial and bedform data

Figure 2.52, which is representative of Member B, shows examples of bedforms in MS-16. This sketch shows fluvial strata that are finer grained than Member A, characterized by matrix-supported conglomerates (Gms), and commonly containing polymictic clasts, including fuchsite clasts in a white arkose matrix. These are interbedded with pebbly sandstones and sandstones, but not interbedded with the clast-supported conglomerates

Figure 2.52
Plan view showing detailed sedimentary features of conglomerates in section MS-16: Member B - Three Nations Formation, Pamour Group

(Gm facies). The conglomeratic units, which are traceable over a distance in excess of 40m, were probably produced by lateral accretion processes that are manifest in a shingling of strata in a lateral manner within this fluvial environment. They appear to represent fluvial strata with normally graded foresets, trough cross beds and other indications of traction currents.

Several orders of bedforms and truncations surfaces occur, namely, first, second and third order erosional surfaces in that order of abundance and in a similar manner to earlier described examples: the higher order surfaces (3rd order) separate the various lithotypes such as pebbly sandstone from conglomerate beds or sandstone beds. Similar relationships have been documented within other members of the Three Nations Formation, namely Members A and C, but also within fluvial strata representative of Member A from the Dome Formation. Member B and C show lateral and vertical arrangements that are similar to gravel bar conglomerates in which the same three lithotypes occur, but the percentage of conglomerates is much higher in fluvial depositional environments (Member B) than in the shelf setting (Member C).

Paleocurrent patterns for MS-16 (Figure 2.53) show a strong unidirectional component to the west, with only a few paleocurrents to the east. MS-17, which also represents fluvial strata (Member A), has a similar unidirectional pattern, except the pattern is even more unidirectional to the west (Figure 2.53). These examples show transport directions that are distinctly different to those of fluvial strata in the underlying Dome Formation, as well as those of the overlying shelf sediments in Member C of the Three Nations Formation.

Figure 2.53. A comparison of paleocurrents from Members A (alluvial) and B (turbidites) and C (shelf sediments), Three Nations Formation, Pamour Group with those from the Dome Formation (Member A-alluvial). Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

Member C of the Three Nations Formation

Description and Interpretation

In total, sections MS-2, Ti 1160, 4, 11, 17B, 17C, and 17D contain representative strata from Member C of the Three Nations Formation, which represents anywhere from 400 to 1500m of sedimentary strata. Stratigraphic correlations show that sections MS- 17B, 17C, and 17D are stratigraphically similar and represent the upper part of the formation (Appendix 5). The middle part of the formation is represented by MS-11 underlain by MS-4, whereas MS-2 and Ti 1160 represent the basal part of the formation.

At MS-2 (Figure 2.40), a pebbly sandstone unit directly overlies the matrix-supported conglomerate bed and represents a transitional unit between the underlying conglomerates of the Dome Formation and the overlying and presumably conformable, marine sandstones of the Three Nations Formation (described below). Significant sedimentary features of this marine sandstone include the occurrence of compound bedforms as illustrated by thinly-bedded (.1-.5 m thick) to thickly-bedded (0.5-1 m thick) trough and lesser planar cross-beds with fairly prominent reactivation surfaces (Plate 3.A), clay drapes, normal graded bedding, units with opposing sediment transport directions suggestive of tidal currents, and several erosional channels (1-3 m deep). Grouping of common sedimentary features and grain-size resulted in the recognition of several larger-scale sedimentary subdivisions (average = 6 m thick) which may represent sedimentary cycles within the shelf sequence.

These strata exhibit the previously mentioned crossbedded and compound bedforms, which appear to represent marine sedimentation in an upper to lower shoreface environment. This type of depositional environment reflects a moderately stable shelf setting.

PLATE 3:
OUTCROPS FROM THE THREE NATIONS FORMATION (PAMOUR GROUP) SHOWING KEY SEDIMENTARY
FEATURES HIGHLIGHTING MANY OF THE BEDFORM CHARACTERISTICS OF THE SHELF SEDIMENTS

(PLATE 3.A):

Detailed view of arkose (shelf sediments) showing compound bed forms, reactivation surfaces and mud drapes on most cosets in Member C of the Three Nations Formation. These represent wave reworking of deposits from the inner shore face: MS-4 (Whitney Township). Scale card is approximately 10 cm long; stratigraphic tops are shown by arrow. Dashed line marks coset boundaries.

(PLATE 3.B):

Outcrop of arkose (shelf sediments) in Member C of the Three Nations Formation showing compound bed forms, reactivation surfaces, mud drapes on most cosets, and major bounding surfaces (4th order). These represent wave reworking of deposits from the inner shore face: MS-4 (Whitney Township). Hammer is approximately 40 cm long, stratigraphic tops are shown by arrow.

(PLATE 3.C):

Outcrop of arkose (shelf sediments) in Member C of the Three Nations Formation showing mud drapes on most cosets, as well as minor mud chips. These represent wave reworking of deposits from the inner shore face: MS-4 (Whitney Township). Scale card is approximately 10 cm long; stratigraphic tops are shown by arrow on the scale card.

(PLATE 3.D):

Outcrop of arkose (shelf sediments) in Member C of the Three Nations Formation containing abundant mud chips. These represent wave reworking of deposits from the inner shore face: MS-11 (Whitney Township). Scale card is approximately 10 cm long; stratigraphic tops are to the right.

Trough crossbedded arkoses in Section Ti 1160 (Figure 2.54) also overlie turbiditic sediments of the Dome Formation (Table 2.5), but the contact relationship between these two rock types is not simple, because the lithologies are interbedded over a vertical distance of at least 70m. This represents a unique section, because such a transitional and gradational contact does not occur in any other section. The transitional nature of the lower contact at MS-2 is similar, in that pebbly sandstones at the base are transitional between the underlying turbiditic conglomerates of the Dome Formation and the trough crossbedded arkoses of the Three Nations Formation, but this transition occurs over a maximum vertical distance of 10m, and nowhere are the two lithologies interbedded. This type of transitional indicates continuity of deposition, perhaps in a deltaic environment. Secondly, the progradation of shoreface and overlying coarser fluvial deposits over deeper water, turbiditic deposits probably represents gravel-rich deltaic cycles (cf. Walker, 1992; Walker and Plint, 1992), which occurred at least three times in the lower 100m of the Three Nations Formation at this locality. Thus, a coarse-grained delta occurs between fluvial strata to the east of section Ti 1160 and the predominant shallow-water deposits to the west, which consist of ubiquitous arkoses with trough cross bedding and only a few interbedded gravel bars. Other important features suggestive of deltaic deposition include loading, dewatering and slump breccias in some of the mudstones and muddy turbidite units.

Figure 2.54
Representative sections of Member C-
Three Nations Formation, Pamour Group

Three Nations Formation: Member C					Facies
Section	type	%	Base Top		
1160	(2-1) ARKE	3	98	100	St
	(2-1) CGLM(M)	9	92	98	Gms, pSt
	(2-3) TBTE	9	86	92	St
	(2-1) CGLM(M)	4	83	86	Gms, pSt
	(2-1) ARKE	7	78	83	St
	(2-1) CGLM(M)	9	72	78	Gms, pSt
	(1-3) TBTE	14	62	72	Tde
	(2-1) CGLM(M)	6	58	62	Gms, pSt
	(2-1) ARKE	31	36	58	St
	(2-1) CGLM(M)	3	34	36	Gms
	UM sill ??		26	34	SILL
	(1-3) TBTE	6	22	26	Tde
	OVERBURDEN		0	22	
MS-11	(2-1) ARKE	5	139	144	St
	(1-1) CGLM(M)	5	134	139	Gms
	(2-1) ARKE	5	129	134	pSl
	(2-1) ARKE	5	124	129	St
	(2-1) ARKE	2	122	124	pSl
	(2-1) CGLM(M)	2	120	122	Gms, Fl
	(2-1) ARKE	15	104	120	St, pSl
	(2-1) CGLM(M)	12	92	104	Gms
	(2-1) ARKE	4	88	92	St, Sl
	(1-1) ARKE	4	84	88	pSl
	(1-1) CGLM(M)	8	76	84	Gms
	(2-1) ARKE	7	69	76	St, pSl
	(2-1) ARKE	3	66	69	pSl
	(2-1) ARKE	6	60	66	St
	(2-1) ARKE	10	50	60	St
	??(2-1) ARKE		36	50	St
	(2-1) ARKE	6	30	36	St
	??(1-1) ARKE		4	30	St
	(1-1) ARKE	4	0	4	St

Table 2.5 Summary of stratigraphic subdivisions of sedimentary strata in sections MS -11, and Ti 1160: Member C -Three Nations Formation, Pamour Group.

MS-4 (Figure E) represents the thickest section of the Three Nations Formation that is relatively well exposed: it also represents the only section that displays the sedimentary features of the lower to middle part of Member C (Figure 2.55).

Thickly bedded (0.5-1 m thick) and trough crossbedded arkoses of Member C are separated by a covered interval of 30 m from the underlying conglomerates of Member B of the Dome Formation. As with similar lithologies identified in MS-2, this 300 m section of marine sandstones contains diagnostic sedimentary features such as compound bedforms of thinly-bedded (.1-.5 m thick) to thickly-bedded (0.5-1 m thick) trough cross-bedded strata (Plate 3.B) displaying prominent reactivation surfaces, clay drapes (Plate 3.C) , mud chips (Plate 3.D), normal graded bedding, and several units showing opposing sediment transport directions suggestive of tidal currents, as well as several erosional channels (1-3m deep), 2-3 m thick gravel bars, and hummocky cross-stratification. Thinning-up cycles predominate over thickening-up cycles, which only occur directly below the first gravel bars in the section, and probably indicate a progradation of coarse-grained detritus.

Grouping of common sedimentary features and grain-size resulted in the recognition of numerous larger-scale sedimentary subdivisions that may represent sedimentary cycles within the shelf sequence: in total there are 40 divisions averaging 6 m thick in this 300 m section. Throughout the stratigraphic section, sedimentary cycles range in thickness from 8 m -in the basal part (0-100 m), to 4 m at 100-160 m height, to 3 m at 160-210 m height, to 6 m at the top of the section (210-300 m).

Sedimentary structures such as the hummocky cross-stratification (HCS), compound bedforms, abundant reactivation surfaces and clay drapes are of

Figure 2.55 A
 Detailed sedimentary features in section MS-4: Member C- Three Nations Formation, Pamour Group

Figure 2.55C Detailed sedimentary features in section MS-4: Member C-Three Nations Formation, Pamour Group

particular significance in identifying this sedimentary sequence as a product of deposition in a stable marine shelf environment. HCS and gravel bars are probably a direct product of major storm surges similar to those that commonly occur on a modern-day storm-dominated and tide-dominated shelf (cf. Walker and Plint, 1992). The significance of conglomerates overlying turbidite lithologies at the base of the section also suggests that these conglomerates may represent strata at or near the shelf-slope break. Thus, MS-4 represents a section from the deep-water basin onto the shallow marine shelf, with conglomerates marking a transition at the slope break. If these interpretations are correct, then Member C of the Three Nations Formation represents a new depositional environment for Timiskaming sediments (Pamour Group) that has not been previously identified near Timmins, Kirkland Lake or the type location near New Liskeard. This shelf sequence may also represent deposition during a time of relative tectonic stability, in contrast to deposition of the turbidite/conglomerate fan facies and the alluvial-fluvial conglomerate facies, both of which occurred during periods of active tectonism.

Section MS-11 (Table 2.5), which is farther to the west, stratigraphically overlies MS-4, but the lowermost part of MS-11 correlates with the uppermost part of MS-4 (Figure 2.47) and contains many of the same sedimentary features. Abundant reactivation surfaces in some of the trough crossbedded arkoses were produced by current transport in opposite directions as shown by numerous herringbone structures in the upper 70m of the section. Other factors contributing to the production of reactivation surfaces are sediment reworking by wave action in a shallow water depositional setting, such as the lower shore face (Walker and Plint, 1992).

The upper part of the Three Nations Formation is exposed in sections MS-17D, 17C and 17B in that order of stratigraphic succession (Figure 2.48). These

poorly exposed sections detail the upper 600m of the 1500m-thick formation (i.e. from 900 to 1500m).

Sections MS-17C, 17D, and 17B show the same lithologies and sedimentary characteristics that occur in MS-11 (Figure 2.54). Conglomerates appear to occur only in the lower 60m (Appendix 5) of this composite section (i.e. from 960-1010m above the base of the formation). The conglomerates occur as separate beds, but also are intermittently interbedded with trough-crossbedded arkoses and pebbly sandstone at a greater stratigraphic height in section MS-17C. The upper part of this section and MS-17B are devoid of any conglomerates, but pebbly sandstones are commonly interbedded with trough-crossbedded arkoses in the upper 400m of the formation.

In the area east of Night Hawk Lake, Member C has a thickness of at least 500m and probably 1500m. This is based on an assumption that the 600m gap that consists entirely of Member C, because the only definite fluvial strata (Member A) generally occur only in the basal 100m of the formation, and because the overlying sedimentary units show a similar lithofacies arrangement that is characteristic of Member C. This spatial arrangement suggests that an apparent conformable relationship exists in both a stratigraphic and lateral sense between Member C and Member A (the latter only occur at the base of the formation).

In a general overview of Member C, Section MS-2 and Ti 1160 represent the lower part of the member, whereas section MS-4 and 11 represent the lower to middle part of the member, and finally the upper 600m of both the formation and Member C are represented by a composite section from MS-17D, 17C, and 17B, in that order of stratigraphic succession.

Detailed spatial and bedform data

Member C contains non-fluvial strata representing marine and shallow water depositional environments. Four critical areas have been studied in detail to establish the lateral continuity and bedform types in Member C of the Three Nations Formation. The oldest of these, which is about 20m above the base of the formation at MS-2 (Figure 2.56), contains no conglomerates, but shows predominant transport from the east, as well as truncation surfaces which outline a 3-fold hierarchy for the bedforms. The next detailed sketch is about 40m above the base, but this occurs in MS-4 (Figure 2.57). The bedform types appear to show a hierarchy of erosional surfaces typified by first, second, third and fourth order surfaces, together with abundant reactivation, mud drapes and transport predominantly from the east.

At a higher stratigraphic level, conglomerates are interbedded with arkose and pebbly arkose and show a lateral continuity of 50m, but largely illustrate a stacking arrangement (Figure 2.58) that appears to be imbricated rather than layer-cake in nature. This section contains characteristic trough crossbeds overlain by low-angle crossbeds, which in turn are overlain by hummocky cross stratified (HCS) bedforms (Figure 2.59). Transport directions at this level are mainly unidirectional to the west. The HCS unit, which contains abundant mud drapes, is indicative of remobilization by storm surges. Trough- and low-angle cross bedding are common erosional features within the associated conglomerates (Plate 4.A) (Figure 2.59) that immediately underlie the distinctive HCS horizon. These contain characteristic bedforms which have flat basal surfaces (Plates 4.B and C), but ripple marked upper surfaces that suggest wave reworking. Abundant reactivation surfaces and mud drapes are present on all major surfaces, including some foresets and coset boundaries (Plate 4.C).

Figure 2.56 Plan view showing detailed sedimentary features and lateral continuity of the upper part of section MS-2; Member C- Three Nations Formation, Pamour Group

Figure 2.57

Plan view showing detailed sedimentary features and lateral continuity in a 19m segment of section MS-4, Member C - Three Nations Formation, Pamour Group

Figure 2.58

Plan view showing detailed sedimentary features and lateral continuity of conglomerates and sandstones with HCS bedforms in the middle of section MS-4, Member C- Three Nations Formation, Pamour Group

Figure 2.59
Plan view showing detailed sedimentary features and lateral continuity
of the lower part of section MS-4, Member C - Three Nations Formation,
Pamour Group

PLATE 4:
OUTCROPS FROM THE THREE NATIONS FORMATION (PAMOUR GROUP) SHOWING KEY SEDIMENTARY
FEATURES THAT HIGHLIGHT CHARACTERISTICS OF HCS AND TIDAL BED FORMS OF THE SHELF SEDIMENTS

(PLATE 4.A):

Outcrop of conglomerates of the gravel bar type (shelf sediments) in Member C of the Three Nations Formation showing bedding, cross stratification and truncations along the upper and lower contacts of the bed. These represent wave reworking of storm surge deposits from a shallow part of the inner shore face: MS-4 (Whitney Township). Scale card is approximately 10 cm long and stratigraphic tops are to the top of the page.

(PLATE 4.B):

Outcrop of arkose (shelf sediments) in Member C of the Three Nations Formation showing hummocky cross-stratification (HCS) bed forms with planar basal surfaces and undulating upper surfaces. Mud drapes occur on the upper surfaces. These represent wave reworking of deposits by a storm surge, and were only preserved because they were below storm wave base: MS-4 (Whitney Township). Scale card is approximately 10 cm long, stratigraphic tops are shown by the arrow.

(PLATE 4.C):

Close-up view of arkose (shelf sediments) in Member C of the Three Nations Formation showing hummocky cross-stratification (HCS) bed forms with planar basal surfaces and concavoconvex upper surfaces. Mud drapes occur on the upper surfaces. These represent wave reworking of deposits by a storm surge, but were only preserved because they were below storm wave base: MS-4 (Whitney Township). Scale card is approximately 10 cm long; stratigraphic tops are shown by the arrow on the card. The hammer handle is oriented parallel to the base of the bed.

(PLATE 4.D):

Outcrop of arkose (shelf sediments) in Member C of the Three Nations Formation showing compound bed forms, reactivation surfaces, mud drapes on most cosets, and opposing directions of transport. These represent wave reworking of deposits from the inter-tidal zone: MS-4 (Whitney Township). Scale card is approximately 10 cm long; stratigraphic tops are to the right. Transport directions are indicated by arrows within the beds.

Coarse-grained sand in this section tends to highlight the occurrence of not only first order surfaces (foresets), but second order bounding surfaces truncated by major bounding surfaces (3rd or 4th order surfaces). Mud draping and reactivation, which is recorded on first, second, third and rarely fourth order bounding surfaces, in order of decreasing abundance, are characteristic of this part of the Three Nations Formation (i.e. Member C). The fourth order surfaces appear to be more common in this part of the section than in other parts of the member. In fact these represent major bounding surfaces separating conglomerate beds from all other lithologies. Changes in the thickness of cosets defines several thinning-up cycles as well as a rare thickening-up cycles at the base of this 20m section. The latter feature may indicate progradation of a shoreface, whereas the thinning cycles are probably indicative of a recession of the main clastic input away from this part of the basin, suggesting a deepening of the basin.

The upper part of MS-4 (Figure 2.60) mainly consists of arkoses displaying both low-angle bedding, and trough cross bedding, and minor conglomerate interbeds. The dominant flow is in a westerly direction, with a few crossbeds indicating flow in the opposite direction. Reactivation surfaces and some mud drapes occur on foresets (first order surfaces) and cosets (second order surfaces). The truncation surfaces have a similar hierarchy to lower parts of the member, with three truncating relationships defining four erosional events, as well as tidal bundles, which occur in thin units that show transport to the east.

Of particular interest are starved ripples, and stratification characterized by tidal bundles that show transport to the east, opposite to the main direction of transport (Figure 2.59). A great number of beds showing westerly transport suggest that these represent the main tidal direction (Plate 4.D), but that easterly

Figure 2.60
Plan view showing detailed sedimentary features and lateral continuity of the upper part of section MS-4, Member C- Three Nations Formation, Pamour Group

transport may correspond to the ebb tide receding from the shore line (producing, in conjunction with the stronger flow, herringbone laminations). Reactivation surfaces (cf. Dalrymple, 1992) occur throughout this 10m section of trough cross bedded arkose, but are particularly noticeable in the uppermost parts (Figure 2.60). Thus, the occurrence of tidal bundles and the bidirectional nature of the paleocurrents are key features that suggest a probable shallow-water tidal environment of deposition.

The middle part of Member C, which is exposed in MS-11 and consists of a mixture of trough cross bedded arkoses, mudstones and Gms conglomerates in the uppermost part, shows predominant transport to the west, but also to the east (Figure 2.61). First, second and third order truncation surfaces have been documented together with some rare fourth order surfaces. Third order surfaces are quite prominent and they separate directions of opposing sediment transport. Mud drapes and reactivation surfaces appear to be fairly characteristic, especially in the lower part (Figure 2.61). Normally graded and ungraded beds predominate, and there is a true lack of reverse grading or other indications of surging flow. This represents a depositional environment containing gravel bar conglomerates in which the bedding ranges from trough cross bedding to low angle cross bedding, possibly representing planar foresets.

All of the above are characteristic of the shelf sediments from Member C of the Three Nations Formation. This member represents the youngest strata of the Abitibi Greenstone belt in the Timmins area.

Paleocurrents from Member C of the Three Nations Formation show a bimodal and bipolar pattern (Figure 2.53) with the main direction to the southwest and a less prominent direction to the northeast. In detail, the current directions shift from the basal to the upper part of the Member (the stratigraphic

Figure 2.61

Plan view showing detailed sedimentary features and lateral continuity of the middle part of section MS-11: Member C- Three Nations Formation, Pamour Group

succession is MS-2, 4, 11, and 17B at the top). In MS-2, the lowermost currents are strongly bipolar and bidirectional, whereas the upper ones are more unidirectional to the southwest. The lowest paleocurrents measured in MS-4, which are largely unidirectional in a manner similar to the upper part of MS-2, reflect similar flow conditions and suggest that these strata occupy a similar stratigraphic interval. The upper currents of MS-4, however, reflect a more balanced bimodal and bipolar current pattern, one which is suggestive of a shallow shelf and tidal influences. This pattern is replaced by a strongly unidirectional pattern higher in the section. In fact, MS-11 shows most current transport to the west, whereas the upper part of Member C (MS-17B) shows a predominant west to northwest transport. Bipolar and bimodal currents dominate along the base and within an interval from 150-300m above the base, whereas the other intervals show current patterns that are nearly unidirectional, or at the very least, weakly bimodal and bipolar. Currents from the upper part of Member C show directions similar to those from Members A and B of the Three Nations Formation. All current patterns attributable to the Three Nations Formation are roughly perpendicular to currents from fluvial units of the underlying, and hence older, Dome Formation.

Discussion

Member A of the Three Nations Formation consists of fluvial strata characterized by abundant conglomerates of the clast supported type (Gm or Gcs facies). These occur at several places including east of Nighthawk Lake at sections Ti 1390, Ti 1391, and MS-17, as well as at PS-18, which is about 40 km to the west in Thorneloe Township. These directly overlie turbiditic strata of the Dome Formation, except in the extreme western region (PS -18), where fluvial conglomerates overlie mafic volcanic flows.

Member B consists of probable fluvial strata dominated by Gms facies (matrix supported conglomerates), but does not contain any clast supported

conglomerates (Gm facies), nor show any reverse graded bedding, which is unlike the fluvial strata typified by Member A, and for that matter any fluvial strata in the other local formations. Only one section, namely MS-16 near the eastern edge of the study area, contains strata from Member B, and probably extends farther to the east (Figure 2.47).

The data from Member B, and probably Member A, show that several orders of bedforms and truncations surfaces occur, namely, first, second and third order erosional surfaces in that order of abundance, and in a manner similar to earlier described examples. The higher order surfaces (3rd order) separate the various lithotypes such as pebbly sandstone from conglomerate beds or sandstone beds.

In total, sections MS-2, Ti 1160, 4, 11, 17B, 17C, and 17D contain representative strata from Member C of the Three Nations Formation, which represents 400 to 1500m of sedimentary strata. Stratigraphic correlations show that sections MS- 17B, 17C, and 17D are stratigraphically similar and represent the upper part of the formation. The middle part of the formation is represented by MS-11 underlain by MS-4, whereas MS-2 and Ti 1160 represent the basal part of the formation. An apparent conformable relationship exists in both a stratigraphic and lateral sense between Members A and C.

Crossbedded sandstones and arkoses interbedded with minor pebbly sandstone and pebble conglomerates of the Gms variety represent Member C, which constitutes 90% of the formation. It presumably represents all of the middle and upper parts of the formation, but also conformably overlies turbiditic sandstones of the Dome Formation at several locations, namely MS-2 and 4. Member C has an onlapping and conformable relationship, because the fluvial facies (Members A or B) were never deposited at these locations. One of these sections, namely Ti 1160, contains evidence for a deltaic environment separating

definite fluvial strata to the east of section Ti 1160 and the predominant shallow-water deposits to the west.

A brief summary for Member C of the Three Nations Formation shows a hierarchy of erosional surfaces typified by first, second, third and fourth order surfaces, together with abundant reactivation surfaces, and mud drapes, and transport predominantly from the east. Interbedded conglomerates largely illustrate a stacking arrangement that appears to be imbricated rather than layer cake in nature. Other important features occurring at higher stratigraphic levels include the presence of hummocky cross stratified (HCS) bedforms, and tidal bundles together with abundant reactivation surfaces, and mud drapes as evidence of sediment reworking by wave action (Tillman, 1985; Walker, 1985a) and tides (Dalrymple, 1992).

Paleocurrents (Figure 2.53) predominantly show a strong unidirectional pattern for both fluvial units, namely Members A and B, whereas for Member C, they show an overall bipolar and bimodal pattern. Several intervals, however, such as near the base and at the top of the member, indicate that transport directions are unidirectional to the southwest and to the west, respectively.

Overview and General Discussion

A comparison of the thickness of stratigraphic units within the various Groups, formations and members reveals some parameters that may be useful for larger scale comparisons (Table 2.6). Each stratigraphic unit typically contains 2-3 depositional units, each of which may represent an individual sedimentary cycle.

A comparison of the formations shows that each member has a certain characteristic range of thicknesses for stratigraphic units and their constituent depositional units.

Member A of the Whitney Formation, which represents interbedded epiclastic and pyroclastic sediments, is characterized by thick stratigraphic and depositional units of 21m and 8m, respectively. Member B, which represents turbidite deposition, is similar to turbidite sequences elsewhere, comprising of thinner stratigraphic and depositional units (14m and 5m, respectively). Member C contains the thinnest stratigraphic and depositional units at 10m and 2m , respectively, but these are comparable to alluvial facies from the Dome Formation (Member A) and Three Nations Formation (Member A), as well as shelf facies from the Three Nations Formation (Member B) .

In the Beatty Formation, the thickness of stratigraphic units averages 15m , but ranges from 3 to 32m, whereas the depositional units average 8m, but range from 2 to 18m. The thinnest units occur in the most distal environments, which contain the highest percentage of fine-grained mudstones, whereas the thickest units occur within the sandy turbidites (sandstone facies) typical of inner fan deposits in sections MS-12C and MS-1. Stratigraphic and depositional units from the most proximal facies (Facies A-inner fan) are 7m and 5m, respectively, thicknesses substantially less than values for Facies B, but also less than the average for the entire Beatty Formation. With the exception of this last scenario, a gross correlation exists between the thickness of units and proximity of the depositional environment to the channel of the submarine fan, because the thinnest units are the most distal.

Section	Total metres	stratigraphic units thickness(m)	depositional units thickness(m)	Formation/ Member
Table 2.6 Comparison of stratigraphic subdivisions and depositional units for sedimentary strata of the Whitney, Beatty, Hoyle, Dome, and Three Nations Formations. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.				
Ti 363	150	16	11	Whitney Fm/A
Ti 360	172	34	8	Whitney Fm/A
MS-15A	42	14	5	Whitney Fm/B
MS-15B	30	10	6	Whitney Fm/B
Ti 3235	200	25	5	Whitney Fm/B
Ti 3236	60	12	5	Whitney Fm/B
Ti 3489	100	16	3	Whitney Fm/B
Ti 1398	40	13	7	Whitney Fm/B
Ti 1841	20	10	7	Whitney Fm/B
Ti 1974	12	6	6	Whitney Fm/B
Ti 1486	16	5	4	Whitney Fm/B
MS-9A	100	50	25	Whitney Fm/B
MS-9C	36	6	4	Whitney Fm/B
MS-9D	31	5	3	Whitney Fm/B
MS-9E	8	3	3	Whitney Fm/B
MS-9F	30	9	5	Whitney Fm/B
MS-15C	70	10	2	Whitney Fm/C
2 total sections		10	10	Whitney Fm/A
14 total sections		13	6	Whitney Fm/B
1 section		10	2	Whitney Fm/C
17 total sections	1117	14	6	Whitney Fm/TOTAL
PS-20	20	8	3	Beatty Fm
Ti 1369	84	12	12	Beatty Fm
Ti 1368	83	12	5	Beatty Fm
Ti 1370	28	4	3	Beatty Fm
MS-1	390	17	1	Beatty Fm
MS-12C	510	32	18	Beatty Fm
6 total sections	1115	14	7	Beatty Fm/TOTAL
K 54-30	170	11	5	Hoyle Fm/A
K 54-24	160	14	8	Hoyle Fm/A
K 54-25	260	13	7	Hoyle Fm/A
PS-19	80	13	10	Hoyle Fm/B
Ti 3568	170	11	5	Hoyle Fm/C
HP 2185	70	9	9	Hoyle Fm/C
Ti 3561	60	6	2	Hoyle Fm/C
Ti 1350	160	15	6	Hoyle Fm/C
Ti 308	190	17	7	Hoyle Fm/C
H 15-62	105	9	3	Hoyle Fm/C
H 1209	90	24	6	Hoyle Fm/C
H 16-12	325	12	5	Hoyle Fm/C
M51-1	190	15	5	Hoyle Fm/C
M21-10	260	14	5	Hoyle Fm/C
M23-23	84	12	12	Hoyle Fm/C
Ti 2371	200	11	4	Hoyle Fm/C
Ti 2378	200	12	8	Hoyle Fm/C
Ti 2374	184	13	5	Hoyle Fm/C

Section	Total metres	stratigraphic units thickness(m)	depositional units thickness(m)	Formation/ Member
Table 2.6 Comparison of stratigraphic subdivisions and depositional units for sedimentary strata of the Whitney, Beatty, Hoyle, Dome, and Three Nations Formations. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.				
MS-EVE SOUTH	230	26	20	Hoyle Fm/C
HP 2585	131	19	15	Hoyle Fm/C
Ti 3057	120	7	3	Hoyle Fm/C
Ti 3058	150	12	8	Hoyle Fm/C
TI 1840	53	7	2	Hoyle Fm/C
3 total sections		13	7	Hoyle Fm/A
1 section		13	10	Hoyle Fm/B
19 total sections		13	7	Hoyle Fm/C
23 total sections	3642	13	7	Hoyle Fm/TOT
MS-1	60	15	1	Dome Fm/A
MS-12A	50	13	1	Dome Fm/A
MS-5	70	7	2	Dome Fm/A/C
MS-8	120	10	2	Dome Fm/A/C
MS-2	70	8	3	Dome Fm/B
MS-13	140	20	8	Dome Fm/B
MS-10	160	15	3	Dome Fm/B
MS-3	85	9	2	Dome Fm/B
MS-6	32	5	3	Dome Fm/B
Ti 2407	125	12	3	Dome Fm/C
MS-7	90	15	11	Dome Fm/C
MS-12B	380	15	3	Dome Fm/C
4 total sections		11	1	Dome Fm/A
5 total sections		10	4	Dome Fm/B
3 total sections		14	6	Dome Fm/C
12 total sections	1382	12	4	Dome Fm/TOT
PS-18	110	18	12	Three Nations Fm/A
MS-17	30	4	4	Three Nations Fm/A
Ti 3591	130	16	1	Three Nations Fm/A
Ti 3590	180	18	3	Three Nations Fm/A
MS-16	70	11	6	Three Nations Fm/B
MS-2	50	7	5	Three Nations Fm/C
MS-4	290	6	2	Three Nations Fm/C
MS-11	100	6	1	Three Nations Fm/C
TI 1160	70	6	3	Three Nations Fm/C
4 total sections		16	5	Three Nations Fm/A
1 section		11	6	Three Nations Fm/B
4 total sections		6	2	Three Nations Fm/C
9 total sections	1030	10	4	Three Nations Fm/TOT

Stratigraphic and depositional units in Member A of the Hoyle Formation have an average thickness of 13m and 7m , whereas 16m and 6m are the comparative values for Member B of the Hoyle Formation.

Stratigraphic units from Member C the Hoyle Formation show a large range in thickness (6 to 26m), but average about 13m, whereas similar data for depositional units range from 2 to 20 m, averaging 5-7m . Further subdivisions of these data show that the lower part of the formation at the Hoyle Pond area has thicknesses of 12 and 5m, whereas 16 and 6m, 15 and 5m, as well as 7 and 3m correspond to the middle part of the section in the Bell Creek area, Hoyle Pond area, and northern Evelyn area, respectively. The upper part of the formation in the Esker Lake area shows similar thicknesses of 12 and 5m for stratigraphic and depositional units. The main anomaly is from the northern Evelyn area, where the middle of the Hoyle Formation has comparatively thin stratigraphic and depositional units. Otherwise thicknesses in all turbidite environments, regardless of their formation or member, appear to be similar, with thicknesses of 15m for stratigraphic units and 5-7m for depositional units. Corresponding units in the Alluvial facies (i.e. Facies A of the Hoyle Formation and Facies C of the Whitney Formation) are thinner.

The three members of the Dome Formation show a distinctive range of data. For instance, the mean thicknesses of stratigraphic units in Members A, B, and C of the Dome Formation are 3-10m, 9-15m, and >16m respectively. The depositional units which make up these stratigraphic units show a similar pattern, with mean thicknesses of 1-2m for Member A, 2-3m for Member B, and 5-6m for Member C. The more proximal high-energy depositional environments have the thinnest units, whereas those from distal (turbidite) environments have the thickest stratigraphic and depositional units.

Similarities in the average thickness of these units in a variety of age intervals within the study area suggest that most of the turbidite systems were

similar, and may indicate a similar type of fan (possibly fans from single point sources) throughout the 40 Ma history of the sedimentary basin. If this is accepted, then interpretations stemming from that premise will be greatly simplified, and variations in the sedimentary fill can be attributed to allocyclic processes, rather than changes in the system that delivered sediment to the basin. This means that the thickness of stratigraphic and depositional units does not represent a diagnostic tool which can distinguish one formation from the other. Anomalies from these norms probably reflect special depositional conditions, such as those that led to deposition of alluvial facies in the basin.

These conclusions appear to agree with the occurrence of turbidites in the lower, middle and upper parts of practically every formation, as well as within most of the members. Certain environments from the turbidite fan dominate some parts of the formation, but not to the exclusion of all other turbiditic environments.

The transition from Member B of the Dome Formation to the overlying Three Nations Formation appears to be gradational and indicative of a subaqueous facies change that cannot be directly attributed to uplift, erosion, and subsequent deposition. Bedding attitudes on both sides of the contact appear to be parallel and concordant.

The thickness of depositional and stratigraphic units in the Three Nations Formation, particularly the fluvial members of the Three Nations Formation (namely members A and B), compare most closely to Member B of the Dome Formation, which represents turbidites that are incised by conglomeratic fans. Member C of the Three Nations Formation, which represents shelf or shallow-water depositional conditions, consists of thin stratigraphic and depositional units. These stratigraphic units are substantially thinner than comparable values from turbidites or from fluvial strata, suggesting that these strata likely represent a different deposit type. The thin nature of depositional units, which are

comparable to fluvial-alluvial strata from other formations, suggests that deposition did not occur in a deep water basin. Alternatively, the thinness of these and other depositional units may be indicative of substantial reworking subsequent to deposition by currents in fluvial deposits, or by wave and/or (combined) current-wave action in a shallow-water basin (i.e. shelf). Such consistent reworking is manifest in the physical appearance of the shelf sediments, which contain numerous bedforms outlining 3 to 4 generations of truncation surfaces, whereas the fluvial strata contain only 2-3 orders of truncation surfaces.

Although studies of paleocurrents are important in basin analysis, all paleocurrent data from the Timmins area has to be evaluated with caution, because strata have been structurally rotated to 90° to 130°. Paleocurrents (Figure 2.38) from fluvial strata of the Dome Formation (Member A) indicate that a bipolar, bimodal pattern exists (Figure 2.38), with a predominance to the southwest and a lesser component to the northeast. A northwesterly orientation for a shore line can be inferred, because the shoreline is always perpendicular to the flow direction of alluvial fans. These directions are roughly perpendicular to the transport direction of the overlying turbidites of the same formation (i.e. the Dome Formation).

A reorientation of paleocurrents in turbidites of the Dome Formation (Figure 2.38) to their presumed original directions (assuming folding about horizontal axes) shows that transport was mainly from the south and southeast. If the transport was perpendicular to the edge of the basin, this suggests that the deeper part of the basin was to the north. This implies a continental source area to the south that provided detritus to the turbidite basin. With time, a facies shift towards the deepest part of the basin (i.e. regression) created shelf environments (Three Nations Formation) that displaced the turbidite facies of deep water (Member B - Dome Formation) and possibly some shallow water origin (parts of

Member C - Dome Formation). If the principal transport directions in the overlying Three Nations Formation represent currents parallel to the shoreline of a shallow-water shelf, then the predominance of east or west currents (Figure 2.53) suggests that a land mass may have been present to the south of the deep water turbidite basin.

Table 2.7 summarizes many of the stratigraphic relationships between and within the five different sedimentary formations, their various members, and the inferred relative sea level changes that are documented by shifting facies in a seaward direction. Most of these changes define progradational shifts of the proximal facies except in the uppermost formation where Member C conformably overlies Member A of the Three Nations Formation. The stratigraphic arrangement of facies in most formations (Table 2.7) suggests that the depositional basins became shallow with time, except for the oldest and the youngest sedimentary formations, namely the Whitney Formation and the Three Nations Formation, where the facies arrangements suggest that deepening of the basin occurred during the late stages of their depositional history.

<u>Group</u>	<u>Formation</u>	<u>Members</u>	<u>Depositional Environment</u>	<u>Turbidite Facies-A:G</u>	<u>relative sea level changes</u>
PAMOUR (youngest)	Three Nations	Member C Member B Member A	shelf fluvial alluvial	N/A N/A N/A	basin becoming deeper erosion of substrate erosion of substrate
PAMOUR	Dome	Member B Member C Member A	turbidite:proximal inner fan turbidite:mid fan alluvial	A, C C, B N/A	basin becoming shallow * basin becoming deeper ?? erosion of substrate
PORCUPINE	Hoyle	Member C Member B Member A	turbidite:mid fan turbidite:inner fan turbidite:outer fan&abysall plain	C, B B D, B and A	basin becoming shallow basin becoming shallow defines CU, and basin becoming shallow note: Members A and B are restricted to western margin of sedimentary basin
PORCUPINE	Beatty	none	turbidite:inner fan	B, A	basin becoming shallow, except in uppermost part where basin is becoming deeper
(oldest)		Member B Member A Member C	turbidite:inner fan & Mid fan turbidite:inner fan alluvial	B, C B N/A	basin becoming deeper in the uppermost part ** basin becoming shallow ?? erosion of substrate
TISDALE	Whitney				

Table 2.7 Comparison of facies relationships and possible relative sea-level changes for sedimentary strata of the Whitney, Beatty, Hoyle, Dome, and Three Nations Formations. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

* alluvial deposits overlain by mid fan deposits show a deepening of the basin, but a later progradation of inner fan deposits suggests that the basin subsequently become shallow

** intercalated pyroclastics and epiclastics probably occur in a shallow basin, especially because only inner fan deposits are interbedded with the pyroclastics

CHAPTER 3: PROVENANCE

MODAL ANALYSES OF CONGLOMERATES IN OUTCROP

INTRODUCTION

This section describes results of megascopic modal analyses of conglomerates that crop out within measured sections (MS) 1 to 17 (Figure 3.1). Observations were recorded to assess variations in clast lithology, shape, size, composition and abundance at 43 stations for which locations and data are tabulated in Appendix 6.

The record for each station consists of sufficient points of clasts plus matrix to reach a tally of 100 clast counts. The counts were made using a wire-mesh grid with points every 10 cm in a 1m² grid. The percentage of matrix was subsequently determined for each station by taking the percentage of matrix to clasts plus matrix.

The advantages and disadvantages of several different point counting methods, including the grid method, have been discussed by Howard (1993). Several disadvantages of the grid method include: fewer clast counts, and an arbitrary grid interval which means that not all clasts within the grid square are counted. An offsetting advantage of the grid method is that the percentage of matrix can be simultaneously determined, allowing examination of matrix-to-clast- ratios from station to station. Individual counts (100 clasts/station) can be subsequently grouped into amalgamated stations consisting of 200-500 points (generally one amalgamated station per measured section) in an effort to reduce standard counting errors caused by low abundances of certain clast types.

All conglomerates are part of the Pamour Group (2.68 Ga), the youngest sedimentary package of the Abitibi Greenstone belt in the Timmins area.

Figure 3.1 Locations of conglomerate point-counting stations and associated measured sections in Tisdale and Whitney townships: Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

Similar data for comparative purposes were not obtained from the Porcupine Group, because the unit does not contain significant amounts of conglomerate.

Petrographic Characteristics of Various Clasts

The first step in modal analysis was to classify the clasts into 15 rock types that are easily differentiated in the field. Some categories were subsequently combined, with the final total representing 12 rock types. These are briefly described in terms of their petrographic characteristics:

Krist clasts (type 1) are typically white to light cream volcanic rock fragments (Plate 5.A), euhedral to rarely broken plagioclase feldspar phenocrysts, and sparse quartz crystals in a fine-grained sericitic matrix. The quartz grains display distinctive embayed boundaries that are indicative of a volcanic origin. Plate 5.A shows an entire outcrop of Krist fragmental (volcanic) clasts in a primary depositional environment that represents the protolith for smaller Krist clasts in conglomerate beds.

Vein-quartz clasts (type 2), a common clast type of gravel bars, are typically white and reach a maximum size of 10 cm (Plate 5.B). Thin-section examination reveals that most of these clasts consist of polycrystalline quartz.

Outcrop and thin section observations have identified several types of altered mafic volcanic clasts (types 4 and 5), most of which show various shades of dark green on both fresh and weathered surfaces (Plate 5.C). Mafic volcanic clasts commonly exhibit trachytic textures and contain 25% plagioclase, 20% clinozoisite, 20% chlorite (Fe-rich) and 10-15% opaque oxides. Some of their primary volcanic features include stretched pipe vesicles, vesicle trains, and clasts with plagioclase-phyric chilled edges. Variability in texture and the percentage of phenocrysts in various

PLATE 5:

OUTCROPS FROM THE PAMOUR GROUP (DOME FORMATION AND THREE NATIONS FORMATION) SHOWING A VARIETY OF CLAST TYPES AND BED FORMS

(PLATE 5.A):

Outcrop of Krist fragmental containing numerous clasts of crystal tuff (K) in a crystal matrix. These subaqueous debris flows constitute the upper unit (Krist Formation) of the Tisdale Group: located near highway 101(Tisdale Township).

(PLATE 5.B):

Gravel bar conglomerates containing quartz vein (QV) clasts and relatively unaltered ultramafic clasts (U) with relic spinifex textures: from MS-4 of Member C, Three Nations Formation.

(PLATE 5.C):

Alluvial-fluvial deposits of Member A, Dome Formation from the lower conglomeratic unit of MS-1. Altered mafic volcanic (M) and porphyry (P) clasts.

(PLATE 5.D):

Alluvial-fluvial deposits of Member A, Dome Formation from the lower conglomeratic unit of MS-1, Altered mafic volcanic (M) and variolitic basalt (VB) clasts.

(PLATE 5.E)

Alluvial-fluvial deposits of Member A, Dome Formation containing abundant altered ultramafic (ss) clasts in the uppermost part of MS-1.

(PLATE 5.F):

Gravel bar conglomerates of Member C, Three Nations Formation containing a large proportion of sedimentary fragments such as mud chips (C) and sandstone (S) clasts: from section MS-11.

mafic volcanic clasts suggest that the source region probably consisted of more than one type of mafic volcanic. Distinctive variolitic basalt clasts (Plate 5.D) represent one of at least three different varieties of mafic volcanic. Although alteration of the original minerals has destroyed most of the volcanic textures, some original compositional differences can be inferred from differences in their alteration-mineral assemblages. In section D (Dome), one clast type is distinctly carbonate-rich, whereas others are predominantly chlorite-rich. Such differences in the alteration patterns between adjacent mafic volcanic clasts suggests that their primary mineral assemblages were different.

Porphyry clasts, which consist of quartz-rich (P1-QFP) and quartz-poor (P2) varieties (types 7 and 17, respectively), are commonly pink (Plate 5.C). In thin section, the mineral assemblages consist of knots and euhedral crystals of plagioclase feldspar in a groundmass of fine-grained sericite. Abundant carbonate within most porphyry clasts is the result of subsequent alteration.

Altered ultramafics (clast type 13), which typically weather brown or light brown, represent another common clast type (Plate 5.E). The original mineral assemblage (Plate 5.B) is totally recrystallized, and commonly replaced by carbonate and rarely by carbonate and talc. Alteration of the original olivine crystals resulted in opaque skeletal grains and at least two generations of carbonate replacement veins. Pervasive carbonate alteration appears to affect the ultramafic clasts more than the fine sand detritus that occurs between the clasts.

Chert, siltstone, and sandstone clasts are light cream to grey coloured, whereas mud chips and fuchsite chips are typically dark green and bright emerald green, respectively (Plate 5.F). Thin-section examination of these rocks, which represent clast types 8, 9, 10, and 14, confirms their basic field

identification. The chert consists of microscopic and polycrystalline quartz. Mud chips and fuchsite chips consist mainly of silty detritus, but the former contains minor amounts of chlorite, whereas the latter contains abundant colourless mica (fuchsite). The sandstone clasts are turbiditic sandstones (wackes) that contain greater than 30% matrix.

Opaque grains, which include both sulphide and oxide minerals, are a minor component of the conglomerates. Thin-section examination reveals that many of these grains are well rounded, suggesting a detrital origin.

Lithologic Variations of Grouped Data

Introduction

Three probable depositional environments, namely alluvial-fluvial, turbidite fan and gravelly bars in a shelf setting, have been identified; the point counts, and the measured sections from which they come, are grouped into these environments and arranged in a west to east direction in Tables 3.1 and 3.2 (these are plotted as pie diagrams in Figure 3.2.). The general spatial and cross cutting relationships of basal foresets within the conglomeratic units suggests that transport was either in a westerly or easterly direction.

To reduce counting errors for modal percentages of individual clasts, the point counts in each stratigraphic section have been grouped into stations consisting of 200-600 points. Increasing the total number of counts from 100 to 600 points, decreases the error by approximately 50%. Changes in the percentage of clast types between stations (see Table 3.1) are only significant if these differences are greater than the margin of error for each sample.

Table 3.2 Size (megascopic modal) data of grouped point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel bar conglomerates. Variations occur in the proportion of pebbles, cobbles, boulders, sandstone interbeds, matrix, clast size, ALCS and error estimates. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

point count	cnts	cm mean	cm ALCS	% size	% peb	% err	% size	% cob	% err	% size	% bod	% err	% ss	% err	% mtx	% err	W to E	DEPOSITIONAL ENVIRONMENT	MS	W to E CHANGES	constant factors	lateral distance each group (km)
PC-DOME	300	13	24	65	±6	±8	28	±6	±7	±3	0	0	33	±6	±6	±6	1a	alluvial-fluvial	D	minor decreases ALCS, clast size, and % of bol	% of pebs, cobs, and matrix	22
PC-1201	300	8	18	54	±8	±4	44	±6	±2	±2	1	1	33	±6	±6	±6	1b	alluvial-fluvial	12			1
PC-101	300	8	20	51	±6	±4	45	±6	±5	±4	0	0	36	±6	±6	±6	1c	alluvial-fluvial	1			3
PC-102	200	4	7	85	±8	±4	15	±6	0		0	0	47	±8	±8	±8	1d	alluvial-fluvial	1			3
PC-501	700	5	11	69	±4	±4	30	±4	1		0	0	35	±4	±4	±4	1e	alluvial-fluvial	5			10
PC-1701	200	7	12	68	±8	±3	33	±6	0		0	0	66	±8	±8	±8	1f	alluvial-fluvial	17			22
PC-1301	300	6	12	62	±8	±3	37	±6	1		0	0	47	±6	±6	±6	2a	TBTE fan	13	minor decreases ALCS, clast size increase ss beds	% of pebs, cobs, bol, and matrix	10
PC-201	500	6	9	75	±4	±4	24	±4	1		0	0	49	±4	±4	±4	2b	TBTE fan	2			3
PC-301	400	5	10	72	±4	±4	27	±4	1		9	9	35	±4	±4	±4	2c	TBTE fan	3			11
PC-401	300	2	3	86	±4	±4	14	±4	0		5	5	44	±4	±4	±4	3a	gravel bar	4,11	minor increases ALCS, clast size	% of pebs, cobs, bol, and matrix	16
PC-1601	300	4	8	86	±4	±4	14	±4	0		0	0	53	±6	±6	±6	3b	gravel bar	16			26
PC-KRIST	200	10	23	49	±8	±4	45	±8	7	±6	0	0	47	±8	±8	±8	4	volcaniclastic	K	minor decreases ALCS, clast size		

peb=pebbles; cob=cobbles; bod=boulders;ss= sandstone beds; mttx= matrix;
 er= error ; cnts= counts; MS= measured section#; TBTE= turbidite;
 ALCS=average large clast size

Table 3.3 Size and shape (megascopic model) data of grouped point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel bar conglomerates. Variations occur in the size of recognizable clast types (types 1-17), percentage of matrix, clast size, ALCS and error estimates. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

SHAPE	ALCS cm	mean clast (wieghted) cm	typical point count	section	t-1 cm	t-2 cm	t-4 cm	t-5 cm	t-6 cm	t-7 cm	t-8 cm	t-9 cm	t-10 cm	t-13 cm	t-14 cm	t-17 cm	mtx %	mtx ±%	ERR
tect lozenges all SR all SA	21	20	PC-33	Dome	5	1	16	9		7					4	33	±8		
	15	6	PC-39	ms-1			6	6		9					5	35	±8		
	7	4	PC-102	ms-1	6		4				2			4		37	±10		
tect lozenges	15	7	PC-42	ms-5		9	7			5	10		5	6	1	43	±10		
tect lozenges	12	7	PC-29	ms-17	7	2	10			10	3		10	9	2	66	±10		
T4 &T7- SA rest are SR	12	6	PC-40	ms-2		3	5			10	5			6	4	42	±10		
T4- SR rest are RD	12	6	PC-41	ms-3			6			6	4	4				55	±6		
T2 &T10- SA rest are SR	8	4	PC-38	ms-16	12	2	7	4		4		3			2	4	53	±10	

SR= subrounded; RD= rounded; tect= tectonic; SA= subangular; T4= clast type #4; ALCS= average large clast size; mtx= matrix; err= error

t1= Krist; t2= Quartz vein; t4= altered Mafic Volcanics; t5= variolitic basalts; t7= P1 or Qz-rich Porphyry; t8= mud chips; t9= sedimentary; t10= chert; t11= unknown; t13= altered Ultramafics; t14= mud chips; t17= P2 or Qz-poor Porphyry

ALLUVIAL FAN CONGLOMERATES

TURBIDITE FAN CONGLOMERATES

GRAVEL BAR CONGLOMERATES

LEGEND

- t1=Krist;
- t2=Quartz vein;
- t4=altered Mafic Volcanics;
- t5=variolitic basalts;
- t7=P1 or Qz-rich Porphyry;
- t8=mud chips;
- t9= sedimentary;
- t10= chert ;
- t11= unknown;
- t13=altered Ultramafics;
- t14 =mud chips;
- t17=P2 or Qz-poor Porphyry

Figure 3.2 Pie diagrams of grouped point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel bar conglomerates: compositional variations in the proportion of recognizable clast types (types 1-17) and percentage of matrix. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

Representative lithologic, size and shape data for each measured section are listed in Tables 3.1, 3.2, and 3.3. Included in these tables are estimates of the standard counting error, given the particular proportion and total population (100-700 counts) as suggested by Patterson and Fishbein (1989) and by Howard (1993).

Table 3. 1 lists lithologic data for the grouped point counts ,whereas Tables 3.2 and 3.3 list size and shape data.

Descriptions

West to east trends (Table 3.1) for alluvial-fluvial deposits show that altered mafic volcanics (aMV) are the dominant clast type, except in the extreme eastern regions, where altered ultramafic (aUM) clasts are more common (Plate 5.E) . Comparisons between PC 101 and 102 show upward vertical changes that involve an increase in Krist and altered ultramafic clasts and a corresponding decrease in altered mafic volcanic, Qz-poor porphyry (P2) and variolitic mafic volcanic (var MVLC) clasts.

Clast variations in conglomeratic (turbidite) fans (MS-13, 2 and 3) show more variability because a different clast type predominates in each of the three sections. The percentage of altered mafic volcanic clasts increases, and the percentage of altered ultramafic clasts decreases, from west to east. Quartz vein (QV) clasts (Plate 5.B) represent a minor clast type which is more common in the two easternmost sections.

Gravel bars generally contain a greater variety of clast types, and a larger proportion of sedimentary fragments (Table 3.1) such as mud chips and sandstone clasts (Plate 5.F) than either turbidite fans or alluvial-fluvial deposits.

The only possible west to east trend shown by gravel bars is an increase in proportion of sedimentary clasts, and a corresponding decrease in volcanic clasts (i.e. altered mafic volcanic and altered ultramafic clasts).

Interpretation

From west to east, parallel to the main transport direction, alluvial-fluvial deposits show a progressive increase in abundance of sedimentary and altered ultramafic clasts, together with a corresponding decrease in altered mafic volcanic and porphyry clasts (both P1 and P2) (Plate 5.C) . By contrast, sedimentary rocks and other rock types that hosted quartz veins were the dominant source area in the eastern regions; mafic volcanics and porphyries were less important source rocks.

An increase in proportion of altered mafic volcanic clasts and a corresponding decrease in altered ultramafic clasts suggests that the predominant source of altered mafic volcanic clasts for the turbidite fans was to the west and decreased in an easterly direction, because altered ultramafic rocks are more common in the eastern region.

Changes in the proportion of clasts typical of gravel bars are difficult to interpret, because of a lack of comparative data. The main trend is a decrease in the proportion of altered mafic volcanic clasts in an easterly direction. Again, this suggests that the main source region for altered mafic volcanic clasts was probably to the west, and areas to the east received fewer altered mafic volcanic clasts.

Size Analysis of Grouped data

Descriptions and Interpretations

Size and shape data for all amalgamated stations (point counts) are arranged (Tables 3.2 and 3.3) in a west to east direction for each of the three depositional environments. Changes in clast type suggest that some large-scale trends occur in a west to east direction. Some factors such as the percentage of pebbles, cobbles, matrix and boulders (except for alluvial deposits) are considered to be constant within each of the three environments (alluvial fans, turbidite fans, and gravel bars), because all changes are within acceptable error limits. Other similarities between alluvial fans and turbidite fans include minor decreases in both average large clast size of the ten largest clasts (ALCS), and of mean clast size. No significant changes occur in the percentage of boulders for conglomerates associated with turbidite fans, whereas alluvial fans show a slight decrease in an easterly direction. The percentage of sandstone interbeds also increases in an easterly direction for conglomerates associated with turbidite fans.

Gravel bar conglomerates, in contrast to other conglomerates, generally show minor increases rather than decreases in ALCS and clast size in an easterly direction.

Changes in the size of individual clast types (Table 3.3) in an easterly direction are different for each of the different depositional environments (alluvial, turbidite fan, and gravel bars); the data for turbidite fans indicates that for most clast types (i.e. types 7-porphry and 9-sandstone), the clast size decreases in an easterly direction. The largest clasts are quartz-rich porphyry (P1) clasts followed by altered mafic volcanic clasts. Shapes range from

subangular to subround to round; altered mafic volcanic and P1 clasts are mainly subangular, suggesting that these clasts were transported the least.

The size data for alluvial deposits show three different trends in an easterly direction: one trend shows decreasing followed by increasing clast size for several clast types (4-aMV, 7-P1 or qz-rich PORP, 17-P2 or qz-poor PORP); another trend, namely increasing clast size, is typical for Krist, sedimentary and altered ultramafic clasts (T-1, 10 and 13, respectively); a third trend shows an initial increase followed by a decrease in clast size for quartz vein and chert clasts (T-2 and 9, respectively), but data are sparse. The largest clasts in the eastern areas are altered mafic volcanic clasts followed by P1 clasts, whereas chert and other sedimentary clasts, followed by altered ultramafic clasts, are the largest clasts in the western regions. Mafic volcanic clasts underwent the least transport in the western regions, whereas most of the sedimentary and ultramafic detritus was derived from a source area to the east (i.e. MS-5 and-17).

Shape data indicate that most clasts have been tectonically modified into lozenges. An indication of their original shapes is revealed within low strain areas such as MS-1, wherein the original shapes range from subrounded at the base to subangular at the top of conglomerate unit. A variation of this type, which outlines a decrease in maturity with time (stratigraphic level), may be an indicator of the onset of renewed tectonism to produce locally derived, and hence immature, detritus.

Because of a lack of size data for the gravel bar conglomerates, a reliable interpretation is not possible. The clasts, however, are generally smaller than in either alluvial or turbidite fan conglomerates. Because the largest clasts in gravel bars are Krist followed by altered mafic volcanic (types 1 and 4, respectively),

they are inferred to have been the least transported, reflecting proximity to their source areas.

Lithologic Variations of Grouped Data-SECOND METHOD

The point count data can be viewed in another manner by combining the various clast types (1-17) into three main rock types, namely volcanic, granitoid(including porphyry) and sedimentary (Tables 4, 5 and Figure 3.3).

Description

Alluvial-fluvial conglomerates show a decrease in the percentage of volcanic clasts and a corresponding increase in percentage of sedimentary clasts in an easterly direction. A similar trend occurs in conglomerates associated with the turbidite fans.

No consistent trends are apparent for the gravel bars because of sparse data. The gravel bars show the lowest percentage of volcanic clasts, but they also contain the highest percentage of granitoid and sedimentary clasts compared to the other depositional environments.

Interpretation:

Changes in the percentage of clast types for both alluvial-fluvial and turbidite fans suggest that the predominant source areas for volcanic rocks probably was to the west, whereas the source area for sedimentary clasts was to the east. By contrast, a relatively constant percentage of granitoid clasts suggests that porphyry bodies were exposed in both regions. Conglomerates from both alluvial-fluvial and turbidite fans show that they had similar sources, but the gravel bars, which had a different provenance, because of their higher percentage of granitoid and sedimentary clasts, had a local source.

Table 3.5 Lithologic (megascopic modal) data of grouped point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel bar conglomerates. Variations occur in the abundance and ratios of volcanic:sedimentary: granitoid clasts. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

point	section	POINTS	Volcanics %	Granitoids %	Sediments %	V/G	G/S	V/S	environment	direction
count										
PC-DOME	DOME	300	63 ±6	37 ±6	0	1.7	0	0	all-fluvial	west
PC-1201	ms-12	300	81 ±4	17 ±4	2 ±2	4.76	8.50	40.50	all-fluvial	
PC-101	ms-1	400	63 ±6	30 ±6	7 ±6	2.15	4.41	9.48	all-fluvial	
PC-102	ms-1	200	91 ±4	6 ±3	3 ±2	16.64	1.83	30.50	all-fluvial	to
pc-15	ms-8	100	85 ±8	12 ±6	3 ±4	7.08	4.00	28.33	all-fluvial	
PC-501	ms-5	600	81 ±3	9 ±2	10 ±3	8.61	0.90	7.77	all-fluvial	
PC-1701	ms-17	200	21 ±6	41 ±7	38 ±7	0.52	1.09	0.57	all-fluvial	east
PC-1301	ms-13	300	98 ±2	2 ±2	0	49.00	0.00	0.00	TBTE fan	west
PC-201	ms-2	500	60 ±4	36 ±4	4 ±2	1.65	8.62	14.19	TBTE fan	to
PC-301	ms-3	400	45 ±5	29 ±5	26 ±4	1.54	1.07	1.65	TBTE fan	east
pc-16	ms-11	100	0	8 ±6	92 ±4	0.00	0.09	0.00	gravel bars	west
PC-401	ms-4	200	83 ±4	5 ±3	12 ±5	16.60	0.42	6.92	gravel bars	to
PC-1601	ms-16	300	11 ±4	50 ±6	39 ±6	0.21	1.27	0.27	gravel bars	east
					all-fluv=alluvial-fluvial; TBTE=turbidite					

ALLUVIAL FAN CONGLOMERATES

TURBIDITE FAN CONGLOMERATES

GRAVEL BAR CONGLOMERATES

LEGEND

Figure 3.3 Pie diagrams of grouped point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel bar conglomerates: compositional variations in the proportion of volcanic: sedimentary: granitoid clasts and percentage of matrix. Archean sedimentary suite of the Abitibi Greenstone Timmins, Ontario.

Size analysis

Descriptions

Systematic changes in the size of volcanic, granitoid and sedimentary clasts in all depositional environments outline distinctive trends in an easterly direction (Tables 3.4 and 3.5).

Alluvial conglomerates show several trends: decreasing clast size illustrated by volcanic clasts; decreasing followed by increasing clast size for granitoid clasts; and increasing clast size for all sedimentary clasts.

Turbidite fans, however, show a slight decrease in clast size for all clast types: volcanic, granitoid, and sedimentary.

An interpretation for gravel bars is not presented because the data are too sparse.

Interpretation

A lack of consistent trends suggests that there were several source areas for the alluvial conglomerates. A tectonically active source area can be inferred by the reversals in clast-size trends: an initial fining-up trend typical of fluvial systems is followed by a coarsening-up trend produced by subsequent uplift that caused an influx of coarser-grained detritus.

A consistent decrease in clast size for all clast types in the turbidite fans suggests a source area that was tectonically stable. Although these conglomerates are associated with turbidites, they also illustrate a fining-up trend typical of fluvial systems or of fully turbulent flow: the fining-up trends occur both vertically and laterally.

Volcanic, granitoid and sedimentary clasts in gravel bar conglomerates are smaller than either alluvial-fluvial or turbidite fan conglomerates, suggesting transport over greater distances than in the other depositional environments.

DETAILED POINT COUNTING DATA

Introduction

An earlier section discussed the general, overall trends that were produced by grouping point counting data into amalgamated stations (one per section) and by reclassifying clasts as volcanic, granitoid or sedimentary clast types. Stemming from this type of analysis, detailed point counts that relate to the individual stations (100 clasts/station) (Figure 3.1) can be examined. Detailed shape, size and lithologic data for conglomeratic clasts should identify any local or small-scale stratigraphic and lateral trends within each of the three depositional environments. This type of information can be missed by large-scale analysis using only amalgamated point counts.

It is also possible to see whether conclusions drawn from the grouped data are similar to those developed by examining the more detailed and closely spaced point counting data which, however, produces larger counting errors. Complete descriptions are given in Appendix 7; only the highlights are discussed below. These conclusions, which are in agreement with previous methods, also show evidence in the sedimentary record, indicating the erosion or unroofing of specific lithologies at certain stratigraphic levels.

Lithologic, size and shape data for the individual stations (1-43) in each measured section are listed in Tables 3.1, 3.2, 3.3 and 3.6 and are plotted in Figures 3.4, 3.5, and 3.6. Included in these tables are estimates of the standard counting error which corresponds the particular proportion and total population (100 counts) for each clast type. Standard counting errors were calculated according to methods outlined by Patterson and Fishbein (1989) and by Howard (1993).

Table 3.6: Size (megascopic modal) data of individual point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel conglomerates. Variations occur in the proportion of pebbles, cobbles, boulders, sandstone interbeds, matrix, clast size, ALCS and error estimates. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

point count	cnts	mean clast cm	ALCS cm	% size PEB	err	% size COB	err	% size BLD	err	% ss 2ND	err	% MTX	err	stratigraphic changes	W to E changes
ms-1															
pc-1	100		22	59	±10	39	±10	2	±3	0				increase followed by decrease ALCS, clast size	
pc-39	100	6	15	63	±10	37	±10	0		0					
pc-19	100	9	23	40	±10	52	±10	8	±6	0					
pc-2	100		20	40	±10	50	±10	10	±6	0				decrease in % of pebbles overall	
PC101	300	8	20	51	±6	45	±6	5	±4	0					
pc-31	100	4	7	84	±8	16	±8	0		0					
pc-32	100	4	6	86	±8	14	±8	0		0					
PC202	200	4	7	85	±8	15	±6	0		0					
ms-2															
pc-3	100		4	94	±4	6	±6	0		0				increase-% of cobbles, ALCS	
pc-4	100		16	78	±8	20	±8	2	±3	0					
pc-5	100		6	66	±8	31	±8	3	±4	0					
pc-40	100	6	12	59	±8	41	±8	0		0				decrease % pebbles	
pc-6	100		6	78	±8	22	±8	0		0					
PC102	500	6	9	75	±4	24	±4	1		0					
ms-3															
pc-7	100		6	67	±8	33	±8	0		19	±8			increase clast size and ALCS	
pc-8	100		6	90	±4	10	±6	0		0					
pc-41	100	6	12	72	±8	27	±8	1		18	±8				
pc-9	100		16	62	±8	36	±8	2	±3	0				decrease % of ss beds and matrix	
PC103	400	5	10	72	±4	27	±4	1		9	±4				
ms-4, 11															
pc-10	100	1	2	70	±8	30	±8	0		0					
pc-11	100	2	4	94	±4	6	±6	0		0				too separated to compare	
pc-16	100	2	4	93	±4	7	±6	0		16	±8				
PC104	300	2	3	86	±4	14	±4	0		5	±4				

peb=pebbles;
 cob=cobbles;
 bod=boulders;
 ss=sandstone
 beds;
 mtx= matrix;
 er= error
 cnts= counts;
 MS= measured
 section#;
 TBTE=
 turbidite;
 ALCS=average
 large clast
 size

Table 3.6: Size (megascopic modal) data of individual point counting stations for alluvial fan conglomerates, turbidite fan conglomerates, and gravel bar conglomerates. Variations occur in the proportion of pebbles, cobbles, boulders, sandstone interbeds, matrix, clast size, ALCS and error estimates. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

point count	cnts	mean clast cm	ALCS cm	% PEB	err ±%	size peb	% COB	err ±%	size cob	% BLD	err ±%	bol size	% 2ND	err ±%	ss	% MTX	err ±%	stratigraphic changes	W to E changes
ms-5																			
pc-12	100		8	88	±4	9	±4	3	±4									decrease in % of pebbles,	
pc-20	100	4	10	82	±8	18	±8	0		0									
pc-42	100	7	15	58	±8	42	±10	0		0									
pc-43	100	5	14	75	±8	25	±10	0		0									
pc-13	100		10	72	±8	28	±10	0		0								increase followed by decrease	
pc-14	100		10	50	±8	49	±10	1		0								ALCS, clast size	
pc-15	100		10	61	±8	39	±10	0		0									
PC-105	700	5	11	69	±4	30	±4	1		0									
ms-12a																			
pc-22	100	7	16	56	±8	42	±10	2	±3	0								decrease ALCS, clast size	
pc-23	100	8	20	50	±8	47	±10	3	±4	0									
pc-24	100	9	19	58	±8	42	±10	1		2	±3								
PC-112	300	8	18	54	±8	44	±6	2	±2	1									
ms-13																			
pc-17	100	8	16	60	±8	40	±10	0		0								decrease followed by increase	
pc-18	100	3	5	91	±4	9	±6	0		0								ALCS, clast size, % of cobbles	
pc-21	100	8	16	36	±8	62	±10	2	±3	0									
PC-113	300	6	12	62	±8	37	±6	1		0								increase followed by decrease	
																		% of pebbles	
ms-16																			
pc-38	100	5	10	74	±8	26	±8	0		0								decrease ALCS, clast size	
pc-28	100	3	8	88	±4	12	±6	0		0								% of cobbles	
pc-27	100	3	5	95	±4	5	±4	0		0								increase in % of pebbles	
PC-116	300	4	8	86	±4	14	±4	0		0									

peb=pebbles;
cob=cobbles;
bod=boulders;
ss= sandstone
beds;
mtx= matrix;
er= error
cnts= counts;
MS= measured
section#;
TBTE=
turbidite;
ALCS=average
large clast
size

ALLUVIAL FAN CONGLOMERATES

Figure 3.4 Pie diagrams of individual point counting stations for alluvial fan conglomerates from measured section (MS) D, 12 and 1: compositional variations in the proportion of recognizable clast types (types 1-17) and percentage of matrix. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins Ontario.

ALLUVIAL FAN CONGLOMERATES

MS-5

m=33

PC #12

m=31

PC #20

m=47

PC #42

m=38

PC #43

m=31

PC #13

MS-5 UPPER

PC #14
m=28 PC #15
m=35

MS-17

m=53
PC #29 m=78
PC #30

LEGEND

t1=Krist;
 t2=Quartz vein;
 t4=altered Mafic Volcanics;
 t5=variolitic basalts;
 t7=P1 or Qz-rich Porphyry;
 t8=mud chips;
 t9= sedimentary;
 t10= chert ;
 t11= unknown;
 t13=altered Ultramafics;
 t14 =mud chips;
 t17=P2 or Qz-poor Porphyry

Figure 3.5 Pie diagrams of individual point counting stations for alluvial fan conglomerates from measured section (MS) 5 and 17: compositional variations in the proportion of recognizable clast types (types 1-17) and percentage of matrix. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

TURBIDITE FAN CONGLOMERATES

Figure 3.6: Pie diagrams of individual point counting stations for turbidite fan conglomerates from measured section (MS) 13, 2 and 3, and gravel bar conglomerates from measured section (MS) 4, 11 and 16: compositional variations in the proportion of recognizable clast types (types 1-17) and percentage of matrix. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

All trends for individual clast types, described below, confirm many of the lithologic and size changes previously outlined using grouped data. Only the significant changes (i.e. greater than the counting error) will be discussed.

CONGLOMERATES ASSOCIATED WITH ALLUVIAL-FLUVIAL DEPOSITION

Variations in the relative proportions of clasts as a function of stratigraphic height illustrates several trends in MS-1. The major change is a substantial upward increase in the proportion of altered ultramafic clasts (aUM) (Plate 5.E) and a corresponding decrease in the percentage of altered mafic volcanic (aMV) clasts over the entire upper 60 m of the section. This trend probably illustrates the unroofing of ultramafic flows underlying an upper mafic volcanic unit. Both altered mafic volcanic and variolitic basalt clasts (Plate 5.D) decrease in abundance within the lower part of the conglomerate unit. There is also a corresponding increase in the abundance of matrix and P2 clasts as a function of increasing stratigraphic height. These trends are indicative of the progressive unroofing of a quartz-poor porphyry as well as a progressive increase in matrix content that corresponds to a decrease in ALCS (Table 3.2).

Comparisons between MS-5 and MS-3 show a decrease in the proportion of altered ultramafic clasts and a corresponding increase in the proportion of sedimentary and quartz vein clasts; the proportion of all other clast types remains about the same (Figure 3.4).

CONGLOMERATES ASSOCIATED WITH TURBIDITES

Unlike conglomerates in MS-1, those in MS-2 and 3 are associated with turbidites and probably represent channel-fill conglomerates cutting the turbidite sequence of the Dome Formation (Pamour Group).

Vertical or stratigraphic changes are defined by an upward decrease in altered ultramafic clasts and a corresponding increase in P2 (Qz-poor) clasts. This can be interpreted as indicating changes in source region with time. At MS-3, stratigraphic (vertical) changes are indicated by an increase in the proportion of both sedimentary and P1 clasts, and a corresponding decrease in quartz vein and mafic volcanic clasts. Again, these trends suggest the progressive unroofing of a source region which consisted of mafic volcanic rocks containing quartz veins, underlain by sedimentary and P1 rock types.

GRAVELLY BAR CONGLOMERATES: MAINLY IN A SHELF SETTING

Typically these matrix-supported conglomerates, which represent a minor component interbedded and associated with sandstones and pebbly sandstone beds, only occur within the Three Nations Formation of the Pamour Group.

At MS- 16, (Table 3.1 and Figure 3.5) only one stratigraphic trend was identified. An upwards decrease in the percentage of altered mafic volcanic clasts and a corresponding increase in the percentage of fuchsite chips (mud chips?) suggests that the mafic volcanic source area, which actively shed detritus during deposition of the basal conglomerates, became less important during deposition of the younger overlying conglomerates, where sedimentary clasts predominate. The origin of the fuchsite chips could have economic significance, because they either represent ultramafic fragments with relic spinifex textures, or mud chips that have been hydrothermally altered during the main gold mineralization event post-dating deposition and deformation (i.e. younger than 2.68 Ga).

SIZE AND SHAPE ANALYSIS

Introduction

Modal analysis of conglomerates in outcrop include size and shape data for many of the stations, together with the previously discussed compositional variations at all 43 stations. The probable depositional environments of the Pamour Group are represented by: alluvial-fluvial environments (MS-1, 5, 12, 17, and Dome), channel fill conglomerates associated with turbidites (MS-2, 3 and 13), and gravel bars that are part of a marine-fluvial shelf environment (MS-4, 11 and 16) in the Three Nations Formation.

Size and shape data for the individual point counts, together with average values for each measured section, are listed in Table 3.6. The point counts for each measured section are arranged in ascending stratigraphic order, and in a west to east direction (except for MS-2, MS-3 and D, where there is also a lateral variation).

Tables 3.2, 3.3, and 3.6 contain size data for 43 point counts, and also reveal any stratigraphic and lateral changes in each measured section: Table 3.6 lists the percentage of pebbles, cobbles, boulders, sandstone beds, matrix, mean clast size, and ALCS (average large clast size: ten largest clasts). Table 3.3 lists size and shape data for individual clast types (i.e. 1-17) at a few representative locations within MS-1, 2, 3, 5, and for every point count of MS-16, 17, and D (DOME) sections. These point counts are representative of conglomerates from three different depositional environments: alluvial-fluvial (MS-1, 5, 12, 17, and D), turbidite fans (MS-2, 3, 13), and gravel bars (MS-4, 11, 16).

CONGLOMERATES ASSOCIATED WITH ALLUVIAL-FLUVIAL DEPOSITION

Description

Several trends are apparent within the alluvial-fluvial environments (MS-1, 5, 12, 17, D (DOME)): stratigraphic changes in all sections generally indicate an initial increase followed by a decrease in both the mean clast size and the ALCS . There is also a decrease in the percentage of cobbles and boulders, together with a corresponding increase in the percentage of pebbles in MS-1 and 5.

Individual clasts of altered mafic volcanic clasts from MS -1, 5 , and 12 (Table 3.3) show a general decrease in size with height, whereas no clear trend is apparent for MS-D.

In the least deformed conglomerates (e.g. MS-1), the shapes of most clasts (Table 3.3) generally range between subround and subangular.

Interpretation:

Complementary trends of decreasing ALCS (average large clast size of 10 largest clasts) and percentage of cobbles are both suggestive of waning currents in a typical alluvial-fluvial system. This general trend is also supported by more detailed data that is specific to clast type: variations in the size of altered mafic volcanic clasts from MS-1, 5, and 12 (Table 3.3) also show a decrease with stratigraphic height. Increases in these parameters near the base of each section, however, suggest that an influx of coarse detritus occurred during the early stages of deposition.

Clast shapes, regardless of lithologic type (Table 3.3), range from subround at the base of the conglomerate to subangular at the top. The clasts become increasingly subangular in the higher parts of the stratigraphic section, suggesting that the source regions were farther removed from the streams during deposition of the lower conglomerates.

CONGLOMERATES ASSOCIATED WITH TURBIDITES

Description

Conglomerates in sections MS-2, 3, and 13, are all associated with turbidites and are interpreted as turbidite fan deposits.

Conglomerates in MS-2 show both lateral and stratigraphic variations between the various stratigraphic pairs (Table 3.6), with a general increase in ALCS, clast size, and the percentage of cobbles accompanied by a corresponding decrease in the percentage of pebbles.

In MS-3, stratigraphic changes include increases in mean clast size, ALCS, percentage of sandstone beds, and percentage of cobbles with a corresponding decrease in the percentage of pebbles. Lateral variations that occur in a west to east direction are similar, and include increases in both mean clast size, and ALCS, together with a corresponding decrease in the percentage of sandstone beds and matrix.

A stratigraphic trend for MS-13, which is defined by a decrease followed by an increase in ALCS, clast size, and percentage of cobbles, does not compare to either MS-2 or MS-3.

Interpretation

Conglomerates associated with turbidites (MS-2, 3 and 13) are characterized by lateral and stratigraphic changes that reflect a general upward increase in ALCS, mean clast size, and the percentage of cobbles and possibly an upward increase in the percentage of sandstone beds.

Because each section (Table 3.3) contains only one station with size and shape data, only general conclusions can be offered. Thus for section MS-2, clasts range in size from a maximum of 10 cm for P1 clasts to a minimum of 3 cm for quartz vein clasts. Clast types are subrounded, except the altered mafic volcanic and P1 clasts, which are subangular.

In MS-3, the size of an average clast ranges from a maximum of 6 cm for P1 clasts to a minimum of 4 cm for sedimentary clasts; all clast types are rounded, except for altered mafic volcanic clasts, which are subrounded.

CONGLOMERATES ASSOCIATED WITH SHELF ENVIRONMENTS

Description and Interpretation

Conglomerates in sections MS-4, 11 and 16 are associated with crossbedded arkose and probably represent discontinuous gravel bars deposited in a marine shelf environment, or in the case of MS-16, deposited as fluvial strata with a morphology similar to gravel bars in shelf settings. MS-16, an example of this type of matrix-supported conglomerate (Table 3.6), shows a stratigraphic decrease in mean clast size, ALCS, percentage of cobbles, and matrix, as well as a corresponding increase in pebbles (Member B of the Three Nations Formation). Individual clasts are generally in the pebble size range, but some fining-up trends occur in this environment: Average clasts (Table 3.3) range in size from a maximum of 12 cm for Krist clasts to 2 cm for vein-quartz clasts. Shapes range

from subangular for quartz-vein clasts and sedimentary clasts near the base, to subrounded clasts for all lithologies in the upper half of the conglomerate unit. These clasts basically show an increased textural maturity with stratigraphic height.

As discussed above, the trend of lithologic and size changes shown by individual clast types at individual stations are similar to results from the other two methods of analysis. These other two methods include individual clast types from amalgamated stations, or amalgamated stations with a volcanic:granitoid:sedimentary classification.

PETROGRAPHIC DATA

MODAL ANALYSES OF SANDSTONES

INTRODUCTION

This section describes results of the modal analysis of representative sandstones, mudstones and conglomerates from measured sections (MS) 1 to 17 (Figure 3.1) as well as section K(Krist), D(Dome)+several diamond drill cores. In total, 115 thin sections were examined: only 54 thin-sections (approximately 50%) were of the appropriate grain size for rigorous modal analysis; others were either too fine grained or too altered for point counting. The thin sections were etched and stained for both plagioclase feldspar and alkali feldspar following the method of Houghton (1980). Approximately 300 framework grains from each of the selected sandstone thin sections were identified and counted using the Gazzi-Dickinson method. This method assigns the sand-sized crystals and grains within larger fragments to crystal and grain categories, rather than to the category of the larger (host) fragment. In addition, every attempt is made to establish original detrital compositions in spite of subsequent alterations (Ingersoll et al, 1984). The counting interval was approximately 0.25 mm along each line, and 1 mm between lines, in order to cover the stained portion of each thin section. For coarser-grained sediments, both the interval and line distance were doubled to 0.5 and 2 mm, respectively, to provide a random and representative samples by avoiding the counting of any grain more than once.

The percentage of matrix was concurrently determined by calculating the amount of matrix to that of matrix plus 300 framework grains (i.e. matrix /matrix + 300). A second count of polycrystalline quartz (Qp) was made to

classify these grains into one of five recognizable lithotypes (Qp1 to Qp5). This will be discussed in a later section of this chapter.

Counts also were simultaneously recorded for lithic (L): Lv (lithic-volcanic) and Ls (lithic-sedimentary) grains, to determine their proportions for use in constructing provenance diagrams (QFL, QmFLt, and QmFLq). All original parameters and recalculated parameters are listed in Table 3.7.

Petrographic observations for all 115 thin sections are listed in Appendix 8.

Sample locations are given in Appendix 8 in the last columns ; locations of the measured sections from which they are taken are given in Appendix 6.

The advantages and disadvantages of several different point counting methods, including the Gazzi-Dickinson method, are discussed by Ingersoll et al (1984), Mack (1984), and Girty et al (1988). An important advantage of the Gazzi-Dickinson method is that it eliminates the variation in modal composition with grain size due to the breakdown of fragments into constituent grains. Modal differences are thus due only to mineralogical variations. Because this method emphasizes the detrital compositions of the rocks, it may not be as appropriate as some other point counting methods. The traditional point counting method only counts the constituent quartz (Q), feldspar (F) and lithics (L), and not the individual grains that make up the lithic fragments (grains). The Gazzi-Dickinson method thus reduces the effects of grain size and alteration on composition, thereby allowing accurate estimations of original detrital modes and provenance.

Variations in Textural Data

In Appendix 8, representative samples are categorized according to their stratigraphic section (1-17, D, K, and drill hole), and secondly by stratigraphic order within each measured section. This type of arrangement not only allows the samples to be grouped by their gross lithologic characters (e.g. turbidite, conglomerate or arkose), but also by major time or spatial differences such as Hoyle Formation, Beatty Formation, Whitney Formation, Dome Formation or Three Nations Formation. For comparative purposes, data for volcaniclastic sediments of the Krist Formation that underlies the Beatty Formation is also included in these tables. Basically, 10 different major lithologic groups or environments are listed in Tables 3.8 and 3.9. This table also summarizes, compares and contrasts all pertinent textural data for representative samples from each of the ten environments.

Description

Environments #1, 2 and 3 represent turbidites of the Hoyle Formation (Hoyle Assemblage), Beatty Formation (Porcupine Assemblage), and Whitney Formation (Whitney Assemblage), respectively. Turbiditic sandstones from these environments show many similar features: their original depositional frameworks, which consist of poorly sorted but well-packed grains of quartz, feldspar and minor lithics, have been condensed. In environments #1 and 2, the grade of metamorphism is low (greenschist) but increases to upper greenschist facies (actinolite) in environment #3 (Plate 6.A). Associated siltstones (environment #3B) also show the same grade of metamorphism. Carbonate alteration (Plate 6.B) appears to be pervasive in all three environments. Only in sandstone from the Beatty Formation have some rare original plagioclase feldspar crystals (Plate 6.C) survived metamorphism; none of the sandstones

Table 3.7 Legend and definitions of grain parameters for petrographic point counts using the Gazzi-Dickinson method. Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

SORTING

p POOR
m MODERATE

PACKING

P POOR
G GOOD
TC TECTONICALLY CONDENSED
MS MATRIX SQUEEZED

INDICATORS

* MATRIX
X PRESENT
N NOT PRESENT
R RARE
E# ENVIRONMENT #
NUMBER (1-11)

METAMORPHISM

C CARBONATE
GS GREENSCHIST
UG UPPER GREENSCHIST
OF ORIGINAL FELDSPARS
KF ALKALI FELDSPAR

FABRIC

SPF SERICITE PLANAR FABRIC
SWF SERICITE WRAPPING FABRIC
SCF SERICITE CRENULATION FABRIC
NG NORMAL GRADING

LITHOSTRATIGRAPHIC

HF HOYLE Fm
PG BEATTY Fm
WF WHITNEY Fm
PG PAMOUR GROUP
TN THREE NATIONS Fm
DF Dome Fm

OTHERS

PNS PHENOCRYSTS
PF PLAGIOCLASE FELDSPAR
QZ QUARTZ
GRPH GRAPHITE
Qm MONOCRYSTALLINE QUARTZ

ROCK TYPES

TBTE TURBIDITE
SLST SILTSTONE
ARKE ARKOSE
CGLM CONGLOMERATE
Gcs facies-gravel clast supported and stratified
Gms facies-gravel matrix supported and stratified

Table 3.8: Textural characteristics of Archean sedimentary suite - Abitibi Greenstone belt, Timmins, Ontario.

LITHOSTRATIGRAPHIC AND ROCK TYPES		E	p	m	P	G	TC	MS	C	G	UG	OF	KF	SPF	SWF	SCF	NG	PNS	GRPH
	#																		
TBTE - HF	1	X			X	X			X	X		N	N	X	X				X
TBTE - BF	2	X			X	X				X		R	N	X	X				X
SLST - BF	2A		X		X	X				X		R	N	X	X	X			X
TBTE - WF	3	X			X	X			X			N	N	X	X				X
SLST - WF	3A		X		X	X			X			N	N	X		X	X		X
ARKE - TNL	4		X		X	R			R	X		X	X	X				X	
TBTE - DF	5	X			X	X				X		X	N		X				
SLST - TBTE - DF	5A		X		X	X				X		N	N	X	X	X			
CGLM - Gcs DF	7	X			X	X		X	X	X		X	X	X	X				
CGLM - matrix*	7	X			X	X		X		X		X	N		X				
CGLM - Gcs-DF	8	X			X	X		X	X	X		X	N	X	X				
TBTE fans																			
TF-ARKE -Gms	9		X		X	X		X	X	X		X	X	X			X		
gravel bar																			
KRIST	10		X		X	X		X	X	X		X	N	X	X			PF	embayed Qm
KRIST-mtx*	10		X										N					PF	embayed Qm
Krist- Gms-			X										N					PF+QZ	embayed PF+Qm
CLAST	10		X		X	X		X	X	X		X	N	X	X			PF	embayed Qm
KRIST	10		X		X	X						X	N	X	X			PF	embayed Qm

AT LEAST 2 GENERATIONS
OF CARBONATE: 1 MAY
BE CEMENT
SILT-SIZED MTX

Table 3.9 abbreviations and legend for Table 3.8: textural characteristics of Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario.

Counted parameters Gazzi-Dickenson method	recalculated parameters Gazzi-Dickenson method
Qp polycrystalline quartz	$Q = Q_m + Q_p + Q_c$
Qm monocrystalline quartz	$F = KF + PF$
Qc chert	$L = L_s + L_v$
PF plagioclase feldspar	$L_t = L_s + L_v$
KF alkali feldspar	$L_q = L_c + Q_p$
ser sericite	$TF = PF + KF + ser$
chl chlorite	$TQ = Q_m + Q_p + Q_c$
cb carbonate	$TL = L_s + L_v$
M matrix	$PF = PF + ser$
second or simultaneous counts	$L_v = L_v + chl$
Ls sedimentary lithics	
Lv volcanic lithics	

PLATE 6:

THIN SECTIONS OF ROCKS FROM THE TISDALE GROUP (WHITNEY FORMATION) AND THE PORCUPINE GROUP (BEATTY AND HOYLE FORMATIONS) SHOWING TEXTURES, FABRICS, ALTERATION AND DETRITAL COMPOSITIONS

(PLATE 6.A):

Thin section of turbiditic sandstones of the Whitney Formation showing actinolite -greenschist metamorphism. Note the highly altered state of the plagioclase feldspars represented by sericite alteration products; the quartz grains (Qm) are unaltered.

q=Qm grains; p=plagioclase grains; a=actinolite

(PLATE 6.B):

Thin section of turbiditic sandstones of the Member C of the Hoyle Formation showing abundant carbonate alteration. Note the highly altered state of the plagioclase feldspars represented by sericite alteration products; the quartz grains (Qm) are unaltered.

q=Qm grains; cb=carbonate crystals

(PLATE 6.C):

Thin section of turbiditic sandstones of the Beatty Formation containing minor volcanic (chlorite fragments), and sedimentary grains (s) and some remnant plagioclase feldspar grains(p). Note the highly altered state of most plagioclase feldspars represented by sericite alteration products, the quartz grains (Qm) are unaltered.

q=Qm grains; p=plagioclase grains; s=sedimentary grains

(PLATE 6.D):

Thin section of turbiditic siltstones of Member B of the Whitney Formation containing some fine quartz grains (q) as well as some graphitic (g) laminations (carbonaceous). Note the strong planar fabric parallel to the original bedding surfaces and that the quartz grains (Qm) are unaltered.

contains any alkali feldspar. These sandstones also show remarkably similar sericite-planar fabrics (SPF) and sericite-wrapping fabrics (SWF) common to all three types. Normal grading is not common in any thin sections of turbiditic sandstones from environments #1, 2, and 3.

By comparison, siltstones (environment #3B) have many of the above mentioned characteristics, but some differences include: a finer grain size, and better sorting among the framework grains; siltstones have moderately to well-sorted frameworks consisting of silt-size grains and a few grains of very fine sand. Siltstones commonly have a dominant sericite-planar fabric (SPF) (Plate 6.D) similar to the turbidites, but a sericite crenulated fabric (SCF) replaces the typical, sericite-wrapping fabric (SWF) seen in most turbidites. The content of graphite (Plate 6.D) generally ranges from a trace up to 10%, particularly within associated mudstones of environments #1, 2, 3, and 3b.

Environments #4 to #9 represent sediments of the Pamour Group that unconformably overlie sediments of environments #1 to #3. Only a few textural features are common to all sediments of the Pamour Group. These include: a low grade of metamorphism (greenschist); the presence of some unaltered original plagioclase feldspars in all sediments except siltstones; the presence of fining-up features indicative of normal-size grading; the strongest fabric developed is typically a sericite planar fabric (SPF), and all sediments, except most arkoses, have a condensed framework.

Textural comparisons between the probable shelf sediments (arkoses-environment #4) and turbiditic sandstones (environment #5) are as follows: (1) arkoses are generally better sorted, rarely have a condensed framework (Plate 7.A), contain some alkali feldspar (Plate 7.A), contain only planar sericite tectonic fabrics, and do not contain wrapping or crenulation fabric;

PLATE 7:
THIN SECTIONS OF ROCKS FROM THE PAMOUR GROUP (DOME AND THREE NATIONS FORMATIONS) AND
THE TISDALE GROUP (KRIST FORMATION) SHOWING TEXTURES, FABRICS, ALTERATION AND DETRITAL
COMPOSITIONS

(PLATE 7.A):

Thin section of arkoses of Member C, Three Nations Formation containing some alkali feldspar (k) and showing a framework that is not tectonically condensed: from section MS-4, Three Nations Formation-Member C.
q=Qm grains; p=plagioclase grains

(PLATE 7.B):

Thin section of sandstones (turbidites) of Member B, Dome Formation, containing some original plagioclase feldspar, and lacking late carbonate alteration.
q=Qm grains; p=plagioclase grains;

(PLATE 7.C):

Thin section of conglomerates of Member A, Dome Formation -containing mafic volcanic clasts (v) and some late carbonate alteration (cb) in the interstitial matrix, which appears to be pervasive due to the highly permeable nature of the conglomerates.

(PLATE 7.D):

Thin section of Krist volcanoclastics showing a poorly sorted combination of matrix(m), crystals(p) and rock fragments. The framework consists of moderately sorted plagioclase feldspar and rare quartz pheoncrysts that are embayed: Krist Formation of the Tisdale Group.

(2) The turbiditic sandstones are commonly less affected by late carbonate alteration than arkose, because the latter has a higher permeability. Only arkoses of the Three Nations Formation contain minor but fairly pervasive silica cement and rare sericite cement. The silica cement, which is another key characteristic of the shelf sediments, makes them different from all the other rock types.

Textural differences between turbiditic sandstone and associated siltstones (represented by environments #5, 5B, respectively), are similar to those between environments #3 and 3B. The main difference in the siltstones is a finer grain size, a better sorted framework consisting of predominant silt-sized quartz and feldspar grains, and the presence of a sericite crenulation fabric (SCF) instead of a sericite wrapping fabric (SWF). Late-stage carbonate alteration is generally absent or less intense within the siltstones than within associated the sandstones: the higher permeability of sandstone appears to be the main controlling factor.

The presence of some original (remnant) plagioclase feldspar, and the lack of late carbonate alteration (Plate 7.B), are characteristic of turbiditic sandstones of the Dome Formation of the Pamour Group, in contrast to those of the older Hoyle and Beatty Formations of the Porcupine Group.

Another difference between the Pamour Group and older strata is the higher metamorphic grade (e.g. upper greenschist facies) for sediments of the Whitney formation (Tisdale Group).

Environments #6 to #9 represent various conglomerate types of the Pamour Group. Textural features relate mainly to the sand-sized matrix of conglomerates, but also to relationships between larger clasts and the interstitial matrix (Plate 7.C). Deformation in all of the conglomerates has produced a modified framework of flattened quartz, feldspar, lithic grains and a finer-grained silt-sized matrix; detrital grains are generally well packed and poorly

sorted except for conglomerates from environment #9 (gravel bars), which contain moderately sorted detritus. Late carbonate alteration appears to be pervasive due to the highly permeable nature of all of the conglomerates. Original plagioclase feldspar grains, which have survived several episodes of alteration, occur in all environments. Alkali feldspar grains, however, occur only in the alluvial conglomerates and gravel bars (Plate 7.A) of environments 7 and 9, respectively; neither turbidite conglomerates (environment #8) nor their associated turbiditic sandstones (environment #5) appear to contain any alkali feldspars.

Fabrics in all of the conglomerates consist predominantly of a sericite-planar fabric (SPF) and a less common sericite-wrapping fabric (SWF) that resulted from rotation and deformation of clasts. Normal size grading occurs within conglomerates of all of the depositional environments, even in some that probably represent non-fluvial settings.

Environment #10 is represented by volcanoclastic deposits of the Krist fragmental unit that underlies turbidites of the Beatty Formation. Both differences and textural similarities exist between these volcanoclastic rocks (Table 3.8) and all of the previously described epiclastic rocks. Similarities with most epiclastic rocks include: pervasive carbonate alteration; a condensed framework of feldspar, quartz and lithics, occurring as probable plagioclase and quartz phenocrysts in Krist rocks (Plate 7.D) and as detrital grains in the epiclastic rocks; a similar degree of deformation and low-grade metamorphism typical of greenschist facies; and a planar fabric (SPF) marked by sericite as the predominant tectonic fabric. Survival of some original plagioclase feldspar phenocrysts, in spite of regional deformation, makes the Krist more similar to rocks of the Pamour Group than to older rocks such as the Hoyle and Beatty

Formations of the Porcupine Group. The lack of alkali feldspar, however, is a common factor in all rocks except for some sediments of the Pamour Group.

Sorting is one important textural feature that makes these volcanoclastic rocks different than any previously described epiclastic rocks. Krist volcanoclastics generally represent a poorly sorted combination of matrix, crystals and fragments; however, their frameworks consist of moderately sorted plagioclase feldspar and rare quartz phenocrysts (photo 3.18). By contrast, most poorly sorted epiclastic rocks would have a poorly sorted framework. A comparison of sorting patterns in Krist volcanoclastics and typical epiclastic rocks shows that the closest epiclastic analog would be a pebble conglomerate of uniform clast size with a silt-sized matrix. Another important difference shown by volcanoclastics is the predominance of phenocrysts rather than detrital grains. Crystals of plagioclase feldspar, the dominant framework component of the Krist fragmentals, occur not as detrital grains, but as euhedral and rarely broken crystals. Lesser amounts of monocrystalline quartz, which occurs as embayed crystals, make up the rest of the framework.

The absence of normal graded bedding is another major difference between the Krist volcanoclastics and typical epiclastic rocks of the Pamour Group.

Interpretation

The turbiditic sandstones of environments #1 to #3 are all texturally immature, poorly sorted and tectonically modified sediments; no original plagioclase feldspar has survived subsequent regional metamorphic events, and there is no evidence of any original alkali feldspar. The grade of regional metamorphism ranges from lower greenschist facies for most epiclastics to upper

greenschist facies for sandstones and mudstones of the Whitney Formation of the Tisdale Group. All sedimentary rocks of environments #1 to #3 are characterized by a lack of graded bedding, and the presence of a planar sericite fabric as the dominant tectonic feature. Late-stage carbonate alteration is also common. Obviously these sedimentary rocks have undergone a prolonged period of tectonism and metamorphism. Some, like those of the Whitney Formation, which are of a higher metamorphic grade, probably have also undergone a greater amount of tectonism. A higher metamorphic grade suggests that they may represent the oldest sedimentary strata, and the general stratigraphic position of these sandstones and mudstones below volcanic rocks suggests that they represent a sedimentary suite which is different and older than other sediments such as those of environments #1 and #2 (Hoyle Formation and Beatty Formations, respectively), which unconformably overlie the volcanic rocks. Lithologic and textural differences between the siltstones and sandstones suggest that the former are better sorted and generally contain lower amounts of plagioclase feldspars and their alteration products. This also means that they have a different bulk composition than their associated sandstones, and probably represent sedimentation by a combination of pelagic rainout as well as turbidity currents, in contrast to their associated sandstones which were supplied only by regular turbidite currents.

Comparisons between sediments of the younger Pamour Group and the Hoyle Formation and Beatty Formation reveal several important differences:

- 1) The presence of remnant plagioclase feldspar and chlorite (rather than amphibole) in the younger sediments suggests that they are less metamorphosed than the sediments of the Hoyle Formation and Beatty Formation;

2) The presence of graphite in the fine-grained sediments (Plate 6.D) of the Hoyle Formation and Beatty Formation suggests that these older sediments were deposited in more anoxic and restricted basins than similar sediments of the younger Pamour Group.

3) The lack of any alkali feldspars within turbidites of the Hoyle, Beatty and Dome Formations suggests that these turbidites are more reworked, resulting in the breakdown of alkali feldspar, whereas sediments within the alluvial deposits, shelf deposits and gravel bars of the Pamour Group were only transported over short distances. Alternatively, source rocks containing alkali feldspars (probably porphyry) were exposed during deposition of the shallow-water sediments of the Pamour Group, whereas they were absent (or submerged) during deposition of the older sedimentary rocks (Hoyle Formation and Beatty Formations).

Other differences between turbidites and shelf sediments of the Pamour Group include a better sorted framework of quartz, feldspar and lithic grains for the shelf sediments (Three Nations Formation), which further suggests that the arkoses are more reworked than the turbiditic sandstones. The presence of silica cement in the arkoses, which is absent in the turbidites, suggests that the environment for diagenesis of the shelf sediments was more tectonically stable than the deep-water turbidite basin.

Graded bedding, a common feature in sediments of the Pamour Group, is absent or rare in the older sedimentary rocks. Normal grading was produced during deposition of sandstones and conglomerates either by fluvial or fully turbulent marine currents in a proximal or medial fan environment. Turbidites from the older suites are generally finer grained, and may represent distal fans or abyssal plain deposits.

Reworking of gravels and associated sands by long shore currents probably created the local normal grading in the shelf deposits.

Krist

One of the key differences between the previously described epiclastic rocks and the volcanoclastic sediments of the Krist fragmental unit (Plate 5.A) is the presence of euhedral and rarely broken plagioclase phenocrysts and embayed monocrystalline quartz grains in the latter (Plate 7.D). The presence of euhedral phenocrysts rather than abraded detrital grains suggests that this detritus had a definite volcanic origin, with little or no reworking before deposition. A lack of graded bedding probably indicates that deposition occurred by debris flows or by pyroclastic flows with internal friction; mud or fine ash were the main mechanism for internal support. Rapid deposition by debris flows is also suggested by poor sorting of the matrix, fragments and crystals. Flame structures and normal grading in a fine-grained ash tuff lithofacies, together with a total lack of accretionary lapilli, strongly suggests that deposition occurred in a subaqueous, rather than a subaerial environment. This interpretation also fits the general subaqueous stratigraphic succession: both the basal and uppermost sedimentary unit of the Krist fragmental is a graphitic mudstone in an apparent conformable relationship with underlying subaqueous (pillowed) volcanics and with overlying deep-water turbidites of the Beatty Formation. Neither uplift nor subaerial erosion occurred during deposition of this part of the stratigraphic section; it seems unlikely that the Krist fragmental represents subaerial volcanism.

Compositional Variations

Introduction

The point-count data for the sandstones and conglomerates (Appendix 8) can be recalculated in terms of several key and characteristic grain types that are listed in Table 3.7. Such grain types plotted on provenance discrimination diagrams have been widely used by Dickinson et al (1983) to show relationships between the ratios of grain types and provenance for sandstones in a variety of tectonic settings. The types of provenance discrimination diagrams used in this study include: QFL (a common plot); QmFLt -to examine the relationship of monocrystalline quartz (Qm) to total lithics (Lt); and QmFLq, which examines the relationship between lithic quartz (Lq), monocrystalline quartz (Qm), and feldspar (F); Lq (total lithic quartz) is made up of polycrystalline quartz and chert (Qp and Qc, respectively), and the percentage of matrix as well as the Q/Q+F ratio provide additional compositional features that are used to compare rock types.

Recalculated parameters for the various provenance diagrams are listed in Table 3.10 according to their depositional environment (#1 to #10, as previously discussed), stratigraphic section, and stratigraphic order within each section. These data are plotted in Figures 3.7, 3.8, and 3.9. Numbers in these figures refer to the order in which the samples appear within each depositional environment in Table 3.10. Their relative order reflects a west to east arrangement within each depositional environment; it also represents an ascending stratigraphic order for Environment #4 (the shelf sediments). The estimated (maximum) counting error for each sample and the mean value for each group are listed in Tables 3.11 and 3.12; This standard counting error, which is outlined by Patterson and Fishbein (1989) and by Howard (1993), is calculated by using the proportion of a

particular grain type and the total population (300 counts). The average values (means) of all grain parameters for representative samples of each depositional environment are also listed in Table 3.10 and plotted in the various diagrams. This method is preferable to earlier methods outlined by Van der Plas and Tobi (1965), which are based on standard deviations for the data.

Provenance Plots

Descriptions

QFL plot

Variations in QFL parameters for all sedimentary rocks shown in these diagrams appears to have neither a systematic stratigraphic, nor a west to east (lateral) pattern: sediments of the Hoyle Formation, Beatty Formation and Krist Formation (Figure 3.7) show a wide range of values with no obvious pattern. The Krist volcanoclastics and Whitney Formation sandstones contain the greatest amount of feldspar but the least quartz and lithics; sandstones of the Hoyle Formation show the greatest range (5-25%) in lithic content. Similar data for shelf sediments from the Three Nations Formation also show a considerable range in both lithic and feldspar contents (20% difference), but these sandstones (arkoses) contain less feldspar than the older turbidites: the data indicate two separate and distinctive clusters. Other sediments of the Pamour Group show a wide range in Q and F ratios, but a narrow range in lithic contents (0-10%).

The mean QFL values (Figure 3.7) for each depositional environment show two distinctive clusters: one represents data from environments #1 to #3 (Hoyle, Beatty and Whitney Formations), whereas the other represents environments #4 to #7 of the younger Pamour Group. Table

Table 3.10 Modal analysis: mean values for recalculated grain parameters (Gazzi-Dickinson method) for specimens from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Values are plotted in Figures 7, 8 and 9.

m	sect	SAMPLE NO	total counts	KF %	MEAN QmFLt: 1Qm	MEAN QmFLt: 1F	MEAN QmFLt: 1Lt	MEAN QFL: 2Q	MEAN QFL: 2F	MEAN QFL: 2L	MEAN QmFLq: 3Qm	MEAN QmFLq: 3F	MEAN QmFLq: 3Lq	MEAN M % 2nd COUNT	MEAN Q/TF	E #	lith	REF #
KIDD		6008	300	0	14	86	0	14	86	0	14	86	0	35	14	1	HF-NW-T	1
KIDD		6009	300	0	19	81	0	19	81	0	19	81	0	35	19	1	HF-NW-T	2
t pond		77	300	0	24	62	14	32	62	6	24	68	8	26	21	1	HF-T	3
TI 1840		M1320	300	0	20	43	37	22	43	35	37	61	2	23	31	1	HF-T	4
33		338	300	0	22	66	12	34	66	0	22	66	12	33	25	1	HF-T	5
12D		204	300	0	20	61	19	39	61	10	21	70	9	29	23	2	BF-T	6
12D		205	300	0	19	67	14	26	67	7	19	74	7	40	20	2	BF-T	7
12D		207A	300	0	21	47	32	33	47	20	23	65	12	22	26	2	BF-T	8
12D		207B	300	0	20	56	24	29	56	15	23	68	9	22	25	2	BF-T	9
1		6001	300	0	21	64	15	27	64	4	24	70	6	33	26	2	BF-T	10
1		7	300	0	15	47	37	24	47	24	21	64	15	28	25	2	BF-T	11
1		12	300	0	15	47	37	29	47	24	26	68	6	25	25	2	BF-T	12
1		17	300	0	19	59	22	30	59	11	20	69	11	30	22	2	BF-T	13
1		6004	300	0	17	65	18	28	65	7	20	69	11	23	25	2	BF-T	14
9		160A	300	0	21	69	11	32	68	0	21	69	11	35	23	3	WF-T	15
TI 3235		M1306B	300	0	27	73	0	27	73	0	27	73	0	30	27	3	WF-T	16
15		313B	300	0	19	65	16	35	65	0	19	65	16	20	23	3	WF-T	17
15		316B	300	0	19	69	12	21	69	10	19	69	12	35	22	3	WF-T	18
15		317D	300	0	19	54	17	14	64	3	20	66	14	38	23	3	WF-T	19
2		34B	300	0	29	48	23	47	40	13	33	54	13	15	38	4	TNL-ARKE	20
2		36	300	0	25	46	29	48	46	6	26	51	23	26	34	4	TNL-ARKE	21
4		78A	300	M	26	49	25	47	49	4	28	51	21	15	36	4	TNL-ARKE	22
4		81	300	M	26	53	21	53	38	9	27	54	19	15	33	4	TNL-ARKE	23
4		82	300	M	25	49	25	48	50	2	26	51	23	11	34	4	TNL-ARKE	24
4		84	300	0	32	41	27	57	41	2	33	42	25	10	44	4	TNL-ARKE	25
4		99	300	1	18	40	42	40	40	20	26	52	22	18	33	4	TNL-ARKE	26
4		104	300	0	29	47	24	51	47	2	29	49	22	15	37	4	TNL-ARKE	27
4		106	300	M	27	52	21	37	56	7	30	56	14	15	35	4	TNL-ARKE	28
4		120	300	M	24	37	39	52	37	11	27	45	28	18	38	4	TNL-ARKE	29
4		127	300	1	24	47	29	48	47	5	25	51	24	17	33	4	TNL-ARKE	30

Table 3.10 Modal analysis: mean values for recalculated grain parameters (Gazzi-Dickinson method) for specimens from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Values are plotted in Figures 7, 8 and 9.

Table 3.10 Modal analysis: mean values for recalculated grain parameters (Gazzi-Dickinson method) for specimens from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Values are plotted in Figures 7,8 and 9.																		
m	SAMPLE NO	total counts	KF	MEAN % QmFLt: 1Qm	MEAN QmFLt: 1F	MEAN QmFLt: 1Lt	MEAN QFL: 2Q	MEAN QFL: 2F	MEAN QFL: 2L	MEAN QmFLq: 3Qm	MEAN QmFLq: 3F	MEAN QmFLq: 3Lq	MEAN M % 2nd COUNT	MEAN Q/TF	E #	lith	REF #	
4	140	300	1	22	40	38	54	40	6	25	43	32	13	37	4	TNL-ARKE	31	
11	6003	300	0	26	43	31	54	43	3	27	45	28	15	38	4	TNL-ARKE	32	
3	6007	300	0	37	55	8	45	55	0	37	55	8	33	40	5	TNL-ARKE	33	
3	57A	300	0	31	53	16	38	53	9	35	58	7	28	38	5	DF-T	34	
5	146A	300	0	29	40	31	52	40	8	33	4	23	31	43	5	DF-T	35	
6	150A	300	0	30	43	27	43	43	4	31	45	24	29	42	5	DF-T	36	
6	153B	300	0	38	49	13	48	49	3	39	51	10	27	43	5	DF-T	37	
1	6027	200	0	35	61	4	39	61	0	35	61	4	46	36	7	DF-C-MTX	38	
1	24H	300	0	39	57	4	41	52	7	31	57	4	33	40	7	DF-C	39	
8	154B	300	0	29	48	23	49	48	3	29	51	20	27	36	7	DF-C	40	
5	145A	300	0	33	46	21	51	46	3	34	48	18	27	41	7	DF-C	41	
3	50A	300	0	23	55	22	38	54	8	24	62	14	40	28	8	DF-C	42	
4	67A	300	0	21	66	13	23	66	11	21	77	2	54	22	8	DF-C	43	
17	328	300	2	15	36	49	58	36	6	20	40	40	28	32	8	DF-C	44	
17	329	300	1	18	39	43	59	39	2	19	40	41	24	32	8	DF-C	45	
16	322	300	1	21	33	46	60	33	7	24	37	39	19	39	9	DF-C	46	
16	324	300	1	18	18	64	65	18	17	26	28	47	15	48	9	DF-C	47	
KRIST	402	200	0	9	87	4	13	87	0	9	87	4	80	9	10	KRIST-CLST	48	
KRIST	401B	200	0	5	94	1	6	94	0	5	94	1	51	5	10	KRIST-CLST	49	
KRIST	412C	200	0	7	78	15	22	78	0	7	78	15	46	8	10	KRIST-CLST	50	
1	6028	300	0	14	78	8	22	78	0	14	78	8	46	15	10	KRIST-CLST	51	
KRIST	412A	200	0	14	78	8	22	78	0	14	78	8	33	15	10	KRIST-MTX	52	
GC	6015B	100	0	24	72	2	26	74	0	24	72	2	47	24	10	KRIST-CLST	53	
GC	6015A	100	0	9	89	2	11	89	0	9	89	2	47	9	10	KRIST-MTX	54	

Table 3.10 Modal analysis: mean values for recalculated grain parameters (Gazzi-Dickinson method) for specimens from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Values are plotted in Figures 7.8 and 9.

m	sample	total counts	KF %	mean QmFLt: 1Qm	mean QmFLt: 1F	mean QmFLt: 1Lt	mean QFL: 2Q	mean QFL: 2F	mean QFL: 2L	mean QmFLq: 3Qm	mean QmFLq: 3F	mean QmFLq: 3Lq	mean M % 2nd COUNT	mean Q/TF	E #	lith	REF #
KIDD	mean			20	68	13	24	68	8	23	72	4	30	22	1	HF	55
1	mean			19	57	24	29	57	14	22	69	10	28	24	2	DF-T	56
9	mean			21	66	11	26	68	3	21	68	11	32	24	3	WF-T	57
4	mean			26	46	29	49	44	7	28	50	23	16	36	4	TNL-ARKE	58
3	mean			32	48	20	47	48	4	34	45	16	29	40	5	DF-T	59
TG-C	1	all		24	50	27	45	49	6	25	50	24	32	35	6	DF-C	60
TG-C		mean		28	48	24	50	47	4	26	50	22	33	35	7	DF-C	61
TG-C		mean		22	61	18	31	60	10	23	70	8	47	25	8	DF-C	62
TG-C		mean		20	26	55	63	26	12	25	33	43	17	44	9	DF-C	63
K	mean			12	82	6	15	83	0	12	82	6	50	12	10	KRIST-	64

HF-Hoyle Fm; BF-Beatty Fm; WF-Whitney Fm; DF-Dome Fm; TNL-Three Nations Lake Fm
 T-turbidite; ARKE-arkose; C-conglomerate; GC-Gold Centre area-Krist

Table 3.11: Modal analysis: mean values and errors for recalculated grain parameters (Gazzi-Dickinson method) for specimens from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Values are plotted in Figures 7 and 8.

m	sect	SAMPLE NO	total counts	KF	MEAN	ERR	QmFlt: 1F	MEAN	ERR	QmFlt: 1Lt	MEAN	ERR	QmFlt: 1Qm	MEAN	ERR	QFL: 2F	MEAN	ERR	QFL: 2L	MEAN	ERR	QFL: 2Q	E	lith	REF #	
	KIDD	6008	300	0	86	4	4	0	0	0	14	4	4	86	4	4	0	0	0	0	14	4	4	1	HF-NW-T	1
	KIDD	6009	300	0	81	4	4	0	0	0	19	4	4	81	4	4	0	0	0	0	19	4	4	1	HF-NW-T	2
	t pond	77	300	0	62	5	5	14	4	4	24	5	5	62	5	5	6	3	3	32	5	5	1	HF-T	3	
	TI 1840	M1320	300	0	43	6	6	37	5	5	20	5	5	43	6	6	6	35	5	5	22	5	5	1	HF-T	4
	33	338	300	0	66	5	5	12	4	4	22	5	5	66	5	5	5	0	0	0	34	5	5	1	HF-T	5
	12D	204	300	0	61	6	6	19	4	4	20	5	5	61	6	6	6	10	3	3	39	6	6	2	BF-T	6
	12D	205	300	0	67	5	5	14	4	4	19	4	4	67	5	5	5	7	3	3	26	5	5	2	BF-T	7
	12D	207A	300	0	47	6	6	32	5	5	21	5	5	47	6	6	6	20	5	5	33	5	5	2	BF-T	8
	12D	207B	300	0	56	6	6	24	5	5	20	5	5	56	6	6	6	15	4	4	29	5	5	2	BF-T	9
	1	7	300	0	47	6	6	37	5	5	15	4	4	47	6	6	6	24	5	5	24	5	5	2	BF-T	10
	1	12	300	0	47	6	6	37	5	5	15	4	4	47	6	6	6	24	5	5	29	5	5	2	BF-T	11
	1	17	300	0	59	6	6	22	5	5	19	4	4	59	6	6	5	11	4	4	30	5	5	2	BF-T	12
	1	6001	300	0	64	5	5	15	4	4	21	5	5	64	5	5	5	7	3	3	28	5	5	2	BF-T	13
	1	6004	300	0	65	5	5	18	4	4	17	4	4	65	5	5	5	7	3	3	28	5	5	2	BF-T	14
	9	160A	300	0	69	5	5	11	4	4	21	5	5	68	5	5	5	0	0	0	32	5	5	3	WF-T	15
	TI 3235	M1306B	300	0	73	5	5	0	0	0	27	5	5	73	5	5	5	0	0	0	27	5	5	3	WF-T	16
	15	313B	300	0	65	5	5	16	4	4	19	4	4	65	5	5	5	0	0	0	35	5	5	3	WF-T	17
	15	316B	300	0	69	5	5	12	4	4	19	4	4	69	5	5	5	10	3	3	21	5	5	3	WF-T	18
	15	317D	300	0	54	6	6	17	4	4	19	4	4	64	5	5	5	3	2	2	14	4	4	3	WF-T	19
	2	34B	300	0	48	6	6	23	5	5	29	5	5	40	6	6	6	13	4	4	47	6	6	4	TNL-ARKE	20
	2	36	300	0	46	6	6	29	5	5	25	5	5	46	6	6	6	6	3	3	48	6	6	4	TNL-ARKE	21
	4	78A	300	M	49	6	6	25	5	5	26	5	5	49	6	6	6	4	2	2	47	6	6	4	TNL-ARKE	22
	4	81	300	M	53	6	6	21	5	5	26	5	5	38	5	5	5	9	3	3	53	6	6	4	TNL-ARKE	23
	4	82	300	M	49	6	6	25	5	5	25	5	5	50	6	6	6	2	2	2	48	6	6	4	TNL-ARKE	24
	4	84	300	0	41	6	6	27	5	5	32	5	5	41	6	6	6	2	2	2	57	6	6	4	TNL-ARKE	25
	4	99	300	1	40	6	6	42	6	6	18	4	4	40	6	6	6	20	5	5	40	6	6	4	TNL-ARKE	26
	4	104	300	0	47	6	6	24	5	5	29	5	5	47	6	6	6	2	2	2	51	6	6	4	TNL-ARKE	27
	4	106	300	M	52	6	6	21	5	5	27	5	5	56	6	6	6	7	3	3	37	5	5	4	TNL-ARKE	28
	4	120	300	M	37	5	5	39	6	6	24	5	5	37	5	5	5	11	4	4	52	6	6	4	TNL-ARKE	29
	4	127	300	1	47	6	6	29	5	5	24	5	5	47	6	6	6	5	2	2	48	6	6	4	TNL-ARKE	30
	4	140	300	1	40	6	6	38	5	5	22	5	5	40	6	6	6	6	3	3	54	6	6	4	TNL-ARKE	31

Table 3.11: Modal analysis: mean values and errors for recalculated grain parameters (Gazzi-Dickinson method) for specimens from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Values are plotted in Figures 7 and 8.

					KF	MEAN	ERR	MEAN	ERR	MEAN	QmFLt: 1Lt	ERR	MEAN	QmFLt: 1Qm	ERR	MEAN	QFL: 2F	ERR	MEAN	QFL: 2L	ERR	MEAN	QFL: 2Q	ERR	E	#	lith	REF
m	sect	SAMPLE NO	total counts	% KF	QmFLt: 1F	QmFLt: 1F	ERR	QmFLt: 1Lt	ERR	QmFLt: 1Qm	QmFLt: 1Lt	ERR	QmFLt: 1Qm	QmFLt: 1Qm	ERR	QFL: 2F	QFL: 2F	ERR	QFL: 2L	QFL: 2L	ERR	QFL: 2Q	QFL: 2Q	ERR	#			
11	3	6003	300	0	43	6	31	5	26	5	43	6	3	2	54	6	4	TNL-ARKE	**	32								
3	3	6007	300	0	55	6	8	3	37	5	55	6	0	0	45	6	5	TNL-ARKE	****	33								
3	5	57A	300	0	53	6	16	4	31	5	53	6	9	3	38	5	5	DF-T	****	34								
6	6	146A	300	0	40	6	31	5	29	5	40	6	8	3	52	6	5	DF-T	****	35								
6	6	150A	300	0	43	6	27	5	30	5	43	6	4	2	43	6	5	DF-T	****	36								
6	6	153B	300	0	49	6	13	4	38	5	49	6	3	2	48	6	5	DF-T	****	37								
1	1	6027	200	0	61	7	4	3	35	7	61	7	0	0	39	7	7	DF-C-MTX	*	38								
1	8	24H	300	0	57	6	4	2	39	6	52	6	7	3	41	6	7	DF-C	*	39								
8	5	154B	300	0	48	6	23	5	29	5	48	6	3	2	49	6	7	DF-C	*	40								
5	17	145A	300	0	46	6	21	5	33	5	46	6	3	2	51	6	7	DF-C	*	41								
17	17	329	300	1	39	6	43	6	18	4	39	6	2	2	59	6	7	DF-C	*	42								
17	3	328	300	2	36	5	49	6	15	4	36	5	6	3	58	6	7	DF-C	*	43								
3	4	50A	300	0	55	6	22	5	23	5	54	6	8	3	38	5	8	DF-C	****	44								
4	16	67A	300	0	66	5	13	4	21	5	66	5	11	4	23	5	8	DF-C	****	45								
16	16	322	300	1	33	5	46	6	21	5	33	5	7	3	60	6	9	DF-C	***	46								
16	KRIST	324	300	1	18	4	64	5	18	4	18	4	17	4	65	5	9	DF-C	***	47								
KRIST	KRIST	402	200	0	87	5	4	3	9	4	87	5	0	0	13	5	10	KRIST-CLST	*****	48								
KRIST	KRIST	401B	200	0	94	3	1	1	5	3	94	3	0	0	6	3	10	KRIST-CLST	*****	49								
KRIST	KRIST	412C	200	0	78	6	15	5	7	4	78	6	0	0	22	6	10	KRIST-CLST	*****	50								
1	KRIST	6028	300	0	78	5	8	3	14	4	78	5	0	0	22	5	10	KRIST-CLST	*****	51								
KRIST	KRIST	412A	200	0	78	6	8	4	14	5	78	6	0	0	7	6	10	KRIST-MTX	*****	52								
GC	GC	6015B	100	0	72	9	2	3	24	8	74	9	0	0	26	9	10	KRIST-CLST	*****	53								
GC	GC	6015A	100	0	89	6	2	3	9	6	89	6	0	0	11	6	10	KRIST-MTX	*****	54								

Table 3.11: Modal analysis: mean values and errors for recalculated grain parameters (Gazzi-Dickinson method) for specimens from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Values are plotted in Figures 7 and 8.

m	SAMPLE NO	total counts	KF %	MEAN QmFLt: 1F	ERR QmFLt: 1F	MEAN QmFLt: 1Lt	ERR QmFLt: 1Lt	MEAN QmFLt: 1Qm	ERR QmFLt: 1Qm	MEAN QFL: 2F	ERR QFL: 2F	MEAN QFL: 2L	ERR QFL: 2L	MEAN QFL: 2Q	ERR QFL: 2Q	E #	lith	REF #
mean values petrography plots:																		
1	mean			57	6	24	5	19	4	57	6	14	4	29	5	2	DF-T	56
9	mean			66	5	11	3	21	5	68	5	3	1	26	5	3	WF-T	58
4	mean			46	6	29	5	26	5	44	6	7	3	49	6	4	TNL-ARKE	60
3	mean			48	6	19	4	33	5	48	6	5	2	45	6	5	DF-T	61
DF-C	1	all		50	5	27	4	24	5	49	5	6	2	45	6	6	DF-C	62
DF-C		mean		48	6	24	4	28	5	47	6	4	2	50	6	7	DF-C	63
DF-C		mean		61	5	18	4	22	5	60	6	10	3	31	5	8	DF-C	64
DF-C		mean		26	5	55	6	20	4	26	5	12	4	63	5	9	DF-C	65
101	mean			82	6	6	3	12	5	83	6	0	0	15	6	10	KRIST-	66
HF-Hoyle Fm;BF-Beatty Fm; WF-Whitney Fm;DF-Dome Fm; TNL-Three Nations Lake Fm																		
T-turbidite;ARKE-arkose;C-conglomerate; GC-Gold Centre area-Krist																		
* alluvial fluvial ** shelf ***																		
gravel bars ****turbidite																		
***** volcanoclastic																		

Table 3.12: Modal analysis: mean values and errors for recalculated grain parameters (Gazzi-Dickinson method) for specimens from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Values are plotted in Figures 7 and 8.

m	sample	MEAN QmFLq: 3F	ERR QmFLq: 3F	MEAN QmFLq: 3Lq	ERR QmFLq: 3Lq	MEAN QmFLq: 3Qm	ERR QmFLq: 3Qm	MEAN M % 2nd	ERR MTX	MEAN Q/TF	ERR Q/TF	E #	lith	REF #
sect	NO													
KIDD	6008	86	4	0	0	14	4	35	5	14	4	1	HF-NW-T	1
KIDD	6009	81	4	0	0	19	4	35	5	19	4	1	HF-NW-T	2
t pond	77	68	5	8	3	24	5	26	5	21	5	1	HF-T	3
TI1840	M1320	61	6	2	2	37	5	23	5	31	5	1	HF-T	4
33	338	66	5	12	4	22	5	33	5	25	5	1	HF-T	5
12D	204	70	5	9	3	21	5	29	5	23	5	2	BF-T	6
12D	205	74	5	7	3	19	4	40	6	20	5	2	BF-T	7
12D	207A	65	5	12	4	23	5	22	5	26	5	2	BF-T	8
12D	207B	68	5	9	3	23	5	22	5	25	5	2	BF-T	9
1	6001	70	5	6	3	24	5	33	5	26	5	2	BF-T	10
1	7	64	5	15	4	21	5	28	5	25	5	2	BF-T	11
1	12	68	5	6	3	26	5	25	5	25	5	2	BF-T	12
1	17	69	5	11	4	20	5	30	5	22	5	2	BF-T	13
1	6004	69	5	11	4	20	5	23	5	25	5	2	BF-T	14
9	160A	69	5	11	4	21	5	35	5	23	5	3	WF-T	15
TI3235	M1306B	73	5	0	0	27	5	30	5	27	5	3	WF-T	16
15	313B	65	5	16	4	19	4	20	5	23	5	3	WF-T	17
15	316B	69	5	12	4	19	4	35	5	22	5	3	WF-T	18
15	317D	66	5	14	4	20	5	38	5	23	5	3	WF-T	19
2	34B	54	6	13	4	33	5	15	4	38	5	4	TNL-ARKE	20
2	36	51	6	23	5	26	5	26	5	34	5	4	TNL-ARKE	21
4	78A	51	6	21	5	28	5	15	4	36	5	4	TNL-ARKE	22
4	81	54	6	19	4	27	5	15	4	33	5	4	TNL-ARKE	23
4	82	51	6	23	5	26	5	11	4	34	5	4	TNL-ARKE	24
4	84	42	6	25	5	33	5	10	3	44	6	4	TNL-ARKE	25
4	99	52	6	22	5	26	5	18	4	33	5	4	TNL-ARKE	26
4	104	49	6	22	5	29	5	15	4	37	5	4	TNL-ARKE	27
4	106	56	6	14	4	30	5	15	4	35	5	4	TNL-ARKE	28
4	120	45	6	28	5	27	5	18	4	38	5	4	TNL-ARKE	29
4	127	51	6	24	5	25	5	17	4	33	5	4	TNL-ARKE	30
4	140	43	6	32	5	25	5	13	4	37	5	4	TNL-ARKE	31

Table 3.12: Modal analysis: mean values and errors for recalculated grain parameters (Gazzi-Dickinson method) for specimens from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Values are plotted in Figures 7 and 8.														
m	sect	SAMPLE NO	MEAN QmFLq: 3F	ERR QmFLq: 3F	MEAN QmFLq: 3Lq	ERR QmFLq: 3Lq	MEAN QmFLq: 3Qm	ERR QmFLq: 3Qm	MEAN M % 2nd	ERR MTX	MEAN Q/TF	ERR Q/TF	E	REF #
11		6003	45	6	28	5	27	5	15	4	38	5	4	32
3		6007	55	6	8	3	37	5	33	5	40	6	5	33
3		57A	58	6	7	3	35	5	28	5	38	5	5	34
5		146A	4	2	23	5	33	5	31	5	43	6	5	35
6		150A	45	6	24	5	31	5	29	5	42	6	5	36
6		153B	51	6	10	3	39	6	27	5	43	6	5	37
1		6027	61	7	4	3	35	7	46	7	36	7	7	38
1		24H	57	6	4	2	31	5	33	5	40	5	7	39
8		154B	51	6	20	5	29	5	27	5	36	5	7	40
5		145A	48	6	18	4	34	5	27	5	41	6	7	41
17		328	40	6	40	6	20	5	28	5	32	5	7	42
17		329	40	6	41	6	19	4	24	5	32	5	7	43
3		50A	62	5	14	4	24	5	40	6	28	5	8	44
4		67A	77	5	2	2	21	5	54	6	22	5	8	45
16		322	37	5	39	6	24	5	19	4	39	6	9	46
16		324	28	5	47	6	26	5	15	4	48	6	9	47
KRIST		402	87	5	4	3	9	4	80	6	9	4	10	48
KRIST		401B	94	3	1	1	5	3	51	7	5	3	10	49
KRIST		412C	78	6	15	5	7	4	46	7	8	4	10	50
1		6028	78	5	8	3	14	4	46	6	15	4	10	51
KRIST		412A	78	6	8	4	14	5	33	7	15	5	10	52
GC		6015B	72	9	2	3	24	8	47	10	24	8	10	53
GC		6015A	89	6	2	3	9	6	47	10	9	6	10	54

Figure 3.7 QFL provenance discrimination diagrams for the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. Data derived from modal analyses (>300 points) with comparative Phanerozoic provenance data.

Figure 3.8 QmFLt provenance discrimination diagrams for the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. Data derived from modal analyses (>300 points) and compared to Phanerozoic provenance data.

Figure 3.9 QmFLq provenance discrimination diagrams for the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. Data derived from modal analyses (>300 points) and compared to Phanerozoic provenance data.

The matrix compositions of turbidite fan conglomerates from the Dome Formation are, however, virtually identical to those of turbiditic sandstones from the Beatty Formation, and this may imply a similar origin for both rock types.

A comparative analysis of average (Mean) QFL values indicates that sediments of environments #9 and #10, which represent gravel bars of the Three Nations Formation and volcanoclastic rocks of the Krist fragmental unit, are compositionally separate and distinct from all other epiclastic rocks.

Figure 3.7 displays data derived by visual estimates of thin sections unsuitable for point counting. Compared to the other 54 sandstone samples, these were either too fine grained or too altered to be included in the regular modal analyses. They are listed in Table 3.13, and their locations are tabulated in Appendix 8. The QFL plot displays only mean (average) values for samples from the seven different depositional environments, including two samples of siltstones (S samples) associated with turbidites of the Beatty Formation. Although there is a wide range in data, the older turbidites have a higher feldspar content than sediments of the Pamour Group. There is also a large difference in feldspar content between sandstones and siltstones from the same deep-water turbidite environment, with the siltstones containing less feldspar.

Table 3.13 Mean grain parameters (QFL) for Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Data derived by visual estimates of sedimentary specimens that are either too fine-grained or too altered for modal analysis.

SLIDE #	E sample #	TQ	TF= PF+ KF	TL	KF (%)	ROCK TYPE	reason why sample not point counted
162	1	6012	60	30	10	graphitic SLST -TBTE- HOYLE Fm-NW	too fine & altered
163	1	6013	60	30	10	SLST -TBTE- HOYLE Fm-NW	too fine & altered
164	1	6014	60	30	10	SLST BRX -TBTE- HOYLE Fm -NW	too fine & altered
160	1	6010	70	30	0	TBTE- HOYLE Fm -NW	too fine & altered
161	1	6011	60	40	0	TBTE- HOYLE Fm -NW	too fine & altered
89	1	M1319 T	30	60	10	TBTE- HOYLE Fm	too fine & altered
1	*****		57	37	7	mean-TBTE- HOYLE Fm	too fine & altered
172	2	340B	40	58	2	TBTE-SLST-BEATTY Fm	too fine
2	2	006	60	35	5	TBTE - BEATTY Fm	too fine
4	2	022	30	60	10	TBTE - BEATTY Fm	too fine
50	2	160B	60	30	10	TBTE - BEATTY Fm	too fine
51	2	164	60	30	10	TBTE - BEATTY Fm	too fine
52	2	170B	60	30	10	TBTE - BEATTY Fm	too fine
2	*****		51	41	8	TBTE -SLST - BEATTY Fm	too fine
159	3	315	30	60	10	TBTE -WHITNEY Fm	too altered & meta
162	3	317A	30	65	5	TBTE -WHITNEY Fm	too altered & meta
88	3	M1308	20	70	10	TBTE -WHITNEY Fm	too fine
89	3	M1309	70	25	10	TBTE -WHITNEY Fm	too fine
84	3	M1314 T	30	60	10	TBTE -WHITNEY Fm	too fine
86	3	M1316 T	30	60	10	TBTE -WHITNEY Fm	too fine
87	3	M1317 T	30	60	10	TBTE -WHITNEY Fm	too fine
88	3	M1318 T	30	60	10	TBTE -WHITNEY Fm	too fine
91	3	M1321 T	30	60	10	TBTE -WHITNEY Fm	too fine
92	3	M1322 T	55	35	10	TBTE -WHITNEY Fm	too fine
93	3	M1323 T	50	30	20	TBTE -WHITNEY Fm	too fine
94	3	M1324 T	30	60	10	TBTE -WHITNEY Fm	too fine
3	*****		36	54	10	mean-TBTE-BEATTY Fm	too fine
85	3	M1315 T	20	70	10	volciclastic- WHITNEY Fm	too fine
76	3A	M1306A	40	50	10	TBTE-SLST- WHITNEY Fm	too fine
80	3A	M1310 S	70	20	10	TBTE-SLST- WHITNEY Fm	too fine
81	3A	M1311 S	70	20	10	TBTE-SLST- WHITNEY Fm	too fine

Table 3.13 Mean grain parameters (QFL) for Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Data derived by visual estimates of sedimentary specimens that are either too fine-grained or too altered for modal analysis.

SLIDE #	E sample #	TQ	TF= PF+ KF	TL	KF (%)	ROCK TYPE	reason why sample not point counted
82	3A M1312 S	70	20	10		TBTE-SLST- WHITNEY Fm	too fine
83	3A M1313 T	30	60	10		TBTE-SLST- WHITNEY Fm	too fine
77	3A M1307 gr S	20	70	10		TBTE-SLST- WHITNEY Fm	too fine
	3A *****	50	40	10		mean-TBTE-SLST-WHITNEY Fm	too fine
73	4 90-01B	60	30	10	1	ARKE -TNL Fm	not stained-cover slips
74	4 90-02	60	30	10		ARKE -TNL Fm	not stained-cover slips
75	4 90-03	60	30	10		ARKE -TNL Fm	not stained-cover slips
	4 *****	60	30	10		mean-ARKE -TNL Fm	not stained-cover slips
58	5 182	60	30	10		TBTE -SLST -Dome Fm	too fine
11	5 25e	50	50	0		TBTE -SLST -Dome Fm	too fine
17	5 47	50	50	0		TBTE -SLST -Dome Fm	too fine
18	5 49	80	20	0		TBTE -SLST -Dome Fm	too fine
64	5 192	80	10	10		TBTE -SLST -Dome Fm	too fine
65	5 193B	80	10	10	<1	TBTE -SLST -Dome Fm	too fine
	5 *****	67	28	5		mean-TBTE-SLST -Dome Fm	too fine
	6 *****	90	56	13		mean-CGLM-Gcs- -Dome Fm	too altered & coarse
7	7 200A	50	50	0		CGLM -Dome Fm-mtx	too coarse
8	7 200b	32	68	0		CGLM -Dome Fm-mtx	too coarse
5	7 024	50	50	0		CGLM- MATRIX-Dome Fm	too coarse
123	7 6031	17	80	3		CGLM- MATRIX-Dome Fm	too coarse
37	7 143B	50	40	10		CGLM-Gcs-Dome Fm	too altered & coarse
42	7 149B	60	30	10	<1	CGLM-Gcs-Dome Fm	too altered & coarse
47	7 155c	60	30	10	<1	CGLM-Gcs-Dome Fm	too altered & coarse
56	7 181B	60	30	10		CGLM-Gcs-Dome Fm	too altered & coarse
57	7 181D	60	30	10		CGLM-Gcs-Dome Fm	too altered & coarse
123	7 6031	20	80	5		CGLM- matrix	too coarse
38	8 195	60	30	10		CGLM-Gcs-Dome Fm	too altered & coarse
67	8 1400 Hoyle	60	30	10		CGLM-Gcs- ore zone-Dome Fm	too altered & coarse
153	8 027	50	40	10		Dome Fm- CGLM cutting TBTE	too coarse
154	8 30	50	40	10		Dome Fm- CGLM associated with TBTE	too coarse
155	8 144B	50	40	10		Dome Fm- CGLM associated with TBTE	too coarse

Table 3.13 Mean grain parameters (QFL) for Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Data derived by visual estimates of sedimentary specimens that are either too fine-grained or too altered for modal analysis.

SLIDE #	E sample #	TQ	TF= PF+ KF	TL	KF (%)	ROCK TYPE	reason why sample not point counted
156	8	191B	50	40	10	Dome Fm- CGLM associated with TBTE	too coarse
28	9	068	50	50	0	CGLM-Gcs- -Dome Fm	too altered & coarse
54	9	176A	55	45	5	ARKE -Gms gravel bar-TNL Fm	too altered & coarse
72	9	90-01A	50	40	10	ARKE -gravel bars Gms faciesPAMOUR GROUP	not stained-cover slips
117	10	401A	5	90	5	KRIST	volcaniclastic
121	10	413				Krist- tuff- SLST	too fine
97	11	Dome aMV		PF		MVLC- altered basalt	volcanic-not sed
98	11	Dome var MV		PF		MVLC- variolitic basalt	volcanic-not sed
100	11	Dome QPF	30	PF		QFP -PAYMASTER TIMISK AGE	intrusive-not sed
20	11	052B- T	0		0	CGLM-Gcs- PAMOUR GROUP- clast	volcaniclastic
174	11	517				PAMOUR GROUP- CGLM deformed	too altered
122	11	6021				-CLAST -PORP; NOT PAYMASTER	intrusive not sed
175	11	DOMÉ UM				UM flows - dun brown- Deloro Gp	volcanic not sed
TQ=total quartz; TF=total feldspar; TL=total lithics; KF=alkali feldspar; BIO= biotite TBTE=turbidite; SLST=siltstone; ARKE=arkose; CGLM=conglomerate; Gcs=clast supported; Gms=matrix supported; BRX=breccia;							
estimates- mean values							
1		57	37	7	0	mean-TBTE- HOYLE FM	
2A		52	41	8	0	mean-TBTE -SLST - BEATTY Fm	
2B		36	54	10	0	mean-TBTE- BEATTY Fm	
3A		50	40	10	0	mean-TBTE-SLST- Whitney Fm	
3B		20	70	10	0	volcaniclastic- Whitney Fm	
4		60	30	9	>1	mean-ARKE TNL Fm	
5		67	28	5	<<1	mean-TBTE -Dome Fm	
6		51	43	6	<1	mean-CGLM-Gcs- -Dome Fm	
10	Krist	NO	PF	?		Krist- sedts??, older than PORCUPINE GP	

QmFLt plot

This plot shows the relationship between monocrystalline quartz (Qm) and total lithics (Lt) as a function of feldspar (F) content (Figure 3.8).

Variations in QmFLt parameters for all sedimentary rocks show a few systematic changes in a west to east direction, but only volcanoclastic rocks of the Krist fragmental form a compositionally distinct group which is different from all of the epiclastic rocks. Typically, the volcanoclastic rocks contain more feldspars, but also contain less quartz and lithic grains.

Most turbidites of the Hoyle Formation and Beatty Formations (Figure 3.8), show a wide range in values, with almost complete overlap between groups. Only turbidites of the Hoyle Formation (#1 to #5) illustrate a fairly consistent trend of increasing lithic content in an easterly direction.

Comparisons between shelf sediments (arkose) of the Pamour Group and older turbiditic sandstones show that the former generally contain lower amounts of feldspar (F), but higher amounts of Qm and lithics (Figure 3.8 part a). Although the lithic content is higher, the range of values is narrower than any epiclastic rocks in the Hoyle, Beatty Porcupine and Dome Formations. The shelf sediments thus represent a discrete cluster that is different in composition from any of the older turbiditic sandstones.

QmFLt data from conglomerates and turbiditic sandstones of the Dome Formation show a wide range in values (Figure 3.8), with conglomerates showing the greatest variability. Although the data are in part overlapping, they also outline a moderately-well developed trend of increasing lithic content in an easterly direction for both the turbiditic sandstones and conglomerates. As the proportion of lithic fragments increases, the ratio of feldspar to quartz also changes, with a decrease in feldspar content accompanying a corresponding

increase in lithic content for conglomerates and turbidites of the Dome Formation, whereas the feldspar content remains constant as the total lithic content increases in sandstones of the Hoyle Formation.

Average values (means) for representative samples of each depositional environment are plotted in the triangle at the extreme right (Figure 3.8) and show distinct clustering of data into several discrete groups, comparable to results using QFL and QmFLq plots. Some conglomerates and shelf sediments of the Pamour Group are almost identical in composition, whereas turbiditic sandstones and other conglomerate types (gravel bars and turbidite fans) are different. Another cluster of points represents conglomerates from turbiditic fans of the Dome Formation, together with turbiditic sandstones of the older sedimentary units. These rocks generally contain more feldspar, but also contain fewer lithic grains. Volcaniclastic rocks of the Krist fragmental unit represent the most feldspathic and lithic-poor rock type, whereas gravel bars of the Three Nations Formation contain the most lithic grains, with a relatively high proportion of feldspar. A common composition for all older turbiditic sandstones, and matrix from conglomerates of the turbidite fans, suggests that they probably have a common source region.

QmFLq plot

This plot examines the relationship between monocrystalline quartz (Qm) and lithic quartz (Lq) as a function of feldspar (F) content; (Lq) consists of both chert (Qc) and polycrystalline quartz (Qp).

QmFLq parameters for the entire suite of sedimentary rocks (Figure 3.9), show that volcanoclastic rocks of the Krist fragmental unit are substantially different from any of the epiclastic sediments. Typically, the volcanoclastic rocks contain less quartz and lithic grains but contain more feldspar. These plots also illustrate some systematic trends in a west to east direction :

Most turbidites of the Hoyle and Beatty Formations (Figure 3.9) show a narrow but overlapping range in ratios. Only turbidites of the Hoyle Formation (#1 to #5) illustrate a trend of decreasing feldspar content combined with a slight increase in lithic quartz in an easterly direction.

Similar data from shelf sediments of the Three Nations Formation show a wide range of values, but without a consistent stratigraphic trend. Compared to any of the older turbiditic sandstones, the arkoses (shelf sediments) generally contain a higher percentage of both monocrystalline quartz (Qm) and lithic quartz (Lq). Many of the conglomerates and turbiditic sandstones of the Dome Formation show wide ranges of QmFLq values: some contain less lithic quartz, whereas others contain more lithic quartz (Lq) than the shelf sandstones. Only conglomerates show a systematic increase in lithic content in an easterly direction. Increases in lithic content for both depositional environments appear to occur at fairly constant quartz to feldspar ratios, which suggests that the changes are mainly influenced by an increase in the supply of lithics, and not by a decrease in feldspar or quartz.

Mean QmFLq values for sediments of each depositional environment tend to cluster in several groups, in a manner similar to previous QFL and QmFLt plots. Volcaniclastic rocks of the Krist fragmental are the most feldspathic, and plot near the lower left corner of the diagram, whereas turbiditic sandstones of the Dome Formation are the least feldspathic of all the epiclastic sediments (Figure 3.9).

Interpretation

The various provenance plots illustrate the different relationships between grain types for sediments of all ten depositional environments.

The scatter of data on the QFL plot, a generalized plot which combines many grain types, indicates a lack of systematic west to east or stratigraphic variation in composition within any of these depositional environments. In most cases, this means a large overlap of data within each grouping.

The similarity between modal and visually estimated data in the QFL plot shows visual estimates (Figure 3.7) provide an adequate means of comparing the validity of both methods.

The data also suggest that for the same deep-water turbidite environment, siltstones are less feldspathic than sandstones. This bulk composition difference in part may have been caused by a different method of deposition, because siltstones were deposited by a combination of pelagic rainout and turbidity currents, whereas their associated sandstones were supplied by turbidity currents.

The QFL, QmFLt and QmFLq plots generally show a discrete clustering of data into three groups. This suggests that sediments from the various depositional environments can be separated on the basis of characteristic ratios

for the key grain types. All of the older turbiditic sandstones likely have a common source, because they all have a similar composition. Differences in composition between these sandstones and turbiditic sandstones of the younger Dome Formation, which contain more quartz and lithic grains, indicates that they have a different source region. Shelf sediments and their associated gravel bars of the Three Nations Formation, likewise have a different source region. Similarities between various groups, however, shows that the shelf sediments and alluvial conglomerates of the Pamour Group have a common source, which is different from turbiditic sandstones of the Dome Formation. Although all conglomerates are of the same general age (e.g. Pamour Group), scatter in the data suggest that not all conglomerates are of the same composition or from the same source area. Because fan conglomerates and their associated turbidites are dissimilar in composition, these sediments may have had a different provenance. Similarities in composition between Dome (Timiskaming) conglomerates and the older turbiditic sandstones, however, suggest that they, and not the younger turbidites, have a common source .

The Krist volcanoclastics (or an older Krist-like unit), could represent a viable source rock for almost all of the epiclastic rocks. Erosion, followed by subsequent transport and deposition, could have increased the quartz content by 10 % to 30% due to winnowing out of some feldspars. A 10% increase in quartz corresponds to the difference between Krist volcanoclastics and all older turbidites, whereas a 30% increase in quartz corresponds to the difference between the Krist fragmentals and shelf sediments of the Three Nations Formation.

QmFLt plots (Figure 3.8), which display the relationship of monocrystalline quartz (Qm) to total lithics (Lt) as a function of feldspar (F)

content, show compositional changes that outline a few trends in a west to east direction. A trend of increasing lithic content in an easterly direction is illustrated by turbidites of the Hoyle Formation (#1 to #5), as well as conglomerates (#1 to #8) and turbidites (#1 to #7) of the Pamour Group. In addition, a decrease in feldspar content accompanies a corresponding increase in lithic content for conglomerates and turbidites of the Pamour Group, whereas the feldspar content remains constant as the total lithic content increases in sandstones of the Hoyle Formation.

Relationships between lithic quartz (Lq), monocrystalline quartz (Qm), and feldspar (F) are illustrated by the QmFLq plot; Lq (total lithic quartz) is made up of polycrystalline quartz and chert (Qp and Qc, respectively). A combination of the QmFLt plot and QmFLq plot (Figure 3.9), shows that percentage of Lq (total lithic quartz) represents a large proportion of total lithics (Lt). Several depositional environments, namely turbidites of the Tisdale and Porcupine Groups (#1 to #5) and conglomerates of the Dome Formation (#6 to #8), illustrate an easterly increase in total lithic quartz (Lq). A similar increase in both Lt and Lq suggests that lithic quartz (Lq) is the main constituent of Lt (total lithics) in both environments, whereas it is a less important component in turbiditic sandstones of the Dome Formation. A source area consisting mainly of sedimentary rocks probably was located near the eastern part of the depositional basin. By contrast, sediments in the western regions of the basin had a nearby source that consisted mainly of volcanic rocks.

All three provenance plots fail to illustrate any systematic variations within the shelf sediments (arkoses) of the Three Nations Formation. This occurs in spite of a closely spaced sampling program with excellent stratigraphic control : 10 of the 13 samples are from one measured section (MS-4), whereas the other

define a west to east distribution from MS-2 to MS-11 and then to MS-4 in an easterly direction. It appears that compositional variations within shelf sediments are neither related to stratigraphic evolution of the sequence (i.e. with time) nor correlative with transport processes *from* west to east. Thus, random lithologic variations within the shelf sediments occur, but the controlling factors are unknown.

Other Provenance Discrimination Plots

Introduction

Several other plots, namely Q_m/Q_{m+F} (Figure 3.8) and % matrix plots, are also used to examine the relationships between sandstone composition and depositional environment. The Q_m/Q_{m+F} plot relates monocrystalline quartz (Q_m) to the percentage of total feldspar for each sample. This parameter probably reflects the relative degree of compositional maturity for each sedimentary sample, with lower values indicating relatively immature sediments that have undergone little reworking before deposition. The percentage of matrix for each sample is defined as all fine-grained detritus ($<.03$ mm) compared to the total of 300 framework grains plus matrix (e.g. $matrix/matrix+300$). The total matrix count probably contains an undetermined percentage of pseudomatrix and epimatrix (Dickinson, 1970). The matrix plot shows that immature sediments generally have a higher percentage of matrix than mature or recycled sediments.

Variations in the percentage of Q_m/Q_{m+F} , and the percentage of matrix for all samples, are illustrated in Figure 3.10 and listed in Table 3.10; mean values for samples from each depositional environment are shown as data sets #63 to #78. These data are arranged in a west to east direction for each depositional environment in an attempt to reveal regional variations.

Description

Q_m/Q_m+F Plot

The data (Figure 3.10) illustrate a large range of values, but only turbiditic sandstones from the Hoyle Formation show a systematic increase of the Q ratio in a west to east direction; none of the other depositional environments shows any clear trends.

The uniformity of ratios within each depositional environment, however, means that each has a characteristic value (or range of values), which can be used to separate and identify it from all others. The highest ratios occur within shelf sediments and turbidites of the Pamour Group, whereas the lowest ratios occur within sandstones of the Hoyle Formation and volcanoclastic rocks of the Krist. Mean Q values for each depositional environment, which are represented by data sets #55 to #64, provide a quick comparison of their probable degree of maturity. All of the older turbiditic sandstones (Hoyle, Beatty, and Whitney Formations) are more mature than the Krist, but less mature than sediments of the Pamour Group. Thus, this ratio represents another method for separation of the younger turbidites of the Dome Formation from all older turbidites. Conglomerates of the Pamour Group show the greatest degree of data variability. The highest Q values, which represent a high degree of reworking, occur in gravel bars of the Three Nations Formation, whereas the lowest values are more typical of conglomerates of the Dome Formation that are associated with turbidite fans.

Matrix Plot

Matrix content, another parameter similar to the previously discussed Q_m/Q_m+P ratios, is indicative of the relative textural maturity of the sediment:

mature sediments contain less matrix than immature sediments (Figure 3.10 and Table 3.10). Turbidites of the Hoyle Formation and conglomerates of the Dome Formation show systematic decreases in percentage of matrix in a west to east direction. No other depositional environments show any clear trends, but each depositional environment appears to have a characteristic value that makes it distinct from all other environments.

The Krist volcanoclastic sediments have the highest matrix values, whereas the lowest values are from shelf sediments (arkoses) of the Three Nations Formation. The range of matrix content for each depositional environment illustrates that older turbiditic sandstones contain less matrix than Krist rocks, but contain more matrix than sediments from the Pamour Group. The highest degree of textural maturity occurs in sediments of the Pamour Group in general, and shelf sediments in particular, whereas volcanoclastic rocks of the Krist are the least mature. Again, differences in matrix contents show that the older turbidites (Hoyle, Beatty and Whitney Formations) and the younger turbidites (Timiskaming Group), are compositionally distinct with respect to matrix content. The older sandstones generally contain more matrix, and thus are less mature than younger turbidites.

The matrix content of conglomerates probably represents their original silt or clay content prior to deposition; some original clay may have been removed during subsequent reworking. Matrix content in the various conglomerate types is highly variable, with low values for gravel bars and high values for conglomerates associated with turbidites. These data suggest that, with respect to matrix content, compositional differences exist between the various types of conglomerate, and that not all of the conglomerates have undergone the same degree of reworking. Gravel bars and associated shelf sediments probably

represent the most reworked sediments, whereas conglomeratic turbidite fans and alluvial-fluvial fans probably represent the least reworked sediments.

Interpretation

Data from turbidites of the Hoyle Formation, and from conglomerates of the Pamour Group outline trends of increased maturity in an easterly direction. This interpretation is based on both matrix and Q_m/Q_{m+P} plots. No other depositional environments show any clear trends.

In shelf sediments of the Three Nations Formation, neither the percentage of matrix nor $Q/Q+F$ ratios, are controlled by stratigraphic factors (i.e. time). The lack of systematic stratigraphic variations (Figure 3.10) in areas with close stratigraphic sampling means that stratigraphic controls are unlikely.

The uniformity of data (the percentage of matrix and $Q/Q+F$ ratios) within each of the ten depositional environments suggests that these values can be used to separate and identify each environment from all others. In fact, turbidites of the Dome Formation can be identified and separated from those of the Hoyle, Beatty and Whitney Formations by the percentage of matrix and $Q/Q+F$ ratios: the older sandstones have more matrix and a lower Q ratio. As previously discussed, the various conglomerate types can also be separated on their characteristic Q ratios and matrix contents.

These data, which are indicative of both compositional and textural maturity, suggest that the Krist volcanoclastic rocks represent the least mature and reworked detritus, whereas the shelf sediments and associated gravel bars are the most mature and reworked of all of the sedimentary rocks. All turbidites, and most conglomerates (except the gravel bars) are less mature and reworked

than the shelf sediments. Sediments of the Porcupine and Tisdale Group, are in general, less mature and less reworked than those of the Pamour Group.

Variations In the Percentage and Nature of Polycrystalline Quartz (Qp)

Introduction

The percentage of polycrystalline quartz (Qp) listed in Appendix 8 and plotted in Figure 3.11 was determined during the initial petrographic analysis of approximately 300 framework grains per sample. A second count of polycrystalline quartz (Qp) was completed (Table 3.14) to classify them into one of five recognizable lithotypes: Qp1 to Qp5 as listed in Table 3.15.

Qp1 is the most common and consists of a mosaic of fine-grained and equigranular quartz crystals (Plate 8.A). Qp2 differs from Qp1 because it contains a mixture of both fine-grained and coarse-grained quartz (Plate 8.B). Polygonal (triple point) contacts are characteristic of most internal crystal boundaries for both Qp1 and Qp2 grains. Both types are similar to polycrystalline quartz from a metamorphic provenance as described by Abdel-Wahab (1992).

Qp3, an uncommon lithotype (Plate 8.C), also consists of both fine- and coarse-grained quartz granules with characteristic sutured or intersertal grain boundaries, suggesting a possible metamorphic origin for these grains. Qp4 (Plate 8.D) commonly consists of only two to three amalgamated quartz crystals that are coarse-grained and joined by straight, rather than polygonal, crystal boundaries. Qp5, which also represents a rare grain type, consists of a few large quartz grains armoured by silica cement. The epitaxial cement and original detrital grains are not in crystallographic continuity, but appear as two distinct crystals of quartz with the cement mantling a core of detrital quartz.

PLATE 8:

THIN SECTIONS OF ROCKS FROM THE PAMOUR GROUP (DOME AND THREE NATIONS FORMATIONS)
SHOWING THE VARIETY OF TEXTURES AND DETRITAL COMPOSITIONS IN POLYCRYSTALLINE QUARTZ
GRAINS.

(PLATE 8.A):

Thin section of polycrystalline quartz grains: Qp1 grains (labelled "1") are the most common and consists of a mosaic of fine-grained and equigranular quartz crystals with polygonal internal contacts. From Member A of the Dome Formation: Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

Also shown: q=Qm grains; p=plagioclase grains

(Plate 8.B):

Thin section of polycrystalline quartz grains: Qp2 grains (labelled "2") differ from Qp1 in containing a mixture of both fine-grained and coarse-grained quartz with polygonal internal contacts. Sample from Member A of the Three Nations Formation which contains all five types of polycrystalline quartz (not all shown in the photo).

Also shown: q=Qm grains; p=plagioclase grains; 1=Qp1 grains

(Plate 8.C):

Thin section of polycrystalline quartz grains: Qp3 (labelled "3"), an uncommon lithotype, consists of both fine-and coarse-grained quartz granules with characteristic sutured and intersertal grain boundaries, suggesting a possible metamorphic origin. Sample from Member C of the Three Nations Formation which contains all five types of polycrystalline quartz (not all shown in the photo).

Also shown: q=Qm grains; p=plagioclase grains; 1=Qp1 grains; 2=Qp2 grains

(Plate 8.D):

Thin section of polycrystalline quartz grains: Qp4 (labelled "4") commonly consists of only two to three amalgamated quartz crystals that are coarse grained and joined by straight, not polygonal, crystal boundaries. Sample from Member C of the Three Nations Formation which contains all five types of polycrystalline quartz (not all shown in the photo).

Also shown: q=Qm grains; p=plagioclase grains; 1=Qp1 grains; 2=Qp2 grains

Table 3.14 Modal analysis: lithologic and size data for Qp (polycrystalline quartz) grain for specimens from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Values are plotted in Figures 3.11 and 3.12. Sample locations are in Appendix 8.3.

R	measured	total	mean	mean	range	Qp	ERR	Qp1	Qp2	Qp3	Qp4	Qp5	E	mean	Qp1	Qp2	Qp3	Qp4	Qp5
#	section	sample	modal	grains	grains	mm	%	%	%	%	%	%	#	values	size	size	size	size	size
			cnts	mm	(sand)									%Qp	mm	mm	mm	mm	mm
24	4	84	300	0.6	cL	0.2-1.0	22	5	23	61	11	6	0	4	1.00	0.80	1.00	1.00	
25	4	104	300	0.8	cL	0.4-1.0	19	4	55	36	9	0	0	4	1.00	0.80	1.00	1.00	
26	4	106	300	0.8	cU	0.4-1.2	13	4	15	68	8	3	3	4	0.40	0.50	0.60	0.20	0.40
27	4	120	300	0.4	mL	0.2-1.6	25	5	39	58	3			4	0.80	1.00	1.60		
28	4	127	300	0.6	cL	0.4-1.0	23	5	46	35	12	4	3	4	0.80	1.00	1.00	0.40	0.80
29	11	6003	300	0.6	cU	0.3-1.2	28	5	96	4				4	0.30	0.30			
30	2	6007	300	0.4	mU	0.2-1.2	4	2	100					5	0.50				
31	2	25c	300	0.1	fU	.08-.2	12	4	40	20		31	9	5	0.20	0.20		0.20	0.20
32	8	154B	300	0.4	mU	0.2-.8	12	4	31	69				5	0.40	0.40			
33	5	145	300	0.2	fL	0.1-.6	10	3	38	41	3	17	0	5	0.50	0.60	0.40	0.40	
34	5	146A	300	0.7	cL	0.1-.8	7	3	82	12		6		5	0.70	0.40			
35	6	150B	300	0.2	fU	0.1-.3	11	4	59	29	3	3	6	5	0.30	0.30	0.30	0.30	0.30
36	6	153B	300	0.1	fL	.05-.2	5	2	63	38				5	0.10	0.10			
37	3	57A	300	0.1	fL	0.1-.2	5	2	40	27	7	20	7	5A	0.10	0.20	0.20	0.10	0.10
38	D	517		10	pebs	> 1 cm	10	3	100					7					
39	1	24h	300	0.25	vf *	.01-.6	4	2	62	23		8	8	7	0.20	0.10		0.20	0.10
40	1	6027	300	0.8	vcgr	0.6-1.6	4	2	100					7	1.00				
41	5	144B		10	pebs	> 1 cm	10	3						7		y			
42	17	328	300	1.2	vcL	0.4-1.6	39	6	86	14				7	1.20	1.00			
43	17	329	300	1.2	vcL	0.4-1.6	39	6	95	5				7	1.20	1.00			
44	2	30		10	pebs	> 1 cm	10	3						8	12	y			
45	3	50A	300	mtx	md	0.5	11	4	71	21		8		8	0.40	0.40		0.40	
46	4	67A	300	<.05	vf	0.04-.1	2	2	100					8	0.10				

Table 3.14 Modal analysis: lithologic and size data for Qp (polycrystalline quartz) grain for specimens from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Values are plotted in Figures 3.11 and 3.12. Sample locations are in Appendix 8.3.

R #	measured section	total modal	mean grains	mean grains (sand)	range grains	Qp %	ERR	Qp1 %	Qp2 %	Qp3 %	Qp4 %	Qp5 %	E #	mean values %Qp	Qp1 size mm	Qp2 size mm	Qp3 size mm	Qp4 size mm	Qp5 size mm
1	H	77	300	0.3	mL	0.1-.4	5	2	57	21	21		1	6	0.10	0.20		0.10	
2	33	338	300	0.3	mL	0.2-1.2	6	3	94	6			1		0.30	0.20			
3	1	7	300	0.25	mL	.05-.5	9	3	59	30	11		2	3	0.30	0.20		1.00	
4	1	12	300	0.4	mL	0.2-.8	2	2	57	43			2		0.60	0.60			
5	1	17	300	0.05	vf	.05-.1	1	1		100			2			0.60			
6	12B	204	300	0.2	fU	0.2-.8	2	2	100				2		0.80				
7	12B	207	300	0.2	fU	0.1-.8	4	2	67	33			2		0.20	0.20			
8	12B	207B	300	0.2	fU	0.1-.4	2	2		100			2			0.20			
9	1	6001	300	0.2	fU	0.1-1.2	1	1	100				2		0.30				
10	1	6004	300	0.4	mU	0.2-1.2	6	3	100	0			2		0.50				
11	9	160A	300	0.4	mU	0.2-.6	8	3	43	57			2		0.40	0.40			
12	3489	M1323		0.4	vf	.04-.1	10	3					3						
13	3489	M1324		0.2	fU	.01-.03	10	3					3						
14	15	313B	300	0.2	fU	0.2-1.2	16	4	77	23			3		0.20	0.20			
15	15	315		0.5	cL	0.4-1	5	2					3	10					
16	15	316B	300	0.04	vf	.05-.3	12	4	100				3		0.20				
17	15	317A		0.5	vf	0.50-1	5	2					3						
18	15	317D	300	0.6	cL	0.4-1.6	14	4	100				3		0.80				
19	2	34B	300	0.2	mU	0.2-.6	10	3	63	28			4	19	0.40	0.40		0.40	
20	2	36	300	0.2	mU	0.2-.6	20	5	57	26	13		4		0.40	0.40	0.40	0.40	
21	4	78	300	0.6	cL	0.4-1	18	4	53	32			4		0.60	0.50	0.50	0.50	0.40
22	4	81	300	0.4	mU	0.3-1.0	14	4	35	35	14		4		0.60	1.00	0.80	0.40	2.00
23	4	82	300	0.6	cL	0.2-1.0	21	5	22	62	11		4		1.00	0.80	1.00	1.00	

Table 3.15 Definitions of grain parameters and characteristics for the 5 grain types of Qp (polycrystalline quartz) specimens from the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. Values are listed in Table 3.14 and plotted in Figures 3.12.					
type	character	internal grain relations	most common	likely origin	alternative origin
Qp1	mosaic of fgr QZ crystals:equigranular	triple point internal boundaries	1	sedimentary ?	metamorphic ?
Qp2	mosaic of fgr & cgr QZ crystals: fgr<cgr:	triple point internal boundaries	2	sedimentary ?	metamorphic ?
Qp3	mosaic of QZ crystals:equigranular	sutured grain boundaries	4	metamorphic ?	epithermal veins
Qp4	cgr QZ crystals:	straight crystal boundaries	3	volcanic ?	epithermal veins
Qp5	cgr QZ crystals:	armoured compound QZ grains with some rimming silica cement	5	diagenetic ?	epithermal veins

Figure 3.11 Provenance discrimination diagram: Total Qp plot for specimens from the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. Data derived from modal analyses (>300 points). Values are listed in Table 3.14.

In these grains, the original (Qp) polycrystalline quartz was affected by diagenesis either before or shortly after deposition.

Qp1 and Qp2 both contain greater than three crystal units per grain, whereas Qp3, Qp4 and Qp5 generally contain 2-3 crystal units per grain.

Description

Total Qp plot

A large range of values is indicated by variations in the percentage of total Qp (Figures 3.11 and Table 3.14). Turbiditic sandstones of both the Hoyle Formation and some of the Beatty Formation (#3 to #11) contain only minor amounts of Qp. By comparison, those from the Whitney Formation (of the Tisdale Group) (#11 to 18), contain up to 3 times as much Qp. Vast differences between groups are illustrated by mean Qp values of 6, 3 and 10 (%), which correspond to sediments of the Hoyle, Beatty and Whitney Formations, respectively. Elevated levels of Qp are most common within arkoses from the Three Nations Formation (#20 to #29). Their total Qp values average 19% and range between 14-28% of all framework grains. Error estimations for this group, however, indicate that few significant changes are greater than the margin of error. Further comparisons between the shelf sediments and turbiditic sandstones of a similar age indicate that the latter contain substantially less Qp than shelf sediments: the mean Qp value for the shelf sediments is 19%, compared to 8% for turbiditic sandstones. Variations are, however, minor within all samples of the turbiditic sandstones, because most changes are less than the margin of error. The various types of conglomerates show a large range in Qp values. Some, like those associated with turbidite fans, have low values (11%) that are comparable to turbiditic sandstones of the Beatty Formation. Others, such as alluvial conglomerates (18% Qp), are comparable to shelf sediments. The

average Qp content of gravel bars is 31%, but ranges from a low of 13% to a high of 45%, representing the highest Qp values (Figure 3.11) in any of the epiclastic rocks. Gravel bars also show an easterly trend defining an increase in Qp content.

The Krist volcanoclastic sediments generally contain less than 10% polycrystalline quartz (Qp), a total which is low compared to epiclastic rocks of the Pamour Group, but comparable to many of the older turbiditic sandstones of the Hoyle, Beatty and Whitney Formations.

Plot of Variations in Grain types (Qp1-Qp5)

The various types of polycrystalline grains (Qp1-Qp5) occur in rocks from nearly all depositional environments, but some are more common than others (Figure 3.12 and Table 3.14). Qp1 followed by Qp2 are the most common grain types in turbiditic sandstones of the Hoyle and Beatty Formations; rare Qp4 grains also occur. A poorly defined trend, which represents 3 samples from the Whitney Formation, shows an increase in Qp1 grains and a corresponding decrease in Qp2 grains in a west to east direction.

Shelf sediments and turbiditic sandstones of the Pamour Group contain all 5 grain types, but not in the same sample. Qp1 is the most common grain type, followed by Qp2, Qp3, Qp4 and Qp5, in order of decreasing abundance. Variations in the percentage of Qp1 and Qp2 grains within shelf sediments outline both a lateral and stratigraphic trend (north to south direction). These trends are defined by an initial decrease followed by an increase in Qp1 grains, which accompanies opposite changes in the percentage of Qp2 grains.

Unlike the shelf sediments, turbiditic sandstones of the Dome Formation apparently do not show any systematic variation in the ratios of the various Qp

Figure 3.12 Modal analysis: relative abundance of the 5 types of Qp (polycrystalline quartz) grains for specimens from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. Values are listed in Table 3.14.

grains. Other differences, which include a lower frequency and percentage of Qp3 grains compared to shelf sediments, suggest a decreased input from metamorphic terranes.

Qp1 and a lesser percentage of Qp2 grains are common in conglomerates, together with minor amounts of Qp, Qp4 and Qp5.

Unlike the epiclastic rocks, Krist volcanoclastic rocks contain only a few Qp1 grains, and some of these probably are amygdaloidal infillings rather than discrete detrital components. These characteristic features suggest that the Krist volcanoclastic rocks had a different source than any of the previously discussed epiclastic rocks.

Size Analyses

A comparison of the various Qp grain types and their relative size suggests that for most examples, the largest Qp grains are also the most abundant (Table 3.14): Qp1 grains are generally the largest. In other cases (25%), all Qp grains are approximately the same size, regardless of their relative abundance. When sparse Qp3 grains, which probably represent detritus from metamorphic terranes, occur together with Qp1 grains, they are invariably equal to or larger than the size of the Qp1 grains. This relationship is mainly illustrated by sediments of the Pamour Group, particularly within the shelf sediments and turbiditic sandstones.

A correlation between the size of polycrystalline quartz grains, mean grain size and the range of grain sizes shows that, depending on the depositional environment, some Qp grains are smaller than, equal to, or greater than the mean grain size of the sample. The size of Qp grains in most turbiditic sandstones of the Hoyle and Beatty Formations, which is generally smaller than

the mean grain size, represents some of the smallest grains found in that sample. Within shelf sediments, however, Qp grains are commonly larger than the mean grain size and commonly represent the largest grains of that sample. By contrast, Qp grains in turbiditic sandstones and conglomerates of the Pamour Group are commonly about the same size as the mean grain size for that sample.

Interpretation

Data from the total polycrystalline quartz (Qp) plot show that samples from the various depositional environments can be differentiated on the basis of their differing Qp content (Figure 3.11). Shelf sediments and turbiditic sandstones of the Pamour Group contain the highest amounts, whereas turbiditic sandstones of the Hoyle and Beatty Formations contain the lowest values. Volcaniclastic rocks of the Krist Formation also contain low amounts of Qp. Such differences suggest that sediments which underwent the least amount of reworking contain low amounts of Qp, whereas those that represent reworked sediments contain higher amounts of Qp. In addition, the younger rocks (Pamour Group), generally contain higher Qp values than the older sequences such as the Hoyle and Beatty Formations. A nearby source region for polycrystalline quartz was probably exposed, and provided detritus during deposition of the Pamour Group (Timiskaming strata), whereas this source was less prominent or absent during deposition of the older strata.

Conglomerates contain variable amounts of (Qp) polycrystalline quartz. Some gravel bars contain up to 45%, whereas other coarse conglomerates, such as alluvial types, have low values and show no consistent variations or trends. Gravel bar conglomerates show a trend of increasing Qp content in an easterly direction, suggesting that the source area for the Qp detritus was probably located in the east.

The relative complexity of the source region for each environment is indicated by the variety of (Qp) polycrystalline quartz in each depositional environment (Figure 3.12). Because only Qp1 and Qp2 grain types occur in the older turbiditic sediments, the detritus probably came from only a few sources. Shelf sediments and turbiditic sandstones of the Pamour Group, however, show a large diversity of polycrystalline quartz (Qp), which suggests that there were many sources. In fact, the shelf sediments do not illustrate simple stratigraphic changes, but reflect an initial decrease followed by an increase of Qp1 grains at the expense of Qp2 grains. Such changes in the relative abundance of detritus supplied to the shelf sequence suggest that changes must have occurred in the source region.

Size analysis of the various grain types (Table 3.14) shows that, depending on the environments, some Qp grains are smaller than, equal to, or greater than the mean grain size. These comparisons probably reflect the transport history of Qp grains relative to the rest of the detritus in each environment. Small Qp grains for turbiditic sandstones of the older sedimentary sequences suggest that transport probably occurred over a long distance, whereas large Qp grains typical of shelf sediments of the Timiskaming strata are suggestive of transport over a short distance. When the mean grain size is the same as the Qp grain size, Qp grains probably underwent approximately the same amount of transport as the nearby detrital material: this occurs within turbiditic sandstones and conglomerates of the Pamour Group.

Qp1 grains, which are the largest grains in most samples, are also the most abundant of the various polycrystalline grain types (Table 3.14 and Figure 3.12). This size to abundance relationship, however, does not hold when Qp1 and Qp3 grains occur in the same sample, as they do in shelf sediments and turbiditic

sandstones of the Pamour Group. Qp3 grains, which probably represent detritus from metamorphic terranes, are invariably larger than or equal to the size of the Qp1 grains, even if they represent only a minor percentage of total Qp. Both of these relationships suggest that during deposition, a nearby source of metamorphic quartz provided detritus to shelf sediments and turbiditic sandstones of the Pamour Group. This source was either not exposed or at some distance from the basin during deposition of the older epiclastic rocks.

Qp5 grains, which are most abundant within shelf sediments and turbidites of the Pamour Group, represent original quartz grains that are armoured by silica cement. This process could have occurred before erosion of a protolith or subsequent to initial deposition of the shelf sediments. If this process occurred before erosion, it identifies a quartz-rich protolith that underwent diagenesis and cementation before erosion. Alternatively, if the process occurred after deposition, it does not necessarily imply a sedimentary protolith, because diagenesis and cementation post dates deposition: this second theory appears to represent a more plausible explanation.

The presence of silica cement also suggests that diagenesis of shelf sediments may have occurred under a more stable tectonic environment than for the older, deep-water turbidites of the Hoyle and Beatty Formations. Alternatively, it may suggest that sediments of the Pamour Group are less deformed than the older turbiditic sandstones, because original detrital grains armoured by silica cement would only be preserved in relatively undeformed sediments.

Discussion:

If the findings of Basu et al (1975) and Girty et al (1988), which are valid for Recent unconsolidated sediments, can be applied to the Timmins area, then it may be possible to infer probable source regions in Archean sedimentary rocks from the study area by studying the various types of polycrystalline quartz (Qp) grains. These researchers recognized polycrystalline quartz (Qp) grains as an important provenance indicator. Their initial research, which examined the nature of polycrystalline quartz (Qp) grains within the sand-sized fraction of stream sediments from different provenance areas and from some first-cycle sandstones from a known source area, concluded that this type of analysis could be applied with caution to ancient sandstones. Unmetamorphosed sediments are preferable, because undulose quartz in deformed sedimentary rocks may have been strained in either the sedimentary strata or in the source rocks, creating ambiguity that may be difficult to resolve. Polycrystalline quartz (Qp) grains are less ambiguous, because under most metamorphic conditions, except upper amphibolite or granulite facies, their polycrystalline character does not change.

The four primary variables that plot at the four apices of a diamond are: quartz showing undulose or non-undulose extinction, and polycrystalline quartz containing greater than 3 quartz grains, or those with less than 3 quartz grains. Such petrographic analysis was completed on all sedimentary samples from Timmins containing polycrystalline quartz; the results are listed in Table 3.16, and mean values are plotted in Figure 3.13.

The triangular plot shown in figure 3.13 represents the upper half of the diamond-shaped provenance diagram, because >25% of all Qp grains contain greater than 3 quartz crystals. Three provenance fields, which represent primary

(including plutonic-volcanic), middle and upper rank metamorphic, and low rank metamorphic fields, correspond to the lower right, middle, and upper left portions of diagram, respectively. Three distinct source areas, which are represented by grains in the various sedimentary suites of the Timmins area, are indicated by the distribution of mean values. Turbiditic sandstones of the Hoyle Formation and volcanoclastic sediments of the Krist Formation represent sediments that were derived only from primary rocks, such as unmetamorphosed volcanic rocks and lesser amounts of plutonic rocks. Turbiditic sandstones from the older Hoyle and Beatty Formations and the younger Dome Formation, as well as associated turbidite fan conglomerates from the Dome Formation, represent sediments that were derived from a source area consisting of middle and upper rank metamorphic rocks. Low rank metamorphic rocks were the apparent source area for alluvial conglomerates, arkosic shelf sediments and associated gravel bars. All are part of the Pamour Group and represent the youngest sedimentary strata of the Abitibi Greenstone belt in the Timmins area. The distribution of data points along two lines on the diagram suggests that, in spite of different source areas, many of the epiclastic rocks of the Pamour Group show the same relationships with respect to undulose, non-undulose and polycrystalline quartz. The ratio of undulose to non-undulose quartz decreases with an increase in the percentage of Qp. By contrast, the second line, which represents data from all older rocks and turbiditic sandstones from the Pamour Group, indicates that changes in the percentage of Qp does not affect the ratio of undulose to non-undulose quartz. Interpretations of these trends are uncertain, except that the two distinct groups of sediments also correspond to major age differences between the younger Pamour Group and all of the older sedimentary and volcanoclastic rocks.

Table 3.16 Modal analyses: relative abundance of Qp grains (polycrystalline quartz), Qm grains(monocrystalline quartz) with non-undulatory extinction (QZ NU), and Qm grains(monocrystalline quartz) with undulatory extinction (QZ U). All specimens are from the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. Values are plotted in Figures 3.13.

measured section	sample	Qc	Qm %	Qp %	NU	U	Qp+Qc %	U	Qm	U	Qm	A	B	C	E	A	B	C	REF #
												Qp	Qm	Qm	#	Qp	Qm	Qm	
													U	NU			U	NU	
																mean values			
d K 54-24	6008	0	14	0	14	0	0	0	14	0	0.00	0.00	1.00	1					1
d K 54-24	6009	0	19	0	19	0	0	0	19	0	0.00	0.00	1.00	1					2
d K 54-25	6010	0	70	0	70	0	0	0	70	0	0.00	0.00	1.00	1					3
d K 54-25	6011	0	60	0	60	0	0	0	60	0	0.00	0.00	1.00	1					4
d K 54-30	6012	0	60	0	60	0	0	0	60	0	0.00	0.00	1.00	1					5
d K 54-30	6013	0	60	0	60	0	0	0	60	0	0.00	0.00	1.00	1					6
d K 54-30	6014	0	60	0	60	0	0	0	60	0	0.00	0.00	1.00	1					7
Hoyle t pond	077	3	24	5	24	0	8	0	24	32	0.25	0.00	0.75	1	0.13	0.00	0.88		8
33	338	6	22	6	22	0	12	0	22	34	0.35	0.00	0.65	1					9
12D	204	7	21	2	19	2	9	2	19	30	0.30	0.07	0.63	2	0.27	0.07	0.66		10
12D	205	7	19	1	17	2	8	2	17	27	0.30	0.07	0.63	2					11
12D	207A	8	23	4	21	2	12	2	21	35	0.34	0.07	0.59	2					12
12D	207B	7	23	2	21	2	9	2	21	32	0.28	0.07	0.65	2					13
1	6001	5	24	1	22	2	6	2	22	30	0.20	0.08	0.72	2					14
1	007	5	21	9	19	2	14	2	19	35	0.40	0.06	0.54	2					15
1	12	4	26	2	23	3	6	3	23	32	0.19	0.08	0.73	2					16
1	17	10	20	1	18	2	11	2	18	31	0.35	0.06	0.58	2					17
1	6004	5	20	6	20	0	11	0	20	31	0.35	0.00	0.65	2					18
(Quarry)	340B	0	30	y	27	3	0	3	27	30	0.00	0.10	0.90	2					19
d 3235 @104 m	M1313 ; TBTE	0	15	y	14	2	0	2	14	15	0.00	0.10	0.90	3	0.22	0.08	0.70		20
d 3235 @174 m	M1314 ; TBTE	0	30	y	27	3	0	3	27	30	0.00	0.10	0.90	3					21
d 3489 @96 m	M1323 ; TBTE	0	30	10	27	3	10	3	27	40	0.25	0.08	0.68	3					22
d 3489 @108 m	M1324 ; TBTE	0	60	10	54	6	10	6	54	70	0.14	0.09	0.77	3					23
15	313B	0	19	16	17	2	16	2	17	35	0.46	0.05	0.49	3					24
15	315	0	20	5	18	2	5	2	18	25	0.20	0.08	0.72	3					25
15	316B	0	19	12	17	2	12	2	17	31	0.39	0.06	0.55	3					26
15	317A	0	30	5	27	3	5	3	27	35	0.14	0.09	0.77	3					27
15	317d	0	19	14	17	2	14	2	17	33	0.42	0.06	0.52	3					28

Table 3.16 Modal analyses: relative abundance of Qp grains (polycrystalline quartz), Qm grains (monocrystalline quartz) with non-undulatory extinction (QZ NU), and Qm grains (monocrystalline quartz) with undulatory extinction (QZ U). All specimens are from the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. Values are plotted in Figures 3.13.

measured section	sample	Qc	Qm Qp %	NU	U	Qp+Qc %	U	Qm	NU	TOTAL %	A	B	C	E	A	B	C	REF #
2	34B	3	33	10	20	13	13	13	20	46	0.28	0.29	0.43	4	0.44	0.22	0.34	29
2	36	3	26	20	16	10	23	10	16	49	0.47	0.21	0.32	4				30
4	78A	5	28	16	17	11	21	11	17	49	0.43	0.23	0.34	4				31
4	81	5	27	14	16	11	19	11	16	46	0.41	0.23	0.35	4				32
4	82	2	27	21	16	11	23	11	16	50	0.46	0.22	0.32	4				33
4	84	3	33	22	20	13	25	13	20	58	0.43	0.23	0.34	4				34
4	99	9	26	13	16	10	22	10	16	48	0.46	0.22	0.33	4				35
4	104	3	29	19	17	12	22	12	17	51	0.43	0.23	0.34	4				36
4	106	1	30	13	18	12	14	12	18	44	0.32	0.27	0.41	4				37
4	120	3	27	25	16	11	28	11	16	55	0.51	0.20	0.29	4				38
4	127	1	25	23	15	10	24	10	15	49	0.49	0.20	0.31	4				39
4	140	4	25	28	15	10	32	10	15	57	0.56	0.18	0.26	4				40
2	025c	2	32	12	30	2	14	2	30	46	0.30	0.03	0.66	5	0.30	0.03	0.66	41
2	6007	4	37	4	35	2	8	2	35	45	0.18	0.04	0.78	5				42
6	150B	13	31	11	29	2	24	2	29	55	0.44	0.03	0.54	5				43
6	153B	5	39	5	37	2	10	2	37	49	0.20	0.04	0.76	5				44
6	154B	8	29	12	28	1	20	1	28	49	0.41	0.03	0.56	5				45
6	160A	3	21	8	20	1	11	1	20	32	0.34	0.03	0.62	5				46
3	50A	3	24	11	23	1	14	1	23	38	0.37	0.03	0.60	5				47
3	57A	2	35	5	33	2	7	2	33	42	0.17	0.04	0.79	5				48
1	024h	0	39	4	23	16	4	16	23	43	0.09	0.36	0.54	7	0.38	0.25	0.37	49
1 @390 m	6027	0	35	4	21	14	4	14	21	39	0.10	0.36	0.54	7				50
1 @390 m	6028	0	14	8	8	6	8	6	8	22	0.36	0.25	0.38	7				51
5	145A	8	34	10	20	14	18	14	20	52	0.35	0.26	0.39	7				52
5	146A	16	33	7	20	13	23	13	20	56	0.41	0.24	0.35	7				53
17	328	1	20	39	12	8	40	8	12	60	0.67	0.13	0.20	7				54
17	329	2	19	39	11	8	41	8	11	60	0.68	0.13	0.19	7				55
2	30	0	50	10	30	20	10	20	30	60	0.17	0.33	0.50	8				56

Figure 3.13 Modal analyses: relative abundance of Qp grains (polycrystalline quartz), Qm grains(monocrystalline quartz) with non-undulatory extinction (Qm NU), and Qm grains(monocrystalline quartz) with undulatory extinction (Qm U). All specimens are from the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. Values are plotted in Table 3.16.

A direct comparison of Precambrian sedimentary rocks to Holocene stream sediments and undeformed Paleozoic sandstones (Basu et al, 1975) may be difficult unless factors affecting undulosity and polycrystallinity in quartz are understood. Folding and faulting can produce strain in detrital quartz subsequent to deposition, and thus tectonically stable areas are most desirable for study. Recrystallization, which probably represents a less important factor, can reduce the undulosity of quartz. A lack of polycrystalline quartz could indicate that there is little quartz of that variety in the source region, but it could also indicate that quartz had a long residence time in the sedimentary cycle, because polycrystalline quartz will break down and produce monocrystalline quartz.

Comparisons with the initial study of Basu et al, (1975) could be misleading because their observations were restricted to a sand size of 0.25-0.5 mm, whereas the Timmins data cover a full range of grain sizes from very fine sand to granules. It is uncertain how these differences might affect the results, comparisons and interpretations.

Interpretations of depositional environments and source areas for sedimentary rocks of the Abitibi Greenstone belt also can be made on the basis of comparisons to similar, well-documented sediments of Phanerozoic orogenic belts. Detrital modes and provenance discrimination diagrams are one method widely used by Ingersoll et al. (1988) and Dickinson et al. (1983) to show relationships between the ratio of grain types and provenance for sandstones in a variety of tectonic settings. If the Timmins data presented in Figures 3.7 and 3.8, are compared to standard reference diagrams derived by Dickinson et al, (1983), several key provenance indicators are apparent. For QFL diagrams (Figure 3.14),

which largely reflect compositional maturity, most of the Timmins data indicate a basement uplift provenance, but a few samples also plot in the dissected arc region. A comparison with other Archean turbidites (McLennan, 1984) indicates that nearly all turbidites from the Timmins area represent the most common type of Archean turbidite, namely the quartz intermediate variety, with quartz values ranging from 18 to 65% Q in the QFL plot. Some quartz-rich turbidites occur in the north central Superior Province (Thurston, 1990).

The use of another provenance diagram, namely, the QmFLt plot (Figure 3.15) is probably more appropriate because a large proportion of Qt (total quartz) for the Timmins data consists of polycrystalline quartz (Qp). Qp is grouped with Lt (total lithics) to emphasize the true lithic nature of the sample rather than its compositional maturity. Most of the Timmins data indicate that the provenance fields are basement uplift, dissected arc or transitional arc. Mean values for each main lithologic group suggest that turbidite fans of the Pamour Group as well as turbidites of the Hoyle and Whitney Formations have a basement uplift provenance, whereas data from the other environments suggest a magmatic arc provenance (the dissected arc and transitional arc fields) with plutonic source rocks more common than volcanic source rocks (see Dickinson, 1985). If the basement uplift source is correct, these turbidites may be genetically related to a rift basin or alaucogen. The other data points indicate a variety of sources, such as variably dissected magmatic arcs, or a continental arc, or a forearc basin, or a trench, but not an island arc setting. Comparison of Archean and Phanerozoic turbidites by means of the Qm-F-Lt plot indicates that there is a similarity between Timiskaming data from the Timmins area and the Franciscan Assemblage of California (Figure 3.15). The latter represents a Cenozoic subduction complex, oceanward of a major fore-arc basin, namely the Great

(modified from Dickinson, 1988)

Figure 3.15 QmFLt provenance discrimination diagrams for the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. Data derived from modal analyses (>300 points) and compared to Phanerozoic provenance data.

Sequence (Dickinson, 1982). The less feldspathic nature of the GVS turbidites suggests that they were derived from a relatively undissected portion of the magmatic arc, whereas the turbidites of the adjacent Franciscan Assemblage were derived from deeper levels of the arc containing more plutonic sources with a high feldspar content. A comparison of the Phanerozoic assemblages to the Archean-age strata in the Timmins area also suggests that none of the latter were eroded from an undissected volcanic arc but from deeper levels. In general, the entire Archean suite contains less lithic grains and monocrystalline quartz but more feldspar than either of the Phanerozoic examples. Within the Archean suite, the most feldspathic rocks are represented by turbidites of the Porcupine Group, namely those of the Hoyle and Beatty Formations.

Another powerful provenance diagram used by Dickinson (1982) is the Qp-Lv-Ls diagram (Figure 3.16), which examines the relationships between polycrystalline quartz (Qp), volcanic lithic grains (Lv), and sedimentary lithic grains (Ls). Comparison of Archean and Phanerozoic turbidites by means of the Qp-Ls-Lv plot indicates that the sedimentary rocks of the Abitibi Greenstone belt (in the Timmins area) are similar to slope basins from the Pacific Northwest, but unlike the GVS and Franciscan Assemblage of California. Most of the data from Timmins (Figure 3.16) indicates a provenance of mixed orogenic sands. These sources are transitional among arc orogen, subduction complex, collision sutures and fold thrust belts. According to these parameters, no single region can be identified as the sole source of detritus. The probable sources for the youngest sedimentary rocks (Pamour Group) are the highlands flanking a rifted continental margin. By contrast, the source for most of the older turbiditic sediments probably was transitional between an arc and a subduction complex. Interpretations for similar Paleozoic data by Mack (1984) suggests that such

Figure 3.16 QpLvLs provenance discrimination diagrams for the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. Data derived from modal analyses (>300 points) and compared to Phanerozoic provenance data.

intermediate compositions probably represent a collision that juxtaposed a variety of source rocks into a single orogenic belt. Possible arc-arc or arc-continent collision and rifting are indicated by the composition of these sandstones. At the very least, it suggests that the Timiskaming strata have a strong rift-related affinity and could represent deposition within basins that formed during rifting or during transform tectonics (Figure 3.16). Such data suggest that a highland region was exposed and provided detritus during deposition of the Timiskaming strata. According to the previously discussed polycrystalline quartz plots (Figure 3.13), this source area consisted of low-grade metamorphic rocks. Source regions for the older turbidites probably were deeply dissected magmatic arcs and possibly an accreted terrane that consisted of an arc and subduction complex. The nature of polycrystalline quartz (Figure 3.13) suggests that the source region must have consisted of high to medium rank metamorphic rocks, that were part of a dissected arc containing associated plutonic rocks within the core region of the arc.

In general, the petrofacies of mixed provenance may reflect derivation from complex orogens, where varied source terranes were tectonically juxtaposed. Alternatively, they may have been produced by mixing sediment from varied sources exposed within large drainage systems of major rivers. The second alternative may be less likely, because only minor fluvial strata have been identified within the Timmins sedimentary basin.

Other comparisons on a QmFLt plot (Figure 3.15) indicate that Timiskaming data from the Timmins area are similar to the Franciscan Assemblage of California (Dickinson, 1982). The latter represents a Cenozoic subduction complex that is oceanward of a major fore-arc basin (Great Valley Sequence: GVS). The less feldspathic nature of GVS turbidites suggests that they

were derived from a relatively undissected portion of the magmatic arc, whereas turbidites of the adjacent Franciscan Assemblage were derived from deeper levels of the arc containing more plutonic source rocks with abundant feldspars. Similar data for the Timmins data, would, by analogy, suggest that sediments from the older Hoyle and Beatty Formations were derived from deeper levels of the arc than strata of the younger Pamour Group, which represent Timiskaming-age sedimentation.

CHAPTER 4: GEOCHEMISTRY- RARE EARTH ELEMENT DISTRIBUTION AS A TOOL IN PROVENANCE STUDIES

Introduction

When used in conjunction with sedimentology, geochemistry, particularly REE (Rare Earth Element) geochemistry, is a powerful tool for solving geological problems related to provenance. REE abundances from rock samples are commonly normalized against a standard set of chondrite values to compare compositions to the composition of the primitive mantle (on the assumption that chondrites approximate the composition of the primitive mantle). Other standards, such as post-Archean Australian Shale (PAAS) and North American Shale Composite (NASC), are useful for examining changes with time. REE abundances are useful because they are not greatly affected by subsequent diagenesis and metamorphism, and are less affected by heavy mineral fractionation than other trace elements such as Zr (McLennan and Taylor, 1991). Basically, they provide a good index of crustal composition.

REE analysis of sedimentary rocks has been used as a crustal sampling technique, because erosional and transportation processes for sedimentary rocks are a very efficient and unbiased sampling mechanism to record crustal development from Archean to the present day (Taylor and McLennan, 1991). REE patterns of most igneous rocks and sedimentary rocks derived from them, commonly show the presence of a negative europium anomaly, which can be directly attributed to the presence of plagioclase feldspar in the source region. Because plagioclase is only stable at shallow levels in the Earth (<40 km) (Taylor and McLennan, 1985), europium (Eu) depletion generally indicates that partial melting was an important mechanism, and that intracrustal rather than mantle processes were dominant. Differences in trace-element signatures between

Archean and post-Archean sedimentary rocks suggests that the Archean crust also had a different composition. The general absence of Eu depletion suggests that during the Archean, mantle processes predominated over intracrustal processes. Therefore, the REE data serve to document secular changes with time such as crustal compositions and processes in the Archean and the evolution of a more differentiated crust in which intracrustal processes dominated during post-Archean time.

The provenance of sedimentary rocks can also be determined by identifying particular protoliths that have distinctive REE signatures. In essence, the chondrite-normalized REE plot for sediments represents a mixing curve between two or more protoliths or end members. Fortunately, each type of igneous suite has its own set of REE characteristics that are typified by a particular slope, presence or absence of Eu depletion, light rare earth (LREE) depletion or enrichment, and/or heavy rare earth (HREE) depletion or enrichment. Difficulties arise, however, in determining the exact percentage of each protolith within a sedimentary rock: what provenance mix produced the resultant sedimentary REE pattern, and does it represent a unique solution or can there be more than one combination? Fortunately, supplementary petrologic data can generally eliminate all but a few possibilities. The REE patterns of sedimentary rocks have also been classified and interpreted by Taylor and McLennan (1985), Taylor, McLennan and Maynard (1990), McLennan and Taylor (1991), Henderson (1984), Feng and Kerrich (1990) and Feng (1992). Most of these studies have centered on the comparison of REE patterns between Phanerozoic sedimentary rocks, where individual plate tectonic settings are well constrained, and Archean sedimentary sequences, where the tectonic settings are more problematic. Similarities and differences in REE patterns should reflect

differences in provenance and tectonic setting, whether the age of deposition for the sedimentary rocks is Archean or Phanerozoic. With these criteria as a framework, many Archean sedimentary suites from greenstone terranes have been characterized as showing a variety of REE characteristics. The most common REE pattern, called type 1, which shows LREE enrichment, flat HREE pattern and no Eu depletion, corresponds to most sediments from Kalgoorlie, Kambalda and the Fig Tree sequences. These patterns are derived by mixing a bimodal igneous suite with REE patterns similar to Types 2 and 3 or by an intermediate felsic component common in modern island arcs.

Sedimentary rocks from the Yellowknife Supergroup and some from Kalgoorlie exhibit Type 2 REE patterns, which show both LREE enrichment as well as HREE depletion. Tonalite and trondjemite are igneous rocks that show similar REE patterns. HREE-depleted samples are restricted to the Archean and likely reflect the signature of garnet fractionation during the igneous history of the source rocks. Provenance components with this type are absent from post-Archean sedimentary rocks, and are less common than type 1 patterns.

A few Archean turbidites from the Kambalda and Fig Tree suites have REE patterns that are essentially flat, with either slight LREE depletion or enrichment (Type 3). Because Archean mafic-ultramafic volcanics have a similar REE pattern, they are probably the dominant provenance source for these sediments.

REE signatures from high-grade terranes of Archean age, such as the Kapuskasing Structural Zone, are identical to sediments from greenstone belts of lower (greenschist) metamorphic grade, whereas those attributed to shallow-water deposition have REE signatures similar to post-Archean sedimentary suites such as PAAS, and NASC, with a negative Eu anomaly. The presence of a

negative Eu anomaly signals the importance of intracrustal processes, which implies that a stable craton must have existed at least on a local scale during the Archean. HREE depletion suggests that the fractionation of garnet was important in igneous rocks that were subsequently eroded and incorporated into most Archean sedimentary rocks. The variety of Eu depletion and enrichment of many Archean sediments suggests that their provenance included mainly localized and inhomogeneous source regions.

Unlike most Archean sedimentary suites, many modern turbiditic sediments have distinctive REE patterns with a negative Eu anomaly, which suggests that their main provenance region has undergone significant intracrustal partial melting. Some possible provenance regions of this type include: older continental crust, young undifferentiated arc, and young intracrustal arcs (McLennan and Taylor, 1991). Archean greywackes are mainly derived from felsic volcanic rocks, tonalites and trondjemites rather than andesites.

An empirical association was made by Taylor and McLennan (1985) between tectonic setting, quartz content, and the REE signatures of turbidites. Quartz-poor greywackes are generally common on leading-edge or convergent type boundaries, whereas quartz-rich greywackes are more typical of trailing edge or Atlantic-type passive margins. The former have an andesitic source, a REE profile with low HREE values and a flat curve, whereas the latter has LREE enrichment and Eu depletion typical of a provenance that has a strong continental influence. The geochemical signature of back-arc basins, strike-slip basins and Andean margin basins are all grossly similar, and therefore they are difficult to distinguish solely on the basis of REE trends. Quartz-intermediate greywackes, which occur in recycled orogens, continental blocks and dissected

arcs, are transitional between quartz-poor and quartz-rich greywackes. Thus, the main differences between the REE abundances of Archean and post-Archean sedimentary rocks are:

- 1) the REE patterns of Archean sedimentary rocks show considerably more variability from flat to steep curves
- 2) the total REE abundances are less in the Archean
- 3) the slope of the curve La/Yb_N is greater in sediments of Archean age, indicating LREE enrichment
- 4) Archean sedimentary rocks rarely have a Eu anomaly

These features suggest that chemical differentiation of Archean crust was related to melting at mantle depths. Post-Archean mantle processes were intracrustal and produced substantially more andesite.

Archean felsic volcanics typically have steep REE patterns with HREE-depletion, indicating garnet as a fractionating phase. The mixing of tonalites (or Felsic volcanic end member) and a mafic suite of volcanic rocks probably produced sedimentary rocks with the same geochemical signature as andesite. Thus, two alternative mechanisms have been proposed, namely the mixing model and the erosion of an andesite source terrane.

Description

Twenty-six rocks, which consist of 22 sedimentary samples, 2 volcanoclastic samples (Krist) and 2 duplicate samples, were analyzed for REE by the ICP-plasma method at X-Ray Laboratories, Toronto. The data are presented in Figures 4.1 and 4.2, as well as in Table 4.1 as ppm of REE and as chondrite-normalized REE ratios (part b) using a chondrite standard from McLennan and Taylor (1985).

R# E#		sample	RATIOS														Table 4.1 Rare Earth Element Analyses for sedimentary rocks of the Archean Abitibi Greenstone belt, Timmins, Ontario. Chondrite normalized values are plotted in Figures 4.2 and 4.3.										Y	LA/YB N	LA/Tb N	Th/U	Tb/YB N	
		Normalized	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu																
1	1	PB6011	54-25	35.69	28.63	25.55	20.68	16.45	11.84	11.44	8.62	6.82	5.06	5.22	5.62	6.85	7.09											5.33	5.21	4.14		1.26
2	1	PB6013	54-30	28.07	22.88	21.90	18.28	14.72	11.15	9.80	6.90	4.72	3.48	3.61	5.62	4.84	6.04											3.56	5.80	4.07		1.43
3	1	PB6014	54-30	52.59	46.29	41.61	32.49	25.11	18.51	16.67	13.79	12.86	10.22	10.04	11.24	9.27	8.92											11.11	5.67	3.81		1.49
4	1	PB338	33	86.65	69.28	56.93	43.32	24.24	18.28	15.36	8.62	6.30	4.38	4.42	5.62	4.03	3.67											4.89	21.49	10.05		2.14
7	1	MEAN	MEAN	50.75	41.77	36.50	28.69	20.13	14.94	13.32	9.48	7.68	5.79	5.82	7.02	6.25	6.43											6.22	9.54	5.52		1.58
5	2	PB340B	1	81.20	65.62	54.01	40.23	24.24	16.78	15.36	10.34	8.14	5.84	6.02	5.62	5.24	4.72											6.22	15.49	7.85		1.97
6	2	PB6001	1	61.31	46.92	38.69	29.25	17.75	14.14	11.76	8.62	6.56	5.17	5.22	5.62	4.84	4.20											5.33	12.67	7.11		1.78
7	2	S PB6002D	1	61.31	52.04	44.53	34.88	23.81	17.82	15.69	10.34	8.92	7.19	7.23	5.62	6.85	6.30											7.56	8.94	5.93		1.51
8	2	S PB6002	1	57.77	48.90	42.34	33.19	22.94	16.09	15.36	10.34	8.40	6.85	6.83	5.62	6.45	5.51											7.11	8.95	5.58		1.60
9	2	PB6004	1	61.85	47.96	39.42	28.97	17.32	13.68	11.44	6.90	6.30	4.72	5.22	5.62	4.44	4.46											5.33	13.95	8.97		1.55
10	2	S PB6005	1	76.29	65.41	56.20	44.02	33.77	28.05	21.90	13.79	11.81	9.44	9.24	8.43	8.87	8.40											9.78	8.60	5.53		1.55
2	2	MEAN	MEAN	66.62	54.48	45.86	35.09	23.30	17.76	15.25	10.06	8.36	6.54	6.63	6.09	6.12	5.60											6.89	11.43	6.83		1.66
11	3	PB313B	15	8.45	7.63	8.76	8.02	8.23	10.57	7.19	6.90	7.09	6.74	7.23	8.43	6.45	6.04											7.11	1.31	1.22		1.07
12	3	PB313BD	15	8.45	7.42	8.03	7.59	8.23	9.54	7.19	6.90	7.09	6.52	6.83	8.43	6.85	6.04											7.11	1.23	1.22		1.01
13	3	PB315	15	46.87	41.17	37.23	30.80	22.94	17.13	16.34	12.07	10.24	8.31	8.43	8.43	6.05	4.46											8.89	7.75	3.88		2.00
14	3	PB316B	15	40.05	28.42	22.63	16.03	9.96	7.47	6.21	3.45	2.62	1.91	1.61	1.40	1.61	1.84											2.22	24.83	11.62		2.14
15	3	PB317A	15	35.69	26.85	21.17	14.77	8.23	6.32	5.56	3.45	2.36	1.69	1.61	1.40	1.61	1.31											1.78	22.13	10.35		2.14
3	3	MEAN	MEAN	34.36	27.66	23.95	18.72	13.48	11.47	9.62	7.14	6.29	5.28	5.39	5.70	4.78	4.21											5.67	11.45	5.85		1.67
16	4	PB6003	11	38.42	26.75	21.90	15.89	9.09	8.05	7.52	3.45	3.67	2.81	2.81	2.81	2.82	3.15											3.56	13.61	11.14		1.22
17	4	PB6016	4	45.78	36.47	29.93	21.94	12.55	11.49	7.84	3.45	2.62	2.13	2.01	1.40	2.02	2.36											2.22	22.71	13.28		1.71
18	4	PB6017	4	93.46	72.31	58.39	41.49	24.68	17.93	15.69	10.34	8.92	7.08	6.83	8.43	6.85	6.30											8.00	13.63	9.03		1.51
4	4	MEAN	MEAN	59.22	45.18	36.74	26.44	15.44	12.49	10.35	5.75	5.07	4.01	3.88	4.21	3.90	3.94											4.59	16.65	11.15		1.48
19	5	PB6007	2	35.69	29.36	25.55	19.27	13.85	11.03	8.82	5.17	4.72	3.82	3.61	2.81	3.63	3.94											4.00	9.84	6.90		1.43
20	5	S PB6006	2	69.48	55.17	45.26	34.18	20.78	16.90	13.73	8.62	7.35	6.07	6.02	5.62	5.65	5.25											6.67	12.31	8.06		1.53
5	5	MEAN	MEAN	52.59	42.27	35.40	26.72	17.32	13.97	11.27	6.90	6.04	4.94	4.82	4.21	4.64	4.59											5.33	11.07	7.48		1.48
21	7	PB328	17	37.87	26.85	21.17	15.33	8.66	7.01	5.56	1.72	1.84	1.35	1.20	1.40	1.21	1.57											1.33	31.31	21.97		1.43
22	7	PB329	17	34.06	24.03	18.25	13.64	7.79	6.32	4.90	3.45	1.84	1.24	1.20	1.40	1.21	1.57											1.33	28.16	9.88		2.85
7	7	MEAN	MEAN	35.97	25.44	19.71	14.49	8.23	6.67	5.23	2.59	1.84	1.29	1.20	1.40	1.21	1.57											1.33	29.73	15.92		2.14
23	9	PB322C	16	43.05	32.39	25.55	18.85	10.82	8.62	7.19	3.45	3.15	2.25	2.41	1.40	2.42	2.36											2.22	17.79	12.49		1.43
24	9	PB3240	16	43.05	29.99	22.63	15.75	8.23	5.98	5.23	3.45	2.10	1.80	2.01	1.40	1.61	1.57											1.78	26.69	12.49		2.14
9	9	MEAN	MEAN	43.05	31.19	24.09	17.30	9.52	7.30	6.21	3.45	2.62	2.02	2.21	1.40	2.02	1.97											2.00	22.24	12.49		1.78
25	10	PB412	K	37.60	30.62	25.55	19.41	12.12	10.23	7.84	3.45	2.89	1.91	2.01	1.40	2.02	2.10											1.78	18.65	10.90		1.71
26	10	PB6015	K-GC	33.51	25.29	21.90	16.32	9.96	8.28	7.19	3.45	2.36	2.02	2.01	1.40	2.02	1.84											2.22	16.62	9.72		1.71
10	10	MEAN	MEAN	35.56	27.95	23.72	17.86	11.04	9.25	7.52	3.45	2.62	1.97	2.01	1.40	2.02	1.97											2.00	17.64	10.1		1.71

The source for sedimentary samples comes both from outcrop sections and drill core sections. The samples were chosen because each has a corresponding thin section and a complete petrographic description including point counts. Thus, for each of these geochemical samples, the REE chemistry can be interpreted in terms of petrographic constraints and criteria. Another criterion is that each of the 10 recognized depositional environments should be represented by several geochemical samples. Thus, it is possible to classify, interpret and compare the REE characteristics of each depositional environment. This type of data is critical for the following reasons:

- 1) to interpret a provenance for the sediments
- 2) to support a provenance postulated by petrographic evidence,
- 3) to contradict a provenance postulated by petrographic evidence
- 4) to help establish an overall tectonic setting that explains the geochemical, petrologic and lithostratigraphic relationships between the various sedimentary lithologies and how these relate to their associated volcanic, plutonic, and basement rocks. Some of these source rocks may have been entirely eroded, so that the sediments represent the only record of their existence.

Locations for all samples are listed by measured section (MS) in Appendix 8 and location map (Figure 4.1). Most groups represent closely spaced sampling except Environment #1, which comprises samples from drill core to the west of the Kidd Creek Mine, and another sample from the east end of the sedimentary basin in Evelyn Township.

REE abundance can be neatly summarized (Table 4.1) by total REE (TREE), slope of the total REE curve (La/Yb ratio), the slope of the Light Rare Earth (LREE) portion of the curve (La/Tb ratio), and the slope of the Heavy Rare Earth (HREE) portion of the curve (Tb/Yb ratio). The slope of the

Figure 4.2 Comparison of Rare Earth Element Analyses from sedimentary rocks of the Archean Abitibi Greenstone belt, Timmins, Ontario
Chondrite normalized values are listed in Table 4.1.

REE curve ($\text{La}/\text{Yb}_\text{N}$ ratios) show a range of 5-22 (Figure 4.2) for group 1 (Hoyle Fm. of the Porcupine Group), 5-7 for group 2 (Beatty Fm. of the Porcupine Group), 8-9 for group 2S (shales from the Beatty Fm.), 1-25 for Group 3 (Whitney Fm. of the Tisdale Group), 13-23 for Group 4 (Three Nations Lake Fm. of the Pamour Group), 9-10 for Group 5 (Dome Fm. of the Pamour Group), 12-13 for Group 5S (shales from the Dome Fm.), 28-32 for Group 7 (fluvial conglomerates from the Dome Fm. of the Pamour Group), 17-27 for Group 9 (gravel bar conglomerates from the Three Nations Lake Fm. of the Pamour Group), and 16-19 for Group 10 (volcaniclastic detritus from the Krist Fm. of the Tisdale Group). Likewise, there is a considerable range in LREE, HREE slopes and total REE abundances within each group and between each group (Table 4.2), and therefore, mean REE values (calculated) for each of the different depositional environments are listed in part C of Table 4.1 and plotted in Figures 4.2 and 4.3. The highest and lowest $\text{La}/\text{Yb}_\text{N}$ ratios belong to groups 7 and 1 respectively, whereas LREE fractionation is greatest in Group 7 and least in Group 3. In terms of HREE fractionation, all groups are similar, but Group 7 indicates the greatest HREE depletion, because it shows the greatest slope. No curves show any europium depletion or enrichment, a feature that is characteristic for most Archean sedimentary rocks.

Groups 2, 2S, and 5S have the greatest abundance of total REE, because most of the lithologies from these depositional environments consist of mudstones, or in the case of #2, fine-grained turbiditic sandstones. As documented elsewhere in the REE literature (McLennan and Taylor, 1985), the finer-grained sediments commonly contain a higher total abundance of REE than associated coarse-grained sedimentary detritus.

Figure 4.3 Comparison of Rare Earth Element ratios for sedimentary rocks of the Archean Abitibi Greenstone belt, Timmins, Ontario, key ratios. Chondrite normalized values are listed in Table 4.1.

A comparison of Th/U ratios from all depositional environments shows a narrow range of low values (3-4). Only environment #1, which has a much higher ratio of > 8 , is substantially different. For some unknown reason, Environment#1 appears to contain substantially more Th than all other depositional environments.

A comparison of REE data from the sedimentary rocks of the Timmins area normalized against PAAS (post-Archean Australian Shales) (Figure 4.4) and NASC (North American Shale Composite) (Figure 4.5) show several important features. All ten depositional environments of the Timmins suite illustrate a large peak corresponding to a surplus of Eu in comparison to the standard; the latter have the pronounced Eu depletion that is typical of all post-Archean rocks. The maximum enrichment of Eu corresponds to 100-160% of the standard values. By comparison to PAAS or NASC, the Archean sedimentary suite shows overall depletion of 80 to 30% in total REE (TREE), and a slight depletion of HREE relative to LREE. The latter is illustrated by the slight negative slope of each curve towards Yb. These fractionation trends show that members of the Archean sedimentary suite are more fractionated than PAAS, which in turn are more fractionated than NASC.

Interpretation

The lack of a Eu anomaly in the REE signature of the Archean sedimentary suite suggests that the fractionation of plagioclase was not an important process in the igneous history of the provenance terrane. In other words, shallow crustal processes were not important mechanisms during the petrogenesis of these rocks. The lack of shallow crustal differentiation suggests that many of these rocks were derived from the mantle. Obvious differences exist between the REE

Figure 4.4 Comparison of Rare Earth Element Analyses for sedimentary rocks of the Archean Abitibi Greenstone belt, Timmins, Ontario, and standard values from Post Archean Australian Shale (PAAS).

Figure 4.5 Comparison of Rare Earth Element Analyses from sedimentary rocks of Archean Abitibi Greenstone belt, Timmins, Ontario, and standard values from North American Shale Composite (NASC): all Paleozoic in age.

signatures of Archean sedimentary suites from the Timmins area compared to post-Archean sedimentary suites represented by PAAS and NASC. Increased fractionation of REE and HREE either suggests that felsic volcanics or chemically similar tonalites represent the main provenance for these Archean sediments. The lower abundance of total REE content in these sediments also suggests that the source may represent an area with both depleted REE and depleted HREE. The depletion of HREE was probably caused by the fractionation of garnet before or during the initial formation of the igneous rocks in the provenance area.

Discussion and Conclusions

Previous work by Feng and Kerrich (1990) and Feng (1992) produced several REE analyses for some sedimentary rocks of the Timmins region as part of a larger regional study of the entire Abitibi Greenstone Belt and the adjacent Pontiac Subprovince. Results from this work are plotted in Figure 4.6; the 5 curves represent mean values from a total of 18 REE analyses taken from 5 sample locations. In general, the results are similar to those described above. The slope of the REE curves are about the same, but some of the REE abundances are slightly higher for data cited in Feng and Kerrich (1990). Some of these higher values can be mainly attributed to the sampling of shales in at least two of the 5 locations. Variability in total REE abundance of both the Beatty Formation and Dome Formation probably occurs because each formation was sampled at two different and widely separated locations. Thus, data from these formations represent 4 of the 5 sampling locations in the Timmins area.

Feng and Kerrich (1990) identified the sedimentary rocks in the Timmins suite as part of a LMEP suite (low mafic element population), which contains

Figure 4.6 Comparison of Rare Earth Element Analyses for sedimentary rocks of the Archean Abitibi Greenstone belt, Timmins, Ontario, and values from Feng and Kerrich, (1990): Chondrite normalized values.

<5% MgO, and has a mixed provenance of felsic and lesser mafic rocks. The proposed mixture is 75% felsic and 25% mafic end members. These data were derived by Feng and Kerrich (1990) using standard felsic and mafic end members of an Archean bimodal volcanic suite and a standard mixing model (Taylor and McLennan, 1985). The same type of analysis was completed by the author on data reported in Table 4.1. This type of analysis involves generating a series of mixing lines that represent a total spectrum between the two end members at 10% increments: from 90% felsic, 10% mafic to 90% mafic, 10% felsic and including the two standard end members of 100% felsic volcanic and the other with 100% mafic volcanic (Figure 4.7). The total REE slope, LREE slope, and HREE slope of each mixing line are respectively represented by the La/Yb, La/Tb, and Tb/Yb ratios for that particular felsic:mafic combination. A comparison of these standard ratios and total REE abundances to similar data from Timmins (Figure 4.8), facilitates classification of the Timmins REE data in terms of the percentage of felsic volcanic versus mafic volcanic detritus in a particular sample (Table 4.2). The REE pattern for sediments derived from two standard end members should lie somewhere between the upper line representing felsic volcanics, and the lower line representing mafic volcanics. A comparison of all parameters except total REE abundance (Table 4.2) is internally consistent: the REE slope, the LREE slope, and to a lesser extent the HREE slope, all predict a similar proportion of felsic to mafic volcanics for the provenance terrane. The average calculated value for all ten depositional environments (Mean total FV source or R#1) in Table 4.2 is 95% standard felsic volcanic end member and 5% mafic volcanic end member. On further examination of the data, the tabulated values from the mixing model also indicate that some predicted values are greater than 100% of the standard felsic volcanic end member, particularly in depositional environments # 4, 7, 9, and 10.

Figure 4.7 Comparison of Rare Earth Element Analyses from sedimentary rocks of the Archean Abitibi Greenstone belt, Timmins, Ontario, using standard values from a mixing model by Taylor and McLennan (1985): Chondrite normalized values are listed in Table 4.2

Figure 4.8 Comparison of Rare Earth Element ratios for sedimentary rocks of the Archean Abitibi Greenstone belt, Timmins, Ontario, key ratios. Chondrite normalized values are listed in Table 4.1.

Table 4.2 Comparison of Rare Earth Element Analyses for sedimentary rocks of the Archean Abitibi Greenstone belt, Timmins, Ontario, and standard values from mixing model: Chondrite normalized values are plotted in Figures 4.1 and 4.7.

type		La/Yb N	La/Tb N	Tb/Yb N	total REE	
MVLC	standard	1.00	1.01	0.99	38.94	
FVLC	standard	16.67	9.75	1.71	172.44	
MUDSTONE	archean	6.76	5.55	1.22	104.92	
MIXING						STANDARD VALUES
FV100		16.67	9.75	1.71	172.44	taken from Taylor and McLennan,
FV90		14.22	8.90	1.60	159.09	-1985
FV80		12.06	8.05	1.50	145.74	
FV70		10.14	7.19	1.41	132.39	
FV60		8.42	6.32	1.33	119.04	
FV50		6.88	5.45	1.26	105.69	
FV40		5.48	4.57	1.20	92.34	
FV30		4.21	3.69	1.14	78.99	
FV20		3.04	2.80	1.09	65.64	
FV10		1.98	1.91	1.04	52.29	
MV100		1.00	1.01	0.99	38.94	TNL=Three Nations Lake
		La/Yb N	La/Tb N	Tb/Yb N	total REE	Th/U
		ACTUAL VALUES -TIMMINS DATA				
	E#1	5.56	7.85	1.39	83.91	8.25
	E#2	14.08	6.83	1.88	128.26	3.71
	E#3	11.45	5.85	1.67	57.21	3.78
	E#4	16.65	11.15	1.48	93.55	3.85
	E#5	9.84	6.90	1.43	69.75	3.23
	E#7	29.73	15.92	2.14	56.31	3.98
	E#9	22.24	12.49	1.78	68.54	3.53
	E#10	17.64	10.31	1.71	63.91	3.82
	E#2 S	8.78	5.93	1.58	130.06	3.73
	E#5 S	12.31	8.06	1.53	126.41	3.67
COMPARISON TIMMINS DATA TO STANDARDS: IN PERCENTILE OF FV FROM MIXING CURVE						
	1 G1M	95	93	94	41	MEAN TOTAL FV SOURCE
	2 G2M	70	68	87	50	MEAN NORMAL FV SOURCE
	2 E1	40	80	70	40	
	2 E2	90	70	110	70	
	2 E3	80	50	100	20	
	2 E5	70	70	70	30	
	2 E2S	60	60	90	70	
	2 E5S	80	80	80	70	
	3 G3M	133	130	105	28	MEAN FRAC FV SOURCE
	3 E4	100	120	80	40	
	3 E7	180	160	130	20	
	3 E9	140	130	110	30	
	3 E10	110	110	100	20	
TYPE	E#	La/Yb N	La/Tb N	Tb/Yb N	total REE	
		%FV	%FV	%FV	%FV	
						FRAC=FRACTIONATED
						GM1=GROUP 1 MEAN

When the data are grouped on this basis, it suggests that there are two data subsets, one with felsic volcanic components >100% and the other <100%. The average value for the more fractionated (FV) felsic volcanics, is 130% (data set R#3), whereas the average for the other data group (R#2) is 70%. Depositional environments, which represent deep-water sedimentation (data set R#2) regardless of their relative age, have a provenance that contains 30% mafic volcanics and 70% felsic volcanics; the total felsic volcanic component is substantially less than the average for all 10 environments (data set R#1), or for sediments that have a fractionated felsic volcanic source (data set R#3). Some REE values from the sediments actually exceed the upper line, suggesting that another felsic volcanic rock type, which had a steeper REE slope and a greater abundance of rare earths, makes up the main part of the provenance. This feature is especially true for depositional environments #4, 7, and 9, which all represent relatively shallow-water sedimentary facies of the youngest sedimentary group in the region, namely the Pamour Group. Environment #10, which represents shallow-water deposition of volcanoclastic rocks from the Krist Formation (Tisdale Group), is also a member of this data set.

Total REE abundances of sediments (TREE) are lower than the values predicted by the mixing model using the standard end member for felsic volcanics. The source region therefore must have consisted of a felsic volcanic component that was already depleted in HREE, and in total REE, relative to the standard felsic-volcanic end member. Based on the mixing model and total REE values, sediments from E#3- Whitney Formation and E#10-Krist Formation, contained the lowest proportion of felsic volcanics at 30% and 20%, respectively. These parameters support a symsedimentary model for the Whitney Formation, where large volumes of mafic volcanics provided the principal source, and any

felsic source (either volcanics or tonalites) was far removed from the depositional basin. Similar data for the Krist Formation, however, must be treated in a different manner, because these rocks mainly represent primary volcanic detritus that has undergone only slight modification during and after deposition. The low proportion of inferred felsic-volcanic end member emphasizes the depletion of both HREE and total REE in these volcanic-volcaniclastic sediments. Thus, the Krist Formation probably erupted from a magma chamber that was already depleted in both HREE and total REE.

A comparison of total REE abundances (TREE) between shales and sandstones in similar depositional environments such as 2 and 2S and 5 and 5S, shows that the shape and slope of the REE curves are similar, but that the abundance of REE is always greater in the shales. This is similar to data published by Feng and Kerrich (1990), and Taylor and McLennan, (1985), and illustrates the general affinity of REE for clay minerals versus coarser-grained detritus. In fact, the sedimentary rocks with the coarsest detritus, namely #7 and #9 also show the most fractionated HREE curve and the lowest abundance of both HREE and total REE (TREE).

In all ten depositional environments, similarities in the slope and shape of REE curves suggests that a common hinterland must have been large and exposed for 30-40 MY. This figure represents the minimum time-span from 2710 Ma to 2670 Ma, a period spanning sedimentary deposition from the base of the Whitney Formation, Tisdale Group to the top of the Pamour Group. Because this hinterland appears to have been the main source of detritus, it implies that an accretionary prism is an unlikely part of any realistic tectonic-depositional model for the Timmins basin. A lack of similarity between REE signatures of sediments from most Paleozoic back-arc or island-arc basins to the Timmins data also

suggests that the latter does not represent an island arc basin. A lack of andesite and other calc-alkalic volcanics in the Timmins region likewise makes a continental arc (fore arc) depositional basin analogous to the Great Valley Sequence of California unlikely.

The hinterland was on average providing approximately 70% to 95% felsic components, compared to only 5-30 % mafic volcanic detritus. The high volume of felsic component suggests that a large continental mass was contributing a substantial volume of detritus to the depositional basins. Rock sequences similar to the Minnesota River Valley gneiss (> 3.0 Ga) or Opatica gneiss (2.8 Ga) are the only candidates for such an older craton. A less likely explanation involves eroding large volumes of felsic volcanic rock of calc-alkaline affinity from the hinterland regions and depositing the detritus into these basins. The source of these volcanics is largely unknown, because the Kidd-Munro volcanics, which represent an older source region, are tholeiitic rather than calc-alkaline. The Blake River Group, 100-200 km to the east in the Kirkland Lake -Noranda region, represents the nearest exposed mass of calc-alkaline volcanics. Another large source area of felsic volcanic rocks proposed by Feng (1992) is the Baby Group Volcanics near Val d'Or. These felsic rocks, which have large negative Eu-anomalies ($\text{Eu}/\text{Eu}^* = 0.77$), are the likely source for sedimentary rocks of the Pontiac Subprovince. Model Nd ages for the Pontiac and LMEP sediments, according to Feng (1992), suggest that the Pontiac sediments show older model ages and provenance from a continental source, whereas the LMEP sediments have younger model ages and represent a mixture of younger and older crustal sources (3 Ga). Although detrital zircon ages for the Pontiac are grossly similar to sediments of the Pamour Group of the Timmins area, the latter represent weakly metamorphosed rocks, whereas the former are high-grade

metasedimentary gneiss with a complex tectonic history; superficial comparisons between the two groups are difficult.

In the Timmins area, the Krist Formation and other equivalent formations of this type may provide an alternative source for felsic rocks, but the total REE content of these calc-alkaline rocks is too low to provide the REE abundances that are characteristic of the sedimentary rocks in the Abitibi Greenstone Belt. Other problems related to this hypothesis include the petrographic evidence (discussed in a previous section of the text), which suggests that the Krist Formation contains insufficient quartz phenocrysts and polycrystalline quartz to meet the minimum sedimentary criteria for any of the sedimentary units, except perhaps the Hoyle Formation of the Porcupine Group. The sediments from the Timmins area also lack the large volumes of volcanic-lithic detritus that typically occur in basins associated with continental arcs.

Thus, the most attractive alternative remains a continental provenance for the bulk of the detritus in these sedimentary basins. Petrologic evidence presented and discussed elsewhere in the text tends to support this hypothesis. A large proportion of continental detritus generally suggests a continental tectonic setting, perhaps a rift-type setting, or a typical continental basin such as a pull-apart basin (also see Figure 5.4) containing only minor mafic volcanic (oceanic) detritus. The stratigraphic and sedimentologic framework for a pull-apart basin include several key provenance features such as mismatched source regions and depositional basin (Thurston and Chivers, 1990). In fact, most of the sediments were not derived from their nearby volcanic rocks. These sediments probably do not represent an accretionary prism, but more likely represent a continental source that is either not presently exposed, or was entirely eroded. Most stratigraphic relationships and sedimentological evidence support such a

depositional environment in close proximity to major structural intraplate boundaries such as the Porcupine-Destor Deformation Zone in the Timmins area. Mueller and Donaldson (1992) proposed a similar depositional setting along the Porcupine-Destor Fault for the Duparquet Basin in Quebec. Using geochemical evidence as the criterion, Feng (1992) also suggested that strike-slip faults moved sedimentary terranes to their present localities, adjacent to juvenile arc complexes such as the Abitibi or Wabigoon greenstone belts. However, as previously discussed, the juvenile prism model does not accommodate some of the current petrological and geochemical evidence. Feng (1992) and many other researchers have indicated that the geochemical data derived from the sediments support the existence of much older continental crust elsewhere during development of the Archean Abitibi greenstone belt. These older terranes were probably located to the south, and were overridden by the Grenville Province at about 1 Ga.

Evidence for or against a pull-apart model is largely manifest in the basin fill of these small basins; a detailed discussion is given in chapter 2. Unfortunately, a true comparison with Phanerozoic pull-apart basins is difficult for a number of reasons. Archean basins should better define time factors, which would in turn define: basin age, sedimentation rates, subsidence rates, and the relative ages for strata, as well as determining whether unconformities are diachronous or synchronous. Because of poorly constrained time factors, most comparisons are on a macroscopic scale (Thurston and Chivers, 1990). For example, it is difficult to prove that depocenters migrated in opposite directions without having a better control on the age of the sedimentary strata. The same problem occurs when comparing stratigraphic sections from one pull apart basin to the next. How can correlative strata be recognized when relative ages of the

strata are largely unknown? Basin analyses of the Timiskaming strata (Pamour Group) have so far produced only a few reliable paleocurrent measurements, and only sparse data on basin geometry. By contrast, basin analysis of the Tertiary-age Ridge Basin (Ingersoll, 1988), the proto-type for pull-apart basins, has provided diverse paleocurrent patterns that point towards migrating depocenters within the pull-apart basin.

CHAPTER 5: SUMMARY AND CONCLUSIONS

OVERVIEW OF BASIN ANALYSIS

Basin analysis techniques have been applied to numerous Precambrian sedimentary basins with various degrees of success. The absence or scarcity of recognizable ocean crust (ophiolites) and continental crust (basement) in Archean sequences presents some basic problems that affect direct comparison of Archean and Phanerozoic strata. Archean basins have yielded less quantitative data, because most are more structurally complex than Phanerozoic basins of the same type. Comparisons with Phanerozoic basins can be made mainly on a macroscopic scale, utilizing interpretations based on lithofacies mapping, and possibly within a crude sequence-stratigraphic framework. Most actualistic depositional models, based on plate tectonic processes, can be applied to Precambrian sedimentary sequences. The models, however, must be more cautiously applied when dealing with Archean strata than with Proterozoic strata. These comparisons show that many similarities, but only a few differences, exist between sedimentary sequences, basin-forming processes and plate tectonics in the Precambrian and those in the Phanerozoic. Most of the differences can be explained by evolutionary processes during the Archean. Accordingly, Precambrian basins can be grouped into one of three plate-tectonic settings, namely, divergent margins, convergent margins and transform margins (or strike-slip motion). Each has a distinctive and diagnostic sedimentary package, which is a record of protracted tectonism, uplift and erosion. Thus, identifying and interpreting the nature of the sedimentary basin fill is the key to erecting a well constrained tectonic and depositional model that explains the evolution of the Abitibi Greenstone belt in the Timmins area for the

period beginning with the termination of volcanism and ending with the deposition of the youngest beds in the youngest stratigraphic unit.

Lithofacies mapping utilizing 14 km of section, in conjunction with the recognition of unconformable relationships, are the main methods of basin analysis for most of the sedimentary strata of the Abitibi Greenstone belt in the Timmins area. To facilitate the recognition of lithofacies and larger sedimentary cycles, detailed descriptions of some sedimentary parameters, such as bedding thickness and the percentage of mudstone beds, have provided the basis for classification into four different types. This approach, which is particularly valid for turbiditic sandstones, makes for an easier interpretation of the depositional environment within any turbidite fan model.

Turbiditic sandstones of Archean age can be best compared to the deep-sea fan model of Mutti and Ricci Lucchi (1972), where facies A to G represent specific areas on the deep sea fan (Figure 1.2). Some sub-facies have been added to this nomenclature, namely facies D_a and D_o, which refer to Facies D from the abyssal plain, and Facies D from the outer fan, respectively. This model is preferable to more recent refined models which require detail which is not readily determined from most highly deformed Archean terranes. The fan model of Mutti and Ricci Lucchi (1972), specifically developed from ancient active margin fans (convergent margins) allows a range of interpretation. If the model is a submarine fan with a point source (Figure 1.2), then stratigraphic differences can be attributed to a series of facies shifts of that single fan throughout the basin.

Interpretation stemming from facies shifts within either a multiple source (Figure 1.3A) ramp (Barrett and Fralick, 1989), or a slope apron (Figure 1.3B) from a linear-source (Reading and Richards, 1994), differ from that of a point source fan, because there is more than one source for detritus to enter the basin. A poor correlation of strata, together with a poor understanding of the

three-dimensional characteristics of these turbidite systems, means that as a first estimation, the simplest model, namely the submarine fan from a point source, is probably the most appropriate. The other models could be valid, but data to support them are either scarce or ambiguous. However, inferred rapid and extremely frequent progradations of inner fan deposits in the Timmins area support a multiple source ramp (Figure 1.3) as a more realistic model for many of the turbidite deposits within all of the formations, except perhaps the Beatty Formation.

Most sedimentary sections commonly show thinning- and fining-up patterns on a local scale as well as on a larger scale. The scarcity of coarsening- and thickening-up cycles indicates that "distinct positive megasequences" shown by fining and thinning trends, predominate over "distinct negative megasequences". Both terms were defined by Mutti and Ricci Lucchi (1972), with the former indicating the filling of a submarine channel typical of the inner fan zone, and the latter indicating progradation of proximal facies over more distal facies, which is typical of the outer fan environment.

NATURE OF THE SEDIMENTARY BASIN FILL

The following revisions of stratigraphic nomenclature are proposed: The name Pamour Group (new name) identifies the Group that contains the youngest rocks in the area, namely the Dome Formation and overlying Three Nations Formation, which both occur in a narrow strip to the south of the Porcupine Destor Fault (Figure 5.1). Both of these formations have been subdivided into three members, namely A, B, and C (Table 1.1).

The Porcupine Group was previously named, but is here redefined as consisting of the Beatty Formation and the Hoyle Formation. The latter

Figure 5.1 General geology and synopsis for the sedimentary strata of the Abitibi greenstone belt, Timmins, Ont.

formation underlies much of the sedimentary basin to the north of the Porcupine-Destor Fault, whereas the former occurs only in the Porcupine syncline. The Hoyle Formation has been subdivided into three members, namely A, B, and C, whereas the Beatty Formation remains unsubdivided.

The Tisdale Group, which formerly consisted only of volcanic rocks, has been redefined to include the Krist Formation as its youngest unit, underlain by pillowed mafic volcanic flows which are in part intercalated with, and underlain by, sedimentary rocks of the Whitney Formation. The redefined Tisdale Group now represents a mainly volcanic package with a minor sedimentary component (Whitney Formation) in its upper part, and a fragmental, intermediate to felsic volcanic unit at the top (Krist Formation). The Whitney Formation, which consists of Members A, B, and C, represents pre- and syn-volcanic sedimentation before deposition of the Krist Formation, which in turn represents the final volcanic activity of the Abitibi Greenstone Belt in the Timmins area. The stratigraphic section from the base of the Whitney Formation to the top of the Krist Formation thus contains evidence for the termination of volcanism. This important characteristic may in fact signal a terminal collision or docking of two or more plate-tectonic regimes, and represents a significant event in the tectonic history of the Abitibi Greenstone Belt in the Timmins area.

Inferred depositional environments for the Whitney Formation of the Tisdale Group range from epiclastic to pyroclastic to volcanic flows. The range of depositional environments varied from deep water turbiditic to fluvial, and possibly included shallow marine environments. Some of the pyroclastics may represent subaerial volcanics, because they are intercalated with trough cross-bedded arkoses and conglomerates of typical fluvial facies. These conglomerates

indicate that paleocurrent flow was mainly to the northeast(Figure 2.38), . The occurrence of the fluvial facies, as well as volcanics and pyroclastics together with epiclastic rocks, appears to be more common along the eastern edge of the Whitney Formation near Nighthawk Lake. This facies arrangement suggests that the deepest part of the basin was to the west. Unfortunately, no paleocurrent data were available from any turbidites of the Whitney Formation to confirm westward transport.

In summary, the Whitney Formation represents a pre- to syn-volcanic sedimentary sequence, which has 100-200m of turbidites underlying mafic volcanic flows at one location. The total thickness of the original and undeformed Whitney Formation is, however, difficult to estimate because of fold repetition of shallow dipping strata near Nighthawk Lake: a 1000m thickness is postulated, but may be as thin as 200m.

Distribution of the various turbidite facies throughout the Whitney Formation suggests that Facies C, D and B ((Mutti and Ricci Lucchi (1972) occur in that order of abundance; thus, inner fan, mid fan, outer fan, abyssal plain and possibly slope facies have been identified. Progradation and regression of the inner fan facies is documented in many of the sections. Repetition of this facies shift in the vertical dimension suggests that several channel migrations are recorded in the sedimentary sequence of the Whitney Formation. However, no conglomeratic inner fan deposits (Facies A) have been identified within this formation. An alternative explanation for the repeated progradations of inner fan deposits over a relatively narrow stratigraphic interval, is that these units represent inner fan deposits from several different fans (i.e. a multiple source or ramp model for turbidite fans). In other words, the source was not from a single fan.

Sedimentary rocks from the Beatty Formation of the Porcupine Group, which occur only in the Porcupine syncline (Tisdale Township), directly overlie a volcanoclastic-pyroclastic unit known as the Krist Formation. As such they represent the first major sedimentary unit that was formed after the cessation of volcanism (post volcanic) and the first sedimentary unit of the deep-water turbidite basin. The upper contact of the formation is an angular unconformity with the overlying Dome Formation.

Turbidites represent the only depositional environment of the Beatty Formation. A variety of lithofacies has been identified, namely, inner fan, mid fan, outer fan, slope and abyssal plain.

Most lithofacies represent inner fan deposits dominated by Facies B with several, thin intervals of Facies C typical of mid-fan deposits. Along the northwestern margin of the formation, an upward transition of Facies A, C, D₀ and C is suggestive of channel abandonment with time, and a subsequent but minor progradation of a mid fan facies over deep-water sediments of the abyssal plain. The youngest strata of the formation were generally deposited in distal and quiet water environments representative of either the abyssal plain or the outer fan.

The occurrence of conglomerates representative of Facies A demonstrates that this area was the most proximal of all inner fan deposits within the Beatty Formation.

The predominance of thinning- and fining-up patterns, at least on a local scale, suggests that the turbidite sequences are mainly characterized by positive megasequences, which either indicate channel abandonment, or the filling of a submarine channel on a local scale.

Member A of the Hoyle Formation (Porcupine Group) occurs along the western margin of the basin, west of Kidd Township. It consists of a 430m thick package of sediments, which are intercalated with lesser volcanic rocks in the upper parts. The lower sequence, which is a stratigraphic package of 124m, consists of graphitic mudstones (Figure 2.14) of abyssal plain deposits (Facies D_a), with minor incised sandy turbidite (Facies B) and conglomerate (Facies A) channels. The middle sequence mainly consists of Facies D_o and D_a, which are characteristic of abyssal plain and outer fan deposits with some inner fan (Facies B) and mid fan deposits (Facies C) at the base and the top of this 136m sequence.

Mafic volcanic flows and intercalated conglomerates, which are representative of proximal inner fan deposits, define the unique characteristics of the upper sequence (Figure 2.15). Facies shifts in the sections show that the lower sequence had a few progradations of inner fan facies over abyssal plain sediments, but these represent minor episodes. Only mid-fan facies prograded over the abyssal plain and outer fan facies in the middle sequence, whereas inner fan facies of the proximal type dominate the upper sequence, indicating major progradation of a submarine channel. Most conglomerates probably represent debris flow units with a mud matrix and large sedimentary and mafic volcanic clasts up to 8 cm. These proximal inner fan deposits, which contain such large clasts, could represent channels close to their source. The middle and lower sequences of Member A largely consist of abyssal plain and outer fan deposits, Facies D_a and D_o, respectively. The presence of a substantial thickness of graphitic mudstones in the lower unit distinguishes it from either of the overlying sequences.

The various spatial and temporal relationships suggest that the entire composite section, and by definition Member A, represents a pre-to syn-volcanic

epiclastic sequence of substantial thickness. The age of the volcanics is unknown, but believed to be approximately 2715-2700 Ma on the basis of similarity to volcanics from the Tisdale Group.

Member B of the Hoyle Formation occurs along the western margin of the sedimentary basin. Most lithofacies from Member B and the upper sequence of Member A, represent inner fan deposits dominated by Facies A as well as Facies B, with several thin intervals of Facies C (mid-fan deposits).

East of Murphy Township, the Hoyle Formation consists of turbidites which consistently overly mafic volcanic rocks that are similar to the Tisdale Group. This makes the sequence part of a basin that formed after the cessation of volcanism, presumably after 2.7 Ga. These have been designated as Member C of the Hoyle Formation.

The basal sequence of the Hoyle Formation occurs near the Hoyle Pond Mine (Figures 2.19 and 2.22). It consists of inner fan deposits directly overlying mafic volcanics as in sections H12-09 and 16-12 or, as is in the case for 5 other sections, mudstones and distal deposits directly overlying mafic volcanics. The latter type commonly form the base of coarsening-up and a few thickening-up cycles that are typical of negative megasequences.

Proximal inner fan facies, which are represented by conglomerate, are rare and only occur in one section. This conglomerate does not, however, directly overlie mafic volcanic flows, but occurs some 20m higher in the section. Graphitic mudstones and muddy turbidites, which represent facies D_a and D_o, respectively, are common in the basal sequence of the Hoyle Formation. This occurrence of abundant graphite probably suggests that deposition occurred in a restricted, anoxic environment. In general, a variety of depositional

environments representing various portions of the turbidite fan directly overlie the mafic volcanic substrate.

The middle part of the formation consists of mid fan deposits (Facies C) at the base, inner fan deposits (Facies B) intercalated with mid fan deposits in the middle, and inner fan deposits (Facies B) at the top of a composite section that is 400m thick and near Hoyle Pond (Figures 2.21 and 2.22). In total, four major progradations of inner fan deposits are recorded in this composite section (approximately one for every 100m of the sequence). These probably indicate deposition during major low stands of the deep water basin.

Strata in the Esker Lakes area, which is far removed from the edge of the depositional basin, probably represent the upper parts of the formation. It is difficult to determine the true stratigraphic position, because all strata have undergone folding and deformation. The total composite section from this area, about 400m thick, mainly consists of mid fan deposits near the base (Facies C), outer fan and abyssal plain deposits of Facies D_O and D_a in the middle part, and inner fan deposits (Facies B) in the upper part (Figure 2.25). In fact, such stratigraphic changes suggest that mid fan, outer fan, and inner fan deposits dominate the lower, middle and upper sequences of the Hoyle Formation in the Esker Lakes area: this represent the only example of the upper part of the formation. Inner fan deposits of Facies B, which have prograded over outer fan deposits in both the middle and upper sequences, and over mid fan deposits in both the lower sequence and the upper 60m of the composite section, record a total of 14 progradations within 400m of section. A predominance of inner fan deposits makes this composite section very different from any of the other sedimentary sequences that are directly attributable to the middle of the Hoyle Formation. This also indicates that the depositional conditions at some localities

within the turbidite basin evolved with time from abyssal plain and outer fan deposits to an inner fan system. Again, the high frequency of inner fan deposits suggests that more than one delivery system must have brought detritus into the deep-water basin from the hinterland regions. Thus, the lack of conglomerates representing the most proximal parts of the channel, in spite of abundant inner fan deposits, may be indicative of many feeder systems, none of which formed a major distributary channel system, or delta and submarine canyon system transitional to the deepwater basin. This also suggests a multiple-source fan, rather than a turbidite fan that originated from a single point source.

The Dome Formation (500m thick) of the Pamour Group (Figures 2.1 and 2.3) extends from the Dome Mine in Tisdale Township to and beyond the eastern border of Whitney Township.

Member A, restricted to the basal part of the Dome Formation, occurs in sections MS-1, 12A, 5, 8, and D (Dome). These conglomerate occurrences have been interpreted as alluvial strata because of the coarseness of the detritus (commonly of boulder size), the presence of traction features indicative of stream flow (such as crossbeds and internal scours), the occurrence of coarsening and fining trends in successive beds indicating surging and waning flow so typical of fluvial systems, the absence of interbedded sandstones, and the predominance of clast-supported conglomerates.

Member A, which occurs only along the basal contact and thus constitutes the lower part of the Dome Formation in many places, represents alluvial-fluvial deposition. Elsewhere, Member B or C occupy the basal portion of the Dome Formation, which directly overlies mafic volcanic flows. This may represent transgression or onlap pattern for the younger member (i.e. Members B and C) of the Dome Formation. The absence of Member A along the basal contact reflects

either non-deposition or removal by erosion before the deposition of turbidites (Members B and C).

In terms of the hierarchy of bedforms within alluvial strata (Member A), first-order erosion surfaces representing foresets are enveloped by second-order surfaces representing cosets, which are rarely truncated by third-order surfaces that commonly separate distinctive lithological units. No major bounding (fourth-order) surfaces have been identified. Second-order surfaces (cosets) also separate beds which have opposite directions of transport. The paleocurrent patterns for Member A outline a bimodal and bidirectional pattern, with the main direction to the southwest (Figure 2.38), which is contrary to that of the overlying turbidites of Member B and C, as well as of strata in the overlying Three Nations Formation.

Member B represent turbidites with closely associated conglomerates that either incise the turbidite sequence or represent slope-break conglomerates. Several measured sections, namely MS-2, 3, 6, 10, 13, and the base of MS-4, contain examples of Member B of the Dome Formation.

The internal geometry and spatial elements of these conglomeratic units suggests that they differ from conglomerates which occur in MS-1 and MS-12A, etc. (Member A). Some of these factors include: more sandstone and matrix-supported conglomerate beds, a different style of bedding exemplified by low-angle truncations, unidirectional flow direction from the east, a predominance of reverse-grading in many of the conglomerate beds, a lack of internal scours between the various conglomerate beds, the lack of locally derived sedimentary clasts in the basal conglomerate, the extreme traceability of this conglomeratic unit, the apparent conformable relationship with adjacent stratigraphic units, particularly the overlying sandstones, and finally the overall channelized nature

of this contact which only shows minor scours (10-20 cm) on a local scale.

Member B , which represents deposition of proximal conglomerates from the inner fan regions of a submarine channel (Facies A), generally occurs along the upper contact, and thus constitutes the upper part of the Dome Formation.

These also overlie mafic volcanics at the base of the epiclastic sequence near the Pamour Mine in Whitney Township. Such evidence suggests that a major progradation of turbidite channels occurred in both the lower and upper parts of the formation. The transition from conglomerates of Member B to the overlying arkoses and sandstones of the Three Nations Formation is documented by the changing nature of the conglomerate with time (stratigraphic changes), by the nature of the upper contact, and by facies transitions in the lower strata of the overlying sedimentary unit at MS-2. This basically illustrates a fining-up trend with increasing matrix content in the conglomerates, whereas pebbly sandstones, which represent the basal unit of the overlying unit, grade upwards into pebble-free strata. In total, this transition appears to be gradational and indicative of a subaqueous facies change that cannot be directly attributed to uplift, erosion, and subsequent deposition of the younger unit at this location; Bedding attitudes on both sides of the contact appear to be parallel and concordant.

Member C of the Dome Formation consists of turbidites which do not contain any conglomeratic interbeds. These turbidites directly overlie mafic volcanics in sections Ti 2704, MS-14, and Ti 1373. Elsewhere, turbidites of Member C directly overlie conglomerates of Member A (alluvial facies) in an apparent conformable relationship at MS-5, 8 (Figure 2.31), and 12B. One key section, namely MS-12B , illustrates an unusual occurrence of deepwater turbidites overlying alluvial deposits in an apparent conformable relationship. This contact represents a hiatus between the two contrasting depositional

environments, but there is little physical evidence to support this, except for an erosional scouring at the base of the turbidite sequence.

In order of abundance, Member C mainly consists of turbidites from mid fan deposits (Facies C) interbedded with minor intervals of inner fan (Facies B) and outer fan deposits (Facies D). This member represents greater than 300m of strata from the thickest stratigraphic sections of the Dome Formation (MS-12B), but such lithologies locally occur along the basal contact or the upper contact to the east of Nighthawk Lake. Member C probably represents the middle of the Dome Formation throughout much of the study area.

Another interesting feature is the apparent contradictions displayed by thinning and fining cycles on a local scale (1-3m) in comparison to larger-scale trends. In these stratigraphic sections, this may represent evidence for the predominance of aggradational over progradational processes. In other sections, the small-scale trends are synchronous with the large-scale features, which suggests that progradation was probably more important than aggradation. Although this last example appears to represent the norm, the rare or widespread occurrence of contrary trends may be useful in solving correlation problems related to turbidite systems.

Paleocurrent patterns, based on the direction of flute casts in turbidites of the Dome Formation (Figure 2.38), indicate that the main transport was probably from a continental source in the south, towards the deepest part of the basin, in the north.

Member A of the Three Nations Formation (Pamour Group) consists of fluvial strata characterized by abundant conglomerates of the clast-supported type (Gm or Gcs facies). These occur at several places, including east of Nighthawk Lake in sections Ti 1390, Ti 1391, and MS-17, as well as in PS-18,

about 40 km to the west in Thorneloe Township. These directly overlie turbiditic strata of the Dome Formation, except in the extreme western region (PS -18), where fluvial conglomerates overlie pillowed mafic volcanic rocks.

Member B consists of probable fluvial strata dominated by Gms facies (matrix-supported conglomerates), but does not contain any clast-supported conglomerates (Gm facies), nor show any reverse graded bedding. These strata thus lack features typical of the fluvial strata of Member A, or for that matter, fluvial strata from other formations. Only one section near the eastern edge of the study area, namely MS-16 (Figures 2.50 and 2.51), contains strata from Member B; it probably extends farther to the east (Figure 2.46).

The data from Member B (Figure 2.51), and some from Member A, essentially show that several orders of bedforms and truncation surfaces occur. These are first-, second- and third-order erosional surfaces, in that order of abundance, and in a manner similar to examples described earlier: the higher order surfaces (3rd order) separate the various lithotypes such as pebbly sandstone from conglomerate beds and sandstone beds.

In total, sections MS-2, Ti 1160, 4, 11, 17B, 17C, and 17D contain representative strata from Member C of the Three Nations Formation, which represents anywhere from 400 to 1500m of sedimentary strata. Stratigraphic correlations show that section MS- 17B, 17C, and 17D are stratigraphically similar and represent the upper part of the formation. The middle part of the formation is represented by MS-11 underlain by MS-4, whereas MS-2 and Ti 1160 represent the basal part of the formation. An apparent conformable relationship exists both in a stratigraphic and lateral sense between Member A and Member C, because the former only occurs at some places along the base of the formation.

Cross-bedded sandstones and arkoses interbedded with some minor pebbly sandstone or pebble conglomerates of the Gms variety represent Member C, which constitutes 90% of the strata in the formation. It presumably represents all of the middle and upper parts of the formation, but also conformably overlies turbiditic sandstones of the Dome Formation at several locations, namely MS-2 and 4. Member C has an onlapping and conformable relationship, because the fluvial facies (Members A or B) were never deposited at these locations. One of these sections, namely Ti 1160, contains evidence for a deltaic environment separating definite fluvial strata to the east of section Ti 1160, and the predominant shallow water deposits to the west.

Some of the oldest strata in Member C of the Three Nations Formation, located some 20m above the base of the formation in MS-2, contain no conglomerates, but show a predominant transport from the east, as well as truncation surfaces which outline at least 2 crosscutting relationships that define a 3-fold hierarchy for these bedforms. Progressively younger strata in MS-4, which are about 40m above the base and characteristic of Member C, show a hierarchy of erosional surfaces typified by first, second, third and fourth order surfaces, together with abundant reactivation and mud drapes; the transport was predominantly from the east. Other important features occurring at higher stratigraphic levels include the presence of hummocky cross stratified (HCS) bedforms, tidal bundles, abundant reactivation surfaces, and mud drapes as evidence of sediment reworking by wave action. Conglomerates are interbedded with arkose and pebbly arkose, and show lateral continuity for at least 50m, but in an imbricate, rather than layer cake, stacking. The truncation surfaces display a hierarchy similar to the lower parts of the member, and show three crosscutting relationships that define 4 erosional events, in addition to thin

tidal bundles, which show transport to the east. The dominant flow was westerly, with a weak flow in the opposite direction.

Paleocurrents from the Three Nation Formation (Figure 2.53) largely show a bimodal and bidirectional pattern in a predominant southwest and lesser northeast direction, except for unidirectional patterns to the west for both fluvial units (Members A and B). Some beds in Member C, such as near the base and near the top of the member, indicate unidirectional transport directions, to the southwest and to the west, respectively. If these directions represent longshore currents in a shallow marine basin, then a continental source probably was to the south, with the shoreline probably oriented in a southwest direction.

In all five formations, the thickness of stratigraphic and depositional units in turbidites is similar. These conclusions appear to agree with the physical evidence which shows that turbidite environments occur in practically every formation: in the lower, middle and upper parts of each formation, as well as within various members. However, thinner units in Member C of the Three Nations Formation, which represents shelf or shallow-water depositional conditions, suggests that these lithologies likely represent a different deposit type comparable to fluvial-alluvial strata from other formations. Thus, the data suggest that deposition occurred in shallow water, and that the strata underwent extensive reworking by wave and/or combined current-wave action, producing 3 to 4 generations of truncation surfaces, whereas currents produced only 2 or 3 truncation surfaces within the fluvial strata.

Table 2.7 summarizes many of the stratigraphic relationships; most changes define progradational shifts of proximal facies in all formations, except in the uppermost formation (Three Nations Formation), where Member C conformably overlies Member A. Stratigraphic arrangement of the facies in most

formations (Table 2.7) suggests that the depositional basins became shallow with time, except for the oldest and the youngest sedimentary formations, namely the Whitney Formation and Three Nations Formation, in which the facies arrangements suggest that deepening of the basin occurred during late stages of their depositional history.

A crude comparison to a sequence stratigraphic framework shows that the basal units in the following formations consisted of fluvial strata indicative of low-stand deposits from a probable low-stand systems tract: Whitney, Hoyle, Dome and Three Nations. The base of the Beatty Formation consists of turbidites cut by a conglomeratic fan that probably was a product of low-stand sea-level in a low-stand systems tract. Therefore, many of the definitions and boundaries for the various formations presented herein may also correspond to parasequence boundaries, including some major flooding surfaces.

PROVENANCE

Megascopic modal analyses of conglomerates were completed within measured sections (MS) 1 to 17 (Figure 3.1). Observations were recorded at 43 stations to assess variations in clast lithology, shape and size as well as variations in composition and abundance of the conglomerates for which locations are given in Appendix 1. All conglomerates are part of the Pamour Group (2.68 Ga), the youngest sedimentary package of the Abitibi Greenstone belt in the Timmins area.

The first step in modal analysis was to classify the clasts into 15 rock types easily differentiated in the field. Some clast categories were subsequently combined, with the final total representing 12 rock types, briefly described in terms of their petrographic characteristics: t1(type 1)=Krist; t2=quartz vein; t4=altered mafic volcanics; t5 =variolitic basalts; t7=P1 or Qz-rich porphyry; t8 =mud chips; t9= sedimentary; t10= chert ; t11= unknown; t13=altered ultramafics; t14 =mud chips; t17=P2 or Qz-poor porphyry.

From west to east, parallel to the main transport direction, alluvial-fluvial deposits (Member A-Dome Fm) show a progressive increase in abundance of sedimentary and altered ultramafic clasts, together with a corresponding decrease in altered mafic volcanic and porphyry clasts. An increase in proportion of altered mafic volcanic clasts and a corresponding decrease in altered ultramafic clasts suggests that the predominant source of altered mafic volcanic clasts for the turbidite fans (Member B -Dome Fm) was to the west and decreased in an easterly direction.

The largest clasts in the eastern areas are altered mafic volcanic clasts followed by P1 clasts , whereas chert, and other sedimentary clasts, followed by altered ultramafic clasts, are the largest clasts in the western regions. Mafic

volcanic clasts underwent the least transport in the western regions, whereas most of the sedimentary and ultramafic detritus was derived from a source area to the east (i.e. MS-5 and-17).

Shape data indicate that most clasts have been tectonically modified by varying degrees into tectonic lozenges. An indication of their original shapes is revealed within low strain areas such as MS-1: the original shapes range from subrounded at the base to subangular at the top of the fluvial conglomerate unit (Member A-Dome Fm). A variation of this type, which outlines a decrease in maturity with time (stratigraphic level), can also be an indicator of the onset of renewed tectonism to produce locally derived and hence immature detritus.

The point-count data can be viewed in another manner by combining the various clast types (1-17) into three main rock types, namely volcanic, granitoid and sedimentary (Tables 3.4, 3.5 and Figure 3.3). Changes in the percentage of clast types for both alluvial-fluvial (Member A-Dome Fm) and turbidite fans (Member B-Dome Fm) suggest that the predominant source areas for volcanic rocks was probably to the west, whereas the source area for sedimentary clasts was to the east. By contrast, a relatively constant percentage of granitoid clasts suggests that porphyry bodies were exposed in both regions. Conglomerates from both alluvial-fluvial and turbidite fans show that they have a comparable source; however, gravel bars (Members C-Three Nations Fm) have a different source, because they contain only ultramafic and vein-quartz clasts.

For each of the three depositional environments, any small-scale (local) stratigraphic and lateral trends are identified by changes in the shape, size and lithology of conglomeratic clasts on a local scale i.e. within individual measured sections. This type of information can be missed by large-scale analysis using only amalgamated point counts. In fact, many inferences from the grouped data

are similar to those from the more detailed and closely spaced point counting data, which, however, produces larger counting errors. Thus, these two data sets are complementary, because they basically support the same conclusions.

From an economic standpoint, provenance and alteration studies of different conglomerates provide powerful tools for unraveling the complex geological history of the gold mineralization, even if it was largely controlled by structural factors. Within conglomerates of the Pamour Group, the occurrence of numerous porphyry, vein-quartz and fuchsitic clasts suggests that intrusion of at least some porphyries, quartz veins and associated hydrothermal alteration predate those lode gold veins that were emplaced during the main mineralization event (<2.68 Ga). Only ultramafic and vein-quartz clasts occur within gravel bars that are part of the shelf sequence (Member C of the Three Nations Formation). These results suggest that there is a distinct and different provenance corresponding to alluvial conglomerates from the Whitney, Dome and Three Nations Formations, which differs from provenance of the channel-fill conglomerates of Member B of the Dome Formation, as well as differing from provenance of the gravel bars in Member C of the Three Nations Formation. The latter are hosted within marine sandstones representative of the stable shelf sequence.

The raw point-count data for sandstones from all formations (Appendix 2) can be recalculated in terms of several key and characteristic grain types that are listed in Table 3.7. Plots of such grain types on provenance-discrimination diagrams have been widely used to show relationships between the ratio of grain types and provenance for sandstones in a variety of tectonic settings that may be analogous to the ten depositional environments within the study area. In fact,

several moderately developed trends are outlined by compositional changes in a west to east direction.

The scatter of data on the QFL plot, a generalized plot which combines many grain types, indicates a lack of systematic west to east or stratigraphic variation within any of these depositional environments, but also suggests that for the same deep-water turbidite environment, siltstones are less feldspathic than sandstones. This bulk composition difference may have been partly caused by a different method of deposition, because the siltstones were deposited by a combination of pelagic rainout and turbidite currents, whereas the associated sands were supplied only by turbidity currents.

For QFL and QmFLt diagrams (Figure 3.14), most of the Timmins data indicate that the predominant source area was a complex basement uplift, but a few samples indicate some contribution from deeply eroded volcanic arcs. In general, sediments from the various formations can be separated on the basis of characteristic ratios for the key grain types. All of the older turbiditic sandstones likely have a common source, because they all have a similar composition. Differences in composition between these sandstones and turbiditic sandstones of the younger Dome Formation, which contain more quartz and lithics, indicates a slightly different source. Similarities between various groups, however, show that the shelf sediments and alluvial conglomerates of the Pamour Group have a common source, which was different from that of the turbiditic sandstones of the Dome Formation. Because fan conglomerates and their associated turbidites are dissimilar in composition, the source regions were not the same. Similarities in composition between Dome (Timiskaming) conglomerates and the older turbiditic sandstones, however, suggests that they, not the younger turbidites, have a common source region.

The Krist volcanoclastic (or possibly an older Krist-like unit), could only represent a viable source rock for most of the epiclastic rocks, if processes of erosion, subsequent transport and deposition, increased the quartz content by 10-30 %.

Several plots comparing the percentage of matrix and $Q/Q+F$ ratios, which is also indicative of both compositional and textural maturity, suggest that volcanoclastic rocks of the Krist represent the least mature and reworked detritus, whereas the shelf sediments and associated gravel bars are the most mature and reworked of all of the sedimentary rocks. Sediments of the Porcupine and Tisdale Group are, in general, less mature and less reworked than those of the Pamour Group.

Data from the total polycrystalline quartz (Q_p) plot show that samples from the various depositional environments can be differentiated on the basis of their differing Q_p content (Figure 3.11). Shelf sediments (Member C-Three Nations Formation) and turbiditic sandstones (Members B and C, Dome Formation) of the Pamour Group contain the highest amounts, whereas turbiditic sandstones of the Hoyle and Beatty Formations contain the lowest abundances.

Plots of polycrystalline quartz (Q_p) show a large diversity, including up to 5 types (Q_{p1} to Q_{p5} see Plate 8) of polycrystalline quartz in the Pamour Group, indicating a complex source region. Q_{p3} grains, which probably represent detritus from metamorphic terranes, are equal to or larger than the size of Q_{p1} grains. A nearby source of metamorphic quartz provided detritus to shelf sediments and turbiditic sandstones of the Pamour Group. This source was either not exposed or was at some distance from the basin during deposition of the older sedimentary rocks. A lack of polycrystalline quartz suggests that there

was little quartz of that variety in the source region. Alternatively, it can indicate that quartz had a long residence time in the sedimentary cycle, because polycrystalline quartz will eventually break down to produce monocrystalline quartz.

Qp-Ls-Lv plot (Figure 3.16) indicates that most sediments had a provenance analogous to mixed orogenic sands, which are transitional among arc orogen, subduction complex, collision sutures and fold thrust belts, whereas the probable sources for the youngest sedimentary rocks (Pamour Group), was probably a rifted continental margin or pull apart basin (Figure 5.2). This sketch is for an idealized basin, with most key elements for a pull apart basin along the Porcupine-Destor fault system (Mueller et al, 1992). The important elements are the two master faults, the up thrown and down thrown blocks, shallow water, and the development of numerous fan deltas, and turbidite fans along the margins of the basin. Also note the occurrence of porphyry stocks along the margins of the pull-apart basin, in a manner similar to the spatial relationships in the Timmins area.

Interpretations for a Qp-Ls-Lv plot of Paleozoic data by Mack (1984) suggests that such similar and intermediate compositions probably represent a collision that amalgamated a variety of source rocks into a single orogenic belt. According to the previously discussed polycrystalline quartz plots (Figure 3.13), this source area consisted of low-grade metamorphic rocks. By contrast, the source for most of the older turbiditic sediments is transitional between an arc provenance and a subduction complex, where varied source terranes were tectonically juxtaposed.

Figure 5.2 Depositional model for a pull-apart basin or a modified rift basin.
Archean sedimentary suite of the Abitibi Greenstone belt,
Timmins Ontario.

PROVENANCE INTERPRETED FROM GEOCHEMICAL PARAMETERS

In conjunction with sedimentology, REE (Rare Earth Element) geochemistry is a powerful tool for solving geological problems related to provenance. REE curves for sedimentary strata essentially consist of a series of mixing lines that represent a total spectrum between the two standard end members of 100% felsic volcanic and 100% mafic volcanic. The average calculated value for all ten depositional environments is 95% felsic volcanic and 5% mafic volcanic, but one data subset shows that the deep-water deposits contain 30% mafic volcanic and 70% felsic volcanic, and another data subset shows that the shallow-water and fluvial sediments (Pamour Group) have REE values near 100% felsic volcanic (standard end member), because they were derived from a highly fractionated felsic volcanic (or tonalitic) source.

Similarities in slopes and shapes of the REE curves for all environments suggest that a large source area must have been exposed for 30-40 million years. It also implies that erosion and deposition occurred in a typical continental setting such as a pull apart basin (Figure 5.2), rather than in an accretionary sedimentary basin such as an island arc or a forearc basin. The continental source is not now exposed, and is presumed to have been entirely eroded. Stratigraphic relationships and sedimentological evidence support such a depositional environment in close proximity to major structural intraplate boundaries such as the Porcupine-Destor Deformation Zone in the Timmins area.

SYNOPSIS

REE data in conjunction with compositional data from sandstones support the following interpretations :

- 1) The provenance was predominantly continental.
- 2) Although most of the turbiditic sandstones overlie mafic volcanics, they do not represent an erosional product from this volcanic belt, and hence they do not represent a simple case of accreted terranes, but rather either represent transport by large fluvial systems into the basins, or alternatively, these strata are in their current spatial arrangement (overlying a volcanic substrate) because of obduction involving the thrusting of large slabs of sedimentary strata during mountain building (orogeny).
- 3) A common source region (hinterland) was exposed for a period of approximately 40 MY.
- 4) The source rock was fractionated with respect to HREE (Heavy Rare Earth Elements) and LREE (Light Rare Earth Elements), which is atypical of andesites. In fact the source rocks had a REE signature similar to the Krist Fragmental, but contained a higher total abundance of REE than the latter.
- 5) Because the source is not currently exposed, this region has been either entirely destroyed by erosion, or was consumed and reworked during the Grenville orogeny: The source area probably was south of the present position of the Grenville Front.

Petrographic evidence suggest the following interpretations :

6) Shales and sandstones from the same depositional unit have different compositions, with the shales containing less feldspar. These differences may reflect their mode of deposition (mainly pelagic rainout for the muds, and turbidity currents for the sands).

7) Several key grain types, which are useful for interpreting provenance and likely tectonic setting for each of ten depositional environments, also separate these environments into three main clusters. The fluvial conglomerates do not have the same source as conglomerates associated with the turbiditic fans, nor those conglomerates associated with gravel bars and sandstones from the marine shelf.

8) Data from the polycrystalline quartz (Qp) diagrams show a large diversity of polycrystalline quartz, including up to 5 types in the Pamour Group (Qp1 to Qp5) from a complex source region. A nearby source of metamorphic quartz provided detritus to shelf sediments and turbiditic sandstones of the Pamour Group. This source was either not exposed, or was at some distance from the basin during deposition of the older sedimentary rocks. The various types of polycrystalline quartz grains imply a largely continental source for the Pamour Group, as well as for some of the older strata (e.g. those in the Porcupine and Tisdale Groups).

Implications based on this basin analysis are as follows:

- 9) Evidence in the sedimentary record suggests that these strata were not likely deposited in basins related to an island arc terrane, which represents the petrogenetic interpretation generally accepted in the past for the Abitibi Greenstone Belt.

- 10) The main evidence from the basin analysis suggests that deposition occurred either in a pull-apart basin (Figure 5.2), or in basins related to continental rifting and the eventual production of oceanic crust following the docking of two continental plates, or between oceanic and continental crust to mark a major orogeny at about 2.7 Ga. True comparisons are difficult between Archean transform basins and those of Paleozoic age, because, among other factors, the Archean basins lack well-defined time lines for detailed palinspastic reconstruction. However, on a macroscopic scale (Thurston and Chivers, 1990), many of the comparisons appear to be valid and more convincing than those for any of the alternative depositional settings, including basins adjacent to fore-arcs or island arcs.

REFERENCES

- Abdel-Wahab, A.A., (1992).
Provenance of Bebel El-Zeit sandstones, Gulf of Suez, Egypt. *Sed. Geol.*, vol 75, pp. 241-251
- Aitken, S.A., (1990)
The Pamour One Mine-Site Investigations, Timmins, Ontario;
unpublished M.Sc. thesis, Queen's University, Kingston, Ont. ; 191pp.
- Barrett, T.J., and Fralick, P.W. (1989)
Turbidites and iron formations, Beardmore-Geraldton, Ontario:
applications of a combined ramp/fan to Archean clastic and chemical
sedimentation. *Sediment.*, Vol 36, p. 221-234.
- Bass, M.N., (1961)
Regional tectonics of part of the Canadian Shield; *J. Geol.*, v.69, p.668-702.
- Basu, A., Young, S.W., Suttner, L.J., James, W.C., and Mack, G.H., (1975)
Re-evaluation of the use of undulatory extinction and polycrystallinity
in detrital quartz for provenance interpretation. *Jour. Sed. Petrol.*, vol 45, pp. 873-883.
- Berger, B.R. (1992)
Geology of Hoyle and Gowan townships, District of Cochrane; Ontario
Geological Survey, Open File Report 5833, 99p.
- Bleeker, W., and Parrish, R. (manuscript submitted)
Precise age and life span for Kidd Creek: implications for the formation
of giant VMS deposits and the geology of the Abitibi Greenstone belt.
Canadian Journal of Earth Sciences.
- Burchfiel, B.C., and Royden, L.H. (1988)
Afterword: A general approach to Basin analysis. p. 373-374. IN
Royden, L.H. and Horvath, F., (eds) The Pannonian Basin: A study in
Basin Evolution. AAPG Mem. 45
- Burrows, A.G., (1924)
The Porcupine gold area; accompanied by Map 33a; Ontario Dept.
Mines, Vol 33, pt. 2, p.1-84

- Burwash, E.M., (1896)
Geology of the Nipissing Algoma Line; Ontario Bureau of Mines,
Volume 6, section 5, p.167-84. accompanied by sketch map.
- Corfu, F., Jackson, S.L. and Sutcliffe, R.H. (1991)
U-Pb ages and tectonic significance of late Archean alkalic magmatism
and nonmarine sedimentation: Timiskaming Group southern Abitibi
belt, Ontario. Canadian Journal of Earth Sciences, 28, p. 489-503.
- Dalrymple, R.W. (1992)
Tidal Depositional System. pp. 195-218. IN Walker, R.G., and James ,
N.P. Eds (1992), Facies Models (3rd edition) : response to sea level
change ,Geological Association of Canada, Geoscience Canada Reprint
Series 2, 409 p.
- Dickinson, W.R., (1985)
Provenance and sediment dispersal in relation to Paleotectonics and
Paleogeography of sedimentary basins. IN New Perspectives in Basin
Analysis: Kleinspiel et al editors. p. 3-25.
- Dickinson, W.R., (1982)
Composition of sandstones in circum-Pacific subduction complexes
and Forarc Basins. AAPG Bull., Vol 66, pp 121-137
- Dickinson, W.R., (1970)
Interpreting detrital modes of graywackes and arkoses. J. Sediment.
Petrol., Vol 40, pp 696-707
- Dickinson, W.R., Beard, L.S., Brakenridge, G.R., Erjavec, J.L., Ferguson, R.C.,
Inman, K.F., Knepp, R.A., Lindberg, F.A., Ryberg, P.T., (1983)
Provenance of North American Phanerozoic sandstones in relation to
tectonic setting. Geol. Soc. Amer. Bull., vol. 94, p.222-235.
- Dunbar, W.R., (1948)
Structural realtions of the Porcupine Ore Deposits; p. 442-456 IN
Structural Geology of Canadian Ore Deposits, Can Inst of Mining and
Met. Symposium, 948 pp.
- 1988: Eriksson, K.A., Kidd, S.F., and Krapez, B.
Basin analysis in regionally metamorphosed and deformed Early
Archean terranes: examples from Southern Africa and Western
Australia. IN New Perspectives in Basin Analysis, Kleinspehn, K., and
Paola, C., eds., Springer Verlag, New York, p. 371-404.

- Evans, J.E.L., (1944)
Porphyry of the Porcupine district, Ontario. Geol Soc. Amer. Bull., V.55, p.115-1142.
- Feng, R. (1992)
Tectonic juxtaposition of the Archean Abitibi Greenstone belt and Pontica sub-Province: evidence from geobarometry, geochemistry and Ar-Ar geochronology of metasedimentary rocks and granitoids. Unpublished P.hD. Thesis, University of Saskatchewan, Saskatoon, Sask., 222 pp
- Feng, R. and Kerrick, R., (1990)
Geochemistry of fine-grained clastic sediments in the Archean Abitibi greenstone belt, Canada: implications for provenance and tectonic setting. Geochim. Cosmochim. Acta, vol. 54, p.1061-1081.
- Ferguson, S.A., (1968)
Geology and Ore deposits of Tisdale Township. Ont. Dept. of Mines, Geological Report 58, 172 p. and several maps and sections.
- Girty, G.H., Mossman, B.J., and Pincus, S.D., (1988)
Petrology of Holocene sand, Peninsular Ranges, California and Baja Norte, Mexico: Implications for provenance-discrimination models. Jour. Sed. Petrol., vol 58, pp. 881-887.
- Gray, Matthew, D., (1994)
Multiple Gold Mineralizing Events in the Porcupine Mining District, Timmins Area, Ontario, Canada. Unpublished Ph.d dissertation, Colorado School of Mines, Boulder, Colorado, USA; 211 pp.
- Henderson, P. (1984),
IN Rare Earth Element Geochemistry. Henderson, P. (ed). Elsevier, Amsterdam, 513p.
- Hodgson, C.J., (1983)
The Structure and Geological Development of the Porcupine Camp- A Re-Evaluation; p. 211-224 IN The Geology of Gold in Ontario, edited by A.C. Colvine, Ontario Geological Survey, Miscellaneous Paper 110, 278p.

- Hogg, N., (1950)
The Porcupine Gold Area; Canadian Mining Journal, Nov., 1950, p. 102-106.
- Holmes, T.C., (1944)
Some porphyry-sediment contacts at the Dome mine, Ontario; Econ. Geol., vol 39, p. 133-141
- Houghton, H.F., (1980)
Refined techniques for staining plagioclase and alkali feldspar in thin section. Jour. Sed. Petrol., vol 50, pp. 629-631.
- Howard, J.L., (1993)
The statistics of counting clasts in rudites: a review, with examples from the upper Palaeogene of southern California, USA. Sediment., Vol 40, p. 157-174.
- Hurst, M.E., (1936)
Recent Studies in the Porcupine area; Can. Inst. Min. Met., Trans., Vol. 39, p.448-458
- Hurst, M.E., (1939)
Porcupine area, District of Cochrane, Ontario; Ontario Dept. of Mines, Map 47a, scale 1 inch to 2000 feet.
- Hyde, R.S. (1980)
Sedimentary facies in the Archean Timiskaming Group and their tectonic implications, Abitibi Greenstone Belt, Northeastern Ontario, Canada. Precambrian Res. V. 12, p.161-195
- Ingersoll, R.V. (1988)
Tectonics of sedimentary basin. Geol Soc. Am. Bull., V.100, p. 2506-2520.
- Ingersoll, R.V., Bullard, T.F., Ford, R.L., Grimm, J.P., Pickel, J.D., and Sares, S.W., (1984),
The effect of grain size on detrital modes: a test of the Gazzi-Dickinson point-counting method. Jour. Sed. Petrol., vol 54, p. 103-116.

Jackson, S.L., and Fyon, J.A. (1991)

The Western Abitibi Subprovince in Ontario. p. 405-485. IN Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1. 711 pp.
Thurston, P.C., Williams, H.R., Sutcliffe, R.H., and Stott, G.M. (EDS)

Leahy, E.J., (1971)

Geology of the Night Hawk Lake area, District of Cochrane, Ont. Dept. of Mines and Northern Affairs, Geological Report 96, 74 p.
Accompanied by map 2222, scale 1 inch to 1/2 mile.

Lichte, F.E., Meyer, A.L. and Crook, J.G., (1987)

Determination of the rare-earth elements in geological materials by inductively coupled plasma mass spectrometry, Analytical Chemistry, V.59, p.1150-1157.

Mack, G.H., (1984)

Exceptions to the relationship between plate tectonics and sandstone composition. Jour. Sed. Petrol., vol 54, p. 212-220.

McLaughlin, D. B., (1956)

Keewatin-Timiskaming unconformity at Porcupine, Ontario. Geol Soc. Amer. Bull., V.67, p.939-940.

McLennan, S.M., (1984)

Petrologic characteristics of Archean greywackes. J. Sediment. Petrol., 54, p. 889-898.

McLennan, S.M., and Taylor, S.R., (1991)

Sedimentary rocks and Crustal Evolution: Tectonic setting and secular trends. J. Geol., 99, p. 1-21.

McLennan, S.M., Taylor, S.R., McCulloch, M.T., and Maynard, J.B. (1990)

Geochemical and Nd-Sr isotopic composition of deep sea turbidites: crustal evolution and plate tectonic associations. Geochim. Cosmochim. Acta, vol. 54, p.2015-2050.

Mustard P.S., and Donaldson, J.A. (1988)

Early Proterozoic ice-proximal glaciomarine deposition: the lower Gowganda Formation at Cobalt, Ontario, Canada. Geol. Soc. Am. Bull., V.98, p. 373-387.

- Mueller, W., and Donaldson, J.A. (1992)
Development of Sedimentary Basins in the Abitibi Belt: An overview.
Canadian Journal of Earth Sciences, 29, p. 2249-2265.
- Mueller, W., Donaldson, J.A., Dufresne, D., and Rocheleau, M. (1991)
The Duparquet Formation: Sedimentation in a late Archean successor
basin, Abitibi Greenstone belt, Quebec, Canada. *Canadian Journal of
Earth Sciences*, 28, p. 1394-1406.
- Mutti, E. and Ricci Lucchi, F., (1972)
Turbidites of the Northern Apennines: Introduction to facies analysis
(English translation by T.H. Neilsen, 1978). *International Geology
Review*, 20. 125-166.
- Parks, W.R., (1899)
The Nipissing-Algoma Boundary: Ontario Bureau of Mines, Volume 8,
part 2. p.175-196. Accompanied by Map 8C, scale 1 inch to 8 miles.
- Patterson, R.T., and Fishbein E., (1989)
Re-examination of the statistical methods used to determine the
number of point counts needed for micropaleontological quantitative
research. *J. Paleont.*, vol 63, p.245-248.
- Piroshco, D., and Kettles, K., (1991)
Structural Geology of Tisdale and Whitney Townships, Abitibi
Greenstone Belt, District of Cochrane, Northeastern Ontario. Ontario
Geological Survey, Open File Report 5768, 115p.
- Pyke, D.R., (1982)
Geology of the Timmins Area, District of Cochrane; Ontario Geological
Survey, Geological Report 219, 141p. Accompanied by Colour Map
2455, scale 1:50 000, 3 charts, and 1 sheet microfiche. 115pp.
- Reading, H.G., and Richards, M. (1994)
Turbidite systems in deep-water basin margins classified by grain size
and feeder system. *AAPG Bull.*, vol 78, p. 792-822.
- Taylor, S.R. and McLennan, S.M., (1985:)
The Continental Crust: its Composition and Evolution. Blackwell,
Oxford, 312 pp.

Thurston, P.C. (1990)

The Superior province - emphasizing greenstone belts, variations in greenstone sequence development emphasizing Canada. pp. 1-52. IN Ho, S.E, Robert, F., and Groves, D.I., (compilers) Gold and Base-metal mineralization in the Abitibi Subprovince, Canada.

Thurston, P.C. and Chivers, K.M. (1990)

Secular variations in greenstone sequence development emphasizing Superior province Canada. *Precambrian Research*, V.46, p. 21-58.

Tillman, R.W. (1985)

A spectrum of shelf sands and sandstones. pp. 1-45. IN Tillman, R.W., Swift, D.J.P., and Walker, R.G., eds (1985), Shelf sands and sandstone reservoirs: Society of Economic Paleontologists and Mineralogists, Short Course 13, 708 p.

Van Der Plas, L., and Tobi, A.C. (1965)

A chart for judging the reliability of point counting results. *Am., J., of Sci.*, Vol 263 pp. 87-90.

Veizer, J. (1983)

Geologic Evolution of the Archean-Early Proterozoic Earth. IN The earth's earliest biosphere and Evolution, Princeton, Princeton Press, p. 240-259.

Veizer, J., and Jansen, S.L. (1979)

Basement and sedimentary recycling and continental evolution: *J. Geol.*, V.87, p.57-82.

Veizer, J., and Jansen, S.L. (1985)

Basement and sedimentary recycling -2:Time dimensions to global tectonics. *J. Geol.*, V.93, p.625-643.

1989: Veizer, J., Lanznicka, P., and Jansen, S.L

Mineralization through geologic time: recycling perspective. *Am. Jour. Sci.*, V.289, p.484-524.

Walker, R.G. (1992)

Turbidites and submarine fans. pp. 239-263. IN Walker, R.G., and James, N.P. Eds (1992), Facies Models (3rd edition) : response to sea level change, Geological Association of Canada, Geoscience Canada Reprint Series 2, 409 p.

Walker, R.G. (1985a)

Geological evidence for storm transportation and deposition on ancient shelves. pp. 243-302. IN Tillman, R.W., Swift, D.J.P., and Walker, R.G., eds (1985), Shelf sands and sandstone reservoirs: Society of Economic Paleontologists and Mineralogists, Short Course 13, 708 p.

Walker, R.G. (1985b)

Comparison of shelf environments and deep-basin turbidite systems. pp. 465-502. IN Tillman, R.W., Swift, D.J.P., and Walker, R.G., eds (1985), Shelf sands and sandstone reservoirs: Society of Economic Paleontologists and Mineralogists, Short Course 13, 708 p.

Walker, R.G., and Plint, A.G. (1992)

Wave- and storm-dominated shallow marine systems. pp. 219-263. IN Walker, R.G., and James, N.P. Eds (1992), Facies Models (3rd edition) : response to sea level change, Geological Association of Canada, Geoscience Canada Reprint Series 2, 409 p.

Appendices 1 to 9:
Data supplement to
**A SEDIMENTARY BASIN ANALYSIS OF THE
ABITIBI GREENSTONE BELT
IN THE TIMMINS AREA,
NORTHERN ONTARIO,
CANADA**

Appendix 1 Detailed sedimentary data (graphic logs) from strata of the Whitney Formation -Tisdale Group: Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all section.

Sections include:

Ti 360

Ti 363

MS-15a

MS-15b

MS-15c

MS-9c

MS-9c

MS-9e

MS-9f

Ti 1398

Ti 1841

Ti 3235

Ti 3236

Ti 3489

	Breccia-
	Pebbly sandstone :pS
	Breccia- "Agglomerate" unit
	Conglomerate-Gm facies: clast-supported and stratified (Gcs)
	Conglomerate-Gms facies: matrix-supported
	Conglomerate-Gms facies: matrix-supported
	Graphite-rich Mudstones- Tde facies- turbidite distal facies
	Mudstones- Tde facies turbidite distal facies
	Shelf sandstones: arkose- St, Sp facies
	Turbiditic sandstones: sandstone (proximal) facies- Ta, Tae
	Turbiditic sandstones: regular Turbidite facies-Tabdce
	Covered
	Glacial deposits
	Mafic volcanic rocks
	Ultramafic rocks: flows or sills
	Mafic tuffs
	Felsic tuffs
	Felsic tuffs:Krist fragmental
	QFP-quartz feldspar porphyry
	Mafic or diabase dike

Unified legend and symbols for stratigraphic sections in all appendices:
Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

LITHOLOGIC VARIATIONS

Classification of Turbidites based on percentage of mudstone beds

Mudstones (abysal or distal type)	Type 4	> 70% mud
Muddy Turbidites (distal type)	Type 3	> 30% mud
Regular Turbidites (medial to proximal type)	Type 2	21-30% mud
	Type 2	11-20% mud
	Type 2	6-10% mud
Sandy Turbidites (proximal type): sandstone facies	Type 1	< 6% mud

mud %

Bedding features symbols and lithologies

	split core
	mudstone beds
	breccia
	mud chips
	pebbles
	carbonatized
	Pyrite
	strained
	flow tops
	megaclasts
	rafted clasts
	coarse-tailed fining up
	fining up
	coarse-tailed coarsening up
	sheared
	fuchsite chips
	gravel bars
	agglomerate
	thickening-up cycle
	thinning-up cycle
	sheared
	imbrication
	mudcracks
	reactivation surfaces
	mud drapes
	loadcasts
	fault
	coarsening up
	fining up
	major scour at base of channel
	chaotic bedding
	low-angle tabular bedding
	convolute bedding
	high angle planar crossbeds
	hummocky cross-stratification
	planar-tabular bedding
	herringbone cross-stratification
	climbing ripples
	lenticular bedding
	oscillatory ripples
	wavy parallel bedding
	trough cross-stratification
	flaser bedding
	current ripples

BEDDING THICKNESS

Classification of Turbidite based on thickness of bedding

	amalgamated bedding contact
	erosional bedding contact
Type 4 (abysal or distal type)	α laminated (< 1 cm)
Type 3 (distal type)	β very thinly bedded (< 10 cm)
Type 2 (medial or distal type)	γ thinly bedded to medium bedded (10-50 cm)
Type 1 (proximal type)	δ thickly bedded (50-100 cm)
Type 1 (proximal type)	ϵ very thickly bedded (> 100 cm)

Combined nomenclature:
(1-1) TBTE= very thickly bedded or
thickly bedded Turbidite containing
<6% mudstones
(proximal turbidities:sandstone facies)

ABBREVIATIONS :

alcs= average large clast size
az = azimuth
BI = biotite
brx = breccia
CA= core axis
CB = carbonate alteration
CGLM = conglomerate
cgr= coarse grained
CH= chlorite
CU = coarsening up
FAB = tectonic fabric- foliation
fc = fuchsite
fgr = fine grained
FI = Fine laminated facies
FLVC = felsic volcanic
FU = fining up
Gm = -clast supported and stratified conglomerate facies (Gcs)
Gms = -matrix supported and stratified conglomerate facies
HCS = hummocky cross stratification
mgr= medium grained
MVLC = mafic volcanic
NO = north
PC# = point count number
PDF = Porcupine Destor Fault
Pebs= pebbles
PF = plagioclase feldspar
pS = pebbly sandstone facies
pSl = pebbly sandstone containing low angle cross bedding
pSt = pebbly sandstone containing trough cross bedding
QCV = quartz carbonate vein
QFP = quartz feldspar porphyry
QV = quartz vein
QZ = quartz
sd = sand
SED = sedimentary clasts
SI = sandstone containing low angle cross bedding
SO = south
St = trough crossbedded sandstones
SU = sulphide
Tabcde= the various divisions of the Bouma cycle for turbiditic deposits
TBTE = turbidite
THU = thinning up
TKU = thickening up
UM = ultramafic

Ti 363 Cody Twp az=290; dip -50 to 48° @end;

UTME 497810 N 5370430;

TOPS down hole to West

Interbedded volcanics, tuffs
and sediments-TBTE :WHITNEY Fm
same as Ti 360;Bedding
thickness

GRAIN SIZE

%
M
U
DM
E
T
E
R
SBedding
featurescobble
pebble
granule
sand
silt
clay
vc mfv

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Bedding
thickness

Bedding
features

GRAIN SIZE

%
M
U
D

M
E
T
E
R
S

cobble
pebble
granule
sand
silt
clay

vcmfv

Ti 1398a Whitney Twp

372

; tops up hole to NW; bearing=135 ;
dip -50 ; 40 m section of
sediments overlain by UM flow;
intersects the Porcupine Destor Fault
UTM E 491835 N 5373400

SUMMARY :going down down hole: Um flow
underlain by sediments and volcanoclastic
to chloritic tuffs

also intersects by PDF crumbly zone of UM

60m of
OVERBURDEN

series of ultramafic flows
with some flow top breccias
and spinifex flow features
FAB=40° to CA

Porcupine Destor Fault zone
crumbly UM rocks- 30 m
thick zone 106 to 136 m

thin UM flows 30- 40 cm

fab=50° to CA
very crumbly flow tops

fab=30° to CA

fab=30° to CA bedding?
unconformity? difference in CA on both sides of
contact but contact appears conformable

biotite rich sedb cbt abundant white not very QZ
rich bititote 30% and PY
1-5% cubic late py

fab=70° to CA

fab=70° to CA

sedb colour lt gy not green and finely laminated
and siliceous, less cbt veinlets, shows tops up hole
and lower contact gradational over several cm

crenulation cleavage fab=20° to CA

β
β

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α^{ch}

α

Bedding
thickness

GRAIN SIZE

%
M
U
D

Ti 3236 Tisdale Group - Whitney Frn 375

Whitney Twp, az=230 , dip @ collar 55°

steepens to-60° @ end;

UTM E490385 N 5372380

Bedding
features

cobble
pebble
granule
sand
silt
clay

vcmfv

α

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β_{ch}

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90

80

70

60

50

40

30

20

10

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fine sand not graded, propably mafic tuffs,
crenulated not massive like mafic flows,

very crenulated tuffs, dark green, no graphite
type 2 interference pattern cut by crenulation leavage

fabric @15° to CA

fabric @30° to CA

TBTE-sandstone facies- Tae, Ta type
sandstone:siltstone:mudstone
95:00:05
fabric @15° to CA

reworked tuffs - green and chloritic

M1317 volcanoclastic @37.3m
thin section -reworked tuff

banded UM flows
altered

Tuffs- chlorite rich in nature

QFP unit could be intrusive

OVERBURDEN-22 M

Appendix 2 Detailed sedimentary data (graphic logs) from strata of the Beatty Formation -Porcupine Group: Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all section.

Sections include:

MS-1

MS-12c

PS-20

Ti 1368

Ti 1369

Ti 1370

Ti 1486

ms-12c
Beatty Fm. sediments
part of the Porcupine syncline
vertical scale 1:2000
or 1 cm to 20 m of section
the south facing limb
of the syncline

area of detailed sections

area of detailed sections

area of detailed sections

GRAIN SIZE

%
M
U
DM
E
T
E
R
S

Ti 1370 Tisdale Twp;

telescoped core; az=090 , dip=45-40
tops down hole

UTM E 482525 N 5371470

 α α α α α α α α α α α

cobble
 pebble
 granule
 sand
 silt
 clay
 vcmfv

mudstones- muddy TBTE-distal facies
 Tde type
 sandstone:siltstone:mudstone
 00:10:90

muddy TBTE-distal facies Tcde type
 sandstone:siltstone:mudstone
 30:10:60
 Tcde rippled

muddy TBTE-distal facies Tde type
 sandstone:siltstone:mudstone
 60:10:30
 some graphite

muddy TBTE-distal facies Tde type
 sandstone:siltstone:mudstone
 60:10:30

Gms 3 cm subrounded clasts SED+Krist;
 mtx vcgr sd

dk green chlorite rich rock
 dike?

Gms 3 cm clasts SED+Krist;
 mtx vcgr sd

OVERBURDEN- 20 m

Appendix 3 Detailed sedimentary data (graphic logs) from strata of the Hoyle Formation -Porcupine Group: Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all section.

Sections include:

H 12-09

H 15-62

H 16-12

H 23-23

HP 2185

M-21-10

K 54-24

K 54-25

K 54-30

M-21-10

M-51-1

PS-19

Ti 308

Ti 1350

Ti 2371

Ti 2374

Ti 2378

Ti 3057

Ti 3058

Ti 3561

Ti 3568

MS-EVE-SOUTH

DDH Ti 1350 Hoyle Formation

Hoyle Twp; az=190; dip -55 constant;
Tops up hole; to NORTH 1:600 scale;
UTME 489210 N 5380028

130 M of TBTE- muddy and distal
Tde types of the Holye Assemblage

Appendix 4 Detailed sedimentary data (graphic logs) from strata of the Dome Formation -Pamour Group: Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all section.

Sections include:

MS-2

MS-3

MS-5

MS-6

MS-7

MS-8

MS-10

MS-12a

MS-12b

MS-13

Ti 1373

Ti 2407

MS-10 PAMOUR PIT #3 : (SUPERPIT)

UTM E 491680

N 5374280

DOME FORMATION: MEMBER B

@78%

Bedding thickness

Bedding features

GRAIN SIZE

cobble
pebble
granule
sand
silt
clay

%
M
U
D

METRES

ms-12b

TBTE-DOME Fm.

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18

Appendix 5 Detailed sedimentary data (graphic logs) from strata of the Three Nations Formation -Pamour Group: Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all section.

Sections include:

MS-4

MS-11

MS-16

MS-17

PS-18

Ti 1160

Ti 3590

Ti 3591

Bedding
thicknessBedding
features

GRAIN SIZE

%
MUD
MUD-CLAYSms-4
(detailed
sections)UTM E 493270
N 5374080

Lithofacies

abundant mud drapes
capping fine sandstone

st

abundant mud drapes

st

depositional subdivisions

depositional subdivisions

PC#10

Gm

Tde

Gm

Tde

Bedding
thickness

Bedding
features

GRAIN SIZE

%
M
U
D

cobble
pebble
granule
sand
silt
clay

vcmfv

ms-4
(detailed
sections)

UTM E 493270 447
N 5374080

Lithofacies

st, pst

major horizon containing HCS
bedforms: storm beds

SI, HCS

SI, St

abundant fuchsite chips
and QFP clast present

PC#11

abundant fuchsite chips

Gms, St, Sp, SI

depositional subdivisions

St

abundant mud drapes
mainly on cosets

St

St. Sp

Gms, St, SI

St

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area of detailed sketch

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T+k

T+k

T+k

T+k

T+k

T+k

T+k

T+k

T+k

Bedding
thickness

Bedding
features

GRAIN SIZE

cobble
pebble
granule
sand
silt
clay

%
M
U
D

M
E
T
E
R
S

MS-11 (detailed)
Lithofacies

MS-17 PAMOUR GROUP; FACING SOUTH, AZ=180°
 MATHESON TWP; NEAR HIWAY 101,
 EAST OF NIGHTHAWK LAKE
 UTM 503165 N 5377085

Bedding
thickness

Bedding
features

GRAIN SIZE

%

M
U
D

M
E
T
E
R
S

MS-17c

455

NIGHTHAWK LAKE NEAR MS-17
AZ=180 AND TOPS ARE TO THE SOUTH
UTM E 503950 N 5375420

Appendix 6 UTM TABLES

Appendix 6 Locations for drill holes (ddh), measured sections (MS), outcrops and individual point counting stations for conglomerates, of the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

3 pages

TOWNSHIP	DDH or MS	DIRECTION (deg az)	DIP	length (metres)	major unit	UTM E (metres)	UTM N (metres)	R#
Appendix 6. Locations for drill holes (ddh), measured sections (MS), outcrops and individual point counting stations for conglomerates, of the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario.								
KIDD	K54-30	270	DIP-55-48 ^	641	HF	470595	5392127	8
KIDD	K54-25	30	DIP-55-44 ^	596	HF	470718	5392066	9
KIDD	K54-24	30	DIP-55-53 ^	602	HF	472915	5392203	10
TISDALE	TI 1486	180	DIP-45-30^	227	Tisdale Group	482457	5372515	14
TISDALE	TI 1370	90	DIP-45-40^	87	BF	482525	5371470	15
TISDALE	TI 1368	270	DIP-45-40^	96	BF	482650	5371145	16
TISDALE	TI 1369	270	DIP-45-36^	163	BF	482725	5371470	17
WHITNEY	TI 2407	150	DIP-90-80^	630	PG-TNL ?	484900	5370700	18
HOYLE	TI 0308	180	DIP-45-25^	204	BF	485915	5380440	19
WHITNEY	TI 1373	360	DIP-47^	225	BF	487125	5372560	20
HOYLE	H12-09	180	DIP-52-44^	356	BF	487700	5371500	21
HOYLE	H23-23	180	DIP-45^	50	BF	489080	5373060	22
HOYLE	TI 1350	190	DIP-55^	250	BF	489210	5380028	23
WHITNEY	TI 3235	180	DIP-55-50^	261	WF	490220	5372260	24
WHITNEY	TI 1974	360	DIP-45^	37	PDFZ WF	490250	5372330	25
WHITNEY	TI 3236	230	DIP-55-60^	140	WF	490385	5372380	26
WHITNEY	TI 1841	145	DIP-45^	64	HF	491060	5375680	27
WHITNEY	TI 1840	145	DIP-47^	109	HF	491390	5375660	28
HOYLE	HP-2185	180	DIP-55^	60	HF	491785	5377060	29
WHITNEY	TI 1398	135	DIP-50^	253	Tisdale Group	491835	5373400	30
WHITNEY	TI 3489	360	DIP-45^	157	WF	493510	5373330	31
HOYLE	H16-12	180	DIP-50-32^	379	HF	493600	5372200	32
MATHESON	TI 3561	180	DIP-55^	173	HF	494645	5380960	33
MATHESON	M21-10	180	DIP-60-40^	270	HF	494820	5373440	34
MATHESON	M51-1	180	DIP-55-21^	198	HF	494820	5377900	35
MATHESON	TI 3568	180	DIP-55^	161	HF	495215	5380290	36
EVELYN	TI 3057	270	DIP-55-48 ^	191	HF	496000	5387880	37
EVELYN	TI 3058	270	DIP-55-48 ^	201	HF	496260	5387620	38
CODY	TI 1160	180	DIP -55-48^	153	PG	496739	5375637	39
CODY	TI 0360	290	DIP -52-55	229	WF	497420	5369060	40
CODY	TI 0363	290	DIP -50-48^	171	WF	497810	5369060	41
EVELYN (S)	TI 2585	360	DIP-55-48 ^	190	HF	499250	5385290	42
MATHESON	TI 3591	180	DIP-45^	130	PG	503190	5376320	43
MATHESON	TI 3590	180	DIP-45^	200	PG	503310	5376395	44
GERMAN	TI 2371	180	DIP-50 -42^	200	HF	513585	5378740	45
GERMAN	TI 2374	180	DIP-50 ^	200	HF	513585	5378930	46
GERMAN	TI 2378	180	DIP-50 ^	200	HF	513585	5378830	47
DENTON	PS-19	140	START	210	HF	447930	5353800	48
THORNLOE	PS-18	140	START	100	PG	463330	5354010	49
TISDALE	KRIST -TIM		O/C		KRIST	467300	5367350	50
TISDALE	KRIST -GC		O/C		KRIST	480100	5368600	51
TISDALE	KRIST	215 BL	START		KRIST	480700	5369380	52
TISDALE	DOVE	270 BL	START		PG ??	481520	5367480	53
TISDALE	MS-12A	185	START	440	PG	482400	5369200	54
TISDALE	MS-12C,D	185	START	560	PG	482500	5368600	55
TISDALE	MS-14	90	START	100	PG	483160	5367450	56
TISDALE	MS-13	180	START	140	PG	483460	5369300	57
TISDALE	MS-1	190	START	447	PG+BF	484020	5370830	58
TISDALE	PS-20	140	START	20	BF	484440	5369700	59
WHITNEY	MS-2	145	START	122	PG	484960	5370950	60

TOWNSHIP	DDH or MS	DIRECTION (deg az)	DIP	length (metres)	major unit	UTM E (metres)	UTM N (metres)	R#
Appendix 6. Locations for drill holes (ddh), measured sections (MS), outcrops and individual point counting stations for conglomerates, of the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario.								
WHITNEY	O/C:342			20	PG	485800	5371650	61
WHITNEY	MS-7	160	START	90	PG	486650	5372060	62
WHITNEY	MS-8	170	START	120	PG	489970	5373600	63
WHITNEY	MS-9	360	START	130	WF	490110	5372820	64
WHITNEY	MS-5	160	START	68	PG	491120	5374160	65
WHITNEY	MS-11	210	START	141	PG	491430	5373560	66
WHITNEY	MS-10	145	START	162	PG	491680	5374280	67
WHITNEY	MS-6	145	START	34	DELOORO +PG	492560	5374560	68
WHITNEY	MS-3	145	START	100	PG	492660	5374270	69
WHITNEY	MS-4	160	START	290	PG-TNL	493270	5374080	70
HOYLE	O/C:077			14086	HG	493500	5381500	71
CODY	MS-15A	5	START	40	WF	495900	5369520	72
CODY	MS-15C	20	START	70	WF	495950	5369880	73
CODY	MS-15B	20	START	30	WF	496100	5372000	74
CODY	O/C:314				WF	496190	5368880	75
CODY	O/C:315				WF	498600	5372000	76
MATHESON	PS-33	180	START	50	HF	499560	5385330	77
MATHESON	MS-17	180	START	30	PG	503165	5377085	78
MATHESON	MS-17B	180	START	230	PG	503240	5375170	79
MATHESON	MS-17C	180	START	90	PG	503950	5375420	80
MATHESON	MS-17D	180	START	20	PG	504540	5375460	81
GERMAN	MS-16	180	START	70	PG	507760	5376740	82

TOWNSHIP	DDH or MS	DIRECTION (deg az)	DIP	length (metres)	major unit	UTM E (metres)	UTM N (metres)	R#
Appendix 6. Locations for drill holes (ddh), measured sections (MS), outcrops and individual point counting stations for conglomerates, of the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario.								
PC#33	DOME	342:Banerman St U/C 314:Nighthawk L 315:Nighthawk L 077:tailings pond-Hoyle			PG-ALL	481520	5369774	83
PC#34	DOME				PG-ALL	481541	5369777	84
PC#35	DOME				PG-ALL	481601	5369747	85
PC#22	MS-12A				PG-ALL	482496	5367992	86
PC#23	MS-12A				PG-ALL	482496	5367975	87
PC#24	MS-12A				PG-ALL	482496	5367927	88
PC#37	KRIST	PG= Pamour Group -ALL=Alluvial Fan TBTE=Turbidite GRV BAR=Gravel Bar TNL=Three Nations Fm BF= Beatty Fm WF=Whitney Fm C=conglomerate HF=Hoyle Fm Deloro=Deloro Group PDFZ=Porcupine Destor Fault Zone BL=Baseline MS=measured section PS=preliminary section: not as detailed as MS DDH=diamond drill hole and hole number deg=degree az= azimuth			KRIST	482600	5369330	89
PC#36	KRIST				KRIST	482640	5369230	90
PC#17	MS-13				PG-TBTE FAN	483460	5369276	91
PC#18	MS-13				PG-TBTE FAN	483460	5369279	92
PC#21	MS-13				PG-TBTE FAN	483460	5369156	93
PC#31	MS-1				PG-ALL	484020	5370732	94
PC#32	MS-1				PG-ALL	484020	5370692	95
PC#1	MS-1				PG-ALL	484027	5370773	96
PC#2	MS-1				PG-ALL	484027	5370770	97
PC#19	MS-1				PG-ALL	484027	5370768	98
PC#39	MS-1				PG-ALL	484027	5370766	99
PC#4	MS-2				PG-TBTE FAN	485032	5371049	100
PC#3	MS-2				PG-TBTE FAN	485033	5371050	101
PC#40	MS-2				PG-TBTE FAN	485040	5371044	102
PC#5	MS-2				PG-TBTE FAN	485041	5371042	103
PC#6	MS-2				PG-TBTE FAN	485053	5371041	104
PC#15	MS-8				PG-ALL	489968	5373595	105
PC#13	MS-5				PG-ALL	491082	5374151	106
PC#14	MS-5				PG-ALL	491082	5374148	107
PC#12	MS-5				PG-ALL	491120	5374159	108
PC#20	MS-5				PG-ALL	491120	5374157	109
PC#42	MS-5				PG-ALL	491120	5374154	110
PC#43	MS-5				PG-ALL	491120	5374151	111
PC#16	MS-11				PG-GRV BAR	491280	5373385	112
PC#7	MS-3				PG-TBTE FAN	492610	5374174	113
PC#8	MS-3				PG-TBTE FAN	492638	5374248	114
PC#41	MS-3				PG-TBTE FAN	492638	5374246	115
PC#9	MS-3				PG-TBTE FAN	492666	5374246	116
PC#10	MS-4				PG-TBTE FAN	493270	5374370	117
PC#11	MS-4				PG-GRV BAR	493283	5374242	118
PC#29	MS-17				PG-ALL	503165	5377077	119
PC#30	MS-17				PG-ALL	503165	5377070	120
PC#38	MS-16				PG-GRV BAR	507760	5376727	121
PC#28	MS-16				PG-GRV BAR	507768	5376680	122
PC#27	MS-16				PG-GRV BAR	507812	5376678	123

APPENDIX 7:

DESCRIPTIONS OF POINT COUNTING DATA FROM CONGLOMERATES
OF THE PAMOUR GROUP: DOME AND THREE NATIONS FORMATIONS

Point counting stations (Table 3.1) are arranged in ascending stratigraphic order in each measured section, except for MS-2, MS-3 and D (DOME), where the locations of stations define a lateral as well as a stratigraphic distribution.

Point counts 3, 5, and 6 define a 200 m lateral (easterly) distribution for MS-2, whereas point count 3 overlain by point count 4, and point count 5 overlain by point count 40 constitute stacked pairs that cover a stratigraphic distance of 5m, but are laterally separated by a distance of 80 m. Point counts 7, 8 and 9, which are separated by 50m, define a 100 m laterally (easterly) distribution at MS-3, whereas point count 41 directly overlying point count 8 covers a 3 m stratigraphic thickness. Point counts 33, 34 and 35 at section D (DOME) occur over a distance of 80 m in a easterly (lateral) direction, but also span 30 m in a north to south (vertical) direction.

CONGLOMERATES ASSOCIATED WITH ALLUVIAL-FLUVIAL DEPOSITION

MS-D(Dome), 12, 1, 5, 17, which only contain conglomerates of a probable fluvial-alluvial origin, are arranged in a west to east direction (Table 3.1):

MS-D (Dome)

The following point counts, taken from an outcrop near the Dome open pit, are arranged in ascending stratigraphic order as well as in a west to east direction (PC 33, 34, and 35).

In decreasing abundance, the main clast types are:

aMV>P1>P2>variolitic basalt (similar to Plate 5.C)

Several changes occur in the percentage of clast types both in a west to east (lateral) direction as well as in a north to south (stratigraphic) direction. In both cases, an increase in the percentage of P1 clasts corresponds to a decrease in the percentage of altered mafic volcanic and P2 clasts.

MS-12

The main clast types listed in decreasing abundance are:

aMV>aUM>P2>chert (similar to Plate 5.C)

Conglomerates of the Dome Formation (Pamour Group) unconformably overlie turbidites of the Beatty Formation (Porcupine Group) at both MS-12 and MS-1 (Figure 3.1). A laterally limited distribution of stations at MS-12 means that only vertical variations of clast types can be tested over a distance of 44 m; no lateral variations can be tested. The following point counts are taken from MS-12 and are arranged in ascending stratigraphic order (PC 22, 23, and 24). General trends illustrate an increase in P2 clasts as a function of increasing height. Changes in the proportion of other clast types are less than the counting error and by definition do not represent significant changes.

MS-1

Conglomerates, which constitute the upper 60 m of section MS-1, are part of the Dome Formation (Pamour Group) that unconformably overlies turbidites of the Beatty Formation (Porcupine Group). These represent the youngest sedimentary package of the Abitibi Greenstone belt in the Timmins area.

Stations PC 1, 19, 39 and 2 (Figure 3.3) represent the lower part of the conglomeratic section (from 386 to 398 m), whereas PC 31 and 32 are from the upper parts (426-448 m) of the section. The limited lateral distribution of the

point counts means that only stratigraphic changes can be tested.

The main clast types, listed in decreasing abundance are:

aMV>P2(Q-) $\pm$ SED $\pm$ var MVLC (Plates 5.C and 5.D)

Variations in the relative proportions of clasts as a function of stratigraphic height illustrates several trends. The major change is a substantial increase in the proportion of altered ultramafic clasts (aUM) (Plate 5.E) and a corresponding decrease in the percentage of altered mafic volcanic (aMV) clasts over the entire upper 60 m of the section. This trend probably illustrates the unroofing of ultramafic flows underlying an upper mafic volcanic unit. Both altered mafic volcanic and variolitic basalt clasts (Plate 5.D) decrease in abundance within the lower part of the conglomerate unit. There is also a corresponding increase in the abundance of matrix and P2 clasts as a function of increasing stratigraphic height. These trends are indicative of the progressive unroofing of a quartz-poor porphyry as well as a progressive increase in matrix content that corresponds to a decrease in ALCS (Table 3.2).

MS-5

The main clast types, listed in decreasing abundance are:

aUM>aMV>CHERT>P1 (similar to Plate 5.E)

The following point counts taken from MS-5 are arranged in ascending stratigraphic order: PC 12, 20, 42, 43, 13, 14. Their limited lateral spacing means that variations in the proportion of clasts only compares the composition of conglomerates at different stratigraphic levels covering a maximum vertical distance of 46 m; no lateral along-strike variations can be tested.

There is a gradual and consistent increase in percentage of altered mafic volcanic clasts and a corresponding decrease in altered ultramafic clasts going up

section. Several minor variations indicate that a major but temporary influx of both sandstone and chert clasts occurred about 6 m above the base at PC #42. These patterns are not reflected by overlying or underlying point counts, and suggest that this anomalous point count represents a different provenance than those represented by PC 12, 20, 43, 13, and 14).

Variation of clast types in a lateral direction between measured sections (MS) can be tested by comparing data from MS-5 to MS 8 in the west and MS-3 farther to the east (Figure 3.1). The data suggest that there are few differences between MS-5 and MS-8. Comparisons between MS-5 and MS-3 show a decrease in the proportion of altered ultramafic clasts and a corresponding increase in the proportion of sedimentary and quartz vein clasts; the proportion of all other clast types remains about the same (Figure 3.4).

MS-17

PC 29 overlain by PC 30 are the only point counts from MS-17. The main clast types listed in decreasing abundance are:

aUM>P1>SEDS>FC CHIPS>CHERT>QV>K>P2>aMV (similar to
Plate 5.F as well as Plates 3.D and 4.A)

Changes in the percentage of clasts at MS-17 indicates that there is a general increase in the proportion of quartz vein, sedimentary, and fuchsite (chip) clasts (Plate 5.F) and a corresponding decrease in P1, chert, and altered ultramafic clasts as a function of increasing stratigraphic height.

CONGLOMERATES ASSOCIATED WITH TURBIDITES

MS-13

Unlike conglomerates in MS-1, those in MS-13 are associated with turbidites and probably represent channel-fill conglomerates cutting the turbidite sequence of the Dome Formation (Pamour Group).

At MS-13, the main clast types listed in decreasing abundance are:

$aUM > aMV > P1$ (Similar to Plate 5.E)

This section, which represents a total vertical height of 140 m, contains two conglomerate horizons separated by a 90 m thick turbidite unit. The following point counts taken from MS-13 are arranged in ascending stratigraphic order : PC 17, 18, and 21.

At MS- 13, the only trend is an upwards decrease in the percentage of altered mafic volcanic clasts, and a corresponding increase in the percentage of altered ultramafic clasts (Figure 3.5).

MS-2

Conglomerates of MS-2 (Figure 3.1) contain several main clast types that are listed in decreasing abundance as:

$P2 > aMV > aUM > QV$ (Plate 2.A)

A decrease in P2 (QZ-poor) and altered ultramafic clasts, together with a corresponding increase in the altered mafic volcanic clasts define a trend in an easterly direction.

Vertical or stratigraphic changes are defined by a decrease in altered ultramafic clasts and a corresponding increase in P2 (Qz-poor) clasts. This can be interpreted as indicating changes in source region with time.

MS-3

The main clast types listed in decreasing abundance are:

aMV>SEDS>P1>QV (Plate 2.B)

MS-3 and MS-2 are similar, and probably represent the same depositional environment. Also, both show a vertical and lateral distribution of point counting stations. In MS-3, the locations of point counts (PC 7, 8, 41 and 9) demonstrate a similar distribution in a W to E direction over a distance of 100 m, and over a vertical distance of 5 m at one location (PC# 41 overlying PC #8).

Essentially, all changes occurring over the strike length of 100 m are within the error limits of the individual clast types for each point count (100 points: see Table 3.1). Thus, no significant changes are caused by transport in either a westerly or easterly direction. Stratigraphic (vertical) changes are indicated by an increase in the proportion of both sedimentary and P1 clasts and a corresponding decrease in quartz vein and mafic volcanic clasts. Again, these trends suggest a progressive unroofing of a source region which consisted of mafic volcanic rocks containing quartz veins, underlain by sedimentary and P1 rock types.

GRAVELLY BAR CONGLOMERATES: MAINLY IN A SHELF SETTING

Typically these matrix-supported conglomerates represent a minor component interbedded and associated with sandstones and pebbly sandstone beds: they only occur within the Three Nations Formation of the Pamour Group.

MS-16

The main clast types listed in decreasing abundance are:

SEDS>P2>QV>P1>mud chips±MV

(similar to Plate 5.F, as well as Plates 3.D and 4.A)

The following point counts taken from MS-16 (Figure 3.1), are arranged in ascending stratigraphic order: PC- 38, 28, and 27.

At MS- 16, (Table 3.1 and Figure 3.5) only one stratigraphic trend was identified. An upwards decrease in the percentage of altered mafic volcanic clasts and a corresponding increase in the percentage of fuchsite chips (mud chips?) suggests that the mafic volcanic source area, which actively shed detritus during deposition of the basal conglomerates, became less important during deposition of the younger overlying conglomerates, where sedimentary type clasts predominate.

Others

At MS-4 and 11, the point count stations are too separated for a proper stratigraphic or lateral comparison.

Appendix 8 Original counting data: grain parameters (Gazzi-Dickinson) for samples from the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all samples.

measured section	sample	Qm %	Qm tot count	Qm 1st count	Qm 2nd count	Qm 3rd count	Qc % tot count	Qc 1st count	Qc 2nd count	Qc 3rd count	Qp % tot count	Qp 1st count	Qp 2nd count	Qp 3rd count	E#	R #
Appendix 8.1 Original counting data: grain parameters (Gazzi-Dickinson) for samples from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all samples.																
d K 54-30	6014	60				***									*****	1
d K 54-30	6013	60				***									*****	1
d K 54-30	6012	60				***									*****	1
d K 54-25	6010	70														1
d K 54-25	6011	60				***										1
d K 54-24	6008	14	42	14	16	12										1
d K 54-24	6009	19	19													1
Hoyle t pond																1
33	077	24	84	24	25	25	3	9	0	0	5	14	5	4		1
	338	22	67	22	21	24	6	17	5	8	6	17	6	5		1
12D	204	21	64	23	21	20	7	22	5	11	6	2	0	3		2
12D	205	19	54	20	18	16	7	20	5	14	5	1				10
12D	207A	23	69	22	21	26	8	25	8	6	11	4	4	4		11
12D	207B	23	68	23	23	22	7	22	14	4	4	2	1	2		12
(Quarry)	340B	30									Y					13
1	6004	20	61	21	17	23	5	15	1	2	6	18	7	2		14
1 @390 m	6021	20												9		15
1 @390 m	6027	35	69	25	44						4	8	7	1		16
1 @390 m	6028	14	43	18	16	9					8	22	12	4	6	17
1 @390 m	6031	4	11								Y					18
1	006	?														19
1	007	21	61	21	24	19	5	6	3	2	1	9	27	8	7	20
1	12	26	79	24	25	30	4	11	4	6	0	2	7	0	1	21
1	17	20	59	19	19	21	10	30	9	1	1	3	1	1	1	22
1	6001	24	73	23	31	19	5	14	7	4	3	1	3	1	1	23
6	160A	21	64	21	19	24	3	8	5	3	0	8	23	7	12	24
9	164	Y												3		25
d 3235 @104 m	M1313 ; T	15				**	Y				Y					26
d 3235 @174 m	M1314 ; T	30				**	no				Y					27
d 3235 @201 m	M1316 ; T	50				**										28
d 3235 @227 m	M1315 ; T	50				**										29
d 3235 @62m	M1307; grap s	Y					?									30
																31

Lv, Ls, Ser, Chl,
values all determined
on a subsequent
SECOND COUNT

measured section	sample	Qm %	Qm tot	Qm 1st	Qm 2nd	Qm 3rd	Qc % tot	Qc 1st	Qc 2nd	Qc 3rd	Qp %	Qp tot	Qp 1st	Qp 2nd	Qp 3rd	E#	R #
Appendix 8.1 Original counting data: grain parameters (Gazzi-Dickinson) for samples from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all samples.																	
d 3235; @ 44.5 m	M1306A	40					?				?					3	32
d 3235; @ 44.5 m	M1306B; grap s	27	27				?				?					3	33
9	160B	Y														3	34
d 3226 @112 m	M1318 ; T	40				**										3	35
d 3226 @058 m	M1317 ; T	20				**										3	36
9	170B	Y									Y					3	37
d 1840 @40 m	M1319 ; T	20				**										3	38
d 1840 @46 m	M1320; T	37	110	34	40	36	2	6	0	1	5					3	39
d 1398 @212 m	M1309;	Y					Y									3	40
d 1398 @212m	M1308 ; Bi	Y					Y				?					3	41
d 1398 @242m	M1310 ; s	25				**	?				?					3	42
d 1398 @250 m	M1311 ; s	30				**	?				?					3	43
d 1398 @253 m	M1312 ; s	40				**	?				?					3	44
d 3489 @108 m	M1324; T	60				**					10					3	45
d 3489 @38 m	M1321; T	50				**	10									3	46
d 3489 @96 m	M1322; T	55				**	10									3	47
d 3489 @96 m	M1323; T	30				**					10					3	48
15	316B	19	57								12	36			< .2 mm	3	49
15	317A	30									5					3	50
15	317d	19	61								14	41	8	15	18	3	51
15	313B	19	56								16	48	14	17	19	3	52
15	315	20									5%					3	53
2	34B	33	94	34	32	31	3	10	4	1	5	10	32	6	11	4	54
2	36	26	55	17	21	40	3	10	3	2	5	20	61	14	24	4	55
4	78A	28	85	23	26	36	5	15	2	5	8	16	49	18	7	4	56
4	81	27	82	28	22	32	5	14	6	6	2	14	51	9	12	4	57
4	82	27	78	29	27	25	2	6	4	2	0	21	63	23	21	4	58
4	84	33	99	32	33	34	3	8	5	3	0	22	66	14	21	4	59
4	90-01A	Y;					Y					\$\$\$ means Qp2				4	60
4	90-01B	Y;					Y					abundant				4	61
4	90-02	Y;					Y									4	62

** means Quartz is intergrown with PF

measured section	sample	Qm %	Qm tot count	Qm 1st count	Qm 2nd count	Qm 3rd count	Qc % tot count	Qc 1st count	Qc 2nd count	Qc 3rd count	Qp % tot count	Qp 1st count	Qp 2nd count	Qp 3rd count	E#	R #
Appendix 8.1 Original counting data: grain parameters (Gazzi-Dickinson) for samples from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all samples.																
4	90-03	Y					Y				Y				4	63
4	99	26	77				9	26			13	38			4	64
4	104	29	88				3	8			19	58			4	65
4	106	30	89				1	4			13	40			4	66
4	120	27	81	*** means only present in matrix			3	8			25	76			4	67
4	127	25	76				1	3			23	68			4	68
4	140	25	74				4	13			28	84			4	69
13	192	Y					?				?				5	70
2	025c	32	95	33	31	31	2	7	3	1	3	12	35	7	12	16
2	6007	37	111	39	34	38	4	13	2	9	2	4	11	1	6	4
8	154B	29	76	27	31	28	8	24	8	8	12	36	12	11	13	5
5	146A	33	98	27	4	3	16	32	14	16	21	7	17	4	0	18
6	150B	31	93	32	28	33	13	38	11	17	10	11	34	11	10	13
6	153B	39	76	40	43	35	5	15	6	6	3	5	16	5	2	9
3	49	40														5
3	57A	35	10	4	2	3	2	7	2	2	3	5	15	5	5	5
Dome	517	Y									10					5
12	181B	Y					\$ means Qp1 abundant				Y					7
12	181D	Y									Y					7
12	182	Y									?					7
13	195	Y														7
1	024h	39	11	1	2	1					4	13	9	1	3	7
8	155c	Y														7
5	144B	50				***	Y				10					7
5	145A	34	10	3	3	3	8	24	11	8	5	10	29	13	9	7
5	143B	Y					Y									7
17	328	20	56	19	12	1	1	4	1	3	0	39	117	41	36	40
17	329	19	56	21	14	2	2	6	3	2	1	39	133	31	47	55
13	193B	Y					?				***					8
13	191B	Y					5				<1.2 mm				1.6 mm	8
2	30	50				***	Y				<1.2 mm	10			\$\$\$	8

measured section	sample	Qm	Qm tot	Qm 1st	Qm 2nd	Qm 3rd	Qc	Qc tot	Qc 1st	Qc 2nd	Qc 3rd	Qp	Qp tot	Qp 1st	Qp 2nd	Qp 3rd	E#	R #
Appendix 8.1 Original counting data: grain parameters (Gazzi-Dickinson) for samples from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all samples.																		
2	027	Y				...											8	94
5	149B	Y															8	95
3	50A	24	71	30	16	25	3	8	6	2	0	11	24	7	5	12	8	96
3 ext	1400 Hoyle	Y															8	97
4	67A	21	64	27	21	16						2	6	3	0	1	8	98
11	176A	Y										Y					9	99
11	6003	27	82	28	28	26						28	85	27	26	32	9	100
16	324	26	79	26	32	21	2	6	3	2	1	45	133	31	47	55	9	101
16	322c	24	72	24	21	27	3	9	0	8	1	36	108	34	40	34	9	102
Krist- 101	401A K	no					1										10	103
Krist- 101	401B K	5					1										10	104
Krist- 101	402 K	9										4					10	105
Krist- 101	412A K	18										10					10	106
Krist- 101	412C K	11										22					10	107
Krist- 101	413 K	25															10	108
Krist-GC	6015A	9										2					10	109
Krist-GC	6015B	24										2					10	110
ref suite	COBALT	Y																111
ref suite	Dome aMV											Y						112
ref suite	QPF(Paymaster)	10 phen										Y						113
ref suite	DOME UM flows	5																114
ref suite	Dome var MV	no										Y						115

measured section	sample	KF %	F tot	F 1st	F 2nd	F 3rd	F %	Ser tot	Ser 1st	Ser 2nd	Ser 3rd	Chl tot	Chl 1st	Chl 2nd	Chl 3rd	E#	RF #
Appendix 8.2 Original counting data: grain parameters (Gazzi-Dickinson) for samples from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all samples.																	
d K 54-30	6014	0	40													1	1
d K 54-30	6013	0	40													1	2
d K 54-30	6012	0	40													1	3
d K 54-25	6010	0	30													1	4
d K 54-25	6011	0	40													1	5
d K 54-24	6008	0	86	258	86	84	88	Y								1	6
d K 54-24	6009	0	81	81				Y								1	7
Hoyle t pond	077	0	68	173	32	70	71	Y								1	8
33	338	0	66	197	68	64	65	3	10	7	0					1	9
12D	204	0	70	211	71	67	69	24	72	29	17	27	1	3	1	2	10
12D	205	0	74	222	75	68	79	40	12	3	3	4	Y			2	11
12D	207A	0	65	194	66	69	59	18	55	18	18	19	3	2	3	2	12
12D	207B	0	68	205	61	72	72	12	37	16	13	8	1			2	13
(Quarry)	340B	0	60					Y								2	14
1	6004	0	69	207	70	70	67	Y					2	5	1	2	15
1 @390 m	6021	0	80										Y			2	16
1 @390 m	6027	0	61	122	78	39							Y			2	17
1 @390 m	6028	0	78	235	70	80	85	Y								2	18
1 @390 m	6031	0	3	9												2	19
1	006	0	?					30								2	20
1	007	0	64	193	68	67	58	9	27	8	12	7	2			2	21
1	12	0	68	193	65	69	68	2	5	2	2	1	4	4	0	2	22
1	17	0	69	208	71	67	70	Y					Y			2	23
1	6001	0	70	210	69	64	77	Y					3	8	3	2	24
9	160A	0	69	203	67	66	73	13	39	15	17	17	NO			3	25
9	164	0	20					no								3	26
d 3235 @104 m	M1313 ; T	0	Y					30					Y			3	27
d 3235 @174 m	M1314 ; T	0	Y					42					20			3	28
d 3235 @201 m	M1316 ; T	0	70					15					5			3	29
d 3235 @227 m	M1315 ; T	0	70					3					5			3	30
d 3235 @62m	M1307; grap s	0	Y					Y					20			3	31

measured section	sample	KF %	F tot	F 1st	F 2nd	F 3rd	F count	Ser %	Ser tot	Ser 1st	Ser 2nd	Ser 3rd	Chl %	Chl tot	Chl 1st	Chl 2nd	Chl 3rd	E#	RF#
				count	count	count	count		count	count	count	count		count	count	count	count		
Appendix 8.2 Original counting data: grain parameters (Gazzi-Dickinson) for samples from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all samples.																			
4	90-03		Y					Y										4	63
4	99	1	52	159				7	22									4	64
4	104	1	49	146				7	22									4	65
4	106	1	56	167				10	31									4	66
4	120	1	45	135				8	23									4	67
4	127	1	51	153				9	26									4	68
4	140	1	43	129				3	15									4	69
13	192	0	20					?										5	70
2	025c	0	54	161	56	56	49	3										5	71
2	6007	0	55	164	58	50	56	Y										5	72
8	154B	0	51	154	53	50	51	13	40	14	14	12		1				5	73
5	146A	0	44	131	55	45	31	Y						Y				5	74
6	150B	0	45	135	46	45	44	1	2	1	1	0		NO				5	75
6	153B	0	51	152	49	49	54	1	2	1	1	0		NO				5	76
3	49	0	20					10						Y				5	77
3	57A	0	58	175	53	67	55	3	9	2	7	1		1	2	0	0	5	78
Dome	517	0	Y					Y						20				7	79
12	181B	0	Y					5						3				7	80
12	181D	0	Y					5						3				7	81
12	182	0	20					5						no				7	82
13	195	0	20											10				7	83
1	024h	0	57	171	55	61	55	Y						Y				7	84
8	155c	1	Y					5										7	85
5	144B	0	50					Y										7	86
5	145A	1	48	144	46	46	52	Y						Y				7	87
5	143B	0	Y					Y						10				7	88
17	328	1	40	120	19	38	43	Y						10	31	1	1	7	89
17	329	2	40	120	35	44	41	Y						10	31	1	1	7	90
13	193B	1	20					?						20				8	91
13	191B	0	50											15				8	92
2	30	0	50					Y						Y				8	93

measured section	sample	Lv %	Lv tot count	Lv 1st count	Lv 2nd count	Lv 3rd count	Lv %	Ls tot count	Ls 1st count	Ls 2nd count	Ls 3rd count	LOCATION UTM	LOCATION UTM	E#	REF #
Appendix 8.3 Original counting data: grain parameters (Gazzi-Dickinson) for samples from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all samples.															
d K 54-30	6014	Y					@ 363m					470232	5392127	1	1
d K 54-30	6013						@ 210m					470385	5392127	1	2
d K 54-30	6012	Y					@ 136m					470460	5392127	1	3
d K 54-25	6010						@ 215m					470718	5392281	1	4
d K 54-25	6011						@ 449m					470718	5392515	1	5
d K 54-24	6008						@ 209m					472915	5392203	1	6
d K 54-24	6009						@ 477m					472915	5392403	1	7
Hoyle t pond	077	6	14	3	8	3						493500	5381500	1	8
33	338	no					1	1				499560	5385300	1	9
12D	204	7	22	6	8	8	3	9	2	5	2	482400	5369032	2	10
12D	205	7	20	10	7	14						482400	5369000	2	11
12D	207A	14	42	12	11	19	6	19	7	6	6	482400	5368920	2	12
12D	207B	9	28	11	7	10	6	18	4	5	9	482400	5368922	2	13
(Quarry)	340B											482570	5369700	2	14
1	6004	1	2	0	0	2	6	19	5	5	9	484013	5370781	2	15
1 @ 390 m	6021											484013	5370771	2	16
1 @ 390 m	6027											484013	5370771	2	17
1 @ 390 m	6028											484013	5370771	2	18
1 @ 390 m	6031											484013	5370771	2	19
1	006	?										484020	5370654	2	20
1	007	12	37	12	15	10	11	34	11	14	9	484020	5370639	2	21
1	12	7	21	9	9	3	7	34	7	0		484020	5370134	2	22
1	17	8	25	11	5	9	3	34	3	0		484020	5370096	2	23
1	6001	2	21	9	9	3	7	21	8	0	0	484020	5370828	2	24
9	160A	n										490110	5372820	3	25
9	164						Y					490110	5372944	3	26
d 3235 @ 104 m	M1313 : TBTE	no					?					490220	5372158	3	27
d 3235 @ 174 m	M1314 : TBTE	no					?					490220	5372088	3	28
d 3235 @ 201 m	M1316 : TBTE	no										490220	5372058	3	29
d 3235 @ 227 m	M1315 : TBTE	no										490220	5372038	3	30
d 3235 @ 62m	M1307 : graphitic siltstones	no					?					490220	5372198	3	31

measured section	sample	Lv	Lv tot	Lv 1st	Lv 2nd	Lv 3rd	Ls %	Ls tot	Ls 1st	Ls 2nd	Ls 3rd	LOCATION EASTING (metres)	LOCATION UTM NORTHING (metres)	E#	RF#
Appendix 8.3 Original counting data: grain parameters (Gazzi-Dickinson) for samples from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all samples.															
d 3235; @ 44.5 m	M1306A	no					?					490220	5372216	3	32
d 3235; @ 44.5 m	M1306B ; graphitic siltstones	no					?					490220	5372215	3	33
9	160B											490226	5372880	3	34
d 3236 @112 m	M1318 ; TBTE	no										490270	5372380	3	35
d 3236 @058 m	M1317 ; TBTE	no										490325	5372380	3	36
9	170B						no					490610	5373264	3	37
d 1840 @40 m	M1319 ; TBTE	no										491390	5375610	3	38
d 1840 @46 m	M1320; TBTE						35	10		3	1	491390	5375620	3	39
d 1398 @212 m	M1309;						Y					491835	5373189	3	40
d 1398 @212m	M1308 ; Bi-rich sed											491835	5373188	3	41
d 1398 @242m	M1310 ; siltstone	no					?					491835	5373150	3	42
d 1398 @250 m	M1311 ; siltstone	no					?					491835	5373159	3	43
d 1398 @253 m	M1312 ; siltstones	no					?					491835	5373156	3	44
d 3489 @108 m	M1324; TBTE											493510	5373431	3	45
d 3489 @38 m	M1321; TBTE											493510	5373370	3	46
d 3489 @96 m	M1322; TBTE											493510	5373430	3	47
d 3489 @96 m	M1323; TBTE						10					493510	5373443	3	48
15	316B											495950	5369880	3	49
15	317A											495950	5369980	3	50
15	317d						3	8	2	0		495950	5370000	3	51
15	313B											496100	5372000	3	52
15	315											498600	5372000	3	53
2	34B	2	5	3	1	1	8	25	8	8		484960	5370858	4	54
2	36	3	8	1	4	3	3	8	5	0		484960	5370878	4	55
4	78A	1	1	1		0	4	12	4	4		493270	5374035	4	56
4	81						2	5	1	1		493260	5374002	4	57
4	82	1					2	5	1	2		493260	5373999	4	58
4	84	1					2	5	1	2		493250	5373994	4	59
4	90-01A											493240	5373964	4	60
4	90-01B						Y					493240	5373954	4	61
4	90-02						Y					493240	5373944	4	62

measured section	sample	Lv %	Lv tot count	Lv 1st count	Lv 2nd count	Lv 3rd count	Lv %	Ls tot count	Ls 1st count	Ls 2nd count	Ls 3rd count	LOCATION EASTING (metres)	LOCATION UTM	E#	RF#
Appendix 8.3 Original counting data: grain parameters (Gazzi-Dickinson) for samples from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all samples.															
4	90-03											493240	5373934	4	63
4	99	15	46				Y	11	34			493240	5373944	4	64
4	104	1	4				1	4				493240	5373937	4	65
4	106	1	2				6	18				493240	5373934	4	66
4	120	6	17				5	14				493230	5373893	4	67
4	127	2	6				3	9				493230	5373860	4	68
4	140	Y					6	17				493220	5373807	4	69
13	192	?					?					483500	5368892	5	70
2	025c						2	5	2	0		484960	5370925	5	71
2	6007											484960	5370926	5	72
8	154B	3	3	1	1	1	1					489970	5373500	5	73
5	146A	1	4	2	1	1	7	20	6	7	7	491090	5374100	5	74
6	150B	1					3	9	8	0	1	492560	5374558	5	75
6	153B	1	4	1	1	1	2	7	3	2	2	492560	5374530	5	76
3	49	10					Y					492660	5374240	5	77
3	57A	1	4	1	2	1	8	17	5	6		492760	5374200	5	78
Dome	517											483425	5369774	7	79
12	181B	Y										482500	5373430	7	80
12	181D											482500	5373418	7	81
12	182						no					482500	5373408	7	82
13	195											483450	5368802	7	83
1	024h	2	5	0	1	4	5	5	7	4	4	484013	5370771	7	84
8	155c	Y										489970	5373594	7	85
5	144B						Y					491080	5374125	7	86
5	145A	Y					3	9	3	4	2	491090	5374050	7	87
5	143B	Y					Y					491120	5374150	7	88
17	328	no					6	19	0		7	503165	5377074	7	89
17	329	no					2	6	0		2	503165	5377070	7	90
13	193B	?					?					483470	5368912	8	91
13	191B						Y					483500	5369286	8	92
2	30											484930	5370862	8	93

Appendix 9 Locations of samples for REE analyses, the Archean sedimentary suite of the Abitibi Greenstone belt, Timmins, Ontario.

				LOCATION	LOCATION
				UTM	UTM
R#	E#	sample	MS	EASTING	NORTHING
				(metres)	(metres)
Appendix 9 Samples for REE analysis from the Archean sedimentary suite of Abitibi Greenstone belt, Timmins, Ontario. UTM coordinates (locations) are given for all samples.					
1	1	PB6011	54-25	470718	5392281
2	1	PB6013	54-30	470460	5392127
3	1	PB6014	54-30	470460	5392127
4	1	PB338	33	499560	5385300
5	2	PB340B	1	484013	5370781
6	2	PB6001	1	484013	5370781
7	2 S	PB6002D*	1	484013	5370781
8	2 S	PB6002	1	484013	5370781
9	2	PB6004	1	484013	5370781
10	2 S	PB6005	1	484013	5370781
11	3	PB313B	15	496100	5372000
12	3	PB313BD*	15	496100	5372000
13	3	PB315	15	498600	5372000
14	3	PB316B	15	495950	5369880
15	3	PB317A	15	495950	5369980
16	4	PB6003	11	491418	5373496
17	4	PB6016	4	493240	5373944
18	4	PB6017	4	493240	5373944
19	5	PB6007	2	484960	5370925
20	5 S	PB6006	2	484960	5370925
21	7	PB328	17	503165	5377074
22	7	PB329	17	503165	5377070
23	9	PB322C	16	507750	5376674
24	9	PB324	16	507760	5376710
25	10	PB412	K	482762	5369356
26	10	PB6015	K-GC	480100	5368620